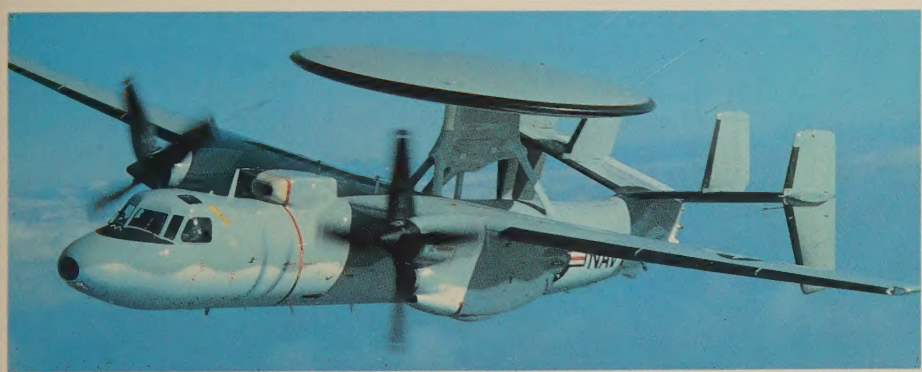

The Naval Institute Guide to **WORLD** **NAVAL WEAPONS** **SYSTEMS 1991/92**



NORMAN FRIEDMAN

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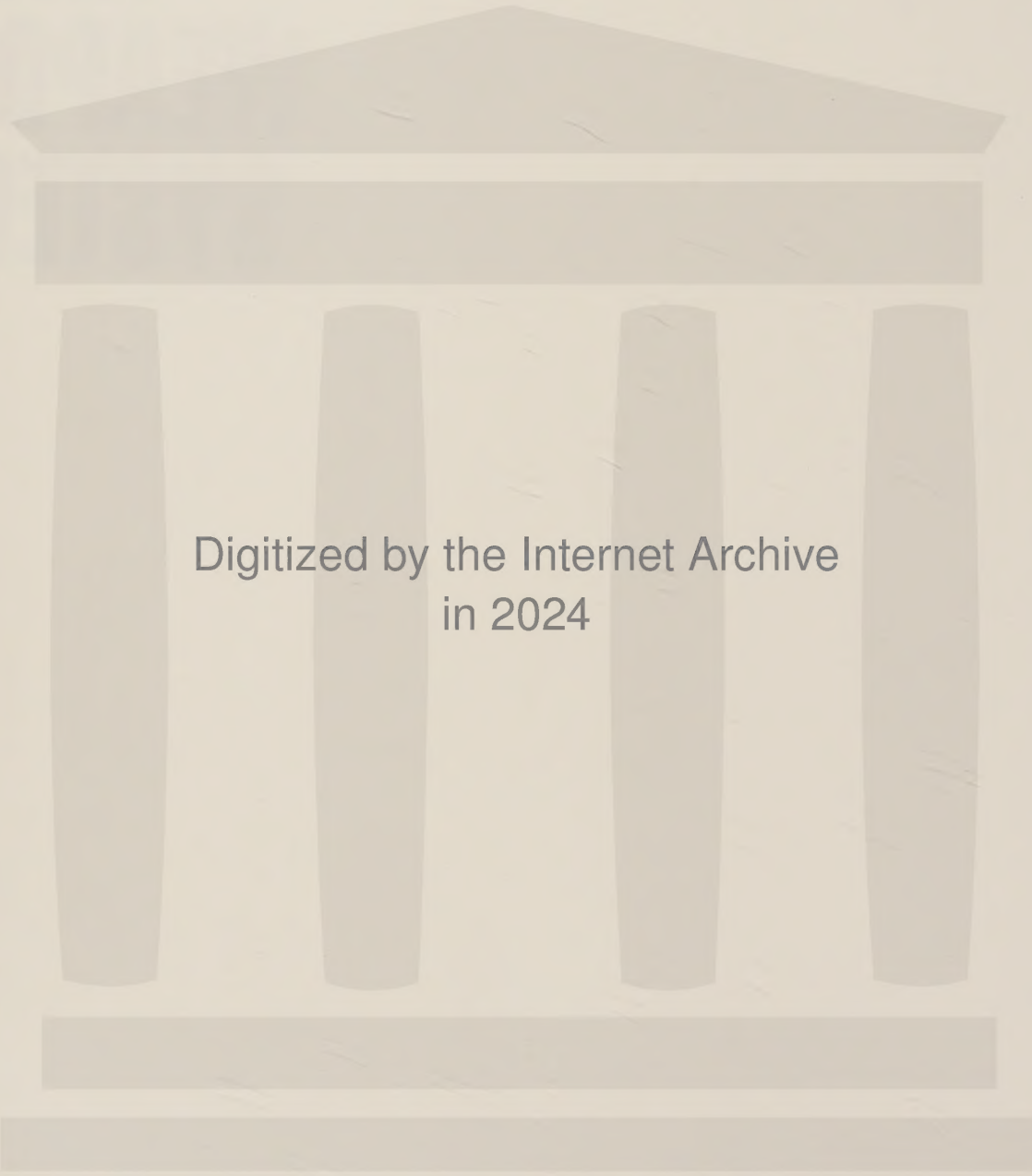
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WORLD NAVAL WEAPONS SYSTEMS



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**The Naval Institute
Guide to**

**WORLD
NAVAL
WEAPONS
SYSTEMS
1991/92**

Norman Friedman

**Naval Institute Press
Annapolis, Maryland**

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Introduction

As this book goes to press, Western defense policies are shifting radically to take account of vast changes in the international situation. With the threat of land attack in Europe greatly diminished (vanished, if the Soviets are to be taken at their word), large investments in armies and tactical air forces no longer seem wise. It seems possible, however, that the West will not reduce naval forces proportionally. One reason is that these forces sometimes deal with Third World threats that are still real. Another is that, despite the withdrawal of Soviet land forces from Central Europe, the Soviets are still at the borders of the West, deploying their navy on NATO's northern flank. At least through 1990, the Soviets had not reduced naval production commensurate with their claimed reductions in the production of tanks and land-based tactical aircraft. A skeptical observer of foreign policy might well wonder whether the Soviets saw their fleet as a potential means of pressuring the West, e.g., in the event that the U.S.S.R. does not receive sufficient economic aid. Alternatively, Soviet naval production may involve such long lead times that ship building programs may not reflect any decisions to cut for some years.

By early 1991, moreover, there was some question as to whether the Cold War really was over. Faced with severe internal problems, the Soviet government reacted increasingly with classic anti-Western rhetoric, such as a charge that Western banks had caused the collapse of the Soviet economy. Such charges seemed intended primarily for internal consumption, but the Soviet leadership seemed embarrassed that it could no longer separate internal from external messages. Even so, the reversion to past patterns of behavior was not encouraging to the West. There had been some hope that Mr. Gorbachev had made irreversible changes, not only internally but also in Soviet foreign policy, and had admitted that the West was not the problem and that Soviet military forces were vastly overgrown. These admissions justified the deep cuts negotiated during 1990, in the START (for strategic forces) and CFE (for conventional forces in Europe) treaties.

The Soviet military leadership never found the cuts particularly attractive. At first it appeared that the General Staff was going along because Mr. Gorbachev offered to modernize the military's industrial capabilities so that it could match the West technologically. By late 1990, however, it was clear that the General Staff was restive at best. Public statements by Soviet politicians and government officials amounted to a claim that the immense cost of the military, a cost unjustified by any real external threat, had been a major factor in the Soviet economic disaster, and these statements reduced the military's prestige. Deep cuts in European forces translated into unemployed (and often homeless) officers. The withdrawal from Eastern Europe, moreover, looked more and more like the military defeat of a large army that had never actually seen battle, and this defeat was hard for the military to accept because of its technological and economic causes. To many Soviet officers, what they perceived as a capitulation to the Western enemy seemed to be the result of treason committed by the politicians. Senior military officers in Moscow, including some in the Soviet parliament, began to talk about reversing the concessions of 1989-90.

These trends were particularly worrisome because the Soviet administration seemed less and less able to control the Soviet Union, including the Soviet armed forces. In the past, despite nominal lines of control from government to General Staff, actual control often rested with the Communist Party, which formed a kind of invisible government. Largely to modernize the Soviet economy, Mr. Gorbachev tried to break the Party's hold, substituting a real and overt government for the older, informal one. He was no longer pursuing that path by the beginning of 1991, but he was forced to live with a largely discredited Party and with interest groups, including the military, that were openly pursuing their own agendas. The lines of control were frayed at best. This problem extended to all areas of the Soviet system.

There was no mechanism that automatically coordinated the agreements reached by the Foreign Ministry with what was ac-

tually done at the military level. For instance, in December 1990 a Foreign Ministry official claimed that, during the previous year, only four new submarines had been completed, an example of arms reduction. Told by a Westerner that the true number was nine, the official could only reply that the military never quite bothered to tell the Foreign Ministry how many were actually built (the figure of four applied only to nuclear attack submarines and left out such insignificant types as Oscars and ballistic-missile submarines). This was not a matter of clandestine subversion. At about the same time, a writer in a major Soviet newspaper proudly described measures to evade the CFE ceilings, measures that included the nominal transfer of army divisions to naval control.

When Foreign Minister Eduard Shevardnadze resigned late in 1990, he cited a growing fear of dictatorship. He might as well have cited his ministry's declining influence within his own state (or, perhaps, the disintegration of his government). After all, he had negotiated arms-control agreements with the expectation that his military would have to follow them up.

Increased military influence on the course of Soviet policy was perhaps also a consequence of Mr. Gorbachev's desperate need to prevent the disintegration of his empire. Observing the failure of the Soviet economy to respond to his treatment thus far, senior officers were unlikely to accept deep cuts or liberalization as the price of labor modernization. It seemed likely, rather, that they would demand a return to earlier practices, including hostilities with the West, in exchange for intervening in the republics. However, it was becoming increasingly clear that only the West could supply the capital and technology the Soviets needed for modernization (but perhaps the Soviet social/political system could not and cannot usefully absorb that capital and technology).

The result is a very difficult dilemma for whoever governs the Soviet Union, a dilemma clearly illustrated during the crisis over Kuwait. To obtain Western resources and cut running costs, Mr. Gorbachev had to become conciliatory, demonstrating that his country was no longer the wild card of diplomatic poker. He could not, therefore, support Saddam Hussein's aggression, at least not publicly (there is evidence that some of his military felt and acted otherwise). The logical consequence was that he had to support the eventual attack on Iraq. However, that support would have enraged many Soviet client states in the Third World. To acquiesce in the collapse of a former client, Iraq, at the hands of a U.S.-led coalition would have been to lose all the influence the Soviets sought in key areas such as the Middle East. Moreover, a Soviet military increasingly unhappy with the government's conciliatory policy found the strong U.S. presence in the Gulf, so close to the southern Soviet border, worrisome at best. Hence the frantic Soviet attempt to abort the ground attack on Iraq by means of a "peace plan" that would have avoided any punishment for the rape of Kuwait and would have ensured Saddam's survival.

As a result of these developments, Western governments may soon find themselves regretting the drastic reductions announced early in 1990. The great question in 1991 is whether the Soviet Union will manage to hold together over the next few years. If it does, it may well be by internal military control, and the military regime is unlikely to be very well disposed toward the West. Because of the state of the Soviet economy, however, no Soviet regime is likely to be able to continue the current level of military power for much longer. Moreover, enough information has already leaked out to suggest strongly that the current military machine has severe weaknesses. It will probably be some years before they can be repaired, if indeed they can be overcome without considerable liberalization.

Thus, the issue for the West may well be whether to maintain forces suited to combat against the Soviets or to reduce those forces drastically to finance research on new types of weapons. Advocates of stealthy aircraft and missiles could certainly prefer the latter choice. It remains to be seen whether current naval technology is approaching a revolution that would justify such a choice. It may well be that the only revolution in sight is the

advent of much more powerful computers and signal processors, and this would be relatively inexpensive. This book describes numerous existing systems that have been radically improved by the insertion of more powerful computers, often at what must have been limited cost.

In Kuwait, Saddam Hussein very graphically demonstrated the need for Western forces, particularly naval forces, capable of intervention in the Third World. Although the battle inside Kuwait and southern Iraq was fought largely by ground and air forces, that battle could not have occurred at all without the prior and continuing presence of large naval forces. The principal reason is the difference in mobility between land and sea forces.

Naval forces are inherently mobile because they are so nearly self-contained. Before 2 August 1990, no one really expected Saddam Hussein to invade and annex Kuwait. He had had a running border dispute with Kuwait, and he had stationed large forces near the border, but it was generally assumed that the forces were present to exert pressure, not to invade a sovereign country. There was no particular reason for the United States or any other country to intervene in what seemed to be a commercial dispute over oil revenues. For that reason, no U.S. or other Western forces were present in the area when the Iraqi army struck.

At that point there were two immediate issues. One was to deter Saddam Hussein from direct aggression against or intimidation of Saudi Arabia and the small Gulf oil states. The other was to bring pressure to bear to force him to relinquish Kuwait. Neither objective was attainable without the use of force, and the only Western forces that could reach the Gulf quickly were warships. The only available quick-reaction offensive forces were on board U.S. carriers, which soon arrived in the Gulf and in the Red Sea. Carrier attack aircraft and marines using equipment landed from the preloaded Maritime Prepositioning Ships based at Diego Garcia and Guam provided a uniquely valuable deterrent against further Iraqi action. It is true that long-range land-based bombers might have flown into the area, but their only option would have been to attack. Had they flown to bases in Saudi Arabia, they would have been impotent without masses of support equipment and munitions.

The initial pressure to withdraw was also naval, in the form of a United Nations-supported blockade. A blockade was an attractive option because it was a form of pressure that could be applied instantly (as soon as warships could take positions in the Gulf and Red Sea). An instant blockade stopped Saddam from swallowing up Kuwait, laughing off some protests, and publicly claiming that any later military campaign was a completely separate act of aggression against him. He tried to make such claims anyway, but the continuing and highly publicized blockade prevented the international community from appearing helpless. Whether blockade (i.e., economic sanctions) alone would have driven Saddam from Kuwait was another question entirely. Among other considerations was Saddam's probable unwillingness to back down from an operation mounted in part to enhance his prestige, which had suffered badly from the unsatisfactory end of the Iran-Iraq War.

Thus, there was always a distinct possibility that Saddam would not leave Kuwait unless he was forced out. U.S. policy from August 1990 on seemed to have been to prepare for a military option while pursuing diplomacy and applying economic pressure. From this standpoint, one virtue of the blockade was that it reduced the flow of spare parts to the Iraqi military. Before the outbreak of war, it was widely reported that much of Iraq's modern equipment was maintained only by last-minute orders for spares, a practice sometimes called "maintenance by DHL," i.e., by air courier. Much overhaul work had to be done abroad. For example, the United Nations embargo caught much of the Iraqi MiG-21 fleet undergoing overhaul in Yugoslavia. Hussein himself had tried to dissolve Iraq's image of limited industrial capability by staging an arms show in Baghdad in 1989, displaying a variety of purported Iraqi-developed missiles and other weapons. However, close examination of photographs

strongly suggested that many or all of the missiles credited to Iraqi industry were really standard Soviet types with crucial parts removed, or with nonfunctional elements of other missiles added for appearance.

With the embargo, the coalition bought valuable time, during which intelligence about Iraqi defenses was gathered and collated and the force within Saudi Arabia was built up. There was little point in even threatening military operations until forces in Saudi Arabia comparable to Iraqi forces both in numbers and in sustained fighting capability had been accumulated. The mobility of naval and marine amphibious forces comes at a price: because they carry their munitions and spares with them, these forces cannot sustain high-intensity combat for very long without withdrawing for replenishment. Only with time can very large dumps of equipment be built up to support much larger ground-based forces for longer. Because of its weight and bulk, the build-up equipment had to come by sea. Even though the men and the aircraft arrived by air, they could not have done very much without the supporting materiel. As late as November 1990, carrier-based aircraft still represented the majority of U.S. air capability in the theater.

Even after the ground-based aircraft had taken the lead in sustained capability, the mobility of the naval forces remained important because it made Iraqi forces spread out to be ready for all of the many options open to the sea-based attackers. This dilution reduced the opposition that attacking ground or land-based-air forces would encounter. For example, the mere presence of a powerful marine amphibious force off the Kuwaiti-Iraqi coast made it impossible for large numbers of Iraqi troops to quit their positions spread out along the coast to reinforce others along the ground border, yet the marines could not possibly have attacked along the entire coastline. The Iraqis' lack of any maritime reconnaissance complicated their problem: they could not know where the marines were going to land until just a few minutes before the assault began.

This introduction was written during February 1991, and of course all the lessons of Desert Storm had yet to be learned. It was, however, gratifying to see that the claim made in 1990, that U.S. and other Western equipment finally really works, had been so strongly borne out in practice. Visible success is terribly important because any operation in the Third World, such as Desert Storm, is played out not only for its immediate results but also for the edification of other Third World regimes. Conversely, failure (or even expensive success) would tend to encourage other Third World countries to adopt a hostile stance toward the United States and its allies. Many will probably see the success of Desert Storm as the victory of Western materiel and techniques over forces largely, though hardly completely, modeled on and equipped by the Soviet military. That impression cannot fail to improve Western prestige.

The success of the attack missiles, such as Tomahawk and SLAM, was striking mainly because it was so public. Desert Storm was, after all, the first time Tomahawk was used as a precursor to manned air strikes. However, an even greater success was the swift and total destruction of the Iraqi air defenses, which proved to be the key to the air and ground campaigns that followed. At the time of writing it was not clear just how that destruction had been accomplished, and thus just how applicable the operation was to other Third World problems.

It may be that the Allies enjoyed overwhelming but very special advantages, and it remained to be seen whether the abject failure of the Iraqi air defenses was largely the result of incompetence or careful Allied intelligence-gathering over the five months leading up to the attack. After all, the Allied forces almost certainly enjoyed the advantage of information supplied by the purveyors of the air defenses, including the Soviets (who may now rather regret their cooperation). In that case, the lessons of the air-defense-suppression campaign would have little future applicability. However, it may also be that the keys to success were highly accurate missiles, such as Tomahawk, and a command-and-control system capable of coordinating very large numbers of attackers. In that case, it may be much wiser

to invest further in command and control and in antiradar weapons than to produce stealthy aircraft. If, however, the Iraqi air-defense system was very much a special case, then a carrier battle group trying to make a quick strike cannot expect similar success in the future, and special aircraft may be absolutely essential.

Perhaps the greatest question raised by Desert Storm is whether Third World countries like Iraq have been able to make full use of the advanced technology on which they have spent so much of their national wealth. Before the war, Iraq's integrated air defense was often cited as an example of the much increased threat that many future U.S. naval air strikes would have to penetrate. The reality seemed to have been far less impressive.

It seems likely that Iraqi ineffectiveness was largely the result of inattention to command and control, perhaps unavoidable given a lack of educated personnel. Command and control determines just how well weapons can approach their potential destructiveness. The less effective the command-and-control system, the less accurately the published performance figures reflect combat effectiveness. Hence the emphasis in this book on sensors and on command and control. In a land war like that in Kuwait, for example, command and control determines how well a senior commander can perceive the course of a battle and order units to deal with an enemy's moves. The best command-and-control systems provide detailed information in virtually real time and allow a battle to be controlled in detail, enabling a force to react very fluidly. The more rigid and less fluid the command-and-control system, the slower an army is to react to changing events. It appears that the Iraqis failed partly because, whatever the maximum performance of their expensive weapons, they never had a command-and-control system to match, so they were entirely unable to deal with the rapidly moving forces that destroyed them. Although the example is not naval, the lesson clearly extends to all other forms of warfare. It is possible, for example, that the key to destroying or neutralizing Iraq's air defenses was not so much the efficacy of particular Western weapons as it was the flaws of the system that integrated the sensors with the weapons. These flaws, both in technique and in equipment, may have been evident even before the system was fatally stressed. A senior U.S. officer who spent time with the Iraqi forces during the Iran-Iraq War commented that he was not at all surprised that bombs hit Baghdad well before any sirens sounded, i.e., well before the Iraqi national air-defense system was aware of what was happening.

Performance is not, of course, entirely a matter of reliable microchips. Reportedly, the ex-Kuwaiti missile boats operated by the Iraqis failed to engage the Lynx helicopters that sank them because the boats' lightly built structures vibrated badly enough to throw fire-control radars off target. The BEAB pencil-beam radars repeatedly locked on, just to be thrown off by slight helicopter movements. By the time the problem was being corrected, the helicopters' Sea Skua missiles were making it irrelevant. The boats also suffered because their ECM and ESM antennas were so close to the water that they were overwhelmed by multipath effects. One conclusion is that the small but highly sophisticated attack boats so widely touted may be much less effective than is generally supposed. At the very least, such boats would seem to require air-defense missiles (preferably self-guided so that the vibrations of the launching boats do not throw off the missiles' guidance).

One of the surprises of the war, at least as of late February 1991, was the paucity of sophisticated Iraqi weapons, of the sort so publicly but fraudulently displayed in Baghdad in 1989 and also so widely discussed in the Western press before the war. It seems remarkable in retrospect that observers at the time were so credulous, and their willingness to believe official Iraqi statements makes one wonder what other announced Third World weapons and related equipment really does not exist. In addition, many countries may have simply copied Western equipment without permission, paying little attention to Western-oriented intellectual property laws.

Reference books such as this one are largely based, either directly or indirectly, on material released by defense manufacturers, much of it handed out at the many international arms and air shows. Sometimes the weapons advertised are still paper projects, and sometimes claims of sales are false, but it is difficult to recognize sheer fraud. In peacetime, fraud usually does not matter. The run-up to the war in Kuwait was a very different matter. Saddam Hussein badly wanted to deter the West from military action. He believed that his potential enemies, particularly the United States, would shrink from any action entailing large numbers of casualties. It is striking that the whole spectrum of media coverage generally emphasized the fighting power of the Iraqi army, even though by 1990 it was clear that the Iran-Iraq War had ended, not in some sort of splendid victory for Iraq, but rather in mutual exhaustion. Periodically, the press circulated stories of major illicit transfers of technology to Iraq (e.g., fuel-air explosives and cluster bombs), tending not to discover that fuel-air explosives were at best difficult to use and that cluster bombs were fairly ancient. The interesting postwar question is to what extent Iraq orchestrated such stories. Had the coalition perceived that the Iraqi army was essentially war weary and ill equipped at the command-and-control level, would military action not have come much earlier? How much of the public and official image of other Third World military forces is similarly inflated?

It may fairly be argued that professional intelligence agencies would have done (or have done) better. However, three points should be remembered. At least in the United States, unclassified studies of the likely progress of a war with Iraq, based very largely on the published record, had enormous impact in Congress and throughout the Washington community. The reason was that whatever intelligence had been collected could not (or would not) be sanitized for general use. An estimate of, say, twenty thousand American deaths in the liberation of Kuwait had enormous political effect when Congress was considering whether to authorize the use of military force.

Second, at least until very recently in the United States, professional intelligence efforts have been focused almost exclusively on the Soviets. Much of the information about Third World military organizations and particularly Third World military producers is taken from standard unclassified reference materials.

Third, there is little reason to imagine that classified professionals are less credulous than published ones: secret does not always mean true. After all, during the run-up to the ground war, the White House, which had access to all intelligence sources, made no attempt to discredit any of the gloomy scenarios; the President merely argued that Saddam Hussein had to be stopped and that the cost of doing so later would greatly exceed the cost of doing so right now. There is every evidence that Central Command, in its planning, had just as much respect for the Iraqi army as did the civilian commentators in the United States. In each case the impressive paper image camouflaged real Iraqi deficiencies. The allied plan did exploit some major Iraqi weaknesses (particularly in command and control), but the collapse of the Iraqi army seemed to have caught everyone by very happy surprise.

The question for the future is whether that surprise points to some grave deficiency in the U.S. way of evaluating potential enemies. In particular, the United States seems to focus on numbers, whether of ships or of soldiers, and on the nominal or maximum performance of the weapons. Western analysts seem much less capable of factoring in subtleties, such as weak or slow command and control. For example, by now the West is well aware of the characteristics of the MiG-29, which is being tested by the German air force. The MiG-29's aerodynamic performance is exceptional, but its maintainability is apparently quite appalling. Both are easy to quantify. It is much more difficult to quantify another important factor: cockpit layout. A MiG pilot has to shift attention frequently just to flip the switches needed in air combat. "Switchology" like this is not an abstract issue. Early in the recent war, one Iraqi MiG

shot down another because, to save time, the pilot had taped down some of the switches that otherwise would have provided a way to veto the firing of a missile at whatever target the plane had locked onto. What the pilot did was, apparently, standard practice. Clearly, it is difficult to estimate how poor internal arrangement (which may partly result from the absence of an effective central computer) affects the performance of a large number of MiGs flying over Central Europe, for example. It is easier to assume that, apart from some aerodynamic details and missile ranges, a MiG is equivalent to an F/A-18 or an F-15. However, that analysis is worthless if switchology is not merely a detail but a fatal disaster.

In the United States and probably in all or most NATO countries, mathematical projections of combat outcomes determine the course of weapon and force procurement. Abstract mathematical techniques, then, are not a trivial issue. The mathematical techniques are attractive because they provide decision-makers with clear-cut numerical predictions, but they have never really been tested, not even compared with historical evidence to see whether a model predicted events correctly. There is, then, no real evidence as to whether the mathematics has any reality behind it. In the past, mathematical techniques have been criticized because they do not take tactics into account, particularly the way tactics change either during a battle or during a campaign. They may also fail to take into account issues of morale and determination or command and control, all of which were absolutely critical to the outcome in the Iraqi-Kuwaiti desert. There is some evidence that both in the Falklands and in Kuwait, the projections were seriously in error. The West is now cutting many programs, often on the basis of such mathematical projections. Perhaps the most valuable lesson to be learned from events in Iraq and Kuwait is that it is time to notice that this particular emperor is very nearly naked.

One major surprise of the war (as well as of the UN-sponsored embargo preceding it) was the extent to which naval (and other) forces that in the past had been mortal enemies have operated in close coordination. With the wind down of any cold war, the opposing powers do not immediately become close friends. However, they do discard any idea of near-term hostilities. Just this sort of cooperation occurred frequently in the latter part of the nineteenth century, when navies nominally intended to fight one another joined forces to conduct peacekeeping or policing operations in the Third World, where all had much the same goals: stability and a reasonable degree of friendship commensurate with trade. These navies had not discarded the roles they would play in major war, but those roles had been put off.

In 1890 coordination meant little more than a conference among commanders before operations began. All the ships were within sight of each other, and fatal errors cannot have occurred very frequently. Any reader of this book knows that coordination is now far more complex and generally requires the automatic exchange of data, of tactical plots in particular. To say that NATO warships are compatible means that all share Links 10 and 11 and that they carry tactical data systems designed to show a common picture. What happens when NATO forces must operate with neutral navies, or even with the Soviets, who do not share our systems? We need some way to share the linked data on a strictly temporary basis, perhaps by using portable terminals. Such equipment may actually be aboard Soviet warships in the Persian Gulf, in the hands of the U.S. Navy's liaison teams.

Why does real-time data exchange matter at all? In 1890 the main instrument of power projection was the naval gun, controlled entirely by the firing ship. Now the most effective instruments are long-range missiles and aircraft. They are also the best weapons for attacking ships. It is reasonable to assume that outbound aircraft are friendly, but naval air strikes must return to their own ships and would, for example, have to overfly most of the warships in the Persian Gulf. Surviving enemy aircraft may well elect to follow air strikes back to the carriers. If ships find themselves forced to engage any airplane coming within

some predetermined keep-out distance, we will make very few strikes before we lose all our aircraft.

The U.S. Navy found one solution to this problem in 1945, preventing Japanese aircraft from following American strikes home to the carriers by assigning sections of fighters to visually inspect the returning groups of attack aircraft and to shoot down any interlopers. At that time the fleet enjoyed plentiful air resources, and enemy aircraft were relatively easy to identify by sight. Now the fleet has many fewer fighters. Visual identification is much more difficult, partly because aircraft must be engaged at long range, but also because both sides use very similar (or identical) airplanes. For example, both Kuwait and Iraq bought French-built Mirage F-1s.

The only really sure way of identifying aircraft without their cooperation is by following their flight paths. During Vietnam, for example, we stationed an NTDS ship in the Gulf of Tonkin to identify and track all air traffic crossing the area because we did not want to shoot down an airliner, or one of our own aircraft, inadvertently. Because of its relatively limited radar horizon, that ship, and any picket ship, also relied on information from early-warning aircraft. AEW aircraft can, in theory, observe aircraft as they take off from ships or from bases ashore, track them out to the target areas, watch their strikes, and then follow them all the way home. Whether AEW aircraft can conduct this tracking function in practice depends on the capacity of the airborne computers since several hundred aircraft may be airborne at once. Another factor is the precision of the airborne radars, which may find it difficult to distinguish aircraft flying very close together (and which may then erroneously mix friendly and enemy aircraft tracks).

Current naval air-defense systems ought to be reasonably effective, so the critical decision is when or at what to fire. The *Stark* incident taught every CO in the world the lesson that it is better to shoot first than to suffer the consequences of hesitation. In the Soviet navy, in addition, there is reason to believe that ships carry heavy concentrations of antiaircraft weapons because the Soviets credit individual weapons with relatively small kill probabilities. That factor would tend to bias a Soviet commander to engage early. Similar considerations would apply to any other navy with little belief in the efficacy of installed antiaircraft weapons. It always pays to open fire as early as possible. A captain relying entirely on the ship's on-board sensors will almost have to treat every nearby airplane as unfriendly.

These considerations explain the Canadian navy's provision of an ADLIPS tactical data system for its replenishment ship deployed to the Persian Gulf during the run-up to the war.

This discussion may seem far too gloomy in view of the success Allied forces enjoyed during the war against Iraq: hundreds of aircraft flew attack missions for well over a month without encountering any blue-on-blue problems. It seems likely, however, that at least the initial strikes had to be planned very carefully and rigidly to avoid accidental interception. Rigid control probably meant manual planning, and hence less than the most efficient use of the aircraft. That trade-off was perfectly acceptable because of the enormous power available. Moreover, there seemed not to have been an urgent timetable that might otherwise have forced commanders to accept more blue-on-blue risks. In the only projected air campaign of like size, a NATO-Warsaw Pact war in Europe, air operations would have been much more urgent because they would have been aimed at stopping a rapidly advancing enemy army. Because air support of the land campaign is so fluid, it cannot be so rigidly controlled. In the campaign against Iraq, however, the destruction or flight of the bulk of the Iraqi air force greatly simplified the problem. In the absence of enemy air attack, allied antiaircraft gunners had no occasion to develop the usual jitters that lead to the deaths of aviators by friendly fire.

The conclusion is that careful planning can overcome the classis blue-on-blue problem, and that assessment in turn would seem to support current efforts at developing 3D, computerized, air-mission planning systems, such as the projected ISPS, which would combine greater efficiency (and timeliness) with safety.

Such systems have become practicable as computer power has become less expensive and more reliable.

Iraq may well turn out to have been a specially fortunate case. In the Falklands, for example, on at least one occasion, British fighters flew into their own ships' firing zones while the ships were engaging Argentine bombers; to avoid shooting down their own fighters, the ships had to break off the engagements and allow the bombers to penetrate unopposed. Fear of blue-on-blue engagements has been a major factor in the development of U.S. carrier battle-group tactics. Similarly, one of the standard considerations in NATO's war planning during the 1970s and 1980s was the expectation that about 40 percent of all friendly aircraft would be shot down by NATO forces. Neither case involved integrating forces with radically different engagement doctrines or without access to standard data links. Fear of blue-on-blue is so strong that the standard U.S. Navy tactical command system, NTDS, is biased against engaging any airplane labeled friendly. The *Stark* never engaged the Iraqi airplane that attacked her largely because that track had been labeled friendly (there was no label for neutral, only unknown/assumed enemy). The *Stark* could have engaged the track, but an engagement would have required a specific effort to override the NTDS safeguards. This experience will probably motivate ship's commanders to do everything possible to engage approaching aircraft unless they are sure those aircraft are friendly.

Today's commanders would like to rely on IFF for identification, but experience has shown the combat limitations of these systems. Any concentration of ships and aircraft in a very small area, especially along a coast, will cause interference among IFF responses and, thus, identification and tracking difficulties. In neither the Falklands nor Lebanon was identification complicated by the presence of friendly forces that did not share tactics, data links, or IFF systems, so operations in the Persian Gulf had even greater potential for confusing the IFF picture.

If the intervention in the Persian Gulf were a special case, the identification problem would probably be an acceptable risk. But history suggests that the crisis over Iraq's invasion of Kuwait is the prototype for many future interventions, almost always by mixed forces. How well the Gulf peacekeeping force coordinates operations now will not only affect the outcome of this crisis but will also serve to deter, or encourage, future aggression.

The experience of war in and around the Gulf tends to reinforce another point made in the previous edition, that modern weapons are often less lethal than imagined and that damage assessment is too often overlooked. It is quite clear that modern weapons can be directed to particular points in enemy territory, but it is difficult to keep in mind that a bomb hitting or even penetrating a bunker does not necessarily destroy either the bunker or its contents. Bomb damage can be repaired, and with a sufficient gap between bombing and post-strike coverage, it can be faked to protect other targets (which may appear to have been hit). The Iraqis certainly resorted to decoying, both simulating vehicles and simulating bomb damage. For example, the roof of the notorious dual-use bunker on the outskirts of Baghdad had several false bomb holes painted on it. They seem to have been less than effective, partly because the attack schedulers knew the building had not been hit prior to the raid that destroyed its insides.

Readers will be painfully aware that existing reconnaissance systems, some of which are described in the Strike/Surface Warfare section, are inferior to earlier ones, such as that carried by the RA-5C Vigilante. Superior systems are still under development. The best existing U.S. system, on board the mothballed SR-71 Blackbird, was not available for the war. As a result, commanders in the theater had to wait much too long to assess the effects of strikes. Such delays may be entirely acceptable during a campaign against fixed targets, but they greatly detract from attacks on mobile targets such as tanks.

The lethality gap was particularly evident at sea, where Sea Skua missiles disabled Iraqi surface combatants, such as ex-

Kuwaiti fast attack boats, by hitting their superstructures. The boats were not sunk, and they were the targets of later strikes because no one could be sure that they had been rendered entirely ineffective. Experience seems to show that modern Western antiship missiles just do not have sufficient destructive power to kill most warships. In a protracted campaign, a ship or fast attack boat tied up at the pier will probably attract additional attacks. Because of the limited number of weapons available, any unnecessary attacks would prevent more productive uses of the weapons. Much the same might be said of a tank burned out inside but appearing intact. It is useless except as a decoy, but its usefulness as a decoy is high.

Lethality has another aspect. Readers will notice that virtually no air-delivered weapon weighs more than about 2000 lb. All carrier aircraft in the world carry their weapons externally, as do most land-based aircraft. External carriage imposes severe limits on a weapon's length, diameter, and weight. The current limit is perfectly acceptable as long as the targets are those common in the major U.S. scenario of European war: vehicles and reinforced-concrete aircraft hangarages. In Iraq, however, there was another class of target, the deeply buried command bunker. It could have been argued that the only really effective deterrent to Saddam Hussein would have been a weapon capable of hitting and killing him in his bunker, about 40 ft below ground level. At the very least, the threat of such attack would have forced Mr. Hussein to use surface facilities, in which he would have been much more vulnerable to the fury of his compatriots, and thus would have contributed materially to his downfall.

Ironically, this problem was solved half a century ago. During World War II the RAF introduced "earthquake" bombs, heavy-cased weapons that, falling at supersonic terminal velocity, would penetrate so deeply into the earth that they would explode below their targets, destroying them with shock waves. They were enormous bombs: 12,000-lb Tallboys and 22,000-lb Grand Slams. The Addendum describes the 4700-lb GBU-28 developed during the recent war specifically to penetrate deep Iraqi bunkers. It was delivered by an F-111F and is probably somewhat too long for carrier aircraft (nor can it be delivered by B-1 and B-2, which can carry nothing larger than a Mk 84).

This second edition of *The Naval Institute Guide to World Naval Weapons Systems* is substantially larger and more complete than the first, and it has been almost completely reillustrated.

The most obvious new feature of this edition is a detailed account of combat-direction systems (CDSs), such as the British ADAWS, the French SENIT, and the U.S. NTDS, and also of the computers that ultimately determine the capabilities of these systems. CDSs mediate between sensors and weapons, not only on board ships but also in an increasing number of naval aircraft. The sensors and weapons determine the ultimate combat potential of a ship or aircraft, but the CDS generally determines the extent to which that potential can be met.

Automated CDSs are needed to keep track of many different targets. The requirement to track multiple bogeys automatically first emerged in air warfare. However, as sonar (particularly passive sonar) range has increased, it has turned out that ASW participants, too, require computers to track and target multiple contacts. ASW actions may move much more slowly than air engagements (hence the witticism "awfully slow warfare"), but they are intricate and must sift an enormous amount of data: the U.S. SQQ-89 system requires about twice as much computer program as Aegis.

Most of the naval CDSs are intended to make combat itself more manageable, and they have little influence on combat plans. Now new systems intended for precombat planning are beginning to appear. They permit a commander to see the likely effects of various, alternative approaches, much as spreadsheets allow financial analysts to try alternative investment strategies. The naval problem is, of course, infinitely more complex, but

in both cases the benefit of comparing different tactics is much the same. Perhaps the most extreme examples are the new planning tools for the deployment of tactical aircraft. Systems such as the French Circe 2000 and the developmental U.S. ISPS allow quick comparison of the virtues and defects of alternative routes for air attacks against land targets. The new U.S. Afloat Planning System for land-attack Tomahawk missiles (see the Addendum) is a simpler equivalent of these systems. In the case of the Afloat Planning System, the line between planning and combat is blurred because the machine sends its data directly to the missile. There is no realistic manual alternative. With tactical air forces, however, manual strike planning is a well-established process.

The tactical planning systems replace vast amounts of staff work traditionally applied to "what-if" questions. The need for automated CDSs has long been obvious, and enormous sums have been spent on them. It remains to be seen whether the promise of the new tactical planning systems will make them attractive enough to survive the post-Cold War drawdown.

As in the past, the single major gap in our knowledge of CDSs is the Soviet Union's systems. Published or publishable information is virtually nonexistent. However, there is still reason to believe that the Soviets lack Western-style integrated combat systems and still rely heavily on manual (grease-pencil) compilation of a tactical picture. For example, the proliferation of short-range air-defense weapons on board most Soviet warships probably indicates an inability to react quickly enough to engage incoming attackers at long range, i.e., it probably indicates a lack of automation. If so (presumably as a consequence of the relatively primitive condition of the Soviet computer industry), then the Soviets' very impressive weapons cannot currently perform up to anything like their full potential: Western navies enjoy an enormous, if ill-defined, advantage because of their CDSs. But that advantage may be a fleeting one. As export controls are relaxed, it may be possible for the Soviets to buy the commercial equivalents of the elements of Western-style combat systems.

This is not to say that Soviet naval capabilities will surge as soon as the first few personal computers or workstations arrive in Leningrad. CDSs are much more than a few computers: they require elaborate software (not to mention human engineering) and careful integration with existing weapons and sensors. Software testing generally entails the creation of one or more land-based test sites. Merely plugging computers into existing manual systems can be disastrous (the U.S. cruiser *California* literally did not function on her initial trials because of software problems in her incompletely integrated system; she took a year to fix).

In the past, computers of all types were extremely expensive, and only major warships could be fitted with automated CDSs. Other ships had to make do with the manual systems developed during World War II. However, since the late 1960s computer costs have fallen so dramatically that even many current fast attack craft have on-board computers. At the same time, relatively few ships built without computerized CDSs have been fitted with them, partly because such systems function effectively only when they are fully integrated with their sensors and weapons. Consequently, the ships of the world's navies still fall into pre- and post-computer classes.

That distinction becomes more significant as older ships, either entirely without computers or with early low-performance units, are retired. For example, the U.S. Navy plans to lay up (or, more likely, sell) the entire *Knox* class. These ships never had automated CDSs of any type. The consensus is that without such systems, ASW ships cannot hope to track multiple targets passively. Thus a nonautomated ship cannot make full use of her towed-array sonar. All later U.S. ASW ships either have, or are having installed, an automated ASW CDS in the form of SQQ-89. One conclusion is that the retirement of the *Knox* class represents a far less significant loss of capability than bare numbers would suggest. Another is that any navy buying

these ships would probably want to fit them with some type of automated CDS.

Although the cost of civilian computers has fallen and their reliability has improved, their ability to directly replace their much more expensive military counterparts remains in question. On the one hand, some commercial-grade computers are at least as rugged as their military counterparts. For example, the Canadian navy tested a new sonar algorithm by using a commercial PDP computer and discovered to its surprise that this machine outlasted the standard military computers during that cruise. Because commercial machines are not subject to elaborate procurement practices (sometimes denoted by the shorthand of "Mil-Spec"), they have very much shorter development times and, thus, can embody more advanced technology at a relatively low price. The U.S. Navy has adopted some commercial workstations (desktop computers, or DTCs), which bring down the cost of some important tactical improvements. They do not, however, conform to full military specifications. Procurement has, therefore, been limited to what are called tactical decision aids (as opposed to mission-essential devices), on the theory that a ship can fight even though her decision aids may have been disabled.

Buying commercial computers carries a hidden cost. Military computers change very slowly, and the customer can demand strict control of their configurations. Software that works perfectly on one UYK-7 will work identically on a UYK-7 made ten years later. The world of commercial computers is very different. Machines with identical designations may embody engineering changes that affect software performance in subtle but important ways. Hardware that is sold as perfectly compatible or equivalent may have differences that users quickly notice, often to their misfortune. This problem is by no means insurmountable, and it ought not to deter any Western navy from increased reliance on commercial computer products. However, navies will need to take a different approach to procurement and testing.

The U.S. Navy's next generation computer resources program (NGCR) may have already developed the appropriate approach. NGCR will accept commercial components that are fully compliant with stated software requirements. The question will be just how well the navy can test that compliance. Readers who bought extra boards for their open-architecture personal computers (such as IBM PCs and their clones) know that on occasion the supposedly fully compatible boards caused problems because they handled software just a bit differently from the original computer. The problems were by no means common, but their naval equivalents would have been unfortunate in combat. The navy will have to avoid the strong temptation to regard all nominally equivalent components as truly equivalent and should refuse to choose simply on the basis of price.

This edition includes considerably expanded coverage of airborne sensors, weapons, and countermeasures because the main threat to naval forces throughout much of the world is still from land-based air forces. In addition, accounts of Soviet air weapons and sensors have been expanded to take account of the capabilities of the Su-27 and MiG-29 fighters that the new carrier *Admiral of the Fleet Kuznetsov* and her successors will carry. There is still no public information concerning possible successors to the heavy air-launched antiship missiles, the AS-4 and AS-6, that the Soviets introduced during the 1970s. Given Soviet progress in other areas, it is difficult to imagine that no successors exist.

It has been possible to provide much fuller accounts of some of the weapons and sensors described in the previous edition. For example, this edition describes the different versions (Mods) of many U.S. systems in detail. In many cases, different Mods of the same device or system are so different that we might legitimately consider them different systems.

The Addendum, which was current as of the end of March 1991, includes a detailed description of I-2000, the bunker-attack bomb first used in the war against Iraq. The Addendum

also includes the most complete list yet published of Soviet communications antennas, substantial new material on current and planned U.S. and NATO data links, and some recently declassified material on the origins, rationale, and development of the NATO SOSUS system.

To compensate for the additional entries, and also for the greater detail in some sections, I have deleted some historical material. That includes descriptions of some abortive systems that were interesting for their connections to current projects. Interested readers should consult the first edition of this work. However, I have not deleted any weapons systems or naval sensors in current service or in reserve, and I have added some older systems still in service but inadvertently omitted in the previous edition. The goal of this edition, and all future editions, will be to include all existing naval weapons systems.

Dimensions are given, wherever possible, as diameter $\times$ length (wingspan or fin span as a separate item). For radars, the first dimension is the horizontal one, which determines the horizontal beamwidth. Dimensions are generally in the units (English or metric) used by the country of origin. Where that is metric, English units are given in brackets. Dimensions for some Soviet systems are given in English units (feet and inches), even though the weapons have certainly been designed in metric terms, because the published data come from U.S. sources and are surely approximate rather than exact. Ranges are in meters and yards (sometimes in thousands of yards, or kiloyards, abbreviated kyd). Although a nautical mile is 6080 feet (6053 feet in British measurement), it is commonly approximated to 2000 yards, so that a range of 17.5 nautical miles is probably actually 35,000 yards.

An important note on sources. Readers should keep in mind, above all, that this is an UNCLASSIFIED book, a compilation of information from the open literature, from declassified documents, and from brochures provided by the manufacturers of the equipment. I have chosen data on the basis of the plausibility of the source, and also on the basis of their conformity to the known characteristics of similar weapons for which data are better established. In some cases I have identified equipment from available photographs. Official documents generally are not declassified for some considerable time after their origination, typically at least twelve years in the United States, but often as long as thirty in Britain. Because systems change (not only to be improved) over time, data correct at the time the documents were compiled are often only approximately correct when the documents are declassified. Data should, therefore, be taken as typical rather than precise. Virtually all unclassified data on Soviet systems are limited both in accuracy and in completeness. Hopefully, readers with access to better data may find comparisons with Western systems useful.

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relevant because a great number of the systems described here have been in service for so long. Many of the manufacturers represented here have been extremely generous with material, both factual and photographic. I would emphasize, however, that the descriptions and analyses of equipment are my own, and that the manufacturers should not be held responsible for the conclusions I have drawn.

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Any book of this type is inevitably incomplete, and some inaccuracies will slip in. Additions and corrections for the next (1993/94) edition are most welcome; please submit them to the author c/o Naval Institute Press, Annapolis, MD 21402.

PREFATORY NOTES

RADAR

Radar is described at the beginning rather than in a separate section because radars appear in both the surface and air warfare sections.

Radars are generally described by their frequency bands, peak power, pulse width, and pulse repetition frequency (PRF).

Frequency (which is inversely proportional to wavelength) determines how precise the radar beam can be, since beamwidth (in radians) is approximately equal to the inverse of the antenna size in wavelengths. The larger the antenna, the narrower the beam. Moreover, the larger the antenna, the higher the gain: the larger the fraction of the returning echo the radar will detect. Frequency (or wavelength) also determines the kind of technology required to produce the radar signal, and the extent to which that signal will be absorbed by the atmosphere, e.g., by rain.

There are two quite distinct systems of coding frequency bands. One, developed during and after World War II, describes the physical characteristics of the signals and is almost certainly mnemonic. It is used in this book. A second, more recent system is a more systematic division of the possible radar bands. It was developed for electronic intelligence, and it reflects the fact that other nations (particularly the Soviets) use radar frequencies very different from those common in the West. It is used in this book primarily to describe ECM equipment. Details of both systems are given in Table 1.

The original wartime radar-band system consisted of a metric P-band (P for pulse, as in the U.S. APS and SPS designations), and an S-band for short (or centimeter) wavelengths (about 10 cm). An X-band (for exotic) was added during World War II for a newer generation of 3-cm radars. After the war, the P-band was temporarily abandoned in favor of a long centimetric wave-

Table 1: Radar Frequency Designations

The boundaries between bands in the classic radar system have changed over time, but the approximate positions of the bands do not. 1000 MHz is 1 GHz, and older references use cycles rather than Hertz, i.e., Mc/s instead of MHz.

FREQUENCY	U.S. RADAR DESIGNATIONS	ECM BANDS
30-250 MHz		A
100-150	I-band	
150-225	G-band (World War II IFF)	
225-390	P-band	
250-500		B
390-1550	L-band	
500-1000		C
1000-2000		D
1550-3900	S-band	
2000-3000		E
3000-4000		F
3900-6200	C-band	
4000-5000		G
5000-8000		H
6200-10,900	X-band	
8000-10,000		I
10,000-20,000		J
15,250-17,250	Ku-band	
33,000-36,000	Ka-band	
20,000-40,000		K (K-band embraces Ku through Ka)
36,000-46,000	Q-band	
40,000-60,000		L
46,000-56,000	V-band	
56,000-100,000	W-band	
60,000-100,000		M

NOTE: In radio parlance, HF extends up to 30 MHz; VHF is 30-300 MHz; UHF is 300-3000 MHz; SHF is 3000-33,000 MHz. These boundaries approximate wavelengths of, respectively, 10 m, 1 m, 10 cm, 1 cm, and 1 mm.

length (L-band, about 20 cm), and a new compromise band (C, about 5 or 6 cm) was developed. The advantage of the C-band was that it could be used in conjunction with a small antenna (like X-band) but could penetrate rain better than X-band. There was also K-band (about 1 cm), a designation left over from an abortive wartime attempt to rationalize band designations. Some radars are also characterized as UHF, meaning a frequency range somewhat higher than P but lower than L (the term UHF is used slightly differently in radio).

As a rule of thumb, the beamwidth of a linear array, such as a slotted waveguide, is about 1 divided by the array length (in wavelengths), in radians. A similar consideration applies to a circular antenna, uniformly illuminated. At X-band, the beamwidth (in degrees) of such an antenna is about 70 divided by antenna diameter in inches. Many such antennas use tapered illumination, which gives a slightly wider beam but much lower sidelobes; in that case beamwidth is about 85 divided by antenna diameter.

Naval radar operation is much affected by the fact that signals reflect off the sea. At low frequencies (e.g., P-band), reflected and direct signals interfere constructively and destructively, forming a lobe pattern. The lowest lobe can be at an elevation angle well above the sea surface; as a result, P-band radars generally cannot detect low-altitude targets. On the other hand, at higher altitudes, interference can be constructive, and radar range can be greater than it might be in free space (or, for that matter, over land). The lobing phenomenon itself causes targets to fade in and out of detection as they approach; the ranges at which fading occurs are a crude measure of target altitude. At higher frequencies, lobing is much less significant because the areas of constructive and destructive interference are very narrow and tend to wash out as a ship rolls.

The naval environment poses a special problem for the operation of radars. Because a ship is relatively small, and because it must carry numerous antennas in close proximity to its superstructure, its radars may often be affected by reflection off both the ship and other antennas. The effect is particularly noticeable in the sidelobes. For example, a whip antenna vibrating near a radar antenna may impose a modulation on the radar signal. Such effects may limit the extent to which a naval radar can rely on, for example, doppler information extracted from the details of returning echoes.

Quite aside from lobing, radars are affected by back-scatter off the sea, particularly when they are used to detect low fliers. At 0 elevation, with a beam of 2 deg and a pulse of 2 microsec, the radar typically sees a patch of sea about 0.05 nm² at 10 nm. Back-scatter, in m²/nm² at 8–10 nm is:

	RADAR BAND			
	P	S	C	X
<i>Sea State</i>				
0	—	.003	.005	.01
1	—	.03	.05	.1
2	—	.1	.25	1
3 (moderate)	.001	.3	2	10
4 (rough)	.003	5	20	100

Thus in a rough sea, an S-band radar will see 5 m² of back-scatter at 8–10 nm, and any radar return from a small sea-skimmer (typically of 0.1-m² radar cross section) will be altogether swamped.

At very high frequencies, molecules (mainly oxygen and water) in the atmosphere absorb most radiation. There are, however, 3 windows:

35 GHz (8-mm wavelength)—Ka band

94 GHz (3.2-mm wavelength)—M band in the ECM system

140 GHz (2.3-mm wavelength).

The current upper limit on reasonable radar power generation is probably 94 GHz. Millimeter-wave radar touches the far infrared part of the spectrum. In the infrared, which is closer to light, there are windows at

8–14 micrometers (0.008–0.014 mm) and

3–5 micrometers (0.003–0.005 mm).

(The term micron is typically used instead of micrometer, i.e., one-millionth of a meter, or one-thousandth of a millimeter.)

Visible light wavelengths are an order of magnitude smaller, around 0.5 micron, or 0.0005 mm.

Radar power determines how well the radar is able to detect an individual echo. Because detection is cumulative, a large number of relatively weak echoes will have the same net effect as a small number of strong ones. Moreover, the detectability of an individual echo depends not only on its peak energy but also on how long it lasts. Thus maximum radar range is commonly equated to average radiated power, i.e., to the product of peak power, pulse duration, and pulse repetition rate or frequency (PRF). The product of pulse duration and PRF is the duty cycle, the amount of time, as a fraction or percentage of the total time, that the radar is transmitting. For example, a radar transmitting pulses of 1 microsec at a PRF of 500 pulses per second has a duty cycle of 0.0005; if peak power is 1 MW, average power is 500 W.

The radar's ability to distinguish objects at different ranges depends very much on pulse width (pulse duration) and on PRF. Because a radar measures distance by measuring the time between sending and receiving a pulse, it cannot distinguish a distant echo, returned after the next pulse has been sent, from a close-in echo, returned soon after that next pulse has gone out. Because of this second-time-around (STA) problem, unambiguous or maximum radar range is commonly equated to half the time interval between pulses, i.e., to the inverse of the PRF. This is not the same as the range the radar will actually achieve on a given target, but it is often the figure listed as radar range. Since the radar designer maximizes the probability of detection by maximizing PRF, a designer will generally try (but possibly fail) to match PRF-range with a realistic range on the target of greatest concern.

Some radars eliminate many STA echoes by jittering the PRF around an average value. The apparent range of STA echoes will vary with PRF. Thus, such echoes can easily be eliminated. Jittering cannot, however, eliminate the STA echoes of large objects, such as land masses. So PRF remains a measure of effective range.

Radar signals travel at about 186,000 miles/sec (about 162,000 nm/sec, or 300,000 km/sec), so the unambiguous range for a 1000-pps radar is about 81 nm (162 nm between pulses, for a pulse to go out and return). Thus 2000 pps corresponds to about 40 nm, and 500 pps to about 162 nm.

There is 1 important exception to this idea. Pulse-doppler radars use very high PRFs and typically detect targets at ranges considerably beyond their unambiguous range (because actual detection range depends on the average power sent out, i.e., on the product of peak power, pulse width, and PRF). In effect, pulse-doppler radars compromise between operating at a pure frequency (i.e., in a continuous wave, CW, mode) and pulsing. They use variations in the frequency of the target echoes to measure target velocity.

Just as a pulse radar can be limited in its unambiguous range, a pulse-doppler radar is limited in its range of unambiguous velocities. The radar signal is a mixture of pure signals of different frequencies spaced around the nominal radar frequency; each such subsignal is doppler-shifted by the velocity of the target toward or away from the radar (radial velocity). The shift in frequency is given by target radial velocity as a fraction of the speed of light. The different subsignals are separated in frequency by the PRF of the radar. Just as the radar cannot distinguish echoes that return after the next signal has been sent (i.e., whose delay times exceed the pulse repetition interval), a pulse-doppler radar cannot recognize velocities whose doppler shifts exceed the PRF. For example, a velocity of 1000 km/hour (620 mph, 540 kt) shifts an X-band signal (10,000 MHz) by about 9200 Hz. Typically the first speed that cannot be distinguished is called the first blind speed. These considerations explain why

doppler radars often use extremely high PRFs, e.g., 20 kHz (corresponding to an unambiguous range of only 4 nm).

The higher the PRF, the worse the associated ambiguity in pulse range. High-PRF radars typically measure range by varying their carrier (radio) frequency with time, associating a particular range with a particular frequency. For example, frequency can rise up to a maximum, then fall back to the initial frequency. The frequency shift associated with range is mixed with the frequency shift associated with target doppler, and the radar must sort between them. One solution is to insert a constant-frequency segment at the end of each period of changing frequency; the frequency shift of this segment is the target doppler shift. Another is to vary frequency smoothly up and then down. The target doppler adds to the rising frequency on one half cycle and subtracts on the other. This scheme also uses a flat (constant-frequency) segment to measure target doppler.

Doppler data may be important in itself if the radar is being used to predict target motion. It is also the most important means by which the radar distinguishes among multiple targets. Given measurements of the target dopplers, the radar can associate the appropriate rising and falling frequency segments for the different radars (de-ghosting). Since a target must be detected on all 3 segments of the frequency cycle, maximum detection range is shorter than in the pure-doppler case. Fighter radars, therefore, generally have a separate velocity-search mode, operating at a pure high PRF. They can switch to a range-while-search (FM-ranging) mode.

Some fighter radars, such as the AWG-9 of the F-14 Tomcat, have an additional raid-counting mode. Beyond some particular range, several aircraft will fit within each radar resolution cell. Raid counting protects a fighter from locking on to the raid as a whole and, hence, losing the ability to deal with any particular airplane before it is too late. Between search scans, the radar spotlights (scans narrowly) the radar target(s) representing the raid for precise doppler measurement. Several aircraft flying together will have slightly different doppler shifts, and the spread in the radar return is measurable. A multiple-aircraft symbol appears on the display. As the range closes, and the target covers a larger angle, the radar automatically widens the spotlight scan.

FM-range accuracy is limited by the precision with which the frequency of the returned signal can be measured, i.e., by the width of the filters (real or mathematical) making up the doppler filter bank; that width in turn is limited by the integration time, the length of time during which frequency ramps up or down (this time interval is also a measure of maximum unambiguous range). The total extent of frequency change is limited by the requirement that the lowest-doppler targets be distinguishable from clutter. All of these considerations greatly limit the accuracy of FM ranging for a high-PRF (doppler) radar.

High PRF is attractive partly because it can give a high probability of target detection even at a relatively low peak power. (Radar detection is a cumulative process, each pulse having some probability of being picked up, so detection depends on average power, not peak power, and average power can mean many relatively weak pulses per second.) Since counterdetection generally depends on the strength of the particular pulse picked up by the target's radar detector, the high-PRF/low-peak power solution may amount to a somewhat stealthy radar.

Anywhere near the ground an airborne radar will pick up the echo of its sidelobes (and, in cases in which the radar points down, its main lobes). Suppression of this clutter becomes a major radar design objective, particularly for radars intended to operate over land (which scatters much more of the signal back toward the radar; the sea tends to scatter the signal forward, away from the radar). Because the main lobe looks toward the ground, it encounters very strong STA echoes, which can entirely overshadow the echo from a target. The target echo can, however, be separated out by means of its doppler shift, since the ground (as seen by the airborne radar) may have a very different doppler shift, reflecting its very different velocity.

The ground will reflect a variety of radar lobes, both main

and side. For a radar pointing down at a shallow angle, the sidelobes all see the ground at relatively short range. The main lobe sees the ground at a much greater range, closer to the range of any potential target. Thus a radar giving unambiguous range information (i.e., at low PRF) can exclude much sidelobe clutter by avoiding short-range targets, but the radar may not easily distinguish the strong echo of the main lobe from a real but very low flying target (this distinction depends on pulse width, i.e., range resolution).

The alternative is to use relative doppler shifts. The sidelobes, striking the ground at different angles, give different radial-velocity components, corresponding to a range of doppler shifts, from very low frequency (associated with the lobes pointing almost directly at the ground) up to the main lobe, whose image of the ground may show a shift corresponding to a large fraction of the airplane's speed over the ground. The shift will be strong but relatively narrow in frequency. The sidelobe clutter will be weaker, but it will extend over a very wide range of frequencies, corresponding to everything between 0 and the actual velocity of the airplane over the ground.

An airplane flying nose-on toward the radar will have a very high relative velocity and a large corresponding doppler shift, well away from the shifts of the ground clutter. The plane can, therefore, be detected at long range. On the other hand, an airplane flying away will have a very small relative velocity, hence a small doppler shift, and that plane may be swallowed in the ground clutter. Modern fighter radars typically operate at very high PRFs (often hundreds of kHz) so that they can effectively and unambiguously detect nose-on (closing) targets. At very high PRFs, it is difficult to resolve range ambiguity, and available methods reduce the detection range. For this reason, for example, the longest-range mode of the AWG-9 radar (used to control the Phoenix missile) is velocity, i.e., doppler search.

A medium-PRF mode is often available as a compromise to permit detection of tail-aspect (low-relative velocity) targets. Both range and doppler are ambiguous. The strong main lobe peaks in frequency are far enough from one another (because the PRF is great enough to keep the signal components well part) that target signals can be distinguished. On the other hand, there is still enough range precision to separate the close-in sidelobe clutter. Range measurement in general is easier than with high PRFs. Both high- and low-speed targets still have to compete with sidelobe clutter.

The doppler blind zones are eliminated by shifting among several quite different PRFs, each maintained for a brief period. Such switching limits maximum range because there is never very much time to integrate over numerous pulses. One common scheme is 3:8, the cycle consisting of 8 PRFs covering overlapping doppler ranges, any 3 of which must be clear for detection. An earlier alternative is to use 3 widely separated "major" PRFs. Each is flanked by 2 "minor" PRFs. Range ambiguity is avoided by switching from the major PRF to the 2 minor ones in succession (one for resolution, the other to eliminate ghosts). The problem is that because the minors are close to the major, their blind zones may be adjacent. Using a cycle of widely spaced PRFs (without minors) eliminates the problem.

Most shipboard radars exemplify the low-PRF case, and the big airborne early-warning radars also employ low PRFs, for long unambiguous range. Fighters generally use high-PRF transmitters that can switch to medium PRF. Radars for close-in weapons such as Phalanx are generally high-PRF pulse-doppler types.

Pulse width determines resolution, the ability to distinguish between 2 targets that are close together. Radar signals travel at about 300,000 km/sec, so a pulse length of 1 microsec corresponds to a distance of about 300 m. Resolution is generally slightly greater than the length associated with 1 pulse length, since the radar cannot quite distinguish 2 pulses end-to-end.

Waveguides and other radar components can carry only a limited amount of energy. If that limit is exceeded, they break down. For example, an overloaded coaxial or waveguide may arc (spark), so that no signal at all is transmitted. Since radar range

depends on average power rather than on peak power, 1 alternative is to spread that power over a pulse varying in frequency (a chirp). The returned echo can be compressed ("pulse-compressed") into the equivalent of a very energetic short pulse. Pulse coding is another approach to the same problem. Different portions of the extended pulse are differentiated, e.g., by polarization. The resulting pulse bears, in effect, a coded signature that can be distinguished from the surrounding noise. In either pulse compression or pulse coding, the key is that the radar can distinguish between different parts of the long returning pulse, so that it can be made equivalent to a much shorter pulse.

Pulse compression or coding has another advantage: stealth. A pulse-compression radar spreads its energy over a series of frequencies, using a short pulse in each. Although total average energy may be considerable, there may be relatively little peak energy in any one pulse; therefore, a countermeasures receiver may find such pulses difficult to detect. The longer the train of pulses, the lower the peak power (for a given average power, i.e., for a given detection range). Recent pulse compression radars with very low peak power, such as the new Canadian SPS-503 and the French DRBV 26C, are designed specifically for low probability of intercept. Ultimately the pulse train (extending across different frequencies) could occupy nearly all the time between initial pulses. Such a radar could be described as frequency-modulated continuous wave (FMCW) or as spread-spectrum (for low probability of intercept), and the only current public example is PILOT (see Sweden in the Antiaircraft Warfare section).

Radar beam dimensions are horizontal $\times$ vertical; the horizontal dimension measures how accurately the radar can locate a target in bearing without concentrating on that particular target (e.g., by beam switching or monopulse techniques). Antenna dimensions are, similarly, width $\times$ height. Scan rate or data rate is the rate at which the antenna spins and, therefore, the rate at which data about the location of any particular target are renewed. The faster the scan, the higher the target speed with which the radar can cope. On the other hand, the faster the scan, the shorter the time during which the radar dwells (stares) at any particular target and, therefore, the lower the probability that a target will be detected.

Typically, a distinction is drawn between search and tracking radars. A search radar scans continuously. A pure tracking radar follows a particular target, using some technique of beam switching or beam comparison (e.g., monopulse) to detect target motion. Any scheme for associating successive target locations (as detected by a search radar) to establish an approximate target track blurs this distinction. The quicker the scan, the more accurate the track. Very quick scanning radars with the appropriate associated memory are, therefore, described as track-while-scan (TWS) radars. As more and more search radars are associated with computers for automatic detection and tracking (ADT), and as more information is extracted from radar echoes, TWS operation is becoming more universal.

Some further points deserve brief mention here. Radar tracking generally requires the radar to compare several beam positions, i.e., to measure when it is off the correct direction. One method is conical scanning (conscan), in which the beam spins. Each position of the spinning beam is somewhat off the proper radar direction, but the beam is symmetrical about the direction at which the radar antenna is pointed. Thus, if the radar return is constant while the beam spins, the radar is pointing right at the target. If 1 beam position shows a higher return, then the radar is pointing off, and the point in the scanning cycle at which the return is greatest can be used to show the appropriate correction. The 2D equivalent of conscan is a nodding radar, pointing its beam alternatively to left and right (or above and below) the target. Conscan is simple to design, but it is subject to a relatively simple countermeasure. If a strong signal is sent back out of sequence, the tracker may pick it up in a sidelobe. In this way a jammer mounted on the target can appear to the tracker to be well off to one side; it can capture the tracker and

lead it astray. This technique is called angle-stealing or angle-gate pull-off.

The usual counter is monopulse, a technique in which the radar continuously and simultaneously puts out multiple beams, continuously comparing their signals. Since there is no cycle associated with this sampling, there is no way that a point jammer can insert a deceptive signal out of sequence. The tracker can be led astray only by signals from several distinct sources, separated in location, a technique called "cross-eye."

Three current technical developments deserve brief mention here. One is the rise of solid-state transmitters (see, for example, the French DRBV 26C, the British AWS-7, and the U.S. SPS-40). This trend is distinct from the much earlier movement from vacuum-tube to solid-state technology for radar control and data processing. That left one big vacuum tube, the radar transmitter, which had to be cooled and protected. Now solid-state transmitters are powerful enough to be used, in combination, in place of the tubes. The solid-state transmitters are more reliable; they require less power (and emit less heat); and they cannot burst. Moreover, since numerous transmitters are used together, the failure of any one of them does not put the entire radar out of action. For the U.S. Navy, the first major solid-state transmitter is that replacing a klystron in some SPS-40 radars. This transmitter is expected to achieve a mean time between failure (MTBF) of 10,000 hr, and it will probably be followed by an SPS-49 solid-state transmitter. The SPS-40 unit uses 112 2500-W modules, each of which uses eight 400-W peak-power transistors working in parallel.

A second major technical development is the appearance of better and less expensive means of electronic beam forming and movement. In the past, phase shifters were expensive and unreliable, and many electronically scanned radars used frequency-scanning (in one dimension) instead. That method was effective, but it limited the extent to which a radar could hop among frequency bands, since the angle of elevation of the radar beam depended entirely on the wavelength of the signal. Now phase shifters are much less expensive, and newer radars tend to employ them rather than the older technology of frequency-scanning. The next step is the active-array radar, in which the elements of the antenna themselves transmit the signal. There would then be no need to apply a phase shift to a signal produced by a separate unitary transmitter. The new Japanese OPS-24 is the first active-array radar to have entered operational service (see the Addendum).

A third development is software-controlled transmission. In most radars, pulse characteristics are determined by hard wiring. They are extremely difficult to change. There may be special wartime operating characteristics, but they, too, are hard-wired; and even when compromised, they cannot easily be changed. However, a number of current airborne radars, such as APG-65, are software controlled, so that their signal characteristics are quite easily changed. This ability will potentially allow the system to counter current methods of radar recognition by pulse analysis. It may still be possible to recognize a radar by the detailed structure of its pulses, but that type of recognition is several orders of magnitude more difficult.

The major types of radar scope in current use are:

A-scope Range vs. signal strength, with range measured horizontally. This was the first type of radar display. The great remaining advantage of the A-scope is that jamming can more easily be distinguished from a real signal, both appearing as spikes.

A/R-scope Precision A-scope, typically for fire control. A precision sweep is a magnified version of the main sweep, its range notch corresponding to a range step on the main sweep. The range step can be moved to the target. When the range notch of the precision sweep is on the target, the target range is gated for tracking.

B-scope Range vs. bearing, distorted so that all signals at a given

bearing are in 1 vertical line. This reduces the spread of signals at long range and is often used for gunfire control.

PPI Plan position indicator, the classic maplike radar display. Usually the ship or airplane is at the center, but PPIs can be off centered. A PPI is, in effect, a rotating A-scope in which the spikes of the former are replaced by brightening on the face of a CRT.

RHI Range-height indicator, in effect a PPI showing range and altitude instead of range and bearing. It is the natural display for 3D radars.

OPTRONICS AND INFRARED DEVICES (PHOTONICS)

An increasing number of naval sensors operate passively, either in the visible band (optronics) or in the infrared. Optronics is the combination of optics and electronics, as in a television; optronic devices are sometimes also called electro-optical (EO) for the means by which they convert light signals into usable electronic ones. Optical and infrared technology have enough in common to be treated together, although there are important differences. Since both optronics and IR generally involve the detection of photons (which produce electrical signals by knocking electrons from one energy level to another), optronic and IR devices are sometimes lumped together under the heading photonics, as in the coming generation of submarine masts.

An optical device detects radiation, reflected from an object. Generally that radiation is sunlight, although there is an important class of image-intensifiers that provide passive night vision based on reflected starlight or moonlight. Typical wavelengths are about 0.4–1.1 microns (commonly 0.7–0.95 microns).

Unlike an optical device, an IR detector is concerned mainly with heat radiated by an object, such as the hot plume of exhaust gas, aerodynamically generated heat, or even a person's body heat. IR technology includes both seekers (as in air-to-air missiles such as Sidewinder) and thermal (night) imagers, the latter working on much smaller signal-to-noise ratios (i.e., on much smaller differences between target temperature and background temperature). All objects hotter than their surroundings emit some heat, and the wavelength at which the maximum radiation is emitted varies with the temperature: the hotter the object, the shorter the wavelength. The shape of the curve of emissions also changes, so that the ratio of the strength of emission at one wavelength to that at another will also change. The farther apart the 2 readings, the more drastic the change in their ratio as the temperature changes. The emitted spectrum generally contains a line structure characteristic of the object, but this structure is generally too complex to be used operationally.

There are 2 classes of IR detectors, cooled and uncooled. The cooled detectors respond to individual photons striking them; cooling is necessary to reduce the amount of extraneous activity. Most current missile seekers and imagers fall into this category. There are also uncooled detectors, generally measuring the heat difference between an object and its surroundings (pyroelectronics). At present they are used primarily in short-range low-resolution devices, such as the detectors firefighters sometimes use to search rubble for survivors. For the future, however, they are attractive because they can operate without bulky cooling systems. Moreover, since they need not wait until they cool to operational temperatures, they can (at least in theory) be used in faster-reacting missiles. The distinction between cooled and uncooled is not altogether precise, however, since even uncooled detectors of standard types can often function to some extent against hot enough sources, such as jet engines.

Current imagers, which work against relatively cool heat sources, must be cooled to well below ambient temperature. Their technology, then, includes not only that of the detector and related signal processor, but also the cooling mechanism. In air-to-air missiles such as Sidewinder, the cooling source may be a bottle of liquid gas that cools by expansion; in

many optronic/IR detectors, the mechanism is a closed-cycle refrigerator.

IR radiation is defined as wavelengths too long to be visible, i.e., from 0.8 or 0.9 microns up. IR devices operate in a few "windows" through which radiation easily passes: 1.5–1.8, 2.1–2.4, 3–5, and 8–14 microns. The last 2 are the most commonly used in military and naval systems. The different windows are sometimes called different IR "colors," so that a 2-color IR device generally works at both the 3–5- and 8–14-micron bands. Typically the 3–5-micron range is defined as mid-IR (MIR), and the 8–14-micron band as LWIR (long-wave IR). The hotter the source, the shorter the wavelength at which it provides maximum radiation. Thus devices intended to detect very hot objects, such as jet engines and active guns, often operate in the mid-IR; they include missile seekers. Imagers intended to detect cooler sources operate best in the LWIR region, although many operate in both bands.

Compared to radar, photonic devices suffer much more severe weather limitations. Generally they cannot penetrate clouds or rain, although IR signals will penetrate haze better than visible light. Variations in temperature and water vapor in the atmosphere will tend to bend both visible light and IR radiation. Generally longer-wave IR will suffer less than shorter wave in haze and fog. Some typical transmission factors are

Visible Light	3–5 Microns	8–12 Microns
1.00 (no fog)	1.0	1.0
0.5 (fog)	0.87	0.97
0.10	0.36	0.66
0.01	0.01	0.22

That is, when only 1% of the light is penetrating, 22% of the LWIR radiation is still available.

Typical IR detectors are lead sulfide (1–3 microns), indium antimonide (3–5.5 microns), mercury-doped germanium (8–13 microns), and mercury cadmium telluride (2–14 microns; photoconductive at shorter wavelengths and photovoltaic and photoconductive at longer ones). Lead sulfide cuts off at about 3 microns when uncooled and at 4 microns when cooled. Indium antimonide does not extend its range when cooled but does become more sensitive. For shorter wavelengths, silicon is effective at 0.4–1.2 microns. Television cameras typically use antimony sulfide (0.4–0.7 micron).

A jet pipe radiates most strongly at 3.75 microns, and early air-to-air missiles homed on this radiation. Because an airplane's jet pipe is visible only within about 30 deg of dead astern, violent maneuvers often sufficed to break the locks of such missiles. The hot plume of exhaust gas radiates most strongly at 3 microns (carbon dioxide) and at 4.2 microns (water vapor), and extension of the seeker to these wavelengths greatly enlarges the area astern within which a missile seeker can operate. This is still a signature visible largely from astern, although someIRSTs (such as the French VAMPIR) can detect the rising plume of a missile exhaust from ahead. A fast airplane or missile is heated aerodynamically, and its skin will glow in the infrared; it can, therefore, be detected from ahead. A supersonic target, flying at Mach 1.25 at low altitude, will radiate most strongly in the 8.6-micron range, although some radiation will spill over into the upper end of the 3–5-micron range. The figures above show why indium antimonide was so much more effective than lead sulfide, since it could detect not only a hot jet pipe and exhaust radiation, but also the shorter-wavelength radiation from aerodynamic heating.

Aerodynamic heating is not the only source of forward-aspect IR detection. Sunlight will glint off glass and even aircraft structure, and the IR portion of this glint can be detected.

Thermal imagers will generally have to detect relatively cool heat sources, all of which will radiate at relatively long wavelengths. Typically they will detect temperature differences as small as 0.1°C, and differences of about 10°C will be detectable at ranges as great as 10–20 km. In contrast, a missile seeker

will be looking at hot tailpipes, with temperatures of hundreds of degrees, and even an aerodynamically heated wing leading edge may be 65°C hotter than its surroundings.

Devices divide into point detectors for tracking (such as the seekers of most air-to-air missiles) and imagers, such as television cameras. A point or spot tracker cannot distinguish different IR sources (of the same character) within its field of view; thus, it is vulnerable to flare countermeasures. The simplest counter-countermeasure is to examine the characteristics of the detected target, e.g., to compare its image in 2 different wavelengths so as to measure its apparent temperature. That comparison may be done in 2 portions of the same color (2 shades) or in 2 colors (which generally requires 2 separate detectors). Such processing greatly complicates the design of an IR decoy, since the decoy generally relies on sheer power (often generated at a temperature quite different from that of the target) to provide sufficient brightness. Two-shade or 2-color processing will also make it easier for a seeker to distinguish the sun from an appropriate target.

Generally a reticle, a series of openings in an otherwise opaque screen, is spun in front of a point detector. The reticle defines a beam pointing slightly off the missile axis, and the overall effect is much like that of a conically scanning radar. If the missile is pointing directly at the heat source, the signal does not vary with time, since the spinning beam always intersects the source in the same way. Otherwise, the signal strength varies as the reticle spins, and the variation is used to generate the correction signals that point the missile (or, more precisely, the tracker) at the target. Because the tracker associates a particular direction with a particular point in the scanning cycle, it is vulnerable to countermeasures in which the apparent target signature is flashed; it can mistake the flashing signature for time variation due to its own scanning.

Rosette scanners reduce this vulnerability by adopting a more complex scanning pattern, in which the scanned point covers more of the available area. It swings back and forth as well as in a circular path. A spiral scan is a simpler variation on this theme. Alternatively, the reticle can spin off-center to produce a signal whose frequency varies over time. In each case, because the association of direction with time is no longer simple, a simple flashing signal will no longer necessarily convey directional information, and thus will no longer serve to throw off the missile seeker. This immunity to countermeasures is purchased at the cost of greater complexity in the missile scanner; some arrangement of prisms and mirrors must replace the simple reticle of the circular-scanning seeker.

The alternative to a scanning seeker is a staring seeker, consisting of an array of point detectors. Such an array might be considered broadly equivalent to monopulse, as opposed to conical-scanning operation, with the same immunity to a time-varying countermeasure. Such detectors are sometimes described as offering IIR performance.

Imagers generally form their product by sampling the brightness, either in the optical or in the IR spectrum, of an image formed by one or more lenses. In a standard television camera, the image is formed on a plate inside the imaging tube, and this plate is electronically scanned; tube output voltage is proportional to the brightness of the portion of the plate hit by the scanning electron beam.

Alternatively, the pickup device may be a CCD (charge-coupled device), a matrix of photosensitive sites on the surface of a solid-state device. The electric charge at each site is proportional to the amount of light (the number of photons) striking it; a typical silicon device will respond to wavelengths 0.4–1.1 microns, with peak response at 0.7–0.8 microns. The charge at each site is turned into an electrical signal, and thus the image focused on the CCD array can be read out electronically (the individual charges are read out in sequence, just as the electron beam reads the image off a photocathode). Depending on the material of which it is made and the character of the array elements, a CCD array can be designed to function either in the visible or in the IR spectrum; the CCD camera is a focal-plane

array device. A CCD array can be considerably more sensitive than a conventional video tube, and thus a camera incorporating it can function at low light levels.

The conventional television detector is a fully analog device, in the sense that the position of the sampling electron beam will vary continuously over the width of the plate in the tube. The CCD imposes some quantization, since each diode is separate.

In a television camera, the electron beam scans horizontally across the image to form a line, and the lines are displaced (rastered) vertically down the image to form a complete frame. Resolution is measured by the number of lines per frame. Although picture brightness will vary continuously along each line, the system is generally arranged so that resolution is the same vertically and horizontally. Picture shape is defined by aspect ratio (or one might say that the appropriate aspect ratio is the one for which horizontal resolution matches vertical resolution). For example, the standard U.S. television frame employs 525 lines, and the aspect ratio is 4:3; it follows that each line consists of 700 picture elements ($\frac{4}{3}$ times the number of lines). The entire scene is represented by a total of 367,500 pixels. The television displays 30 such pictures (frames) each second. Just as in radar, this type of sequential scanning defines a data rate that determines just how well the television can detect rapid motion, in this case rapid angular motion.

A television-type sequential or serial scanner splits its image into a series of lines, so that picture elements that are close together vertically will be far apart in time. It is, therefore, much easier for the system to compare elements close together horizontally, since they lie along the same scanning line.

Low-light-level television (LLTV) interposes some form of light intensification between the optics and the viewing screen. In the simplest such devices, starlight scopes, the incident light falls on a photocathode, which releases electrons. These electrons can then be processed to produce a stronger signal. Vietnam-era starlight scopes used very large voltages, typically 10 or 30 kV, to accelerate electrons given off by the photocathode. The electrons in turn struck a phosphor screen, which glowed. Such voltages required bulky equipment and large power supplies. In particular, Vietnam-era starlight-scope technology would not be suitable for NVGs, which are now common on board airplanes and helicopters.

The key to compactness is an electron multiplier, a micro-channel plate (MCP). The initial electrons are accelerated over a short distance via an electrostatic lens. The MCP is an array of glass capillaries (channels) down which electrons are accelerated. They collide with the channel walls, which are coated with secondary electron emissive material. As in the original starlight scopes, these electrons in turn are used to produce a brighter secondary image, typically on a phosphor screen that glows when it is struck by electrons. The MCP does not distort the form of the image, and the entire device can be quite compact. In a typical modern set of aviator's NVGs, the accelerating voltage is 1–3 kV, the typical light gain is 30,000, and the spectral response is over the 0.3–0.91-micron band, covering the ultraviolet to the near infrared. Distortion is about 7%, and magnification is close to 1, i.e., the final image is very nearly the same as an image of the scene in natural light. The same technology can create an electrical signal corresponding to the amplified image, and this signal in turn can be displayed on a television screen.

MCP devices are considered second and third generation light intensifiers, the difference being the use of gallium arsenide photocathodes in the third generation, replacing tri-alkali materials such as sodium potassium cesium antimonide. The new material increases electron emission, for a given light level, by a factor of about 10. These materials also differ in their response to different wavelengths of light. A second-generation tube is most sensitive at 0.5 micron, but a third-generation tube works at 0.6–0.9 micron, so that its range extends well into the near infrared. That extension is useful because the night sky provides much of its illumination in the near-infrared region (the day sky

is lit mainly in the visible range). Thus the third-generation tube not only makes better use of what it receives, it also receives much more energy in the first place. Third-generation tubes first appeared in the 1970s.

In each case, the initial very weak image is converted into electrons, which are then amplified either by acceleration (which makes the individual electron more energetic) or by a combination of some acceleration and multiplication; the electrons are then used to create a secondary image on a phosphor screen.

There are three kinds of LLLTV. One uses a starlight scope as the input to a conventional television image tube. Another uses a CCD as its imager, since a CCD can be much more sensitive than a conventional video tube. Finally, the combination of a starlight scope image intensifier and a CCD detector can provide an image under conditions of very low light.

There is no IR equivalent of the television electron-beam imaging tube. Instead, an imager will generally use a rapidly rotating (5–10,000 rpm) mirror, whose sides are at slightly different angles, to break up the image in the focal plane, illuminating one or more detectors at a time. Until about 1960 there were only single-element detectors, so scanning always had to be 2D, one mirror scanning in each direction. By the early 1960s there were linear arrays, which were characteristic of Vietnam-era FLIRs. 2D arrays of discrete detectors appeared in the late 1970s.

A typical imager uses multiple detectors, across which the image of the scene may be scanned. For example, a FLIR imager typically uses a vertical array of detectors, which scan across the scene. Unlike a television, a FLIR produces all of the lines across the scene simultaneously. They are multiplexed to produce lines in sequence for television viewing. Since it generally cannot accommodate as many detectors as a standard television provides lines, the FLIR image will often not be of television quality. In some cases, even though the detecting array is linear, scanning is not only horizontal but also vertical, so that a smaller and lighter array can still cover a wide field of view.

The U.S. common module FLIR uses 180 detectors in its vertical linear array, scanning across 480 pixels horizontally. Two horizontal scans are interlaced, so that in effect there are 360 vertical positions. The sampling rate per channel is $480 \text{ pixels} \times 30 \text{ Hz (frames/sec)} \times 2 \text{ (interlacing)}$, for a total of 29 kHz. An equivalent serial scanner would scan at a rate of 5.2 MHz because the head would have to cover all 360 vertical positions as well as the 480 pixels; the associated mirror system would have to scan at more than 60,000 rpm. The same performance could also be achieved by a hybrid device, with several detectors in both the serial (horizontal) and parallel (vertical) directions; in this case scanning would be slower, and the use of several detectors in the horizontal direction would improve the signal-to-noise ratio.

There are also 60- and 120-element U.S. common module detectors (DT-591 and -594), both operating in the 7.7–11.75-micron band. Hughes produces a standard 160-element parallel-scanning FLIR module.

Current naval aircraft common module FLIR systems are AAQ-16 for the V-22, AAR-50 for the F/A-18 (navigational FLIR), AAS-36 in the P-3, AAS-38 in the F/A-18, and OR-263/AA in the S-3.

Many British systems use TICM (thermal-imaging common modules), which are serial scanners using SPRITE (signal processing in the element) detectors. SPRITE is a linear array that is mathematically equivalent to a point detector: the output of each element is added up, with an appropriate time delay, for a net improvement in signal-to-noise ratio. A vertical array of SPRITEs would be equivalent to the arrays in current U.S. FLIRs, scanning a scene in parallel. TICM was first proposed in the mid-1970s and thus represents a later technology than the U.S. common modules. Class I is a man-portable direct-viewing system made by Thorn-EMI; Class II is a mid-performance module, made by GEC-Marconi (which defeated Barr & Stroud). The Class II TICM is to be used on board U.S. AV-8B Harrier IIs.

FLIR is sometimes distinguished from DLIR (downward-look-

ing IR), a line-scan device used for reconnaissance. A DLIR scans a few IR detectors across an airplane's line of sight, using the forward motion of the airplane to provide the other scanning direction. The resulting images are recorded either on film or on magnetic tape. As in the somewhat analogous case of airborne synthetic-aperture radar, the image is viewed on the ground, but a slightly time-late version can be displayed in the air.

Both FLIRs and DLIRs first entered service during the Vietnam War, where they were important sensors. Both were means of viewing a scene in reduced illumination, and both therefore competed with, and complemented, light intensification devices.

Post-Vietnam developments were generally in detector sensitivity. In many modern systems the individual detectors of the vertical array are replaced by linear arrays. The individual elements of such a subarray see the scene one at a time, and their outputs can be integrated (using suitable time delays) to produce a better and less noisy result.

The ultimate detector development is a staring array (focal-plane array) on which the image is focused. The image is self-scanned, i.e., its subelements are sampled electronically. No mirror is needed, and the system is physically very stable, so that signals can be integrated over a long time to eliminate noise. Such a system may, therefore, be able to operate without much cooling. However, the staring array will rarely be able to cover a very wide area (field of regard) at a reasonable level of resolution. Typically its designer will have to accept either limited resolution or else some mechanical means of stepping to scan over a wider area. In the latter case, the staring array is, in effect, a better version of the linear detector already described. Since the array itself is stepped, it cannot move very quickly, and frame time may be lengthy. Scanning systems tend to be best for wide field coverage; staring systems provide more sensitivity.

Because the array stares continuously at a scene, it can easily register change from frame to frame. If the array stares continuously at the scene, then in theory elements of the scene can be read off in any desired order. Elements that are close together in the scene are also close together in any electronic representation of the scene taken from the array.

A focal-plane array is a 2D detector array on a single chip, with the preprocessor integrated into the same chip. Analog outputs are multiplexed, so that there is a single output into the analog-to-digital converter. This output is equivalent to the output of the imaging tube of a television. The alternative is a series of discrete detectors, each feeding into an analog-to-digital converter and multiplexer. The effect of the large number of elements of the focal-plane array is to improve field coverage; their small size makes for better resolution and better signal-to-noise ratio; and on-chip processing makes for less noise and also for faster readout. Typically the scanning (multiplexing) algorithm is built into the processing chip, so scanning within the array is always sequential. Such arrays can be arranged to stare at a scene, or they can be used as elements scanned across an image. A typical current chip accommodates as many as 512×512 individual detectors in a 12-mm square, 16 mm thick. Individual detector elements are tens of microns across.

Signal processing in the focal-plane array is a development of the mid- to late-1980s. At present the U.S. DoD is seeking the development of large inexpensive focal-plane arrays using mercury cadmium telluride, platinum silicide, and extrinsic silicon detectors. The goal is to match the cost and capability of current television CCD focal-plane arrays; the projects include on-chip preamplification and multiplexing.

Work is also proceeding on better uncooled detectors. In 1986 Plessey displayed a lightweight 64-element linear array of pyroelectric detectors; the company offered a 128-element array, suitable for use in a FLIR. At this time it also offered a 16×16 -element staring array and expected a 64×64 -element array, with sufficient resolution for its operator to recognize a tank, to be ready for production in 1990. The company expected

to have a 256×256 array, sufficient for an air-to-air missile, in 1992. By 1995 Plessey hoped to be able to duplicate TICM II performance with pyroelectric detectors.

The great current challenge is to manufacture focal-plane arrays at low prices. In 1990 a 64×64 -element indium antimonide array cost about \$50,000 (in FY86 dollars, the cost per pixel is about \$10). This price is far too high to realize the potential advantages of focal-plane arrays in tactical weapons. In 1986, for example, a DoD estimate showed a need for more than 340,000 64×64 -element arrays between 1991 and 1996, which in turn would cost about \$17 billion. A producibility program, the Infrared Focal-Plane-Array Initiative, was, therefore, proposed (and funded by Congress in 1989); its goal is to reduce the cost per pixel to 10¢, i.e., to 1% of the 1986 figure. The companies involved are Rockwell, Hughes, and Fairchild, and the materials are indium antimonide, mercury cadmium telluride, and platinum silicide. Foreign equivalents to this initiative include the French SOFRADIR (primarily for a new antitank missile, Trigat) and a Japanese program.

Two other important developments should be mentioned. One was the discovery that a tracking circuit could be applied to a television image. If some part of the image could be defined clearly enough, then the tracker could keep pointing the camera at it and thus could guide a missile or a fire-control system. This development applies to daylight television, LLLTV, and also to thermal imagers. It was the basis of Vietnam-era electro-optical "smart bombs" such as Walleye and their successors.

The other discovery was that appropriate circuitry or software could be made to notice important features in a television scene, alert operators to their presence, and then track them. This development is the basis ofIRST devices, such as the French VAMPIR and the Canadian-U.S. SAR-8. AnIRST scans a scene, for example, turning through 360 deg, and searches for particular features.

In both cases, signal processing and image recognition are necessarily relatively primitive. The most obvious criterion for object recognition is relative contrast, which shows up as a sudden change in signal strength pixel to pixel, or from one portion of a scanning line to another. In each case, the primary operation in tracking is comparison of the image from frame to frame.

Contrast trackers typically follow the centroid of a dark area or an edge. In centroid tracking, an area of the overall scene is defined by gates above and below and to either side. The tracker breaks the gated area into quadrants, calculating the total intensity of each. The intensity is treated like the output of one channel of a monopulse seeker, the tracker pointing toward the most intense quadrant. An edge tracker is a variation on this theme: the edge is detected and then tracked by centroid techniques.

The other, more sophisticated option is correlation tracking. If a sufficiently varied area of the television image is chosen, then the tracker can compare the complex profile of that area with alternative areas on the next frame. In many cases, the human operator points the seeker or tracker at the target by enclosing the area to be tracked within gates; the gates define the area of the next frame that must be searched.

Each of these techniques has its advantages and disadvantages. Spot or centroid tracking is simple, although it may become confused if the target passes near some alternative dark object. Edge tracking is simple, and an edge will not change very rapidly as the missile approaches its target and the scale changes. On the other hand, the missile may tend to slide down the edge and onto another dark object should the target merge with any alternative target. High-contrast spots and lines are the easiest objects to recognize and are, presumably, often the basis for missile detection inIRSTs. Both centroid and edge tracking are most effective against extended targets. Centroid tracking is only fair against point targets (it is easy to confuse because it calculates a centroid over a wide area), and edge tracking is useless in such cases (a point target has no discernible edge).

Correlation tracking is potentially far more stable than the

other alternatives, since the signal being tracked contains much more information and, thus, is much more difficult to swamp in optical noise (i.e., in false targets). However, correlation also often (though not necessarily) involves much more processing than edge or spot tracking. Typically a correlation target must be inserted by a human operator. However, the search function of anIRST is in some ways a correlation function since theIRST is always comparing the contents of its search area with the contents seen on the previous scan. Correlation tracking is a special case of contour matching.

The tracking techniques can be realized using fairly simple analog circuits, by comparing the lines within the gates of one frame with the corresponding lines of the next. Overall target location would be determined by averaging out the target location given by each line. Such operation avoids processing the picture pixel by pixel, but it also precludes any recognition of the target as an entity since the lines must be handled separately and sequentially.

Signal processing can, of course, be much more elaborate on a pixel-by-pixel basis. There now exist computer programs for limited image recognition by shape. Images may also be classified, at least tentatively, by their measured temperature (apparent color), their apparent size, and their measured speed. Because the image is very rich in detail, any substantial processing entails very great computing power. The numbers are much like those encountered in television: a signal rate of 5 million pixels/sec might well be encountered. The processor would form images based on whether each of those pixels was above or below some selected threshold, and thus it would have to examine each one every second. Threshold crossings must be correlated from pixel to pixel to decide whether individual pixels were isolated points or were parts of extended images. Moreover, clutter, which may resemble real targets, must be eliminated. Such processing entails the use of numerous parallel channels.

Photonic detectors suffer from 2 inherent defects. First, the overall scene they observe tends to be much richer in detail than the scene observed by, say, a radar. It may, therefore, be much more difficult for an automatic system, such as a missile seeker or anIRST, to separate out the limited number of features of interest, such as the target itself. The earliest electro-optical devices succeeded because a human operator could select out a sufficiently distinctive aiming point for the tracking circuits to distinguish as the missile flew. However, currentIRSTs are worthwhile precisely because they can recognize particular targets before human operators can do the same.

Second, these devices are all passive; therefore, none can measure range to a target. Optronic/photonic fire-control devices often incorporate a ranging laser, whose weather-penetration capability is broadly comparable with that of the passive tracker.

LASERS

Lasers are already very widely used for range finding (as range-only radars) and for target designation; they are beginning to be used for communications and for weaponry. All follow the same basic principle, but at very different wavelengths and power levels. In most cases, the value of the laser lies in its very pure coherent light, easily distinguishable against a very noisy background and thus capable of carrying substantial information. Purity means not only purity of wavelength (frequency), but also coherence: the laser beam is pure in phase as well as in overall frequency. In effect, the laser beam is a single very strong light wave, rather than the usual incoherent mixture of many beams with different phases. This coherence shows in the characteristic speckled (spatial interference) pattern shown by a laser beam in air.

The beam is narrow because it is coherent. If the laser aperture were infinitely wide, the beam would not diverge at all. As with radar, the laser beam diverges (has some width) because the aperture through which it emerges is only a finite number of wavelengths wide. However, because light has so short a

wavelength, a laser beam is often only a few mrad in width, so that it is still fairly narrow at a great distance.

Although it is commonly claimed that a laser has no side-lobes, in fact there is inevitably some leakage of radiation to the side, so that a laser link cannot be entirely covert. In one embarrassing case, a laser target designator operated in the infrared so as to avoid optical detection. Unfortunately, the likely targets were tanks, which normally used their FLIRs even in the daytime; in this particular case the IR bandwidth of the FLIRs included the laser frequency, and the presence of side-lobes ensured that tanks other than the intended victim could detect the designating laser.

Laser operation can produce very short light pulses, in the case of a laser producing a range of wavelengths simultaneously. Such energy concentration in time can be considered an alternative to concentration (purity) in wavelength or frequency (color). As in radar, the shorter the pulse, the wider its content in terms of frequency. The purer the frequency, the longer the pulse.

The basis of laser operation is that atoms (and other atomic systems, such as semiconductors) have well-defined and well-separated energy levels. When they fall from level to level, they can emit photons, whose frequencies (wavelengths) are proportional to the difference in energy levels. Moreover, the probability that an excited atom will emit a photon of a particular energy and phase increases in the presence of another photon of just that energy and phase. Hence the coherence of a laser. The laser medium is pumped up into an excited but fairly stable (metastable) state. Then an atom decays to a lower energy level, emitting a photon. That photon causes another atom to emit a second, and the process avalanches. Typically the laser medium is enclosed by mirrors so that the photons (quantized light waves) reflect back and forth, causing further emission. In the simplest arrangement, 2 flat mirrors are at either end of a solid laser rod; the 2 mirrors must be an integral number of half-wavelengths apart to form what amounts to a resonant cavity. There are also other mirror arrangements, better suited to gas lasers. In any case, 1 of the 2 mirrors is partially (typically 1%) transparent; the laser beam exits through it.

The laser can fire spontaneously (one of the metastable atoms will soon decay), or it can be fired by a master pulse sent through it, along its optical axis, perpendicular to the mirrors.

A laser uses several of the energy states of its medium. Atoms are pumped up into an unstable state above the metastable state, and they decay rapidly down into the metastable state. Without these multiple levels, the laser cannot populate the metastable state because the pumping radiation also stimulates radiation out of the metastable state. The population of the metastable state is said to be inverted because normally it would be so much smaller than that of the ground (lowest-energy-level) state; this relationship is inverted by the pumping action. The initial quick decays consume some of the pumping energy, turning it into incoherent radiation. Not all of the pumping energy is absorbed by the laser material, and atoms can decay without radiating the laser photons. Lasers are, therefore, relatively inefficient converters of energy, with efficiencies of no more than a few percent.

Solids, liquids, and gases can all be used as lasing materials, provided they have appropriate energy-level structures. The pumping process in a solid tends to heat the solid, and that heating in turn limits the power such a laser can develop to about 1 kW/m of length. Really high power demands a flowing medium, which can dissipate the pumping energy. Each atom or molecule of the flowing medium is active while it passes through the open laser cavity.

Most lasers are pumped by broad-band lamp (optically) or by electrical discharge (through the laser material). The choice depends on the nature of the lasing material. Typically, solid and liquid lasers are optically pumped. Semiconductor and gas lasers are electrically pumped.

Three pumping schemes have been proposed for high-energy laser weapons: gas-dynamic lasers, electro-discharge lasers, and

chemical lasers. A gas-dynamic laser uses collisions between its hot molecules to place them in metastable states. The chemical laser uses an energetic reaction, typically producing hydrogen fluoride; the product, which is in the metastable state, is suitable for laser operation. In all of these gas lasers, the gas streams through the laser cavity, perpendicular to the line along which the laser beam resonates and projects. High-powered chemical lasers present special problems for shipboard installation because their exhaust gas is often quite toxic.

Some typical laser materials, with their dominant wavelengths, are

Alexandrite	0.7–0.82 micron. Typical repetition rate 40/sec; typical of many tunable crystal lasers. Used as target designator.
GaAs	0.850 micron (semiconductor laser). Power conversion efficiency can be as high as 57%. Used for signaling in fiber optics and as seeker head.
GaAlAs	0.8–0.95 micron. Used as seeker head.
Ruby	0.694 micron. Typical repetition rate 6/min; now obsolete for military applications. Used as range-finder.
Nd: Glass	1.06 microns. Typical repetition rate 10/min; now obsolete. Pulse energy 10 times that for ruby. Used as range-finder, target designator.
NdYAG	1.064 microns. Typical repetition rate 20/sec; low energy (range-finder). Also used as target designator and weapons-guidance data link and as decoy for laser-guided bombs.
CO	4.9–5.7 microns. Typically used as a laser jammer. Output power of 100 kW and efficiency 60+ % demonstrated.
CO ₂	10.6 microns (gas laser). Typical repetition rate 2/sec; pulse energy 40 W in a burst. Can tune 9.6–10.6 microns. Uses: range-finder, target designator, beam-rider, LADAR, laser jammer, laser decoy, high-energy laser (HEL).
DF	3.6–4.2 microns (chemical laser). Used as jammer and HEL.
HF	2.6–3.3 microns (chemical laser: hydrogen fluoride). Typical HEL.
XeCl	0.31 micron (blue-green).
XeF	0.35 micron.

A real laser material inevitably offers a range of transition energies. The laser spectral line is said to be broadened. For example, electrons in a solid occupy bands of energy, and they drop from one band to another. In a gas, lines are broadened by collisions between atoms. In a disordered material, such as a liquid or a glass, individual atoms will be surrounded by varied numbers of other atoms, so their energy levels will differ slightly.

At low levels of pumping energy, this natural broadening results in a broad range of stimulated emission. Above a threshold level, however, the resonant character of the laser cavity or solid selects out a narrow range of wavelengths, and the characteristic very narrow range of laser frequencies results.

The principal current naval laser applications involve relatively low energies, for target designation, for range-only radar (range finding), for LADAR, and for signaling (as in the case of the experimental air-to-submarine channel, and also within fiber-optic systems). Typically, current laser range-finders operate at 0.6 to about 1 micron; laser designators, in the 1.4–1.8-micron band, and laser trackers at longer wavelengths, in the mid-infrared (3–5 microns).

Typically a laser will fire raggedly and spontaneously, spreading the energy of its pumping pulse over time (in a typical example, a pulse with a peak power of 1 kW might be spread over 130 microsec). However, many laser applications require that the laser be pulsed over much shorter times, which in turn can be achieved by sealing the laser cavity completely except for a

short pulsing time. The pulsing technique is called Q-switching; given the same laser characteristics as those above, it can produce a 15-nanosec pulse with a peak power of 10 MW (the total power is of course the same).

Q-switching opens and closes the laser cavity; when the Q-switch is off, no light leaves. When the shutter is opened, the stored energy is suddenly released as a strong, short pulse. One such technique is a Pockels cell, which responds to an electric current passing through it. Alternatively, a saturable absorber can be inserted into the cavity. The absorber precludes laser action until a threshold has been crossed; then it is saturated and ceases to prevent lasing. In this case, the combination of pump, laser, and absorber sets the pulse rate. Semiconductor-diode lasers are unique in that they do not require Q-switching.

A typical LADAR might use a pulse rate of 20/sec, the beam being 1 mrad wide. A 120×120 -deg field of regard (FoR) then represents 693,600 laser positions or lasels, and given the PRF, each frame requires 578 min (116, which is still far too much, at 100 pulses/sec). These figures show that laser radar is really practical only when the beam scans over a very limited FoR (or when multiple beams are used in parallel). For example, in a 2×1 -deg FoR, there are only 578 lasels, and frame time (equivalent to data rate in a conventional radar) is 29 sec at 20 pulses/sec. Existing LADARs (which are sometimes also called LIDARs) generally operate at either 1.06 or 9.2–10.8 (nominally 10.59) microns, with a very narrow field of view (based on the considerations above).

Blue-green lasers present particularly interesting possibilities because they can penetrate considerable depths of seawater. As early as the mid-1960s, such beams could reach down as much as 400 ft, and for a time it seemed likely that a shallow-water submarine-hunting LADAR was practicable. The effort was abandoned because insufficient return energy was available, probably because too much was lost to internal reflection when the beam passed through the water surface on the way up. More recently, analogous downward-looking LADARs have been used for shallow-water surveying and for mine location (ALARMS).

The press has carried references to LADAR in connection with torpedo defense. If the main problem in the early LADAR was in fact losses due to reflection at the surface of the water, then a LADAR totally immersed should be more practicable. Up to short ranges (perhaps a thousand yards), it should be able to detect objects more reliably than a sonar, providing it can scan rapidly enough (or, more likely, providing it scans over many sectors simultaneously). Such a LADAR would be a natural complement to a very high speed underwater projectile.

It has been possible to generate very high laser energies for some time, but laser weapons (other than the recent British "dazzler") are still almost as far away as they seemed two decades ago. There are two problems, propagation and actual damage to the target.

The atmosphere is not homogeneous, and the beam bends as it passes through. The beam director, therefore, must adapt to changing atmospheric conditions, some of them caused by the beam itself. At least at present, beam directors for high-energy lasers are quite massive. In addition, the atmosphere absorbs the beam. Water vapor is a particular problem for a beam directed close to the sea surface. As it heats, the air changes its index of refraction, and it bends or spreads the beam (blooming).

The beam can transfer energy either continuously or in a short pulse. A continuous-wave laser heats its target, and there is always some question as to whether evaporation from the target will carry away energy quickly enough to protect it. Alternatively, a short pulse will transfer energy very quickly, almost like a kinetic-energy projectile, smashing into a target. Such a laser has the additional advantage that it may be so short that the air will not heat enough to bloom it as it passes through.

ECM

Electronic countermeasures figure in several sections of this book, and these notes will be limited to items common to all

warfare areas. ECM splits into passive devices, electronic support measures (ESM), intended to detect and identify characteristic emissions, and countermeasures (ECM), intended to disrupt hostile sensors or communications. Some of the basic alternatives are worth mentioning.

An ESM device has to determine the main parameters of the emitter: direction, intensity, frequency, pulse width, PRF, and scan rate or pattern. There are several approaches to this problem.

One is the broad-band (crystal video receiver or CVR) receiver, which can respond to any of a very wide variety of signals within its bandwidth. It identifies a signal by frequency band, but it cannot tell where in the band that signal is located. CVRs are relatively simple and lightweight, and they are normally used in radar-warning receivers (RWRs) and in small ships' ECM systems. They may be matched with devices that detect and measure the pulse width and PRF, and these use these data to identify an emitter.

A second approach is the tunable receiver (scanning superheterodyne receiver or SHR). A narrow tuning band sweeps through the receiver's bandwidth. If the sweep is very rapid compared to the duration of the signal, then such a receiver will probably detect and identify the signal. However, if the signal is brief enough, the tuner may well miss it. Typically, a mechanical tuner may sweep a few GHz per second, and an electronic tuner may improve this to a GHz per microsecond. However, typical radar pulse widths are also on the order of microseconds. SHR performance can be improved by breaking down any given frequency band into narrower channels.

Finally there are instantaneous frequency measurement (IFM) receivers, which have a high probability of intercepting a signal because they are always open to the entire frequency band. They tend to be less sensitive than the SHR because they have to respond to so broad a range of frequencies. IFM is becoming common in shipboard systems, but it is rarely used in aircraft. The main drawback of IFM is that it may be unable to deal with several signals in close succession, since it requires a finite time to process each signal. This is not an unsolvable problem, but it does increase the complexity of the equipment.

Sensitivity is generally inversely proportional to channel width; the wider the channel, the less sensitive the receiver. Thus an IFM is less sensitive than an SHR.

The most important distinction within ECM is probably the difference between simple noise jamming, which seeks to blot out a signal, and deception. Noise jamming can cover a wide range of frequencies (barrage jamming), or it can be directed to a particular, narrow frequency band (spot jamming). The best counter to noise jamming is frequency agility (the signal's frequency moves away from the jammer's). The higher the basic frequency, the broader the range of frequencies a barrage jammer must cover.

Because radars have finite sidelobes (i.e., cannot concentrate all of their energy or their reception in one direction), jamming signals can always enter via those sidelobes and appear (to the radar) to be coming from the direction in which the radar is pointing.

Deception generally depends upon some measurement of the radar PRF, scan rate, and pulse width, since the jammer must send back a false echo. The echo may confuse the radar in range (e.g., range-gate pull-off) or in bearing (via the sidelobes). Consequently, jittered or varied PRF is a counter-countermeasure because the radar may reject signals that do not conform to the precise pattern of its variation in PRF.

Jammers are often described as responsive or as repeaters. A responsive jammer measures the frequency of the received signal and sets an oscillator. The frequency data are, therefore, typically stored and processed digitally. The response can continue after the pulse has ceased. It need not be at precisely the received frequency. For example, if an enemy frequency-hopping radar is known to execute a particular pulse pattern, the responsive jammer can be programmed to match it. The response of such a jammer is limited by the finite time it takes

the associated oscillator to reach the appropriate frequency. Current linear hyperabrupt transistor oscillators can tune over 25 GHz/microsec, over a total bandwidth of 4.5 GHz, with a settling accuracy of 2 MHz in 100 nanosec. Total response time is longer; current technology can provide a response accurate to within 2 MHz within 250 nanosec.

A repeater is a simpler analog device. It simply amplifies the received signal, with or without a time delay; the incident pulse fires its TWT at the appropriate frequency. Because no frequency measurement is made, the response can be extremely quick, typically in 100 nanosec. A repeater is, therefore, a natural counter to a tracking radar, with its high pulse rate.

Repeaters are often built around frequency memory loops (FMLs), which store an exact replica of the received pulse. The storage device is often a coaxial, a waveguide, or an acoustic delay line. The radar pulse is fed into the line, whose memory switch closes a set time after the beginning of the pulse is detected. The pulse energy then circulates within the delay line. It picks up noise on each circulation, and thus the information in it is gradually lost. The jammer taps it and amplifies it to produce a replica signal. A typical FML has a frequency range of 8–16 GHz, carrying a signal accurate to within 3 MHz (distortion would be introduced by the characteristics of the delay line), with a duration of 7.5 microsec. The line itself is 150 nanosec long (duration measures how quickly a signal in the line would decay to uselessness). There are also dual-delay memory loops. A typical example can switch between lengths of 150 and 300 nanosec, with a 15-microsec duration.

Effective jamming operation typically requires that jamming energy be concentrated on the target; jamming antennas are, then, typically paired with target trackers. In some cases, as in Scimitar, the tracker (receiver) antenna is identical to the jammer antenna. SLQ-32 is probably unique in using the same antenna for initial detection, target tracking, and jamming. More generally, although the tracker can function as a search antenna, it has too narrow a beam for efficient search. Ships, therefore, generally have separate coarse direction-finders for initial detection. Soviet systems are unusual in using an intermediate tracker to cue the tracker associated with the jammer. Such operation is analogous to the combination of broad-beam search radar, narrow-beam target indication radar, and very narrow beam fire-control tracking radar in many warships.

Finally, it is useful to distinguish between a variety of direction-finding or tracking techniques used by ESM and ECM systems: interferometric, monopulse, and (single) directional antenna.

An interferometric direction-finder consists of a series of omnidirectional antennas. Each detects a signal with a slightly different time delay, the amount of the delay depending upon the direction from which the signal comes. This technique is used in some airborne systems (such as the U.S. sonobuoy reference systems) and in such submarine sonar systems as PUFFS (BQG-4). The classic interferometer is the Adcock, consisting of 2 pairs of vertical antennas, each half a wavelength wide, at right angles. Crossed-loop direction-finders also fall into this category.

The direction of the signal can be read off in several ways. The entire antenna can be rotated; the elements of the array can be sampled by a rotating goniometer; or the elements of the antenna can be grouped into 2 subantennas with patterns at right angles. The 2 groups can drive the 2 pairs of plates of a CRT, showing the angle of any intercepted signal instantaneously. The latter technique was invented in the 1920s by Robert Watson-Watt, who also invented the British form of radar (others independently devised other forms of radar in other countries virtually simultaneously).

A rotating loop takes about 10 sec to find a direction; a rotated goniometer takes about 3. World War II experience showed that an instantaneous CRT system could cut direction-finding time to half a second or less. That capability was particularly important after the Germans drastically reduced the duration of their signals to defeat conventional direction-finders, and, of

course, it would be important in a direction-finder attempting to deal with short radar pulses. A modern system would replace the CRT with a computer comparator and would do better because the computer would sense the presence of a signal much more quickly than a human operator.

The stage beyond the Watson-Watt system is to form more than 2 beams, using what amounts to a phased array. The first major application of this principle was the German Wullenweber circularly disposed array of World War II; coincidentally the Germans applied much the same technique to their wartime GHG passive sonar. It was adopted postwar by both the Soviets (as Krug) and the United States. Compared to an Adcock, a Wullenweber provides better directivity because its more numerous elements give a much narrower beam pattern. In the Wullenweber, about a third of the elements were used at any one time, the relative delays being fixed to form a narrow beam. A goniometer selected the appropriate third and applied the delays; it rotated among the elements of the array. This operation was exactly analogous to the use of a commutator in early scanning sonars. As in a scanning sonar, this technique suffers from the weakness that it does not stare in all directions simultaneously. A modern array would use preformed beams; it would sample all directions simultaneously and would form beams in all directions at the same time, via a computer memory.

A monopulse direction-finder compares the strength of the signal as it is detected by a series of antennas pointing in different directions. The antennas are often spirals or broad-band cones. Examples are shipboard wide-open ESM systems and aircraft RWRs. Monopulse is usable only when the wavelength is short enough that individual antennas can be sufficiently large (in wavelengths) to have fairly narrow (at least not overlapping) beams. On shipboard, then, it cannot be used at HF or VHF frequencies and is limited to radar direction finding. Interferometry is used at lower frequencies.

Although both interferometers and monopulse direction-finders can rotate to focus on a particular signal, both techniques are more commonly used in fixed form. Their beams are formed, in effect, electronically.

In contrast, a directional antenna, such as a dish, has a narrow pattern. Typically, it scans, passing its beam over the direction of the incoming signal. For a given total size, a directional antenna generally provides much greater gain (hence longer range) and much greater accuracy, but its coverage of a given signal is necessarily intermittent. In recent years, then, the tendency has been to use monopulse rather than spinner antennas for radar direction finding. High gain has been reserved for trackers used to direct jammers, as in the Signaal Ramses or the Soviet Side Globe.

Electronically scanned antennas can provide some of the virtues of a highly directional antenna but at a high scanning rate; the Hughes SLQ-17 is an example. A lens antenna, such as that used in SLQ-32, is a more monopulse-like alternative, providing the equivalent of a large number of high-gain antennas producing adjacent beams simultaneously.

IFF

Because IFF (identification, friend or foe) applies to so many radar systems, it seems best to treat it here. Since the middle of World War II, the standard system, both in the West and in the Soviet Union, is the interrogator-transponder. A radar is fitted with, or associated with, an interrogator with approximately the beamwidth of the main radar. The interrogator sends a coded pulse or pulse train in approximately the same direction as the main radar, but at a different frequency. The transponder on the target sends back a reply, at a third frequency. Generally, the reply is coded to indicate the details of the target's identity. Over the years, frequencies have increased, and interrogators have become more directional; in some cases, the text gives details for the interrogators associated with particular radars.

All of the many interrogators on board a single ship (not to mention in, say, a fleet) are entirely independent, so that all may interrogate the same incoming target. As a consequence,

the transponder of any particular target may be unable to reply to all of them, since it can send its code to only 1 interrogator at a time. The only current exception to this problem is the single integrated IFF antenna used in conjunction with the U.S. SPY-1 radar (see that entry in the Antiaircraft Warfare section): it limits a single ship's interrogations.

Moreover, the interrogator-transponder system can be a liability in combat, since an enemy with access to the interrogation codes can use them to trigger transponders aboard approaching targets and thus can use IFF itself to track targets. That makes the coding of interrogators particularly important, and this requirement in turn makes for relatively complex systems.

IFF is not a universal identification system; it is a means of positively identifying some radar targets, leaving all others unidentified (and hence either neutral or foe). Moreover, because a potential target may not reply to a particular interrogator (for example, because it is replying to others at the same time), IFF errors can occur even for friendlies. Additionally, the more complex the coding for security, the better the chance of error. It is commonly assumed that in wartime large numbers of aircraft will fall victim to IFF errors, on both sides of any conflict.

There is also a danger that a nearby ship will receive the reply intended for another, either through the main lobe or through a sidelobe. Such false replies are called "fruit," and they are eliminated or "defruited" by assigning each interrogator its own pulse repetition frequency (PRF): special circuits eliminate any reply with a different PRF. It is also possible for a single target to receive interrogations from 2 radars in line, so that the reply intended for 1 is received by the other, and thus is associated by the other radar with an entirely different, nonreplying target. Multiple interrogation signals can also overlap and confuse a transponder.

The current NATO system, Mk 10, was introduced during the Korean War. There was no Mk 9; Mk 10 was developed as Mk X, the X standing for the future system (it replaced Mk V of 1945). This system interrogates at 1030 MHz and replies at 1090 MHz. A coded Selective Identification Feature (SIF) was added in the mid-1950s. Capacity is 4096 identification codes, in 3 modes (1, 2, and 3). This system is used for both military and civil aircraft, and the responses typically carry coded information. Civil aircraft provide flight call sign and altitude. Military aircraft provide a basic IFF response plus other data. Mode 3 is military, Mode A is joint military/civil (often called Mode 3/A), Mode B is civil (identification), and Mode C is civil (altitude reporting). A further Mode D is not currently used but is available for expansion of the system.

Mk 10A has an Automatic Code Changing (ACC) capability, with more code combinations. Because Mk 10A and the civil ATC system use the same message format, there is always a possibility that an enemy will find it relatively easy to fabricate false Mk 10A messages.

Early in the 1960s the United States added a cryptographic facility, Mode 4. The interrogator as well as the transponder is coded to prevent an enemy from tracking by using a false interrogator to trigger transponders. Mk 10/10A plus Mode 4 is designated Mk 12, which is now standard in much (though not all) of NATO. Mk 12 has never extended throughout NATO partly because it is much more expensive than Mk 10 and partly because its greater degree of coding makes the system as a whole more vulnerable to jamming, which might confuse the codes.

In the early 1970s, NATO set up a working group to define a NATO Identification System (NIS) that would replace Mk 10/12. By 1981 Britain, West Germany, and the United States were all developing prototypes. Britain and West Germany favored a higher-frequency (S-band) system, the United States and France an L-band system compatible with Mk 10/12. In April 1985 NATO agreed to adopt the U.S. solution. Britain and Germany had claimed that L-band was too crowded but accepted the L-band system when the United States agreed to add a radar interrogator mode (i.e., interrogation at radar frequencies in the S- and X-bands to supplement the previous standard of 1090

MHz; however, as at present, responses would still be at the standard frequency of 1030 MHz). This scheme meets a requirement stated by the European NATO partners, allowing interrogation by a radar not fitted with a separate interrogator.

This new system, called Mk 15, will use two types of interrogation, one using spread-spectrum interrogation, the other a radar mode using pulse-position keying. Where possible, the radar mode will be integrated directly into weapons systems.

In a larger sense, identification must be based not only on electronic replies but also on observed behavior. For example, schemes for air operations in Europe commonly involve special corridors, including altitude, along which returning strike aircraft can expect to return without being shot down. To avoid funneling enemy strikes into the same areas, the corridors are changed very frequently. Similarly, a fighter returning to a carrier would not only "squawk" or send the proper IFF reply but would also behave in a particular preassigned way. Otherwise, the fighter would probably be shot down. Systems based on flight profiles can help to allow for possible electronic failure or battle damage, but they cannot be perfect.

These inherent problems have prompted considerable work on noncooperative means of identification, using the physical characteristics of the approaching target. In the past, at least in the United States, the most popular have been the measurement of the rates of rotation of jet engines' compressor blades (since the blades make prominent radar returns), and the direct imaging of an approaching airplane. Neither has ever been implemented.

A third alternative is positive tracking of all the aircraft in an area. That was done in the Gulf of Tonkin during the Vietnam War, when a computer-equipped ship tracked literally all air contacts. In theory, much the same thing could be done by an Aegis ship in, say, the Mediterranean. However, identification by tracking requires the cooperation of neutrals, who in effect must identify themselves when they take off. If they do not, identification must fall apart—as in the *Vincennes* incident of 3 July 1988.

The shooting down of the Iranian airliner by the USS *Vincennes* illustrates these points. Because the airliner was not a U.S. military aircraft, it could not send an appropriate IFF signal. The signals it did send seemed to correspond to those that the Iranians had used earlier for F-14s, but that was a deduction from observed Iranian behavior, not necessarily a positive identification. After all, the Iranians might well change their own IFF codes quite often. Thus the captain of the *Vincennes* could not be sure what the IFF return meant. He tried to contact the airliner by radio but received no reply, and the airliner itself did not swerve away, as Iranian airliners had in the past. He did not shoot, however, since the negative information he was receiving did not necessarily mean that the airliner was hostile. Then he was told (incorrectly, as it turned out) that the aircraft had begun to descend, to dive. To the captain, that was a positive signal of hostile intent. This reading in turn was based on a series of known Iranian threats and an expectation that the Iranians might well try a suicide attack. Apparently, the error in reporting the height was partly caused by an inconsistency in the display of target data: height was given in digital (numerical) form, whereas the track of the airplane (range and bearing) was shown graphically. Under the stress of combat (the ship was swerving to keep her after 5-in gun bearing on 2 Iranian gunboats), it was apparently too easy to misreport numbers.

The incident well illustrates the central problem of identification: one might be able to determine the physical character of an approaching target, but how can one interpret the intent of the target's operator? Although Captain Rodgers undoubtedly believed he was facing an Iranian F-14, in fact his ship could have been crashed just as effectively by an airliner. A system that merely told him what type of airplane was approaching could not have sufficed. This problem will most likely recur in other areas, where several countries might be operating the same or similar equipment.

MISSILE GUIDANCE

There are 3 basic types of missile guidance: inertial, command, and autonomous.

Inertial guidance systems measure the motion of a missile through space, sensing and integrating accelerations to find the missile's velocities. Inertial systems were initially used only in long-range ballistic missiles because these systems were so expensive. There are 2 types: a hard-wired system, in which the missile attempts to fly a precomputed path, correcting whenever the missile deviates; and a computer-based system, which constantly recomputes the necessary flight path based on the actual flight of the missile. The latter requires less fuel for correction, and thus is suited to greater ranges. It allows for operational flexibility, since only the launch location and the target need be entered into the computer. In the absence of such a system, a missile must be fired at a single preassigned target from a preassigned site.

In recent years inertial sensors, such as gyros, have become much cheaper, and some form of mid-course inertial guidance is now quite common. Often it is described as strapdown, which means that the inertial sensor lacks the full range of measurement, i.e., cannot measure pitching motions. That is acceptable in a short-range missile, or in a missile constrained by a radar altimeter to fly a flat path.

Command guidance may be of several forms: commands may be sent through a wire or fiber-optic cable or a radio link; or the missile might be a beam-rider, controlled by the movement of a radar beam (in at least one case, a laser beam). The basic attraction of command guidance is that the intelligence of the weapons system can be concentrated in a director that need not be limited in size or cost, rather than in an expendable missile of very limited size. The main limitation on command guidance is the loss of accuracy as the range increases. An advantage of beam riding is that it is somewhat difficult to jam: the missile's antenna that senses the beam faces rearward instead of forward, toward the target. The jammer must, therefore, concentrate on the more distant (and more sophisticated) tracker, rather than on the nearby missile. That is why Bofors advertises its laser beam-rider, RBS 70, as unjammable.

Much depends on whether the beam tracks the target itself. In most early beam-riders, such as the British Sea Slug and the U.S. Terrier, a single tracking radar generated the beam, and the missile, therefore, continuously pointed at its target. Because it had to follow target maneuvers, it could lose a good deal of its energy along the way. On the other hand, in the contemporary U.S. Talos (now extinct), the beam motion was programmed so that the missile flew along an energy-efficient up-and-over path. It homed semiactively only as it approached the target.

Autonomous or self-sensing guidance takes many forms. It does make the missile more accurate as it approaches its target; on the other hand, the missile seeker is of limited size, and it may not be able to deal with countermeasures. Moreover, it may be difficult to design a seeker that can distinguish some kinds of targets.

Usually missiles incorporate some compromise between these elements. In the case of antiaircraft fire, semiactive homing is quite widely used. Semiactive homing is a type of command guidance, to the extent that the missile director tracks the target. However, the missile actually tracks the radiation reflected from the target (usually radar, sometimes laser). The missile's estimate of target position, therefore, becomes more accurate as it approaches the target. The greatest drawback to semiactive homing is that the tracking radar must be powerful enough to provide the missile with sufficient reflected illumination from the moment that it is launched. This requirement limits effective range. One alternative is to use command guidance or inertial guidance (i.e., a preset autopilot) to bring the missile relatively close to the target before turning on the semiactive seeker. That is the solution chosen in the U.S. Aegis and Phoenix systems.

Missile guidance determines missile flight path. Here command guidance has an advantage, since it can bring the missile

along the most efficient flight path possible. Any form of full autonomous homing or semiactive homing results in a less energy-efficient path and, therefore, in a shorter range for a given missile.

The simplest and least efficient path is pursuit because the missile turns to fly along the line of sight to the target. The missile's rate of turn equals the rate of turn of the line of sight, and quite violent maneuvering may be required as the missile approaches its target. Pursuit is effective against slow targets, or against targets approached from the rear (e.g., by IR-guided missiles). It is also effective at very short range. Missiles using command-to-line of sight guidance (such as the French Crotale Navale and the British Sea Wolf) follow pursuit paths that limit the system's effective range. For missiles launched from shipboard, command-to-line of sight is effective for point defense but not really for defense against crossing targets. To the extent that major Soviet systems such as SA-N-1 and SA-N-3 appear to employ command-to-line of sight guidance, they are effective for the defense of individual ships but not of formations of ships.

Proportional navigation requires the missile to measure the rate of change of the line of sight and to maneuver at some fixed or variable multiple of that rate of change. The navigation ratio may change during flight to optimize missile performance. Proportional navigation systems require the missile to compare the direction to the target with the direction in which it is flying. That is sometimes done by a doppler comparison between the reflected energy from the target and a broad reference beam from the launcher. In such cases the missile requires a set of rearward-facing reference antennas. The reference beam has to be broad because the missile generally is not in the tracking beam itself. Proportional navigation improves missile range performance, and also improves performance against a maneuvering target, since the missile need not maneuver violently to follow the details of target motion. In effect, proportional navigation aims the missile not directly at the target but at a computed interception point ahead of the target.

Proportional navigation can also be applied to IR missiles. In these cases the reference is an internal gyroscope. The missile tracks the forward edge of the target. As a consequence, it tends not to be distracted by decoys (flares) dropping away to the rear of the target. The French Mistral is the only publicized example, but for some years Sidewinder has been credited with the ability to hit the forward portion of its target. That suggests that it, too, employs proportional navigation, and that this form of guidance is an important anticountermeasure feature. Presumably the only way to decoy a proportional-navigation missile would be to fire the decoy ahead of the target.

In contrast, command guidance generally involves some quite different flight path. The main alternatives are:

- A constant-bearing or collision course, which requires the missile to be fired with a sufficient lead angle to meet the predicted position of the target.
- A fixed lead angle path.
- A line-of-sight path, which requires the missile to follow the line-of-sight from launcher to target (as in a beam-rider).

These concepts apply not only to missiles flying through the air but also to torpedoes. A straight-running torpedo is inertially guided. Lightweight torpedoes are self-guided, although they may have inertial (preset) run-outs before their homing devices are activated. Most heavy torpedoes are command (wire) guided, until they reach a homing basket. In a few cases they are wire guided all the way.

DIGITAL VS. ANALOG EQUIPMENT

One of the major themes of this book is the displacement of analog equipment by digital types. Although many navies still operate old analog equipment (which suffices for their purposes and which would be expensive to replace), analog equipment is no longer being manufactured (at least in the West). Digital technology has triumphed in the last quarter century. Cheaper and more reliable digital computers have made digital methods

much more attractive than analog, and in turn the pressure to adopt digital methods partly explains the need for greater and greater computer capacity. A comparison between digital and analog methods gives some idea of the limits that current computer capacity imposes.

Initially, the impetus for adopting digital techniques was largely their precision and flexibility. However, digital operation provides something much more powerful. All signals (raw and processed) are carried in the same memory, and in the same form, so they can be compared directly. It is easy to run the same signal through several parallel processes since the signal can be copied without any loss of precision. Most important of all, the program that runs the processor is carried in the same memory. It can easily be changed. And as the program runs, it can modify itself; more accurately, it can determine which of many different possible paths the machine takes, based on the results of earlier computation and, often, of external inputs during computation.

This sort of flexibility is impossible in an analog machine because the analog processor is literally a physical equivalent of a mathematical operation or series of operations. Change means physical change, by adjusting some part of the processor. It is possible to imagine some self-adjustment, but only at the cost of great complexity.

In some very primitive sense, a programmable digital computer can be aware of the data passing through it; it naturally makes decisions based on these data, and then applies those decisions to its own operation.

CDSs are a case in point. The early analog types, such as the U.S. EDS and the British ADA, handled each track separately (in effect, each track had its own analog memory channel), bringing them together only in a summary plot. The system could not in itself use the summary character of the plot; only a human operator could compare tracks to decide which targets to engage. Digital systems such as the U.S. NTDS and the British ADAWS carry all their track data in a single memory. They can compare tracks to decide which represents the greatest threat, and they can correlate track data with data supplied by external sources. These data can also be fed directly into WDSs.

Flexibility does carry a cost in processing speed. In some special cases, therefore, specialized microchips with fixed programs are used. The most important case is the series of FFT chips used in sonar and radar processing. Early digital computers (valued for their speed and precision) did not always have sufficient memory space for elaborate programs and so were sometimes provided with fixed (hard-wired) programs. Hence the contrast, common in the literature of the 1950s and 1960s, between digital and general-purpose digital computers. Even these machines, however, did not require the manufacture of mechanical components specific to particular sets of ballistics, such as specially shaped cams, which were common in earlier electro-mechanical analog computers.

Flexibility carries one other great drawback. It is difficult to ensure that none of the possible paths through a program will have unfortunate unintended consequences. The more complex the program, the more possible paths through it, and the more possible sets of inputs that can cause the system to travel those paths. Hence the enormous current emphasis on software testing, often carried out at a special site designed to simulate operational use, including operator errors. Such error testing is sometimes called "Murphy testing."

The potential for error increases as the software defines not only operations inside the machine, but the meaning (to the machine) of the buttons available to the operator. That is quite common; users of personal computers soon discover that the software enables the machine to recognize, e.g., that the pressed key (marked "A") corresponds to an A in the machine's memory. Specialized software can be bought to change the significance of the keys, as in converting the standard QWERTY keyboard to the more efficient Dvorak. The important military use of this sort of software is in making all or most of the keys multifunction so that a board of manageable size can be used

to control a whole sequence of operations, or different operations depending on the role the console fills at any particular time. Much, therefore, depends on whether the system correctly interprets the significance of any particular key at any particular time. There are also human factors. Most typists make occasional errors, but that is acceptable if the computer shows them what they have typed and allows for corrections. However, some systems may not provide this sort of feedback. Even though the software is, in theory, flawless, it may still succumb to Murphy's law.

Software development and testing is often done on standard commercial machines, more readily available than the specialized naval computers that will actually run it operationally. Many naval computers are, therefore, designed to run programs that can also run on major commercial computers. The first example was probably the IBM System/4 Pi series, whose programs could run on standard System/360 machines.

The difference between analog and digital systems is in how signals are represented so that they can be processed. Signals come from the external world (such as the image falling on a FLIR, or radar or sonar echoes) or from devices within a ship (such as inputs and outputs of fire-control devices). Ultimately, they are processed so that decisions can be made on their basis. These decisions may be mechanical (the pointing of a gun) or they may be more complex (the decision that a FLIR image represents a friendly airplane). Whenever some sensor or device intervenes between a raw signal and a human or mechanical decision maker, signal processing must occur.

Analog systems construct a mechanical, electrical, or electronic equivalent to the signal (including the accompanying noise). That is not to say that the analog will reproduce the real signal precisely; there will always be errors of translation. An analog system displays the world in what amounts to continuously varying shades of gray. However, some very light grays may be represented as too white, and some very dark grays may seem too black or too light. This sort of nonlinear distortion is inevitable. It adds noise to the noise that every signal carries with it. Further analog processing introduces further distortion and further noise, if only because no physical device is entirely linear, i.e., none handles all signal strengths (and, usually, all frequencies) in the same way.

In a mechanical fire-control system, for example, target bearing is introduced by rotation of a shaft, driven by a synchro that in turn is driven by an operator following the target visually. There is inevitably some slip in the synchros at each end. The input shaft cannot be entirely rigid, and its twist must distort the input slightly. Similar slippage occurs within the computer; the more complex the calculation, the greater the slippage. Further slippage occurs in transmitting the product of the calculation to the gunner.

A digital system operates very differently. It approximates the physical signal varying over time by a series of discrete samples (represented by numbers) taken at close, regular intervals. No such representation can account precisely for variations occurring between sampling times. However, if the samples are taken close enough together, and if the signal varies smoothly enough, then signal behavior between sampling times can be accurately estimated by interpolation.

The signal can be imagined as a combination of signals of different constant frequencies; their strengths are calculated by Fourier transform of the original signal. Those components with frequencies much higher than the sampling rate will account for portions of the signal that cannot be estimated accurately by interpolation. If they are small enough, interpolation will be reasonably accurate. A signal with a maximum frequency can be represented exactly by a series of samples taken at twice that maximum. Thus, in theory, the output of a passive sonar receiving signals of up to 1 kHz in frequency could be represented precisely by samples taken at a rate of 2 kHz, i.e., by 2000 samples/sec. This sampling theorem indicates the information content in a given signal or, alternatively, the processing requirement that a given signal entails.

In practice such precision cannot be realized; higher sampling rates are needed. For example, since each sample takes a finite length of time to collect, the real system loses some accuracy in sampling. The maximum data rate of the system may be imposed by some physical limitation, such as the capacity of the associated data bus, and it may be insufficient to deal with really rapidly varying signals. This consideration helps to explain pressure for higher-capacity data buses.

Sampling considerations determine the load a sensor imposes on its processor. A passive array sonar, for example, may receive signals with noticeable frequencies of up to 1 kHz, so it must sample at a rate of at least 2 kHz. If the sonar has 100 transducers, the processor receives data at the rate of 200 kHz: 200,000 samples/sec. Processing will often occur in 2 steps: beams will be formed, and then each beam will be broken down by frequency, in hopes that the target will be stronger than the noise in a narrow beam and within a narrow frequency range in that beam. Each beam requires 1 multiplication and 1 addition per transducer (i.e., per sample), 400,000 calculations/beam/sec. A mere 25 beams require 10 million calculations/sec before frequency data are extracted. Each beam is represented by 2000 samples/sec.

Frequency (spectral) analysis is by FFT, numerous samples being combined to search over a narrow frequency range. The greater the number of samples, the finer the resolution of the FFT, but also the greater the processing load. Typical FFTs are taken on 1024, 2048, or 4096 samples. Successive FFTs generally overlap, e.g., a new 2048-point FFT might start every 1024 samples. A 2048-point FFT requires 70 operations/sample, and ancillary operations add more. In practice a processor might run several parallel FFTs to cover different narrow frequency bands. These FFTs would have to be conducted for each beam. The final processing load would be hundreds of thousands of operations per beam per second. That is why sonar processors have to be so powerful.

Sampling also explains the need for preprocessing, which generally means analog reduction of the complexity of the signal (filtering) before it is reduced to digital form. For example, a radar signal may be received at a frequency of 10 GHz, but the important information in it, the rate at which echoes arrive, is superimposed at a rate of tens of kHz. In this case preprocessing strips away the 10 GHz carrier signal so that the digital signal processor is not swamped by irrelevant information.

Display is the inverse of sampling; the results of digital computation must be displayed to the operator. In this case the important frequency is determined by the human eye, which cannot register very rapid changes. The eye thus interpolates between successive images (as in a movie). It also retains an image, so that the very rapidly moving single dot of a television suffices to produce a complete image. Typically, a television screen is refreshed 30 times/sec, to produce what seems like continuous movement.

A TV picture represents a vast amount of data, so much so that televisions are still analog devices. In the United States, for example, a television picture consists of 525 horizontal lines. The picture has an aspect ratio of 4:3, so that for equal resolution in both the horizontal and vertical directions, each horizontal line can be equated to 700 picture elements (pixels), i.e., each picture consists of 525×700 pixels, or 367,500 in all, or 11,025,000 elements/sec (actually only half as much information is transmitted because each signal element can be considered a wave producing both a positive and a negative peak on each cycle). The human eye distinguishes no more than 9 brightness levels, i.e., 4 bits/pixel, so that the total screen equates to a little less than 22 Mbits/sec.

These figures apply to the monitors that display weapons-system outputs. They explain why, until recently, radar monitors were always analog devices. However, to digitize such a monitor is to gain enormously. Each pixel of the screen can be processed separately, e.g., to emphasize some important ones, to add further data, or to distort the scale. Modern systems that can superimpose different radar pictures, or which superimpose

radar and other video, often gain this performance by using digital processing, albeit at a very high cost in processing power.

Digital processing may also buy the ability to make decisions based on the content of particular pixels, since each pixel is assigned a numerical value. For example, a keep-out zone may be shaded in red. The system computer keeps track of the area of the zone by examining the red pixels in turn. The screen itself is now a 2D, digital (i.e., processible) analog of some physical situation. The underlying processor can also use these data in some other way, e.g., by conducting some geometric transformation on the points.

Many systems still use an intermediate step, the cursive display, in which the electron beam paints particular patterns at preset points on the screen. A typical cursive computer screen may display 24 lines of 80 characters each, a total of 1920 characters. Each can be any 1 of about 64 alternatives, hence represented by 1 byte. The typical cursive screen is equivalent to fewer than 2 kbytes. Many displays combine analog video with cursive character generators.

Users of personal computers will appreciate the difference in processing power between a cursive display and a fully digital one: the latter is generally associated with a special graphic board. Even so, it takes up so much processing power that images on screen cannot be made to move very rapidly.

Digital operation requires some physical representation of numbers. Thus far, such representations have always been binary, i.e., in the form of 0s and 1s represented by switches that are either off (0) or on (1), each equivalent to 1 bit of data. Current memories are typically organized in bytes (units of 8 bits each), sufficient to represent the numbers 0–63. Programmers find it convenient to work in half-bytes ("nibbles"), sufficient to represent 0–15; often numbers are expressed in hexadecimal (base-16) form. A byte is then equivalent to 2 hexadecimal digits (which are written using letters for values 10–15).

Even very limited memory capacity requires numerous bits, i.e., numerous switches. Each must be easy to set, read, and unset very quickly. The earliest digital computers used vacuum tubes (which are, literally, switches) in circuits that could adopt 2 alternate stable electronic configurations. They were both cumbersome and unreliable, and memory was lost when power was turned off. Digital equipment first became really practical with the advent of magnetic cores or drums, numerous examples of which remain in service. In contrast to the vacuum tubes, the magnetic core or drum retains its polarization (its 1 or 0) whether or not computer power is on. The current standard memory device, the semiconductor, reverts to the earlier pattern of carrying its 0 or 1 as a stable electronic configuration. Like its vacuum tube predecessor, its information content is lost whenever the power is turned off.

No matter how large the memory, it is of finite size, so all numbers must be approximated by a limited number of digits. Nothing can be quite exact; the system is always rounding off as it calculates. For example, each number might be represented by only 3 digits, so that the fraction $\frac{1}{3}$ would be carried as 0.333. In this case, multiplying by 3 would give 0.999 rather than 1.0. That might have little significance, but squaring the result would give only 0.998 instead of 1.0, and errors would increase as the calculation became more complicated. Systems are typically designed to round off as they calculate, to limit errors, but even so they must suffer as calculations become lengthier.

Digital machines represent numbers in 1 of 2 ways. They can be in the form of fixed numbers of digits (fixed-point operation). For example, an 8-digit machine might carry $\frac{1}{3}$ as 0.333333, and 15.75 as 15.750000. It would have to carry one-billionth as 0, however, because it cannot accommodate more than six 0s after the decimal point. Similar problems arise with numbers greater than 99.999999. The alternative is floating-point operation, in which numbers are represented as products of significant digits (called the mantissa) and a power of 10 (the exponent). For example, $\frac{1}{3}$ might be represented with a mantissa of 0.33333333 and an exponent of 0; one-billionth might be 0.10000000 with

an exponent of -8 . The machine gains enormously in dynamic range, but at the cost of more complex processing (each arithmetic operation now involves 2 sets of numbers, exponents and mantissas).

The rounding-off process, by which real-world numbers (which cannot generally be represented by a limited number of digits) are reduced to the limited numbers of digits in a machine, in effect mixes those real signals with noise. The mathematics of information associates a particular signal-to-noise ratio with a particular number of bits used to represent the samples that in turn represent signals. The greater the number of bits per sample, the less the rounding-off noise. Alternatively, it might be said that, given a particular signal-to-noise ratio, there is no point in using more bits per signal than would be needed to keep the rounding-off noise at the same level. The number of bits increases only logarithmically with the signal-to-noise ratio. Using 1 bit/sample is equivalent to accepting a signal-to-noise ratio of 3 (4.7 dB); 4 bits is equivalent to a ratio of 255 (24 dB); a byte (8 bits) is equivalent to a ratio of $>65,000$ (about 58 dB).

These figures all apply to a system in which all the samples are normalized (divided by the largest possible sample size) for easy comparison and translation into fixed-point form. If each is represented by 1 byte, then that means that each must be represented by a number between 0 and 255. The intervals have to be wide enough so that noise will only rarely boost a signal across an interval, or subtract enough to drop a signal to the level below. Hence the relationship between noise strength and the number of bits representing a given signal.

In a real system, the level of representation chosen is based on the physical capacity of the system (e.g., the size of the words the computer can handle). For example, early digital sonars used clippers, which turned each data point into a 0 or 1, simply because they could not accommodate more detailed data.

A digital system must contend, then, with the effects of rounding off numbers as they are passed through more and more stages of computation. An analog system suffers from physical noise introduced as signals representing numbers pass from devices representing any one operation to devices representing another; it may also suffer from imprecision in translation from one kind of physical analog to another, as in an electro-mechanical computer. The digital system overcomes physical noise in transmitting the signals representing digits by adding extra check bits, such as parity bits; changes in the parity bits alert it to errors in transmission. There is no analog equivalent.

The great advantages of digital operation are fully realized only when data from all of a ship's sensors can be processed together and used together to drive displays and weapons. That in turn entails precise timing and rigidly defined signal standards. All the signals are discrete, and all of them have to be kept distinct. That is easy within a computer, but a ship whose combat system is built around a digital computer must use data from many different sensors and sources, each with its own analog-to-digital converter. When digital computers began to appear in U.S. naval weapons systems in the 1960s, problems were encountered in tying together devices that had never been designed to work together. This experience explains some of the pressure to develop new, fully digitized versions of radars and sonars. It also explains why it is relatively difficult to fit an existing ship with a fully integrated digital CCS. Even combinations of different digital machines may encounter timing problems.

DESIGNATION SYSTEMS

AUSTRALIA

Australia uses the U.S. triservice (AN) designation system, but numbers are in an 800 series, e.g., the Barra sonobuoy is SSQ-801.

CANADA

The Canadian government uses the U.S. triservice (AN) designation system, but numbers are in a 500 series. Thus SPS-501 is the first, not the 501st, Canadian naval radar.

FRANCE

The French government uses a unified triservice electronic designation system, similar in spirit to the U.S. AN system. Each piece of equipment is designated by four letters (the quadrigramme) and a number, with a letter suffix to indicate modifications. The first letter indicates the main function; the second, the process employed; the third, the normal mode of installation; and the fourth, the particular function of the system. In contrast to the AN system, the third and fourth letters can change depending upon the main function.

In addition, in at least some cases, letters are assigned in blocks that further describe the equipment.

Radars in the 10-19 block are X-band; the 20-29 block indicates either L- (20 cm) or P- (2 m) band; the 30-39 block indicates X-band; and the 50-59 block indicates C-band (5 cm).

Sonars in a 20-series are hull mounted; sonars in a 40-series are towed fish; sonars in a 60-series are towed arrays.

MAIN FUNCTION LETTERS (FIRST LETTER)

A	electronic warfare
B	test equipment
C	switchboard (commutation)
D	detection
E	transmitters (emitters)
F	electric generators
G	mine countermeasures
H	not used
I	information processing
J	imagery (electro-optics)
K	not used
L	not used
M	measurement
N	navigation
Q	miscellaneous, not covered in other categories
R	receivers
S	fire-control systems
T	transceivers
V	guidance (for weapons)

PROCESS LETTERS (SECOND LETTER)

A	artillery (fire control)
B	chemical energy (batteries, etc.); ballistic missiles (fire control)
D	doppler
E	wind generators; electricity (measurement)
F	wire (<i>fil</i> , in French)
G	gyroscopic; gas generators
H	magnetic
I	infrared and light intensification
J	inertial; bombing (fire control)
L	laser; mechanical generators
M	mixed; missiles (fire control)
N	nuclear and radioisotope
P	fluidic, hydraulic
R	radio-electric or electronic
S	sound; solar generators
T	thermal generators; television and CRT; torpedoes (fire control)
U	ultrasonic; electric
X	other processes
Z	satellite communication

SPECIAL PROCESS LETTERS FOR INFORMATION PROCESSING (SECOND LETTER)

A	analog
B	magnetic band
C	magnetic card
D	magnetic disk
E	magnetic memory element
G	magnetic drum
K	punched card

- M analog/digital
- N digital (numerical)
- O microfilm; optical memory
- P paper
- R punched tape
- S semiconductor memory
- T cathode-ray tube

MODES OF INSTALLATION (THIRD LETTER)

- A aircraft
- B surface ship (*bâtiment*)
- C man-carried (*cadre*)
- D vehicles and man-portable
- E missile
- F fixed
- M mobile
- N surface ships and submarines
- P man-portable (*portatif*)
- R submerged
- S semifixed
- T portable
- U submarine
- V vehicle

PARTICULAR FUNCTIONS (FOURTH LETTER)

- A analysis (identification); countermeasures; signaling device; attack (sensors and imagery); in generators, 400 Hz; self(auto)-protection (mine warfare); measurement of voltage and current; landing (*atterrissage*) in navigation; amplification; direction (*asservissement*) in fire control
- B jamming; in generators, direct current for battery-charging; in mine warfare, buoys; non-electrical measurements (e.g., acoustic); information processing (fire control)
- C multiplex; fire control; generator control; in mine warfare, classification; calculation (computing); positioning in curvilinear coordinates (navigation) (i.e., Loran-like systems); vector control (fire control)
- D surveillance—alert; detection; power distribution; in mine warfare, sweeping (*dragage*); coding (computing); detection (imagery); distance measurement (navigation)
- E listening; emission (in test equipment and in guidance); scouting; in generators, 50 Hz for electronic equipment; writing-recording (computer); standards of measurement; illumination (navigation); engagement (fire control)
- F frequency measurement; facsimile; telephone-telegraph (test equipment)
- G direction finding (goniometry); graphics; in generators, 50 Hz for general use; mine warfare (test equipment); signal generators (measurement); electrical distribution (fire control)
- H radio; in generators, 60 Hz for general use; printing (impression) for computers; hyperfrequency measurement (spectral analysis, envelopes, noise factors, etc.); vertical measurement (navigation)
- I identification
- J interception; information transmission; in mine warfare, immunization; accelerometry (navigation)
- K calculator; radioactivity (sensors and imagery); in generators, energy conversion; data conversion (computers); guidance (including autoguidance and wire guidance) in fire control
- L deception; security; in mine warfare, localization; reading (computers); measurement of semiconductor tube and crystal characteristics; localization and pursuit in fire control
- M mixed; also mines; in mine warfare, mine-hunting; input/output (computers); oscilloscopes (measurement); modems (miscellaneous equipment); management (fire control)

- N navigation; also teletype; in mine warfare, neutralization; bearing measurement (navigation); control of nuclear explosives (fire control)
- O in mine warfare, obstruction (antisweep)
- P telephony; in generators, production of direct current for various purposes; perforation (computers); pursuit (imagery); bridges for electrical measurement; position in polar coordinates (navigation)
- R localization, reception; missile guidance (sensors and imagery); reproduction (computers); marking (navigation); reception (fire control)
- Q indicators for measurement (galvanometers, magnetometers, etc.)
- S weapons system; also position—altitude (sensors and imagery); translation (computers); analysis of low-frequency signals (measures of distortion, phase, wave analysis, etc.); altimetry (*sondage*; navigation)
- T transceiver; teleprinters; terrestrial objects (sensors); sorting (triage) for computers; marking (imagery); test or multifunction equipment (measurement); position in geographical coordinates (navigation); launching or firing (fire control)
- U regulation of direct current; general functioning (fire control)
- V guidance (command); television; surveillance (*veille*, in sensors); in mine warfare and in computers, imaging (visualization); speed measurement (navigation); display of the tactical situation (fire control)
- W propulsion, energy; visiphone; meteorology; in mine warfare, surveillance; verification (computers); power measurement (wattmeter)
- X special; testing (fire control)
- Y teletype; information storage (computers); miscellaneous, special (fire control)
- Z training

GERMANY (WEST)

West Germany follows the U.S. AN designation system for shipborne sonars, except that all are prefixed D (Deutsch), as in DSQS-21. The serially assigned numbers do not coincide with U.S. numbers and are assigned in blocks (e.g., in sonars, the 11-series for minehunting sonars and the 21-series for search sonars).

ITALY

For naval radars, Italy uses the U.S. triservice (AN) system of designators, with the prefix MM (Marine Militare), with a 700-series, e.g., MM/SPS-768. There are also company designators. It appears that blocks of numbers within the overall series are reserved for special applications, as some of the numbers are too high to reflect a single sequence. It also appears that all naval radars and other electronic equipment, whether air- or shipborne, are in the same single numerical sequence.

Air force electronic equipment is designated in a 200-series.

JAPAN

Japan uses the U.S. triservice (AN) system of designators, except for different platform letters:

- E other
- H aircraft (sonobuoy and dipping sonar applications)
- L land-based fixed
- O surface ship
- R small, portable
- Y general use
- Z undersea (submarines, but also minehunting surface ship sonar)

The prefix N (as in NOLR-1) indicates a combination of other equipment. In many cases with electronics, the U.S. system is used with the prefix J, as in JVRC or JAN/GRC for a radio transceiver. In some cases U.S.-supplied (or license-built) equipment retains its U.S. designation; in others, it is redesignated with a J prefix.

In some cases a Type number system is used, e.g., Type 1 fire-control system. However, most Type numbers indicate the date of designation (not production) in terms of Japanese Fiscal years. Thus Type 63 is a designation adopted during Japanese Fiscal Year 1963. The Japanese fiscal year runs 1 April–31 March and is designated by the calendar year in which the FY begins (e.g., JFY63 began on 1 April 1963). This system corresponds to British practice and is 6 months away from the U.S. fiscal year (which runs 1 October–30 September).

Finally, equipment under development is given a serial designation, with a prefix: G for torpedo, K for mine, S for sweep gear. Thus a torpedo developed as G-9 was adopted for service as Type 73.

NETHERLANDS

Dutch naval electronic systems are generally developed by Hollandse Signaal Apparaten (HSA), and it is not altogether clear whether the HSA designations are imposed by the Royal Netherlands Navy. Radars are divided into

DA target indication (*doels aanwijzing*)

LW air search (*lucht waarschuwing*)

ZW sea search (*zee waarschuwing*)

Fire-control systems, both for surface ships and for submarines, are designated by the letter M and by a number; in some cases the combination WM is used. The numbers are not in sequence of development, but often indicate alternative (and roughly contemporary) levels of capability.

TAIWAN (GRC)

Taiwan uses the U.S. AN system, except that equipment is prefixed CS, as in CS/SPG-24; CS stands for the equivalent of the U.S. Defense Advanced Research Projects Agency.

USSR

All Soviet equipment is developed by design bureaus, and each bureau maintains an internal designation series. In addition, equipment accepted for service use is given a service designation. The chief example is aircraft designations. Published histories of Soviet aircraft design provide numerous examples of internal (bureau) and service designators, e.g., Tu-95 and Tu-20 for the same bomber (Bear). A recent Polish history of the MiG bureau provides a few internal numbers for air-to-surface missiles, and there is reason to believe that the practice is universal. Many Soviet weapons seem to have acquired names, either as covers for designations or as popular references. Finally, Soviet economic planning requires that each product within the economy be assigned what amounts to a national part number, identifying the item by producing ministry. Few of these numerical designations have ever been made public.

Very few of these internal Soviet designations, of whatever type, have become public knowledge. Typically, therefore, NATO has assigned reporting names and numbers. The numbers are in a NATO-generated sequence and may not include prototypes or, in some cases, weapons fielded in small numbers or covertly. Since they reflect the dates on which weapons are first observed, the sequence of the numbers may not reflect the development sequence. The chief series are:

AA air-to-air missiles

AS air-to-surface missiles (both strategic and tactical)

SS surface-to-surface missiles (both strategic and tactical).

Some reporting designations may or may not reflect Soviet practice. For many years Soviet unguided antisubmarine rockets have been designated RBUs, the number indicating the nominal range. These are probably actually the Soviet designators. The few reported Soviet torpedo designators seem to reflect Soviet rather than NATO practice, but some of them do not really fit any obvious system.

NATO's reporting names for Soviet electronic equipment often reflect either signal characteristics or physical appearance. For most naval systems, they combine an animal's name with some physical characteristic.

UNITED KINGDOM

The Royal Navy uses a Type Number system, originally adopted for radio sets. Equipment is designated in blocks, e.g., 900 for naval radars (1945–65, roughly). There is some evidence of blocks within these series, so that numbers are not sequential. For example, Type 992 was developed well before Type 967. In addition, some numbers are left blank, either to allow for improvements or for security purposes. When a block is exhausted another is designated. Modifications are indicated by suffixes but not all letters are used. Nor are they necessarily in alphabetical order. Typical radar modification letters are M, P, Q and R.

Some aircraft-related systems are designated in the NATO triservice AN series, in a 900 block (e.g., the AQS-903 acoustic processor).

The chief current blocks are:

1–99	radios, etc., through about 1945
100	sonars, up through the 1960s
200	World War II naval radars and IFF
600	radio transmitters and jammers
700	hydrophones
900	radars, post-1945
1000	radars, from the 1950s on
1200	VHF/UHF radio transceivers (recently opened)
2000	modern sonars

From 1945 on special designations were used for complete weapons-related systems (with sequence numbers, to indicate versions). Some of the following are obsolete, but most survive in one way or another.

ADAWS	Action Data Automation Weapon System
CACS	Computer-Assisted Command System (ADAWS successor)
CDS	Comprehensive Display System (analog predecessor to ADAWS)
DPT	Digital Plot Transmission (predecessor to Link 10/11)
FPS	Flyplane Predictor (computer) System (gunfire control system, including radar and director with Flyplane computer; replaced by MRS)
GDS	Gun-Direction System (now obsolete)
GSA	Gun System Automation
GWS	Guided Weapon System. The GWS series is divided into blocks:
GWS 1	area defense (Sea Slug)
GWS 20 series	point defense (Sea Cat, Sea Wolf)
GWS 30 series	area defense (Sea Dart)
GWS 40	ASW (Ikara)
GWS 50	antiship (Exocet)
GWS 60	antiship (Harpoon)

Subsystems are designated by the overall GWS designator, e.g., Sea Slug used a Mk 1 missile launcher, but Sea Cat (GWS 20 series) used Mk 20, and Sea Dart, Mk 30.

LRS	Long-Range (gun) System (defunct)
MDS	Missile-Direction System (MDS 1 for Sea Slug)
MRS	Medium-Range (gun) System
TCS	Torpedo-Control System (surface ship)
TCSS	Torpedo-Control System (submarine), now superseded by computer systems
UCS	Underwater Control System (for mortars, torpedoes)
WSA	Weapon System Automation (e.g., gun and missile)

Electronic *outfits* are designated by 2 or 3 letters, the first letter indicating the role. The second letter indicates the category within the role. Second letters were not assigned sequentially; in some cases they are mnemonics (e.g., AWA, for a wide antenna). Third letters (if assigned) are sequence letters within the series. The main examples are:

- A antenna (radio and radar), as in ANU
- C radio receivers, e.g., CUH; includes COMINT (HF, VHF)
- D computer system; DB series for surface ships and DC for submarines. This prefix is also used for decoys (DL series).
- F radio direction-finders; FH series for HF, FM for MF, FV for VHF, in each case with a numerical suffix, as in FH-4. Radar (SHF) direction-finders are prefixed U, as below.
- H teachers; but HO indicates a Hull Outfit (sonar dome), always HO with a number
- K distribution control (internal communication switchboard), e.g., Outfit KMY in a Type 23 frigate
- L radar track extractors (e.g., LFA for Type 996 radar of a Type 23 frigate)
- J radar display, with 1 or 2 additional letters
- Q some displays
- R data link (e.g., Outfit RBB for helicopter transponder; Outfit RJL(1) is the LAN for the Type 23 frigate command system); also sound recorders and reproducers
- T transmitters, when part of a larger system
- U ESM, with 1 or 2 additional letters, e.g., UAP
- Y electronic subsystems

In many cases, particularly in electronic countermeasures, the system has a code name, and it is not always clear whether there is any associated designation. More generally, most British weapons have names rather than numerical designators. However, some are described by their Naval Staff Requirement (NSR) or Staff Target (NST) or corresponding Air Staff designators, generally a four-digit figure. Reportedly, these numbers are applied randomly; presumably they are required for computerized accounting. With the amalgamation of service purchasing under a unitary Ministry of Defence, practice has changed and now there are Staff Requirements (Air) and (Naval) (and corresponding Staff Targets), each with a three-digit suffix.

UNITED STATES

U.S. electronic equipment is designated by 3 letters in an AN (triservice, originally army-navy) series. The first indicates the platform, the second the type of equipment, and the third the function. Numbers run in sequence within each designation, so that there can be both an SPS-49 radar and an SQS-49 sonar. In each case, the full designation is prefixed by the letters AN (multiservice), e.g., AN/SPS-49; the first 2 letters will generally be omitted. In a very few cases, examples of an earlier system survive: Mark numbers applied to fire-control radars (e.g., Mk 13 on board the battleships). These numbers fit the postwar SPG-series, with Mk 49 becoming SPG-49, for example. However, they were never retroactively identified within the AN series.

Experimental versions of equipment are indicated by a 2-letter code denoting the developing agency. Thus SPS-49(XN-1) would be the first Navy Department (i.e., contractor) prototype of the SPS-49 radar. The other major navy suffixes are XB, for the Naval Research Laboratory; SG, for the Naval Ocean Systems Center in San Diego; XJ for the Naval Air Development Center, Warminster, Pennsylvania; XU for the Naval Underwater Systems Center, New London; XAN for the Naval Avionics Center, Indianapolis; XCA for the Naval Weapons Center, Crane; XCL for the Naval Weapons Center, China Lake; XDV for the Naval Surface Weapons Center, Dahlgren; XGS for the Ground Support Division (Naval Air Engineering Center), Lakehurst; XIH for the Naval Ordnance Center, Indian Head; XMG for Point Mugu; XUC for the Naval Undersea Center, San Diego; XPC for the Naval Coastal Systems Laboratory, Panama City; XWH for the Naval Weapons Station, Earle; and XWO for the Naval Surface Weapons Center, White Oak. The suffix XZ was used for the old Bureau of Naval Weapons.

Different versions of systems are indicated in 2 ways. Originally, each version had its own suffix letter, e.g., SPS-6C as

compared to SPS-6B or -6D. More recently, a distinction has been made between variable systems, which differ by deletion or addition of subcomponents, and modifications that are interchangeable with earlier versions. Variable systems are indicated by (V) plus a number, as in SPS-49(V)5. Modifications are indicated by suffix letters, as before.

Parts of systems, or subgroups of equipment, receive 1- or 2-letter designators, e.g., CP for a computer or OL for an indicator. Sometimes the designation is written out to include the designator of the associated system, e.g., TB-16/BQQ is a towed body that is part of several BQQ-series submarine sonars. Typically, parts of systems are distinguished from subsystems (groups), but both are designated in this way.

U.S. missiles and rockets are also designated within a triservice (3-letter) system, but in this case each number is used only once. In some cases, such as Harpoon, the 3-letter designator is actually changed to reflect a different application of the same basic weapon. In recent years weapons' designators often have not been made public until very late in the development process (for example, veterans of the Sea Lance program cannot recall ever having seen a standard designator). This practice may have been adopted to conceal gaps in the list denoting highly classified ("black") programs such as stealth weapons. Code names are published, for budgetary reasons, but without any indication of their significance, and one name may cover several weapons (or vice versa).

U.S. aeronautical equipment (such as bomb guidance units, missile launchers, and warheads) is designated within a system developed by the U.S. Air Force in 1960. Although it superficially resembles the missile designation series, that air force system is entirely different, having been designed to embrace not only equipment carried on board aircraft but also ground-based materiel such as tractors and fuel tanks. This system does not include jet and rocket engines or photographic equipment. As might be expected of so broad a system, it is cumbersome (the air force initially wanted to expand the AN system to cover all aeronautical items, but the Office of the Secretary of Defense rejected that as unwieldy). Equipment is denoted by an initial letter A/, then by a 3-item code. Aircraft components are designated by 3 letters, the last of which is K. Aircraft-associated units are designated by 3 letters, the last of which is U. In the case of ground equipment, the designator consists of a letter indicating the type, a 2-digit number, and a letter indicating function, e.g., A/S32P-5, the fifth self-propelled (S), mechanical (32), protective (P) device (in this case, a fire truck). The only example in this book is A/N37U, a sweep-control device.

In the case of aircraft or missile units, the first 2 letters form a code, and designations include a letter after a slash to indicate the installation. The most important 2-letter codes and installation codes are indicated below.

This system was not applied retroactively, so designations such as Bomb Mk 82 survive.

Finally, in accordance with older procedures, U.S. naval weapons (and many systems' components) other than missiles themselves are organized by Mark number. Marks are applied, for example, to fire-control systems (and, separately, to gun directors), to gun mounts (in sequence whatever the caliber), to missile-launching systems (and, to add to the confusion, to the launchers proper), to rocket motors, to torpedoes, to warheads, and to weapons systems (built around unified control systems) as a whole. Examples of the latter are Mk 7 for Aegis and Mk 15 for Phalanx (see the table below). In at least some cases, Mark series were blocked to differentiate underwater from surface systems, e.g., Mk 101 was an underwater fire-control system, not the 101st fire-control system. However, when the original series reached 100, it continued interleaved with the special underwater series.

In addition, all U.S. nuclear weapons are assigned Mark numbers (by the Department of Energy, formerly the Atomic Energy Commission). Any application of a weapon is indicated by a prefix letter, e.g., the B77 bomb would be a bomb version of the Mk 77 warhead, and W77 would be the same weapon configured

as a missile warhead. Similarly, all reentry vehicles seem to have Mark numbers in a single series.

1. ELECTRONICS (THE "AN"-SERIES):

◆ Platform Letter

A	airplane
B	submarine ("boat")
C	air-portable (obsolete)
D	missile ("drone")
F	fixed
G	ground use (general)
K	amphibious
M	ground-mobile
P	man-portable
S	ship (or water surface)
T	ground-transportable
U	universal (land/water)
V	ground (vehicular)
W	waterborne (surface/submarine)
Z	piloted and pilotless airborne vehicle combination

◆ Type of Equipment

A	infrared
B	pigeon (obsolete)
C	carrier (wire)
D	radiac
E	nupac (obsolete)
F	photographic (not for U.S. use)
G	telegraph, teletype
I	interphone or public address
J	electro-mechanical or inertial wire covered
K	telemetry
L	countermeasures
M	meteorological
N	sound in air
P	radar (pulsed)
Q	sonar and underwater sound
R	radio
S	special, magnetic, etc. (or combination)
T	telephone (wire)
V	visual
W	weapons
X	facsimile or television
Y	data processing (integration of sensors)

◆ Function

A	auxiliary equipment (e.g., antennas, displays)
B	bombing
C	communications (transceiver)
D	direction finding, surveillance
E	ejection or release
G	fire control (gunnery) and searchlight direction
H	recording/reproducing
K	computing
L	searchlight control (obsolete)
M	maintenance and/or test
N	navigational
P	reproducing (obsolete, use H)
Q	multifunction or special
R	receive (passive detection)
S	search
T	transmit (e.g., jam)
W	weapons control
X	identification (IFF)
Y	multifunction (phased-array radar)

GROUP INDICATORS

OA	miscellaneous
OD	indicator
OE	antenna
OG	amplifier

OH	simulator
OJ	consoles
OK	control (used in towed-array reeling equipment)
OL	data analysis and data processing
OM	modulators, demodulators
OP	power supplies
OR	receivers
OT	transmitters
OU	converters
OV	generators
OW	terminals
OX	coders, decoders, interrogators, transponders
OY	radar sets (not to be used if more specific indicators apply)
OZ	radio sets (not to be used if more specific indicators apply)

COMPONENT INDICATORS

AM	amplifier
AS	antenna
AT	antenna (now obsolete)
BA	battery (primary)
BB	battery (secondary)
CA	computer (auxiliary parts)
CD	controlling device
CP	computer
CU	coupler
CV	converter (e.g., from frequency to frequency, or medium to medium)
CW	radome
DA	dummy load
DT	detecting head (e.g., hydrophone)
F	filter (electrical or electronic)
FR	frequency measurement
G	generator
GO	goniometer (DF device)
J	interface
KY	keying device (used for cryptographic devices)
LS	loudspeaker
M	microphone
MD	modulator, demodulator
ML	meteorological device
MU	memory unit
O	oscillator
OC	oceanographic device
OS	oscilloscope
PL	plug-in unit
PP	power supply
PT	mapping and plotting unit (electronic)
PU	power equipment
R	receiver
RD	recorder-reproducer
RL	reeling machine
RO	recorder
RP	reproducer
RR	reflector
RT	receiver/transmitter
SA	switching unit
SB	switchboard
SG	signal generator
SM	simulator
SU	optical unit (electro-optical)
T	transmitter
TA	telephone
TB	towed body (e.g., in towed array or MAD)
TD	timing device
TF	transformer
TG	positioning device
TH	telegraph
TR	transducer
TT	teletype, facsimile
V	vehicle

2. MISSILE-ROCKET DESIGNATIONS:

◆ Launch Environment

A	airplane
B	multi-environment
C	coffin
F	infantry
H	silo-stored (fired from surface)
L	land (fixed silo)
M	mobile
P	soft pad
R	ship
U	underwater

◆ Function

D	decoy
E	special electronic
G	surface attack
I	intercept (antiaircraft)
Q	target drone
T	training
U	underwater attack
W	weather

◆ Type

M	missile (guided)
N	probe
R	rocket

3. AIR EQUIPMENT DESIGNATIONS:

◆ Two-Letter Code

BB	explosive items (not warheads)
BD	bombs, simulated (dummy)
BL	bombs, aircraft (live)
BN	buoys
BR	bomb racks, shackles
BS	munitions stabilizing and retarding devices
CB	cluster bomb unit, consisting of a clustering device or dispenser (SUU) and bomblets (BLU or BDU); may function on board the airplane or after it is dropped
CD	clustering device containing bomblets to be dispensed from an SUU; may or may not be required to make the BLU/BDU compatible with the dispenser (SUU)
CP	computer
CY	cartridge case
DS	target detector (e.g., in proximity fuze)
DT	timing device (e.g., intervalometer)
FM	fuze, munitions
GA	gun, aircraft (e.g., in gun pod)
GB	guided bomb
GD	dummy guided missile (for training)
GP	gun pod (GA plus SUU)
GT	gun turret (excludes gun pods)
GU	guns, non-aircraft
KA	unfilled clustering device
KB	simulated cluster bomb unit
KD	simulated clustering device
KM	miscellaneous kits (used for early "smart" bombs)
LA	launcher, aircraft (e.g., missile rails)
LK	links, ammunition
LM	launching mechanism, ground
LU	illumination (light) (e.g., searchlight)
MA	miscellaneous armament
MJ	countermeasures munitions (e.g., bombs containing chaff or flares)
ML	miscellaneous live munitions
PA	external munitions dispensers (e.g., pods, tanks, clip-ins or other devices mounted externally)
PG	gun ammunition
PJ	projectiles
PW	internal munitions dispensers

RB	rocket and launcher units (combination of LAU and conventional rockets, RLU; excludes CBU)
RL	rocket, live (e.g., FFAR, HVAR)
RV	reentry vehicle (dummy or practice type)
RW	reentry vehicle (live)
SA	sights, gun-bomb-rocket
SP	self protection (as in the SPU-1/W Magnetized Orange Pipe for aerial minesweeping)
SU	suspension and release unit stores (munitions dispenser); may provide a clustering device (CD) to provide compatibility with the ordnance being transported; also may be a CBU less its BLU's
TD	target devices
WA	warhead section
WB	body section
WC	control section
WD	loaded warhead
WE	empty warhead
WG	guidance section
WP	propulsion section
WT	training or dummy warhead

◆ Application Code

A	aircraft or missile
B	aircraft or missile transported (mission expendable)
C	combined air and surface
E	ground (not fixed)
F	ground (fixed)
M	ground movable
N	aircraft or missile transported (not mission expendable)
P	personal use
S	ground, self-propelled
U	multi-installation
W	waterborne (surface or submerged)

4. WEAPON SYSTEM MARK NUMBERS

Mk 1	Weapons Control System (Typhon; abortive)
Mk 7	Aegis
Mk 15	Phalanx (CIWS)
Mks 20-24	TAS (Target Acquisition System; only Mk 23 entered service)
Mk 31	RAM (RIM-116 missile)
Mk 32	Tomahawk (ABL launcher)
Mk 33	DD 963 5-in-gun system using guided shells
Mk 34	DDG 51 class 5-in-gun system
Mk 35	SEAL boat gun system (abortive, for SWCM boat) using 25-mm gun in EX-90 mount, with remote sighting and control
Mk 36	Tomahawk submarine-launched missile system (Mk 44 launching system) using SWG-2 control
Mk 37	Tomahawk vertically launched missile system, using SWG-3 control
Mk 38	Dragon III assault missile, for marines
Mk 39	Iowa class 5-in/38 gun system
Mk 40	Iowa class 16-in/50 gun system

Many of these designations were applied ex post facto for convenience in referring to the system as a whole.

ABBREVIATIONS

A-Scope	radar display (range only)
AA	antiaircraft, also active adjunct (sonar)
AAC	antiaircraft common (ammunition)
AAM	air-to-air missile
AAW	antiaircraft warfare
ABF	advanced bomb family (U.S.)
ABM	anti-ballistic missile
ABRS	assault ballistic rocket system (U.S., by LTV)
ACINT	acoustic intelligence

ACLS	automatic (aircraft) carrier landing system	ASIC	application-specific integrated chip
ACM	antiarmor cluster munition	ASLCM	advanced sea-launched cruise missile
ACQ	acquisition	ASM	air-to-surface missile
ADA	new U.S. standard military computer language	ASMD	antiship missile defense
ADAC	French airborne radar designation; also U.S. all-digital attack center (in submarines)	ASMP	French air-launched strategic cruise missile
ADAR	adaptive receiver for horizontal line array (HLA) sonobuoy (U.S.)	ASP	airborne signal processor; also advanced signal processor
ADAWS	action data automation weapons system (British)	ASPJ	airborne self-protection jammer (U.S.)
ADF	auxiliary detonating fuze	ASROC	antisubmarine rocket (U.S.)
ADI	air-defense initiative (U.S.), complement to SDI	ASSM	abortive multinational antiship missile project of the 1970s, forerunner of the current ANS project
ADT	automatic detection and tracking	ASTAB	automatic status board
ADVCAP	advanced capability (version of EA-6B aircraft)	ASUW	antisurface (ship) warfare
AE	active enhancement (U.S. sonobuoy program)	ASW	antisubmarine warfare
AEM	adaptive energy management	ASWS	advanced standoff weapons system (U.S.)
AERP	active emission receiver processor (U.S., for sonar)	ATA	advanced tactical aircraft (U.S. A-12)
AEW	airborne early warning	ATB	advanced technology bomber (U.S. B-2)
AGC	automatic gain control (ECCM measure)	ATC	air-traffic control
AGPB	advanced general-purpose bomb	ATD	automatic target detection
AGPO	angle-gate pull-off (ECM technique)	ATF	advanced tactical fighter (U.S. F-22 or F-23)
AI	artificial intelligence	ATI	airborne tracker-illuminator
AIMS	IFF Mk XII system (U.S.); also advanced integrated MAD system (Canadian)	ATLIS	French laser designation pod
AIO	action information organization (British term for CIC)	ATT	automatic target tracking, also acoustic target tracker
AIWS	advanced interdiction weapons system (U.S.)	AUWE	Admiralty Underwater Weapons Establishment (British)
AJ	antijam (communications)	B-Scope	radar display (rectangular plot of range vs. bearing)
ALCM	air-launched cruise missile	BAC	British Aircraft Corporation
ALFS	airborne low-frequency sonar (U.S. program)	BAe	British Aerospace
ALWT	advanced lightweight torpedo (U.S. Mk 50)	BB	bottom bounce (sonar)
AM	amplitude modulation (as opposed to FM)	BBC	broad-band chaff
AMCM	airborne mine countermeasures	bbl	barrel (e.g., of a gun)
ammo	ammunition	BDF	base-detonating fuze
AMRAAM	advanced medium-range air-to-air missile (U.S. AIM-120)	BDI	bearing-deviation indicator (for target following in sonar)
AMTI	airborne moving target indication	BGAAWC	battle-group AAW coordinator (U.S.)
AM-X	joint Italian-Brazilian attack aircraft	BHP	brake horsepower
ANL	automatic noise leveling (ECCM technique)	BIT(E)	built-in test (equipment)
AP	armor piercing	bit	binary digit (0 or 1)
APAM	antipersonnel/antimatériel	BL&P	blind-loaded and plugged (inert target ammunition)
APDS	armor-piercing discarding sabot (ammunition)	BN	bombardier navigator
APFDS	armor-piercing fragmenting discarding sabot (ammunition)	BPDMS	basic point-defense missile system (U.S.: Sea Sparrow)
APFSDS	armor-piercing fin-stabilized discarding sabot (ammunition)	BT	bathymograph, to obtain a temperature profile of the sea
APHE	armor-piercing high-explosive (ammunition)	BVR	beyond visual range (in air-to-air combat)
APHE-SD	armor-piercing high-explosive self-destruct (warhead)	byte	hexadecimal digit (eight bits, i.e., base-64 digits)
API	armor-piercing incendiary (ammunition)	ca.	circa
API-T	armor-piercing incendiary tracer (ammunition)	C ²	command and control (C-squared)
approx	approximately	C ³	command, control, and communications (C-cubed)
ARBS	angle-rate bombing system (U.S. AN/ASB-19)	C3I	command, control, communications, and intelligence
ARE	Admiralty Research Establishment (British)	CAAIS	computer-assisted action information system (British)
ARM	antiradar missile	CAD	computer-aided design
ARP	antiradar projectile	CAINS	carrier aircraft inertial navigation system
ASAM	advanced surface-to-air missile, generic U.S. term	CAIR	countermeasure, airborne, IR
ASALM	advanced strategic air-launched cruise missile (U.S.)	CAM	computer-aided manufacture, often combined with CAD (in CAD/CAM)
ASAT	antisatellite (weapon)	CANE	computer-aided navigational equipment (British)
		CANCASS	Canadian command-activated sonobuoy (CASS)
		CASS	command-activated sonobuoy system
		CATIC	China Aero-Technical Import and Export Corp.

CBU	cluster bomb unit	dBm	decibel-milliwatt (measure used in ECM)
CCD	charge-coupled device (electronic component)	DC	direct current, also depth charge
CCS	combat-control system	DCAN	Direction Construction Armes Navale (French)
CCTV	closed-circuit television	DCN	Direction Construction Navale (French)
CDC	command-display console	DCU	distributed computing unit
CDS	combat-data system	DECM	defensive (also deceptive) electronic countermeasures
CEM	combined effects munition	deg	degree
CEP	circular error probable (half of all shots will fall within this radius)	DELEX	destroyer life-extension program (Canadian)
CFA	crossed-field amplifier (radar transmitter)	DEMON	demodulated noise (ASW signal-processing technique)
CFAR	constant false-alarm rate (in radar)	DF	direction finding
CIC	combat information center (U.S.; equivalent to operations room [British])	DFT	discrete Fourier transform
CIGARS	console internal generation and refresh system, modification to U.S. UYA-4 console of NTDS system	DGA	Delegation Generale pour l'Armement, the French government organization responsible for weapons development for all 3 services
CIWS	close-in weapons system	DICANCASS	Canadian DICASS sonobuoy (ASW)
CLOS	command to line of sight (missile guidance)	DICASS	directional command-activated sonobuoy (ASW)
CMOS	complementary metal-oxide-semiconductor (type of computer-chip technology)	DIFAR	directional LOFAR (in ASW)
CNO	chief of naval operations (U.S.)	DIGISMAC	digital scene-matching (cruise-missile guidance); also abbreviated DSMAC
CO	commanding officer	DIMUS	digital multibeam steering (ASW)
CODAR	correlation display analyzing recorder (ASW), to obtain position data by correlating the outputs of 2 or more passive sonobuoys	DLC	down-link communications
COMINT	communications intelligence	DLIR	downward-looking infrared
conscan	conical scan (in radar)	DMA	direct memory access
COOP	craft of opportunity program (generally in minesweeping)	DMCC	dual maintenance of close contact (sonar)
CORT	coherent receive/transmit (in radar)	DME	distance-measuring equipment (passive; U.S.)
CPA	closest point of approach	DMT	dual-mode tracker
CPIC	coastal patrol and interdiction craft (U.S.)	DMTI	digital MTI
CPMIEC	China Precision Machinery Import/Export Corp.	DND	Department of National Defence (Canadian, Australian)
CRBFD	close-range blind-fire director (British)	DoD	Department of Defense (U.S.)
CRT	cathode-ray tube (display)	DOP	Development Options Paper (U.S.)
CRZ	controlled-reaction zone	DP	dual-purpose
CP	command-plotting/plotter	DRAI	dead-reckoning analyzer/indicator (submarine)
csc ²	coscant-squared, a typical vertical shape for radar beams; it provides constant power at a given altitude at all ranges. The expression "30 deg csc ² " means a beam that has cosecant-squared shape up to 30 deg of elevation.	DRAM	dynamic random-access memory
CSDC	combat system display console (U.S.)	DRARM	dual-role ARM
CSEDS	combat system engineering development site (U.S.)	DRT	dead-reckoning tracer
CSLC	coherent sidelobe-canceling receiver	DSARC	Defense System Acquisition Review Council (U.S.)
CSU	compact sonar for submarines (U-boats) (German)	DSCS	Defense Satellite Communications System (U.S.)
CU	control unit	DSMAC	see DIGISMAC, above
CVR	crystal video receiver	DT	directional transmission (in sonar)
CVT	controlled variable time, for a fuze	DTCN	Direction Technique Construction Navale (French)
CW	continuous wave (nonpulsed); also chemical warfare	EAC	equal angle coverage
CWAT	CW acquisition and tracking	ECM	electronic countermeasures
CWI	continuous wave illuminator/injection	ECCM	electronic counter-countermeasures
CZ	convergence zone (sonar)	EDATS	extra-deep armed team sweep (British)
DARPA	Defense Advanced Research Projects Agency (U.S.)	EDM	engineering development model
DASH	drone antisubmarine helicopter (U.S. QH-50, obsolete)	EEPROM	electrically erasable programmable read-only memory (in a computer, ROM that can be electrically erased for reprogramming; it cannot be erased by the computer itself, hence is read-only)
dB	decibel, a measure of relative size; it is 10 log (base 10) of a ratio. Thus, 3 dB is a factor of about 2, and 10 dB a factor of 10; -3 dB is about a half. The reference value in the ratio is often implicit, as in radar, when it is the performance of a notional antenna radiating power equally in all directions.	EEZ	exclusive economic zone (defined by Law of the Sea Treaty)
		EFA	European fighter aircraft (multinational project)
		EHF	extremely high frequency
		ELF	extremely low frequency
		ELINT	electronic intelligence
		EMCON	emissions control (electromagnetic silence)
		EMATT	expendable mobile ASW training target (U.S.)

EMI	electromagnetic interference; also the name of a British electronics manufacturer	GFCS	gunfire-control system (U.S.)
EMSP	enhanced modular signal processor (U.S.)	GHG	Gruppen-Horch Gereat (array listening system), the wartime German low-frequency passive sonar from which several postwar systems were derived
EMP	electromagnetic pulse		
EMR	extended memory reach (in a computer)	GHz	gigahertz (thousands of MHz)
EO	electro-optical	GMFCS	guided-missile fire-control system (U.S.)
EPROM	erasable programmable read-only memory	GOPS	billion (giga) operations/sec (for computers)
ERAPS	expendable reliable-acoustic-path sonobuoy	GP	general-purpose (as in bomb)
ERDL	extended-range data link	GPS	global positioning system
ERP	effective radiated power (in jamming)	GRP	glass-reinforced plastic (construction material)
ESF	electronically set fuze, replacing mechanically set fuzes		
ESM	electronic support (surveillance) measures	HALE	high-altitude long-endurance (drone)
ESS	enhanced Sea Sparrow (U.S. missile project)	HARM	high-speed antiradar missile (U.S. AGM-88)
ESR	equivalent service rounds, measure of gun wear	HBX	high explosive (more powerful than TNT)
est	estimated	HC	high capacity (as in a shell)
ETF	electrical time fuze	HCER	high-capacity extended-range
EW	electronic warfare; also early warning	HCHE	high-capacity high-explosive (ammunition)
FA	frequency agility	HDW	Howaldt, a German shipbuilder
FAC	fast attack craft	HE	high explosive
FAE	fuel-air explosive	HEAT	high-explosive antitank (shaped charge)
FCS	fire-control system	HEER	high-explosive extended-range
FDAL	frequency domain adaptive line enhancement (sonar technique)	HEI	high-explosive incendiary
FET	field effect transistor	HEL	high-energy laser
FEWSG	Fleet Electronic Warfare Support Group (simulating enemy jamming for training) (U.S.)	HE-SD	high-explosive self-destruct (ammunition)
		HF	high frequency
FFAR	folding-fin aircraft rocket (2.75-in caliber)	HLA	horizontal line array (U.S. sonobuoy)
FFT	fast Fourier transform	HLASM	helicopter-launched air-to-surface missile
FIAR	Fabbrica Italiana Apparecchiature Radioelettroniche (Italian manufacturer)	HOTAS	hands-on throttle and stick
FIR	finite impulse response (type of radar receiver, for ECCM)	HP	horsepower (or high power or high pressure or horizontal plotter)
FLIR	forward-looking infrared	hr	hour(s)
FLOPS	floating-point instructions per second (measure of computer speed, as in 1 MFLOPS, i.e., 1 million FLOPS per second)	HS	ASW helicopter squadron (U.S. Navy)
		HSA	Hollandse Signaal Apparaten (also known as Signaal)
FLOT	forward line of own troops	HTP	high-test peroxide (concentrated hydrogen peroxide)
FM	frequency modulation (as opposed to AM)	HUD	heads-up display
FMC	U.S. defense manufacturer, formerly Food Machinery Corp.	HUMINT	human intelligence
FMCW	frequency-modulated continuous wave	HVAR	high-velocity aircraft rocket (5-in caliber)
FM/FI	fault monitoring/fault isolation	Hz	hertz (cycles per second)
FMS	foreign military sales (U.S.)		
For	field of regard (field over which a sensor can scan)	IADT	integrated automatic detection and tracking
FOV	field of view	IAI	Israel Aircraft Industry
FPB	fast patrol boat	IAM	inertially aided munitions (U.S.)
FRAM	fleet rehabilitation and modernization (U.S. program, applied to many destroyers now serving in foreign navies)	IC	internal communication (circuit) in U.S. usage; also integrated circuit
FRESCAN	frequency scanning (electronic scanning technique in radar)	ICW	interrupted continuous wave
FSD	full-scale development	IFF	identification friend or foe
FSED	full-scale engineering development	IFM	instantaneous frequency measurement (in ESM)
FSK	frequency-shift keying (symbols differentiated by different frequencies)	IIR	imaging infrared
ft	foot/feet (12 inches)	ILS	instrument landing system, often as VOR/ILS
FTC	fast time constant (radar ECCM technique)	in	inch
FY	fiscal year (U.S.: 1 October–30 September)	INF	Intermediate Nuclear Forces
FYDP	five-year defense program (U.S., compiled annually)	INS	inertial navigation system
		I/O	input/output
G	force of gravity	IOC	initial operational capability
g	gram	IR	infrared
GAO	General Accounting Office (U.S.)	IRDS	infrared detecting set
GDS	gun direction system	IRGP	infrared guided projectile
GE	General Electric Company	IRST	infrared search and track (or target designation)
GERDSM	French ASW and mine warfare development establishment	IRU	inertial reference unit
		ISAR	inverse synthetic-aperture radar
		ISUS	integrated-sensor underwater system (German)
		ITAWDS	amphibious warfare data system (U.S.)
		ITSS	integrated tactical surveillance system (U.S.)

ITT	invitation to tender (British equivalent to an RFP)	m	meter
IUSS	integrated undersea surveillance system (U.S.)	M	Mach (number), multiple of speed of sound
JCS	Joint Chiefs of Staff (U.S.)	MAD	magnetic-anomaly detector (in ASW)
JDF	jamming direction-finder	MAP	military assistance program (U.S.)
JFY	Japanese fiscal year	MARV	maneuverable reentry vehicle
JMSDF	Japan Maritime Self-Defense Force (navy)	MASC	multi-array signal conditioner (U.S., in sonar)
JSCAMPS	Joint-Service Common-Airframe Multiple-Purpose System (U.S. RPV program)	max	maximum
JTIDS	joint tactical information distribution system (U.S., NATO)	MBAT	multibeam array technology
k	kilo, thousand. In electronics, a kilobit (or -byte) equals 1024 rather than 1000 bits (bytes).	Mbit	Megabit, million bits (approximate)
K	degrees Kelvin (i.e., above absolute zero)	Mbps	Megabytes per second (measure of data rate)
kg	kilogram, 2.204 lb	Mbyte	megabytes, million bytes (approximate)
KDA	Oerlikon gun designation (Swiss). The first letter, K, indicates that the weapon is a gun (mounts are prefixed G); the second letter indicates the caliber (A for 20-mm, B for 25-mm, C for 30-mm, D for 35-mm); the third letter is a modifier (for guns, typically A, B, or C). Other typical gun designations are KAA, KBA, and KBB.	MCAR	multiple channel aural reception (sonar)
KIPS	thousands (kilo) of instructions/sec (for computers)	MCC	maintenance of close contact (sonar)
K-Kill	catastrophic kill, as opposed to mobility or firepower kill	MCM	mine countermeasures
km	kilometer	MCOPS	millions (M) of complex operations/sec (for computers)
KOPS	thousands (kilo) of operations/sec (for computers)	MCP	microchannel plate
kT	kilotons, thousands of tons (equivalent TNT)	MDC	mine-destruction charge
kt	knot(s) (nautical miles per hour)	MEKO	modular frigate (by Blohm & Voss)
kV	kilovolts	MEL	British and Canadian electronics manufacturer
kW	kilowatts	MEM	maximum energy management
kyd	kiloyards, thousands of yards	MF	medium frequency
LADAR	laser radar	MFCC	multifunction common console
LAMPS	light airborne multipurpose system (U.S. helicopter)	MFCS	missile fire-control system
LAN	local area network (for computers)	MFLOPS	millions (M) of floating-point operations/sec (for computers)
LANTIRN	low-altitude navigation-and-targeting IR system for night (U.S.)	MFR	multifunction radar
lb	pound(s)	MG	machine gun (also motor generator, to transform AC to DC current)
LCAC	landing craft air cushion (U.S.)	MGC	manual gain control (in radar)
LCS	low-cost sonobuoy (U.S.); also low-cost seeker	MHC	minehunter, coastal
LED	light-emitting diode (for electronic displays)	MHz	megahertz (millions of cycles per second)
LF	low frequency	microsec	microsecond, millionth of a second
LFDM	low-flier detection mode (in radar)	MIDAS	mine detection-and-avoidance system (U.S.)
LGB	laser-guided bomb	min	minute or minimum
LIDAR	light (i.e., laser) radar	MIPS	millions (M) of instructions/sec (for computers)
LLGB	low-level laser-guided bomb	MIR	mid-IR
LLTV	low-light-level television	MIRV	multiple independent reentry vehicles
LNFE	low-noise front end	mJ	millijoules
LOAL	lock-on after launch	Mk	mark (number, for designations)
LOBL	lock-on before launch	mm	millimeter
LOCWS	laser obstacle and cable warning system	MMW	millimeter-wave (length)
LOFAR	low-frequency analysis and recording (ASW)	MNS	mine neutralization system (U.S.)
LOVA	low-vulnerability ammunition	MoD	Ministry of Defence (e.g., British)
LPI	low probability of intercept	Mod	modification to equipment of a given Mk number, as in Mk 46 Mod 5 torpedo
LRCCM	long-range conventional cruise missile	MOP	magnetized orange pipe (U.S. mine sweep)
LRDMM	long-range dual-mode missile	MOPS	millions (M) of operations/sec (for computers)
LRU	line-replaceable unit	MOSS	mobile submarine simulator (U.S.)
LSI	large-scale (electronic) integration	MoU	memorandum of understanding
LST/SCAM	laser spot tracker/strike camera	mph	miles per hour
LTV	Ling-Temco Vought, U.S. manufacturer	MPSM	multipurpose submunition (warhead)
LWIR	long-wave infrared	mrad	milliradian (thousandth of a radian)
		MRBF	mean rounds (fired) before failure
		MR-RPV	mid-range RPV (U.S.)
		MRV	multiple reentry vehicle
		msec	millisec, thousandth of a second
		MP	medium power
		MPA	maritime-patrol aircraft
		MPC	multipurpose console
		MSB	minesweeping boat
		MSC	minesweeper, coastal
		MSD	minesweeping drone
		MSI	medium-scale integration, as opposed to LSI and VLSI; also minesweeper, inshore
		MSL	minesweeping launch
		MSO	minesweeper, ocean
		MSOW	modular standoff weapon (NATO)

MT	Megatons, millions of tons (TNT equivalent); also mechanical time, for a fuze	PK	probability of kill
MTBF	mean time between failure	POM	program objective memorandum (U.S. defense plan)
MTI	moving-target indicator (or indication)	PPI	plan-position indicator (maplike radar display)
MTT	moving-target tracker	pps	pulses per second
MTTR	mean time to repair (also multitarget tracking radar)	PRC	People's Republic of China
MW	Megawatt, million watts	PRF	pulse repetition frequency
NADGE	NATO air-defense ground environment	PRI	pulse repetition interval
NAVAIR	Naval Air Systems Command (U.S.)	PROM	programmed read-only memory
NAVSEA	Naval Sea Systems Command (U.S.)	PSP	programmable signal processor
NDB/NSB	nuclear depth bomb/nuclear strike bomb	pt	point
NEL	Naval Electronics Laboratory (U.S.)	PTA	passive-tracking algorithm; also proposed technical approach, in U.S. procurement
NFT	Norsk Forstvarsteknologi, a Norwegian defense manufacturer, formerly Kongsberg	PUFFS	passive underwater fire control (U.S.)
NIS	NATO identification system (IFF)	PWO	principal warfare officer (British equivalent to U.S. TAO)
nm	nautical mile, 6080 ft	QRC	quick-reaction contract, a U.S. procurement technique used during the Vietnam War
NMOS	n-channel metal-oxide-semiconductor (type of computer chip technology)	RAAF	Royal Australian Air Force
NMR	nuclear magnetic resonance	rad	radian, measure of angle (1 radian is about 57.3 deg)
NOSC	Naval Ocean Systems Center (U.S.)	RAF	Royal Air Force (British)
NRL	Naval Research Laboratory	RAM	random access memory (in computers); also rolling airframe missile (U.S.) and radar-absorbing material
nsec	nanosecond (billionth of a second)	RAN	Royal Australian Navy
NSR	Naval Staff Requirement (British)	RAP	rocket-assisted projectile (shell); also reliable acoustic path (ASW)
NSSMS	NATO Sea Sparrow missile system	RBOC	rapid-blooming off-board chaff (U.S.)
NSWC	Naval Surface Warfare Center (U.S.)	R&D	research and development
NST	Naval Staff Target (British)	RDF	Rapid Deployment Force (U.S.)
NTDS	naval tactical data system (U.S.)	RDT	rotationally directed transmission (sonar)
NTU	New Threat Upgrade (U.S. program)	RDT&E	research, development, testing, and engineering
NUSC	Naval Underwater Systems Center (U.S.)	RDX	high explosive (more powerful than TNT)
NVG	night-vision goggles	RF	radio frequency
ODT	omnidirectional transmission (sonar)	RF/IR	combined radio (or radar) and IR
OFD	optical fire director	RFA	Royal Fleet Auxiliary (British)
ONI	Office of Naval Intelligence (U.S.)	RFP	request for proposal
OPV	offshore patrol vessel	RGPO	range-gate pull-off (ECM technique)
OR	Operational Requirement (U.S.)	RISC	reduced-instruction-set computer
ORDALT	ordnance alteration (U.S.)	RLO	radar lock-on
ORTS	operational recording and testing system (U.S.)	RHAW	radar homing and warning
OSD	Office of the Secretary of Defense (U.S.)	RHI	range-height indicator (for radar)
OTC	officer in tactical command	rms	root-mean square
OTCIXC	OTC information exchange channel	RN	Royal Navy (British)
OTH	over the horizon (in radar); OTH-B is OTH by means of backscatter (off the ionosphere). A forward-scatter OTH system uses a beam that scatters off the target, then goes beyond to a separate receiver. OTH-B uses transmitter and receiver close together, bouncing the reflected wave back off the ionosphere between target and radar.	rnds	rounds
OTH-T	over-the-horizon targeting (U.S. term)	RNEE	Royal Navy Equipment Exhibition
PACS	plotting and combat summary display (U.S.)	RNTF	Royal Navy Torpedo Factory (now closed)
PADLOC	passive-active detection and localization (sonar, U.S.)	ROM	read-only memory (in computer)
PAIR	performance and integration refit (conversion of SQS-23 sonar to SQQ-23)	ROV	remotely operated vehicle (generally underwater)
PAL	permissive action link (in nuclear systems, to prevent unauthorized use)	RPC	reflected power canceler or remote power control (British: guns)
PD	probability of detection; also point detonating (fuze)	RPG	rocket-propelled grenade (antitank weapon)
PDD	point detonating delay (fuze)	rpm	revolutions per minute
PDF	point (instantaneous) detonating fuze	RPV	remotely piloted vehicle; see also UAV
PDMS	point-defense missile system (U.S.)	RRDT	random rippled directional transmission
PEAB	Philips Elektronikindustri AB (Swedish manufacturer)	RSLS	receiver sidelobe suppression
PFHE	prefragmented high-explosive (ammunition)	RTLOS	remote track launch on search (missile tactic)
PGM	precision guided munition ("smart weapon")	RTN	Italian (Selenia) radar designator
PI/DF	passive identification direction finding	RTV	recoverable test vehicle
		RV	reentry vehicle (for a missile)
		RVC	radar-video converter (to digital data)
		RVP	radar-video processor
		RWR	radar-warning receiver
		SACLANT	Supreme Allied Commander Atlantic
		SADARM	sense and destroy armament (submunition)

SADS	SubACS acoustic detection system (U.S.)	SSPK	single-shot kill probability
SALGP	semiactive laser-guided projectile	SSTx	solid-state transmitter
SAM	surface-to-air missile	STA	second time around, referring to radar pulses arriving back at the radar after the next pulse has been sent
SAP	semi-armor-piercing	STAE	second-time-around echo (radar)
SAR	synthetic-aperture radar; also search and rescue	STC	sensitivity time control (ECCM technique)
SCCS	submarine combat-control system	STIR	separate track and illumination radar (U.S.); also Signaal track and illumination radar (Dutch); also surveillance and target indication radar (British)
SCEPS	stored chemical energy propulsion system (for torpedoes; see U.S. Mk 50)	SURTASS	surveillance towed-array sonar system
SCI	special compartmented information (generally information outside the usual classification system; information is often "sanitized" to remove SCI so that it can more freely be used by operating forces) (U.S.)	SWCM	special warfare craft, medium (SEAL craft, U.S.)
SDC	sensor - data converter / situation - display console	SYS	sensor (radar) integration computer (U.S.)
SDI	strategic-defense initiative (U.S.): defense against ballistic-missile attack	2D	two-dimensional
SDT	steered directional transmission (sonar)	3D	three-dimensional
SEAL	Sea-Air-Land (U.S. Navy special forces)	3P-HV	programmed-proximity prefragmented high-velocity explosive (Bofors ammunition)
sec	second	TABP	towed-array broad-band processor (U.S.)
SEM	standard electronic module (U.S.)	TACAN	tactical air navigation beacon (U.S.)
SEPADS	sonar-environment prediction-and-display system	TACCO	tactical coordinating officer
SFCS	submarine fire-control system	TACSIT	tactical-situation display (in U.S. submarines)
SHAB	steerable hull array beam-former (U.S.)	TACTASS	tactical towed-array sonar system
SHF	super high frequency	TADIL	tactical digital link (U.S. and NATO)
SHINPADS	shipboard integrated processing-and-display system (Canadian)	TAO	tactical action officer
SHP	shaft horsepower	TAPS	towed-array broad-band processing system (British)
SHR	superheterodyne receiver	TARP	towed-array range processor/processing for U.S. long thin array)
SIAC	submarine integrated attack center	TAS	target acquisition system (U.S.); also tactical Arctic sonobuoy (U.S.)
SID	situation information display	TASP	towed-array signal processor
SIDS	sensor interface data system (U.S.)	TASS	towed-array sonar system
SIGINT	signals intelligence	TB	towed body (U.S. designation)
SIMAS	sonar in-situ mode assessment system	TCSS	torpedo-control system, submarine (British)
SINS	ships' inertial navigation system	TDC	torpedo-data computer
SLAM	standoff land-attack missile (modified Harpoon)	TDD	target-detection device (proximity fuze)
SLAT	supersonic low-altitude target; also surface-launched air-targeted	TDHS	tactical data-handling system (ASW)
SLB	sidelobe blanking (in radar)	TDI	target doppler or deviation indicator (sonar, for target tracking)
SLBM	sea-launched ballistic missile	TDMA	time division multiple access (type of data link)
SLC	sidelobe cancellation (in radar)	TDS	tactical data system
SLCM	sea-launched cruise missile	TDT	target designation transmitter
SLEP	service-life extension program (U.S.)	TELCOM	two-way wire guidance for Mk 48 torpedo (U.S.)
SLMM	submarine-launched mobile mine	TENCAP	tactical exploitation of national (intelligence) capabilities (U.S.)
SMA	Segnalamento Marittimo ed Aero (Italian manufacturer)	TERCOM	terrain comparison (cruise missile guidance)
SNIA	French rocket motor manufacturer	TEWA	threat evaluation and weapons assignment
SOR	specific operational requirement (U.S.)	TG	transmitter group (in sonar)
SOSUS	sound surveillance system (U.S. and NATO)	TI	target indication (British)
SPAT	self-propelled acoustic target	TICM	thermal-imaging common module
SRAM	static random-access memory	TMA	target-motion analysis (for ASW ranging and fire control)
SRARM	short-range ARM (U.S.)	TMAD	target-motion analysis display
SRBOC	super rapid-blooming off-board chaff (U.S.)	TOR	Tentative Operational Requirement (U.S.)
SRDT	steered rotationally directed transmission (sonar)	TOW	tube-launched optical wire-guided missile (U.S., antitank)
SRSSM	short-range surface-to-surface missile	TP	target practice (ammunition)
SS	submarine	TP-FP	target practice fragmentation projectile
SSB	single sideband (radio); also diesel-powered ballistic-missile submarine	TP-T	target practice tracer (ammunition)
SSBN	strategic ballistic-missile submarine (nuclear powered)	TPX	explosive (torpex, more powerful than TNT)
SSI	sector scan indicator (sonar, for target tracking)	TRAM	target recognition and attack multisensor
SSK	ASW submarine (nonnuclear)	TRDT	tribeam rotationally directed transmission (sonar)
SSLV	standard small launch vehicle		
SSM	surface-to-surface missile		
SSN	nuclear submarine		

TRF	tuned radio frequency (wide-band type of receiver)	VGPO	velocity-gate pull-off (ECM technique)
TRIASP	tri-advanced signal processor (U.S., in sonar) (three ASP packaged together, for the BQQ-5C sonar)	VHF	very high frequency
TRUMP	<i>Tribal</i> -class modernization program (Canadian)	VHSIC	very high speed integrated circuit
TSC	tactical support center (U.S., for ASW)	VIS	visual
TSS	tactical surveillance sonobuoy (U.S.)	VLA	vertical-launch ASROC (missile) (U.S.)
TT	torpedo tube	VLAD	vertical line array DIFAR (U.S. sonobuoy)
TVM	track via missile (guidance technique)	VLF	very low frequency
TWS	track-while-scan	VLS	vertical launch system
TWT	traveling wave tube (radar transmitter)	VLSI	very large scale integration (of electronic circuits)
UAV	unmanned air vehicle (this more general term is replacing RPV in many cases)	VME	versatile memory Eurobus, a current standard internal computer data bus
UDACS	Universal Display and Control System (Boeing ASW system)	VOR	VHF omni-range (for air navigation)
UEP	underwater electric potential	VP	patrol (ASW) squadron (sometimes used for patrol aircraft) (U.S. Navy)
UHF	ultrahigh frequency	VQ	ECM squadron (U.S. Navy)
ULC	up-link communications	VSTOL	vertical/short takeoff and landing
UVPROM	ultraviolet programmable read-only memory (the read-only feature is disabled when the appropriate ultraviolet light is shined on the memory)	VT	variable time (proximity), used for a fuze
VA	attack squadron (U.S. Navy) (with a number)	VTOL	vertical takeoff and landing
VAB	variable-action button (of a console)	VX	test squadron (U.S. Navy) (with a number)
VAW	AEW squadron (U.S. Navy) (with a number)	W	watts
VDS	variable-depth sonar	WAA	wide-aperture array (U.S.)
VECG	video extractor and control group (in radar)	WBL	wide-band limiting (in radar)
VERDIN	VLF emergency digital information network (secure radio for submarine broadcasts, U.S.)	WCS	weapons-control system (U.S.)
VF	fighter squadron (U.S. Navy) (with a number)	WDC	weapons-delivery computer
		WDS	weapons-direction system (U.S.)
		WP	white phosphorus (shell)
		WPB	wide pulse blanking (in radar)
		WRA	weapons replaceable assembly
		XBT	expendable bathythermograph
		yd	yard(s)
		yr	year(s)

WORLD NAVAL WEAPONS SYSTEMS

SURVEILLANCE AND CONTROL

A fleet's visible elements are its ships, submarines, and aircraft. These elements are tied together by communications links, many of them satellite-borne. Increasingly, a fleet's operations are motivated by external sources of operational intelligence data. Many of the sources and systems involved are sensitive and so cannot be described. Much of the West's knowledge of the Soviet systems, for example, has been obtained by careful sifting of intelligence obtained at great cost, and this information is by no means publicly available. Thus the systems described in this section should be considered samples of a larger whole, indications of the very important invisible elements of modern navies.

Such systems are not nearly as new as they may seem. Before World War II, for example, the U.S. Navy operated a Strategic High-Frequency Direction-Finding system around the rim of the Pacific, specifically to track the Japanese Fleet. The system fed information to naval headquarters in Washington, D.C., which in turn would have directed the CinC U.S. Fleet in Pearl Harbor into position to deal with his enemies. With the success of Allied code breaking during World War II, centralized operational intelligence became more common and more important. It remains important now, although, of course, the degree of success with which we track, say, Soviet submarines must be a matter of speculation in any unclassified discussion.

The central question in the design of all such systems has always concerned the amount of raw data a deployed commander should be provided. In World War II, it was obvious that the deployed commanders required a great deal of raw data, and great pains were taken to protect the channels by which those data were transmitted. Afterward, as the United States and its allies came to believe that a major war, if it ever occurred, would soon escalate to a nuclear exchange, the operational aspect of intelligence seemed less and less important. Systems with an operational potential, such as SOSUS (Sound Surveillance System), were valued primarily for their war-warning potential, their data prepared principally for the National Command Authority. Now it seems clearer that a war might remain non-nuclear for quite some time, perhaps throughout its course. In that case, tactical war-fighting becomes more important; and some of the same intelligence systems built up for the National Command Authority are being turned, in part, to the needs of the deployed commanders. This development explains such systems, discussed below, as JOTS (Joint Operational Tactical System) and OSIS (the Ocean Surveillance Information System).

For the United States, the investment in existing intelligence-gathering systems is so large that new tactically oriented systems cannot likely be built, at least in the short term. Instead, existing systems are being used, where they are appropriate. These systems do *not* include such classic intelligence-gatherers as photographic satellites, which cover only very limited areas at any one time, or deep-space nuclear-detonation detectors.

The other key question for the United States is to what extent fixed, as opposed to mobile (i.e., integral with tactical formations such as battle groups), intelligence systems should be supported. If the United States had to face only the Soviet Union, there would be no question: full coverage of northern waters would have the highest priority, and nowhere else would full coverage be particularly valuable. However, the single greatest asset of sea power is its mobility, its ability to deal with the unexpected—which, since 1945, has usually meant conflict in the Third World. The question of mobile surveillance has not yet really arisen, but that is only because the United States' Third World enemies have not yet had serious naval forces requiring the use of more than existing fleet assets. That may well not be the case in the future, and the United States may even have to face the Soviets outside their home waters. This issue affects systems such as SOSUS and ROTH (the Relocatable Over-the-Horizon Radar).

For the Soviets, the situation is rather different. Much of the Soviet intelligence program, including at least some (and perhaps all) space and long-range direction-finding assets, is con-

centrated in the hands of the GRU, the intelligence arm of the General Staff. It is unlikely that the GRU would ever have thought in other than operational terms; the Soviets may well rely on agents in place in other countries for such purposes as war-warning. In any case, the Soviets seem much more willing than the Americans to use intelligence data for operational purposes, whereas in the West the emphasis has been much more on protecting invaluable sources (including technical ones) to avoid losing war-warning capabilities.

On the other hand, the Soviets concentrate much more power in the hands of their central command structure, so that deployed commanders, in the Western sense, probably do not exist at all. Intelligence assets, such as most satellites, report to the central command. Deployed forces are ordered into position to attack on the basis of these reports, in some cases using satellite or other off-board data as a basis for attacking. This organization relies heavily on long-haul communications, and the Soviets are well known for their redundant command links.

From a technological point of view, perhaps the most important development has been the changing fortune of HF radio. HF communications have very long ranges because HF signals bounce off the ionosphere, but a long range subjects an HF system to intercept and to DF. HF also suffers in practice from the vagaries of the variable ionosphere.

The effect of external command/control and intelligence is to extend the horizon of an individual ship. However, most of the information so obtained is given in terms of geographical (i.e., earth-oriented) coordinates: the incoming force of bombers is in this position, flying this course, at this speed. Only if a ship at sea has reasonably accurate navigational data can it take full advantage of such information. Thus, this section includes some specialized navigational systems, such as the U.S. global positioning satellites. When these devices provide really accurate information, they can be used to guide weapons, such as cruise missiles, to specific points on the earth. The question then is whether the intelligence systems providing initial targeting data are nearly as precise as the navigational systems exploiting them. For example, it is not too useful to guide a missile to within a foot of a presumed target when the actual target is a mile away. Not knowing the target's location precisely enough is a central problem in all long-range ballistic-missile firings.

Accurate navigation is also essential to successful mine countermeasures. The minehunter or -sweeper must know precisely which channel its predecessors have cleared and precisely where it goes from there. This section, therefore, also includes accounts of the standard in-shore precision-navigation systems now in use on board Western mine-countermeasures ships. Soviet systems are presumably roughly equivalent.

The big fixed systems share and sift information so that it can be fed to ships at sea. Ships have analogous combat systems, such as the British ADAWS series, the French SENIT, and the American NTDS, whose function is to coordinate information available on board ship (including that provided by external sources) and then to present all the information in a form suitable for decision making (including weapons assignment and control).

Like the big external systems, the on-board combat system is by no means a new idea. The classic warship information center consisted of the plot, a presentation of the situation around a ship: information was provided by lookouts and signals from other ships. During World War II this idea was extended and elaborated as the British and American Navies developed the AIO/CIC. Perhaps the most important difference between a CIC and a classic plot is that the CIC must handle data that change very rapidly (such as fast air contacts); CIC must also integrate more different kinds of data (radar, visual, ESM).

The most important of CIC's functions is to filter data, deciding which information is likely to be accurate and which information is relevant. The advent of the CIC brought into question the classic way of fighting a ship. A plot, which was usually adjacent to the bridge, was a convenient source of in-

formation for the captain stationed on the bridge or in the conning tower. However, the CIC provided that captain with information on events far beyond visual range. Captains, therefore, either commanded from the bridge (and left a senior subordinate, the CIC evaluator, in CIC) or commanded from CIC. As CICs have become stations for weapons control, their importance has increased; in current U.S. practice, the TAO, who actually fights under the captain's direction, is stationed in CIC. In the future, at least in the U.S. Navy, captains will generally be expected to fight their ships from CIC.

Perhaps the single most important postwar development was the automation of CIC function, in the form of tactical data or combat-direction systems such as NTDS.

The second very important postwar development in internal ships' systems was the data bus which replaced the mass of specialized (e.g., sensor-to-display) connections.

All the data from the sensors, for example, can be fed into a common bus from which computers can strip what they need. Computers and display consoles can then be added or subtracted from a system without rewiring, since each is linked only to the common bus. Weight and space can be saved, since each console and each computer does not need a separate data cable. Instead, each is plugged into a common bus, just as each is plugged into a common electric-power grid. The success or failure of such systems depends on the carrying capacity of the bus, and it can be argued that some systems, like some in the U.S. Navy, do not use buses because the available buses have insufficient capacity.

Data busing is already quite common in Western businesses' computer systems, which link individual processors to LANs. A bus-linked combat data system is analogous to an LAN and its work stations, plus, perhaps, a powerful central computer or minicomputer. Of current interest is the extent to which systems developed for specialized naval computers should be able to interface with off-the-shelf commercial equipment.

A great deal depends on the topology of the data bus, which may be in the form of a ring or a star or may be linear. In a standard ring or linear system, the failure of any element in the system generally causes the entire system to fail; it can be resurrected only after the failed element has been disconnected or fixed. That arrangement limits the system's ability to tolerate combat damage. A star arrangement can tolerate the failure of any element except the key element at the center of the system. All of these arrangements are associated with software systems that allow the different devices on the bus to enter their data without interference. The main alternatives are to use a master scheduler, which determines which device is entering its data, or to use a "token-passing" protocol, in which a particular device transmits as long as it has priority, then passes priority to the next device. Token-passing generally requires a ring topology. The other major consideration is whether the system as a whole replicates its data base in many places, or whether the system uses a single master device for data-base storage, other devices (such as fire-control consoles) requesting data as needed.

The best-known Western data bus is MIL-STD-1553B, which was defined in 1978 (1553A dates from 1975). It is a single twisted-cable pair carrying data in 16-bit words (with a parity-checking bit and 2 synchronization pulses) at up to 50 kword/sec (800 kbit/sec) at a frequency of 1 MHz. The maximum length of the cables is 100 m, and a terminal can carry up to 32 stubs (I/O points), 1 of which is allocated to a bus controller; the bus controller keeps signals from different systems separate. It is rare for the cables to approach the maximum length or for the terminal to have all 31 stubs. The 1553B bus is standard on board many NATO aircraft, where it is used to control underwing stores.

MIL-STD-1773B is the fiber-optic version of MIL-STD-1553B.

A higher-capacity standard U.S. bus is under development; it will probably have a capacity of 20 Mbit/sec, split-channel operation (as in the French DIGIBUS), 64 remote terminals, and a maximum message length of 4000 words, compared to 32 words for MIL-STD-1553B. The impetus toward greatly increased bus

capacity is the much higher speed expected of the new VHSIC electronics. The new bus will probably be introduced in the mid-1990s.

In British service, MIL-STD-1553B is called DEF STAN 00-18.

There is also a standard commercial aircraft bus used in some aircraft tactical data systems, ARINC 429. ARINC 429 was adopted for civil aircraft (large airliners) in 1977-78; it is a screened twisted-wire pair connecting a single transmitter to up to 20 receivers, with a data rate of 100 kbit/sec or an alternative low rate of 12-14 kbit/sec, always in 32-bit words.

The standard French system is DIGIBUS (Dassault), which is related to the Bus Standard Marine of the French Navy. DIGIBUS is 2 twisted, shielded cable pairs, 1 carrying data and the other protocol messages; it can accommodate up to 32 ports, including bus-control ports. Maximum length is 100 m. However, bus repeaters are now being developed to extend this length to 300 m, plus subbus couplers for subbuses of up to 100-m length, each accommodating 31 more ports. DIGIBUS operates at 1 MHz and has a capacity of 40 kword/sec (16-bit words). DIGIBUS was originally called GINABUS (*Gestion des Informations Numériques Aéroportées*, i.e., airborne digital data management) and was developed jointly by Dassault and ESD in 1973-76; the Bus Standard Marine was developed from it in 1975-77. DIGIBUS is now standard in the French military (specification GAM-T-101) and is a proposed NATO standard.

In Germany, Blohm & Voss has specified a new bus architecture for its MEKO Mk 3 frigates, the first of which are the Portuguese MEKO 200 PN frigates of the *Vasco da Gama* class. Each weapon and electronic functional unit is fitted with a Multi-Interface Computer Unit (MICE) that connects it to the digital Data Information Link network (DAIL), an Ethernet. MICE has sufficient computing power to adapt all of the available modules (weapons, electronics, masts, pallets) to the DAIL requirements. The current DAIL is a coaxial cable; at least 2, and up to 8, can be used. The DAIL bus can also be a fiber-optic cable. In a MEKO, there are 2 separate networks, A for command/control and B for navigation and own-ship data. However, they are interconnected, and 1 can take over the other's function. In the case of the Portuguese frigates, the single DAIL bus connects the STACOS command/control system, the EW system, the NATO Sea Sparrow, the 100-mm gun, the double STIR, the weapons-control system, the radars, and the sonar. Blohm & Voss calls each system element, including its MICE interface, an Intelligent Functional Unit (IFE). MICE/DAIL has been under development since 1981. An experimental network, using 3 MICE, was tested in 1984.

MHIDAS (Multiple High Integration Distributed Architecture data-bus System) is the Selenia bus of the new SADOX/IPN systems. A single bus can be up to 300 m long, with branches up to 50 m long; it can support up to 64 bus-access modules. Each module can couple up to 4 users to the bus, for a total of 256 per bus. Data are transmitted in time-division multiplexed form, at up to 10 Mbit/sec, each word 1-4 bytes long (and each message 16-1024 bytes in length). Messages can be assigned 3 levels of priority, the bus providing priority 1 messages an average access time of 50 microsec (100 for priority 2, 200 for priority 3). Expected average throughput is 5 Mbit/sec, or 5000 messages/sec (100 bytes each, on average). MHIDAS is normally a cable bus; Selenia also offers a fiber-optic version.

Signaal has developed a 10-Mbit/sec system, which can use up to 4 triaxial cables in parallel. It is based on a commercial Ethernet LAN. Signaal has suggested that military buses may actually be less demanding than their civilian counterparts because the devices connected to military buses have much more predictable bus loadings. Perhaps many current civilian LANs can easily be militarized.

The newest British official system is DEF STAN 00-19, previously known as ASH or the ASWE (Admiralty Surface Weapons Establishment) Serial Highway. At present it is limited to British surface warships. The transfer rate is 1.5 Mbit/sec (16-bit words), using a screened single twisted-cable pair. Up to 63 computers can be accommodated in a total length of 300 m.

Racal offers a naval version of PLANET (Private Local Area Network), which can communicate both voice and digital data. The data interchange rate is 19.2 kbit/sec (normally 9.6 kbit/sec). The company, however, claims that PLANET easily carries digitized voice data at 64 kbit/sec.

The newest U.S. system is USQ-82, the Shipboard Data Multiplex System (SDMS), which can use up to 5 buses in parallel. FMC has produced UDICON, which is rated at 10 Mbit/sec using a single twisted-cable pair.

SAFENET (Survivable Adaptable Fiber-Optic Embedded Network) has been chosen as the next-generation U.S. naval LAN data bus. Work began in June 1984, and in 1987 SAFENET became part of the NGCR (next-generation computer resources) program. This token-ring bus was designed so that the same hardware could be adapted both to current software (protocols) and to evolving, more sophisticated software, which could support features such as multicast (messages transferred to several users simultaneously), and which has a higher inherent capacity: SAFENET I (IEEE 802.5 standard) is to operate at 16 Mbit/sec among 64 users, and SAFENET II (FDDI standard) at 100 Mbit/sec among up to 256 users. SAFENET can be configured to carry 2 separate data streams. For example, in the TFCC system (FDDS) one carries secret-level data (GENSER), the other specially classified (compartmented) data.

The most likely future data-bus technologies are fiber-optic cables, which are already in widespread use ashore in telephone networks, and microwave waveguides.

The systems described here are general purpose and found on board surface ships. Pure AAW combat systems and pure submarine combat systems are described, respectively, in the AAW and ASW sections.

SURVEILLANCE/CONTROL

Surveillance Systems

All navies oriented toward coast defense necessarily maintain shore-based surveillance systems as the basis of patrol boat and antiship strike operations. In many cases the shore headquarters is automated, and deployed seaborne craft and aircraft are connected to it by data link. Such linkage provides the deployed craft with the same tactical picture, and so may help prevent erroneous attacks on friendly forces. Systems of this type might be termed shore environments, just as automated air-defense information systems are commonly termed air-defense environments. Over-the-horizon surveillance, generally by aircraft (but also by land-based ESM), is an essential element of any such system.

Probably the first example of such a shore environment was the German navy's AGIS combat-direction system (described below, under shipborne systems). It seems likely that the Israeli Navy used a very similar system in the October War of 1973, although details are lacking. A shore-based environment would have provided the deployed Israeli missile boats with the locations of the Arab missile boats, and those data in turn would have permitted the Israelis to launch their long-range chaff on time and in the right place. Conventional manual messages might have sufficed but probably would not have been sufficiently timely.

The Litton system currently being manufactured for Korea also fits into this category, as does the Swedish STINA system (described below).

This list is likely to be incomplete. Reportedly, the Royal Netherlands Navy has a coastal radar net, for surveillance and EEZ control, that can pass targeting data to ships and aircraft. Many Third World countries operate small radar-equipped maritime-surveillance aircraft, often with commercial data links, but it is not clear to what extent these links are used to set up an integrated tactical picture. In at least some cases they are no more than aids to over-the-horizon targeting for individual fast attack craft. Nor is it clear to what extent Soviet coastal surveillance is integrated to the point of using automatic data links

(although it is clear that the Soviets do use data links for over-the-horizon targeting).

Almost certainly, too, more or less automatic shore environments support the fast attack boats operated by the Danish, Italian, and Norwegian navies.

FRANCE

◆ SYSCOM NG

SYSCOM NG is a shore-based naval command/control system, broadly analogous to the U.S. FCC and the British OPGON. The staff objective was written in September 1989, and the system is to become operational at the end of 1992.

SWEDEN

◆ STINA (9CSI 500)

STINA is the Swedish Navy's coast-surveillance and information system, developed by PEAB (now BEAB). STINA was designed in close cooperation with both the Navy and the Swedish Coast Guard, to provide coastal and offshore maritime-traffic control in peacetime, and combat information and communications in war. The central control panel can accept up to 13 radio, 20 telephone, and 12 radar inputs. The operator initiates automatic target tracking by placing a roller ball symbol over a radar blip, or by feeding in location, speed, and course data. Up to 200 surface targets can be automatically tracked, and low-flying air targets can be added as an option. Target positions are all stored in a disk memory, and any STINA center can transmit them automatically to another via a radio data link, or to naval or Coast Guard vessels.

The standard operator's position consists of a 41-cm color or monochrome PPI showing synthetic radar video and other processed target data, a smaller monochrome alphanumeric display, a keyboard, and a communications terminal. A typical STINA center contains 2 or 3 operators' consoles plus a commander's console (alphanumeric display and communications terminal); the commander's graphic display is a separate color, raster-scan, summary-plot unit, and a similar (slaved) unit can be provided to the operators. The operators' consoles (as a unit), the commander's console, and the 1 or 2 graphics displays are all connected to a data bus, which also carries the local main computer with disk memory. A harbor master's office can house a simpler station, consisting of 1 operator's console and 1 color graphics display, with a display generator but without any main-frame computer. In each case, the data bus includes a modem for communication with other STINA centers. An area commander has up to 3 such consoles, plus 1 or more color, raster-scan summary displays. There are 6 range scales, and particular target categories can be selectively displayed. The disk memory can play back the last 24 hr of data at 30 or 300 times real time (i.e., in about 50 or 5 min).

The major system sensor is the PEAB (BEAB) coastal radar, fixed or mobile, using an automatic plot extractor (ATD) for unattended operation; extracted plots are passed to the STINA center by narrow-band radio data link. A single STINA center can accept automatic plots from up to 6 radars.

The main computer is built around a Philips CPU 857M minicomputer; it has 2 disk drives, 1 a cold standby. The graphics processor uses a related minicomputer.

STINA entered service about 1979. By 1981 STINA had been installed in regional control centers at Stockholm, Gotland, and Malmö; the program called for 2 more. At that time PEAB hoped that the regional centers would be integrated into a national-level naval command system, 9CS600, using enhanced display facilities and a TDMA (time-division multiple access) data link to communicate with both the regional centers and deployed air and naval forces.

◆ STRIKA/SUMP

Ericsson's coastal-surveillance and weapons-control systems are for Swedish coastal artillery and (SUMP) for naval command centers. STRIKA and SUMP both use the CCIS system bus ap-

proach of the new Ericsson shipboard tactical data systems; the system computer is a Censor 900E series machine, and the terminal is the Ericsson ADT (alphanumeric display terminal). A typical 1- or 2-operator station has one 23-in vertical PPI, 1-3 ADTs, keyboards and roller balls or joysticks, and a communications terminal. STRIKA is now entering Swedish coastal-artillery service.

UNITED KINGDOM

◆ OPGON

OPGON is the British automated, national naval central-command information system, based at the naval headquarters at Northwood. OPGON supports 150 local display terminals there, as well as remote workstations aboard deployed flagships and 1 at SACLANT headquarters in Norfolk, Virginia. As of early 1989 OPGON was to have been extended to the German naval headquarters at Glücksburg, to the Allied Forces Northern Europe headquarters at Kolsås near Oslo, and to SACEUR headquarters at Brussels. An OPGON terminal was installed on board the U.S. flagship *Mount Whitney* for North Atlantic exercises. The system seems broadly comparable to the U.S. FCC, which OPGON preceded.

The initial feasibility study for OPGON was conducted in 1974, and the system became fully operational in 1985. Throughout, ICL has been the hardware and software contractor. The standard workstation consists of an Aydin color graphics display alongside a DRS 20 alphanumeric display, the latter incorporating a badge reader (to prevent low-level personnel from seeing more highly classified data); both displays have separate keyboards. The graphics display shows past, present, and predicted positions (and tracks) of all British naval vessels, together with maritime air patrols and reported contacts; coastlines and depth contours are also shown.

The central data base is held by 2 ICL 2966 mainframes, with Tandem TXP computers for input and output and for local displays. There is also an alternative naval headquarters housing a duplicate data base, periodically refreshed.

In September 1988 ICL was awarded a Dutch contract to build an OPGON headquarters for Commander, Benelux Channel Command, based at Den Helder.

Project definition of an upgraded OPGON was conducted in 1988; improvements will include the provision of intelligent workstations on board some major fleet units, presumably the light carriers. Such workstations might be analogous to the U.S. JOTS, which is currently installed on board these ships. The upgraded system is called MCCIS (Maritime Command-and-Control Information System), and as of early 1989 the British government planned to award 14-month competitive project-definition contracts. This upgrade is partly NATO funded.

USSR

◆ SOSS

Soviet Ocean Surveillance System is the generic Western name for the integrated system the Soviets use to detect, track, and target Western ships. SOSS is a natural outgrowth of the Soviet coast-defense system built up from before World War II. A combination of intelligence and passive sensors (originally, primarily HF/DF) detects ships approaching Soviet waters, and active sensors (mainly aircraft radars) are used as a follow-up for targeting. The passive sensors are supplemented by human agents (HUMINT or human intelligence), by intelligence-gathering ships (AGIs) operating near Western bases, and by warships (tattletales) that often trail Western naval formations. In recent years, SOSS has been supplemented by both passive and active satellites, but the principle of operation remains the same.

SOSS is designed to detect and target ships approaching the Soviet Union, rather than to protect a moving Soviet naval formation from the approach of hostile ships or aircraft. The system, therefore, feeds a central naval command-authority, which in turn directs Soviet ships, aircraft, and missiles to intercept the approaching enemy force. The home-defense, rather than

the formation-defense, role of SOSS is probably reflected in its criterion for target detection. Since there is considerable sea space beyond Soviet frontiers, the system can afford a low probability of detection on a day-by-day basis. In contrast, a surveillance system protecting a moving naval force cannot afford leaks.

Before the advent of satellites, SOSS's direction-finders were mainly land-based. The Soviets now operate both passive-(EORSAT, Electronic Ocean Reconnaissance Satellites) and active-radar (RORSAT, Radar Ocean Reconnaissance Satellites) satellites, which should, in theory, represent a global capability. However, the EORSATs still almost certainly report only to the central naval command in the Soviet Union. The RORSATs can link down to attacking units, but they are not the primary search sensors of the system.

For example, a carrier's transit from a U.S. base to a forward area would probably first be detected by a human source in or near the U.S. base. The carrier would be seen as it left its base by an offshore AGI and might be picked up by an offshore submarine tattletale, although the Soviets do not have enough fast submarines to use as regular tattletales. The next detection would be of the carrier's electronic emissions, picked up either by a shore-based HF/DF station or, perhaps, by an ESM satellite. This detection would necessarily be passive; any active sensor would be overloaded with data because there are just too many ships at sea at any time. However, once the passive sensors had defined the area of interest, it would be worthwhile to send out reconnaissance aircraft to confirm the carrier's position, course, and speed and, if necessary, to provide targeting data. Once the carrier was located, it could be trailed by a tattletale. The latter's mission would be not so much to confirm the carrier's movements as to confirm which ship within the battle group was the high-value target; the Soviets would view the others as missile absorbers.

Once the tattletale had joined, an attack could be mounted, using either a radar-equipped reconnaissance airplane followed by ASM-armed bombers, or a Bear-D providing OTH data to a submarine or surface ship, or a RORSAT in a similar role.

The Soviets captured the German Wullenweber HF/DF systems at the end of World War II and about 1952 began producing a Soviet version, KRUG, an array about 115 yd in diameter, consisting of 120 equally spaced monopole antennas. Direction-finding accuracy is reportedly about 1 deg, over a range of 6–20 MHz. The HF array was later supplemented by an inner concentric ring of monopoles that extended coverage into the VHF range.

The Soviets reportedly also use a somewhat less accurate land-based HF/DF antenna, Fix-24, consisting of 24 monopoles located at 15-deg intervals around a 150-m circle.

Since HF/DF is used by all the Soviet services, it is not clear from the unclassified literature to what extent, if any, particular networks are intended primarily for naval purposes. Because the Soviets take service unification seriously, through their unified General Staff (and its specialized intelligence branch, the GRU), one might speculate that there is no particular net reserved for the navy, but rather that the unified GRU net filters naval data down to naval headquarters. However, each of the four Soviet fleets reportedly has its own SIGINT (signal intelligence) collection site(s). Presumably, the GRU can also draw on HF/DF sites abroad, in Soviet client states.

UNITED STATES

◆ OSIS

Ocean Surveillance Information System (OSIS) is the combination of all the U.S. Navy's existing operational intelligence systems, joined to support tactical operations. Although tactical support might seem to be an obvious idea, in fact until the mid-1970s most intelligence was collected and disseminated for strategic purposes such as war-warning and for analysis. In the late 1970s the information began to be exploited for tactical purposes, under a program called TENCAP (Tactical Exploitation

of National [Intelligence-Gathering] Capabilities). Examples included Outlaw Hawk (1974–75) and Outlaw Shark (1975–76), which collected and collated intelligence-grade data to provide the commander of a ship (in these cases, respectively, the carrier *Kitty Hawk* and a submarine) with a reasonably complete picture of naval activity around him, beyond the immediate range of his sensors.

The object of Outlaw Shark was to provide a useful means of targeting long-range OTH antiship missiles, such as Tomahawk. The flow of operational intelligence between FOSIF Rota and the carrier *John F. Kennedy* was tapped at Naples, and edited material sent to the submarine via a special data link. Because timeliness was important, the intelligence data were sent event by event rather than by the usual scheduled broadcast, and the messages themselves were streamlined accordingly. Some arrived only 6 min later than the events they described, an important advantage for a missile, like Tomahawk, with a finite seeker-window.

OSIS represented a conscious choice to exploit existing sources of data (designed for quite different purposes) rather than to develop entirely new surveillance systems, such as the Soviet-style active-radar satellites. The choice was logical because U.S. naval requirements could not justify full and continuous surveillance of the surface of the seas, but the fleet needed information about enemy warships in its vicinity, particularly to use long-range antiship missiles effectively. The strength of OSIS is the ability to maintain large volumes of data at the analysis (data-processing) nodes and to transmit information quickly and securely. The system was initially constructed in the 1970s, and late in 1982 TRW was given a contract for an OSIS baseline upgrade.

OSIS assets include a ground HF/DF system, Bulls Eye (and a shipboard adjunct, Classic Outboard), EP-3 aircraft, and the White Cloud satellite described below, as well as SOSUS and its adjuncts (described below).

OSIS employs 6 major sites: the Naval Ocean Surveillance Information Center (NOSIC) at Suitland, Maryland; 3 Fleet Ocean Surveillance Information Centers (FOSICs) at the CINCLANTFLT, CINCPACFLT, and CINCUSNAVEUR headquarters (Norfolk, Pearl Harbor, and London); and 2 Fleet Ocean Surveillance Information Facilities (FOSIFs) at Rota, Spain, and at Kamiseye, Japan, to support the 2 forward-deployed fleets. OSIS collects surveillance data from the variety of naval and national intelligence systems and correlates these data to provide a picture of all naval movements at sea.

OSIS is being updated through an OSIS Operational Baseline Upgrade (OBU), which is being installed in the FOSICs and FOSIFs. The object of OBU is to improve OSIS's timeliness to nearly real time (to 95% accuracy) without heavy investment in new sensors, by updating the OSIS data base with each satellite pass and each new sensor reading. Given the degree of noise in existing data, this goal is probably somewhat unrealistic.

◆ FCC

Flag Command Center is the shore station of the commander of the Atlantic or Pacific Fleet. In theory, FCC is his wartime battle station. The FCC communicates directly with the TFCC on board the flagship of a deployed battle group and receives data from the national World Wide Military Command/Control System (WMCCS) and from national-level elements of the Navy Command/Control System (NCCS), such as OSIS. An FCC includes a special decision area arranged to display all-source intelligence information, with desks for intelligence and operations officers. The CNO approved development of an automated Integrated Information Display (IID) for FCCs in 1981, to replace the mass of wall charts, maps, viewgraphs, and plots currently used. In theory, the FCC performs the same role as a ship's CIC, though on a much grander scale, integrating available sensor data obtained both throughout the navy and by national means (TENCAP).

In wartime the FCCs would also control some national ASW forces via ASWOCs (ASW Operations Centers), and submarines

through the fleet SUBOPCONCENs (Submarine Operational Control Centers).

FCCs are being provided for the 2 fleet commanders, at Norfolk and at Pearl Harbor. In theory, the commander of the Atlantic Fleet has 2 operational subordinates, commanders of the Second and Sixth Fleets (the former based in Norfolk); the commander of the Pacific Fleet has the Third and Seventh Fleets. However, the situation is rather more complex. The commander of the Atlantic Fleet is also the commander of the Second Fleet, and in wartime would transform the Second Fleet into the main component of the NATO Striking Force Atlantic. Similar arrangements presumably apply in the Pacific.

In each case, the fleet commander, going from a strategic to an operational role, would have to decide whether to try to command from the shore. Opinions on this point have been mixed, individual admirals feeling very strongly either for or against command from on shore. For example, as commander, Atlantic Fleet, Admiral H. C. Mustin argued that in wartime long-haul communications (on which the FCC concept depends) would not be reliable; he expected to ride into battle on board one of the carriers of his battle force.

The issue of FCC viability is tied to the question of whether the United States will build battle force-capable flagships for the 4 numbered fleets. It might be argued, for example, that in wartime such a fleet might include up to 4 carriers, and that coordination of their hundreds of aircraft might require a substantial data-handling capacity outside the carriers themselves. The earlier flagships were retired because their cruiser hulls wore out, and there was insufficient money at the time (late 1960s and early 1970s) for replacements.

◆ NCCS

The existing Navy Command and Control System was not designed as an integrated entity. The current system still uses 1960s-era computers. They cannot support the sort of data rates required to provide the fleet with the operational information that can be distilled from the very detailed data that more recent sensors feed into the shore part of the system. For example, a submarine equipped with Tomahawk antiship missiles requires a detailed picture of the ships within 250–300 nm of her, and that data can come only from the shore NCCS. The submarine is fitted to process the data, and the satellites have the requisite capacity, but that data must still be collated, formatted, and coded ashore for onward transmission by the submarine operating authority controlling the particular submarine. A new navy front-end (communications) processor (NFEP) is, therefore, being produced to support all the NCCS ashore nodes. Work is currently proceeding on a shore targeting terminal (STT), which supports the submarines, and also on the force high-level terminal (FHLT), which supports ashore ASW sector commanders. NCCS also includes the maritime-defense-zone (MDZ) command/control system, currently being used by the Coast Guard for drug interdiction.

The NFEP system's design was completed during FY89. As of early 1990, full-scale software-engineering design was scheduled for completion during FY91, the system entering service in the fourth quarter of FY92 (July–September 1992). This schedule may well be stretched further since the planned FY90 program has already been deferred to FY91. A series of STT upgrades is now being developed.

◆ OSS

The Operational Support System is used in the FCCs to combine, display, and transmit information to deployed commanders in TFCCs. The 7 FCCs use JOTS systems, and they communicate with the deployed TFCCs via OTCIXS. OSS upgrades the current information-management system and provides modernized access to the DoD-wide WWMCCS (worldwide military command/control system). An OSS upgrade is currently under development. The first stage is to install new computers (DTC II) and large-screen displays. This baseline system employs the Fleet Command Center Battle-Management Pro-

gram (FCCBMP) and Operations Support Group Prototype (OSGP). The second stage standardizes the centers, each of which will ultimately have about 15 computer consoles, presumably DTC II. This version includes the OSIS baseline upgrade (OBU). The planned FY91 program includes development of a Capabilities Assessment Expert System (CASES).

The OSS program, which began in FY89, is being run by the Naval Ocean Systems Center (NOSC) at San Diego. The operational requirement was issued in December 1987. OSS incorporates recent DARPA work on large data-base systems.

Command Aids

Command aids as described here are primarily oriented toward external sources of data or toward data bases loaded before a ship or a force enters an operational area. They often interact with combat-direction systems (tactical data-handling systems), which, although they make use of externally provided data (via data links), are oriented primarily to a ship's own sensors and weapons.

FRANCE

◆ Aidcomer

Aidcomer is a French command-assistance system that can feed data into a tactical data system; the name means *aide du commandement à la mer*. A naval staff objective was issued in December 1987, and the system was first tested on board the carrier *Foch* off Lebanon in September 1989. Series production of a version using modified civilian equipment is to begin in 1992, based on a specification issued in December 1989.

Aidcomer uses 2–10 workstations; they are in 5 locations on board a carrier. This system is intended to be the shipboard terminal of the SYSCOM NG naval command-and-control system, and thus is broadly analogous to the U.S. TFCC/JOTS.

The Aidcomer data bank contains permanent information (entered before the ship leaves port) but can be modified when the ship is underway, either via a keyboard or via formatted messages. Subsystems: Sextant, to prepare naval operations, monitoring them in real time and analyzing them later; Disopair, to plan airborne missions and maintain operational readiness; Digiraid, to assist penetration of enemy defenses; Sachem, to receive or automatically route messages to and from the land-based SYSCOM command/control/intelligence system. Aidcomer will be linked to the SISC or SENIT of the ship carrying it, to benefit from real-time updates of the surrounding situation. Aboard a nuclear carrier, a SISC computer will be reserved to exchange information between the 2 systems. Aidcomer will be fitted to at least 1 command ship each in the Atlantic and the Mediterranean, and all large warships will have provision for its installation (components will be easy to transport).

Data bases: Digiraid (tactical air strike planning), Disopair (air operations), Sachem (communications), Sextant (naval operations).

Aidcomer is being developed by Cap Sesa Defense, Syseca Temps Reel, Graphael, and Itmi in collaboration with the French naval programming center. Software, written in Lisp, includes a relational data-base-management system and a cartographic system.

◆ CIRCE 2000

CIRCE is a French automated aircraft mission-planning system, for rapid planning of up to 5 missions simultaneously. It was conceived as a land-based system, but a variant was installed on board the carrier *Foch* in November 1988 to plan Super Étendard strikes. Maps for mission planning are digitized by a scanner, with an accuracy equivalent to 25 m; the system uses a 2-Gbyte digital optical disk (30-cm diameter) to store a map representing a surface area larger than that of the United States at a scale of 1:5 million–1:250,000. The system data base can include more detailed images, including satellite photos and 1:50,000 maps. The same disk stores terrain elevation data. The

pilot selects the area to be displayed in high resolution and can change scale, recenter, zoom, reproduce 3D terrain perspective, then use these data to plan the mission. The local library includes such relevant data as aircraft and weapons parameters, stored on a 40-Mbyte disk. CIRCE generates all flight documents, loading 2 memories for the airplane to carry, a 2-Mbyte magnetic bubble memory to store terrain data and a data-entry module (2-kbyte EPROM) containing navigation parameters such as turning points and fly-by time. For example, it calculates the amount of fuel required and maps a route to take into account enemy defense, finding an optimum route within available fuel allowances.

GERMANY

◆ TAICOS

Tactical Action Information and Command System, developed by Blohm & Voss and Philips System Technik (PST) of Kiel for the Turkish frigate *Yavuz*, the future flagship of the Turkish Navy. It stores and displays about 120 charts, enlarged sections of which can be displayed. It can also display more detailed data (e.g., concerning shorelines, depth). TAICOS also stores data on own and enemy forces. In addition, it collects, coordinates, and automatically filters track data (from links and from own-ship sensors), position data, course data, and additional information. Presumably, all these data are provided by the ship's STACOS; STACOS is presumably a subset of TAICOS. The main system components, in 2 MEKO modules, are connected by an Ethernet bus.

TAICOS might be considered the prototype of a small-ship equivalent of larger-ship command aids. The *Yavuz* installation is the prototype. The other 3 Series I Turkish MEKOs are fitted for, but not with, TAICOS, but the *Yavuz* installation can be moved rapidly to 1 of them as needed.

UNITED STATES

◆ ACS

Afloat Correlation System is an automated system that assembles off-board surveillance data for the battle group and composite warfare commanders. ACS feeds the TFCC (see entry below) and uses data from OSIS (see entry above), TADIXS B, the Tactical Signals Exploitation System (TASES), and tracks generated within the ship's combat-direction system (ACDS, see entry under tactical systems, below). ACS also sends battle-group track data back to OSIS to help ensure that the larger system carries the same tracks as the fleet at sea. That input helps solve the oceanwide gridlock problem and helps avoid wasting scarce resources. ACS is to be installed on board all TFCC ships and is to operate in conjunction with the new Electronic Warfare Coordination Module and also the Naval Intelligence-Processing System (NIPS).

The goal is to combine ACS with EWCM to form a Force Fusion System (FFS), which would both evaluate threats and handle countermeasures.

TADIXS, the tactical information-exchange data system, is a one-way satellite link transmitting ocean-surveillance information from the FCC (see entry above) to operational units at sea.

ACS might be considered the operational outgrowth of the Outlaw Shark/Outlaw Hawk programs described under the OSIS. Development is planned in 5 phases, all built around a core portion providing limited interim correlator capability. The core will initially be installed in the desktop computer-based Prototype Ocean-Surveillance Terminal (POST). In FY92 POST will be replaced by ACS Phase I, which will employ an improved version of the POST correlation algorithms running on a TFCC-compatible workstation. Phase II will use an advanced multisource, multihypothesis correlation/tracker and add interfaces with other shipboard systems. Phase III will add mainframe computers and parallel processing capabilities to meet higher throughput requirements. Phase IV will complete development of tactical analysis and threat warning capabilities and complete

the currently planned program. The advanced multisource correlator/tracker algorithm is already under development. Work on the multihypothesis correlator/tracker began under the FY88 program. The original ACS Operational Requirement was issued in May 1983.

◆ AFDS

Amphibious Flag Data System, originally developed for the two flagships *Blue Ridge* and *Mount Whitney*; the AFDS requirements were developed in 1964 by a study group convened for the purpose at San Diego.

AFDS combines an integrated operational intelligence center (NIPS, the Naval Intelligence Processing System), an amphibious command-information system (ACIS), and the ship's NTDS. NIPS matches the system on board an aircraft carrier. ACIS is built out of NTDS equipment (based on 1 USQ-20 computer) to provide an amphibious commander with force-loading data (so that plans can be changed if, for example, 1 ship is lost), with the landing plan, with the shore-bombardment and air-support plans, with a bomb-damage-assessment file, and with intelligence data.

Compared to the usual installation, the associated NTDS adds a capability to control aircraft over the amphibious objective area and to coordinate helicopter assault and resupply, close air support, and air defense.

The LHAs and LHDs have limited amphibious flagship capabilities, including austere versions of AFDS. In theory, an LCC would control a MEF-sized operation, whereas the LHA or LHD would coordinate on a lower level (MEB or MEU).

◆ APS

The Afloat Planning System is used to plan flight paths of Tomahawk land-attack missiles. Such planning requires a 3D image of the country over which the missile must fly, including likely threats to the missile, and also the necessary altitude inputs to the missile's terrain-comparison guidance system. The output is a tape whose contents are fed into the missile's guidance system. At present all such tapes are prepared ashore, on VAX 11-780 computers, and as a result ships carrying Tomahawk have little flexibility in the deployment of the missiles. APS will initially be carried on board aircraft carriers in their TFCC spaces; carrier-borne helicopters will ferry tapes to the surface ships carrying the missiles. Ultimately, the system will be aboard all Tomahawk platforms, including submarines (which cannot benefit from the carrier-based APS).

McDonnell Douglas won a competition for a seagoing ruggedized version of the ashore mission-planning system. APS uses a Rolm computer with a 1-Gbyte hard disk, full 3D graphics, and 4 independent CPUs (MIPS R3000s); it is a fully distributed parallel computer. Each CPU is equivalent to 5 UYK-43Bs in throughput. This display is a 1280 × 1024-pixel, 19-in color tube. The graphics engine can generate 100,000 polygons/sec. It can produce a mission tape in 30 sec, compared to 32 min for the VAX; and the tape is absolutely bit-compatible with that produced ashore. This situation is reminiscent of the evolution of Polaris/Poseidon, from full dependence on a computer ashore to a self-contained shipboard operation (see the Strike/Strategic Warfare section).

Total unit cost of the APS is about \$250,000. The first installation will be on board a carrier in 1990.

◆ ASWOC/ASWM

ASW Operations Center is used to support P-3 ASW aircraft. ASWM is the ASW Module on board a carrier, which has a similar function. An ASWOC plans P-3 missions, based on ocean surveillance information (such as SOSUS outputs), and also on data brought back by other P-3s and replayed for analysis. It is built around a central tactical computer, with CRT consoles and a manual plot. Console displays can be projected onto large graphic displays (LGDs) for aircrew briefing and debriefing. The ASWOC supports 4 console stations, so 4 crews can be debriefed simultaneously.

An ASWOC can communicate directly with a NAVFAC (i.e., a SOSUS node) and also (via a dedicated secure link) with the ASW force commander, with other ASWOCs, and with command sites such as FCCs. This digital link operates at 2400 bit/sec and carries both alphanumeric and graphics. The ASWOC also processes information from the merchant shipping and reporting control system. Finally, an ASWOC can also communicate with an airborne P-3C via HF and UHF, linking it to force, fleet, and group commanders and also to lateral commands for quick interchange of ASW information.

Postmission analysis is important because a crew can easily miss a target in flight. That was only a minor problem for aircraft whose crews could monitor only a very few sonobuoy channels, as printed out on their LOFARgram recorders, but a P-3C records many more channels than its crew simultaneously monitors. Hence the need for postmission playback and analysis (although it is also true that visual inspection of a spread-out LOFARgram, after flight, can sometimes reveal targets not detected in flight). The ASWOC, therefore, arose with the P-3C, and it includes a fast-time equivalent of the sonobuoy analyzer on board an ASW airplane.

The ASW Module on board a carrier performs a similar function for the carrier-based S-3; it also controls carrier-based ASW (inner zone) helicopters, and it provides the information on which the force ASW commander relies. Although P-3s or S-3s can in theory function without the support of ASWOCs/ASWMs, in practice they search relatively limited areas and, thus, have to be directed to areas of likely submarine presence. With a barrier, the ASWOC/ASWM ensures that the search pattern is efficient and that it corresponds to the tactical requirement. There are 20 ASWOCs. They are to be modernized (not least to accommodate P-3C Update IV) under a program directed by the Naval Ocean Systems Center (NOSC) at San Diego, and the new version will probably employ DTC II computers. A modernization contract with TRW was canceled in January 1990. The operational requirement for the upgrade was stated in August 1986 (but a C3 upgrade acquisition plan had already been released that May).

◆ CS@SE

The Command Support at Sea Experiment was a test of planned command-center (CIC and TFCC) upgrades (including high-resolution color graphics) by the Applied Physics Lab (of Johns Hopkins University). It is a pointer toward future systems and was probably a major driver toward the current increment 2+ version of FDDS. The displays were large-screen color (as opposed to the current large-screen monochrome) screens and operator console color screens, fed by the Aegis display system (ADS), the shipboard gridlock system with automatic correlation (SGS/AC, i.e., the NTDS picture), FDDS (see below), and the Tomahawk Engagement Planning and Exercise Evaluation (TEPEE) system, so that the experimental displays showed both own-force and OTH data.

Phase I (1987) tested the use of color and advanced graphics on board the cruisers *Ticonderoga* and *Yorktown*, which already had Aegis large-scale monochrome displays.

Phase II (1988), on board the cruiser *Leyte Gulf* and the carrier *America*, added OTH surface tracks as a new element to the display. In the cruiser, the large-screen display showed a combination of real-time (NTDS and own-ship) tracks and nonorganic tracks taken from the Tomahawk Weapons Control System, which in turn derived them from the OTCIXS net. Tomahawk engagement plans and weapons-system performance and response (SPAR) contours were overlaid on the same plot. In *America*, very similar equipment in TFCC took OTH data from the FDDS system and used SGS/AC to add real-time Link 11 data. Both systems also had a secondary small-screen color monitor, the Amplifying Local Display (ALD), at an operator console. This equipment was tested for 15 months on board the carrier and for 10 months on board the cruiser, including major fleet exercises.

The carrier version had additional features, some of them ini-

tially developed for Aegis. The display could be centered on a given latitude and longitude. Range and bearing from any hooked (designated) track to any point on the screen could be displayed. Abbreviated 3-character ship tags could be added to OTH tracks (e.g., "USA" for the carrier *America*).

The system supported Command Conferencing, a means of transmitting graphics directly from one ship to another via OTCIXS, embedded in OTH Gold messages. The receiving ship displays the data either automatically or under user control. The cruiser sent graphics produced by ADS, TEPEE, or SPAR. The carrier used FDDS, JOTS, or overlays received via OTCIXS.

Both ships found the OTH/real-time display valuable but wanted a means of distinguishing between the 2 types of track. In *America*, tracks were normally colored red for hostile and real-time air unknown, blue for OTH tracks and unknown surface, and green for real-time friendly air and other surface (the cruiser did not use track colors). Unfortunately, CS@SE did not correlate real-time tracks with OTH tracks, so some tracks were reported twice, a phenomenon called ghosting. If the OTH tracks were dimmed, ghosting was more obvious since some bright real-time tracks had dim ghosts nearby. However, that did not solve the problem.

Both ships also liked the added on-line data base (detailed maps, airways, political boundaries, cities) associated with the advanced graphics system. Because the display was in color, boundaries were filled in, for better clarity. Finally, color proved quite valuable as a means of compressing information so that it could be more easily assimilated.

The ALD proved useful. It could, for example, show a plot of altitude vs. time for a selected target (the Aegis display shows only range and bearing); such a plot would have precluded the Iranian Airbus shoot-down. The same screen could also show range vs. time, speed vs. time, bearing vs. time, speed vs. altitude, and altitude vs. range. A selected track could be tagged to show the altitude and direction of dive or climb on the main large-screen display; this, too, would have precluded the Iranian disaster. The ALD was more normally used to preview large-screen displays and run playbacks. It could display alphanumeric, and it was the operator entry screen. The ALD mimicked the function of the Aegis Baseline 4 ALD, so presumably later Aegis ships will normally enjoy these functions.

Aside from the graphics, CS@SE could store 24 hrs of tracks and play them back (at different speeds) at will, so that a staff could examine past track data in detail.

CS@SE was supported by a Sun 4/260 computer (a commercial relative of the ruggedized DTC II) with two 280-Mbyte hard disks; the large-screen display was a BarcoData 400 Graphics. The 24-hr track file consumed over 500 Mbytes. There was little space for the additional data bases tried or desired: detailed filled maps (10 Mbytes), political boundaries (5 Mbytes), cities (100 kbytes), airways (2 Mbytes), airfields (70,000 of them: 35 Mbytes), bathymetric data (over 40 Mbytes), and elevation data (over 50 Mbytes).

◆ ISPS

The Integrated Strike Planning System is a current project to develop an automated means of planning air strikes. Current planning is done with strip charts and maps. ISPS should require more massive computer resources than are currently available in any other planning system since it must take into account terrain (in 3 dimensions), enemy defenses, and aircraft and weapons characteristics. Outputs should include not only pilot instructions, but also graphics showing the strike route from the pilot's point of view for prestrike familiarization. Ultimately, such a system should be able to plan a strike route that minimizes an aircraft's exposure to defenses, or that maximizes strike effectiveness under varying conditions. The French navy already has a system of this type called *Circe 2000* (see above), but it has only a fraction of the capability required for ISPS performance.

ISPS is an umbrella program, including systems such as APS and also the intelligence-processing systems. McDonnell Doug-

las already has a TAMPS (tactical aircraft mission planning) package, which provides digital maps, threat data, and aircraft characteristics. It is not yet on board ships, but it is compatible with standard workstations. Other likely competitors include General Dynamics.

Formal adoption of ISPS would help push DTC III (or perhaps a DTC IV) toward high 3D graphic performance because so much of the route-planning function involves 3D modeling. As of the summer of 1990, it seemed likely that ISPS would be released for competition within about 6 months, and that some form of ISPS would appear within 2 yr.

◆ JOTS

The Joint Operational Tactical System will provide the commanders of virtually all ships with a summary OTH tactical picture, derived mainly from the OTCIXS satellite net. The current form uses the same computer (DTC II) as FDDS (see the separate TFCC entry below) and a subset of the FDDS software. JOTS was originally a separate system, an attempt to achieve some of the TFCC performance goals using an easily obtained non-Mil Spec computer, DTC I (an HP 9020) to run FDDS software. The DTC I version is now designated JOTS I, and it is being superseded by JOTS II. The JOTS concept, of standardizing hardware and achieving increased capability by modular additions of software in a distributed system, has now been extended, so JOTS II is a subset of the current version of TFCC. The standard JOTS workstation (the DTC II computer), software, and message format (JINTACCS, as in JTIDS/Link 16) are now used in FCCs (see separate entry) and may well become standard in the national-level worldwide military command/control system.

This development is a tribute to the very rapid advance of computer power, as the specialized central computer and simple terminals of the original TFCC (see separate entry) were superseded by very powerful machines inexpensive enough to be used in a fully distributed network. JOTS began as a poor man's TFCC, run on one powerful workstation, almost certainly as a reaction to the slow production of TFCCs. Its workstation was so powerful that it could actually outperform the specialized Mil Spec TFCC design. Its basic computer was so inexpensive that it could be planned for very widespread installation.

That is probably the first instance of a very important development. Hardware is now quite inexpensive, although software is still very costly. However, once a piece of software has been developed, it can be reproduced quite cheaply. Thus, the cost of an additional example of the hardware/software combination can be quite low, as long as it need not be modified for a particular user. With JOTS, there is little need for modification because the main input, the OTCIXS net, is standard for all users. Unlike NTDS or its successors, JOTS is not tied to any shipboard sensors (it can tap into the ship's NTDS circuit) and so need not be modified for application to a particular ship. Hence the expansion of JOTS to virtually all U.S. warships, from frigates and major amphibious ships and auxiliaries up.

JOTS has 2 functions. It maintains an OTH picture, using updates from nonorganic sensors transmitted mainly over OTCIXS. Second, it is a staff planning tool, capable of projecting ahead the consequences of various alternative decisions. Thus, its software includes both track keeping and a variety of tactical decision aids (TDAs). An incidental effect of the decision aids is greatly to reduce the amount of staff work needed to support a numbered fleet or battle-force commander. In the past the numbered fleet flagships required very large staff spaces, and much of the large staff was needed to do what amounted to supporting calculations (e.g., nuclear-strike planning). The TDAs should greatly reduce staff manning requirements, although they are available to any JOTS user.

Information used by JOTS and by TFCC/FDDS (see below) divides into organic and OTH. Organic information comes from a ship's own sensors and also from Links 11 and 14 within the ship's force. It is characterized as real-time; it is the NTDS or

CDS picture. OTH information is provided mainly by the OTCIXS satellite broadcast, and it is intelligence derived. It cannot, by definition, arrive in real time, but it is used to help build a tactical picture. Presumably, the delays inherent in obtaining such information are acceptable because it concerns objects far from the force, particularly potential Tomahawk targets, which are ships well beyond the force horizon.

JOTS maintains identical data bases (OTH tactical pictures) for all its users. As a user updates the data base, the updated data are transferred to other JOTS users. A JOTS user can, in theory, maintain a global data base. In practice, he or she will generally apply filters to limit updates to the area of interest. In addition, filters can be applied to limit access to specially classified data. Current plans are for all ships, from major amphibious units and frigates on up, to be fitted with JOTS, many in the form of a single terminal.

The standard flagship version of JOTS I is a star network of 5 standard DTC I (HP 9020) computers, 1 acting as communications manager. The DTC Is have 55-Mbyte hard disks, tape drives, one or two 19- or 25-in color monitors, digital Kurta pads for access to the JOTS data base, and 8-port multiplexers. Typically, there are 2 DTC Is in a carrier CIC. On board the carrier *Eisenhower*, for example, 1 showed worldwide ship locations, the other theaterwide data. Reportedly, in 1988 DARPA experimentally connected a similar pair of computers on board the carrier *Vinson* to an intelligence data base, probably carried on optical disks. When a ship shown on a screen was tagged, other screens showed photographs and other detailed descriptive data. The combination was called SDMS (Spatial Data Management System).

JOTS automatic contact data come from up to 3 Link 14 broadcasts, the OPINTEL broadcast (including BLUFORLOC [Blue Force Location]), OTCIXS Rainform (OTH) Gold broadcast, Link 11 (requires special link-monitor unit), "FOTC" (OTH targeting) and/or HITS (high-interest target system, via GENSER teletype), FDDS/TWCS (Tomahawk weapons-control system) broadcast via OTCIXS, TADIXS broadcast, TACINTEL (tactical intelligence, special classified information), and other 9020-based units (such as TEPEE). The system is also connected to the Prototype Ocean Surveillance Terminal (POST). For organic data, JOTS taps into own-ship NTDS and navigational data. It transmits via the OTCIXS and High-Interest Target (HIT) nets; the main JOTS net is OTCIXS.

The current TDAs are EMCON planning, C3CM satellite planning, Chainsaw (fighter tactics) planning, vector-logic-grid (fighter tactics) planning, aircraft-search planning, refueling-route planning, communications planning, ASW-search planning, barrier-search planning, area-search planning, fuel-consumption planning, surface surveillance, CAP stationing, surveillance air intercept, Tomahawk launch, multi-unit Harpoon launch, 2-track analysis, AAW surface-ship screening, ASW passive screening, sonobuoy-field management, SEATAK, intercept analysis, maneuvering board, MTST analysis, time statistics, line-of-bearing (LOB) firing, closest point of approach (CPA), and position and intended movement (PIM). JOTS produces acoustic propagation loss curves, IREPS radar-range predictions, HF-spectrum-propagation predictions, and predictions of satellite vulnerability. It also conducts contact analysis (tracking algorithms, history plots, contact predictions, constructions of containment areas, and solutions for dynamic bearings/ranges).

JOTS I software was originally derived from work done on the FDDS system, and some FDDS improvements were not implemented in JOTS. Restructuring of the program to JOTS II began in the spring of 1989; JOTS and FDDS were merged because both could use the same software and hardware. The only real difference is that FDDS is more elaborate, with more computers.

JOTS I was succeeded by 3 parallel programs: VIDS (Visually Integrated Display System), conceived as the JOTS upgrade, and TFCC installations for the cruiser *Belknap* and the carrier *Saratoga*. VIDS and the *Belknap* system used JOTS I software re-

written in UNIX and C so that they could run on the HP 835 computer, which turned out to be the unsuccessful competitor for the DTC II contract. They differed in the extent to which they could accommodate a commercial window package, X (not at all in VIDS, partly in *Belknap*, not at all in *Saratoga*).

When the ruggedized Sun-4 workstation won the contract, attention turned to a standardized system using the new DTC II workstation: JOTS II. JOTS II also introduces a standardized man-machine interface. VIDS has already been removed from the Sixth Fleet flagship *Belknap*. The first full JOTS II/TFCC increment 2+ is on board the carrier *Independence*. It fully implements the X (windows) program, and it incorporates EWCM and POST 6.0 (which is no longer a separate piece of hardware). As of the spring of 1990, the USS *Independence* installation is scheduled for operational test and evaluation at the end of June.

On board a ship the elements of JOTS II/TFCC are linked by a fiber-optic bus, initially a version of Ethernet but ultimately SAFENET II.

Current planning calls for JOTS on board all the cruisers, the destroyers, the missile destroyers, the frigates, the ocean-going amphibious ships, and major auxiliaries. The carriers and some other ships will have TFCCs. JOTS is also installed on board British flagships, including the light carriers. These units do not share the U.S. OTCIXS net directly. Instead, OTCIXS is transmitted to the naval command center at Northwood, filtered there, combined with British national intelligence, and retransmitted to the ships. Compared to the British Opcon, JOTS is superior because it provides graphics. Opcon provides only alphanumeric data, and in this case it is multiplexed with JOTS. The British installations use HP 9020 computers and are to be upgraded with HP 300s.

JOTS is unusual in that it came, not out of a stated operational requirement, but out of a felt operator need. In 1981 RADM Jerry O. Tuttle was ComCarDiv 8, on board USS *America*. He conceived JOTS as an application of the very powerful desktop computer (HP 9845, a precursor of the HP 9020 bought as DTC I), which was already available on board. Costs were held down by using some existing FDDS software. In its original form, JOTS shared data with other ship commanders via a satellite link (CUDIXS, later OTCIXS). As ComCarGroup 2 in 1983, Admiral Tuttle expanded JOTS to the command/control applications described above. The admiral brought JOTS with him when he took over the Fleet Command Center at Norfolk; it became the shore terminal of the Operational Support System (OSS). A JOTS derivative is now used by the U.S. national military command authority and by the deployed CINCs.

At each stage JOTS proved useful even though alternative programs had been proceeding for many years. The key seems to have been the flexibility inherent in the computer. JOTS changed by changing software rather than hardware. The same hardware is used both in crisis and in routine situations, although with different software. JOTS was originally developed entirely with operational (OPTAR) funds rather than through the formal programming and budgeting system. Only quite recently has it been legitimized by designation as a "rapid prototyping" system. In theory, rapid prototyping allows a user to demonstrate proof of concept without designing and developing a system based on theoretically evolved requirements. User needs are addressed in the prototype stage. Such prototyping becomes much more manageable as computer power grows to the point where software, rather than hardware, has to be prototyped.

◆ NIPS (SYQ-9)

The naval intelligence-processing system (NIPS) is the shipboard intelligence center located aboard carriers and amphibious flagships. Automatic retrieval of intelligence information becomes essential as automated planning systems (such as APS) enter service, and also as shipboard CDSs (such as ACDS Block 1) accept such data to supplement operational information. NIPS is being developed to accept data automatically from re-

connaissance and other intelligence sources, and to feed data automatically into combat-planning systems.

The current SYQ-9(V) is built around a UYK-7 computer and 7-17 UYQ-23 displays. It has a single I/O console (OA-7984), 1 or 2 disk memories (UYH-2), 2-8 teleprinters, and a digital, magnetic, recorder reproducer (RD-358/UYK). The (V)1 version has 7 computer displays and 2 teleprinters.

Full-scale engineering development of the current (V)4 version began in FY89. Work began that year on a means of transferring relevant data bases from the Tactical DoD Intelligence Information System (DODIIS) into NIPS. That year, too, an improved communications interface between the Fleet Imagery Support Terminal (FIST), a component of NIPS, and the Imagery Processing Intelligence Exchange (IPIX) began engineering development. NIPS is now being made compatible with the Tactical Aircraft Mission-Planning System (TAMPS), the Tactical EA-6B Mission-Planning System (TEAMS), the Tactical Electronic-Reconnaissance Processing Evaluation System (TERPES, a Marine Corps system), the Standoff Land-Attack Missile System (SLAM), and NCCS-A (the afloat variant of the naval command/control system, including TFCC). During FY90 work began on an interface with the Joint Services Imagery Processing System (JSIPS), the new filmless reconnaissance system (see the Strike/Surface Warfare section). The FY90 program also included initial work on NIPS interfaces to the Tomahawk cruise missile afloat-planning system (APS) and to the digital imagery workstation (DIWS).

SYQ-9(V)4 is expected to enter production in FY91.

◆ Outlaw Hunter/Outlaw Viking

These projects are intended to improve OTH targeting by, respectively, P-3 and S-3 aircraft by providing them with the wide-area tactical picture normally provided to surface ships via the OTCIXS satellite circuit, and typically displayed via JOTS. Aircraft are fitted with UHF satellite receivers for the OTCIXS circuit, as well as GPS receivers that provide them with accurate position information for use with the OTCIXS data. The aircraft terminal is the existing Advanced Tactical Workstation, a DTC computer, similar to that used in JOTS. The program appears to be an airborne equivalent of JOTS, with the same potential for quickly improving force connectivity. It is generally associated with the ongoing ISAR improvements to patrol aircraft radars.

Outlaw Hunter was a quick demonstration project; the first conversion was completed in 1989 in 9 months at a cost of only \$700,000. This figure included all development costs. Further upgrades should take 8 weeks, at a cost of \$250,000. As of early June 1990, the prototype Outlaw Hunter had already participated in several exercises, during which it provided real-time targeting data to Tomahawk and Harpoon platforms. A modified Atlantic-Area Outlaw Hunter will use a lighter-weight modem, which will reduce overall system weight from 1200 to about 150 lb, a reduction allowing the airplane to carry a full load of sonobuoys. This airplane should become operational in January 1991, for a 6-month work-up toward operational test and evaluation in the summer of 1991. Outlaw Viking is planned for FY91. Both are funded by Op-942, using OTH-T funds.

◆ SPAR

System Performance and Response is a set of computer programs running on an HP 9020C (DTC I) computer, installed on board an Aegis cruiser. It determines Aegis detection, statement doctrine, weapons control-system response, and expected missile performance against specific threats. The system takes atmospheric conditions into account.

Because SPAR is, in theory, a planning tool, it does not have to run on a Mil-Spec computer.

◆ TEPEE/TWCS

Tomahawk Engagement Planning and Exercise Evaluation is the means of planning Tomahawk (OTH missile) firings. Its OTH picture is derived from OTCIXS. TWCS is the associated

Tomahawk Weapons-Control System, which actually feeds data into the missile. In a JOTS ship, TEPEE feeds data into JOTS. Its software includes time-of-flight corrections for Tomahawk land-attack missiles, planning for coordination of tactical air strikes with Tomahawk strikes, and scenario generation for battle-group training. The system runs on an HP 9020C (DTC I) computer with a 55-Mbyte hard disk and a 67-Mbyte tape drive. Afloat installations: 4 CV, 4 CVN, 4 BB, 5 CGN, 7 CG, 15 DD, 2 LCC, a total of 41.

TWCS was introduced in 1983 on board the *Iowa* and *Spruance* classes. Initially, Tomahawk was limited to 1-on-1 engagements, partly because of the limited number of platforms, but also because of a lack of experienced battle-group staff. However, the fleet wanted more, and in 1986 the Tomahawk community introduced a Battle-Group Data-Base-Management (BGDBM) capability, initially in COMDESGRU One. Each Tomahawk platform could then perform as:

- (i) Force Over-the-Horizon Track Coordinator (FOTC), responsible for track management and dissemination of a common OTH data base.
- (ii) Participant, accepting the OTH data base from the FOTC only.
- (iii) Nonparticipant, operating as an autonomous OTH-T data-base manager, as was standard prior to the appearance of BGDBM.

In this initial version of BGDBM, all managed track data originated with the master (FOTC) ship, and ships could not use their own organic (sensor and broadcast) data. The system operated relatively slowly (the FOTC ship was in effect a bottleneck), and delays made for inaccurate shooting. This version of BGDBM was analogous to a centralized CDS. At the same time, Aegis ships had their own Aegis/Tomahawk interfaces that did not take BGDBM into account. Such ships, therefore, had to shut down their internal interfaces when accepting FOTC tracks (the communications protocols did not match).

Work on a TWCS block upgrade began in March 1986. This was a more distributed system, in which the ship knowing the most about some specific information made the correlation decision, and no system would be denied information from organic sensors. Each node (each ship) appended its own track number to a contact; the FOTC ship acted as track manager rather than as correlator and manager. FDDS and JOTS operate in much the same way. The 2 prototype platforms are the USS *David R. Ray* and *Arkansas*.

TWCS is a direct outgrowth of Outlaw Shark/Outlaw Hawk, the original attempt to provide OTH-T data for Tomahawk antiship missiles. TWCS originally used a UYK-19 computer, then a Rolm 1602, and then the current 1666B. This system also exists in TFCCs. The system accepts the same data that go into JOTS and provides high-probability classification solutions. It updates missile fire-control solutions until the moment of launch.

◆ TFCC/FDDS

Tactical Flag Command Center supports a battle-group commander and the composite warfare commanders, providing them with relevant material developed by the U.S. Navy's worldwide intelligence systems, on a timely basis. In contrast with Soviet practice, the concept is that existing sources of information, none of them intended primarily for naval surveillance, can be fused to produce a sufficiently accurate tactical picture, well beyond the horizon of the sensors within the battle group, yet still within the potential battle space. Over time the emphasis has shifted from intelligence fusion ashore (the tactical picture being transmitted to the TFCC) to a less centralized form of fusion, in which much of the picture is assembled at the TFCC. TFCC now includes the Afloat Correlation System (ACS), to correlate available off-board intelligence data with data from the force itself (i.e., to fuse it) into a consistent series of tracks. JOTS (see above) is, in effect, a less expensive and less elaborate equivalent of TFCC as originally envisaged.

The computerized FDDS (Flag Data Display System), USQ-81(V), maintains the system's OTH tactical picture, supported by the global OSIS intelligence system via the high-density (2400-baud vs. 75-baud for the normal fleet radio broadcast) OT-CIXS satellite net. It is supplemented by a second net for sensitive intelligence.

TFCC has a lengthy history. It was inspired by a Grumman study of command requirements (1968-72, for NEL [Naval Electronic Laboratory], San Diego). The then Naval Electronic Systems Command prepared RFPs in 1972-73, formulating the TFCC concept: ocean surveillance information would be provided by a fusion center ashore. An interim TFCC was demonstrated on board the carrier *John F. Kennedy* in 1975-76 (see the discussion of Outlaw Hawk and Outlaw Shark under OSIS, above). Development was slow, partly because senior officers could not agree on standardized operating facilities, partly because funds for command/control developments were limited, and partly because system requirements expanded suddenly from command team (battle-group commander) to commander plus 3 composite warfare commanders. Martin Marietta won the design competition in 1975-76 and built a prototype, but the program proved too expensive and was canceled in 1978.

In August 1979 the CNO, Admiral Hayward, broke the project into 3 increments: (1) preparation of TFCC spaces, using existing equipment; (2) installation of special command/control displays; (3) enhancements. In March 1980 a ruggedized version of the Outlaw Shark terminal was chosen as the USQ-81(V) baseline. Three interim TFCCs were temporarily installed to gain operational experience on board the carriers *Midway* (June 1980) and *America* (January 1981) and the cruiser *Josephus Daniels* (February 1981). At this stage TFCC could display an area out to 1500 nm.

In January 1981 the CNO decided to buy 6 systems, 3 for each coast, for the carriers *America* (completed 15 May 1983) *Constellation* (completed 15 July 1983), *Nimitz* (completed 15 September 1983), *Midway* (completed 15 October 1983), *Ranger* (completed 15 February 1984), and *John F. Kennedy*. A seventh TFCC was installed on board an amphibious command ship, and 2 were built ashore, 1 at the Naval Ocean Systems Center and 1 at the Unisys development center at Reston, Virginia. This version was a centralized system analogous in structure to NTDS, with a Rolm 1666B computer supporting Motorola workstations, each of which had only 64k of memory.

In 1983 TFCC was planned for 15 carriers, 4 *Belknap*-class cruisers, the *Long Beach*, and the 2 amphibious flagships. The question was whether to extend the existing installation to the rest of the ships or to redesign it to use the new UYK-43/44 computers. TFCC spaces (increment 1) were installed on board carriers during their SLEP modernizations. However, TFCC design was once again totally revised: the current increment 2+ is a fully decentralized system consisting of workstations. *Saratoga* was to have been the prototype, with Raytheon CWS workstations. However, the CWS was rejected, and *Saratoga* was fitted with DTC IIs instead. The DTC II communications module was not yet ready, so her TFCC retained the Rolm computer as a front-end communications processor.

The TFCC increment 2+ prototype is the carrier *Independence*, which is to undergo operational test and evaluation in June 1990. At this stage TFCC and JOTS have merged, with JOTS a subset of the more elaborate TFCC software; both use essentially the same hardware, except that TFCC uses 2-screen workstations with associated printers. EWCM and ACS, which had been conceived as separate hardware, will now be additional software within the standard TFCC hardware. As with JOTS, computer hardware is now so inexpensive that it is easy to extend the system to more ships. In 1990 TFCC is planned for 34 ships: the carriers, the amphibious flagships, the *Wasp* and *Tarawa* classes, the fleet flagships (*Belknap*, *Long Beach*, *Coronado*, and *La Salle*), and the 2 remaining battleships; there will also be 3 training sites ashore.

The increment 2 and 2+ TFCC is arranged around the battle-group commander's Battle Watch Station, a special T-shaped

desk with 2 chairs facing a large-screen display (LSD). The increment 2+ version of this space also contains two 2-screen and one 1-screen workstations. Additional TFCC workstations are located in spaces such as CIC, the carrier intelligence center (CVIC), and the supplementary plot (SUPPLOT); these workstations are used for track management. The system is tied together by fiber-optic LANs. Its software supports distributed processing among a communications processor (the Data Management Processor, or DMP) and the workstations.

The DMP is responsible for communications, message processing/filtering, and correlation between the inputs of the workstations, i.e., updating the system track file. Automatic track correlation is based on matching attributes in different reports and also on testing possible tracks against physical conditions, such as the maximum speed of a ship. Operators resolve ambiguities manually by forcing track updates or by creating new tracks. The correlator involved has been in use since 1980. Future versions will make better use of ELINT and maneuvering-target statistical-tracking (MTST) data.

The system data base is maintained on a distributed basis by a specially developed Database-Management System (DBMS). Each DTC II maintains a copy of the primary platform file (track file) for local reference; the copies are kept current by a broadcast initiated for each correlation or manual track update. This architecture is equivalent to that of a federated combat data system.

The current TFCC-space configuration shows the T-table for the battle-group commander, in the foreground, with the large-screen projection display above it. The tall consoles in the background are FDDS color workstations for the warfare coordinators. The flat bulkhead panels are automatic status boards. (UNISYS)

Color is used to achieve faster decisions and to present information more clearly (e.g., blue for friendly forces, red for hostile, and green for neutral); maps are filled in and tables are colored for rapid identification. The displays are windowed, and operators have trackballs.

FDDS is connected directly to OTCIXS, to Links 11 and 14, to the Fleet Broadcast, and to Flag Communications. In addition, on board a ship it is connected to POST (see below), to JOTS, to the TFCC Information Management System (TIMS), and to the Cryptologic Combat-Support Console (SSQ-93).

FDDS is one terminal in the FOTC (force OTH coordinator) broadcast. It can act as FOTC or as a participant. FOTC is a track manager; it provides consistent track data rather than individual event data (as in NTDS); ships receiving the broadcast can build up their own track files equivalent to those held by the FDDS ships, as the basis for consistent decision making throughout a force. For example, FOTC serves as a basis for Tomahawk antiship targeting.

UNISYS won a contract for up to 19 enhanced TFCCs in October 1987; the first was installed on board the carrier *Saratoga* in October 1989. The second will go on board an amphibious command ship. As of late 1989, UNISYS had received contracts for a total of 3 installations.

Software is still being developed. The current dynamic displays do not provide representative graphics and symbology; the planned upgrade will be fielded in FY91. The ELINT correlation/tracking update for FDDS will initially deploy with a reduced track-to-track correlation capability (POST 4.2); the full capability will not appear until some time in 1990 (POST release 6.2). The afloat correlation system (ACS) is to be added to TFCCs in 1992 and will be fully capable in 1994 (it was originally scheduled for 1990). The planned EWCM (electronic warfare coordination module) is to enter service in TFCCs late in



1990. As of early 1990, there were 3 alternative versions, 2 developed by naval laboratories and 1 by UNISYS. It should be emphasized that these are all software, rather than hardware, developments; TFCC will continue to be built entirely out of DTC II computers.

Satellite Sensor Systems

USSR

◆ EORSATS

EORSATS is the generic designation for the Soviets' ESM Ocean-Reconnaissance Satellites, which presumably detect radar-frequency (line-of-sight) emissions from the sidelobes of surface ships' radars. The first of these passive naval satellites was Cosmos-651, launched in May 1974. It and its successors were launched into circular orbits at 65 deg of inclination, maintaining a 93.3-min orbital period.

In 1986 the Soviets launched the first of a new generation of EOR satellites, Cosmos-1735, described at the time (by U.S. officials) as the first new design in 15 years. It works in conjunction with Cosmos-1834, launched in the spring of 1987, which has a 259×250 -mile orbit inclined at 65 deg. Both orbits are unusually low, and together the 2 satellites provide coverage of every part of the world every 3 days, compared with every 4 days by earlier systems.

EOR satellites typically provide their data, probably not precise enough for targeting, to a central naval command, which then tasks Soviet naval forces to intercept and identify the contacts.

◆ RORSATS

Radar Ocean-Reconnaissance Satellites, nuclear-powered, can supply data either to a central naval command-authority or directly to a submarine or surface ship. The submarine terminal uses the Punch Bowl antenna.

These satellites are normally launched in pairs in circular orbits 155–175 miles high (to maintain constant position relative to the targets) at an inclination of 65 deg, the pair being 6 deg apart for cooperative tracking. Each is about 14 m long and weighs about 4950 kg; power is supplied by a small 150-kW nuclear reactor (with 50 kg of U-235 fuel). Normally, the satellite is boosted into a very high orbit when its fuel has been exhausted; but in 2 cases (Cosmos-954 in 1978 and again in 1988), boosting has failed, and the satellite has crashed to earth. Useful life is reportedly 60–80 days.

Reportedly, the radar is a side-looking type that uses a slot antenna in the side of the satellite and scans a swath about 400–500 km wide. The radar probably operates at relatively high frequency since it is reportedly ineffective when the target area is obscured by bad weather.

The first operational RORSAT, Cosmos-198, was launched in December 1967, the first test vehicle having been launched in 1965. From 1967 to 1975, 10 out of the 12 Soviet naval satellites launched were RORSATs; but since 1975 passive satellites have predominated. Even among the RORSATs, orbital lifetime was quite limited until 1972—suggesting that the program was not entirely satisfactory. For example, a satellite launched in 1970 during the Jordanian crisis did not survive for a day in orbit, and another, during the Angolan War in 1975, lasted only 1 day. However, in 1972 average lifetimes as great as 4 months were observed. Both active and passive satellites supported the 1975 Soviet naval maneuvers. RORSAT launches were suspended in 1978 after the Cosmos-954 failure but resumed in April 1980.

UNITED STATES

◆ White Cloud

White Cloud is a passive ocean-surveillance satellite-system employing clusters of satellites and functioning as the overhead part of the Classic Wizard ocean-surveillance system. Each satellite is reportedly equipped with IR and mm-wave scanners and with receivers for intercepting radio transmissions. Each cluster

of 3 satellites (plus a mother) orbits at an altitude of about 700 nm and can detect emissions from ships 2000 nm away. The cluster is used so that emitters can be located by interferometry, using the distance between the satellites as a baseline.

The first cluster was launched in 1976, and the fifth cluster was placed in orbit in June 1983.

White Cloud seems to have been conceived as an intercept system to detect and catalog Soviet emitters so that units equipped with tactical ESM devices could identify those emitters. The location capability was necessary to pair the emissions with particular Soviet platforms. However, this capability could also be turned around to track known Soviet platforms, under TENCAP and related programs.

This type of system should be able to detect even line-of-sight systems such as short-wave radars by picking up their sidelobes. Interferometry is limited in its precision; in the late 1970s a program called Clipper Bow proposed to combine White Cloud with an active radar that could locate emitters more precisely. Congress killed Clipper Bow in 1980, ordering the navy to participate instead in similar air force and CIA projects (thus far unannounced).

It should be emphasized that no very limited constellation of satellites (such as White Cloud) can provide continuous coverage of the world's oceans. Instead, the partial coverage that can be obtained can be combined with other sources of information to give reasonably full information on the movements of ship-based emitters. Although the localization of targets is imprecise, the system is effective because of the limited speed of surface ships. No such system can be effective against fast-moving emitters such as aircraft. For these reasons, active radars are required to track Soviet naval bombers, and very large numbers of satellite radars would be required to provide solid coverage.

The navy is currently proposing an IR satellite for wide-area air surveillance (the air force supports an alternative radar system).

Surface Radar/ELINT (Electronics Intelligence) Systems

AUSTRALIA

◆ Jindalee

Jindalee is the Australian project, for sea and air surveillance, that consists of 3 OTH radars. Jindalee also monitors sea-state and wind direction and is currently being used to provide wind- and sea-state maps for the area north of Australia.

The name, meaning "bare bones," originally applied to an experimental OTH radar at Alice Springs. This experimental radar was conceived as the culmination of the earlier Project Geebung, which investigated HF propagation via the ionosphere, between Woomera and Broome. Since this type of propagation is the basic mechanism for OTH radar, project Geebung was, in effect, a feasibility study for such a system. In 1974 the study built Jindalee Stage A at Alice Springs; this system projected a single pencil beam toward Derby to obtain basic performance data, testing the reliability of ionospheric radar-propagation near Australia. The radar was able to detect, for example, civil aircraft at Singapore. Jindalee A became operational in 1978. Its success led to Stage B, at Alice Springs, in 1979. Two beams were steered within a quadrant looking north-westward. Stage B attained "minimum capability" (about 50%) in 1982, and this experimental program was completed at the end of 1985. Experimental targets included Mirage III, F-111, HS 748, and Pilatus Porter aircraft, as well as ships as small as patrol craft.

Target resolution is reportedly 20–40 km. Range may be as long as 4000 km. Propagation is normally off the F-layer of the ionosphere (about 350 km high), but range may be shorter when the E-layer (150 km high) is used, as is sometimes possible. Frequency is about 30 MHz, and transmitter power is about 400 kW. The frequency must be selected to avoid multipath (bouncing off more than one layer) propagation, and also to avoid in-

terference (e.g., with the Milky Way, at about 20.5 MHz). One result of the early studies was the discovery that the ionosphere, at least over Australia, is substantially more stable than had previously been thought.

The Stage B transmitter was built at Harts Range, with the receiver located about 100 km away at Mount Everard, both north of Alice Springs. The transmitter consists of a large array of log-periodic antennas, each about 30 m high, radiating over a cleared area covered with a reflecting wire-mesh mat. The receiver is 2.8 km long, consisting of 492 elements (each a twin in-line broad-band monopole). Beams are reportedly formed by a set of networks of cables cut to precise lengths. That characteristic presumably limits the extent to which the radar can shift frequencies, since the direction of a beam so formed depends on frequency (operation is equivalent to that of a frequency-scanned radar). The equipment was upgraded during 1986, and operations began in January 1987.

Jindalee reportedly incorporates special locally developed software for automatic detection and tracking. The main means of detecting aircraft is doppler; but other methods were developed for ships, and the Australians claim that the latter represent a major advance in OTH radar technology. Given Australia's reported exchanges with the United States, it may be presumed that these concepts are incorporated in the U.S. ROTHr (see below).

The three operational radars of the Jindalee Operational Radar Network (JORN) will be in central Queensland, southwest Western Australia, and southern Northern Territory. As of late 1989 the Australian government planned to award contracts immediately for 2 systems, with an option for a third. Tenders closed on 29 August; the bidders were AWA (Amalgamated Wireless of Australia)/CSA (Computer Sciences of Australia)/Transfield/GE; BHP Aerospace/Raytheon/Andrews Antenna/Logica/Computer Power; and Telecom-GEC Marconi/Lockheed Technology (Australia). AWA won early in 1990, and the first site (Queensland) is to be operational in mid-1994. The Alice Springs radar is being upgraded for further research.

In July 1988 the Australian government announced that it planned to acquire 4 AEW aircraft to fill the gaps in Jindalee's coverage. The probable implication is that Jindalee will provide early warning in a band about 3000 km distant and that the aircraft will track targets and manage the air battle at shorter ranges.

UNITED STATES

◆ ROTHr (TPS-71 [XN-1])

ROTHr is the Relocatable Over-The-Horizon Radar, a system built by Raytheon after that company defeated General Electric in a 1986 competition. ROTHr is intended primarily to provide



The ROTHr receiving array. (Raytheon)



The ROTHr transmitter array. (Raytheon)

a fleet commander with early warning of the approach of Soviet antiship bombers; ROTHrs are to be emplaced so that their beams sweep the likely paths along which the bombers may fly. It is clear that those paths may change with major shifts in the political situation. A fleet's surveillance assets should be able to shift with the fleet; ROTHr approaches that ideal by being relocatable over a period of weeks or months. ROTHr will also be able to detect ships. ROTHr was chosen as preferable to a much more expensive alternative, a system of radar satellites that would have provided continuous coverage of the entire globe.

Like other OTH radars, ROTHr operates by bouncing its HF beam off the ionosphere. Ionospheric conditions vary from place to place in the world. To be truly relocatable, therefore, ROTHr incorporates a quasi-vertical incidence (QVI) sounder and a radar-backscatter grounder for propagation management assessment (PMA), which provides automatic adjustments according to changing ionospheric conditions. Transmission is FMCW at an average power of about 200 kW, for a reported range of 1600 nm on ships and aircraft.

The system consists of 3 separate sites: a transmitter (about 1200 ft long) 50–100 nm from a receiver, and an Operations Control Center (OCC) at the receiver. The transmitter consists of a series of wires strung from short masts; the receiver is a double array of dipoles about 8500 ft long. Beams are formed digitally in the signal processor, roughly as sonar beams are formed digitally in a DIMUS sonar.

Full-scale tests began about April 1987. The receiver was located at the Naval Security Station at the North Carolina border, near the Dismal Swamp, and the transmitter was about 25 miles east of Richmond (Whitehouse, Virginia), i.e., 75–100 nm apart. About 10 ROTHrs will be built, beginning with 3 under the FY88–89 budget. The test unit is emplaced at Amchitka, in the Aleutians; of the other 3, 1 will go to Guam, 1 probably to Amchitka (each covers a 60-deg sector, so more than 1 can usefully be employed at a given site), and 1 to Virginia (for operational evaluation and training). The operational ROTHr at Amchitka entered service in 1989. Each ROTHr costs \$65–85 million.

In May 1990 it was reported that Japan plans to buy a Raytheon ROTHr radar to track Soviet Far East forces off the Siberian coast and in the Sea of Japan. The radar is to be located on Iwo Jima (no site in the Home Islands was deemed satisfactory). It is included in the FY86–90 Five Year Plan (FY90 is 1 April 1990–31 March 1991).



ROTHR coverage of 1.6 million square miles of the Caribbean, from a radar located in Virginia. (Raytheon)

Strategic Underwater Sensor Systems

UNITED STATES

◆ FDS

Fixed Distributed System is an alternative to, and possible successor of, SOSUS. The name implies the use of a large number of elementary detectors, fixed in place, as compared to the small number of big beam-formers used in SOSUS. A U.S. Navy schematic drawing released in 1989 shows lines of upward-looking point hydrophones, 5 in a line, each line about 50 nm from the next; 3 such lines form a barrier. Individual hydrophones are shown as 13 nm apart. The sensors are probably linked by a fiber-optic cable since fiber optics is necessary to carry the volume of data involved. Presumably, the individual sensors exploit reliable-acoustic-path (RAP) propagation, with an individual range on the order of 12 nm. Because each sensor is likely to be much smaller than a SOSUS array, it might be much more practicable to develop a rapidly relocatable equivalent to FDS, a successor to the failed RDSS program.

Compared to SOSUS, FDS would cover a much smaller area, but with a much higher probability of detection. FDS would, therefore, be laid in a strategic strait or choke point.

FDS was announced in 1984. In 1989 the navy issued an RFP for the FDS shore station and information processor, to be awarded on a competitive basis. As of early 1989 AT&T was prime contractor, and the full system was expected to be in service by the second quarter of FY95.

◆ SDS

Surveillance Direction System is envisaged as the integrating element of the integrated undersea-surveillance system (IUSS); the IUSS consists of SOSUS, SURTASS, FDS, and the new LFA

(low-frequency adjunct). SDS is intended to identify a contact in any one system and cue others to seek contacts representing the same object. As of early 1989 a draft RFP was expected in the late spring or early summer, with the formal RFP following in the fall, and a decision on competing contractors due in the fall of 1990 or later. This schedule parallels that of the FDS.

◆ SOSUS

This system of large fixed underwater arrays has been in service since about 1955, increasing in extent and sophistication over time. SOSUS was apparently inspired by the discoveries, just after World War II, of the deep sound channel and of the convergence-zone effect. SOSUS was originally suggested as a means of detecting submarine operating areas so that coastal convoys could be rerouted. However, it was later discovered that, with appropriate signal processing, a system of SOSUS arrays could cover much of the North Atlantic and North Pacific Oceans and thus could be used to cue patrol aircraft. Only in the late 1960s did then-Secretary of Defense Robert S. McNamara explicitly connect SOSUS with the P-3 Orion program.

The role of long-range submarine detection has changed over time. In the late 1950s SOSUS was valued as a means of detecting Soviet strategic submarines that, it was assumed, would have to approach American waters to fire. Later, it was assumed that the Soviets would surge large numbers of submarines into the North Atlantic just before attacking Western Europe: SOSUS was, then, primarily a war-warning sensor. However, it was also a means of tracking attack submarines in the open ocean and, therefore, a means of cueing patrol aircraft to deal with them. SOSUS could provide at least an approximate picture of Soviet submarines' patrol areas and could, therefore, also be used as a guide for evasion, whether by convoys or by naval forces.

The overall effectiveness of the SOSUS/P-3 combination depends upon several connected factors: first, the probability of detection by SOSUS; then, the size of the areas in which SOSUS locates a submarine; finally, the ability of the P-3 to redetect the submarine within that area. SOSUS is a passive system, but it uses several arrays whose beams should cross to locate a contact within a limited area.

In the current system, raw data are initially processed by NAVFACs (Naval Facilities), which pass their products to Regional Evaluation Centers (RECs: 1 each for Atlantic and Pacific) and then to Main Evaluation Centers (MECs), which have access to information from other sources. In 1974 it was announced officially that there were 22 SOSUS arrays; there has been some speculation that this total includes only arrays off the coasts of the continental United States.

It now appears that SOSUS was the first application of the LOFAR narrow-band signal-processing technique. The prototype array, at Eleuthera in the Bahamas, was about 1000 ft long and consisted of 40 hydrophones forming beams about 5 deg wide. When the array was first built, about 1952, each beam had to be processed separately, and detection/classification took about 5 min. The beam could then be shifted to another bearing, using delay lines. At this time the goal was to achieve detections at 50–500 miles. It is clear that these specifications no longer even vaguely apply, but they indicate the likely improvements in SOSUS: beam preforming capabilities, so that all beams can be sampled simultaneously; larger arrays at greater depths, to make better use of propagation within the deep sound channels and to achieve greater gain; and low-loss transmission lines, to send data back to the shore stations. The original installation was designed to detect snorkelers: in 1952 such submarines were quite loud by current standards.

One improvement to SOSUS has been publicly described. In common with the airborne LOFAR systems of the 1950s and 1960s, SOSUS used a time-compression (analog) method, Deltic, to build up the signatures the system recognized. That scheme was effective as long as the threat consisted of relatively noisy diesel submarines and then noisy first-generation nuclear submarines. However, the signatures of second-generation nuclear craft (Charlie, Victor, and Yankee classes) were more subtle. A Canadian company, Computing Devices of Canada (CDC), introduced digital acoustic analysis in the 1960s, applying FFTs to extract spectra from sampled inputs. When the original FQQ-1 processor was replaced by a new FFT processor, SPEAR, it was reportedly possible to recognize the new signatures by analyzing their fine structure. CDC later provided recorders to supplement SPEAR analyzers, and these systems were reportedly installed throughout the U.S. and Canadian SOSUS system.

LOFAR, i.e., detection by signature, allows different SOSUS stations to be sure that they are detecting the same submarine (so that they can cross beams to provide range as well as bearing). Moreover, given the signature of the submarine, an airplane using LOFAR buoys should have a better chance of redetection, comparing the known signature to the received signal. This combination (SOSUS plus patrol aircraft) was first extensively tested during the Cuban Missile Crisis in 1962, proving spectacularly successful.

The viability of such long-range passive detectors has been called into question as submarines have become much quieter. The usual alternative has been a low-frequency active system. One, called LORAD, was tested in the late 1950s. It would have reached out to about 5 convergence zones (about 165 nm in mid-Atlantic), and a scaled-down transducer of this type was installed in the tanker *Mission Capistrano*. LORAD would have been deployed on board special mid-ocean pickets, probably converted Victory ships. Improved SOSUS apparently solved the problem. LORAD was suggested at about the same time as the Julie active-passive sonobuoy system (see the ASW section): Julie was abandoned in favor of a better passive detector, Jezebel (airborne LOFAR).

A major SOSUS-upgrade program was reportedly ordered in

1971, including sensors moved forward into the deep ocean basins. That move seems to reflect a belief that prospective Soviet silencing would reduce effective ranges. The projected deep-ocean sensor was SASS, the Suspended Array Subsystem, a tripod, 6 miles on a side, that supported a directional array in the deep sound channel, in water 18,000 ft deep. SASS was never built (presumably, improved signal processing and delays in Soviet silencing solved the problem).

About 1971 a Computer-Assisted Array Processing project was started, to deal with the mass of raw data provided by the big LF arrays. SOSUS reportedly detected both the loss of the U.S. submarine *Scorpion* and the loss of the Soviet Golf-class submarine off Hawaii in 1968, but operators did not notice either (transient) event until the SOSUS tapes were reviewed later, after other indicators had shown that something had indeed happened. The implication is that the operators concentrated on particular spectral lines (as would be natural in a LOFAR-based system), and that transients received little attention.

More recently, SOSUS's effectiveness has been called into question as the Soviets have built quieter submarines. One solution seems to be FDS (Fixed Distributed System), which would cover a smaller area more thoroughly. It is also possible that, in analogy to the active adjuncts proposed for towed arrays, active VLF pingers could be integrated with the existing passive SOSUS arrays.

SOSUS has 2 other major drawbacks, both connected with the sheer size and sophistication of the arrays. First, although the arrays' locations are classified, they probably have not changed very much over the 3 decades of the system's existence, and the Soviets presumably know most or all of them. The arrays have to be located in relatively quiet areas, so there will not be so much local shipping noise as to overwhelm the faint sounds of distant submarines. The arrays and their shore connections may, therefore, be relatively easy to sabotage or attack early in a war. Second, because SOSUS is fixed, it cannot support U.S. ASW operations in areas other than those for which it was laid down, i.e., in areas other than (probably) the North Atlantic and North Pacific. Like other fixed sensors, then, it cannot react to political surprises, such as crises in the Indian Ocean.

The solution to both problems is a portable equivalent of SOSUS. One such is SURTASS, the towed surveillance array (see below). Another, which did not succeed, was RDSS, an air-deployed surveillance system. The requirement for a system like RDSS would seem to persist, and some form of long-range battle-group sensor, such as an air-deployed/retrieved array, may eventually enter service.

The designation SOSUS (Sound Surveillance System) has been applied both to a particular deep-water system and to the full array of fixed detectors, including several technologies, that the United States and its allies possess.

As of 1989, efforts to improve the underwater-surveillance system include development of an adaptive beam-former (ABF) and an integrated acoustic display/wide-band acoustic recall (IAD/WBAR). Here, wide band is presumably in contrast to the narrow-band operation of the past. A system so equipped could backtrack to check for transients near an assumed submarine position. See also SDS, the Surveillance Direction System.

◆ SURTASS (UQQ-2)

Surveillance Towed-Array System, using specially designed towing ships (T-AGOS) and a very long array, is a backup or gap filler for SOSUS. SURTASS replaces the 6 SQR-15 towed arrays deployed in the 1970s. Signals from the array are partially processed on board the towing ship, but most of the work is done at a shore station after the signals have been transmitted by satellite (DSCS) link. The ships are designed to steam 1500 nm to a patrol area, where they tow their arrays at 3 kt. The arrays are 8575 ft long, towed at a depth of 500–1500 ft; the tow cable is reportedly 6000 ft long.

There are 3 classes of SURTASS ships: the original monohull *Stalwarts* (T-AGOS 1-18), 4 *Victorious*-class SWATHs (T-AGOS 19 class), and 8 projected T-AGOS 23-class SWATHs (1 authorized in FY90). The latter are enlarged to incorporate new active towed arrays (ATAS) and also for better seakeeping. In addition, 5 Japanese surveillance ships (AOS, the first in the 1989 program) will tow UQQ-2 and will reportedly carry U.S. crews to operate the sensors.

The 2 main current improvements are the use of a reduced-diameter (presumably longer) array and the installation of the UYS-2 processor on board the towing ships. The latter presumably provides a degree of autonomous processing. A ship so equipped might be much better able to provide direct support for deployed fleet operations, for example, in Third World waters. Full-scale engineering development of the LF active system for the second-generation SWATHS began in 1990.

Full-scale development of SURTASS began in 1976; technical evaluation was completed in March 1978, with operational evaluation in May-June 1978. The first full system test, including the satellite acoustic data link, was conducted in July 1979. SURTASS entered service late in 1984. The first 3 contracts for SURTASS ships were let on 26 September 1980.

TACTICAL COMMUNICATIONS SYSTEMS

Radio Systems

Long-haul naval communications may be by low frequency (LF, using a ground wave, up to 300 kHz) or by medium/high frequency (MF/HF, up to 30 MHz, using a combination of ground waves and sky waves bounced off the ionosphere). Higher frequencies are inherently limited to line of sight, although most antennas are not directional. One important potential exception is bridge-to-bridge communications between 2 ships in contact. Such communications would be highly directional, and the antennas used might be the sort otherwise used for surface search or navigational purposes, outwardly indistinguishable from the radars' antennas. All navies use a combination of MF/HF and shorter-wave, higher-frequency communications, and only a few systems can be listed here. UHF is generally used for ship-to-aircraft and aircraft-to-aircraft, and for short-range ship-to-ship (line of sight). UHF and higher frequencies are generally used for satellite up-links.

Perhaps the most important recent development is the increasing interest in antijam and anti-intercept communications, focusing largely on frequency hopping. Another effort is the attempt to overcome the vagaries of the ionosphere, which is affected by, among other things, the 11-year solar cycle. For HF radio, these 2 developments are linked because the appropriate transmission frequency depends on ionospheric conditions. In the past, finding the appropriate frequency and making contact was sufficiently laborious that frequency hopping was inconceivable. Now the radio can automatically repeat the usual manual steps, and it can often achieve a connection in as little as 10 sec. The logical extension of automatic connection is automatic frequency hopping, typically 10-20 hops/sec (less than 7 millisec per hop). Hopping is unlikely to be fast enough to frustrate interception (hence, HF/DF will remain), since the existing wide-open intercept systems will probably pick up even very short snippets of message. However, hopping can frustrate jamming since it takes some time for an enemy to retune the jammer from 1 bit of message to the next.

Examples of modern HF systems are the French SPIN and the British ASSAT (Advanced Ship-to-Shore Automatic Telegraph). SPIN emphasizes ECM resistance by frequency hopping; ASSAT seems more oriented toward reliable long-haul transmissions. In ASSAT, the shore station transmits a standard message for several seconds on each available frequency, and the shipboard receiver measures the signal-to-noise ratio for each and calculates the best frequency to use; this evaluation continues throughout the transmission. ASSAT is currently being tested.

Another approach is to use the ionization from meteor bursts: meteors leave trails of ions that reflect electromagnetic energy, and there are always, it seems, enough meteors to provide sufficient (if intermittent) communications paths. Because the paths are intermittent, messages may be broken up, and they must, therefore, be quite redundant; the redundancy can be achieved by modern computer-coding techniques. The frequency band is usually 40-50 MHz, although 20-120 MHz can be used. Thus far, meteor burst has only been used for land communications, but it has obvious naval application.

DENMARK

Terma, which manufactures the current Danish naval combat-direction systems (TDS), also manufactures an associated data link, like the Swedish link, the Danish link can transmit both data and text messages. The Terma TDS is intended for use ashore, as part of a coast-defense system. Data-link messages must, therefore, be passed between coastal centers via land telephone lines; they must also be compatible with those used by other land-based command/control systems. Terma developed a Standard Communications Controller (SCC) to solve the interface problems raised by such operation.

FRANCE

◆ Link W

This proprietary data link is associated with the Vega and TAV-ITAC systems, equipment for which is manufactured by SAT.

◆ Syracuse

This system employs repeaters (7-8 GHz) in the 2 French Telecom 1 satellites reserved for military, primarily naval, use, under an agreement made in 1980. The 2 repeaters are horn antennas; the civilian antennas are dishes (14/12 GHz for French industry and for video transmission, covering France, and 6/8 GHz for telephone and television traffic between France and some overseas territories; there are also two 40-MHz repeater channels). Ground coverage extends from the West Indies to the Reunion Islands.

The associated naval system uses a pair of 1.5-m stabilized antennas in radomes, located so that 1 will always have a clear line of sight to the satellite. The antennas track either using preprogrammed satellite data or homing on the satellite's beacon. The terminals are interchangeable; about 20 ships are, or will be, fitted with terminals.

The 2 satellites will last until about 1992. The follow-on, Syracuse II, may be either another add-on to a future civilian satellite or a dedicated satellite.

INTERNATIONAL

◆ NATO Satellites

There is a family of NATO communications satellites (Phases I, II, III) covering the northern hemisphere. NATO III has a maritime role. Both the satellites and their ground stations are managed by Ford Aerospace. The program was conceived in 1965-67; and in 1988 NATO had 22 fixed ground terminals, 1 mobile terminal, and 2 active satellites in orbit. As formally proposed in 1966, the program consisted of 3 phases: I, for experiments and training; II, for reliable voice and code communications among the NATO countries' military and political headquarters; and III, for much of the capacity of the NATO Integrated Communications System (NICS), with access by mobile users. SATCOM III was 1 of the first all-digital communications satellites.

NATO IIIA, IIIB, and IIIC were placed in geostationary orbit over the North Atlantic in 1976-78; and NATO IIID was added as an in-orbit spare in November 1984, partly because the Phase IV characteristics had not yet been determined. Nine new Phase III terminals have been built, and 12 Phase II terminals modernized to Phase III standards. These satellites operate at 7-8 GHz and are compatible with the U.S. DSCS and with the Brit-

ish Skynet 4 systems. Each satellite operates 2 beams simultaneously: 1 for North America, 1 for Western Europe.

Skynet 4 has now been selected for Phase IV, with the first launch scheduled for 1990.

◆ NATO Data Links

These digital links were originally developed by the United States, but they are now used throughout NATO and thus are best listed as an international standard.

Link 1—Data link within NADGE (NATO Air Defense Ground Environment) radar chain. It is comparable to, but not compatible with, Link 11. In 1978 the U.S. Marine Corps obtained an interface, MANTA, to pass Link 1 data into its own tactical data system, which uses Link 11 formats for air information. The U.S. designation is TADIL B.

Link 4—Data link for controlling aircraft, used between airborne controllers and fighter aircraft and also between carriers and their aircraft, replacing voice radio. The current U.S. version is Link 4A, and the U.S. designation is TADIL C. This link is not encrypted, nor is it jam resistant.

Link 10—British tactical digital data system, broadly equivalent to (but not compatible with) Link 11. It was conceived by Ferranti as Link X, a less expensive alternative to Link 11, which the Royal Navy could not afford in the requisite quantities. In the 1960s, then, the British decision was to provide a few special gateways that could connect the less expensive Link 10 systems with Link 11. Data are passed without some of the command and engagement messages associated with Link 11.

The letter "X" of Link X became the numeral 10, which never had been the intended meaning. Link 10 was later sold to the Belgian, Dutch, Greek, and Turkish Navies, as well as to its primary user, the Royal Navy. As of 1978, HMS *Bristol* was probably unique among British warships in her ability to serve as a gateway between Link 10 and Link 11 units. The 3 British aircraft carriers, which are also command-and-control ships, presumably have a similar capability. Link 10 is subject to NATO STANAG 5510. Operating range is reportedly 150–180 nm.

During the Falklands War Link 10 was very successfully used to pass data from ships equipped with MTI radars (which could detect aircraft flying overland) to ships not so equipped. As a result, the Royal Navy decided to employ digital data links much more widely, but also to use Link 11 in place of the less capable Link 10.

Both Links 10 and 11 use about 3 kHz of bandwidth, and both use ground-wave propagation to avoid errors due to multipath sky-wave effects. Link 10 operates at up to 1200 bit/sec, using frequency-shift keying. The system structure as a whole is based on a series of computer-allocated time slots, and each station is allocated a number of slots based on projected needs.

Link 11—Digital encrypted HF or UHF link for the U.S. Navy Tactical Data System. This link is TADIL A (Tactical Digital Link A) in U.S. terminology. Compared to Link 10, Link 11 carries 3 times the data per target and requires about 4 times the dedicated computing power. Link 11 is subject to NATO STANAG 5511.

System architecture is based on a roll-call mode, with each station being called in turn and transmitting data into the network. One designated station controls the entire network. The Link 11/NTDS network operates with very short time delays between transmissions by different stations; the end of 1 message signals the next transmitter to start. The transmitter sends a series of synchronizing pulses, then starts sending data. One technical problem in the early versions of the system was that the receiver of the unit that had just transmitted could not start up quickly enough to receive the synchronizing pulses of the next transmission. Because time delays would be so destructive, it is not possible to transmit Link 11 data through a satellite. Even a distance such as that between Rome and Brussels is reportedly too great, in terms of the resulting time delay.

Link 11 currently operates on both HF (2–30 MHz) and UHF (225–400 MHz), the former for use at up to 300 nm, the latter for 25 nm or less. HF operation is AM; UHF is FM. Link 11 uses both upper and lower sidebands of the radio signal to achieve a degree of diversity. Messages are transmitted as 30-bit data frames, each consisting of 24 bits of encrypted message data plus 6 bits of error-detection code. The system operates at 2 alternative rates, NTDS fast (2250 bits/sec, 75 frames/sec) and NTDS slow (1364 bits/sec, 44.75 frames/sec).

The current Link Eleven Model Five (LEMF) improvement program adds new waveforms and protocols and is intended to be jam resistant in HF. A full-scale engineering-development contract for the Link 11 Improvement Program was let in 1987.

The U.S. LEMF design was completed in FY88. It is based in part on work done under the recently terminated HFAJ (high-frequency antijam) program. LEMF is part of Phase I of a longer-term Link Eleven Improvements (LEI) program, in which Phase II seeks increased capacity and quicker network access. There is also a new message standard (OPSEC 511).

Link 11 improvements include a possible change in software so that critical information is given priority (which is not possible at present). Message formats may be changed to permit the system to handle more tracks at a faster rate. The current Link 11 is limited to perhaps 200 out of a total of as many as 3000 tracks/sec that a major command might require in a major war. Track capacity would be particularly stressed in a hot air engagement, when ships would be seeing on their radars and other sensors not only friendly and enemy aircraft and antiship missiles, but also the defending anti-air missiles, their boosters, decoys, and perhaps even bursts from close-in defensive guns.

There is a current NATO Improved Link Eleven (NILE) program; the partners are Canada, France, West Germany, Italy, Netherlands, Spain, the United Kingdom, and the United States (where the team is based). The goals are better security and jam resistance, and NILE is to be ready for production by early 1991. There is some question of the extent to which NILE and Link 11 will be interchangeable.

The Royal Navy has a receive-only Link Eleven (ROLE) in some ships. As of 1987 the U.S. Navy was developing its own receive-only Link 11 to enable Aegis ships to control the firing of missiles by non-Aegis ships. Techeval/opeval was scheduled for completion in June 1988.

Besides the long-range HF, there is a line-of-sight UHF Link 11 for use between nearby ships and AEW aircraft (E-2Cs and some E-3A AWACS).

Link 11 was conceived by a CANUKUS (Canadian-U.K.-U.S.) Naval Data-Transmission Working Group (NDTWG) formed in 1954 to design a standard intership data-link format and a terminal. By 1956 the group had decided on the Kineplex modulation technique (which is still used), and the 30-bit message format consisting of data plus error detection and correction codes. The final proposal was ratified at Ottawa in late November 1957. The Royal Navy proposed a name, TIDE (Tactical International Data Exchange); the TIDE committee met at frequent intervals through 1960. The TIDE link was made the subject of a NATO standardization agreement (STANAG) in 1960–61. Four alternative links were under consideration at this time: Link 11 (a fast automatic HF link), Link 12 (fast automatic UHF), Link 13 (slower, hence cheaper, automatic HF), and Link 14 (slow semiautomatic HF/UHF). The U.S. Navy pressed for the HF links because it expected to operate its ships in dispersed (primarily antinuclear) formations, and HF (unlike UHF) could pass beyond the horizon. Hence the dominance of Link 11, with Link 14 as a backup for ships not equipped to decode and use Link 11 data.

Reportedly, the TIDE link was initially designated Link II (Roman 2), the earlier British digital link associated with the comprehensive display system (CDS) being Link I. Link III was presumably the original designation for what became Link 10. That would explain the designation of the air link as Link IV; the Roman 2 was misread as an eleven. This history would explain the absence of Links 5–9.

The name TIDE was reportedly inspired by the name of a popular U.S. laundry detergent, Tide; the data link would help clean up a messy tactical picture. Many contemporary television commercials showed Tide (or some other advertised detergent) as superior to an alternative, less expensive, "Brand X." It seems likely that the name Link X (which became Link 10) was inspired by that parallel (Link 10 is, after all, a less capable but also less expensive data link).

Link 14—Teleprinter data link between ships not equipped with NTDS.

Link 16—Link associated with JTIDS, the U.S. Joint Tactical Information Distribution System; it is also called TADIL J. This is the planned replacement for all existing U.S. airborne high-capacity data links. Since the system entails the transmission of common synchronizing pulses, and since the time of arrival of messages can be precisely measured, JTIDS is also, in effect, a tactical navigational system (pulses can be used to measure distance). In theory, JTIDS will also provide highly reliable identifications.

JTIDS operates in Lx-band (960–1215 MHz), hopping frequency randomly over a bandwidth of several hundred MHz on a pulse-to-pulse basis. A JTIDS net is defined by a particular sequence of hopped frequencies. Subscribers in the net are assigned transmission slots within the 12.8-min cycle; each slot is 7.8125 msec (1/128 second) long, so that the cycle contains 98,304 slots. One subscriber is the designated time reference, responsible for maintaining the timing of the net. Within each slot, every other message pulse is redundant, so that messages can be reconstructed even if they are badly jammed. There is also a jitter period at the beginning of each slot, so the actual beginning of the transmission of data varies. The data rate can be doubled (at a price in terms of ECCM), first by eliminating the redundant data (packed-2 structure), and then again by eliminating the jitter (packed-4 structure). This scheme is described as Time Division Multiple Access (TDMA).

Time slots are divided into 12-sec frames (1536 slots) and 64-frame epochs (12.8 min), the epoch being the system cycle. Each slot contains up to 12 Link 16 words (75 bit/word), which can be updated on every frame (the basic cycle is the epoch). The transmission waveform uses a 6.4-microsec pulse as its bit and leaves 6.6 microsec between pulses; each pulse is transmitted in sequence at one of 51 frequencies (3 MHz apart) chosen from a pseudorandomly coded list. Each pulse is subcoded (chipped) by 32 phase modulations; chipping provides additional coding so that a receiver can identify a pulse against background noise. Each net normally supports up to 32 transmitters (each can be allocated more than one slot per frame). Nets differ in their frequency-hopping sequences and time references and can run in parallel. Up to 128 can be stacked with negligible chance that 2 long words will coincide.

The navy developed a higher-capacity system, Distributed TDMA (DTDMA), which permits the operation of several concurrent independent nets (6, 8, or 16; only 1 with TDMA). The navy argued that operating multiple nets was essential because a fleet must operate simultaneously in several dimensions, and each composite warfare commander (AAW, ASW, ASUW) needs a separate net. The air force developed the single-net system because it generally operated in a more centralized way. In 1985, faced with the high cost of developing 2 parallel systems, Congress mandated the choice of a single triservice system, and the navy canceled DTDMA in favor of the existing air force–army TDMA system. This form of JTIDS is also being adopted by some NATO allies.

JTIDS line-of-sight range is about 300 nm, a figure probably limited by the time of transmission (which must be allowed for in the slot's length: 300 nm equates to about 1.6 msec); it can be extended to 500 nm. From a user's point of view, JTIDS provides all subscribers with a common tactical picture, much as NTDS does.

Link 16 is intended to replace Link 4A and to complement

(but not replace) Link 11. It is included in both the E-2C update plan and the F-14D program.

As of 1990 there was also an Interim JTIDS Messaging Standard (IHMS) already in service, which was not interoperable with either JTIDS or Link 11.

NETHERLANDS

◆ VESTA

Signaal's VHF helicopter-to-ship link is used on board current MEKO-type frigates. It consists of a transponder, which provides very accurate location data, and a short-burst (approx 1 sec) data link using voice channels (VC). The data link is intended primarily to transmit the position of a ship as seen by the helicopter's radar; digital position data are sent in FSK form (2100 Hz for a 0, 2400 Hz for a 1) and can be transmitted directly into a ship's tactical data system. Each burst consists of 50 words of 32 bits each. This is not transmission of radar video; it requires that the helicopter-borne radar do automatic target detection. Helicopter position is established by a separate VHF transponder triggered by the ship's 1–10-GHz search radar; the helicopter reply appears on the ship's radar display. The coded pulses are 2.2 microsec long, and typically there are 5 alternate codes (the system can accommodate up to 64). PRF is 20 kHz without the code. Maximum range is 64 nm.

SWEDEN

The Swedish small-craft command/control systems include a PEAB (now BEAB) specialized TDMA (time division multiple access) data link (which can transmit text messages), comparable in principle to JTIDS. All signals are encrypted. The data link is used by the STINA coastal command/control system, described above.

This data link has been exported, at least to Yugoslavia.

USSR

◆ Molniya

The Molniya satellites in high elliptical orbits cover the northern latitudes. They have been launched since 1965: Molniya 1, 33 satellites; Molniya 2, 15 satellites, from 1971; and Molniya 3, 4 satellites, from 1974. Orbital period is about 12 hr, with perigees of about 500 km in the southern hemisphere and apogees of about 40,000 km in the north. The arrangement was initially 120 deg apart (so that 3 satellites could cover the Soviet Union for 9 hr each day); but Molniya 2 and 3 were 90 deg apart, and Molniya 1 satellites were moved to positions between the



The Don-class submarine tender (floating base, in Soviet parlance) *Viktor Kotel'nikov* shows her 2 Big Ball satellite communications antennas, a type of equipment formerly carried by now-defunct *Sverdlov*-class command cruisers. The lattice mainmast carries the Slim Net air-search radar and 2 Square Head IFF interrogators.



The Don-class submarine tender *Dmitriy Galkin* shows the standard Soviet Vee Cone long-range HF antenna on her lattice mainmast. The angle between the cones can be varied, and the sides of the cones are solid in some ships. The weapons and sensors date from the 1950s and 1960s—100-mm guns in open mounts, a Wasp Head main-battery director with a Sun Visor radar, and 2 Hawk Screech secondary fire-control radars.

Molniya 2 and 3 satellites in 1976. Molniya 1 is UHF; Molniya 3 and later satellites operate in the SHF range.

The first synchronous satellite, Cosmos-637, was launched in 1974, and Molniya 1S was placed in synchronous equatorial orbit that year. It was followed by a series of about 11 Raduga/Gorizont satellites, operating in SHF. In 1980 the Soviets launched the first of their Volna geostationary communications satellites.

The Soviet Union evidently employs numerous data links, e.g., that connecting a Bear-D with the submarine or surface ship for which the aircraft furnishes targeting data. However, apart from some identifications of the antennas involved, details have not been made public.

UNITED KINGDOM

◆ Links X and Y

These are Ferranti proprietary data links. Link X came first; it became NATO Link 10 (see above). In the early 1970s Ferranti wanted to sell digital data links to non-NATO navies. Link Y was a version of Link X sufficiently altered (e.g., in message categories) to avoid duplicating the NATO link. Sales included the Argentine, Brazilian, Egyptian, and Thai Navies, and surface-to-air and air-to-air versions have been sold for use aboard Third World maritime-patrol aircraft and missile-firing aircraft (Beechcraft, Boeing, and Fokker). Different users all have their own versions, indicated by suffixes, e.g., Link YB for Brazil, YE for Egypt.

Link Y operates in a time-slot mode, allowing for up to 24 units/cycle, or for more slots for a smaller number of subscribers. The standard message format is two 24-bit words; standard transmission speed is 300–1200 bit/sec (2400–4800 bit/sec optional). The current Ferranti Link Y processor is based on the company's Argus minicomputer. It maintains a track data base of up to 120 tracks, comprising both tracks passed by link and own-ship tracks. This figure is presumably typical of the capacity of a Link Y system. The current version uses a color display and can accommodate data points up to 2000 miles from own-ship position.

Link Y equipment is now also manufactured by Signaal.

◆ Link Z

Ferranti's non-NATO version of Link 14.

◆ Skynet

Skynet is the British military/naval communications satellite system, begun in 1967 with the trials of the NEST ship terminal. Skynet 1 and 2 cover longitudes east from Britain to Australia. Skynet 2B was launched in 1974. The program's sponsor is the RAF, but the Royal Navy is the chief user.

The current version, Skynet 4, was first launched in 1988. It has 300 times the power of its predecessor and provides 2 UHF and 4 SHF channels, and beamwidths down to 3 deg. There is also a single experimental EHF up-link.

The associated ship's terminal is SCOT, operating in the 7–8-GHz (SHF) band (chosen to avoid radar and cosmic interference). Frigates and destroyers use a SCOT 1 (1.1-m dish); larger ships use SCOT 2 (1.8-m dish). An enhanced SCOT 1A was ordered in 1984 for delivery beginning in 1986: it provides a 1.2-m dish for both classes of ships and the equivalent of 4 secure-voice communications channels. Bandwidth is 500 MHz, compared to 50 MHz for SCOT 1; the 1A terminal can be tuned to any 50-MHz channel. All 17 remaining units of the original 21 SCOT 1 terminals are being brought up to SCOT 1A standards. The larger SCOT 2 terminals are also being modified for greater bandwidths. As of 1985 the Royal Netherlands Navy planned to buy SCOT terminals, and the U.S. Navy wanted 8 of them as an alternative to its more expensive WSC-6. For example, the USS *Enterprise* had SCOT antennas in 1986. The German Navy was also considering SCOT.

SCOT is not far from the X-band missile-seeker and fire-control-radar frequencies, so that it may be necessary to shut down nearby ESM equipment when SCOT is in use. Reportedly, that interference contributed to the loss of HMS *Sheffield* in the Falklands. In the future these systems will move into the EHF band.

UNITED STATES

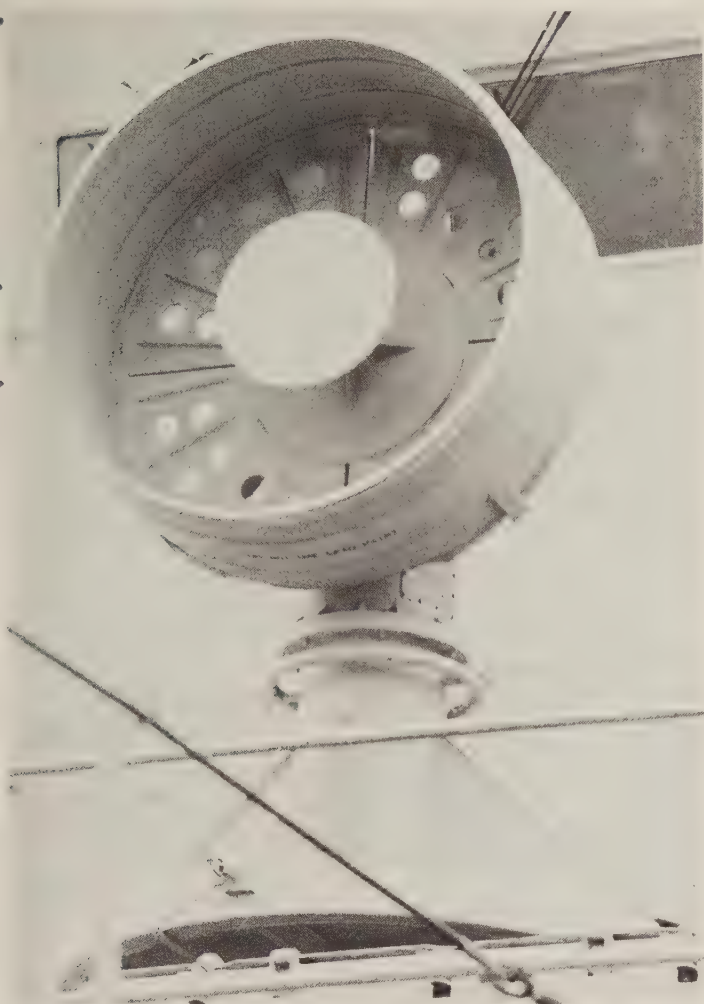
WSC-3 is the U.S. Navy's standard satellite-communications terminal. It is also the standard line-of-sight radio transmitter/receiver, in part because its modular design made modifications simpler. V(2) and V(3) were the original FLTSATCOM terminals. V(6) and V(7), the next to be produced in quantity, were line-of-sight radio terminals. V(8) was a coast guard radio, remotely controlled. V(9) was compatible with AFSATCOM's 5-kHz-channel spacing. V(10) and V(11) are Have-Quick upgrades of V(6) and V(7). V(12) is a V(2) adapted for Trident submarine use. V(13) operates from a 400-cycle power supply, and V(14) has an interface compatible with MIL-STD-1553. RT 1217 is a line-of-sight WSC-3 for the Danish and Norwegian Navies. RT 1217-2 is the relevant Have-Quick version. RT 1244 adds a fast frequency-hopping synthesizer to the WSC-3 used by the Australian and New Zealand Navies.

◆ DSCS

RCA's Defense Satellite Communications System is the main high-volume system for the Defense Department and for diplomatic communications. DSCS serves users such as the fleet commanders, the National Command Authority, and the major U.S. defense agencies. MILSTAR should take over the strategic circuits, with DSCS remaining as the link between fixed tactical users.

Phase II, the current system, consists of 4 satellites in geostationary orbits plus 2 in-orbit spares, all built by TRW. Each has 4 transponder channels, and most of the terminals are fixed on land. Seven DSCS II satellites had been launched as of 1985; estimated service life was 5 yr. All DSCS satellites have a small propulsion plant on board so that they can be repositioned to meet contingencies.

DSCS III (General Electric) will consist of 4 active SHF (7–8 GHz) satellites and 2 in-orbit spares, each carrying a 6-channel transponder (compared to 1 channel in AFSATCOM). There are 4 Earth-coverage horns (2 transmitting, 2 receiving); a 61-beam waveguide lens receiving antenna; two 19-beam waveguide lens



AS-3018A/WSC-1, the standard U.S. UHF satellite communications antenna. It is also used for a directional line-of-sight ship-to-air and ship-to-ship link, and many NATO navies use the antenna for that purpose. This one was photographed in 1988 on board HMS *Bristol*. The antenna is 54 inches in diameter. (H. Lime)

transmitting antennas; a gimballed dish transmitter for selecting the area of coverage; and UHF transmit-and-receive antennas. These satellites should have higher power and, thanks to their movable beams, should be more difficult to jam. As of 1985 the planned total procurement was 14, with 7 having been included in the Defense Department's explicit plans.

One DSCS satellite was procured in FY88, and 2 were scheduled for FY89.

◆ FLTSATCOM

FLTSATCOM is a UHF (244–400 MHz) fleet-communications system that provides worldwide high-priority communications between aircraft, ships, submarines, ground stations, the Strategic Air Command, and the National Command Authority. The system, managed by the Air Force System Command (Space Division), uses 3-axis body-stabilized satellites in geosynchronous orbit. Each satellite has an 8-ft hexagonal body (50 in high), with an 18-turn-helical UHF receive-antenna and a 16-ft-parabolic UHF transmitter antenna. The satellites are powered by two 7×13 -ft solar panels, and they weigh 4250 lb (5100 lb for satellites 7 and 8). Each supports more than 30 voice and 12 teletype channels or, alternatively, 23 high-capacity channels [1 for fleet broadcast; 9 [7 low- and 2 high-power] for navy relay; 12 [all low power] for air force narrow-band; and 1 for DoD wide-band]. Hydrazine engines are used to maintain stability and also to relocate the satellites as required.

The contract for the system's development was awarded to TRW in November 1972, and the first launch was made on 9 February 1978. As of 1988 the 4 oldest (of a total of 7 launched) have already exceeded their 5-yr design lives. Satellite 5 was damaged during launch (6 August 1981) and thus could not perform satisfactorily. Satellite 7 was launched on 4 December 1986 (actually the sixth launch), but Satellite 6 (seventh flight) had to be destroyed soon after launch on 26 March 1987. An eighth satellite has not yet been launched, and satellites 7 and 8 incorporate an experimental EHF package as a prototype for future systems. Thus, in 1988, 5 were operational, with 4 in use and a fifth designated as an in-orbit spare.

The navy issued an RFP for a UHF follow-on satellite in November 1987, and the contract was to be awarded in July 1988. The RFP called for a 39-channel capacity using demand-assigned-multiple-access (DAMA) technology; the satellites are to be fully compatible with FLTSAT and LEASAT, and they will use existing ground terminals (and hence will require 1 SHF up-link to supplement their UHF capability). As an example of this type of system, TRW's proposal called for 3 times the capacity (28 low- and 10 high-power navy relay, 40 high-power air force narrow-band, but no DoD wide-band and no fleet broadcast channels) and twice the lifetime of the existing FLTSAT-COM. It is presumed that this program is affected by the loss of launch capacity as a result of problems with the space shuttle and with the major launch boosters.

The Hughes HS-601 satellite was selected at the end of July 1988, 6 weeks after Australia had chosen that same design. The contract called for 1 satellite plus options on 9 more; these satellites will replace both FLTSAT and LEASAT. The first should be launched in mid-1992, the second late in 1993, 2 in 1994, 3 in 1995, and 3 in 1996, either by shuttle or by expendable launcher. Each satellite will weigh about 2300 lb (FLTSAT weighs about 2200) and will have double the capacity of the earlier vehicle: 21 narrow-band channels (5-kHz bandwidth), 17 relay channels (25-kHz bandwidth), and 1 fleet broadcast channel (25-kHz bandwidth). All but the fleet broadcast channel use UHF up- and down-links (the fleet channel uses SHF, 7–8 GHz).

◆ Have Quick

Have Quick was originally the air force's program, now adopted by the navy, for providing antijam communications, primarily by frequency hopping across the radio net. The primary piece of hardware is the Have Quick A20 control module, which contains the processor, memory, signal interface, and controls. The air force's version applied to airborne ARC-164 UHF radios. The navy's contracts, awarded in 1981, applied to airborne ARC-182 radios and shipboard WSC-3s.

Under this program, the navy has adopted the ARC-182 combination radio (low- and high-power VHF/FM, VHF/AM, UHF/FM, and UHF/AM) with frequency-hopping filters and broadband antennas. The army's Single-Channel Ground and Airborne Radio System (SINCGARS) will be adopted for shipboard use, with airborne UHF relay pods and VHF relay pallets ("poor man's satellites") for communications within the battle group (to limit intercept range). The pod uses 4 ARC-182s, 2 of them modified to carry Link 11. Development of the pod was completed during FY87.

In a typical battle group, a carrier and a cruiser might communicate over a Have Quick link; other users would be the E-2C and the F-14D and the air force AWACS.

As of 1989 there is a new Combination Radio (ARC-210 and Shipboard SINCGARS) program, for airborne/shipboard tactical antijam radio systems, that is interoperable with the other services and with NATO. ARC-210 is a small, secure, jam-resistant UHF/VHF radio using Have Quick I/II and SINCGARS waveforms. Shipboard SINCGARS will provide VHF (FM) jam-resistant communications, a digital communications terminal (DCT), and a VHF relay pallet aboard naval gunfire support and amphibious ships. The radio itself will be an existing type, but the necessary filters and multicouplers are new. ARC-210 is

already being developed for the F/A-18; under the FY88 program, work began on the Shipboard SINCGARS program, with an RFP expected in FY90.

◆ LAMPS Data Link

LAMPS I helicopters communicate sonobuoy data to their ships via an AKT-22 FM transmitter, the simplex analog data link that can carry 2 DIFAR or 2 DICASS channels, as well as a voice channel. Originally the link could also transmit up to 8 channels of LOFAR data. Of the channels, 7 had 10–2000 Hz bandwidth, and 1 had 10–2800 Hz bandwidth. The dynamic range of each channel was 0.16–16 volts (a range of 20 dB). Alternatively, the link could transmit 4 omnidirectional sonar channels (for active buoys, at 26–38 kHz). The 4- and 8-buoy modes were abandoned when the U.S. Navy decided to concentrate entirely on directional buoys. The helicopter antenna (AS-3033) has 2 sections, 1 to receive sonobuoy data, the other to transmit to the ship.

Because AKT-22 operates in S-band (2200–2290 MHz, on 1 of 20 channels), it is limited to line-of-sight range, and thus a LAMPS I helicopter cannot prosecute a target beyond the ship's radar horizon: LAMPS I was intended to operate within 50 nm of the parent ship.

The LAMPS I data link is primarily acoustic. It does not carry radar video from the helicopter's LN-66 radar.

LAMPS III uses a C-band (4435–4535 MHz) duplex digital link (SRQ-4), for sonobuoy data plus radar and ESM data. It cannot transmit radar and sonobuoy data simultaneously. However, the system does carry a full duplex command/control channel parallel with the data channel. Typically, helicopter sensors (ESM and radar) are operated remotely, from the parent ship, and their outputs are presented primarily on board the parent ship. The main data link is line-of-sight, but LAMPS III also has an HF-voice radio link, for distances beyond the horizon. It is intended to operate 100 nm from the parent ship.

◆ Leasat

The U.S. Navy leases some commercial satellites to fill gaps in national systems, e.g., to support operations in the Indian Ocean. Examples are the Comsat General Gap-filler (now obsolete), which provided limited UHF cover of much of the eastern hemisphere from 1976 on, and the Hughes Leasat, a 4-satellite system (orbited 1984–85). Unlike military satellites, these commercial types almost certainly are not hardened against attack (e.g., against EMP). However, their use indicates the number of U.S. communications satellites that can be turned to military use in an emergency.

Leasat is to be replaced by Hughes's UHF Follow-On Satellite (see FLTSATCOM).

◆ Link 11 Data Terminal Sets

The data terminal set (DTS) is the interface between a ship's NTDS system and other ships or aircraft in the same NTDS net. The DTS accepts digital data (which the KG-40 key generator has already encrypted) and converts them into a series of tones for radio transmission. It also detects and corrects errors, controls link protocol, and controls the NTDS interface. Normally, it operates in half-duplex mode, sending or receiving data, but not both (it operates in full duplex mode only when being tested).

Subscribers to the Link 11 net operate either as net control station (NCS) or in picket (PKT) mode, and each unit is assigned its own picket or participating unit (PU) number. The system generally operates in roll-call mode, the NCS polling each PU in its net in turn, then reporting its own message. The NCS terminal must enter each of the PUs. Alternative modes are broadcast (BC), short broadcast (SBC), net sync (NS), net test (NT), and radio silence. In broadcast mode, a station continuously broadcasts to all net participants and must coordinate with the NCS to avoid jamming (except in the case of USQ-79 users). SBC is a single broadcast. NS is an initializing transmis-

sion by the NCS to synchronize the pickets. NT is a test pattern broadcast by the NCS.

This official table of data terminals in service as of 1990 gives numbers active (dates are dates of entry into service):

USQ-36(20)	1964–66	49	CG, CGN, CV, CVN, DDG (DDGs 37–41, 43, 45), FF, LCC
USQ-59(15)	1971–72	9	DDG (JPTDS ships), LHA
USQ-63(15)	1973–74	35	DD (<i>Spruance</i> class), DDG (<i>Kidd</i> class)
USQ-74(61)	1981–87	85	BB*, CG (<i>Ticonderoga</i> class, CG 30), CGN (<i>Truxtun</i>), CV (CV 62), CVN (CVNs 71 and 72), DDG (DDGs 42, 44, and 46 and NTDS <i>Adams</i> class), FFG (<i>Perry</i> class), LHD, AGF*
USQ-76(4)	1983	31	SSN, ASWOC (this is the (V)4 version)
USQ-79(15)	1979	17	NTISA, TACC, TAOC
USQ-83(APE)(61)	1986–89	2	TechEval FF, AGF
USQ-92(20)	1984	2	MULTOTS Detachments 1, 2
MX-512P(80)	1990	—	PHMs, Coast Guard

*Receive Only

In each case, the number in parentheses is the number of PUs the device can support.

AEW and ASW aircraft use versions of USQ-79. USQ-59, -63, and -79 are all based on the same equipment (CV2969). The reference to FF TechEval is *not* to the original ASW tactical data system on board the *Koelsch* and *Voge*, which is much older. MULTOTS is the Multiple Units Link-11 Test and Operational Training System; NTISA is the Navy Tactical Interoperability Support Activity, which tests NTDS programs before they become operational. The reference to a high-capacity DTS for the PHMs and to the Coast Guard suggests an effort to provide all units enforcing the antidrug blockade in the Caribbean with a common tactical picture; the blockade is being run as a maritime-defense zone (MARDIZ).

Los Angeles-class submarines can now share the NTDS net. FFGs 36–61 were all completed with Link 11 (2 way). Earlier *Perry*-class frigates were completed with provision for later installation of Link 11, and this is now being accomplished. The frigates (FF) fitted with an experimental tactical data system are the *Koelsch* (1049) and *Voge* (1047), which had an experimental ASW tactical data system. The *Koelsch* has been transferred to Pakistan, and the *Voge* is in reserve.

The limited PU numbers available explain why NTDS cannot be used directly to control tactical aircraft.

The DTSs should be distinguished from the data-link terminal, USQ-69, which is an operator interface with the DTS and related components.

◆ Milstar

Milstar is the all-service U.S. military communications satellite system, to enter service in the 1990s. It is the first U.S. mm-wave (EHF) communications satellite system (44-GHz up-link, 20-GHz down-link), and the system is to have a minimum of 7 operational satellites at any time (at first there will be 4 synchronous satellites, 1 of them an in-orbit spare, with all 4 in inclined polar orbits). Milstar was considered important enough to receive overriding (Brick Bat) priority. The advantages of going to EHF include escape from the crowded lower-frequency bands, better resistance to ECM (because there are more frequencies and because beamwidths are very narrow), and reduced

terminal size (or, for a given size, a narrower, and hence less easily intercepted, beam).

Lockheed was awarded the prime satellite contract in 1983.

◆ Spinsat

The Office of Naval Research Special-Purpose Inexpensive Satellite is to provide battle-group commanders with their own expendable satellite, the "Commander Class" bus with a 50–75 kg payload and with an on-board rocket motor allowing it to maneuver in space. Spinsat is conceived as an alternative to current practice, which makes satellites too valuable (and too capable) for brief tactical use. Yet a satellite would provide a battle-group commander with the best communications over an extended battle space, and quite possibly with the best hope of detecting an enemy force at the edge of that space. The satellite is made by the Intraspace Corp. of Utah, based on the company's T-Sat design, and the prototype flew on board the Pegasus rocket, carried aloft by a B-52 bomber. ONR's goal is to hold cost to the level of a tank, an airplane, or a small ship. The satellite launcher would presumably be carried on board a ship of the battle group.

◆ Satellite Information Exchange System

The U.S. Navy communications satellites carry a combination of fleet broadcast and other nets. The naval communications system as a whole employs a combination of HF radio and UHF/SHF satellite broadcast, plus automated facilities that assemble and retransmit the broadcasts. The chief nets supported by the satellite information exchange system are:

CUDIXS, the Common User Digital Information Exchange System, carrying general service (GENSER) messages to and from ships.

SSIXS, the Submarine Satellite Information Exchange System, carrying the submarine broadcast messages in unformatted text, plus targeting information in formatted computer-readable standard message formats (RAINFORM formats).

OTCIXS, the Officer-in-Tactical-Command Information Exchange System, the battle group's command/control channel, carrying RAINFORM messages (at 2400 baud), teletype (75 baud), and narrow-band secure voice (2400 baud).

TACINTEL, the Tactical Intelligence Network, exchanging special intelligence data, using the USQ-64(V)5, and carrying both RAINFORM and unformatted messages.

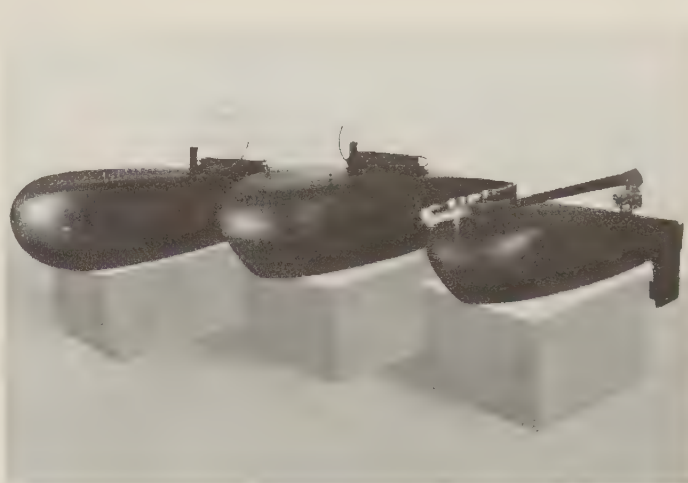
TADIXS, the Tactical Digital Information Exchange System, a 1-way satellite link, carrying ocean-surveillance data from the FCC to deployed forces.

Narrow-band secure-voice channel supporting the High Command Net, linking fleet commanders with battle-group commanders. There is also a Fleet Tactical Net.

Submarine Communications Systems

A submarine's radio communications with surface ships and aircraft are inherently limited because seawater is a barrier to most signals. The primary communications choices for submarines are currently surface radio (HF and above), periscope-depth radio (LF and VLF), and ELF (extremely low frequency) radio. Conventional antennas can transmit signals down to VLF, although VLF antennas can be quite large. For example, the airborne VLF antennas used as backups for communicating with strategic submarines are several thousand feet long and must be trailed from a considerable altitude. The sheer sizes of LF and VLF antennas make it impossible for submarines to transmit at these frequencies; LF and VLF are usable only for communication to submarines.

Only ELF penetrates to great depths, but it requires very large land-based transmitters (which in turn require favorable geological conditions) and has a limited capacity for carrying information. Moreover, because ELF has so great a range, it is subject to jamming, intentional or otherwise, by other nations'



Standard U.S. Navy submarine communications buoys. (Spears Associates)

ELF systems. The U.S. ELF system was originally conceived as a means of alerting strategic submarines, using transmitters so large and so redundant that they might well survive an initial nuclear attack. A test installation opened at Clam Lake, Wisconsin, in 1969; it was given a message-handling capability in 1976 and functioned successfully through 1978. The project was opposed on political (nominally environmental) grounds, and it was canceled by President Carter in 1978. It was revived, in limited (and vulnerable) form, by the Reagan Administration and is now in service. ELF has been extended to all U.S. submarines. The operating frequency is 76 Hz; wavelength is then about 2500 miles. The antenna at Clam Lake, Wisconsin, is 28 miles long, and the one on the upper peninsula of Michigan is 56 miles long. The current system became operational in 1987.

Submarines monitoring ELF broadcasts must trail a long neutrally buoyant wire antenna, but the submarine need not approach the surface. The first major submarine-ELF-receiver contract (with GTE) was announced in 1988, the receiver having been tested successfully in the Pacific Fleet in May 1985. A total of 137 (to equip attack as well as strategic submarines) are to be delivered in 1989–92.

In mid-1987 the British announced that they were building an ELF site in Scotland (Glen Gally Forest, near Fort William). A French ELF system, Astarte (with a transmitter at Rosnay), was to enter service in 1988–89.

The Soviet Union has the type of geology needed for ELF transmission; the basic idea is very well known, and the technology involved is not very complicated. In 1987 it was reported that the Soviets were building an ELF station.

Deeply penetrating land and waters, ELF is always receivable. It acts as a bell-ringer, informing a submarine commander that the sub must come near the surface to receive a more conventional message, e.g., by HF or satellite link.

Although an ELF transmitter, with its very long buried antenna, could in theory be hardened against nuclear attack, existing ELF systems are generally not so protected. For example, the U.S. system was initially conceived as a hard communications device, but only the soft demonstrators were actually built.

A submarine must put an antenna either through or very near the surface to receive all of the usual long-haul naval signals (HF or satellite-transmitted SHF, UHF, or EHF). For example, many submarines are equipped with buoys containing wrapped-wire HF antennas. Higher line-of-sight frequencies are useful either for air-to-submarine communications or for submarine-to-satellite communications. One advantage of very short wavelengths (such as SHF or EHF) is that the antennas can be so small that they can be housed atop periscopes.

At lower frequencies (VLF), radio waves can penetrate the water's surface down to 10–30 ft. Typically, reception requires

either a wire loop (which may be in a towed buoy) or a towed linear floating antenna. Using a towed wire limits the submarine's depth, speed, and course. Moreover, any method of communicating requires the submarine to place an object near the surface, where the antenna is more visible and marks the submarine's position.

GTE, the supplier of current U.S. submarine strategic-communications equipment, has proposed a compromise radio system, SubTACS (Submarine Tactical Communications System), operating at low frequency (but not quite ELF frequency), with a higher data rate (about 15 words/min, 300 times that of ELF). Like ELF, SubTACS employs a trailing-wire (rather than a floating-wire) antenna, and the existing standard ELF receiver can be modified to accept SubTACS's signals. Effective range is 1000+ nm, and a submarine can listen at any speed and at keel depths of about 250 ft. These range and penetration figures are far beyond those of a conventional VLF (periscope-depth) system. Compared to ELF, SubTACS is a transportable system, requiring no special geological conditions; its antenna is an insulated 12-km-long antenna cable laid on the surface of the earth. That characteristic makes the system a candidate for the U.S. requirements for reconstitutable strategic communications (i.e., for systems that can be reassembled in the event of a nuclear attack). Alternatively, the transmitter and antenna can be adapted to installation on surface ships. Signals can penetrate seawater, ice, and also the earth itself.

SubTACS is a GTE private-venture (IR&D) program, begun late in 1987, with some U.S. Navy support. As of March 1989, the company hoped to conduct a demonstration experiment late in 1989 or early in 1990.

One alternative that has been proposed in recent years is the use of blue-green lasers. Such lasers penetrate to substantial depths (they were once proposed as antisubmarine sensors, but did not penetrate quite well enough for 2-way use), and they can carry considerable amounts of information. Effective information transmission is limited, however, because the laser must scan its relatively narrow beam over the wide area in which a submarine may be located, repeating the message frequently enough for any submarine touched by the beam to receive all of the information. No operational blue-green-laser communications system currently exists, but the U.S. Navy and the U.S. DARPA have been developing a suitable space-based laser, which was tested (in airborne-form) in 1987.

This test, called "Project Y," showed that clouds did not prevent transmission to a submarine at operational depth. The navy is also conducting "Project Lambda" (i.e., upside-down Y) to investigate laser-communications up-links from submarines, although it is difficult to imagine that such up-links could not be intercepted easily.

Plans for the U.S. Navy's laser-communications satellite, SLCSAT, were reportedly abandoned because of cuts in the FY89 budget. However, navy-funded SLCSAT studies have continued.

In September 1989 it was reported that under its FY89/90 program DARPA was running a major 2-way laser submarine-communications study, between submarines and high-altitude long-endurance unmanned aircraft (HALEs), as an outgrowth of the agency's Tactical Air-Launched Communications (TALC) program. DARPA was working on an HALE transmitter/receiver, as well as a transmitter/receiver for the submarine, concept exploration of an LPI uplink, and modification/integration of an HALE. There was some fear that TALC was drawing funds that might otherwise have gone into a laser satellite program.

CANADA

◆ WQC-501

This new underwater telephone was first fitted in the modernized *Oberon* class (SOUP program). WQC-501 is manufactured by Safare-Crouzet, which makes the French TUUM-2. Transmission is omnidirectional, with a rated range of 20 km. This range can be reduced, for greater security, by reducing the power

output. Operating modes are voice, key, transponder, and automatic transmission. The standard submarine outfit includes both an omnidirectional transducer and 4 directional transducers, plus a transducer-switching unit and a power amplifier. The frequency used is the NATO standard, 8.0875 kHz, carrying both voice and Morse signals (the latter at 712 Hz). Signals are single-sideband modulated, with a maximum power level of 94 dB.

FRANCE

◆ TUUM-2

The standard underwater telephone, made by Safare-Crouzet, has a range of 10 km (20 km with a 1-kW amplifier). The basic design operates at standard NATO frequency, but the unit can be modified to operate at alternative frequencies. Characteristics are similar to those of the WQC-501 (see above), but there is no transducer-switching unit. The customer decides whether to install directional or omnidirectional transducers.

Strategic Communications The current command link for SSBNs uses the VLF (20-kHz) transmitters at Kerlouan and Rosnay, which were built specifically for the strategic submarine program. An airborne VLF system, Astarte (*Avion station relais de transmissions exceptionnelles*), analogous to the U.S. TA-CAMO, is based on 4 Transall aircraft. Astarte is being developed and was scheduled to enter service in 1988-89. It will be hardened against EMP.

ITALY

◆ TS-200/TS-510

These underwater telephones operate at NATO standard frequency (8.3-11.1 kHz), with a single sideband and CW transmission. TS-200 has 2 modes: omnidirectional (vertical beamwidth of 90 deg), and directional (about 28 deg of vertical beamwidth).

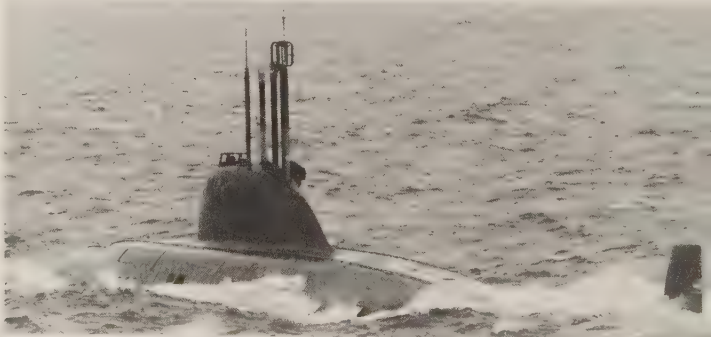
TS-510 is a smaller omnidirectional unit with a smaller transducer.

USSR

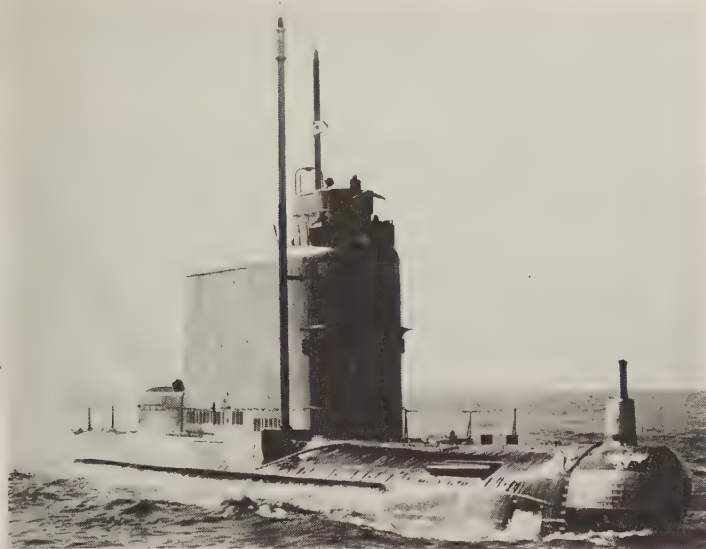
◆ Whale Tongue

Whale Tongue is the standard Soviet acoustic-communications device, used for submarine-submarine and submarine-surface ship communications. Whale Tongue is fitted to all destroyers and larger surface combatants and to all Soviet submarines.

For many years, the Soviets have been credited with superior, and probably covert, means of coordinating their submarines and surface ships. The Soviet style of naval command/control requires considerable direction from above and would demand an effective system for communicating with submarines. At the same time, because the Soviets tend to use stereotyped tactics, they might be able to tolerate a very low information rate, or a very limited repertoire of messages, so that developing a satis-



A Victor-I class submarine displays her Park Lamp antenna (open loops on the aftermost mast). Although possibly usable for direction-finding, Park Lamp is almost certainly primarily a VLF receiver, usable at periscope depth, analogous to the U.S. Navy's loop antennas (originally radio direction-finders) of World War II. (U.S. Naval Institute)



A Golf-II-class ballistic-missile submarine shows her communications-buoy housing, abaft her sail. The tall sonar dome forward is an underwater telephone. (U.S. Navy)

factory secure and covert underwater communications system would be easier. The U.S. Navy appears to have been far less successful in this endeavor, perhaps because the more flexible U.S. tactics require much greater information exchange.

Radio Links Submarines currently rely on VLF. The standard mast-mounted VLF/LF receiving antenna is Park Lamp (which is often described as an ECM or navigational antenna). In addition, strategic and some tactical missile submarines (Charlie-II, Oscar) tow buoys, which are often carried in prominent housings. Of the new classes of attack submarines, Akula seems to be unique in towing a communications buoy. Many submarines (including all strategic submarines) also have satellite antennas (Pert Spring). Submarines operating the SS-N-12 and SS-N-19 missiles have been equipped with a radar satellite down-link antenna (Punch Bowl).

Bear-J aircraft function as strategic communications links analogous to the U.S. TACAMO. These aircraft entered service in 1985.

UNITED KINGDOM

Underwater telephones are listed under sonars.

UNITED STATES

◆ BRC-6 (XSTAT)

The Expendable Submarine Tactical Transceiver, a 2-way expendable buoy for UHF communication between a submarine and an airplane, is produced by Sippican. XSTAT is launched from a submarine signal ejector. After launching, a lifting body separates from the buoy, remaining attached to the submarine (and, therefore, to the terminal) by a 40-ft tether cable. Very fine wire (0.008-in diameter, up to 10,000 ft long) unreels from the flying body, maintaining a connection to the rising buoy. When the buoy reaches the surface, it deploys an antenna for 2-way radio voice communication. The buoy normally receives; it is placed in a transmit mode by keying the microphone on the submarine. The antenna itself is a quarter-wave ground-plane with 4 radials. It feeds from a battery useful for 45 min, but the life of the system is really controlled by the length of fine wire, which unreels as the submarine steams away from the nearly stationary buoy. Typically, the wire lasts for 8 min at 10 kt, or for 20 min at 4 kt.

This form of operation contrasts with that of the air-launched communications buoys described below, which are essentially

transponders, converting a submarine's acoustic signals into radio signals for air transmission, and vice versa.

◆ SLOT (AN/BRT-1)

Sippican's submarine-launched 1-way transmitter, a buoy launched through the submarine's signal ejector, carries a 4-min tape-recorded message (either voice or CW) and a radio transmitter. The message is recorded using a BRM-2 test set and can be checked by playing back through the buoy transmitter. SLOT can be set to delay transmission either by 5 min or by 1 hr, giving the launching submarine time to clear the datum created by the buoy. The buoy can function in sea-states up to 5, and it rises at 2 m/sec. Transmission is by VHF (on a sonobuoy frequency), and an aircraft or surface ship can command the buoy to turn off by using a UHF signal. The buoy then floats until sunk by its scuttle timing unit; selectable lifetime is 1, 3, or 8 hr. Dimensions are 3×39.12 in, and weight is 7.25 lb.

BRT-2 is a SLOT buoy manufactured by Electrospace.

◆ BRT-3 through -5

BRT-3, -4, and -5 are submarine-launched expendable buoys to provide improved bad-weather submarine identification and position. They operate for 30 min; each buoy transmits a characteristic tone: 300 Hz for BRT-3, 2700 Hz for BRT-4, and 900 Hz (pulsed, amplitude-modulated) for BRT-5. These devices date from 1974. All are launched from submarine signal-ejector tubes, which limit overall dimensions to 3×11.5 in (weight 1.4 lb).

◆ BRT-6

Hazeltine's 1-way UHF satellite communications system for submarines, consisting of a buoy launched from a standard 3-in signal ejector, carries a tape-recorded message and is usable up through sea-state 5. The satellite channel can be preselected (290–315 MHz). Data are transmitted digitally into the SSIXS system, and 1–15 transmissions can be made. The buoy is normally preset for 2400 bits/sec; alternatively, 75, 300, 600, 1200, 4800, or 9600 bits/sec can be selected. As with BRT-1, a message transmission delay can be selected (in this case in 5-min increments), with output selectable between 25 and 100 W. The buoy scuttles within 30 min after its final transmission. Dimensions are 7.6×103.1 cm, and weight is 4.4 kg.

This device was technically evaluated on board USS *Baltimore* and operationally evaluated on board USS *Sea Horse*; approval for full production (AFP) was granted in 1983.

There is also a Hazeltine submarine-launched 1-way satellite relay UHFSATCOM buoy (BRT-6). Work on a tethered 2-way UHFSATCOM buoy, comparable in concept to XSTAT (BRC-6), began under the FY89 program.

◆ Probe Alert

See SQS-26/53 sonar.

◆ OUTPOST

This Sippican-developed 2-way communications buoy uses a 20-km fiber-optic link in place of the fine wire of BRT-1. OUTPOST is now in advanced development at NUSC New London.

◆ SLATE

This submarine-launched UHF expendable transceiver buoy is launched through a 3-in signal ejector and connected to the submarine by a fine wire. SLATE is presumably an earlier alternative to BRC-6.

◆ SSQ-71

The air-dropped 2-way air-submarine acoustic-communications buoy (ATAC) can be tuned to 1 of 3 radio channels. It is in current production. This A-size buoy weighs 25 lb.

◆ SSQ-86

This A-size communications buoy (25 lb) is tunable to 1 of 99 RF channels.

◆ SUS

Sound Underwater Signal is a small device dropped by an airplane to send signals to a submarine. For example, SUS can indicate an emergency, telling the submarine to stay down; ask an unknown submarine to surface for visual identification; or act as a bell-ringer, asking the submarine to establish radio communications. The current version is the Sippican Mk 84 Mod 1, replacing the earlier Mk 64. An earlier version of SUS was the sound source in the Julie explosive echo-ranging system (see the ASW section).

Mk 84 can be launched at 100–10,000 ft, at speeds of 30–380 kt. It sinks at 14.5 ft/sec, spin-stabilized by its canted tail fins. The signal, which lasts 45–128 sec, consists of 2 tones (2.95 and 3.5 kHz), coded by pulsing for either 0.5 or 1.5 sec. The tones may alternate at 2 different pulse lengths, for 4 signals, or the SUS can transmit steadily at 3.5 kHz, for a fifth signal. The signal's source level is 160 dB. The desired signal is selected before launch by using a switch on the side of the SUS. Dimensions: 3 in × 15 in (6.5 lb).

◆ TACAMO

The national command link to strategic submarines is currently operating on board the EC-130G/Q aircraft, but the TACAMO's electronics are being transferred to the E-6As because they are hardened against EMP. The communications suite is designated USC-13; it receives over the VLF-to-UHF range and transmits in VLF, using a dual (long and short) trailing antenna. Messages are received from the navy's shore bases and from airborne national command posts (ABNCPs), via satellite and other emergency radio links.

The long trailing antenna is half the wavelength of the transmission; the short antenna, which is active, is trailed at a length tuned to that of the long reflector. About 35,000 ft of long and 5,000 ft of short antenna are available, but typically the long antenna is unreeled to a length of 16,000–20,000 ft. The signal is vertically polarized and can penetrate the sea's surface. Transmitting frequencies are 14–30 kHz.

The current upgrade program has 2 phases. Block I provides a high-power transmitter to ensure that the TACAMO aircraft can communicate with U.S. Air Force airborne national command posts over the central United States. It also adds a VLF/LF high-power transmitter and dual trailing-wire antennas to replace the current obsolete system. Block II improvements include provision for the E-6A to use the Milstar communications and GPS navigation satellites. The existing Verdin (VLF submarine communications) communications system (processor and modulator/demodulator) will be replaced in 2 phases. Phase I is a replacement to host the Phase II Enhanced Verdin System (EVS), which should improve communications performance. A new Compact VLF (CVLF) system will ultimately replace the current receiver/demodulator and transmitter/modulator (except for its high-powered elements) and the Verdin and EVS processors. A new high-power solid-state transmitter system (HPTS) will replace earlier 200-kW vacuum-tube equipment; HPTS is being developed for both the E-6A and the air force command posts. Block II also includes the TACAMO Message Processing System (TMPS). Full-scale development of these improvements was originally scheduled for FY90, with techeval/opeval in FY91. However, a cut in the FY88/89 budget pushed Block II into FY93, with the exception of the provision for Milstar.

The term TACAMO derives from the order to a submarine commander to "Take charge and move out." Work on the system began in 1962, and the 2 TACAMO squadrons became operational in 1968. The decision to upgrade to the E-6A was taken in 1977. Although escalating costs prompted some considera-

tion of cancellation, the contract for 15 new E-6A aircraft was awarded in 1986, and the first E-6A flew in February 1987.

◆ Towed Devices

U.S. submarines employ towed buoyant cables and towed buoys, both manufactured by Spears Associates. These devices grew in importance during the late 1970s and early 1980s because they appeared to be the best way to provide submarines with the sort of UHF receiving capability needed for full battle-group integration, i.e., the ability to receive Link 11 on at least an intermittent basis (the *Los Angeles*-class submarines, then being built, had been bought as battle-group escorts). UHF also became more important at that time because it was the frequency of the fleet satellite; by 1975 a program was underway to provide all submarines with WSC-3 UHF satellite receivers. The satellite system was so arranged that a submarine could request stored tactical messages at a convenient time, rather than having to put up an antenna for regular fleet transmissions as in the past). UHF does have 1 major drawback: it requires that the receiver be at or very near the surface. This consideration led to renewed interest in both cables and towed buoys.

The standard buoyant cable antenna (BCA) is 2000 ft long (1900 ft of it deploying cable), with a diameter of 0.65 in, allowing for reception at 10 kHz–30 MHz or at 10 kHz–200 MHz, depending on the version. The submarine can also transmit HF signals from the portion of the antenna near the surface. The antenna can be deployed either by an electric winch outside the pressure hull (the "Bustle" device demonstrated on board a U.S. nuclear attack submarine in the 1970s) or by a hydraulic unit inside the pressure hull (which is standard). The cable includes an in-line amplifier, which can operate over the 2–400 or 2–30 MHz range.

The main disadvantage of the towed buoyant antenna is that, as the submarine increases speed, the cable tends to stream directly astern. Since the antenna must lie at or very near the surface to be effective at high frequencies, it is usable (at those frequencies) only at relatively low speed. However, because it is a very broad band device, it can receive VLF signals at higher submarine speeds, when it is well below the surface.

The cables listed above are presumably outgrowths of the new antenna program of the early 1970s, which produced the BRC-2 in-line transceiver, $\frac{5}{8}$ in (0.675 in) in diameter. BRC-2 used twin hydrofoils and a stabilizing counterweight to keep itself at the surface; by 1975 it had demonstrated 2-way communication with an airplane at a range of over 100 nm while the submarine was running at 300 ft at 13 kt. In this case the antenna was a whip extended up from the cable; the antennas described above do not have any such elaborate fittings.

There are 3 standard towed buoys:

OE-305/BRR 97.5 × 30 × 24.38 in (height less fin); 41 in high including the fin; air weight 900 lb (buoyancy 750 lb); payload volume 2 ft³ (95 lb)

BRR-6 90 × 36 × 24.38 in; height 35.38 in including fin; 900/750 lb; 2 ft³ (95 lb)

BSQ-6 72 × 26 × 19.5 in; height 31.25 in including fin; 650/300 lb; payload 3 ft³ (200 lb)

All 3 are proof against 650 lb/in² of sea pressure. They are made of fiberglass-reinforced plastic, and their shape causes them to follow the contour of the sea surface at a shallow depth, to avoid broaching and thus revealing the submarine's presence. Buoys are typically towed at up to 15 kt, and they can contain both receivers and transmitters. BSQ-6 is presumably a descendant of the BSQ-5 buoy designed in the early 1970s as the Buoy Integrated Antenna System (BIAS), suitable for receiving VLF through UHF signals and transmitting HF through VHF. It was designed specially for towing just under the surface and, like its predecessors, was limited to 15 kt. Its new feature was that its body contained part of the transceiver electronics, thus minimizing significant line losses experienced at UHF frequencies

(the line from the submarine to the buoy operates at a lower frequency).

COMPUTERS

Modern digital computers have 4 basic elements: a processor, fast read/write data storage, program storage, and some means of input/output. In civilian machines, the contents of fast read/write storage is volatile, i.e., is generally lost when the machine loses power, but many military machines have nonvolatile running memories. Input/output generally includes a connection to some form of mass memory, in nonvolatile form. All of these elements are familiar to users of personal computers: the processor is the basic chip (e.g., an 8088); the fast storage is the RAM (random access memory); the programs actually being executed are stored with the data in the RAM; and the input/output channels are, typically, the computer screen, a printer, and the disk drives.

The computer memory is typically organized in words of fixed length (in bits, the binary digits whose value is either 0 or 1). Each word has its own address, and a program refers to the addresses of the data on which it operates. In theory, then, the maximum size of the memory (in words) is fixed by the largest address that can be written in the form of a single word. For example, the largest 8-bit word is 256; the largest 10-bit word is 1024 (1k). The largest 16-bit word is 64k. Some systems get around this limit, either by using longer address words or by dividing memory into pages, within each of which items of data can be separately addressed.

These limits do not apply directly to mass storage, in which data are organized in files (whose names, however, must generally be entered in a file directory). For example, a typical word-processing program, written for 8-bit computers, can accommodate up to 256 files in its mass storage. The length of each file is limited by the overall size of the mass storage.

Because address capacity is necessarily a power of 2, it is generally given in terms of k (units of 2 to the 10th power, 1024). It may be given as a number of words, bytes (units of 8 bits each), or bits. The standard NTDS word length is 30 bits, and some early computers were similarly organized. More recently the standard length has been an even number of bytes or half bytes ("nibbles"). The current standard is 32 bits.

In many cases a single word does not provide sufficient precision for calculation. Therefore, many machines have a provision for double-precision arithmetic, in which numbers are represented as pairs of words. In the past, the distinction between "scientific" and "business" computers was generally a distinction between machines that could or could not execute double-precision arithmetic. This distinction carries over to the math coprocessors, which generally calculate in terms of longer (multiple-precision) words.

Most of the machines described here employ bit-slice processors, capable of handling data in slices shorter than entire words. Typically, there are separate 2-, 4-, and 8-bit processors, so that the processor as a whole can handle anything between 4 and 32 bits. Bit slicing makes for higher speed when less than full precision is needed, but it also makes for complicated programming.

Computer hardware has developed through 4 fairly well defined generations. First, in the early 1950s, came vacuum-tube machines, which required considerable volume for their processing elements. Many machines of this generation had magnetic-drum storage, in which data were stored as magnetized spots on the surface of a revolving drum. Typically, the drum might rotate at 3600 rpm, so that the average bit could be read at an interval of 17 msec. Drum memory was compact and rugged (if slow), and it persisted into the 1960s in military applications, such as the computer of the A-6 Intruder. By the late 1950s drums were being replaced by magnetic (ferrite) core memories, in which each bit of data was stored in terms of the direction in which a small ferrite ring was magnetized. Core memory was much faster than drum memory and was also

much more flexible (since each core could be addressed independently and randomly), but it also required considerable volume, since (at least at first) each core was about $\frac{1}{16}$ in in diameter. Moreover, each little ring had to be wired by hand. Total memory size was quite limited. Typically, a magnetic core took 1 microsec to read, a considerable improvement over the more compact magnetic drum. A typical vacuum-tube computing speed was 40,000 operations/sec (0.04 Mops), i.e., a typical operation would require 25 microsec.

By the late 1950s it was clear that transistors offered a much more compact and much more reliable alternative, a second generation. The earliest solid-state computers appeared in 1959, using magnetic-core memory. These machines use *discrete devices*: individual transistors and other electronic components are separately wired into the machine. A typical large transistor machine might be capable of 200,000 operations/sec (0.2 Mops), i.e., a typical operation would require 5 microsec.

Transistors and their associated devices could be combined into compact integrated circuits, manufactured as units. The integrated circuit was invented in 1958. The results of this small- or medium-scale integration could be wired into compact (third-generation) processors. A typical large machine might be capable of 1 million operations/sec (1 Mop), i.e., about 1 microsec/operation. The U.S. UYK-7 fits into this category.

Integration made possible the production of memory units far more compact (as well as faster than) magnetic cores. Semiconductor memories first appeared in the late 1960s. In 1970 Fairchild introduced a single chip, the size of a core, that could hold 256 bits of memory, each readable in only 7% of the time it took to read a magnetic core (i.e., 70 nanosec). Four years later the cost per bit of such memory fell below the cost of magnetic cores. Single memory chips can now accommodate as much as 1 Mbit of random access memory.

Core did have one advantage. It held its magnetization even when power was lost, whereas the successor semiconductor memory is volatile (memory vanishes when power is lost, as many users have found to their dismay). For that reason the use of core is often equated to military suitability. In machines that have to be too fast to afford core memories, some form of reliable fast mass memory is needed, so that the contents of the read/write memory can be saved periodically. Military computers commonly also incorporate backup battery power supplies, so that main (read/write) memory can be saved in the event of power failure. Even so, in some cases any power interruption makes it impossible for the associated combat-direction system to keep track of the tactical situation. Moreover, it takes some time to restart the system, during which the tactical situation may have changed too much for much correlation between the saved tactical picture and the real one.

Mass memory is nonvolatile, but it is also much slower than fast internal memory. The classic forms of mass memory are tapes and magnetic disks, but both are sensitive: at one time it was notorious that the shock of catapult firing would often disable the tape cartridge of the AYK-10 mission computer of the S-3A. A current solution to the problem is magnetic bubble memory, which is reasonably fast, is nonvolatile, and has no moving parts vulnerable to shock.

An integrated processor is much smaller than one built of discrete devices. One consequence of integration, then, was the development of a class of small desktop machines, minicomputers, with performance similar to that of the large second-generation machines. The first such machine was the Digital Equipment Corporation PDP-8, first delivered in 1968. The U.S. naval example of this technology was the UYK-20 of 1974.

The next development was large-scale integration (LSI), which made it possible to produce an entire computer (a central processor) on a single solid-state chip, a microprocessor. Typically, LSI is defined by the ability to place 1000 components on a single chip. The next step, VLSI (very large scale integration), is an order of magnitude more compact (10,000 components/chip), and 100,000 devices/chip are not unusual in current ma-

chines. Such processing chips made modern microcomputers (such as personal computers) possible. The first integrated-chip computer, the Intel 4004, appeared in 1971. The first general-purpose microprocessor, the Intel 8080, appeared in 1974, and it in turn powered the first generation of personal computers (microcomputers). Many single-chip processors (8086, 80386, and 68000 series) are employed in current naval devices, and they are described in the U.S. section below.

The processor generally runs much faster than the main memory. From the early 1970s on, a solution to this mismatch was to provide a *cache* of very fast memory at the main processor, to store the next few instructions as well as a limited amount of data. In a typical large commercial computer, an IBM 3090 (1985), the processor cycle time is 18 nanosec (0.018 microsec), but the main-memory cycle time is 200 nanosec; the machine has a cache with an 18-nanosec cycle time. Main memory in this particular machine is 64–128 Mbytes; the cache is 128–256 Kbytes.

Speed *within* the chip depends on the size of the chip (smaller size means shorter electrical connections) and also on the type of device employed. Much current work is going into a combination of VLSI and increased computing speed, VHSIC (very high speed integrated circuits).

Evolution has been very rapid, one rule of thumb being that the number of devices on a chip doubled annually in the 1960s. The rate declined in the 1970s, but it still quadrupled every 3 years. For all of this period, the price per chip remained virtually constant because the process of chip production is akin to printing. It may be expensive to produce a master, but the unit cost of reproductions is low. The most expensive part of computer production, then, is the physical assembly of the chips. The greater the power per chip, the less the work of assembly and the less expensive the machine, as numerous private users well know.

The balance between hardware and software costs has shifted dramatically in recent years. In the 1960s about 75% of total U.S. Defense Department computer spending went to hardware. By the mid-1980s the proportion had more than reversed: 80–85% went to software. As long as most of the cost of a system was spent on hardware, the cost of additional units was basically a multiple of the cost of any single unit. Software, however, is very easy to reproduce (as many software manufacturers have discovered, to their cost). Total software cost is, therefore, virtually the same whether the software is used for 1 unit or 1 million. If software development is the bulk of total system cost, then, it is inexpensive to increase numbers. This change should begin to affect overall policy as very inexpensive hardware enters service in increasing quantities. It seems likely that the mass retirement of earlier-generation ships and aircraft, due to the defense cuts of the early 1990s, will make the new trend apparent in the major Western navies. Until now the presence of large numbers of earlier-generation machines has obscured the economics of the newer machines.

Numerous examples of early solid-state computer technology remain in service, even though much less expensive alternatives exist (or have existed for many years). Perhaps the main reason is that navies still treat computers as major capital items, as indeed they certainly were during the analog and early digital eras. Existing machines represent sunk costs, and they are adequate to their roles. Replacement would require considerable new expenditure, particularly in the case of very widely used machines. A second, and quite important, factor is the high cost of rewriting software for newly acquired machines. In some cases the newer machines are designed specifically to run software developed (and tested) for their predecessors. This is called upward compatibility.

Much depends on the logical organization of data flow within the computer. The central processor itself handles only 1 instruction at a time. If it must also handle input and output, then it must pause to execute those commands as well. In a fast machine, therefore, the central processor may feed its data into an intermediate device. With the data will come an output com-

mand that the device can execute to shunt the data into the appropriate channel. The greater the decentralization of the system, the faster it can run.

A single fast central processor, then, can share its time among numerous output channels. Each channel can be assigned its own series of program commands, the central processor executing a slice of the program associated with 1 channel before shifting to the next. In the early 1970s this time-sharing operation was sometimes called parallel computing (later it was called multitasking). Such an organization made it possible for a single computer to execute numerous relatively simple programs; each user would see its channel as a separate computer. However, time-sharing is inherently inefficient, in that time is lost each time the central processor shifts programs (and saves the last program's data until the next time they become relevant). In many tactical applications the results of 1 calculation may be relevant to another. Other applications may require so much sheer power, expended in repetitive calculation, that any form of time-sharing is unacceptable. As machines have become much more powerful, time-sharing has returned in a slightly different form as the creation of "virtual machines."

In theory, the different virtual machines (run by the same software) can reside in 1 or in several processors. The failure of any one processor will not bring down the system since the program normally run by that processor can be run instead on a virtual machine hived off from another, at a sacrifice in overall speed. Ultimately one processor can, in theory, carry the system load. The Ferranti System 500 command/control system exemplifies this approach.

Whether time-shared or not, the central processor follows a single path through its program. It is a *serial* processor, in that each program step must await the execution of the step before. Overall computing performance, then, depends on how quickly each of those steps can be executed. However, there are computing problems in which some of the steps do not depend upon previous ones; they must be executed whatever the result of the other steps, or the other series of steps. An example would be the addition of a pair of vectors, in which each element of the resulting vector (represented as a series of numbers) is the sum of the corresponding pairs of numbers from the 2 original vectors. Each pair must be added, whatever the result of adding any other pair. Many kinds of signal processing can be represented by such repetitive, parallel arithmetic. Another parallel process is scanning a data base for matching data.

Some machines are pipelined. A pipeline is analogous to a production line, in which different stages of production can be conducted simultaneously, the products going from 1 to the next. Pipelining can, for example, be used by a time-shared (multitasking) computer to prepare for the next set of tasks while 1 set is being executed, the data for the next set being extracted from main memory while the processor is otherwise occupied. The Signaal SMR-4 exemplifies this approach. A simpler form of pipelining is to fetch and set up the next instruction while the last is being executed, on the theory that fetching and preparation take less time than actually executing.

The next step in parallelism is to provide multiple central processors, each computing independently. Current examples are the Loral Aspro and the British Inmos Transputer chip.

In many cases, elements of the computer are connected by data bus rather than by hard (direct) wiring. Just as in other applications, the bus carries all the data produced by and for the elements it connects; the elements strip messages they need out of the stream based on addressing information. Such stripping action becomes more practical as individual computer elements become less expensive and more compact.

A modern computer will use data busing on 3 distinct levels. The highest, involving the fastest flow of data, will connect the processor and the fast memory. In a personal computer, for example, this kind of bus or connection will exist within 1 circuit board. Each board will use this very dense stream of data to produce output at a slower rate. The boards in turn will be connected by a bus within the computer. In a minicomputer

cabinet, this board is the *backplane bus*, so called because it often runs up the back of a cabinet, in which cards are inserted horizontally. It is exemplified by the VME bus in many 68000-series machines. Finally, the computer itself may feed into a large-scale bus. This organization mimics that in some combat systems, in which the tactical data-handling computers are connected by a local-area-network bus, which itself feeds into a weapon/sensor bus.

The program is stored in memory as a series of numbers, indistinguishable from data. Individual instructions consist of a numerical code (which the processor interprets from a special read-only dictionary), and the addresses of the 1 or 2 pieces of data being processed. The richer the repertoire of machine-language instructions, the easier it is to program the computer to carry out a given task. On the other hand, the richer that repertoire, the longer it takes the processor to look up the particular instruction it is to execute. A paucity of machine-language instructions can always be made up for by more elaborate programming. There are 2 current alternatives: machines using increasingly elaborate instruction sets made practicable by larger-scale integration and machines with drastically simplified instruction sets. The latter are called RISCs (reduced-instruction-set computers); they are typified by the 88000-series RISC chips described in the U.S. section below.

An alphanumeric form of machine language, directly translatable into numerical form (but much easier for a programmer to read), is called assembler language, the assembler being the translating program that translates between alphanumeric and numerical form. For example, the machine may read 4B (B is a hexadecimal number equivalent to 12) as the command to add; the programmer finds it much easier to read ADD. In many cases, a processor may be *microprogrammed* to emulate some other machine, so that existing software need not be rewritten. Each instruction is read, interpreted into the machine's own language, and then executed.

Major programs are not written in machine or assembler language, but rather in a higher-order language, more akin to English or to mathematical notation. The U.S. Navy standard is CMS-2. Such programs are translated into machine language by intermediate programs called compilers. The high-order version of a program is written in relative terms; it does not refer directly to the addresses in memory to which the machine-language program must assign particular pieces of data. At compilation time, all such assignments are made automatically. Revision to the program generally requires recompilation because revision will generally involve reassignment of addresses. Compilation is generally inefficient; a compiled program can often be edited to fit limited space and time. Such editing causes problems when the basic program is modified since memory allocations will have to change. As a consequence, although large programs are generally written in terms of independent modules, the machine-language versions of such programs lose their modularity, and hence are difficult to modify piecemeal.

As machines become faster, inefficiency in programming becomes less significant, so postcompilation editing becomes less important. It becomes possible to envisage the use of a single universal high-level language, and thus the development of a series of standardized building-block programs. A system written in such a high-level language should be transferable between different computers. This is not a new idea, but it has become much more practicable with current computer performance. The U.S. Department of Defense has adopted such a language, ADA (named after the Countess of Lovelace, the first programmer, who worked with Charles Babbage in the nineteenth century). ADA is based on a standard commercial language, Pascal.

ADA was conceived by a Department of Defense working group formed in January 1975; a series of alternative languages was tested in 1975-78 under the code names Strawman, Woodman, Tinman, Ironman, and Steelman. The Steelman language, based on a French language developed by CII-Honeywell-Bull, was chosen; and the basic U.S. reference document on ADA was released in July 1980. ADA is also currently the standard

language of new British and Swedish defense software. It is supported by compiler projects in Denmark, Israel, Spain, and West Germany. Much recent effort has gone into developing and testing (verifying) efficient ADA compilers; advertising for particular machines often mentions that verified ADA compilers exist for them.

The promise of ADA has not always been fulfilled; its compiled programs are still somewhat inefficient (editing would negate the central feature of ADA, the transportability of its software). In one case, a program written in ADA produced 4.5 times as much code (when it was compiled) as a comparable program written and edited in assembly language. The new computer, for which the program had been rewritten in ADA, was not fast enough to make up the difference (it was only 3 times as fast as its predecessor). In this case, 2 computers had to be bought to replace a single older, slower one. The moral is that raw computer speed is not in itself a sufficient measure of overall system performance. On the other hand, once the program had been written in ADA, it could still be used when a much faster machine became available. The adoption of ADA is an expression of faith that brute computing power will ultimately solve the inefficiency problem, and that the important efficiency is transportability of software, i.e., that software is the current and future bottleneck.

Like their civilian counterparts, naval computers fall into 4 basic families: supercomputers, mainframes, minicomputers, and microcomputers. The naval equivalent of a supercomputer is a specialized signal processor, usually for sonar; such machines are described in the ASW section. The mainframes are the central computers of command/control systems, and sometimes they are used in other systems as well. Typically, minicomputer equivalents are used for local processing, although distributed command/control systems are sometimes built up entirely from them. Microcomputers comparable to civilian personal computers are found in many "intelligent" displays, and many current computers are built up from standard microcomputer processor chips.

There are also naval equivalents of civilian workstations. A workstation is a much more powerful alternative to a microcomputer, equivalent in power to a minicomputer. A workstation tends to be oriented more toward graphics; a typical civilian application is to computer-aided design or manufacturing. In a naval system, the workstation or microcomputer will often function as a terminal (console) within a larger system. Given the processing power required to support the newer displays, it is sometimes difficult to distinguish between a "smart" display (which may be equivalent to a civilian workstation) and a dedicated computer. In this book, workstations are described under tactical data-handling systems or, in some specialized cases, ASW. In some cases of distributed processing, such as the U.S. JOTS and TFCC, the workstations are the main computing elements; there is no central computer at all.

Moreover, newer mini- and even microcomputers may greatly exceed the performance of older mainframe units still in service, even still in production (because of the high expected cost of replacing the relevant software). One important distinction, which is apparent in the characteristics listed here, is the number of input/output channels. The main computer of a combat-direction system must accept inputs from several different devices, and it must interact with several consoles. A civilian minicomputer or a microcomputer will generally have only a very few input/output channels.

In the computer descriptions below, machines are generally credited with 16-, 24-, 30-, or 32-bit words. In many cases the actual stored word is 2 (for 16-bit machines) or 4 bits (for 24- and 32-bit machines) longer, the extra bits being used to check against transmission errors within the computer. In one case (UYK-43 with HBM), 7 extra bits are used (4 for parity, 3 for scheduler and block selection). The parity check bits have no computational significance, so they are normally not counted in calculations of memory capacity. The 30-bit standard was chosen to match the Link 11 message format, the 24-bit format

to match the alternative Link 10 or Link X. More modern machines have adopted the commercial standards of 16 and 32 bits (2 or 4 bytes) and of hexadecimal (base 16) internal organization.

Current naval minicomputers and workstations are generally built around a standard data bus (backplane bus), VME (originally versatile memory Eurocard, IEEE 1014), 32 bits wide, with a capacity of 40 Mbytes/sec. The U.S. Navy has adopted the Futurebus (IEEE 896) as its next-generation standard. Bus width is 32–256 bits, and capacity is 100–800 Mbytes/sec with the current (1990) protocol. By 2000 capacity should be 200–2000 Mbytes/sec, using a new packet protocol, in which data are sent in blocks (packets) for faster reading by devices on the bus. Futurebus has so much more capacity than is currently needed that one manufacturer, Ferranti, calls it the first bus architecture designed to support multiple generations of technology.

Finally, a note on high-level computer languages. The principal ones mentioned below are ADA (see above), Algol, Fortran, JOVIAL, and Pascal.

Algol (Algorithmic Language) was developed in the late 1950s (formally defined in 1960) specifically to express algorithms (series of operations) rather than single formulas; compared to the earlier Fortran, it has more compact ways of specifying paths through a program (e.g., loops and decision points). Algol was also designed for a more modular form of programming than Fortran.

Fortran was the first high-level calculating language; the name means Formula Translation. It first appeared in 1954 and is similar to the Basic language, which many machines now use.

JOVIAL (often JOVIAL 73) is a U.S. Air Force language, originally Jules' Own Version of the International Algebraic Language (Algol). Jules was Jules Schwartz of the System Development Corporation.

Pascal is an Algol-related language developed in the early 1970s. It was conceived for teaching purposes, as a demonstration that programming could be made systematic, and is specifically designed to detect programming (coding) errors. The original Algol is a subset of Pascal.

The computers described in this section are characterized by their word length, their memory capacity (generally, but not always, in terms of words), their speed, the size of their instruction set, and the number of their I/O channels. Speed is somewhat difficult to characterize in comparable terms. Ideally, computers could be compared in terms of some standard complex operation, such as compilation of a number of on-board and off-board tracks, but in fact command/control systems differ radically in the demands they place on their embedded computers. The speeds listed *are not* the clock rates so often listed for personal computers. A computer clock provides timing impulses, but instructions often require several ticks of the computer's clock. Similarly, the significance of the number of individual instructions in the computer's set is somewhat ambiguous since much depends on the details of the instructions. The number is a measure of the flexibility of the processor and, therefore, of the complexity of programs using it. Instruction sets have become considerably more complex as solid-state components have become smaller and less expensive; quite standard machines of the 1960s and 1970s often had fewer instructions than machines now characterized as special RISC types.

CANADA

The software of the pre-SHINPADS Canadian combat systems is written in NELIAC, a language developed by the U.S. Naval Electronics Laboratory at San Diego in the early 1960s.

◆ AYK-502

The AYK-502 is the tactical computer of the CP-140 Aurora maritime-patrol aircraft and is the Canadian version of the U.S. AYK-10.

◆ USQ-501

Word Length: 32 bits

Memory Capacity: 40 kwords, expandable to 80k

This is the Litton L-304F computer of the Canadian CCS-280 command/control system; the same computer is used in the U.S. E-2C.

◆ UYK-501

Word Length: 25 bits

Memory Capacity: 4 kwords, expandable to 32k in 4k modules

Speed: memory cycle time, 2 microsec; add/subtract time, 8 microsec; multiply time, 110 microsec; divide time, 118 microsec

Instructions: 110 **I/O Channels:** 64

A CDC minicomputer, UYK-501 is used by the Canadian Navy for fire control and tracking and also by the U.S. Navy. UYK-501 entered service about 1967 and is presumably the basis of the Canadian ASROC fire-control system.

◆ UYK-502/UYQ-503/UYQ-504

UYK-502 is a less militarized version of UYK-505 (see below) with a fast semiconductor memory in place of the slower core memory, used primarily to drive displays. Memory capacity is 16–256k in 16/64 kword (16-bit words) increments. The machine can accommodate 4 types of memory: dynamic NMOS RAM (65k modules), core (64k module, can be combined with NMOS RAM in 192k modules), CMOS static RAM (16k modules), and RAM/PROM (4k/12k combinations, 16k total). Typical operating rate is 240 KOPS. There are up to 64 I/O channels. A circuit card can accommodate 1 full duplex fast NTDS channel, 1 full duplex ANEW channel, 1 full duplex slow NTDS channel, 1 full duplex NATO serial, 4 full duplex 188C serials, or 4 full duplex RS-232 serial channels. UYK-502 began as an internal Sperry (UNISYS) Canada program for a low cost processor (LCP) compatible with UYK-20 for noncritical tasks. It was selected by the Canadian government as a primary computer for many Canadian systems, including the SHINPADS combat-direction system.

UYQ-504 is a UYK-502 with a SHINPADS embedded node, so it can be integrated into a SHINPADS system. UYQ-503 combines the SHINPADS nodes and the UYK-502 processor in a single unit. It is a joint project with UNISYS (U.S.) and began late in 1988.

◆ UYK-505

UYK-505 is a Canadian UNISYS-manufactured version of the U.S. UYK-20A, which has memory expanded over that of UYK-20 (160 kwords, expandable to 256k). It is the main computer of the SHINPADS combat-direction system of the Canadian "City"-class and "Tribal Update" (TRUMP) frigates and is the basis of the ADLIPS 90 CDS. The UYK-20A design dates from about 1980 and was roughly simultaneous with that of UYK-502 (above).

◆ UYK-507/UYQ-505

Word Length: 32 bits

Memory Capacity: up to 4 Gwords, see below

Speed: 5 MIPS **Instructions:** 516

I/O Capacity: 16 modules (see below)

UYK-507, introduced in 1990, is intended to supersede the UYK-502/505 series in such naval systems as SHINPADS. It uses some UYK-44 technology but is a separate development. Existing UYK-502/UYQ-504 computers will be upgraded since their cabinets can accommodate the new cards. UYK-505s will be replaced since their UYK-20 cabinets are not compatible. A UYK-507 can emulate a UYK-44 or -502. It is a hybrid, combining new electronics with an old existing cabinet. Consequently, it is much less expensive than a new UYK-44 (but also less rugged, particularly against threats such as EMP and TEMPEST).

Versions: (V)1 is a newly built computer, (V)2 a refurbished UYK-502 or UYQ-504 with fewer slots. As of 1990, the first 6

"City"-class frigates are to receive (V)2s (they have already had their SHINPADS installed), but the last 6 will be fitted with newly built machines. Other possible applications include the data loader/dumper for the new Canadian naval helicopter.

UYQ-505 is a SHINPADS node embedded in a UYK-507, analogous to UYQ-504.

The computer consists of a series of circuit boards connected by buses. The central processor lies on a 32-bit common bus, which also carries the memory interface and the I/O processor, and which can accommodate a coprocessor (for future growth). The I/O processor feeds a separate RMF (reconfigurable modular family, for SHINPADS cards) bus connected to a series of interfaces and to an embedded SHINPADS node set (UYQ-505). Thirteen different types of I/Os can be accommodated, including NTDS fast and slow, NTDS serial, NATO serial, and A-NEW. I/O is in modules; the computer can accommodate up to 16 modules and up to 64 channels.

The processor can directly address 4 Gbytes of memory. It includes an Expanded Memory Reach (EMR) set of registers, to address further memory (up to 16 Gwords) by paging, with 256 groups of 64-page registers for code and 256 groups of 64-page registers for data. The processor uses a 64-kbyte cache memory.

The minimum configuration is 256 kwords of semiconductor RAM plus 2 kwords of bootstrap EEPROM (for start-up). It can be expanded by another 256 kwords of semiconductor RAM or EEPROM, plus 512k-8M words of RAM in 512-kword increments. The much larger number of directly addressable words refers to mass memory. The processor is pipelined. The instruction set is described as ADA-friendly; it includes instructions beyond those in UYK-44, specifically designed for easy compilation of ADA programs.

Cabinet dimensions are 17.5 × 19.0 × 18.5 in (total weight 116 lb).

FRANCE

The standard military programming language is LTR (Pascal derivative).

◆ IRIS 35M

Word Length: 16 bits

Memory Capacity: 16-256k bytes (ferrite cores); increments are 16-64k bytes (each of 3)

Speed: memory cycle time, 1.6 microsec; add/subtract time, 5.4 microsec; multiply time, 14.1 microsec

Instructions: 58 **I/O Channels:** 34-36

This was the smallest of the IRIS computer family, made by CII (Compagnie Internationale pour l'Information, now part of the Thomson group); it was proposed for the small-ship version of SENIT about 1969. It was used in the Pluton tactical-nuclear-missile system; in a land-based command system, ATAC; and in the DLT 4 submarine FCS. IRIS 35M is software-compatible with other IRIS-series computers, such as IRIS 55M (described below). IRIS 35M could be equipped with up to six 1-Mbyte magnetic-disk mass memories. MTBF was 4000 hr.

◆ IRIS 55M

Word Length: 16 bits

Memory Capacity: 512 kbytes, in 32-kbyte increments

Speed: memory cycle time, 1.2 microsec; add/subtract time, 2.5 microsec; multiply time, 5.3-7.7 microsec

Instructions: 80 **I/O Channels:** 24

Made by CII (now part of Thomson-CSF), IRIS 55M was the first French SENIT computer, all previous versions having used U.S. computers. Input/output channels include an NTDS channel (1300 bytes/sec) and a multiplexing channel (which can accommodate 8 external connections) with a rate of 400 bytes/sec. Direct input/output is in 16-bit words, and there are 4 independent memory accesses.

◆ MLX Series

These are new (1989) military (including naval) computers produced by the CIMSA Sintra Division of Thomson-CSF. They

are built around the standard Motorola 68020 microprocessor (future ones will use the 68030, and others planned will incorporate the 88000 RISC chip). The internal bus is the VME, and the operating system is the Unix Series V. MLX 32/20 is based on the 68020 chip (3 MIPS); MLX 32/30, with the 68030, will run at 4 MIPS (clock rate will be 25 MHz).

◆ 15M/05

Word Length: 16 bits

Memory Capacity: 32 kwords, expandable to 64k

Speed: typical instruction time, 1.2-1.8 microsec

Instructions: 98

CIMSA's minicomputer is typically used for signal processing. It is supplied in board as well as chassis form.

◆ 15M/125

Word Length: 16 bits

Memory Capacity: 128 kwords, expandable to 512k

Instructions: 128

These are CIMSA minicomputers. The 15M/125F version has a fast arithmetic processor. The 15M/125S version is used for space applications and has a 64k-memory capacity; it has 135 instructions. The 15M/125X version is the main computer of the Atlantique 2 patrol aircraft. Unlike the earlier machines, it uses 32-bit words. Memory capacity is 1 Mbyte (much the same as in the /125), and throughput is 1 MOPS. The first airworthy prototype was delivered in 1986.

The 125 and 125S versions are made in both full- and half-chassis versions; 125X is made only in a full-chassis version. The 15M/125X version is the one used in the new missile destroyer *Cassard*.

ISRAEL

The 32-bit Elta EL/S-9000 is the standard naval mainframe computer. Throughput is 8.4 MOPS.

◆ EL/S-8600 Series

Word Length: 16 bits

Memory Capacity: 64 kbytes, expandable to 2 Mbytes

Speed: load, 1.34 microsec; add/subtract, 0.66 microsec; multiply, 6.56 microsec; divide, 9.26 microsec

Instructions: 90

These are standard Elbit 16-bit computers for air, land, and sea applications. Data apply to EL/S-8610, which has 15 modules. Another member of the family, EL/S-8611, has only 4.

ITALY

◆ CDG-3032

Word Length: 32 bits

Memory Capacity: 128 kwords (4 memory modules)

Speed: memory cycle, 0.7 microsec; half-word memory cycle, 0.15 microsec

Instructions: 112 **I/O:** 4 modules, 250 kwords/sec/channel

This Selenia machine is the main computer of the IPN series. It was introduced about 1973. Memory is semiconductor (MOS), and operation can be in full- or half-words (16 and 8 bits). The memory can be addressed simultaneously by the main processor and by the I/O channels.

◆ MARA series

Word Length: 16 bits

Memory Capacity: up to 16 Mbytes

Speed: 0.8 MIPS

The acronym of these Selenia computers stands for Modular Architecture for Real-Time Applications. The main naval version is MARA 286, i.e., MARA using an 80286 microprocessor. Data above apply to the version using a single such processor; there are also MARAs with 2 or 3, with maximum memory capacities of 24 and 32 Mbytes and with throughputs of 1.6 and 2.4 MIPS.

MARA can be fitted with circuit boards for a RISC unit, for a bubble memory, and for either a multiprocessor or a mono-

processor application. Other boards can connect it to either an Ethernet or a Selenia MHIDAS bus.

The airborne version of this machine is SL/AYK-204/1; 204/2 and /3 are the multiprocessor versions. SL/AYK-203 is a slower version (0.3 MIPS), using an 8086 processor, with a maximum memory capacity of 1 Mbyte.

◆ NDC-160/E

Word Length: 16 bits

Memory Capacity: 64 kwords (core or semiconductor)

NDC-160/E is the standard computer of the Italian SADO and related systems; it is being superseded by the MARA series described above. There are 2 operating systems, a Disk Operating System and a Time-Sharing Executive.

NETHERLANDS

JOVIAL is the high-level language for the SEWACO systems.

◆ SMR

Word Length: 24 bits

Memory Capacity: 8 kwords (0.5-mm ferrite cores); maximum 64k

Speed: load or store word, 2 microsec; memory cycle time, 1 microsec; add/subtract time, 2 microsec; multiply time, 12 microsec; divide time, 22 microsec

Instructions: 60

I/O: autonomous control; maximum transfer rate, 168 kwords/sec

SMR is the main computer of Signaal SEWACO/DAISY systems. The first unit was delivered in 1970 to a program generation center. The SEWACO I unit, for the *Tromp* class, was first delivered in 1973; it is the 64k version. A 24k version was offered in 1975 for a weapons system including a twin Bofors 12-cm gun, Exocet missiles, NATO Sea Sparrow, and a WM25 fire-control system. The 32k version was delivered to Canada in 1970 for ASWDS (together with two 24k units, presumably for training). The Belgian frigates' SEWACO IV system (1974) uses the 64k version.

SMR (and the later Signaal computers) uses bit-slice arithmetic, in which the 24-bit word is broken down into six 4-bit subwords that are processed in parallel.

In 1971 Signaal estimated MTBF as 4000+ hrs. In a typical 24k configuration, SMR weighs 310 kg; dimensions are 53.5 (wide) × 62 (deep) × 169.7 cm (high). SMR means Signaal Micromin Reckoner (computer).

◆ SMR-4

Word Length: 24 bits

Memory Capacity: 1 Mword internal, 1 Mword external

Speed: memory cycle time, 0.416 microsec; effective cycle time with pipelining and interleaving, 0.250 microsec (can be as little as 0.166 microsec) **Instructions:** 273

I/O: up to 256 peripheral devices; maximum rate 230 kwords/sec; up to 1 Mword/sec with DMA

SMR-4 is the latest Signaal mainframe computer, the basis of the current versions of the SEWACO or STACOS combat-direction systems, e.g., in the Turkish MEKO frigates. It is a development of SMR-MU; the -4 indicates fourth generation in the Signaal series (SMR/SMR-S, SMR-S1, SMR-MU, SMR-4).

The main processor is designed for multiprocessing (time-sharing). There are 16 levels of process priorities, and for each level there is a 256-entry register. Each process (i.e., each time-shared program) is defined by hardware context (the contents of 11 process registers), software context (e.g., 2 process stacks), and the setting of the memory-management unit (MMU). The contexts and the MMU settings are saved when the processor switches to the next process. SMR-4 incorporates memory pipelining to reduce the waiting time involved in reading memory during the shifts from process to process. Memory is organized into 16 logical pages/process, each of 4k, 16k, 18k, 32k, or 64k words.

The memory bus, which connects the central processor to the main memory, can also be connected directly to an Ethernet LAN (in a combat-direction system) and to direct memory ac-

cess (DMA) controllers; external devices can also be coupled directly to the memory bus. There is a separate input/output processor that transfers data to and from the main memory without direct reference to the main processor. Memory access by the application software is controlled by the MMU, which also prevents illegal access to specified parts of the memory (e.g., to provide special protection to specially classified data).

Signaal estimates the MTBF as 2653 hrs; MTTR is 5 min, using line-replaceable units. Weight is about 23 kg; dimensions are 176 (width) × 536 (height) × 672 (depth) mm. SMR-4 was announced in 1987.

◆ SMR-MU

Word Length: 24 bits **Memory Capacity:** 16–64 kwords

Speed: memory load time, 2.25 microsec (12 microsec for double precision); add/subtract time, 2.25 microsec (16.125 and 16.875 microsec in double precision); multiply time, 11.25 microsec (19.875 microsec in double precision); divide time, 10.875 microsec (19.5 microsec in double precision)

Instructions: 146

I/O: up to 62 devices can be connected; maximum I/O rate 120,000 words/sec; maximum DMA rate 400,000 words/sec

Announced in 1978, SMR-MU is a minicomputer superseding SMR-S and is upwardly compatible with the earlier machine (i.e., it can run programs written for SMR-S, but SMR-S cannot run some SMR-MU programs). DMA is optional; it allows a high-data-rate device to be connected directly to the memory. The higher-memory version can have 48 kwords in either 16k modules of read/write memory or in 4 kword modules of PROM (i.e., permanently programmed read-only memory). An earlier version had a basic 4 kword configuration, expandable to 64k, with the 60k in 4k read/write memory modules or else in 4k PROM modules. This version was credited with 151 instructions. In the latest version (1984) the basic configuration is 64 kwords, and the maximum is 2 Mwords, addressable in 8k pages. In 1979 Signaal estimated MTBF as 21,000 hr for the 16k version.

◆ SMR-S

Word Length: 24 bits

Memory Capacity: 4k, expandable to 64k in 4k modules (RAM or ROM)

Speed: load or store word, 4 microsec; add full word, 4 microsec; multiply, 16 microsec; divide, 28 microsec; sin/cos (optional), 8 microsec

Instructions: 56

I/O: 6 channels (up to 64 peripheral devices); data transfer rate 100 kwords/sec

SMR-S is a minicomputer derived from the SMR, using the same word structure, the same instruction set, and the same flexible I/O system. The memory is solid-state MOS (Intel 1k chips) rather than ferrite cores. SMR-S was introduced in 1973. At that time Signaal estimated MTBF as 13,000 hrs. SMR-S weighs 20 kg, and its power supply adds another 20 kg.

◆ SMR-S1

Word Length: 24 bits

Memory Capacity: 4 kwords, extendable to 64k in 4k modules

Speed: load or store, 2.7 microsec; add, 2.7 microsec; multiply, 10.7 microsec; divide, 18.7 microsec; trigonometrical functions, 8.0 microsec (optional)

Instructions: 56

I/O: autonomous I/O control; maximum transfer rate, 150 kwords/sec; HSDC rate, 700 kwords/sec

Introduced in 1975, SMR-S1 is a faster replacement for SMR-S. An optional High-Speed Data Channel (HSDC) allows direct connection of a device with a high-data rate to the memory. Memory is solid-state. Signaal estimated MTBF at 13,000 hr. The mainframe, including 32 kwords of memory and 6 I/O channels, weighs 20 kg. Dimensions are 170 (wide) × 600 (deep) × 540 (high) mm, matching those of the earlier SMR-S.

NORWAY

The current standard high-level language is Mary:

◆ KS500

Word Length: 16 bits

Memory Capacity: 64 kwords, expandable in modules of up to 32 kwords each

Speed: 164 KIPS (Wheatstone test) **Instructions:** 130

KS500 is the standard computer of NFT command/control systems (such as NAVKIS and MSI-3100); it is being superseded by KS900, but as of 1990 it is still in production. Because it is used to integrate a very wide variety of weapons and sensors, many of them designed in the 1950s, it can be connected to an unusually large variety of interface modules.

◆ KS900

Word Length: 16 bits

Memory Capacity: up to 4 Mbytes per board, total of up to 128 Mbytes, plus up to 256 kbytes of EPROM for processor programs

Speed: clock frequency, 15 MHz; typical memory access time, 0.270 microsec

I/O: see below

KS900 is the main computer of the current NFT command/control systems. It is conceived as a process control computer for use in particularly difficult conditions, e.g., in North Sea oil rigs, as well as for military applications. Therefore, application programs are described as processes rather than in more conventional language. The first user was the MSI-90U submarine command/control system.

The main processor is a Motorola 68020, with a 68881 math coprocessor. The computer uses separate microprocessors to control its I/O functions, and its operating system kernel combines the power of the central processor and the subprocessors. KS900 is built around a 32-bit bus with a secondary 180-kbaud serial bus for built-in testing. The bus (backplane) carries a processor card (characteristics above), a Budos interface to the external system bus, a console interface, a mass memory module, an interface to instruments, a serial interface, a graphics interface, and an interface to the built-in test equipment. Each I/O board has its own local microcomputer (68000-series) for local control. Because the modules are all united by a bus, individual microprocessors controlling input/output can load their own programs directly from the mass memory, without intervention by the main processor. Module functions are largely controlled by EPROM software. All of the modules are in extended euroboard module format, 233.4 × 220 mm.

The memory listed above is accessed as local memory by the main processor and as system global memory (via the bus) by the I/O boards. This type of direct access is not too different from the access that allows modular operation in the Hughes Modular Combat System; see the description of that system.

KS900 can accommodate up to 63 user processes and 1 system process, expandable to 255 user processes with additional memory. Each process consists of up to 16 segments, each of up to 512 kbytes.

The system uses Intel i8751 processors for built-in test, communicating with one another via a separate serial bus. These devices operate at a clock rate of 11.53 MHz. This device also acts as the main processor for the console interface module, and also for the raster-scan converter module.

The bus controller itself provides a 65,536-Hz time reference. Although the system as a whole has a bus width of 32 bits, the processor operates on a normal word of 16-bit length, counting 32 bits as a long or double word.

Mass memory is up to 28 Mbytes of magnetic bubble memory, in 512-kbyte capsules (8 to a board). Data transfer rates are 100 kbytes/sec (average) or 400 kbytes/sec (maximum), and data are stored as pages of 128, 256, or 512 kbytes.

◆ SM-3

Word Length: 16 bits **Memory Capacity:** 64 kwords

Instructions: 32 **Speed:** memory cycle time, 0.8 microsec

Kongsberg (now NFT) computer, used in the Penguin system and then in the NATO Sea Sparrow; the U.S. designation (see below under U.S. NavOrd computers) is Mk 157.

SWEDEN

As of 1988, ADA was the standard language of all future defense projects.

◆ Censor 908

Word Length: 4 bytes (32 bits)

Memory Capacity: 16 kbytes (ferrite cores), expandable in 16k increments to 128k

Speed: memory cycle time, 1.0 microsec

Censor 908 is a Standard Radio & Telefon (now Ericsson) minicomputer, part of the Censor 900 series (ca. 1971). It was designed to operate either as a central computer or as a satellite to a Censor 932; the main memory can be accessed independently by the main computer. Up to four 908s can be connected to 1 932. In such a system, a common main memory can serve both the 908s and the 932 master.

◆ Censor 932

Word Length: 4 bytes (32 bits)

Memory Capacity: 4–128 kwords (16–512 kbytes), in 4-kbyte increments up to 128k

Speed: memory cycle time, 1.0 microsec **Instructions:** 80

Censor 932 is a Standard Radio (now Ericsson) main computer, originally designed for use in air-defense centers, and then used in shipboard command/control systems. Its architecture allows for 64 priority interrupts, compared to 32 in the Censor 908 minicomputer. Memory can be supplemented by up to 2 Mwords of ferrite core mass storage.

◆ Censor 932E

Word Length: 32 bits **Memory Capacity:** 512 kwords

Speed: memory cycle time, 0.525 microsec; add word, 2.4 microsec; multiply/divide time, 16 microsec

Censor 932E is the current standard Swedish Navy tactical computer, in the Maril combat-direction system. Operations can be conducted with half- or double-length words. Typical dimensions are 500 (high) × 530 (wide) × 230 (deep) mm; weight is 35 kg.

◆ 9LV System Computer

Word Length: 32 bits

Memory Capacity: 64–256 kwords

Speed: typical execution speed, 0.5–2 microsec

This is the current standard distributed minicomputer of the 9LV Mk 2 system. In the Mk 3 system, it is replaced by a single-board CPU using a 68020 microprocessor, with up to 4 Mbytes of on-board memory (and 256 kbytes of EPROM-carrying programs).

UNITED KINGDOM

The standard high-level language is Coral 66, structured similarly to Algol, with some features taken from JOVIAL and Fortran. Coral 66 is now being superseded by ADA (which became mandatory in British defense projects on 1 July 1987). Fixpac is the assembly language of the Ferranti FM 1600 series computers.

The current standard minicomputer is the Argus F700, and the standard microcomputer of the 1980s was the F100.

◆ Argus M700

Word Length: 16 bits **Memory Capacity:** up to 256 kwords

Speed: 250 KIPS (M700/40: 1.6 MIPS) **Instructions:** over 120

These Ferranti minicomputers are typically used in combination with FM 1600-series main computers. In the basic version, 64 kwords are directly accessible, and total memory (including bus memory) is 256 kwords. M700/20 incorporates a memory-management card and can access all 256 kwords directly. M700/40 is an LSI version, with a 4k cache memory.

M700/42 incorporates up to 256 hardware-implemented sub-routines, such as conversion between fixed- and floating-point formats, square root, and trigonometric functions.

Argus 700 supersedes the earlier Argus 400, introduced in 1966, with 4–12 kwords of memory in ferrite core. Word length is 24 bits, as in the larger Ferranti computers; there are 38 instructions. Speed: add/subtract, 12 microsec; multiply, 18–162 microsec; divide, 162 microsec.

◆ F100-L/F200-L

Word Length: 16 bits **Memory Capacity:** 32 kwords (see below)
Speed: clock rate, 8.5 MHz (13.5 MHz in commercial version); multiply time, 9–13.5 microsec; divide time, 12–16.2 microsec
Instruction Set: 153

F100-L is a standard Ferranti microprocessor, developed for the British Ministry of Defence. It can address up to 32 kwords. The microprocessor, clock-generator, multiply/divide unit, and 2 bus buffers are available as a single hybrid chip (FBH 5092).

F200-L is an improved version, which can address 64K–1M words, on-chip multiply/divide, and higher speed (rated at 300 KIPS).

◆ Poseidon

Word Length: 24 bits **Memory Capacity:** 8 kwords (ferrite cores)
Speed: memory cycle time, 6 microsec; instruction read time, 2 microsec
Instructions: 32

This Ferranti machine was the basis of the earliest Royal Navy automated tactical data systems that were on board HMS *Eagle* (1964) and some "County"-class destroyers (beginning in 1966). As such it may still exist in Chilean service. Poseidon was developed by Ferranti and ASWE (Admiralty Surface Weapons Establishment) in 1959–60, and the first production machines appeared in 1963.

◆ FM 1600

Word Length: 24 bits
Memory Capacity: 16 kwords, expandable to 256k (ferrite cores) (speed roughly halved above 128k)
Speed: memory cycle time, 1.0 microsec; add/subtract time, 1.3 microsec
I/O Channels: 64

FM 1600, which was introduced in 1968, replaced the earlier F 1600. FM 1600 replaced the discrete technology of the earlier machine with small-scale integrated circuits. FM 1600 was the most powerful of the original FM 1600 series. Dimensions: 23 × 21 × 58 in.

◆ FM 1600B

Word Length: 24 bits
Memory Capacity: 4 kwords, expandable to 64k in 4k increments
Speed: memory cycle time, 1 microsec; add/subtract time, 2.7–4.3 microsec (fixed point), 6.3–7.0 microsec (floating point); multiply time, 11.3–13.3 microsec (fixed point), 14.0 microsec (floating point); divide time, 13.0–16.0 microsec; clock rate, 3 MHz
I/O Channels: 20 (maximum)

FM 1600B was introduced in 1968 as a lower-powered alternative to FM 1600 (which was not used in any shipboard systems), with half the computing power in one-fifth of the volume; dimensions are 19 × 16 × 7 in. It was used in CAAIS tactical data systems as well as in submarine tactical systems; some were exported for use by the Royal Netherlands Navy. The original version used 1-microsec memory, but in 1969 a 600-nanosec (0.6-microsec) memory was introduced. When this machine appeared, Ferranti claimed that it was the only available small computer designed for floating-point operation in its central processor; other computers required additional programming (which carried a speed penalty) for such operation. Modules for automatic radar-data extraction and for analog-to-digital conversion for synchros were designed for FM 1600B.

◆ FM 1600D

Word Length: 24 bits

Memory Capacity: 4 kwords, expandable to 64k in 4k or 8k increments

Speed: memory access time, 1 microsec; add/subtract time, 4.7–14.0 microsec; multiply time, 0.9–137.0 microsec; divide time, 68.0–98.0 microsec; typical throughput, 350 KIPS

Instructions: 325 **I/O Channels:** up to 16

This version of FM 1600 appeared about 1972. It uses an 8-bit processor, handling its 24-bit words in slices. It is also capable of double-precision arithmetic. Capacity is equivalent to that of FM 1600B. FM 1600D is a standard airborne computer, in the Searchwater radar processors of the Nimrod and the Sea King early-warning helicopter.

FM 1600C had no naval applications.

◆ FM 1600E

Word Length: 24 bits
Memory Capacity: 32–256 kwords
Speed: clock rate, 12 MHz; floating point divide, 9.6 microsec (from main store); conditional jump, 2.1 microsec; read or write to memory, 0.75 microsec
I/O Channels: 28 (4 high priority)

FM 1600E is the most powerful of the FM 1600 series, the larger equivalent to FM 1600D; both embody medium-scale integration technology. Both are, therefore, small enough to be integrated into the display consoles themselves, so that there is no need for a separate computer room. FM 1600E uses a cache (kernel) plus main storage, and there is provision for program protection through memory partitioning. Of the input/output channels, the 4 high-priority ones have their own buffers and can transfer a word in 6.5 microsec. The other 24 channels are multiplexed in 2 groups; transfer rate is 1 word in 9.0 microsec. The semiconductor memory is in modules of up to 128 kwords each. This computer dates from about 1977.

◆ F2420

Word Length: 24 bits **Memory Capacity:** 3 Mbytes (1 Mword)
Speed: 3.8 MIPS

F2420 is the successor to the FM 1600 series, with 4 times the computing speed and much more memory. The 3-Mbyte memory can be extended to 24 Mbytes using external addressing. As in the U.S. UYK-20/44, the faster and more powerful machine can run programs originally written for the smaller and slower one but can also do much more. F2420 is used in the enhanced version of the Ferranti CAAIS/WSA 400 series, and it replaces FM 1600s in the CACS tactical data system. F2420 is sometimes described as enjoying 6 times the computing power of its predecessors.

This computer was originally named FM 1600F but was renumbered because it embodied major architectural changes.

◆ GEC-Marconi 920ATC

Word Length: 16 bits
Memory Capacity: 64 kwords, plus up to 192 kwords externally (ferrite cores)
Speed: internal memory access time, 0.42 microsec; cycle time, 1.0 microsec
I/O: up to 16 peripherals, including magnetic tape and bootstrap loader; nominal data-transfer rate, 1 MHz (64 and 500 kHz rates are also available)

This is the central tactical computer of the Nimrod MR.2, replacing the 920B of the MR.1 version. 920ATC is also the computer of the AQS-901 acoustic system on board the MR.2. The main computer is housed in a single ATR Short case; maximum weight is 37 lbs. Word length does not include 2 parity bits; 920ATC is sometimes described as an 18-bit computer. The manufacturer describes its floating-point operation in terms of a 16-bit exponent and an 18-bit mantissa, so under some circumstances it would seem that all 18 bits are used.

◆ Transputer

Inmos' Transputer is a single-chip 32-bit processor specially designed for parallel computing; it can communicate both with the unusual I/O channels and also with other Transputer chips.

Transputers are used in the British next-generation surface-ship and submarine command systems (SSCS and SMCS). Reportedly, a single Inmos T800-20 has about 5 times the performance of a 68020 combined with a 68881 floating-point processor. In a typical application, T800 is credited with a speed of 1.75 Mflops, or 12 MIPS of scalar (single-number) processing power.

UNITED STATES

The current standard large computer is UYK-7, and the corresponding minicomputer is UYK-20. They are being replaced by, respectively, UYK-43 and UYK-44. In a few cases, UYK-19 is used instead of UYK-20. The new standard airborne computer is AYK-14. Some special output channels are NTDS slow (41,667 words/sec), NTDS fast (125 kwords/sec), and A-NEW (125 kwords/sec); the last refers to the A-NEW ASW system introduced in the P-3C airplane. AYK-14 has an additional high-capacity digital channel, Proteus (10 Mbit/sec), for communication with a separate on-board acoustic-signal processor.

The current minicomputers are available as SEM (standard electronic module) boards, suitable for embedding in other devices.

The current standard naval programming language is CMS-2 (second generation Compiler Monitor System programming language, adopted in the mid-1960s). This language exists in several versions (dialects), -2M, -2Q, and -2Y. ADA is being introduced for new systems. There is also a special signal processing language, SPL/1, which is also suitable for graphics display processing. Like ADA, SPL/1 is related to the Pascal civilian language.

In recent years the standard Mil-Spec computers have increasingly been supplemented by very powerful commercial machines (DTC I and II) for semitactical applications such as JOTS and FDDS. These machines are generally programmed in the C and UNIX commercial languages.

◆ ASN-91

Word Length: 16 bits

Memory Capacity: 16 kwords (12 kwords protected)

Speed: cycle time, 2.5 microsec; average speed, 125 KOPS

Instructions: 37

I/O Channels: 5 output, 8 input; 67 discrete inputs, 32 discrete outputs

ASN-91 is the IBM tactical (weapons-delivery) computer of the air force A-7D and the navy A-7E. In the A-7E, ASN-91 computes a navigation solution in 0.20 sec and a weapons-delivery solution in 0.03 sec. The computer portion of ASN-91 is designated CP-952; it is the IBM System/4 Pi model TC-2. See also the separate entries for the IBM System/4 Pi series and for the A-7E tactical data system.

ASN-91A(V) (IBM TC-2A) of 1974 had pluggable memory expansion units (total memory could be 16k, 24k, 32k, and 40k words) and a signal converter modified so that it could be installed on a common backplane with the computer.

◆ ASQ-114

See CP-901/ASQ-114, below.

◆ ASQ-155

The IBM central computer of the A-6E, ASQ-155 is an upgraded version of the earlier ASQ-133 (IBM Series/4 Pi Model TC-3), introduced onto the A-6E production line in April 1976. There are up to 60 I/Os, including displays and air-data information, many of them converted from analog form by a Fairchild A/D converter. ASQ-133 is a 32-bit computer (with 4 additional bits/word for parity and storage protection) and 36 instructions; storage is 32k 18-bit words. Speed: 0.9 microsec maximum access time; 2.5 microsec memory cycle; fast conversion speed, 35 microsec digital to analog and 105 microsec analog to digital. ASQ-133A added an expandable memory and a core memory unit for the addition of logic tables. ASQ-155A is similar, but capacity is doubled to 32k 36-bit words. ASQ-133 replaced the Litton ASQ-61 of the original A-6A and -6C, part of the DIANE

(Digital Inertial Aircraft Navigation Equipment) system. ASQ-61 was a 20-bit computer with 22 instructions.

Grumman proposed replacement of the ASQ-61 by a solid-state computer as early as 1967, and the navy funded development work at that time. However, the computer was not replaced until the shift to the A-6E. ASQ-61 used a rotating-magnetic-drum memory; Grumman proposed that the drum be replaced by an IBM solid-state core unit, and this interim improvement was made on aircraft reaching the fleet from June 1970 on.

◆ AYA-6

The tactical computer of the EA-6B is being replaced by AYK-14 in the ICAP-2 version. Memory is 1k of 70-bit ROM words and 8k (expandable to 16k) of RAM (32-bit words): 2700 words of navigation data, 3746 reserved for countermeasures data, and 1264 words for built-in test. AYA-6 is the computer and associated display electronics group produced by AIL, containing the IBM System/4 Pi computer.

◆ AYK-10 (Univac 1832)

Word Length: 32 bits

Memory Capacity: 64 kwords (expandable to 96k)

Speed: memory cycle, 0.75 microsec

Instruction Set: 133 I/O Channels: 18

The Sperry (UNISYS) AYK-10 is the central tactical computer of the S-3A, analogous to the ASQ-114 of the P-3C; it is also the central tactical computer of the Canadian CP-140. There are 2 independent central processors, 2 I/O controllers, and 2 I/O interfaces, all of them cross connected. Both processors have access to the entire memory, which is in 32k units (normally 2, with a growth option to 3). Each 32k unit contains two 16k memory banks. In addition, there is a magnetic drum for mass memory, separated into 2 halves (1 fed by each I/O interface). Each of the 2 I/O interfaces has 6 Type I channels, 4 Type II, 1 Type III, and 1 spare. Type I channels are multiplexed (up to 7 devices/channel). Devices include the sensor operator inputs, the FLIR, ESM data, and navigational data. Type II channels communicate with the tactical display system (4/interface, or 8/computer). Type III channels communicate with the mass (drum) memory. One of the Type I channels is reserved for growth; the spare is presumably also a Type I channel. Another Type I channel is reserved for test purposes. The 18 channels listed above presumably omit these and the drum memory channels.

The drum memory functions both as auxiliary storage for the computer and as the memory of the S-3A's acoustic-data processor. A portion of this memory stores most of the operational subprograms used by the AYK-10. An S-3A also has a 7-track digital magnetic tape recorder, connected to a Type I channel. The computer runs 21 concurrent programs, as well as 4 displays; it uses a 1553B data bus.

Total weight is 410 lb, with a power consumption of 2.3 kW.

In the S-3A, the tactical system includes an OL-82 acoustic processor. An AYK-10A version was developed for the S-3B, which uses the UYS-1 acoustic processor in place of the earlier OL-82 integrated with the AYK-10 in the S-3A. A proposed AYK-10B would have had 256k of main memory and a magnetic bubble mass memory.

AYK-10 is the Univac 1832. The prototype was delivered in 1971. It was the first Univac computer to use medium-scale integration; it was also the first large-scale use of a patented Univac mated film memory, intended to replace the earlier ferrite cores. The metal of the memory was deposited on glass substrates, and UNISYS (then Sperry) claimed that it permitted extremely fast operation (over 2 MIPS); when AYK-10 was announced, it was described as twice as fast as existing machines.

◆ AYK-14

Word Length: 16 bits (can operate on 4-, 8-, 16-, 32-bit data)

Memory Capacity: 4 Mwords in 32-kword (semiconductor) or 64-kword (core) modules

Speed: typically, 300 KIPS–2.3 MIPS; add/subtract time, 0.6 microsec; multiply time, 1.9 microsec; divide time, 3.9 microsec; clock rate, 1 MHz

Instructions: 307 I/O: up to 16 modules (see below)

AYK-14 is the current standard aircraft computer (in the AV-8B, F/A-18, E-2C, EA-6B, P-3C, and SH-6B); about 5000 are in the fleet. Versions are also used in weapons such as the Mk 50 torpedo. Control Data was the original manufacturer (AYK-14 was developed from that company's 480 microcomputer). It entered series production in 1980. Reliability has improved from an MTBF of about 200 hr in 1981 to above 1500 in 1989, and cost has fallen about 8.2%/year, from \$185,000 in 1981 to \$80,000 in 1989. UNISYS is now the second-source producer.

The AYK-14 was designed to be functionally and physically partitioned into replaceable modules so that it could be upgraded. In 1987 Control Data received a contract for a pre-planned product-improved (P3I) version, and deliveries began that year. In this version 3 of the cardlike processor modules are replaced by a single module with twice the processing power and 8 times the memory (using 0.5M- and 4M-memory modules). The single-card processor incorporates both a 16-bit central processor and a 32-bit math coprocessor, the EAU (extended arithmetic unit). There is also a cache memory, and the card has an extended instruction set. This version is used in the F-14D, V-22, Mk 50 torpedo, and new-production F/A-18, EA-6B, and SH-60B aircraft.

Data above refer to this P3I version. The P3I version is the one currently manufactured by UNISYS.

Control Data has also been developing a VHSIC processor module (VPM) for the AYK-14 since 1986. This plug-in module quadruples the processing power of the P3I version and also substantially increases memory. It incorporates a 64k cache memory. Reliability should also be greatly improved; expected MTBF is about 9000 hr. The first experimental VPM was delivered in September 1989, and production deliveries are to begin in 1991. Ultimately, VPM will be inserted in most fleet P3I AYK-14s.

AYK-14 addresses its 4 Mwords by paging, using 16-bit addresses on pages to refer to 19- or 22-bit physical addresses in memory, the choice depending on the chassis type. Physically, the computer uses 2 memory buses, even (EMEMBUS) and odd (OMEMBUS), for efficient overlapping memory access; they are controlled by a memory-control module interface.

A standard AYK-14 can accommodate up to 16 I/O modules, up to 5 of them smart modules incorporating their own on-board controllers, to execute chain programs and initiate data transfers using DMA. The other (standard) modules require the central processor to intervene to move data in and out. An AYK-14 expansion chassis can provide additional I/O bus ports.

The Computing Devices Co., Ltd., of England produces an AYK-14 derivative designated ACCS 2000 (airborne computing-and-communications system), which is the mission computer of the RAF Harrier GR 5. Deliveries of an enhanced version, ACCS 2500, began in 1989.

AYK-14 was the first truly standardized U.S. Navy airborne computer, all previous machines having been purchased as part of a total aircraft systems package. Development began in 1976, initially for the F/A-18 and LAMPS programs; the specification required that AYK-14 be able to emulate the UYK-20 instruction set, so that programs written for the latter could be used by the former. The AYK-14 instruction set includes that of the earlier machine.

◆ CP-642B

Word Length: 30 bits (can operate in 15-bit half words)

Memory Capacity: 32 kwords (ferrite cores)

Speed: memory cycle time, 4 microsec; typical execution time, 8–12 microsec; time to add and store (fixed point), 24 microsec; time to multiply and store (fixed point), 56–72 microsec; time to divide and store (fixed point), 80 microsec

Instructions: 62

I/O Channels: 4, 8, 12, or 16 rapid channels; can have NTDS interface

CP-642B was the central computer used in the original NTDS installations, part of the larger USQ-20 system. The initial version, CP-642A, had a memory cycle time of 8 microsec, and a typical instruction-execution time was 13 microsec. There were 12 input and 12 output channels for external equipment, plus 2 input and 2 output channels for intercomputer communication. In addition to the main memory, there was an auxiliary 16-word memory to store critical instructions and constants for automatic recovery in the event of program failure (crash). CP-642B (1962) introduced the use of control memory (32-word read-only magnetic thin film with a faster cycle time, 2 or 3 microsec), and a –3-volt I/O interface. These features increased data transfer rates to 125 kwords/sec/channel.

Dimensions were 72 in high × 38 in wide × 37 in deep (2400 lb). The components were mounted on 13 roll-out chassis (the more massive predecessors of circuit boards): 8 for logic I/O and arithmetic, 5 for memory.

Design work on the original CP-642 began in 1958, and it entered service in 1961.

NTDS programs for CP-642 were written on an earlier machine, USQ-17 (1955), a 32-kword (30-bit word, 20 microsec average execution time) machine that was probably the first U.S. Navy solid-state computer. Six were built (at least 1 is still in service).

◆ CP-789 (Univac 1218)

Word Length: 18 bits

Memory Capacity: 4, 8, 16, or 32 kwords (2 bay for 16k, 3 bay for 32k)

Speed: cycle time, 4 microsec

Instructions: 96 I/O: 4 or 8 channels

CP-789 is a component of some cruiser NTDS systems, including those upgraded via the New Threat Upgrade (NTU) program. It has 32 words of ROM for starting (bootstrap memory). Clock rate is 1024 Hz.

This computer was designed in 1962 as a military version of the 18-bit Control Unit Tester (CUT). It was an 18-bit spin-off of the CP-642B and was the predecessor of the 16-bit machines. CP-642B could compute in 6-bit slices, which were, in effect, its bytes; in these terms CP-789 was a 3-byte machine (the computer industry had not yet standardized on an 8-bit byte). Univac 1219B was the next-generation 18-bit computer (see Mk 152, below).

U.S. Minuteman missile sites used a double-word version of this computer (1218) as a weapons-system controller about 1969. At that time the specified MTBF was 10,000 hr, but this has been exceeded by several orders of magnitude.

◆ Mk 152 and CP-848/UYK (Univac 1219B)

Word Length: 18 bits

Memory Capacity: 8, 16, 32, or 64 kwords

Speed: 1.8 microsec typical execution time; clock rate, 1024 Hz

I/O: 4, 8, 12, or 16 channels

CP-848 is a second-generation 18-bit computer. Compared to CP-789, CP-848 has faster memory and a core buffer (500 nanosec) to speed I/O. Circuitry is more compact, so memory capacity increases within a 26-in cabinet (2 bays), and I/O capacity within a 3-bay cabinet (38 in wide). I/O modes are (Univac) 1218 normal, 1218 NTDS, and 1219B. This computer was an early application of preassembled circuit boards, what might be called very small scale integration (the individual devices are quite visible).

Mk 152 was the U.S. naval ordnance designation for this machine; it was the first U.S. standardized digital fire-control computer. In this form it has 16 I/O channels plus a slow interface. Memory capacity is 32 kwords, plus a separate 256-word control memory. Mod 0 (1966) weighed 1370 lb (dimensions: 72 in high × 38 in wide × 30.5 in deep). It was used in a digital Talos fire control system (Mk 77 Mod 3). Mod 1 (1966) had 8 I/O channels (1070 lb). Mod 2 (1400 lb, 1968) was similar to Mod 0 but had 8 fast and 8 slow I/O channels, with 2 paper tapes bootstrapped to channel 13, and modified input on channels 11 and 17. Mem

memory access time was 2 microsec. It was part of Fire-Control System Mk 86. Mod 3 (1370 lb, 1969) for the cruiser *Long Beach* (Talos fire-control system Mk 77 Mod 4) had a 40k memory. It was otherwise similar to Mod 0. Mod 5, for digital Tartar (fire-control system Mk 74 Mod 8, 1100 lb, 1972) had a 48k memory and was otherwise similar to Mod 1. Mod 6, for later versions of the Tartar (Mk 74) system and for shore sites, was a Mod 5 with 16 I/O channels (1460 lb). Mod 7 was a modified Mod 5 with a 64k memory for fire-control system Mk 74 Mod 8 (1050 lb, 1980). It added 4 memory stacks and the associated printed cards. In several cases, more capable versions of systems employing Mk 152 computers have UYK-20s instead.

◆ CP-855/UYK (Univac 1230)

Word Length: 30 bits **Memory Capacity:** 32 kwords (ferrite cores)
Speed: memory cycle time, 2.0 microsec; add/subtract time, 2–4 microsec; multiply time, 8 microsec; divide time, 14 microsec; clock rate, 1024 Hz
Instructions: 78 **I/O Channels:** 16

CP-855 was designed as a successor to the CP-642 series, as a second-generation 30-bit computer. Originally designed for NASA (for the Apollo program), CP-855 was not used in the U.S. NTDS system, but it was used in the French equivalent, *Senit III* (on board the frigate *Aconit*).

The 32k memory operates as 2 parallel 16k memories, and there is a separate 128-word control memory (expandable to 256 words). There is also 80k of mass storage. Two memory banks, operating in parallel, allow 2 simultaneous references for I/O, instruction extraction, or operand processing during 1 cycle. This architecture later appeared in UYK-7 and its successor, UYK-43. Special registers permit expansion of memory to 128 kwords, for use with the Univac 1503 expanded memory unit (EMU) and the hardware floating-point option. Typically, an EMU would be connected to a pair of 1230 computers, providing each with 2 or 3 banks of additional memory (16k per bank) and up to 4 I/O channels.

Compared to CP-642B, CP-855 has a larger instruction set, including 15 logical instructions and a hardware square-root instruction. The control memory includes seven 15-bit (17-bit in expanded mode) index registers (CP-642B had seven 15-bit registers). There is a 64-word ROM plus a 128-word fast (0.4 microsec magnetic thin film) control memory. Dimensions: 72 in high × 38 in wide × 37 in deep, 2200 lb).

◆ CP-890/UYK

Word Length: 32 bits (30 data, 2 parity)
Memory Capacity: 32 kwords in 2 banks (cores) expandable to 262 kwords using external chassis (18-bit rather than 15-bit addresses)
Speed: memory cycle, 1.8 microsec; clock rate, 1024 Hz
Instructions: 105, including 27 executive
I/O: 12 or 16 (half fast, half slow)

CP-890 was built specifically for the navigational system (which feeds the strategic-missile fire-control system) of Polaris and then Poseidon submarines. It has also been adopted for British Polaris submarines. The main design limitation was that it had to be able to pass through a 25-in hatch; it was, therefore, built in 3 hinged sections. Aside from high precision (for very accurate navigation), it had to be extremely reliable and was probably the most reliable U.S. Navy computer until quite recently.

CP-890 was the last of the Univac 30-bit computers, ending the series begun with USQ-17 and CP-642. It immediately preceded UYK-7. Architecturally it was almost identical to UYK-7 but was designed for slower speed. However, in practice it was faster, since memory cycle was actually 1.6 microsec, and UYK-7 cycle time was not faster than 1.7 microsec (vs. 1.5 designed). CP-890 used the earliest 3-wire ferrite cores, which are now standard. CP-890 was also the first militarized floating-point computer, the first with I/O memory (64 bits, in the form of chips, in 4 × 16-bit cells). The project began about May 1966, and the first was delivered in 1968; CP-890 remained in production until 1983 or 1984.

Trident submarines use a new 32-bit memory processor with a CP-890 instruction-set architecture. In these ships, much pre-processing was moved back from distributed system elements to the central navigational computer because the latter proved the most reliable element of the overall system. The current standard U.S. air-traffic-control computer (ARTS III) is a modified CP-890 and is still in production.

◆ CP-901/ASQ-114 (Univac 1830A)/Univac 1830B

Word Length: 30 bits
Memory Capacity: up to 64 kwords in 16-kword banks; can address up to 128 kwords; 512-word bootstrap (start-up) memory
Speed: 2-microsec cycle time without overlap; 1-microsec memory cycle with overlap; clock rate, 1024 Hz; typical performance, about 275–300 KOPS
Instructions: 70 basic **I/O:** 4, 8, 12, or 16 channels

The UNISYS tactical computer for the P-3C has been in service since 1968. It performs a function analogous to that of the central computer in a shipboard NTDS system. CP-901 is not the aircraft sonar-signal processor but maintains the current tactical picture, integrating data from the various sensor stations.

The mass memory media are a magnetic drum and a digital magnetic tape set, the latter to retain data for postmission analysis. ASQ-114 is connected to the aircraft sensors by the GE AYA-8 data-analysis programming group.

CP-901(V)6 is a modernized CP-901 developed in 1988, with an extended memory unit (64k increased to 4 Mwords of CMOS and bubble memory) and 16 I/O channels. I/O address capability is increased from 32 to 128 kwords.

The UNISYS designation for CP-901 is Univac 1830A. Univac 1830B (1970) is the main computer of the German AGIS fast attack boat command/control system. Compared to CP-901, 1830B can accommodate up to 8 memory modules (total 128 kwords). It has increased power-supply capability, optional I/O control memory (48 words), and nonbussed output channels. There are 76 basic instructions, and the clock rate is 102.4 kHz. Addresses beyond 32k are written in page mode. This computer was adopted by the U.S. Navy for the hydrofoil *Pegasus* since the ship was intended as the first of a NATO series using the German command/control system. Reportedly, it is designated CP-901B in U.S. service (although CP-901A, described below, is a very different and much later computer). The other 5 *Pegasus*-class ships have UYK-44s.

CP-901 was developed in parallel with CP-890 and can be considered an avionics version of the -890 architecture without the floating-point feature. It has a very similar memory but a less extensive instruction set. Performance is broadly equivalent to that of the Univac 1230 (CP-855) adopted by the French Navy. This and the other 30-bit computers were abandoned in favor of 16/32-bit machines because 32 bits became the commercial standard.

◆ CP-901A

Word Length: 32 bits **Memory Capacity:** 1 Mword (see below)
Speed: 9 MIPS throughput **Instructions:** 68030 set
I/O Channels: 34 (see below)

In October 1989 UNISYS received a contract to design and produce a new version of the CP-901 computer, with improved throughput but with greatly reduced overall size, weight, and power requirements, for P-3C aircraft. A contract for a memory upgrade had already been awarded. The new version will use ADA software, but it also has a CMS-2 compiler for compatibility with existing software. Presumably, CP-901A is part of the planned modernization of existing P-3s (not Update IV).

The new version is an entirely new machine within the same space, weight, and power requirements of the earlier CP-901. -901A uses a dual memory bus like that of other current UNISYS naval computers. Instead of a single central processor, it has 3 Motorola 68030 microprocessors (with card slots for 4 more). Throughput can be increased to 12 MIPS by using the 4 additional microprocessors.

Each of the 3 microprocessors has a local memory of 256 kwords, which can be increased to 1 Mword/processor. The 1 Mword listed above is the global memory available to all 3 processors. All of these are volatile memories (CMOS); there is also a 3-Mword bubble memory for fast mass storage. In addition, each microprocessor has 32 kbytes of bootstrap and diagnostic memory (EEPROM); UNISYS has proposed replacement of this memory by 32 kwords (128 kbytes) of UVPRM. The total global memory (1 Mword CMOS and 3 Mwords of bubble mass memory) can be doubled within the cabinet dimensions.

The I/O channels are two 1553B buses, 4 ARINC 575 serial channels, 10 synchro-to-digital channels, 4 digital-to-synchro channels, 10 A-NEW channels (MIL-STD-1397C), and 4 stroke-display (i.e., cursive video) channels; there are also 3 manual-entry-system (keyboard) interface cards. Growth options are 1 video input channel and 4 color, raster, display channels.

CP-901A incorporates the functions of the AYA-8 logic units and the CV-216 signal data converter, previously separate equipment, in its cabinet. The cabinet is 52 × 13.5 × 17.7 in and weighs about 380 lb; it uses 6 × 9-in printed circuit cards.

◆ CP-1469 (ASPRO)

This Goodyear (now Loral) Associative Parallel Processor was designed for the Grumman E-2C. Production began in 1980, the first prototype was delivered to Grumman in mid-1982, and as of 1989 a total of 46 had been manufactured. In June 1989 Loral was awarded a contract for 10 to support OTH-T by nuclear attack submarines. ASPRO achieves a throughput of 110 MOPS in the space occupied by a 1-MOPS UYK-44.

ASPRO was derived from a series of Goodyear computers embodying a patented multidimensional access memory. Development led to the announcement in 1972 of STARAN, the first commercially available parallel-processing computer. This work derived from a series of studies requiring high-speed searches of existing data files. Goodyear's approach was to associate incoming data with data already on file, and this association or correlation could be done most rapidly using a parallel processor. In 1979 a later version of STARAN was demonstrated as the most efficient means of upgrading the E-2C tactical data system.

ASPRO is designed to handle more than 4000 computations simultaneously, for functions such as track-to-track correlations. It can perform arithmetic operations, such as coordinate transformations or dead reckoning, on numerous tracks simultaneously.

ASPRO is conceived as an add-on to a larger host computer. In a volume of 0.44 ft³ (8 × 10 × 9.5 in, 37 lb), ASPRO contains 1792 processors with 896 kwords of associative storage. Program memory is 32 kwords (32-bit words) with a read/write rate of 5 Mbytes/sec. No net processing rate is available, but the associative processor multiplies two 16-bit words in 108.5 nanosec (0.1085 microsec; 194.5 nanosec for the 1792 items in parallel). The power requirement is 200 W.

◆ MIL-STD-1750

MIL-STD-1750 is a standardized requirement for future air force 16-bit microcomputers; presumably, it will become a triservice standard. Some 1750A computers are to be incorporated in the new A-12 attack bomber (see separate entry on A-12 computer). The standard defines an instruction-set architecture with about 100 instructions, suitable for single-, double-, and triple-precision calculation. The standard machine has 64 kwords of memory. A revised MIL-STD-1750A, defined in 1982, envisages a standard triplex bus (backplane), 1 of whose lines is used for built-in test. The other 2 are a Pi-Bus and an IEEE 488 bus. A typical computer would employ a standard processor, a volatile bulk-memory module, a nonvolatile (mass storage) bulk-memory module, an interface module for a 1553B data bus, a fast data (50 Mbit/sec) dual-redundant bus module (to connect to a fiber-optic bus), and a timing and discrete-switch module. Typical processor performance is 3 MIPS, with 512 kwords of local memory. The volatile memory module has expandable storage

of up to 5 mwords per module; nonvolatile storage (EEPROM) is in modules of 1.5 Mwords. Each bus interface module has its own microprocessor plus 256k of buffer memory.

As in the case of the navy NGCR, the objective is to be able to buy any of a wide variety of commercial machines. Development began in 1976, on the basis of Strawman, an early approach to what became the ADA computer language. The MIL-STD-1750 standard was released to industry on 21 February 1979; the figures above apply to current UNISYS machines intended to meet MIL-STD-1750A. No single manufacturer dominates the 1750A market (UNISYS has about 3% of it); at one time Delco made 21 different 1750A processors. Commonality is limited to dimensions and to the instruction-set architecture.

An attempt to define a 32-bit MIL-STD-1750B failed because the main chip manufacturers, Intel and Motorola, saw little point in encouraging competition. 1750B was, therefore, 1750A with minor changes.

◆ OL-77/ASQ

OL-77 is the central tactical computer of the E-2C, a double version of the Litton L-304 (see below). It is to be replaced by a new high-speed processor, but no choice had been made as of early 1990, and the replacement program had not yet been funded. See also the discussion of the E-2C tactical data system (ATDS) later in this chapter.

◆ USQ-20

USQ-20 was the computer system of the early version of NTDS, including the CP-642 computer described above, plus a separate control console (C-3413) and mass storage in the form of tape drives. System software, the Dynamic Module Replacement (DMR) program, allows the system operator to insert or delete particular program modules into the running operational program. For example, an ECM module can be inserted when needed, then deleted to leave more memory space, without stopping the system. USQ-20 is a modular system in which individual CP-642s can be run in parallel for increased total processing power.

◆ USQ-69B

This UNISYS device is an intelligent version of the USQ-69 data-link terminal, incorporating an 80386 chip with an 80387 coprocessor; it can accommodate up to 40 Mbytes of DRAM memory and a 3.5-in high-density disk. USQ-69B uses the MS-DOS language and can function as a stand-alone computer. Alternatively, it can be installed as a modification to an existing USQ-69, fitting into the latter's logic drawer. The marines plan to connect 12 on an LAN on board an LHD for troop-location planning. Preproduction deliveries began in June 1990, and production deliveries are scheduled for March 1991.

◆ UYK-7

Word Length: 32 bits (can do double-precision arithmetic)

Memory Capacity: 262 kwords (ferrite cores)

Speed: memory cycle, 1.5 microsec; add/subtract time, 1.5 microsec; multiply time, 10.0 microsec; divide time, 17.0 microsec; clock rate, 1024 Hz

Instructions: 130

This UNISYS computer replaced USQ-20B in the NTDS system. UYK-7 was originally conceived for 3 programs: Aegis, the *Spruance*-class destroyer, and the *Los Angeles*-class submarine. The current standard U.S. Navy central computer, UYK-7 is being replaced by UYK-43. UYK-7 can operate either as a single or as a multiple processor. The single-cabinet version has a capacity of 48 kwords of memory and up to 16 I/O channels. Up to thirteen 16-kword modules can be added. Such additions are described as multibay configurations (1-, 2-, 3-, or 4-bay) UYK-7(V) is an upgraded version.

UYK-7 has two unusual features. The main memory can be read as several parallel memories, for faster processing (speed is increased by a factor of 2 in the single-processor version, and by a factor of up to 8 when several processors are used together).

UYK-7 has a bus connecting the memory modules, and up to 3 central processors can be connected to the same bus.

The standard UYK-7 cabinet is 40.88 in high $\times$ 19.80 in wide $\times$ 22.34 in deep (excluding handles); total weight is 527 lb, including the cooling blower.

UYK-7 was developed in 1969.

◆ UYK-15 (Univac 1616)

Word Length: 16 bits

Memory Capacity: 8–64 kwords in 8k increments

Speed: add, 0.750 microsec; multiply, 3.75 microsec; divide, 3.75 microsec

Instructions: 64

I/O: 16 parallel channels; or 8 parallel and 8 serial; or 4 parallel and 16 serial channels

This is the UNISYS computer of the SPS-52 through -52B radars; SPS-52C has a UYK-20 instead. The memory banks (increments) are independently addressable. Dimensions: 14.4 in high $\times$ 20.75 in wide $\times$ 25.75 in deep (approx 170 lbs). UYK-15 appeared about 1970. UYK-15 was unusual in using a very large number of registers (256) but a small number of separate instructions (as in the later RISC computers). There was no separate accumulator for arithmetic results; instead, all computation was conducted from register to register, and the large number of registers could accommodate numerous parameters.

UYK-15 is a ruggedized version of the Univac 1616. Customers included air force intelligence programs. Performance (about 500 KOPS) was roughly equivalent to that of the contemporary VAX 11/780 (which never ran at its rated speed of 3 MIPS). This computer was totally interrupt-driven to cue its program, and was also adapted to a high I/O rate (it was conceived as a front end for mainframes such as the UYK-7). Work on this machine led directly to the development of UYK-20. The architecture is different: UYK-15 has an independent I/O controller and a time-sliced memory, whereas UYK-20 uses an emulator in its processor for handling I/O. Hence, to maintain the same throughput, 2 UYK-20s are equivalent to 1 UYK-15.

UYK-15M was conceived for the integrated radio room of Trident submarines. Because of the I/O limitation, the 2 UYK-15s originally planned were replaced by 4 UYK-20s.

◆ UYK-19

Word Length: 16 bits

Memory Capacity: up to 128 kwords (32k modules); 512-kbyte read-only memory

Speed: clock rate, 20 MHz; memory cycle time, 2 microsec; add time, 1 microsec; floating-point add time, 4.6–10.1 microsec; floating-point divide time, 20.95–29.95 microsec

Instructions: 101

I/O: up to 7; transfer rate, up to 1.32 Mbytes/sec

This Rolm computer competes with UYK-20. UYK-19 is used mainly in electronic-warfare systems; it beat out the UYK-20 for application to both the SLQ-32 ESM system and also the Tomahawk missile targeting system. UYK-19 is also the standard computer of the Hughes Modular Combat System (H930) and drives displays of the Tactical Flag Command Center. The processor of the USQ-81 display (which was part of the Outlaw Shark and Outlaw Hawk predecessors of TFCC) is an enlarged UYK-19.

UYK-19 is a militarized version of the Data General NOVA computer and first appeared about 1974. There are 5 versions, which Rolm designates 5605, 1603A, 1650, 1602B, and 1666B; the last is also designated UYK-64 and uses an expanded instruction set. Data above refer to Model 1602B. Hughes is currently testing a Model 1666 as an upgrade to its Modular Combat System; details of this computer are given below. See also UYK-64 (Rolm 1666B), which is intended as the UYK-19 successor, in analogy to UYK-44, the UYK-20 successor.

See UYK-64, below.

◆ UYK-20

Word Length: 16-bit words (can operate on 4- and 8-bit subwords)

Memory Capacity: UYK-20: 8–64 kwords; UYK-20A: 32–262 kwords (32k increments) (ferrite cores)

Speed: memory cycle time, 0.75 microsec; add time, 0.84 microsec; multiply time, 3.6 microsec; divide time, 6.6 microsec

Instructions: 283 I/O Channels: 16

UNISYS introduced this minicomputer in 1974; the development contract was awarded in March 1973. As built, UYK-20 outperformed the original version of UYK-7. The processor was of MSI (medium-scale integration) design. UYK-20A is a more powerful version, capable of addressing a larger memory. Typical dimensions are 20 in high $\times$ 19 in wide $\times$ 24 in deep (230 lb). UYK-20 is also supplied as a set of 6 $\times$ 2-in SEM-B cards, which can be embedded in another system.

In 1984 MTBF was reported as 2000 hr.

UYK-20 was the first of the series of 16-bit standard naval computers, which now includes UYK-44 and AYK-14.

◆ UYK-43

Word Length: 32 bits (can do half word and double-precision arithmetic)

Memory Capacity: 4 Gwords (see below)

Speed: throughput, 2.25 MIPS; cycle time, 150 nanosec; add time, 150 nanosec

Instructions: 258 I/O Channels: 64

The UNISYS UYK-43 replaces UYK-7 as the standard U.S. Navy shipboard mainframe computer. UYK-43 was designed to be compatible with the earlier machine, so that programs written for UYK-7s could be run on -43s with minimal modification. However, because UYK-43 is so much more powerful, programs written for it can add capability not practicable with the earlier machine. Applications include the Advanced Combat-Direction System (ACDS), which is replacing NTDS. UYK-43 uses VLSI technology. The German navy now uses the UYK-43 (in the new Type 123 frigate), and Taiwan will use it in the new *Perry*-class frigates.

UYK-43 is modular, produced in A and B versions (enclosures). The A enclosure (20 $\times$ 22 $\times$ 69 in, 950 lb) has a single central processor, 1 I/O controller (throughput 3 MIPS), and 5 memory modules and is about 4 times as powerful as a UYK-7. The B version (20 $\times$ 22 $\times$ 72 in, 1795 lb when water cooled, or 29 $\times$ 22 $\times$ 72 in, 1865 lb when air cooled) has 2 central processors, 2 I/O controllers, and 10 memory modules and is about 9 times as powerful as a UYK-7. The A enclosure is designed to pass through a 25-in-diameter submarine hatch; it has the same footprint as a UYK-7. Ferrite-core memory is 32 kwords; semiconductor memory is available in 64k, 128k, 256k, and 512k, 1M, and 2M word modules. The last was first offered in 1987 as a direct replacement for the 512k module. At least in the case of the 512k and larger modules, a battery backup within the module saves data for 30 min in the event of power failure. Module read/write time is 450 nanosec, and the modules are built out of 256k memory chips. Presumably, larger modules will soon be offered, using the newer 1M memory chips.

Although the addressing scheme of UYK-43 allows for up to 4 Gwords, the original central processor was limited to 2 Mbytes (512 kwords). UNISYS developed an Expanded Memory Reach (EMR) Central Processor, which expanded memory reach to 2 Gbytes (512 Mwords). This modification adds 52 instructions to the original instruction set, and extends 8 of the existing instructions.

A UYK-43 can contain 2 central processors, 2 I/O controllers (throughput 3 MIPS each), and up to 10 memory modules. None of the existing memory modules allows the system to approach its theoretical capacity of 4 Gwords; the current maximum within the enclosure is 20 Mwords.

The multiple processors and I/O controllers can, in theory, try to access the same memory module simultaneously. This problem becomes serious as processor execution times drop below the memory bus cycle time, since then the memory cycle becomes the limiting factor in computer speed. UNISYS offers a high bandwidth memory (HBM) to overcome this problem. HBM employs eight 1-Mword memory blocks, each separately addressable; total memory is split into 2 groups of 4 blocks each,

each with its own scheduler. Scheduler rotation time is 0.3 microsec, but each scheduler has access to 4 separate blocks, so overall effective request time is 0.0375 microsec (as long as no 2 devices try to access the same word or the same subblock). In addition, HBM reads from (or writes to) the memory in 4-word bursts. Such bursts require 5 memory bus cycles (1 address, 4 data) rather than the current 8, for a 58% improvement in speed. The bursts write into the cache memory of the central processor. Overall memory performance is improved by a factor of up to 12.

UNISYS claims that UYK-43 is the most reliable military computer yet developed, with an MTBF of 56,000 hr. The original requirement was for a 6000-hr MTBF (MTTR of 15 min).

Sperry (UNISYS) and IBM were awarded competitive contracts for UYK-43 prototypes in December 1980. Engineering development models were delivered in March 1983, and Sperry was chosen in May 1983. Deliveries began in December 1983. Control Data was chosen as second-source producer in 1988 and will compete for 1990 production.

A preplanned product-improvement program added a 32k cache memory (16k instructions, 16k data) and 1024k and 2048k semiconductor memory units. The central processor was modified so that it could address more memory.

Typical applications:

	UYK-43	UYK-44
Aegis cruiser	6	23
Trident SSBN	2	4 or 5
Los Angeles	2	5 or 6

A UYK-43/44 upgrade program was begun in December 1988. It had been delayed in 1987-88 by Congress, pending completion of the NGCR (1996 computer) plan (see below), the fear being that the upgrade would preclude development of a new generation of machines. Plug-in upgrades will be phased in during 1990-94. UYK-43 will get an enhanced central processor (4-6 times more speed), a math coprocessor, and additional memory improvements (new standard mass-memory storage, i.e., a small disk drive). There will also be software upgrades. The coprocessor in UYK-43 was originally provided to improve self-noise monitoring in Trident submarines.

The math coprocessor (Time-Critical Subfunction Coprocessor, or TCS) carries a multifunction processor (MFP) and a vector processor (VP), plus independent memory, use of which does not conflict with the use of the main UYK-43 memory. The 2 processors are connected to the memory and to an interface adapter by a local bus. The MFP consists of a Motorola 68030 microprocessor, a Motorola 68882 floating-point coprocessor, cache memory, EEPROM, and the associated memory interface. Calculations are done in single (32-bit) or double (64-bit) precision, at 0.5 Mflops. The vector processor consists of an AT&T WEDSP32C digital signal processor and 1.5 kbytes of local memory. It can operate at up to 25 Mflops (sustained rate, 5 Mflops) and is under the control of the MFP, operating in parallel with it. TCS carries its own 8-Mbyte memory (expandable to 16 Mbytes). TCS is intended specifically for operations such as FFTs; up to 4 can be installed in a UYK-43 B enclosure. The standard form is 3 printed circuit assemblies: 1 for the processor, 1 for memory, and 1 for the interface adapter. A higher-performance version consists of 4: 2 memories and 2 processors.

◆ UYK-44

Word Length: 16 bits

Memory Capacity: 256 kwords (core); 4 Mwords (semiconductor memory)

Speed: throughput, up to 0.94 MIPS **I/O Channels:** 16

UNISYS' UYK-44 is the current standard U.S. Navy minicomputer (i.e., 16-bit computer). It will replace UYK-20. In addition to stand-alone functions, UYK-44 is embedded in other devices, such as the UYQ-34 multimode display and the SQS-53 and SQQ-32 sonars, as the Militarized Reconfigurable Processor (MRP) and the Militarized Reconfigurable Computer (MRC).

The MRP is designated OL-335(V) Data-Processing Group. The UYK-44 instruction set matches that of the AYK-14 airborne computer, which UYK-44 may ultimately replace. Actual word length, including check bits, is 22 bits.

Three alternative semiconductor memories can each be accommodated on a standard electronic module (SEM) card: 8 × 64k (512k), 8 × 256k (2M), or 4 × 1M (system maximum). Greater capacity means slower operation: the 64k SEM has a cycle time of 120 nanosec; the 256k, 250 nanosec; and the 1M, 350 nanosec. With the 64k SEM, the processor limits overall speed to about 0.930 MIPS; the 256k version runs at 0.934 MIPS, but the 1M version runs at 0.894 MIPS.

The original central processor directly addresses up to 64 kwords of memory. It uses 4 sets of 64 (256) -page registers (1 kword each) to address further memory via an executive mode program. Thus the maximum addressable memory is 256 kwords.

UNISYS offers an Expanded Memory Reach (EMR) version of UYK-44, which doubles the direct addressing ability of the computer by differentiating between instruction and data addresses. Using EMR, the computer can address 256 groups each of 64 code (instruction) pages plus 256 groups each of 64 data pages; each page consists of up to 1 kword. This is a total of 32 kpages (32 Mwords), 16 Mwords of data, and 16 Mwords of instructions. Four of the 64 data-page groups are reserved for I/O, so that I/O page address registers can be manipulated independently of central-processor page address registers.

EMR is standard in embedded versions of UYK-44 delivered after August 1989. The change requires 20 new instructions.

UNISYS won the UYK-44 contract in competition with IBM. Both companies received prototype contracts in September 1980, and UNISYS (then Sperry) won the contest in March 1983. Several Allied navies, including the Japanese, now use UYK-44. Raytheon, GE, and Microlithics have all qualified as second sources for the SEMs out of which the UYK-44 is built.

UNISYS claims that MTBF is 13,000 hr.

An upgrade program began in December 1988. UYK-44 will be fitted with an enhanced processor with 5-6 times greater processing speed, plus memory improvements. The improved processor meets requirements of the SQQ-89 program.

As of November 1988 UNISYS was offering a UYK-44EP (Enhanced Performance), which is probably the upgraded UYK-44. UYK-44EP can operate in either 16- or 32-bit mode and can address 8 Mbytes of memory (configured in words of either length). Using a page addressing scheme, it can address up to 32 Mbytes. The existing 9 UYK-44 processor cards are replaced by 2 UYK-44EP cards, and there is a new instruction set, by means of which the machine can emulate the UYK-20A, UYK-502, AYK-14, and UYK-44. The processor cards carry 64 kbytes of cache memory, as well as 32 kbytes of UVPRM (read-only memory, which can be reprogrammed when scanned with ultraviolet light) for its microcode. Speed is 5 MIPS.

◆ UYK-64(V)/Rolm 1666B/MSE/14

Word Length: 16 bits

Memory Capacity: core: 128 kbytes internal/1920 kbytes external; semiconductor: 2048 kbytes internal (1024 kwords)

Speed: memory access time, 0.4 microsec internal, 0.7 microsec external; core cycle time, 1 microsec internal, 1.1 microsec external; effective memory cycle time (4-way interleaved), 0.1 microsec (1 microsec core); semiconductor cycle time, 0.4 microsec; add time, 0.2 microsec (1.0 core); multiply, 4.4-7.4 microsec; divide, 4.4-7.4 microsec; floating-point divide, 5.0 microsec (9.8 in double precision); typical single-precision throughput, 0.441 MOPS (core 0.268 MOPS)

Instructions: 230

I/O: 59 addressable devices; I/O time: 1.25/0.25-Mbyte/sec core, 1.7/1.25-Mbyte/sec semiconductor

UYK-64 is in effect a second-generation UYK-19. Performance figures are given for 2 versions, 1 using ferrite-core memory and 1 using semiconductor memory of the type now common in small computers. The basic core version has 64 kbytes of internal memory, expandable to 128k; additional memory is con-

tained in external I/O devices or memory chassis. The semiconductor version is built up from 512-kbyte modules. Memory is allocated on the basis of 2-kbyte pages.

The 1666B is upward-compatible with existing UYK-19s, just as the UYK-44 is upward-compatible with UYK-20s. See below for details of the Rolm 1666, a related machine that has been used in TFCC and in the upgraded version of the Hughes Modular Combat System. The 1666B or UYK-64 can be upgraded to the Rolm MSE/14 by replacement of 1 CPU board and 1 optional FPU board.

Rolm offers a Micro 66 processor based on the 1666B instruction-set architecture and, therefore, is directly software compatible with the UYK-64 and upwardly compatible with the UYK-19. The module is the Rolm Model 1822 Micro. It can accommodate 64 kbytes of RAM on a single card, or up to 1984 kbytes (and 12 I/O slots) in a full ATR chassis (Rolm 1666C). Up to 2048 kbytes can be addressed. Memory is in 384k cards. The intermediate half-ATR chassis (Rolm 1866) accommodates up to 832 kbytes of RAM and 4 I/O slots (1 memory card can be replaced by an I/O slot, for 5 slots and 448 kbytes of memory). Estimated throughput rating is 1.5 MOPS (fixed-point). I/O is at rates up to 1.2 Mbytes/sec.

MSE/14 is directly software compatible with UYK-64 and the 1666 series. Model 1800 corresponds to Model 1866 above, and Model 7014 to the full Model 1666C described above. Typical execution times are add, 0.208 microsec; multiply, 0.917 microsec (with accelerator; 3.542 without); divide, 4.708 microsec; floating-point add, 8.125–11.834 microsec; floating-point multiply, 7.5 microsec (with accelerator; 19.384 without). Rolm claims a demonstrated MTBF of 15,000+ hr.

MSE/14 is offered with either a ferrite core (up to 128k) or semiconductor memory (up to 512k). Rolm also makes MSE/800, a 32-bit machine that competes with UYK-43.

◆ UYK-79 and R/VB-XXX-D

UYK-79 is a shipboard version of the Rugged Digital R/630B 32-bit MicroVAX computer, based on the Digital Equipment Corporation MicroVAX 3500. CPU performance is similar to that of the VAX 11/780. The company claims it costs $\frac{1}{3}$ – $\frac{1}{2}$ as much as standard U.S. Navy embedded computers. UYK-79 is being supplied to Sanders, UNISYS, and ESL for integration into 5 combat-support systems in carriers, battleships, *Wasp*-class amphibious ships, and *Spruance*- and *Arleigh Burke*-class destroyers; it is also being tested by the marines ashore. The chassis normally accommodates a MicroVAX II (1 MIPS) or MicroVAX III (3 MIPS) main processor and 16–64 Mbytes of memory. Its bus has 15 Q-Bus slots, configured for single or dual CPUs. Because UYK-79 uses standard commercial technology, it can accommodate numerous off-the-shelf commercial boards, including those that can link it to NTDS and to data links. It can accommodate four 5.25-in removable peripherals (disk or tape drives). Single disk capacity is 71–600 Mbytes; the slots can also accommodate single tape cartridges (95–295 Mbytes). Dimensions are 12.25 in high $\times$ 22 in deep $\times$ 19 in wide. Weight is 85–140 lb, depending on configuration.

R/VB-XXX-D is a new development of UYK-79 based on the IEEE 1014 VME architecture. It can accommodate four 5.25-in peripherals, which can be removable hard disks with a total of 1 Gbyte of mass storage. The related R/VS-XXX-D accommodates 18 VME-compatible cards.

The manufacturer, Rugged Digital Systems, Inc., was formed in August 1982 to develop, manufacture, and market military computer systems based on leading commercial architectures, to combine survivability with full software compatibility.

◆ UYS-1/2

See the ASW section. These are specialized signal processors.

◆ Next-Generation Computer Resources (NGCR)

For its next generation of computers, the navy has chosen to shift from a limited number of special designs to open standards that can be met by any number of functionally equivalent and

interchangeable modules. A data bus (backplane), an instruction-set architecture, and overall cabinet dimensions are specified, together with performance and interface standards. This approach is equivalent to that typified by the open architecture of the IBM PC: the user bought a box (a chassis) containing a data bus and could choose among many manufacturers' modules (cards) that could be inserted into the bus. IBM specified only the bus, the chassis dimensions, and the connection standards. In theory, this approach should make it much easier for the navy to exploit civilian hardware developments, though much depends upon whether the bus has sufficient capacity and sufficient similarity to civilian equipment. The new approach is also reminiscent of the French decision to purchase ruggedized civilian computers rather than specialized military types.

NGCR is intended for a family of machines to be bought from 1996 on, through the next 2 decades. Goals include the introduction of real-time parallel processing, artificial intelligence, fiber optics, and VHSIC technology, and the introduction of distributed operating systems (e.g., in combat direction). The NGCR project formally began in February 1988, and an operational requirement was established in August 1988. The lead command, the Space and Warfare Systems Command, announced in December 1988 that a commercially developed backplane called the "Futurebus" had been chosen; this choice in turn would allow the use of many commercial components. NGCR also uses the new SAFENET I LAN.

◆ BuOrd/NavOrd Computers

The Bureau of Ordnance and its successors gave computers Mark numbers; these devices are outside the normal AN series. Many are still in use, covering the entire range from electro-mechanical analog devices to digital machines. The analog computers were often limited to a single role (such as trigonometric computation to allow for roll and pitch) and also to specific ballistics (not merely for 1 weapon, but even for 1 type of shell). They often also required considerable weight to conduct what might now seem rather trivial computations. Stabilization computers took data from a gyroscope (which was, in effect, a system sensor) and converted it into stabilizing orders. True general-purpose computing came only with Mk 152. The number of distinct computers declined sharply with the introduction of general-purpose types (many fire-control systems use such standard machines as UYK-7 and UYK-20).

Many of the analog machines transmitted their data by synchro, i.e., by turning a dial to which a distant dial was synchronized, transmission between the 2 being electrical. For example, Computer Mk 112 Mod 2 transmitted fuze time orders in the form of 32 sec/revolution. When digital devices replaced the analog units, special synchro-drivers had to be interposed.

Dates indicated in the text are often the dates on which nomenclature was assigned. For an entirely new machine, that might be some time before development was completed. However, for a Mod, that date is probably about the time tests were completed.

The computer series *did not* include the separate Torpedo-Data Computers.

Mk 1 Electro-mechanical analog computer of the Mk 37 Gun Fire-Control System, the first such device to receive a special designation (about 1937). Mk 37 was the first U.S. secondary-battery fire-control device in which the above-decks director was separated from the associated computer. Earlier main-battery computers were designated range-keepers, and this practice persisted through World War II in the case of heavy-caliber fire-control systems. A Mk 1A version was included in the Mk 54 fire-control system installed in a few postwar cruisers. Total weight was 3200 lb (2900 lb in some versions). Available ballistics, in the Mk 37 system, were 8-in/55, 6-in/47, 5-in/54, and 5-in/38. Maximum computing range was 18,000 yd. Maximum speeds: 400 kt horizontally, 250 kt vertically. Mk 1 introduced fully automatic rate control to U.S. practice, and the Mk 37 fire-

control system was the first U.S. naval ordnance application of closed-loop servo practice (initially experiencing severe problems because its feedback made it unstable). Most U.S. ships used the Mk 1A version; Mk 1B was modified for British (Admiralty) use. Mk 1A (and gun fire-control system Mk 37) could generate orders for other calibers, feeding 5-in orders through a Mk 20 converter (1953) whose computing servos combined several Mk 1A outputs into offset differences between 5-in/38 and 3-in/50 trajectories.

Mk 42 Ballistic analog computer of the Mk 56 gun fire-control system. One computer was needed for each set of ballistics to be computed. It operated by a mechanical linkage of 5 mechanical inputs, 1 manual and the others by servo. The results were converted into electrical analog form by the rotation of potentiometers, for introduction into an electric computing network. The unit for primary ballistics weighed 640 lb; the secondary ballistics unit weighed 550 lb, the saving presumably being the result of avoiding duplication between the 2. Ballistics included fuze time computation. Available ballistics were 6-in/47, 5-in/54, 5-in/38, and 3-in/50. Computing range was 15,000 yd.

Mk 47 Electronic/electro-mechanical analog computer of the Mk 67 and 68 gun fire-control systems, successors to fire-control system Mk 37. Weight: 5400 lbs in Mod 3 version (about 1954), 6000 lbs in Mod 4 version for Mk 67 fire-control system. Ballistics were available for the 5-in/54, 5-in/38, 3-in/70, and 3-in/50, and computing range was 18,000 yd. The second set of ballistics (for 3-in/50 or 3-in/70 guns) was provided by a converter Mk 20. This computer had 2 mechanical and 1 electronic sections. Mod 5 was simplified and repackaged (weight was approximately halved). It entered service about 1958. Mod 7 (1961) extended the computing range to beyond 72,000 yd. Target elevation data were entered either by potentiometer (from a Mk 119 computer) or by synchros (from a Mk 100). Mod 8 (1961) had transistors in place of the electronic tubes of earlier versions, as well as new plug-in electronic units (for easier maintenance). This version was part of the Mk 68 Mod 4 fire-control system. Weight was 2450 lb. In this version, maximum target range was 35,000 yd, and maximum range for gun orders was 20,100 yd. CG 26 and later ships had Mod 9, similar to Mod 8 but modified to work with computer Mk 116 Mod 4. Mod 10 (1965) time-shares Horizontal Relative Target Bearing, Star Shell Gun-Train Order, Gun-Train Order, Gun-Elevation Order, and Star Shell-Elevation Order computations and so eliminates the need for a Mk 116 computer. It allowed for ballistics for a new reduced-charge 5-in/54 round. It was used in the Mk 68 Mod 13 fire-control systems of FF 1078-class ships. Mod 11 (1969) included ballistics for RAP shells. It was equivalent to ORDALT 6948 applied to the Mod 10.

Mk 60 Computer for Mk 15 Hedgehog; it calculates and transmits projector train order and indicates time to fire from inputs of target angle, speed, range, depth, and bearing. Firing orders can be corrected to allow for target maneuvers almost up to the moment of firing. Mk 60 weighed 205 lb (plus 350 lb for the associated amplifier).

Mk 93 Surface gun computer (prediction, ballistic computation, trunnion-tilt correction) to supplement small antiaircraft systems (such as fire-control systems Mk 56, 63, and 69). It handles only 1 set of ballistics at a time, but those can easily be changed (ca. 1951).

Mk 101 Analog (magnetic amplifier) fire-control computer for the F-8D/E Crusader (AWG-4 system), to control guns, rockets, and Sidewinder missiles. AWG-4 included a Mk 11 computing sight and was typical of preintegrated airborne fire controls. The pilot selects the commence-firing range before taking off. Because there is no HUD, the pilot cannot see radar data and must, therefore, rely on tones in the headphones: a transfer tone (to indicate that the system has switched from fixed ranging to radar ranging), an alert tone, and a breakaway tone. The alert tone (1200 Hz) indicates that the pilot is half a second from the

firing point; it continues to sound until the breakaway tone (alternating 400/1200 Hz) sounds half a second before the pilot must pull away from the target. Before taking off, the pilot selects transfer ranges of 0, 600, 900, 1200, 1500, and 1800 ft, and breakaway ranges of 1500, 1200, 900, and 600 ft. The sight unit provides a lead angle, the pilot comparing the image of the target and an image centered in the sight. The gyro is initially caged, the pilot in effect estimating the angular speed of the target and pointing the airplane sufficiently off center to lead it. The gyro is then uncaged; and if the lead angle has been correctly estimated, the gyro image will move onto the target. This operation tacitly assumes a fixed value for the preset open-fire range, and the radar tone is used to indicate that the preset range has been met. Typically, a pilot has to track smoothly for 1–4 sec to line up the gyro sufficiently.

The computer causes the sight unit to generate the lead angle for obtaining hits. It controls the sensitivity (kinematic lead) and elevation and azimuth offsets of the gyro. It solves for projectile time of flight (lead time), with additional small corrections related to sight dome temperature. Average shell speed is computed from air density, aircraft velocity (fixed for a given type of airplane at the most probable combat speed), and gun or rocket ballistics. The computer calculates range rate from radar range. It must also take into account such factors as aircraft acceleration and angle of attack.

Mk 101 was a standardized computer, and different airplanes (and, for that matter, different weapons) used it with different adapter computers (not in the main computer series). Mk 101 differed from some previous aircraft fire-control computers in using direct rather than alternating currents; it worked in logarithmic terms largely using a summing or subtracting magnetic amplifier (numbers were converted into logarithmic form by passing currents proportional to them through a network whose output was logarithmic in form).

This computer is probably still in use on board French Navy F-8E(N) Crusaders. The degree of specialization is typical of an analog computer (although it was relatively easy to change the ballistics and other constants in this one, by inserting different adapters). Many aircraft, such as the F-4, had separate bombing and airborne fire-control sets.

Mk 108 Stabilizing computer for the Mk 105 underwater fire-control system (for the SQS-4 sonar and the Mk 11 Hedgehog), 1955.

Mk 110 Stabilizer for a Mk 15 Hedgehog projector, 1955.

Mk 116 Computer (750 lb) to supplement Mk 47 (and thus part of the Mk 68 fire-control system), to produce star-shell orders, 1950; later (about 1959) it was also used to compute gun orders and horizontal-bearing orders for RAT. Mod 3 was installed on *Charles F. Adams*-class destroyers. Mod 4 was the solid-state-electronics version, part of Mk 68 Mod 8 fire-control systems (1962). It could provide surface control only, for 3-in/50 guns.

Mk 118 Analog computer producing missile and launcher orders for Tartar (later SM-1MR) missiles, 1956; installed on board frigates and French Tartar ships. It was part of missile fire-control system Mk 74. The Mod 2 version (1963) eliminated the gun-order section and changed the launcher blind-zone computed output. Mod 4 was part of the Tartar fire-control system (Mk 74) planned for the carrier *Kennedy* (1964, 2000 lb).

Mk 119 Computer of the Mk 76 Terrier (later SM-1ER) missile fire-control system. Weight 4000 lb. It developed launcher and missile orders. The Mod 1 version, for the cruiser *Long Beach*, was compatible with WDS Mk 2. Mod 2 doubled the range (in response to Terrier development) and incorporated an up-and-over (proportional navigation) missile trajectory (1961). It was installed on board CG 26–28 and the carrier CVA 66. Mod 4 (1964) was designed to work with NTDS (about 3100 lb).

Mk 121 Stabilization computer to adapt the Mk 56 fire-control

system for use with the Mk 111 fire-control group and the ASROC missile (1959, about 150 lb).

Mk 123 Computer group for Polaris submarines (*George Washington*-class). A modified version (1963) could control all 3 versions of the missile (A1/A2 and A3).

Mk 124 Computer group for Polaris submarines. It incorporated a target-data input unit, which received ballistic data, bearings, trajectories, and wind spots.

Mk 125 Computer group for Polaris submarines.

Mk 126 Computer group for Polaris submarines.

Mk 128 Digital computer (1959) for analog-to-digital conversion and digital processing. Mod 1 (1962), for weapons-direction equipment Mk 2 (1962, six 600-lb cabinets), added a buffer for interface to NTDS; it included a cabinet that checked the processor. Total weight of this version was 3300 lbs.

Mk 129 Leveling computer (1963, 971 lb) for the level guidance platform and anti-circular-run gyros controlled by underwater fire-control systems Mk 113 and 117 (for torpedoes and SUBROC missiles). It initializes the SUBROC missile and prevents launches that would endanger the submarine.

Mk 130 Digital computer of the underwater fire-control system Mk 113 (1964, 1365 lb). Mk 113 was the first submarine fire-control system to incorporate a digital computer. Mk 130 received data via analyzer console Mk 51, calculating data for multiple targets and also for a consort (i.e., for tactics involving several submarines communicating with one another). There were 6 classes of data: (1) bearings; (2) bearings and range; (3) bearings and range rate; (4) bearings, range, and range rate; (5) target parameter constraints; and (6) bearings, range, range rate to consort, plus bearing of consort to target. Mod 1 (1972, 1372 lb) was part of Mk 113 Mod 8. It calculated target range by TMA, correcting input data by estimating sonar acoustic path, all under the control of analyzer consoles and the attack-control console.

Mk 134 Stabilization computer for underwater fire-control system Mk 114, 1960. Total weight was 160 lb. Mk 114 was an analog system; its successor, Mk 116, used a standard UYK-7 computer weighing 535 lb. Actual fire-control data processing was conducted in an attack console (Mk 53, in this case).

Mk 138 Designation applied (in 1960, long after it had become standard) to the standard submarine circular slide rule, a quintessential analog device. It calculated any 1 of 4 variables from the other 3: bearing rate, speed, range, angle on bow. Speed limits were 1–35 kt. The fixed part was 8 in in diameter, with a 4 $\frac{3}{4}$ -in moving disk showing bearing rate and angle on the bow on log and log-sine scales.

Mk 143 Position-keeping computer for wire-guided torpedo fire, providing command guidance and showing torpedo run and gyro errors. It replaced angle solver Mk 17 and torpedo director Mk 37 in the Mk 114 fire-control system. Mod 1 was for fire-control system Mk 105; Mod 2 was for Mk 111. This computer set torpedoes and displayed the set parameters. The original version incorporated ballistics for Mk 37 Mod 0 and Mod 1 (both high-speed) torpedoes. Mod 3 added ballistics for Mk 48 torpedoes (1965, 1275 lb). Mk 143 combined solid-state electronic and electro-mechanical components; it was programmed by relay switching. Target speed could be up to 60 kt, target range up to 35,000 yds, and target depth down to 3000 ft; torpedo range could be as great as 40,000 yds, and torpedo range rate up to 100 kt. The prototypes were installed on board the first 2 *Garcia*-class frigates in 1963.

Mk 146 Computer group for Mk 84 Polaris free-control system (1961).

Mk 148 Target card computer for Polaris (Mk 80 fire-control system, 1964). It computed geoballistic target information, producing punched cards that could then be inserted into the Mk

80 system. These calculations required 3 cabinets, measuring, together, 33 × 72 × 130 in.

Mk 151 Computer power supply for the Sea Sparrow (BPDMS) fire-control system (1966).

Mk 152 See CP-848, above.

Mk 153 Slide-rule computer for an antiswimmer weapons system (1967), providing elevation-angle data to fire an antiswimmer cartridge from a standard 81-mm mortar.

Mk 154 Digital solid-state computer for SPG-53A and B radars (Ordalt 6894) of the Mk 68 fire-control system. It replaced the 6G synchro unit (75 lb, 1968).

Mk 155 Supplementary ballistic computer (for extended-range and RAP shells) for the Mk 47 computer (1968).

Mk 157 Norwegian-built SM-3 digital computer of the Mk 91 (NATO Sea Sparrow) fire-control system (see the Norwegian section, above). It has DMA NTDS-compatible I/O channels and a teletype for on-line data entry (printed at 10 characters/sec). Input was by paper-tape reader. Mod 0 had a 16k memory. Mod 1 had a 24k memory and a magnetic tape reader (1200 rather than 300 characters/sec) (898 lb, 1981). In Mod 2, memory was increased from 24k to 32k. In Mod 3, ferrite cores were replaced by CMOS chips, and memory capacity was doubled (to 64 kwords, i.e., to 128 kbytes). Processing efficiency increased at least 25%. This computer is used in Mk 91 Mods 2 and 3 for the RIM-7M missile (1988, 898 lb).

Mk 159 Dutch Signaal computer (1972), for the Mk 94 fire-control system (WM 28); the Americanized version, using a UYK-7 computer, is Mk 92. This computer uses a 30-bit word (32 kword capacity, including 512 words of ROM and has 16 I/O channels. Clock rate is 102.4 kHz (i.e., 0.1 MHz). Dimensions: 52 in high × 20 in wide × 24 in deep.

Mk 160 Current standard gunfire-control digital computer, conceived to replace Mk 47 Mod 3 and Mk 116 Mod 3 (1974, originally 1290 lbs). It is the key feature of the Mk 68 Mod 15 fire-control system of modernized *C. F. Adams*-class destroyers and incorporates a UYK-20(V) computer (1290 lbs, 1977). Mod 1 is in the Mod 16 version of the same fire-control system. Mod 4, for the *Arleigh Burke* class (1985), incorporates the UYK-44 minicomputer (2170 lbs, vs. 2045 for Mod 3). Mod 5, for the *Iowa*-class weapons system, has 2 UYK-44 computers and a UYQ-21 display (2200 lbs, 1989).

Mk 161 On-board computer of the Sea Lance missile (5.2 lbs, designated 1985).

◆ A-12 Avionics Computers

IBM is responsible for all of the mission computers and common modules of the new A-12 attack bomber. Deliveries began in November 1989. Reportedly, the standard chassis is a $\frac{3}{4}$ ATR (air-transportable-rack) enclosure, which can carry up to 13 SEM-E modules (circuit cards) with a maximum total performance of up to 13 MIPS. There are 5 standard modules: a CPU running at over 3 MIPS, with 1.4 Mwords of memory; a data-processor module (DPM); a MIL-STD-1750A processor (approx 4 MIPS, 512k program memory, 16k EEPROM, and 4 standard I/O interfaces); a nonvolatile bulk-memory module (BMM), carrying 512k of CMOS memory, 16k of EEPROM for diagnostics, and 4 standard I/O interfaces; a multiplexed data module (MDM), carrying 2 dual-redundant 1553B channels, a MIL-STD-1750A processor, 128k of program memory, 16k of EEPROM, and 4 standard I/O interfaces; and a power-supply module (PSM) on a single SEM-E card. The MDM is based on IBM components already used in the LAMPS III helicopter and the B-1B bomber.

As of early 1990, A-12 avionics development was reportedly running behind schedule, and at least the first aircraft were expected to use A-6 avionics.

◆ DTC I

Hewlett-Packard HP 9020A/C (Model 500) workstation/computer, adopted as a standard naval machine in July 1984, is used in several major systems, including JOTS I. The 2 versions differ primarily in the quality of their color monitors, 9020C offering higher performance. The 32-bit microprocessor is a proprietary Hewlett-Packard chip containing 450,000 transistors, which was an order of magnitude greater than the level of integration achieved by competitors when the machine was introduced. Internal (RAM) memory: 2 Mbyte basic version, expandable to 14 Mbytes (naval versions typically carry up to 8 Mbytes). The machine normally accommodates two 5.25-in floppy disks and 1 or more (up to 7) hard disks (initially 20 Mbyte, but now typically 55 or 130 Mbyte; the final version [1989] could accommodate 304-Mbyte hard disks). HP 9020 was the first multiple-CPU 32-bit workstation; it can accommodate up to 3 floating-point math chips. Each CPU can directly address up to 500 Mbytes. Speed of the single-CPU version is 1.5 MIPS (based on an industry-standard mix of instructions, in which a VAX 11/780 runs at 1 MIPS); the 2-CPU version runs at 2.9 and the 3-CPU version at 4.3 MIPS. Other measures of speed: microinstruction cycle time, 55 nanosec; addition of two 64-bit floating-point numbers, 1.17 microsec; multiplication of two 32-bit integers, 1.25 microsec; multiplication of two 64-bit floating-point numbers, 1.28 microsec; load a register from memory, 550 nanosec.

DTC I was sold to the navy by Tetrtech, which added software and some minor hardware to the basic HP 9020. About 2500–3000 DTC Is were bought, for programs including FFIST (see separate entry), ICADS (integrated carrier ASW prediction system), JOTS I, POST (prototype ocean-surveillance terminal), SCATS (squadron-commander ASW tactical system), SIMAS (sonar condition prediction for SQS-53 sonars), SFMPL (submarine force mission-planning library), SPAR, TAWSIT (tactical ASW interim trainer), and TEPEE (see separate entry).

In each case, procurement of a non-MIL-STD computer, which was presumably less survivable than a standard military machine, was justified on the grounds that it was not mission-essential that a ship or force could still function (albeit on a degraded basis) if the computer failed. This practice is really justified by the sheer ruggedness of modern commercial equipment. In the CS@SE experiment described above, Sun 4/260 workstations and dual hard-disk drives were hard-mounted to the decks of both a missile cruiser and a carrier, with no apparent ill effects despite the lack of shock-mounting. The associated large-screen display did have to be realigned weekly or more often if the cruiser fired her 5-in gun. Compared to the UYK-series machines used in NTDS, CDS, and ACDS, the DTCs tend to have much less I/O capacity. Their availability inspired the development of powerful planning and tactical systems, such as JOTS.

DTC I succeeded HP 9845, a very similar but slower (about $\frac{1}{3}$ as fast) workstation introduced in 1977. HP 9845 was the navy commercial computer of choice, bought through the GSA. The DTC I contract enforced standardization in what was then termed a tactical decision aid.

Hewlett-Packard's Model 835, a follow-on to the 9020, was a competitor for the DTC II contract won by the ruggedized Sun-4. The Model 800 series uses a RISC-based architecture. A typical Model 835 runs at 6 MIPS and has a maximum RAM capacity of 112 Mbytes, with a maximum disk storage capacity of 9.1 Gbytes.

◆ DTC II

DTC II is a desktop tactical computer of the Flag Data Display System (FDDS), a ruggedized C3-4/110 manufactured by C3, Inc. of Herndon, Virginia. DTC II is based on the Sun Series-4/110 32-bit SPARC (RISC technology) microprocessor and has a VME internal bus (backplane) with 9 slots and a patented memory management unit (MMU). The MMU supports rapid switching among 8 register-resident processes. The microprocessor is capable of 7.5 MIPS when operating on integers. Clock rate is

14.28 MHz. Memory is 8, 16, 20, or 32 Mbytes; memory cache is 16 kbytes. The address bus is 28 bits wide (the data bus is 32 bits wide). The computer can support 15-, 19-, and 25-in monitors. Resolution is 1152×900 pixels, with a refresh rate of 66 frames/sec and a bandwidth of 93 Mhz. It can display 256 colors.

DTC II was chosen to succeed DTC I in applications such as JOTS because it was adapted to a much more widely used language (Unix rather than Rocky Mountain Basic) and because it incorporated a standard VME backplane. As in the commercial world, the backplane made it possible to incorporate special-purpose boards. For example, the version of DTC II used in FDDS has perhaps only 1 board in common with a standard DTC II computer. Reportedly, DTC II has proven less than sufficiently rugged in service, and it is not powerful enough to meet currently projected requirements.

◆ DTC III

As of the spring of 1990, a next-generation DTC was in the proposal stage, with a contract award expected in 6–12 months. The next-generation workstation is to embody much more powerful graphics, with a processing rate of 50–100 MIPS (as in DTC I/II, on a scale on which a VAX 11/780 has a speed of 1 MIPS).

The RFP for DTC III had not yet been issued as of August 1990. The question was whether it would be more than an upgraded Sun workstation, a more rugged and faster equivalent to DTC II. When the draft RFP, calling for a modified Sun, was issued, several RISC computer manufacturers protested that they could offer something more powerful, particularly in the area of hardware-implemented 3D graphics. The existing DTC II has relatively little graphics capability, and 3D graphics calculations are all done through software, consuming both memory and time. Originally, the RFP called only for a somewhat better equivalent to DTC II, which would have sufficed for existing applications. However, many potentially important future applications, such as integrated strike planning (see ISPS, below), involve inherently 3D data and extensive calculations (which amounts to graphics) using those data.

◆ AT&T Ultra-Dense Processor/DSP3

Developed under contract to DARPA, this new, compact, parallel processor is rated at 800 MFLOPS. The prototype, 9.5 cm square (12.7 cm including cooling fins), should begin tests in the fourth quarter of 1990, and production examples will be delivered beginning in 1992. The first planned application is to the planned upgraded version of the Mk 48 ADCAP torpedo. The processor consists of 8 stacked boards, each 150 mils (3.8 mm) thick, separated by rubber pads, with the controller and I/O board at the base. Each board carries 4 processing "tiles," and each tile is rated at 100 MFLOPS, using scalable DSP3 parallel-processing architecture (DSP3 was recently delivered by AT&T to DARPA). Each tile incorporates 64 kwords of 32-bit, 25-nanosec, static RAM. AT&T uses metal core boards to conduct heat and ground each set of processors; vertical interconnection to eliminate backplane losses (and to achieve a savings of 10:1 in volume); silicon-on-silicon technology (for high thermal conductivity and a 4:1 savings in board area); and low-dielectric insulation (for low interconnection capacitance and, thus, low power consumption). Although the current system has 8 boards, the controller can accommodate up to 10 (40 nodes, 1 GFLOP throughput). AT&T sees the computer not only as valuable in its own right but also as a building block of a future 1-TeraFLOP (1000-GFLOP) machine.

DSP3 (Digital Signal Processor 3) itself is a fast parallel processor developed by DARPA. Because the new machine has the same architecture, DSP3 can be used to develop its programs. DSP3 accommodates up to 8 processor boards as well as a 68030 control board and a 160-Mbyte hard disk, plus an Ethernet board and 4 VME expansion slots. The computer is built up from AT&T's 32-bit, floating-point DSP32C processors, each of which is associated with a routing chip (ASIC) and 256 kbytes–1 Mbyte of fast memory to form a processing node; each node runs at 40 Mbytes/sec on 4 channels, for a total of up to 160

Mbytes/sec. Throughput per chip is 25 MFLOPS. Each processor board contains 16 nodes and has a throughput of 400 MFLOPS (3.2 GFLOPS, then, for all 8 boards).

The processors communicate via a fast (40-Mbyte/sec) backbone that can be reconfigured for alternative processing topologies (linear mesh, linear systolic, binary and nonbinary tree, and hybrid) to handle different problems. Each processing element has 4 independent ports; the software changes the effective system topology by deciding which port to turn on. This flexibility, which is made possible by the software-controlled ASIC, gives DSP3 its processing power.

Likely applications for DSP3 are beamforming (including adaptive), neural networks, speech recognition, synthetic-aperture-radar processing, solution of large systems of linear equations, and image processing/object recognition.

AT&T also offers a related parallel processor intended specifically for pattern recognition, BT-100, in which the processors are linked into a binary tree structure (each has 1 input and 2 outputs into 2 other processors). Each board carries 8 DSP32 processors (64 MFLOPS of throughput). DSP32 is a 32-bit, 16-MHz chip with a speed of 4 MIPS/8 MFLOPS, and each processing element also contains 64 kbytes of local memory. The links between elements operate at 1 Mbyte/sec. The chip carries 2048 bytes of ROM and 4096 bytes of RAM and can connect to another 56 kbytes of external memory; it has 3 I/O ports: serial, parallel, and external-memory interface. The tree architecture makes for a series of comparisons with a widening range of options. BT-100 is designed to function as a peripheral to a host computer, containing 1-16 boards (56 MFLOPS for the first board, 64 for each additional board).

♦ Massively Parallel Computer/DAP

AMT's distributed array of processors was announced in 1990. A version was displayed at the October 1990 Association of Old Crows meeting, with the claim that something very close to a Cray supercomputer could be packaged in the guidance section of a Sidewinder missile (see Sidewinder in the Antiaircraft Warfare section for this application). DAP was designed specifically for image and signal processing. There are 2 versions, DAP 510 with 1024 processors (32 × 32 array) and DAP 610 (4096 processors, 64 × 64 array, nominally 400% of DAP 510's performance). Both systems are programmed identically, and application software written for 1 can be transferred directly to the other. Claimed specifications for DAP 510 are operation rate 10,000 MOPS, memory 4-128 Mbytes, internal bandwidth 1.3 Gbytes/sec, and I/O rate (concurrent input and output) 80 Mbytes/sec. For DAP 610 these figures are multiplied by 4, except that I/O is 160 Mbytes/sec.

Current experimental applications include SAR data compression (SARCOM) for transmission of radar ice pictures from Alaska to the Fleet Weather Center in Maryland and also for sonar applications. DAP was originally developed for SDI but is probably a key to effective image processing for staring, focal-plane, IR arrays.

The existing DAP computers are fairly large, but AMT plans to package a 4096-processor machine in 4 × 4 × 3 in. Projected characteristics: clock rate 20 MHz, master control unit 2 Mbytes of program storage, internal bandwidth 10 Gbytes/sec, I/O 320 Mbytes/sec, data memory 16-64 Mbytes, 1-bit performance 80,000 MIPS, 8-bit performance 40,000 MIPS, 32-bit floating-point performance 1.2 GFLOPS, power consumption 120-160 W. This is presumably the machine shown in the Sidewinder mock-up.

♦ HAP 1600

Word Length: 16 bits

Memory Capacity: 64 kwords of data, 2 kwords (80-bit words) of microcode (ROM), and 2 kwords of constants (ROM)

Speed: add time, 133 nanosec; multiply, 133 nanosec; divide, 6.0 microsec; 128-pt complex FFT, 450 microsec; 1024-pt complex FFT, 8.3 msec; 1024-pt IIR, 1.2 msec; 1024-pt FIR, 8.2 msec; memory cycle (16 bits), 267 nanosec (32 bits, 400 nanosec)

Instructions: 113 **I/O:** A-NEW channel at up to 1 Mword/sec

Honeywell's auxiliary processors (chips) are intended to supplement standard computers such as AYK-14. HAP 1601, a 16-bit pipelined fixed-point array processor, is the acoustic processor of the Mk 50 torpedo. HAP has also been embedded in a UYK-20 and in an Intel microprocessor. It calculates virtually any algorithm at 20 MOPS. Honeywell claims that throughput is boosted by a factor of up to 35, depending on application.

♦ L-304 (USQ-501)

Word Length: 32 bits

Memory Capacity: 4 kwords, expandable to 128k in 4k or 8k increments (ferrite cores)

Speed: memory cycle time, 1.6 microsec (4 kwords) or 1.8 microsec (8 kwords); add/subtract time, 14 microsec; multiply time, 44-72 microsec

Instructions: 62

I/O Channels: 64 (maximum transfer rate, 312 kwords/sec)

Litton's general-purpose computer is used by the Canadian and U.S. Navies. The technology is small-scale integration. The L-304 series was announced in mid-1965. Two L-304s form the central tactical computer of the E-2C. The Canadian version (USQ-501) is used in the CC-280 ("Tribal"-class) command/control system. The architecture of this machine is similar to that of the somewhat earlier U.S. CP-642 series, which performed an analogous role in NTDS.

L-304F has 5 memory modules, each containing 8k 32-bit words (only 4 of the 5 may be addressed at a time, a software instruction activating or deactivating a given module). The basic computer was designed so that it could be expanded to 80 kwords, but this option was not exercised. Input and output are exercised in blocks of 4095 words (32- or 8-bit), the length of the word depending on the number of data lines in the particular interface.

The central processor and memory connect to 4 buffer/controllers: a recorder/reproducer controller (RRC), an exchange buffer (EXB), an NTDS buffer, and a computer-control drawer (CDR).

The RRC connects to a 9-track magnetic tape unit, unpacking 32-bit computer words for storage in 8-bit form on tape; 8 data lines in each direction connect it with the tape unit. The tape unit is the system mass-storage device and can be used to read system programs into running memory.

The EXB connects with the ship sensors: the radar switchboard, the radar simulator, the ship's log and gyro (via a synchro-digital converter), the surface and air weapons, the EW system, and the underwater combat system. The EXB is known as an L-304F standard interface and provides ship sensors with direct access to the tactical data system. There are 32 bidirectional data lines.

The NTDS buffer has 4 NTDS fast channels; it connects the computer with Link 11, Link 14, and a 1532 (printer and paper-tape reader) console and has a spare connection (32-bit interface) that can be used to link it to another tactical-data-system computer. Link 14 is an output channel only (8 data lines). The Link 11 interface is a 2-way 32-bit channel, including an interface that changes the NTDS fast output of the computer to the NTDS slow mode of Link 11.

The CDR connects the computer to the displays. It connects directly to an electronic marker generator (EMG), fed by the situation display consoles (SDCs) and digital data indicators (DDIs). The system accommodates 2 DDIs and 8-10 SDCs.

System hardware is designed to time-share the different operational programs, allowing for up to 64 independent program levels, each allocated 2 status bits (active/inactive, executing or not) and 8 general-purpose registers. A program level may be active and executing, active and suspended, or inactive (and nonexecuting). Programs are assigned priority levels, and the executive program searches for the highest active level and starts it, suspending any other program levels. The search clock rate is 2 msec (i.e., the rate at which the master executive directs the hardware to search for and run the highest-priority active-program level).

The main operational program consists of 16 work tasks, each of which has a specified minimum period between consecutive cycles.

◆ Rolm 1666

Memory Capacity: up to 1024 kwords in 16-kword modules (plus 512-word ROM)

Speed: add time, 1.1 microsec; multiply, 5.3–5.5 microsec; divide, 9.3–12.7 microsec; floating-point divide, 15.9–16.7 microsec (single precision)

Instructions: 234

This microcomputer replaces the earlier UYK-19 in the current upgraded version of the Hughes Modular Combat System. It is used in the U.S. TFCC (initial version). It is identical to the earlier Rolm 1606 except that the former lacks a floating-point arithmetic processor. There are 3 degrees of precision: 32-bit single precision, 48-bit, and 64-bit double precision.

Memory can be divided into up to 8 distinct sections: the operating system, the DMA processor, and 6 user memories (up to 64 kwords each). These memory areas may be shared or they may be limited to each user. Of the total 1024 kwords, 64 kwords are 1 microsec core memory.

◆ System/4 Pi

The IBM military and space-program computer series was introduced in 1966; at that time it was unusual because it was an off-the-shelf modular series. System/4 Pi computers are used in the A-6E (TC-3), A-7E (TC-2), EA-6B, and AV-8B ARBS (SP-1); the LAMPS III display is run by an embedded System/4 Pi CP-3. These are all basically 16-bit machines (17 bits including the parity bit). System/4 Pi also appears in numerous missiles. There are 3 families: tactical computer (TC), customized processor (CP), and extended-performance computer (SP). IBM hoped to sell CP-series for shipboard fire-control systems but apparently did not enjoy any success.

Characteristics (as originally announced, 1966)

	TC	CP	SP
Data Word	16 or 32 bits	16 or 32 bits	16, 32, or 64 bits
Instruction	8 or 16 bits	16 or 32 bits	16, 32, or 48 bits
Memory	16–64 kbytes	8–32 kwords*	16–128 kwords*
Memory cycle	2.5 microsec	2.5 microsec	2.5 microsec
Add time	9–18 microsec	5–10 microsec	2.1–5.0 microsec
Multiply time	48–54 microsec	29.6–34.6 microsec	9.2–10.4 microsec
Instructions	54	36	70
Interrupts	1 level	4 levels	2 levels (one 6-level)
MTBF	7500 hrs	2500 hrs	not given

*32-bit words

A more powerful 32-bit Advanced System/4 Pi was introduced in 1970 and is used in the F-14. The advanced series consists of 3 families: advanced processor (AP), command/control (CC), and subsystem processor (SP). Applications include the space shuttle (AP-101) and the E-3 AWACS (CC-1), the latter being the most powerful of the series.

IBM's 1966 success in selling a version of System/4 Pi to the air force for the F-111 (a computer ultimately designated AYK-6) helped it displace North American Autonetics as the leading U.S. airborne-digital-computer manufacturer. System/4 Pi was conceived in the spring of 1965 as an alternative to the proliferation of special-purpose airborne computers, pressed by the new manager of the Federal Systems Division, B. O. Evans, against considerable internal opposition. During the next 18 months the originally planned family of 5 types was reduced to 3. Machines within families were differentiated in part by the addition of microprogrammed special-purpose processors. For example, a special sine-cosine calculator reduced computation time for these functions by 60%. IBM claimed that time for data correlation, e.g., in tracking, could be reduced by better

than an order of magnitude. From the first, System/4 Pi was designed to run programs that could be written and tested on commercial Series 360 computers.

◆ Univac 1230

See CP-855, above.

◆ Univac 1830A and 1830B

See CP-901, above.

◆ Intel Chips (iAx86 Series)

Intel produced the 8-bit microprocessor chips that began the personal-computer industry (8080, 8085). Military machines use 16- or 32-bit chips, which offer more processing power and also a larger number of potential memory addresses. The entire series is designed so that each later version can use programs written for the earlier ones. The important chips are the following:

8080 is the original 8-bit microcomputer chip. It appeared in 1974 and had 111 instructions. Because the address bus is 16 bits wide, it can address up to 64 kwords of memory, even though those words are only 8 bits in length. The bus bandwidth, a measure of maximum operating speed, is 0.75 Mbytes/sec, and register-to-register add time is 1.3 microsec. The chip has 256 I/O ports.

8085 is an 8-bit microprocessor, software compatible with 8080 but faster, with a 1.3-microsec instruction cycle.

8086 has the same architecture, addressing modes, and instruction set as 8088 (see below), but it has a 16-bit external bus and incorporates data pipelining for simulated coprocessing (time-sharing). Bus bandwidth is 5 Mbytes/sec, and register-to-register add time is 0.3 microsec. This chip appeared in 1978; it is the basis of the IBM PC XT. As a measure of relative speed, the clock rate of the XT, which has an architecture similar to that of the original PC, is 4.77 MHz, for an 8088-2 chip. Maximum clock rates: 5 MHz for 8086, 8 MHz for 8086-2. The associated math coprocessor is 8087.

8088 is the chip of the IBM PC and its clones. The chip is designed to connect to an external data bus 8 bits wide, but its internal bus is 16 bits wide, for faster and more precise processing. The chip uses a 20-bit address field so that it can address up to 1 Mbyte. There are 165 instructions. As a measure of speed, clock rate of the original PC was 2.0 MHz.

80186 is a faster version of 8086, made in 6- and 8-MHz versions. It enjoys twice the overall throughput of the 8086, partly because it has a faster bus interface (4 Mbytes/sec). It combines 15–20 of the most used 8086 system components into 1. Compared to the earlier machines, it adds 10 new instructions. The associated math coprocessor is 8087.

80286 is related to 8086 but uses 24-bit addresses and can thus directly address up to 16 Mbytes. Memory management (paging) allows 80286 to address up to 1 Gbyte in all. The instruction set has 24 instructions added to that of the 8088/8086. This chip is the basis of the IBM PC AT and AT clones. As a measure of relative speed, the clock rate of these machines is 8 MHz, although some clones have speeds as high as 12 MHz. Intel calculated that an 8-MHz 80286 has at least 6 times the throughput of a 5-MHz 8086. A special memory-protection feature separates data from system code and permits the separation of programs and data from different tasks running through the processor.

80386 is a full 32-bit microprocessor, capable of handling 32-bit words as units rather than as double-precision entities. It can, therefore, address 4 Gbytes of memory. Bus bandwidth is 32 Mbytes/sec, and register-to-register add time is 0.125 microsec. There are 154 instructions. 80386 is the processor of the IBM PS 2 Model 70. In comparison with the earlier 8088, the

Model 70 has an overall clock rate of 20 MHz. The Intel 80386 was introduced in 1985.

80486 is an even faster chip, in which an improved 80386 processor is combined with an improved 80387 coprocessor and 8 kbytes of cache memory, the total requiring 1.2 million transistors. The current 80486 runs at 25 MHz, compared to 33 MHz for the fastest version of the 80386; however, it has a much greater capacity because of integration within 1 chip. The new chip uses pipelining, whereas previous chips in the series took in their data 1 word at a time, the processor often having to wait until main memory could disgorge the data it needed. This waiting becomes more significant as the speed of the chip increases relative to the speed of the main memory, as a memory access must be made within an integer number of clock beats. As a result, many 80386 systems use fast cache memory, just as in larger computers. In an 80486, data are transferred to the processor twice as quickly as in the 80386 (1 vs. 2 clock cycles). Speed is also increased by widening the path from memory to chip, from 32 to 64 bits (i.e., taking in 2 words of data at a time).

As an indication of relative speed, an IBM PS 2 Model 70 with a 486 chip has a clock speed of 25 MHz.

Intel also produces a series of math coprocessors: 8087, 80287, 80387.

8087 is the 2-chip math coprocessor intended to work with the 8086. 8087 adds hard-wired arithmetic, trigonometric, exponential, and logarithmic functions, amounting to a total of 68 more instructions. It is a bit-slice processor, operating on numbers represented by 8-, 16-, 32-, and 64-bit integers and on 32-, 64-, and 80-bit floating-point numbers (the internal architecture of the chip is arranged in terms of 64-bit words). It has eight 80-bit individually addressable register stacks and 14 general-purpose registers. The net effect of 8087 is to multiply the arithmetic performance of 8086 by a factor of 100.

80287 is the coprocessor intended for the 80286. It operates on 32-, 64-, and 80-bit floating-point numbers and on 32- and 64-bit integers. It incorporates over 50 mathematical instructions beyond those in the 80286 repertoire. Clock rate is 6, 8, or 10 MHz, and it incorporates eight 80-bit registers (internal architecture uses 80-bit words).

80387 is the coprocessor intended for the 80386. Total capacity is 108 bytes.

◆ Intel RISC Chips

The i860 (80860) is a 64-bit, 33-MHz (it has performed at up to 50 MHz) RISC processor. The chip contains a RISC core, a floating-point unit (FPU), a memory-management unit (MMU), a graphics unit, and separate data and instruction caches; the entire chip contains over a million transistors. Several of the units employ pipelining to increase their speed; the RISC core pipeline consists of the fetch, decode, execute, and write instruction stages. The floating-point adder and multiplier each use a 3-stage pipeline, and there is a 3-stage pipeline to the external bus (for 3 instruction cycles). The core also uses a dual-instruction mode, executing 2 instructions at once (1 for the core, 1 for the FPU).

The chip has a total of 85 instructions, well down from its predecessors, but quite comparable with total instruction sets of the late 1960s.

Operating at 40 MHz, the chip can execute VAX instructions at 33 MIPS, which is faster than a standard VAX (see below). At peak (which cannot be sustained in a normal program), it executes 80 Mflops in single-precision mode and 60 Mflops in double-precision. This chip can execute a single-precision 1024-point FFT in 1 msec, which is faster than many current dedicated chips. In comparison, a new specialized IBM FFT chip, FTM-4, which is to become available late in 1990, can execute the same operation in 0.078 msec (78 microsec) or a 4096-point transform in 333 microsec. In one current application, i860 is credited with a processing speed of 66 Mflops.

One reason for the very high speed is that the chip can execute

more than one instruction per clock cycle, a performance previously not attainable in a microcomputer chip.

◆ Motorola Chips (68000 Series)

The Motorola chips were first mass produced as the basis of the Macintosh personal computers; their high speed made possible extensive graphics. All of the chips in the series are upward compatible (e.g., 68030 can execute 68000 programs, but not necessarily the other way around). The important chips in the series are the following:

68000, the first in the series, could bit-slice, handling data in segments of 8, 16, and 32 bits. The basic word is 16 bits, but the chip also operates on long words (32 bits). The chip is unusual in having 2 different operating modes, a supervisor mode and a user mode. Supervisor mode instructions, which are used to run the screen in a Macintosh, take priority over user instructions, such as those for computation. Presumably, the bit-slicing is designed for fast graphics since the screen pixels generally are not specified by full 32-bit (or even 16-bit) words. Heavy use of the supervisor mode would slow computing, as many Macintosh users have found. There are 203 instructions. As an indication of speed, the original Macintosh ran at a clock rate of 8 MHz. This chip has a 16-bit data bus and a 24-bit address bus; it is a 16/32-bit microprocessor. The 24-bit address bus suffices for 4 Mwords (although the original Macintosh was limited to 512 kbytes). There are 2 other versions, 68008 (8-bit data bus, 20-bit address bus) and 68010 (which introduces virtual addressing and uses some different instructions).

68020 was the first full 32-bit microprocessor in the series. It could directly address up to 4 Gbytes of memory. The chip includes a 256-byte instruction cache for higher operating speed, and it uses pipelining. Alternative processing speeds are 12.5, 16.67, 20, 25, and 33.33 MHz. This chip can be combined with the 68881 and 68882 math coprocessors and also with the 688851 paged memory-management unit. Up to 8 coprocessors can be accommodated.

68030 is a faster equivalent to 68020, with both instruction and data caches (256 bytes each), and it has more sophisticated pipelining compared to that of 68020. Processor speeds are 16.67, 20, 25, and 33.33 MHz. This chip can be combined with the 68881 and 68882 math coprocessors, up to 8 of which can be accommodated.

68040 is the latest in the series, employing several parallel processors within 1 chip. It combines a main (integer) processor comparable to 68030 with a floating-point unit (FPU), which in effect replaces a coprocessor; memory-management units; and 4-kbyte instruction and data caches. The chip uses multiple independent pipelines and multiple internal buses. The main processor operates at 20 MIPS, and the FPU operates at 3.5 Mflops.

68881 is a floating-point coprocessor designed to operate with 68020 or 68030. It uses 2 kinds of extended-precision data, a long word (80 bits: 15-bit exponent, 64-bit mantissa, 1-bit mantissa sign) and a shorter word (67 bits), the latter for intermediate-precision operation at very high speed. The chip uses 46 instructions (including 35 arithmetic operations), and it carries 22 constants in on-chip read-only memory (e.g., pi, e, and powers of 10).

68882 is an alternative math coprocessor that operates nonconcurrently with the main chip; it can control the bus in the chip independent of the main processor, a feature that can make for higher overall performance.

◆ Motorola RISC Chips (88000 series)

The current 32-bit RISC units are the MC88100 CPU (including a floating-point unit) and the 88200 cache and memory-management unit (CMMU). Typically, one 88100 is connected to two 88200s by a 100-Mbyte/sec bus; the two 88200s provide separate 16-kbyte caches of instructions and data. Motorola

calls the integer and floating-point arithmetic units special-function units (SFUs), and the instruction and physical architecture of the 3-unit chip are designed to accommodate up to 8 SFUs, some of which may be special purpose. Up to eight CMMUs can be attached, for a total cache of 128 kbytes. Other current RISC chips do not have on-board floating-point capability; typically, the central processor and a separate floating-point unit are paired. The 88100 processor has 51 instructions (and uses 7 data types). It has 4 separate buses: a 30-bit data address bus (1G addresses), a 32-bit data bus, a 32-bit instruction address bus, and a 32-bit instruction bus.

In a typical application, the 88100 runs at 20 MIPS (microcomputers using it run at 25- or 33-MHz clock speed). Motorola has indicated that in the future it may redesign the basic RISC chip with a 64-bit bus for faster floating-point arithmetic. It may also move a 16-kbyte cache onto the basic chip. Data General and Motorola have announced an enhanced version of the 88000, for delivery in 1992, which should have up to 10 times the performance of the current version.

◆ VAX

Some current machines are described as micro-VAX types. VAX itself is a Digital Equipment Corporation 32-bit minicomputer series replacing the earlier 16-bit PDP-8 and -11 series. Micro-VAX refers to a word length and an instruction set; 1 advantage of a micro-VAX is that its software can be developed on a standard VAX machine. The current VAX 8842 accommodates 0.256-1 Gbytes of memory and executes instructions at a rate of 22 MIPS.

TACTICAL DATA SYSTEMS

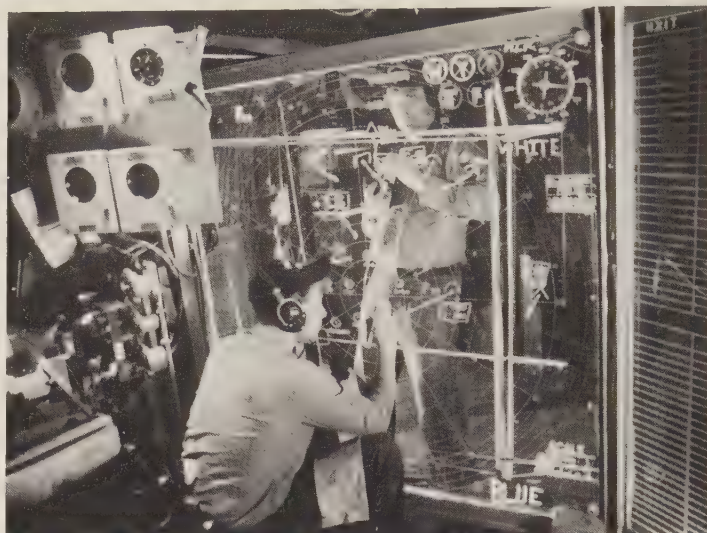
Tactical data-handling systems, or combat-direction systems, perform 2 related functions. First, they integrate available sensor data into a meaningful tactical picture, generally in the form of a 2D summary (or compiled) plot of the surrounding sea and air area. Such a plot includes some attempt to identify the occupants of that surrounding area, at least as friendly vs. enemy. In this sense tactical data systems are command-decision aids.

Second, they often partially or completely automate the results of decisions taken by means of the plot. For example, using an electronic plot, an officer may designate a target for attack. This designation at a console in CIC will result automatically in the proper orders being given to, say, a surface-to-surface missile launcher. In some systems automation extends further. The combat system identifies particularly urgent threats and initiates reactions (such as missile firings) against them. In such cases the display allows the monitoring officer to abort the reaction while it is being made.

The sensors provide instantaneous data: current locations of targets or, in the case of passive sensors (ESM and sonar), lines of bearing. In many cases automatic combination of different sensor data (including data from off-board sensors, such as radars or passive devices on other ships or aircraft) can materially improve the total picture. However, *no* instantaneous picture is really useful for tactical decision making since the essence of the tactical situation is its dynamic. The value of the plot is that it shows not only where everything is at any precise moment, but also enough of the history of the movement of any target to permit projection ahead. Integration of ESM and active-sensor data may also be valuable as a means of *identifying* given tracks.

Much of the purpose of the system is often threat evaluation and weapons assignment (TEWA). Many current systems claim to offer a degree of TEWA, but their capabilities often entail little more than a comparison of range and rate of approach, on the theory that a fast-moving inbound object is likely to be a more serious threat than a slower object farther out. That assumption is relatively naive. The next stage is for the system to try to identify targets by type and then to use an internal data base to advise the monitoring officer (in U.S. practice, the TAO) of what threat each target represents.

Plots long antedated electronics, and the development of computerized tactical data-handling systems was driven initially by the need to compile tracks more rapidly than could be done by hand. That requirement particularly applied to complex air situations, which developed very rapidly and demanded rapid decision making and quick responses. Surface and ASW automation were slower to develop, and indeed many modern frig-



The World War II CIC was a manual means of summarizing all available tactical data; a modern system, such as NTDS, automates the process. Here a vertical plot is maintained on board the battleship *Iowa* in 1984; standard NTDS symbols are used. (U.S. Navy)



A computer can draw synthetic video on a screen. This is a cursive display, in which the synthetic video is superimposed over raw radar video. The next stage is a full raster-scan display, in which the computer can process the raw video on the screen. This ASA-70 console is on board a P-3C Orion. (U.S. Navy)

ates lack automated plots of any type. It may be that the driver toward automation in smaller ships, such as large fast attack boats, is primarily the need to limit manpower while still taking advantage of external sources of data, such as data links both to shore and to airborne radars. Only in recent years has automation become so inexpensive that it can easily be applied to fast attack boats.

The big, digital, tactical data systems (such as the U.S. NTDS) began as air-defense systems, oriented toward the control of interceptor aircraft. They, therefore, emphasized the ability to keep track of numerous relatively distant airborne targets and could tolerate some imprecision in tracking since the pilot (usually assisted by the aircraft's radar) could make up for inaccuracies of a few miles.

There was also a separate line of development, coming out of gun (and then missile) fire control. Typical World War II practice was to assign 1 director (i.e., 1 fire-control channel) directly from CIC or the Operations Room to a target. That practice made for good tracking, but reassignment of the fire-control channel after a target was shot down was necessarily slow since the air-search radars feeding the CIC had broad beams. The solution was to provide a narrow-beam TWS radar dedicated to gun fire control and to maintain more tracks than fire-control channels. When any fire channel (weapon plus director) destroyed a target, it could be reassigned (designated) from 1 of the tracking channels. This practice was scaled up when surface-to-air missiles were introduced; in both cases, the tracking channels were carried by a WDS (U.S. systems of this type are described in the Antiaircraft Warfare section). The U.S. Navy developed one short-range radar specifically for gun designation, SPS-3; the longer-range pencil-beam air-search radars (SPS-39/52) were, in effect, missile-designation radars. These sensors were equivalent to British target-indication radars; the Royal Navy introduced its narrow-beam designation radars earlier because its wartime and early postwar air-search radars had much wider beams than equivalent U.S. sets.

WDSs naturally required a much higher degree of accuracy than the longer-range fighter-oriented combat-direction systems. Ultimately, however, they had much the same function. In most cases the ship's CIC fed targets to the WDS; and when the former was automated (in the U.S. case, using NTDS), the latter could be integrated into it in the form of WDS Mk 11. As missile ranges increased, and as the available battle space expanded, however, the distinction between a long-range air-search radar and a radar suitable for designating shipboard weapons lost much of its logic. The first U.S. attempt to grow a shipboard sensor/combatt system up out of the shipboard weapons was the abortive Typhon, which used an electronically scanned SPG-59 radar. The successful attempt was Aegis. The SPY-1 Aegis radar has a very narrow beam because it is primarily a weapons-designation and -control radar. That characteristic in turn makes for very effective air surveillance, since the radar very rarely sees 2 objects in any 1 search cell (range $\times$ bearing $\times$ altitude) and thus rarely confuses tracks.

The big Western automated, digital, fighter-oriented systems are all descended from a Canadian project, DATAR, conceived in 1949. At that time the U.S. Navy was working on an analog air-plot-compiling system, EDS (Electronic Display System), and the Royal Navy was working on 2 analog plot-compiling systems, CDS (Comprehensive Display System) for air plotting and Cambria for ASW. In each case, the objective was no more than a faster and more accurate compiled plot; any use of the data in the compiled plot would have to be by the officers on watch because of the limits inherent in analog operation. In each case, too, the system was initially based on own-ship inputs only, without any provision for an external data link (although EDS did include a data link in its operational form). The inventors of DATAR chose to represent data in digital form because they could be processed beyond the plot, and also because they were easier to store for protracted periods (analog data had to be stored in delay lines). From the first, DATAR included a digital-data-link concept.

In 1950 and 1951 the Royal Canadian Navy let a contract to CDC for a digital tactical trainer (the Canadian Radar Action Trainer, CRAT), and to Ferranti Canada for the tactical management system, Digital Automatic Training and Remoting (DATAR). The associated digital link was first demonstrated in Ottawa in 1950, data being transmitted from Toronto at 500 bits/sec. At this time both the U.S. and Royal Navies considered the approach far too complex for shipboard use, and the Royal Navy tried to sell its CDS to the U.S. Navy. However, the Canadians persevered and demonstrated a crude form of DATAR—with hard-wired logic, a magnetic-drum memory, and a UHF data link—in August and September 1953 on Lake Ontario, aboard the minesweepers *Digby* and *Granby*.

This demonstration included the first use of the ball tracker now universal in Western tactical data systems. As in the later NTDS, the operator could strobe and hook selected targets, transmitting digitized information into the system. System capacity was 64 targets in a tactical area of 80×80 miles with 40 yd resolution. The computer outfit occupied nearly the entire aft end of each sweeper, using 3800 vacuum tubes per ship (transistors were not yet mature enough); there were severe overheating problems. Considerable interest was shown by both the Royal Navy and the U.S. Navy, but the Canadians suspended work in 1955 because of a lack of funds. At that time the associated computer was a proposed 1-kbyte solid-state machine. DATAR was turned down for the *St. Laurent* class and for the carrier *Bonaventure* in 1955, and then for the *Restigouche* class in 1958.

However, with the appearance of transistors, it was clear to both the Royal Navy and the U.S. Navy that digital systems were practicable; DATAR showed how they could be built. In 1954 the Royal Navy halted work on CDS and Cambria and began design of a hard-wired digital system, ADA. It was based on the centralized CDS approach, with data broadcast by a master ship to other ships of a group. ADA was approved for fitting on board carriers in 1955 and ultimately led to the present ADAWS.

The U.S. Navy established Project Cosmos at the Fleet Programming Center at San Diego; it produced NTDS, which was heavily influenced by DATAR experience (and also by DATAR personnel, such as Stan Knights, the developer of DATAR and its trackball, who was acknowledged in 1960 as the father of NTDS). DATAR also heavily influenced the land-based SAGE air-defense system. Litton sketched an airborne data-handling system based on DATAR in the latter part of 1956; it ultimately became the U.S. ATDS system, carried by E-2s.

Both in Britain and in the United States, the service or the associated defense ministry was the system integrator. It selected contractors for the components, such as the computers and displays, but it retained responsibility for overall system design. Programming was a particular problem, especially since the early systems had to be written in machine language rather than in higher-level language. As a result, program maintenance was extremely difficult: machine-language programs are difficult to understand and thus to debug.

The U.S. approach was to accept commercial software production, with maintenance by naval personnel. However, because so much programming was done in machine language, maintenance was a serious problem, and contractor personnel had to remain at the Fleet Programming Center for many years. The Royal Navy used a team of naval officers to set down specifications for ADA and then ADAWS clear enough to enable contractors to program. That approach proved extremely laborious, and the result was inflexible and difficult to maintain. The Canadians later opted to teach naval officers to write the required software.

The U.S. Navy transferred expertise to France and Italy; early French SENIT and Italian SADO systems are essentially NTDS clones. In each case a national naval programming center was set up. The West Germans initially collaborated with the French, and their SATIR can be considered a second-generation NTDS clone. The newer Spanish TRITAN is also essentially

NTDS. All of these systems employ (or originally employed) standard U.S. Navy or UNISYS computers.

The Dutch SEWACO system is broadly analogous to NTDS but differs considerably in computer configuration.

The major architectural choice in centralized systems is the extent to which the single central computer conducts calculations beyond maintaining a coherent current tactical picture. In the U.S. system, there was a very limited degree of threat analysis, but assigned targets were handled by local computers (fire-control systems) separate from the central computer. The Royal Navy chose a very different approach, in which the central computer was responsible not only for the tactical picture but also for fire-control calculations: many British ships lack any separate fire-control system.

The U.S. choice was driven by the desire to simplify, so as to get NTDS into service as soon as possible, and also probably by fears that such centralization would make it very difficult to program the same sort of system for such radically different applications as carriers and missile cruisers. Moreover, it was easier to insert a relatively decentralized system into ships originally built with separate fire-control systems. The U.S. Navy was also willing to buy a larger number of separate computers. The British applied their ADAWS, initially at first, to ships that would be newly built, so they could make their choice more freely. They also almost certainly wanted to minimize the number of computers required. Hence the need for so many specialized versions of ADAWS.

The boundary between a highly automated fire-control system (which can be fed by a command/control tactical data system) and a full command/control system incorporating fire-control calculations is not very clear. For example, British Type 21 frigates use the CAAIS tactical data system in combination with a WSA 4 automated fire-control system, but some systems descended from WSA 4 can carry out tactical-data (i.e., CIC) functions by themselves. Similarly, it is not always clear whether the Swedish 9LV-series systems are pure fire controls fed by a separate tactical data-handling system, or are themselves highly integrated tactical data/fire-control systems.

The next stage was federated processing, using the naval equivalent of the minicomputers of the late 1960s and early 1970s. At this stage distribution implied considerable degradation in performance, and it was rarely complete. The original impetus was probably British, reflected in the CAAIS systems and then in the Ferranti WSA series. In these systems much of the processing is done by dedicated computers, to reduce the load on the central computer. However, the central computer is still essential as the repository of the compiled tactical picture.

Compared to a fully centralized one, a federated system has a very important advantage. Each console can be programmed independently, so new systems and new functions are relatively easy to fit into the system. Only the channel between the console and the central picture-keeping computer is firmly specified (e.g., the protocols by means of which the console changes the central picture and by means of which it taps that picture). Presumably, the consoles can be separately wired to the sensors feeding them and to the systems they control.

In a federated system, then, the different computers are all directly wired together. Each, therefore, must control system I/O, as well as its own specialized operations. As the load on the system as a whole rises, message handling comes to occupy more and more of the time and power of each of the computers. The system as a whole may be difficult to program (and its behavior difficult to predict) because the operation of any computer in the network depends so intimately on calculations conducted by the others. For example, in a system such as CAAIS, the picture-keeping computer feeds the fire-control computer with target-position data. However, when the latter fires a weapon, it must report weapon trajectory back to the picture-keeper, so that the latter will not count the fired weapon (or, say, its dropped booster) as a new and legitimate target.

There are 2 quite distinct federated architectures. One is star-

like: the picture-keeper connects to a series of secondary machines, each of which connects to particular sensors and/or weapons. CAAIS is a case in point. The other is a linear or ringlike combination of computers, each assigned a particular role, and all wired tightly and directly together. The latter architecture is a step toward a fully distributed system, but it is very different because of the tight relationship between the computers in the network. In the latter case the key feature is that messages are sent directly from computer to computer, without any intervening data bus. Some messages may have to pass through several computers (which may not operate on them) before reaching the appropriate address. The effect of a data bus, if it is combined with the appropriate software, is to separate messages and message handling from the main computers. As in a telephone system, messages need not pass through machines that do not need to hear them.

Federated systems were invented because totally centralized ones have several major drawbacks:

First, the I/O channel of the picture-keeping computer is a choke point whose capacity may be easy to exceed, given modern automatic-detection radar systems.

Second, the more centralized the computer, the more separate functions it must perform on a time-shared basis. The greater the load of data running through the system, the more difficult such time-sharing becomes, as ultimately there is only 1 processor to carry out all the different functions. The British CACS system failed for exactly this reason: as functions were added, it just did not have the capacity to accommodate all of them. It had been just sufficient for a pure ASW ship, but the addition of Sea Wolf must have created problems. The addition of a 4.5-in gun, itself imposing no great computing load, even so was reportedly the final straw.

Third, the computer itself is a point of vulnerability. If it dies, so does the system. In some cases the central computer is really 2 or more machines sharing the computing load. If 1 dies for some reason, the system can be reconfigured to run on the remaining machines. However, reconfiguration normally takes some time, even if some of the machines are running (rather than quiescent) spares. Any temporary loss of the overall tactical picture can be disastrous since platforms reasonably close together may be confused once the system is revived. This is not a new problem, and it has never really been solved.

Fourth, a highly centralized system is not amenable to quick modification. The more centralized the system, the more all-embracing its program and thus the less it can accommodate changes, such as changes in the details of a missile that it controls. This problem also applies to sensors and consoles effectively hard-wired into the central machine.

Against these disadvantages, the central machine has a very important advantage. Since both the tactical picture and at least some of the system functions are bundled together in one machine, it can (at least in theory) execute those functions very quickly to respond to a rapidly developing tactical situation. Clearly such speed can be achieved only if the number of bundled functions is carefully controlled, so the ideal may be a compromise between a fully centralized system and something more federated. The argument against full federation is that each application must wait until it can ingest the tactical picture (or a portion thereof) from the picture-holding (plot-compiling) computer. The argument against full distribution (no central processor at all) will be that each subprocessor must bundle what amounts to a tactical picture and its own application, and that it must lose processing time while amending the tactical picture it holds (using messages from the other processors).

At present, of the major Western combat-system developers, the Netherlands (Signaal) and the United States (NTDS) have opted for more or less fully centralized systems, although considerable amounts of sensor and weapon processing are done outside the central computer. Japanese combat systems are very similar in outline to NTDS. France and Italy have opted for federated systems (TAVITAC, IPN series). Britain, which in the

past favored centralized systems, has opted for fully distributed ones. Of the major foreign buyers, Taiwan has used the H930 modular (distributed) system for some time, and it appears that Korea has similar views. At least in the case of Taiwan, the survivability of the system is an important consideration in making a modular system attractive.

As minicomputers became more powerful, a greater degree of distribution became attractive. The main exemplars are probably the Canadian SHINPADS, the U.S. (Honeywell/Hughes) H930 Modular Combat System, and the British Ferranti 500 and NAUTIS. These systems operate without any central computer at all. The consoles all link to a high-capacity data bus, and all benefit from data-base modifications initiated by any console. This scheme is similar to that employed in fleet-level NTDS, in which all ships share a common tactical picture, but the picture as a whole is not refreshed periodically. Instead, changes are propagated through the system.

For details of the operation of such a distributed system, see the discussion below of the U.S. H930/MCS.

Current distributed systems are based on modern minicomputer technology, the de facto standard apparently being the 68000- or 80286-series processor and the VME internal bus. Examples include the British MINOS, the new Litton console, and the new standard German console.

There are 2 quite different distributed architectures. In 1, weapons, sensors, and processors all ride a common ship bus. Examples are the Hughes H930 and the Plessey NAUTIS. Such a system has no bottlenecks at all. Each processor can execute any function (e.g., track keeping or gun fire control), since all share the same stream of data and messages.

The alternative is to arrange the processors in an LAN, a special-purpose data bus. This bus in turn connects to the weapon/sensor bus or buses. The LAN acts as a central computer complex; but unlike a single-computer system, it degrades gracefully. Each machine in the LAN carries its own version of the tactical picture, updated by actions taken by the other processors (and transmitted within the LAN). Such a system has the advantage that intra-LAN message traffic need not compete with the traffic along the weapon and sensor buses, so picture updates can be quicker and more complete. On the other hand, the nodes at which the LAN connects to the weapon/sensor bus(es) form points of vulnerability. The LAN type of architecture is typified by the Dowty-SEMA SSCS (British) and by the Contraves Cosys 200 (Swiss).

Aside from computer power, perhaps the single central issue in combat-system design is the operator-machine interface. Information must be presented in a manner best suited to very rapid decision. Just as a computer is limited in its throughput, a human operator is limited in the ability to process data presented visually. Different manufacturers have had markedly different responses to this problem. In the case of on-line data, there is a real question as to just how much supplementary data an officer in combat can or should absorb. Some alternatives are described in greater detail below.

In at least 2 systems, the U.S. ACDS (Hughes) and the British Ferranti System 500, effort has gone into supplementing the usual track information with on-line data describing the various targets. The on-line information may be limited to what can be presented in tabular form, or in a very powerful system it may be applied automatically to the track plot. For example, a typical system shows only that an enemy submarine is present at a particular place and that it is traveling at X kt along heading Y. The next stage would be to permit the system to register that the submarine is, say, an Oscar. Once a detailed identification had been made, the system might have an on-line data base that an operator could read. The ultimate stage would be for the system to react automatically to identification by showing, for example, the keep-out zone within which the Oscar might be expected to fire, or perhaps the optimum sonobuoy field locations required for successful prosecution, or even the expected flight profiles of the Oscar's missiles.

Console displays have gone through 3 generations.

The first are radar (analog displays), on which some digital symbols can be superimposed. They can be described, then, as analog with digital injection. The electron guns creating the analog and digital symbols are entirely separate, and the only connection is through the brain of the operator. Many early NTDS consoles exemplify this type of operation. Some early ESM (strobe) displays, on which signal digital data could be superimposed, are of this type.

Then there are pure synthetic-video displays, equivalent to early personal-computer displays. These displays are often described as *cursive* because each symbol is separately written out. They can show symbols and line elements, but they cannot address each pixel of the screen and thus cannot easily combine pictures from alternative sensors. Such displays cannot easily fulfill multiple functions since they cannot be used to dissect or display raw video of any type. Most current displays are of this type.

Then there are pure raster-scan displays, in which the display computer can separately address each pixel on screen. Unlike the earlier radar-cum-symbol displays, raster-scan displays are not synchronized to any particular mechanical radar scan rate. Instead, radar-video data are scan converted to a form compatible with raster display. After such conversion, two dissimilar radar pictures can be displayed simultaneously (e.g., superimposed in different colors). A fully rastered display can show different pictures side by side (windowing) in different scales. Such displays are probably ideal for cross-matching sensor data and are the current trend. They require vast processing power since there are no (physical) hardware character generators.

An important current issue is the value of color. It is argued that the use of color greatly increases the density of information that can be presented, and that monochrome displays cannot begin to provide enough. On the other hand, many people are moderately color-blind, and it may be that a very complicated display overloads the brain of the observer. This is a very difficult practical problem since the issue is one of overload *in combat*, i.e., under great stress that cannot readily be duplicated in a peacetime experiment.

There is also the much larger issue of man-machine interface in the combat system as a whole. The displays are there to help operators compile a tactical picture usable by a decision-making officer (a TAO in U.S. parlance, a PWO in British parlance). That officer may want a composite or summary display physically large enough so others, such as the CO, can discuss the tactical situation. It is difficult to build very large CRTs; this is the same limit that applies to large-screen televisions. At least as of a few years ago, the effective limit on CRT diameter was about 22 in, which is why 22-in displays are so common in the catalog that follows. The current U.S. solution, as manifested in the Aegis system, is a projection screen, similar to that used in current large-screen televisions. Its lines of sight will vary because of vibration, so the image may not be clear, especially during a hot action. At one time the British used a small CRT, photographed it, rapidly developed the film (in about 4 sec), and projected the slightly time late result over a 3-ft distance as the summary (PWO) plot. Some other systems, such as TAVITAC, drive an electronic plotting board, which becomes a summary display.

The ultimate solution to this problem, a large flat-screen television using LCDs, is still some time in the future.

There are also important ergonomic issues. Before computers, the summary plot was a horizontal plotting table, marked up in grease pencil. Generations of naval officers became familiar with it and expected its electronic equivalent to look roughly the same. Numerous systems, therefore, employ horizontal displays, sometimes with several operator positions arranged around them. On the other hand, when CICs were invented, so were vertical plots. A vertical glass board was easier to plot against, and the plotters could work on 1 side while the tactical officers read the other.

It is probably easier for a single operator to read a vertical plot while seated at an associated keyboard. As long as each operator

has a personal console, then, vertical CRTs (similar to those in computer workstations) are probably preferable. Certainly U.S. and U.S.-inspired systems are so configured. As soon as multiple operators must interact at a single summary display (e.g., to save CIC space), then presumably the horizontal or near-horizontal display comes into its own. This choice might be exemplified by the Swedish CEPLO (but note that the Danes are replacing CEPLO with a Terma TDS incorporating vertical screens).

One other line of development deserves mention here: the development up from simple navigational plotting tables. The most elaborate current version is the British CANE. Before World War II, both the Royal Navy and the U.S. Navy developed dead-reckoning tracers, devices in which a spot of light representing a ship's position was driven over a chart. The inputs were ship's speed and bearing. The British version was the ARL (Admiralty Research Laboratory) plotter; the U.S. version was the DRT.

The postwar U.S. NC-2 is the main plot of ships, such as *Knox*-class frigates, which are not equipped with a fully electronic tactical data system. Besides the spot indicating ship's position, 4 targets can be indicated by other spots of light. Inputs are sonar, standard radar indicators (SPA-25 and -50), and a fire-control radar. The points thus displayed are tracked manually, and the only outputs are manual. NC-2 is used primarily for ASW.

DES Defence Equipment and Systems, Ltd., formerly Laurence Scott Defence Systems, Ltd., which manufactured the ARL table, produces the British equivalents of NC-2, the SPL series plotting tables. The current versions store and display own-ship position with automatic scale calculation and chart alignment correction. They can add such tactical features as processing, display, and prediction of contact and target-vessel positions. The simplest of the current series, the "DRT" version, displays own-ship position as a point of light (as in earlier systems) but can also automatically plot using a pen driven by the same X-Y carriage as the light projector. As in the U.S. NC-2, ship's navigational data are taken from the compass and log via synchros (200 pulses/nm, 360°/rev of the compass synchro); it can also be inserted via a keyboard. Radio navigational aids can be connected as an option. The associated chart can be as large as 1016 × 675 mm (40 × 26.6 in); plotting area is 935 × 650 mm (36.8 × 25.6 in), and scale is 1:2000–1:5,000,000.

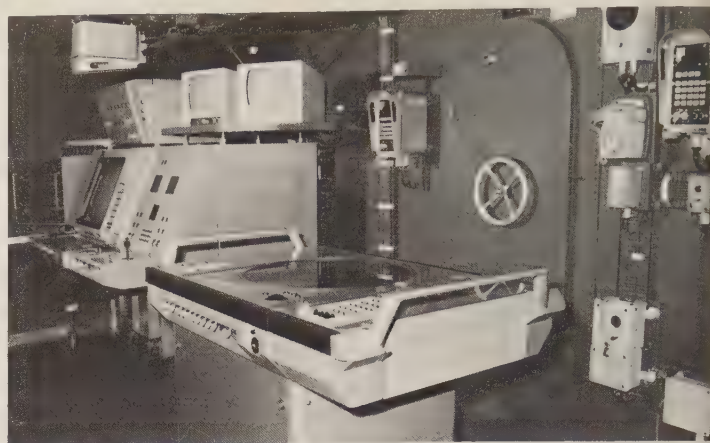
The more elaborate "AIO" version uses a white spot to indicate own-ship tracks and red and green spots for contacts; tactical information from ship sensors is fed in via the keyboard. The automatic pen provides tracks on demand, and a plasma display screen provides stored and calculated data, such as track histories. Tactical information can be provided to ship sensors. DES considers the AIO table an inexpensive alternative to CANE, a statement that shows to what extent the 2 categories, the simple plots and the tactical data systems, have merged.

DES also offers an "MCM" version of its basic plotter, driven by a 16-bit microprocessor. The plot is more precise than in the other systems (large scale is 1:1000, and plot accuracy is to within 1 mm, corresponding to 1 m of real distance). All position and classification data are stored on disk. The paper or film on which data are plotted is scrolled across the plotter by tractor feed. A roller ball allows the operator to transfer topographical features from a working chart to a larger-scale sweep chart. Inputs include navigational aids such as Loran, selected by the operator. The "MCM" table can show a standoff radius (SOR) from a designated point and also warns of drift from a fixed station.

CANADA

◆ SHINPADS

Shipboard Integrated Processing and Display System was developed as the result of a 1974 study of alternative architectures for combat systems. SHINPADS was one of the earliest fully distributed (data bus) systems, chosen because digital equip-



A typical, modern, automated CIC in a small combatant. The vertical console in the background is fed by a sensor (or connected to a weapon). The console in turn is connected to the horizontal summary display in the foreground. The captain or executive officer can use this display to see the tactical picture and to assign weapons to targets. Note the trackball toward the front of the display: such communication is almost completely electronic, targets being entered by ball and keyboard. (CMN)

ment was no longer so expensive that all processing had to be concentrated in a single central computer. All users have access to the entire data base, and consoles are interchangeable (for graceful degradation in case of damage or breakdown). The data bus itself was designed to be transparent to standard NATO interfaces; thus, existing equipment could be connected to the bus.

Although SHINPADS was conceived in 1974, it is only now being implemented, in *Tribal*-class destroyers, under the TRUMP program. In these ships it supersedes the centralized NTDS-like system, CCS-280, which was built around a single Litton USQ-501 (L-304F) computer. SHINPADS is also being installed in the new "City"-class frigates.

Distribution is on 3 levels: by location throughout the ship (for survivability), by function, and by control. All of the mini-computers of the system can be applied to any role, e.g., to processing an array's data. The only difference between, for example, a fire-control computer and an engine-control computer is the software that they are executing. All of the computers are UYK-20s.

The data bus is designed to accommodate up to 256 users, with a maximum length of 300 m. Up to 16 users can be given priority access, if their functions are particularly time-critical. For example, fire-control equipment requires updated information about every 50 millisecc (i.e., about 20 times/sec). That rate can be achieved because the average user's access time is less than 100 microsec. An analysis of typical frigate requirements showed that the data bus would have to pass at least 3 million bits/sec, and the design capacity is over twice that rate (actually 8 million bits/sec [10-MHz clock rate]) to prevent delays. The standard message may have as many as 254 16-bit words, although a special block mode allows much longer messages to be sent.

The bus uses a pair of triaxial cables but is compatible with a future upgrade to fiber optics. To ensure survivability, 1–4 additional bus cables can be added for redundancy. Any 2 of the cables can then be selected as the operating or primary bus. Bus control can be assigned to any node (user interface); if the control node fails, another can replace it.

Messages are sent broadcast, i.e., through the entire data bus, and addressed so that each user can pick off its own messages. Messages intended for several users do not, therefore, have to be retransmitted. There is also a point-to-point signal mode, in which a message is sent to a specific user.

SHINPADS is designated UYC-501(V).

The display is the Computing Devices Company UYQ-501(V),

navalized version of the company's MSD-7001. UYQ-501 is part of a standard Canadian Navy family of digital equipment, using a 19-in, 1024 × 1024-pixel CRT, with 4 Mbits of RAM to service its display. It can, therefore, show complex overlays. The associated graphics processor has 8 Mbits of RAM and can operate in 8 colors. Alternative modes are 525, 625, 875, and 1025 lines of television resolution. This standard console is used in the current Canadian Navy programs: DELEX, TRUMP, and the new frigate.

CDC describes MSD-7001 as part of a line of MAGICS (Multimode Advanced Graphics and Imaging Systems) consoles for command and control. The next version, MAGICS 2, is built around 68020 processors, which allow for simultaneous display of up to 14 outputs on a 19-in screen. Two screens are accommodated vertically in a 24-in console, with a standard VME-bus chassis below. MAGICS 2, intended for the German requirement won by AEG (see the German section below), began tests early in 1989.

◆ CCS-280

CCS-280 is the *Tribal* (DDH 280) class's command/control system, now being superseded as the ships are rebuilt. These ships were intended as squadron flagships and as such can send and receive Link 11 messages as well as Link 14. CCS-280 is built around a single Litton USQ-501 (L-304F) computer, connected to 7 multifunction situation-display consoles (SDC) in the operations room (CIC), connected in series, i.e., sharing the same data base held by the main computer. One console is used for command; the others can shift in role from situation to situation. Typically, 1 is used for air and 1 for surface detection and tracking. One might be used to control the ship's helicopter; others might be used for target evaluation, intercept direction, weapons coordination, and engagement monitoring. There are separate dedicated consoles for sonar (feeding the ASW computer), for fire control (feeding a fire-control computer, for the 5-in gun and the Sea Sparrow missiles), and for EW (feeding a data processor). Link 11 also feeds directly into CCS-280, as do the main navigational sensors (gyro and log). The 32-bit computer has a capacity of 40 kwords (expandable to 80k), and the displays can show objects at ranges of up to 152 nm. This system was 1 of the earliest applications of fault-isolation software.

The consoles show both raw and synthetic video. Operators communicate with the consoles via light pen, keyboard, and trackball. Tracking is manual with update (i.e., rate-aided), and the system can handle surface-target speeds of up to 64 kt and air-target altitudes up to 64,000 ft. CCS-280 can store up to 237 tracks (of which 50 may be targets). Like NTDS, CCS-280 conducts TEWA and also directs interceptions (in this case by both aircraft and the assigned ASW helicopter). The system can also display alternative tactical options.

CCS-280 was installed on board the 2 *Annapolis*-class frigates as part of their DELEX (Destroyer Life Extension) modernization.

CCS-280, then, is a small-ship NTDS equivalent, roughly contemporary with the German SATIR. The Canadian Navy described it as the first operational micro-electronic tactical data system for shipboard situation assessment and control.

A recent Canadian tactical-data history remarks that the "Tribal" design was the first in which the operational requirement emphasized adequate data-exchange capability. The design was federated: the central command/control system interfaced with autonomous weapons- and ship-control subsystems. Thus, the subsystems could continue to function if CCS-280 failed. They would lose their ability to communicate by data link with other ships. Similarly, the failure of any subsystem would not crash the system as a whole. CCS-280 was also intended to support a group commander as well as a commanding officer. This modular design was a new concept, and presumably it was conceived as a way to avoid the computer-capacity squeeze experienced in the fully centralized AIS 240.

The design contract was awarded to Litton (Canada) in September 1966; the main combat subsystems were UCS 280

(ASW), SAWS (surface- and air-warfare system), and EWIS 280 (EW system).

◆ ADLIPS

Automatic Data Link Plotting System, a "poor man's NTDS," was developed as part of the Canadian DELEX (Destroyer Life Extension) program. Like NTDS, ADLIPS integrates shipboard sensors and provides both Link 11 and Link 14 capability. Until ADLIPS had been installed, only the 4 *Tribal*-class destroyers had Link 11 capability. Thus, the older ships could not rapidly exchange ASW data, nor could these ships fully integrate with the *Tribals*. The ADLIPS contract was awarded to Litton of Canada.

Like NTDS, ADLIPS displays both raw radar data and synthetic video, including data received over Links 11 and 14; it also replaces existing obsolete electro-mechanical plotting tables (such as dead-reckoning tracers). ADLIPS was developed using only existing components, which had to be integrated with the existing sensors.

The central computer is the standard U.S. UYK-20(V) mini-computer, rather than the UYK-7 used in contemporary versions of NTDS. The key system decisions seem to have been to minimize the actual computing load (e.g., in target evaluation), and also to distribute that load (e.g., to rely on the existing computerized EW and ASW systems). The only weapons directly controlled by the UYK-20 are the gun and any missile the ship might carry (the ships involved carry only ASROC).

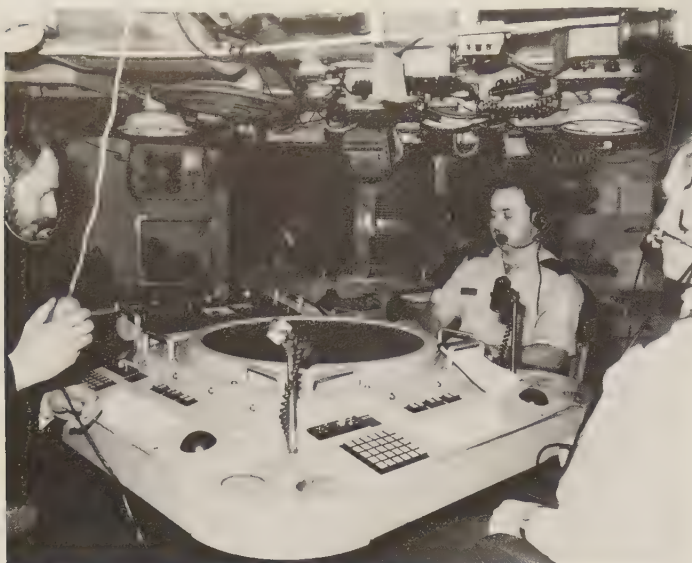
Link 14 data are entered directly (which is unusual in NTDS systems) through a special interface. There is an analog-to-digital converter for radar, log/gyro, and sonar data (the converter transmits data to the gun), and the UYK-20 connects directly to the Canadian ASW Data System (ASWDS), where that system has been installed. A similar computer-to-computer channel connects the ship's EW system with ADLIPS. Finally, Link 11 and other encrypted digital data links feed directly into the computer via a modem and a decrypter.

The main display is the Situation Information Display (SID), a 20-in CRT showing raw video, IFF data, and synthetic video. There are 3 operating stations around the horizontal SID, each with its own trackball and alphanumeric keyboard. This type of display was chosen to minimize space requirements in a relatively crowded operations room (CIC) already filled with radar and sonar displays. There are also 22 × 22-cm plasma displays, which show only synthetic video (bridge, EW control room). The system can carry 140 tracks (100 moving, 40 static) plus 6-min track-position histories for 25 targets and velocity vectors for the 100 tracks. As in NTDS, the operators at the consoles detect the targets, so that each SID can insert 3 targets into the system simultaneously.

The system is federated, in that each SID carries its own replica of the data base and carries out its own display-related computations. However, most of the computing power of the system resides in its central computer. Litton sees the duplication of the data base in the SIDs as insurance against the failure of the central computer.

Development began in August 1979 to replace manual plots in non-TDS ships. ADLIPS is interesting as the simplest and least expensive mechanization of such plots and, thus, should have had considerable export potential. In fact, it never sold abroad, but Litton Canada is trying again with ADLIPS 90. The Canadian Navy bought a total of 19 systems, 3 for its Fleet School and 16 for installation in the *St. Laurent* (2 SIDs, 2 plasma displays), *Modified Restigouche* (2 SIDs, 2 plasma displays), *Mackenzie* (1 SID, 2 plasma displays), and *Annapolis* (2 SIDs, 2 plasma displays) classes. Installation required only about 10 weeks.

The ADLIPS concept was first proposed in a Fleet Operations Study in 1968; the problem as then understood was that ships without a Link 11 capacity could not take full advantage of information available to those with modern tactical data systems. In 1969 the Canadian Navy headquarters proposed a solution in which Link 14 data were automatically projected opti-



An ADLIPS situation information display (SID) in the operations room of a Canadian escort, showing 2 of the 3 sets of keyboards and trackballs. (Litton Systems Canada)

cally onto a perspex surface. That idea, in turn, led to a Canadian Navy Operational Requirement (OER M3/72), released on 8 February 1973, calling for a system that could receive, filter, and plot either Link 11 or Link 14 data (but not both), with Link 11 (digital information) the first priority. In fact, as installed, ADLIPS can receive and display both types of information. The first R&D contract was awarded in June 1973 to Computing Devices Co. of Ottawa, and a prototype system was delivered for initial tests in August 1975. A shipboard prototype went to sea aboard HMCS *Athabaskan* in July 1976. The first production installation was in HMCS *Skeena* in October 1981; the last was in 1985.

The designers sought to limit costs by avoiding any new equipment; hence the use of the standard UYK-20 computer. The only entirely new elements are some unique interface cards and the software.

◆ ADLIPS 90

Like the original ADLIPS, ADLIPS 90 is conceived as a minimum-cost tactical data system. It is built around a UYK-44 (programmed in CMS-2M) and, like ADLIPS, uses a combination of 3-operator SIDs and 1-operator plasma displays. This centralized tactical data system achieves low cost (and, it would appear, software simplicity) by avoiding distributed processing. The design can accommodate a second UYK-44, and each computer has a battery backup in its cabinet. These computers can have up to 1 Mbyte of static RAM.

The system maintains a series of plots (air, surface, subsurface) and can designate targets to own-ship weapons. It can also conduct TEWA; and given its 2-way links, it can coordinate operations with other platforms. The stored tactical plot covers a 1000-nm area. Capacity is 200 dynamic and 80 static tracks (including number, position, and symbol), 6-min history trails for 50 tracks, and velocity vectors for the 200 dynamic tracks. Available graphics include engagement lines, bearing lines, sector screens, intercept lines (presumably ESM bearings), furthest-on circles, and torpedo danger zones.

DENMARK

◆ StanFlex 300 System

Standard Flexible 300 is the first combat-information system designed specifically for rapid reconfiguration. StanFlex 300 consists of 3 standard 2-position multipurpose consoles (each including its own ruggedized commercial-type VLSI computer) on a data bus that also connects the consoles to modular weapons and sensors. The latter can be replaced, using only dockyard

cranes, in 24 hr, and the system reconfigured by software substitution. Up to 3 additional consoles can be added to control additional weapons or other systems. All weapons control is centralized in the Operations Room (there is no local control at all in a classical sense). This type of operation requires very high computing capacity at each machine; the Danish Navy states that the total computing capacity of a StanFlex is 30,000 times that of the first Danish small-ship system, which entered service as recently as 1978. A fiber-optic data bus was considered and tested, but instead a conventional 10-Mbit/sec shielded cable has been used. The bus is duplicated to ensure its reliability.

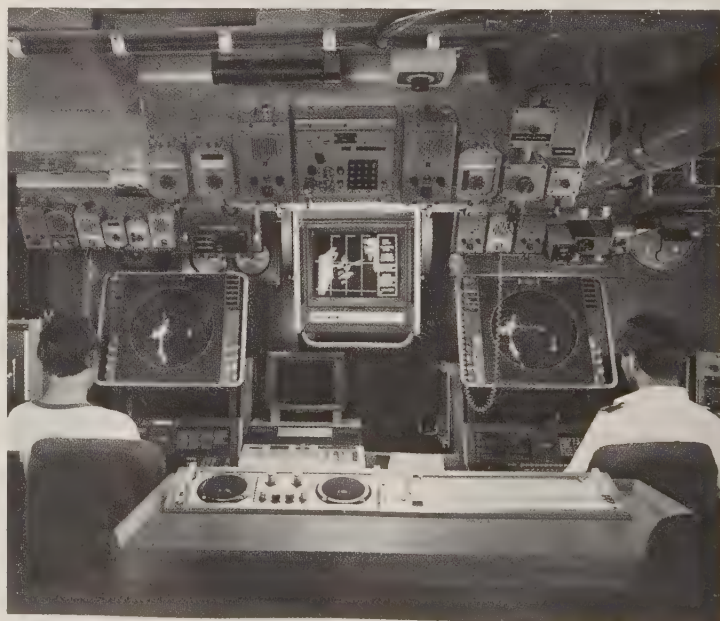
It was originally expected that the machinery would be monitored and controlled from the single data bus so that the ship could operate with an unmanned engine room. The full integration of machinery with the command/control system proved too difficult, and instead the machinery forms a separate subsystem that feeds into the main data bus.

The StanFlex program began as a feasibility study in 1982; project definition followed in 1983, and funds for 7 ships were approved in 1984. The first ship, *Flyvefisken*, was delivered in December 1988. The number "300" is the nominal displacement of the ship (actual displacement depends upon which weapons and sensors are installed at any time). The Royal Danish Navy hopes to fit a similar system to a frigate-sized ship. As an indication of the degree of flexibility built into StanFlex, the same ships are intended to function as missile- or torpedo-armed fast attack craft and also as minehunters, roles that in the past have been absolutely incompatible. In this case, minehunting is possible only because the ship can deploy and control remotely operated vehicles, such as the Swedish SAM and the German Troika, and submarines comparable to the German Pinguin. The minehunting sonar system is the French IBIS 43.

Terma was responsible for the basic system, which employs a Swedish (PEAB 9LV200 Mk 3) fire-control system.

◆ TDS

Terma's Tactical Data System grew out of a Plot Data System (PDS) developed for fishery protection ships; the prototype was aboard the *Vaedderen* in 1982. The Royal Danish Navy saw PDS as a possible approach to a low-cost tactical data system (much like the British CANE) and let a contract in December 1984. The first unit was installed on the fast patrol boat *Bille*.



The Terma tactical data system, with 2 local operational plots (LOPs) flanking a General Operations Plot (GOP). Each LOP has a system terminal (ST) underneath; the ST consists of a pair of plasma displays, a roller ball, and a keyboard. The console between the 2 LOPs handles the data link. (Terma)

The system uses a Motorola 68000-series microprocessor, a VME bus, and Pascal and C-language software. The main elements are the local operator plot (LOP) and the general operational plot (GOP). In a typical installation (*Hvidbjørnen*), the GOP is flanked by 2 LOPs, each of the latter incorporating a system terminal (ST) for data entry.

The LOPs are the operating consoles; the GOP is the summary plot. The latter is a 20-in, color, raster-scan CRT, showing up to 240 tracks (including those received via data link). It stores 1 large and up to 8 small maps, and up to 400 mine positions. Because the GOP is a summary display using external data, it incorporates a latitude-longitude grid (rather than a polar grid centered on the ship). It can display data in 8 colors, and range scales are 2–512 nm.

Each LOP carries a 16-in CRT showing both raw and superimposed synthetic video and up to 50 tracks. Its memory can store up to 8 small maps, each composed of up to 20 vectors. The display also incorporates 2 vectors for measurement purposes and 2 index lines for navigational purposes, as well as optical sight lines and helicopter approach patterns. There are 8 range scales (0.5–128 nm). The associated ST is a keyboard with dedicated function keys, a roller ball, and 2 alphanumeric plasma displays (totes).

The Royal Danish Navy has ordered 20 TDSs to replace the CEPLO systems in its fast patrol boats and fishery-protection ships, and the system has been offered for export. PDS, the forerunner of TDS, was itself a conversion of the Danish version of the Swedish CEPLO. Terma added the tactical aspect to form TDS. The version in the StanFlex corvettes uses TDS components but adds a new computer.

FRANCE

◆ SENIT/TAVITAC/Vega/CTH

Système d'Exploitation Naval des Informations Tactiques, SENIT, is equivalent to and derived from the U.S. NTDS. As with NTDS, SENIT is a national system developed by the government laboratory system. The associated CPM (Navy Programming Center) was established in 1963. TAVITAC (*Traitement Automatique et Visualisation Tactique*) is the Thomson-CSF export version of SENIT. The current type is also known as Vega IIC, Vega having been an earlier Thomson-CSF combat system for fast attack boats.

Versions:

SENIT 1 is for *Suffren*-class anti-aircraft cruisers with a 3D radar. The radar has an automatic plot extractor, and the system as a whole uses 3 Univac 1212 (CP-642) computers: 1 carries the 3D air picture and provides TEWA; a second is provided for redundancy; and the third controls the Malafon ASW missile. The version in the cruiser *Colbert* incorporates a data link to other SENIT-equipped ships. Each UYA-4 console (built under license by Thomson-CSF) shows up to 70 tracks and 96 symbols.

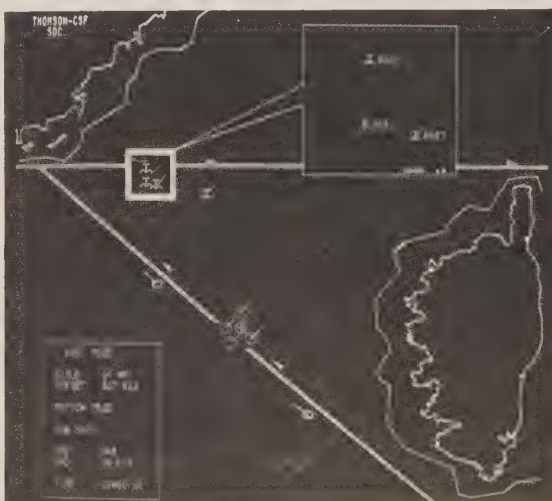
SENIT 2 is a destroyer-size version of SENIT, developed in collaboration with West Germany and thus leading to the German SATIR system. There were 2 versions, 1 for fleet air defense and 1 for a radar picket linked (by radio teletype) to the French national air-defense system, STRIDA. This version has 1 computer. A version incorporating the Tartar surface-to-air missile has 3 computers. SENIT 2 was installed on board 8 destroyers: 3 modified radar pickets (*Surcouf* T53 class), 4 destroyers fitted with the Tartar anti-aircraft missile (*Surcouf* T47 class), and the ASW destroyer *Duperre*. The Tartar refit included replacement of analog fire-control computers with digital units adapted to SENIT. The carrier *Clemenceau* was fitted with the SENIT 2 system taken from the inactivated destroyer *Jauréguiberry* during a September 1977–November 1978 refit. *Foch* was fitted with the SENIT 2 system of the inactivated destroyer *Tartu* during a July 1980–December 1981 refit. SENIT 2 was also planned for the helicopter carrier *Jeanne d'Arc*, but by 1987 this project had been dropped. The computer is Univac 1212 (CP-642).



A TAVITAC command-and-control console with random-scan CRT. (Thomson-CSF)



TAVITAC CIC, showing the command-and-control consoles in place. (Thomson-CSF)



Typical TAVITAC display (western Mediterranean). (Thomson-CSF)

SENIT 3 is a 2- or 3-computer version (with memory extensions) for ASW ships, capable of also handling a tactical air picture. There are 8 tactical consoles, corresponding to the sensors, plus weapons consoles and a computer-driven plotting table. The associated computers are Univac 1230s, and the displays are UYA-4s. This system is on board the destroyer *Aconit* and the 3 F67 (*Tourville*)-class frigates.

SENIT 1, 2, 3 all employ American computers and Hughes UYA-4 consoles and, thus, are fully analogous to NTDS. These are central-computer systems (in some cases, computers are ganged together). Later versions of SENIT introduced French computers.

SENIT 4 is a French-designed system built around the IRIS 55M computer and a new Vizir display with 16-in CRT, keyboard, and trackball. The software language is Maxiris or LTR. There are 10 consoles, each of which can display 130 tracks, plus up to 12 lines each of 18 alphanumeric characters, and 23 lines of target vectors. This is the system in the *Georges Leygues* class. It was planned for the 2 carriers, but existing SENIT 2s were installed instead.

SENIT 5 is a small-ship (2000–6000 ton) version announced in 1976. This is the first federated-architecture version, employing the 64k CII 15M computer. This architecture replaced a central-processor design built around an IRIS 35M computer (16–256k) with 5 Vizir displays, each of which could carry 40 tracks. In the federal-architecture form it consists of a computer, a tape drive, a 3-function RVP (plot extractor), an analog/digital interface, and 2–5 consoles. This modular design allowed for relatively easy addition of facilities, e.g., ASW helicopter control, automatic IFF code extraction, computer extension for Link 11 management, interfaces with weapons-system computers, and disk storage management. There was to have been a PLAD automatic plotting table connected to the system. In the federated version, each console could carry 40 tracks plus 20 symbols and 3 lines each of 18 alphanumeric characters. The system as a whole could carry 60 tracks. SENIT 5 was planned for the A69-class corvette, but it was never used. It is therefore of interest mainly as a step toward SENIT 6

SENIT 6 is a federated system for the *Cassard*-class AAW frigates, built around six 15M/125X minicomputers. A seventh is kept in reserve, and ships have sufficient space to add an eighth (which will be required to handle Link 16). The computers are located in 2 separate rooms, fore and aft. The ship is arranged in 6 subsystems, each presumably served by 1 of the 6 running main computers. Each subsystem has several 15M05E computers for local processing and constitutes an LAN. The subsystems, in turn, are linked by a 1-Mbit/sec Digibus.

One of the main computers runs the display subsystem, carrying the tactical picture, and is connected to 11 single-operator consoles, one 2-operator console (for CO and TAO), and 2 Precilac navigational tables (for ASW: each can carry up to 20 tracks).

The other main computers are dedicated, respectively, to sensor processing, TEWA (for self-defense), area air defense, ESM/ECM, and the data links. The ASW function is autonomous, linked to the system bus. Much of the processing for each weapon and sensor is done locally, outside the system bus.

TAVITAC, also known as Vega IIC, is an export version of SENIT 5, using a less capable microprocessor (15M/125F, with a capacity of 128k, expandable to 512k). TAVITAC has been exported to Saudi Arabia, Colombia (FS-1500-type frigates), and Tunisia. In the Colombian and Tunisian version, the standard console can automatically track up to 16 targets, air or surface. The standard destroyer or frigate installation is 2- or 4-operator consoles, plus a summary console for the TAO. Each console can display 16–32 tracks. There is also provision for a non-NATO data link (e.g., Link W). An expanded version, with 10 consoles, is equivalent to a large-ship SENIT installation.

The Saudi version is more elaborate, with 6 consoles plus an E7000 tactical table. Each console consists of a CRT plus a second display (alphanumeric, television, or plasma), a keyboard, a roller ball, and a video-display panel. The CRT can be monochromatic or color, circular or rectangular. It can carry up to 200 tracks and 100 symbols.

The PRC navy ordered TAVITAC in 1986 for the modernization of 2 Luda-class destroyers.

The next-generation development is TAVITAC 2000. Its main new feature is that it uses hardened civilian equipment instead of specialized military types. Reportedly, TAVITAC 2000 costs half as much as an equivalent system using specialized computers. Economies are so great that Thomson-CSF claims that the cost of the new FL 3000 (*La Fayette*)-class frigate's command/control system will be less than 5% of total cost.

Like earlier SENITs and TAVITACs, TAVITAC 2000 is a federated system built around 1 (in the *La Fayette* class, 2) tactical picture-keeping computers [each with 6 Mbytes of active memory and two 40-Mbyte hard disks]. However, other subsystem computing will be conducted by microprocessors in the Vista consoles. A *La Fayette* system will employ 5 consoles (with space for a sixth); TAVITAC 2000 architecture can accommodate up to 15. All are connected by a 5-Mbyte/sec VME bus, and all are programmed in ADA. Each console contains several 68020-series microprocessors and carries up to 3 displays stacked vertically: two 20-in, high-resolution, raster-scan units (1024 lines $\times$ 1280 pixels) and, below them, a smaller CRT to display alphanumeric data.

The system as a whole can carry up to 800 tracks within a 512 nm radius. Up to 32 ESM and 5 local sonar tracks can be carried and displayed as synthetic video. Each console can handle the entire track file, and the tactical picture is updated through a double buffer (the system need not wait while the picture in the central computer is being updated). A full picture (300 tracks, 30 circles, 30 ellipses, 500 vectors, 2000 shoreline elements, and 2000 characters) can be built up in less than 0.3 sec. Raw radar video can be superimposed on the synthetic video of the displays.

The next-generation Thomson-CSF Cimsa Sintra display is VLX, with a 14- or 19-in color or monochromatic raster display (2000 $\times$ 2000 pixels.) Each such CRT can be supplemented with 9-, 12-, or 15-in plasma, liquid crystal, or electro-luminescent screens.

SISC (*Système Intégré du Système de Combat*) is another SENIT 6 development, in this case being conducted by CPM, for the new French nuclear carriers. The design is still incomplete, but CPM hopes to use 5 to 6 ruggedized civilian computers, each with 5 or 6 times the power of the SENIT 6 computers. One will be a spare, and another will service a new flagship command-assistance system, Aidcomer, broadly comparable to the U.S. FDDS. There will be 20–22 display terminals, each more powerful than the TAVITAC 2000 terminal, and 3 tactical tables. SISC will be tied together by 5 Ethernet D buses. Software may be a mix of ADA and the CPM-written LTR 3.

Vega is a series of modular, small-ship, weapons-control systems and tactical data systems. It is comparable in concept to the contemporary Dutch M20/WM20 series (and to their extensions as mini-combat systems), to the Swiss Sea Hunter, and to the Swedish 9LV200 series. In each case a dedicated air tracker (Castor, Castor II, or Pollux) is combined with a surface-search radar (Triton). In the basic version, targets detected by the main search radar are designated to the dedicated tracker. Versions designed to control Exocet missiles and/or wire-guided torpedoes use the surface-search radar in TWS mode, the main system computer conducting the associated calculations. Vega is unusual in that it is often extended to a full CDS.

Thomson-CSF chose a nonstabilized TWS antenna (Triton) because it can be mounted higher in a ship, for a gain of about 4 km in range, equivalent to 3 min of warning on a 40-kt target. Overall, the system's ECCM benefits from the use of 2 dissim-

lar radars (Triton and Castor/Pollux). Doppler filtering is used to reject clutter, and the system is partly digital.

Vega systems can be divided into Vega I, which uses a hybrid digital-analog computer (BCH), and Vega II, which uses a digital computer (CDE). Before Vega II appeared, Thomson-CSF designated different versions by which search radar and which weapons they use. Vega Triton versions lack any search radar, relying instead on a Lynx optical director. Thomson-CSF designates later versions of Vega I, which use an optical tracker, as Canopus, Canopus A being the simplest (with only the optronic tracker and a TWS radar; it is broadly comparable to the Radop FCS). Canopus B is Canopus A with an associated SATIN B computer; it can handle 16 targets. Canopus C is the same system with a Pollux tracker. Pollux is also the designation for an earlier fully analog system, now apparently extinct. All versions except Vega Pollux PCET (Exocet/Torpedo) incorporate a Lynx optical director.

Vega I typically employs 3 vertical consoles side by side: the fire-control computer, a large-CRT (14-in PPI) search-radar/target-designation console, and a small-CRT console with 1 or 2 joysticks (the air tracker). An additional console can be added to control wire-guided torpedoes.

Vega Castor and Vega Pollux use a digital gunfire-control computer. The simpler Vega Pollux PC/PCET uses an analog gunfire-control computer (for calibers of 57 mm and smaller). The Exocet and torpedo versions of the system (Vega Pollux PCE and PCET) provide the search radar with TWS capability; the main system computer also calculates launching data. In the case of torpedoes, guidance data are displayed on the main surveillance PPI. In these versions the big PPI shows the relative bearing and range between the radar-carrying craft and the target (RBL); it also shows the collision course, the time to intercept a track (CTS), and the CPA. It extrapolates target tracks, generates fixed points, and calculates time since initiation. Data are entered by keyboard. The associated modular (analog/digital) BCH computer has a typical operating time of 2–5 microsec. It conducts FCS calculations for guns and wire-guided torpedoes and can also be adapted to the Bofors 375-mm rocket. BCH also stabilizes the display (when an unstabilized search antenna is used); controls and stabilizes the tracking radar(s) in autonomous search mode; and conducts memory tracking (rate-aided or coasting tracking), constant altitude tracking, elevation search, and ship's speed compensation for MTI receivers.

By about 1974 Thomson-CSF offered 2 search radars as alternatives to Triton: Saturne II and Sea Tiger. The Saturne II version was presumably intended for a possible refit of Swedish destroyers that had originally been equipped with Saturne I radars, but it never entered production. Sea Tiger was used in large-ship versions of the Vega II system by Colombia and Saudi Arabia. At this time the company distinguished between 2 alternative tactical information units (TIUs), Vega I and Vega II, and the company assumed that both versions would use the BCH computer.

The original Vega could be combined with a tactical data system to form SATIN (*Système de Traitement Automatique de l'Information Navale*). SATIN A provides rate-aided tracking of 6 air or surface targets and can also show 1 sonar track and 1 ECM strobe; labels can be applied to all the tracks, and they can be handed off to weapons. The system can solve simple tactical problems, such as azimuth/range to slew to a position or CPA. It uses the main 16-in CRT. SATIN B employs a second hard-wired computer. It automatically tracks 16 air or surface targets by means of a plot extractor (it can revert to rate-aided manual tracking when clutter confuses its automatic tracker), and it automatically displays IFF data. The computer can support 1–6 multipurpose operator consoles (command, weapons allocation, surface and air search, helicopter control). This is a true small-ship CDS, complete with data link (Link W). Capabilities include true-motion display, geographic squaring (conversion from own-ship coordinates, a function that is necessary for data linking), target designation, and tactical computations such as CPA, track extrapolation (time to go), and vectoring to

intercept. SATIN B was derived from equipment developed for a mobile land-based air-defense system, MIDAS. It became Vega II.

Development of Vega I began in 1967, with first sea trials in 1971 on board the Greek *Ipoploiarhos Konidis* (formerly *Kymothoi*), followed by Exocet trials in 1972. This version was designated Vega Pollux PCET (Pollux radar, E for Exocet, T for torpedoes; PC indicated a single rather than dual optical target designators). The first major customer was the German navy, which bought Vega I/43 for its Type 148 missile boats. In this series, Vega Triton lacked any fire-control radar, and Vega Castor used the Castor rather than the Pollux FC radar.

As of 1976, more than 80 Vega systems had either been delivered or were being manufactured; the total is now about 100. Included are 4 for the Greek Combattante II-class missile/torpedo boats (and the first 4 Combattante IIIs) and 20 for German S148s. Other versions:

Vega Canopus A Ghanaian TNC-45 and PB-57 classes.

Vega Pollux Ecuadorian *Manta* class (FPB-36 type; navigational radar and Pollux only); Ecuadorian *Quito* class (TNC-45 type: Triton search radar); Malaysian Combattante IID (*Perdana* class); Portuguese *Baptiste de Andrade* class (using AWS-2 search radar and Diodon sonar; can be fitted with Exocet missiles).

Vega Triton (no tracker) Libyan *Ibn Ouf*-class landing ships.

CTH Because Vega is essentially an FCS, the French navy designates it as CTH (*Conduite de Tir Hybride*). In this form it equips the *Georges Leygues*, *Tourville*, modified T53, and *d'Estienne d'Orves* classes. This version uses the DRBV 51 (higher-gain Triton) and DRBC 32 (instead of Castor) radars.

Vega II was initially the SATIN B system described above. As initially offered in 1974, it was an alternative version of the same basic system (TIU II instead of TIU I); all Vega systems were built up from surveillance radar, tracking radar (including TWS for the search radar), TIU (I, II, and an optional plotting table), computer (BCH plus an optional BCH for ASW), and weapons. The TIU could include an ECM console and a navigational display fed by a navigational radar separate from the 2 main radars.

The Vega II prototype was completed in 1975. The system used a new vertical console with a 16-in display, and it could accommodate a horizontal summary console (22-in CRT) that could carry 16–64 tracks. Versions so fitted were called TAVITAC, in analogy with the earlier SATIN (see TAVITAC, above). As with SATIN B, they could use Link W. It seems unlikely that the non-TAVITAC versions could use any data link since they would lack the capacity to translate coordinates automatically from rectangular to own-ship form. Thomson-CSF offered Link 11 as an option, but the only NATO navy definitely to have bought Vega II, the Greek navy, bought it in non-TAVITAC form.

Vega II added MTI for the Triton TWS radar, a new X-band monopulse tracker (Castor II), and a much more powerful fire-control computer capable of handling 16 rather than 2 targets simultaneously (so that it could engage several targets simultaneously, or shift very rapidly to a second target once the first had been destroyed). The FCS radar had an associated television, the screen for which was on the fire-control console. Unlike the earlier fire-control console, this one had 3 square screens, which might mean there was a radar B-scan alongside the television image, with an optronic director image on the upper screen.

All versions of Vega II currently employ a pair of optronic directors. The fast-attack versions listed below use Pandas (NAJAs in the II/83 version for Tunisia). Only II/53 and II/73 are TAVITAC versions.

Versions:

Vega II/12 The simplest version, without any fire-control radar. This version may be identical to the Radop described under FCSs in the Antiaircraft Warfare section.

Vega II/43 Large strike-craft version, with both radars and 2 consoles (surveillance and fire control). On board Greek Combattante III missile boats (Triton II MTI and Pollux radars). This is probably the Libyan form of Vega II (but with Triton II MTI and Castor IIB radars), on board Combattante IIG-class fast attack boats.

Vega II/53 Fast missile boat version, adding a tactical table to II/43. On board Qatar Combattante IIIM-class fast attack boats (with Triton S and Castor IIB radars).

Vega II/73 Fast patrol boat/ASW corvette version, capable of controlling antimissile weapons (Triton S, Castor II radars); 2 display consoles and 1 fire-control console, with 1 tactical table. Triton S is a coherent radar with much-improved MTI and can detect and track incoming antiship missiles. On board Nigerian Combattante IIIG-class missile boats (using Triton MTI radar).

Vega II/83 Fast patrol boat version with Triton S and Castor IIB, but without the tactical table. On board Tunisian Combattante IIIB missile boats.

Vega II/89 Frigate version, with plotting table, sonar, and 2 BCH computers; the radars are Sea Tigers (TWS) and Castor II, and there is also a Canopus director aft. Each radar/optronic director feeds its own fire-control console, and there are 2 tactical tables and 3 display consoles. The use of 2 high-performance, MTI/doppler, fire-control radars in different bands makes for good capability against sea-skimming missiles. Signal separation between these radars is not as good as in versions using Triton search radar (30 dB rather than 50 dB), but because it is frequency-agile, Castor is less vulnerable to ECM. This is the version on board the Colombian *Almirante Padilla* class.

In addition, the Peruvian PR72P class FCS (Triton and Castor II radars) is probably a Vega II.

Vega III is the large-ship version of TAVITAC developed for the Saudi frigates; it is also presumably the version sold to the PRC navy.

A new version of Vega is currently under development, presumably incorporating the MRR radar in place of both the search and tracker radars of the earlier version (it is described as a coherent tracker). The associated console will probably be the Thomson-CSF color VLX (2000 × 2000 pixels) first shown at Bourget Naval in 1990.

This system may be associated with the low-cost, small-ship, command/control system that the French navy was reported considering in 1989, to allow small ships and aircraft to benefit from Link 11. Presumably, it would be applicable to the new surveillance frigates.

GERMANY (WEST)

◆ AGIS

This command/control system for fast attack boats (*Automatische Gefechts und Informations-system Schnellboote*) uses a data link to exchange data with shore stations, with SATIR-equipped surface ships, and with surveillance aircraft. The ship-board end of the system employs 2 programmable computers, 1 to generate and utilize the tactical situation and to assign targets to the various units of the flotilla, and the other to regulate fire control for the ship carrying the system. AGIS supports 2 torpedo-control consoles, 1 gun-control console, a horizontal tactical display, and a vertical plot. It was designed specifically for Type 143 boats, which were intended to act as flotilla leaders for Types 142 and 148; hence the need for sophisticated data processing, including input from external command systems (via Link 11). The computers are Univac 1830Bs, programmed in the Sycol language. They feed Signaal consoles.

AGIS entered service in 1976, providing a link with the central German maritime headquarters (MHQ) ashore. That link in turn permitted MHQ to form mixed battle groups, including both fast attack craft and aircraft, because MHQ could be sure of the precise location of each during combat. Otherwise, the aircraft might well have killed the fast attack boats by mistake.

The original Type 143 boat carried 2 torpedo tubes aft and required a pair of specialized torpedo-control consoles to control their wire-guided weapons. A modified Type 143A lacks the torpedo tubes (which, with the after 76-mm gun, are replaced by a RAM defensive missile launcher). The space freed by the elimination of the 2 torpedo-control consoles is used to expand AGIS into a Mk II configuration; a multifunction display console is installed. It in turn makes possible combined helicopter-attack boat operations, and this installation of AGIS II is associated with the program to modify German Sea King helicopters to fire antiship missiles. Boats fitted with AGIS II have active and passive ECM integrated into their combat systems.

The German Navy plans ultimately to convert all Type 143 boats to AGIS II configuration, with improved air defense (RAM and ECM). These boats will cooperate with 20 Sea Kings, converted from the search-and-rescue (SAR) role to the surface-attack role, using new radars and carrying Sea Skua missiles. The helicopters will also provide OTH-T for attack boats using Link 11.

From 1982 on the older Type 148 boats were fitted with PALIS, the passive-active link data transmission (and sharing) system. It had been developed during the AGIS program and was intended to unify the tactics of the German fast attack boats. With PALIS, any fast attack boat could cooperate with other units, even dissimilar ones such as destroyers, and with MHQ. Given this system, Link 11 information for the construction of a current tactical picture could be relayed, stored, and correlated with own-ship data as well as with own-ship sensor information. By using electronic data processing, reaction time could be drastically reduced.

PALIS is also installed on board German Type 323 (*Hamel*-class) mine-countermeasures craft.

The specially built ashore MHQ supporting the deployed boats originally used 2 IBM 370/168 computers, which could handle 40 plots/sec. Development of the new MHQ information system began in 1972; the basic system was ready in 1980. As of 1986, work was proceeding on an enlargement to handle all NATO BALTAP command/control, bringing the modernized coastal-radar chain into the system.

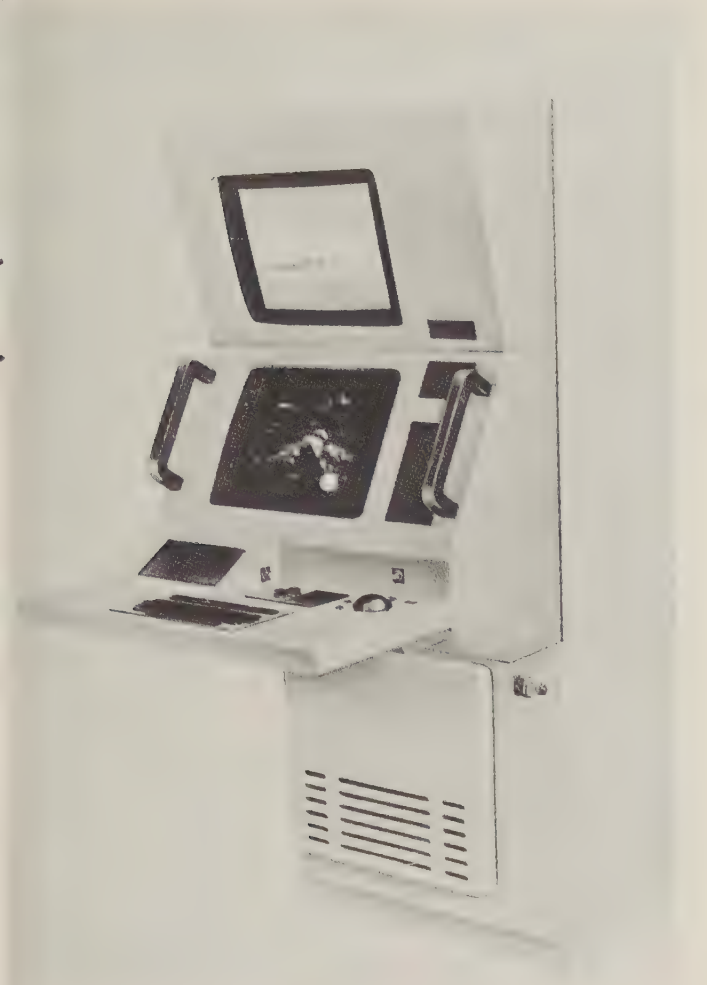
◆ SATIR

System zur Auswertung Taktischer Informationen auf Raketenzerstören is a command/control system for the 3 German *Lutjens*-class missile destroyers and for the Type 122 *Bremen*-class frigates. As originally developed for the *Lutjens* class (which entered service in 1969–70), SATIR is a more compact substitute for NTDS, which in the U.S. Navy was limited to much larger ships. SATIR in turn inspired a U.S. project to extend NTDS to such ships and thus indirectly led to the RVP installation in Australian missile destroyers (see RVP under U.S. radar systems in the Antiaircraft Warfare section). SATIR employs U.S. hardware (USQ-20B computers and UYA-4 displays, as in NTDS, albeit on a more compact scale) and is based on experience with NTDS and with its French equivalent, SENIT. SATIR was the first NTDS-like system on a destroyer, proving sufficiently successful for the German Navy to choose a derivative for its *Bremen*-class (Type 122) frigates (using UYK-7).

When the *Lutjens* class was modernized in 1983–86, a U.S.-type SYS-1 radar integrator was fitted. These ships also have an NTDS data link designated SATIR-1, presumably equivalent to Link 11.

This system was adapted to the *Bremen* class. The ships are very similar to the Dutch "Standard" frigates, but reportedly the introduction of a wholly new combat system (instead of the Dutch SEWACO) was extremely expensive, equivalent to the cost of 2 ships. The Type 122 version differs from the original SATIR in using digital links to sensors, weapons, the integrated navigation system, and CIC displays. Presumably, this integration includes ATD to feed targets into the combat system.

A third iteration has been adopted for the new German Type 123 frigates, ordered late in 1988. This time the central com-



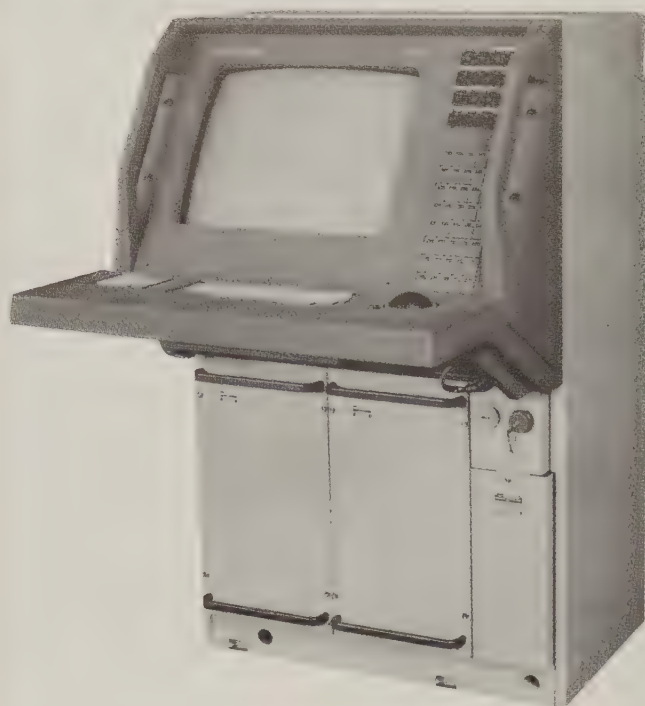
The KAE BM 802 family of workstation consoles is now standard throughout the German military; they are used in the SATIR system of the new Type 123 frigates and also in the COSYS system. BM 802-52 is a double-screen CIC console. This photograph shows it with a medium-size CRT (14 in) above a larger (20 in) CRT. Both are raster-scan color CRTs (1365 × 1024 addressable pixels, equivalent in clarity to a 2000-line display). The console is driven by a 32-bit KAE multiprocessor computer (MPR 2300) using 68030 chips. Others in the series differ in the number and type of displays. BM 802-1/2 have 15-in cursive color CRTs (1440 × 1120 addressable locations on screen, equivalent to 4000 lines); -3 has a 14-in raster color CRT (720 × 560 pixels, 1000 lines equivalent); -4 has the full 14-in raster color CRT. Of these versions, BM 802-2, -3, and -4 can have either 1 or 2 displays. BM 802-51 and -52 each have 2 displays, and BM 802-61 has 1. All but -51 and -52 use both 16- and 32-bit microprocessors (KAE EPR 1300 and MPR 2300). EPR 1300 has a throughput of about 0.3 MIPS and can be expanded to 8 Mbytes. BM 802-51 and -52 can be further upgraded by adding plug-in processor assemblies. All versions have trackballs and keyboards. In addition, the upper and lower screens can be flanked by control panels carrying keys, push-button switches, rotary switches, potentiometers, shaft-encoders, annunciators, and an audio channel (not visible in the console illustrated here). (KAE)

puter is the U.S.-built UYK-43 (successor to the UYK-7). The consoles are probably the new standard German type described under the COSYS system (see entry for Switzerland).

As in the case of NTDS, the navy is the system integrator, and a special official organization is responsible for programming. The developers were the Bundesamt für Wehrtechnik und Beschaffung (BWB) and the Kommando Marine Führungssysteme (KdoMFuSys).

♦ MTDS

The Modular Tactical Data System is proposed for the modernization of existing ships. The baseline MTDS consists of an information processor, a display (a microprocessor controlled workstation), a data link (HF and UHF), radar and navigation



BM 802-61 is the new standard German CIC display console, for tactical display, assessment of the tactical situation, and weapons-control planning. It can accept both digital computer data and raw radar video (it incorporates a radar scan converter). It carries a 20-in monochrome raster-scan CRT (940 × 700 pixels, equivalent to 700 lines). (KAE)

interfaces, and a general-purpose interface to a ship's weapons and sensors. The processor is a single militarized general-purpose computer with a mass storage device. All of these items are connected to a data bus, and the tactical computer is powerful enough to run separate software modules for its different functions, on a time-shared (multitasking) basis. For the computer, the main expansion option is to add a plot extractor and a track computer, both of which feed into the main bus. The display subsystem can be built up to more consoles (a drawing shows 4).

The general-purpose interface is a modular unit with plug-in interfaces adapted to the various ship sensors and weapons.

The data link subsystem combines a fast encrypted digital link in both HF and UHF/VHF (presumably much like Link 11) with a slow teletype link (presumably much like Link 14).

Telefunken Systemtechnik began to advertise MTDS late in 1989; its brochure identifies neither the general-purpose computer nor the planned workstation. Presumably, the bulk of the work done so far has been software development, which would be applicable to a wide range of machines. By early 1990 Telefunken and its partner, AEG, were divesting themselves of their naval activities (as part of a German antitrust decision), and MTDS had been taken over by a new entity, DMT Marinetechnik. No sales have been reported to date, but the existing brochures prominently feature a Chinese *Chengdu*-class frigate (i.e., a *Riga* with HY-2 missiles in place of her torpedo tubes).

ISRAEL

♦ Elbit NTCCS/AIO

Naval Tactical Command-and-Control System was described in 1989 as having been in service aboard the missile boats of two navies for some years. The navies were probably Israel and South Africa or Chile, the boats being Saar 4s. Elbit states that NTCCS has also been marketed as the Elbit AIO.

The system functions partly as a link to a shore headquarters. There are 2 separate data links, 1 to the other deployed units and 1 to the naval headquarters ashore. Both are serviced through a SACU, the Elbit stand-alone communications link.

NTCCS is built around a standard Elbit naval console (NAVSCON) containing a 19-in, color, raster-scan CRT and a plasma alphanumeric screen, with a trackball, touch-sensitive keyboard, and 2 banks of special-purpose keys. A typical load would be 300 tracks, 200 history points, 100 CPAs, 4 EW bearing lines, 1500 mapping vectors, and 400 alphanumeric vectors. The standard system also employs a tabular display console, e.g., alongside the graphic NAVSCON console. Presumably, the console is used for target assignment.

NTCCS as defined by Elbit includes the radar automatic plot extractor(s) and scan converter(s) that feed directly into the NAVSCON console.

The published description is quite limited, but it appears that the system is built around a central computer with a diskette memory for the tactical picture, feeding both a graphic console and a tabular console. Elbit's list of functions includes target-data processing (but not fire control) and correlation of radar and ESM data; the system also computes appropriate chaff rocket patterns. Presumably, this latter calculation is so urgent that it must be carried out by the central computer, whereas target designation and engagement can be relegated to a separate system, e.g., the IAI Gabriel fire-control system (a subset of Reshet, below).

◆ Reshet

Reshet is IAI's command/control system for destroyers. This system first appeared in the early 1980s as the Target Acquisition and Designation System (TADS). It uses a central processor plus 1 or more tactical display consoles (TDCs) and, in some versions, a data-management terminal. Software includes TEWA on the basis of operator-defined criteria. If that description is accurate, it is relatively unusual; most TEWAs are fully embedded in software delivered with the tactical data system.

A typical system consists of a target acquisition and designation (TAD) position, a tactical editor position, and a commander's tactical console. The tactical editor position, which may be unique to this system, would seem to correspond to an Israeli view that only a human operator can be relied upon to sort out false targets caused by jamming and deception. Alternatively, it might be considered a combination of the air, surface, and subsurface tracker positions employed by other navies on larger ships. The simplification implied here is possible because modern radars and sonars often automatically detect and track; in many cases the dedicated trackers find themselves underutilized.

The tactical editor console (tactical display system, TDS) contains a color, raster-scan monitor, with a small alphanumeric panel under it, surrounded by special-purpose entry buttons. There is also a trackball. Typically, it is used for synthetic video. This computer carries the tactical picture and the computing power of the system as a whole.

There are 2 alternative simpler versions for smaller ships:

- single-graphic-console configuration, in which the tactical-editor graphic display is replaced by a tabular display (a data-management terminal, DMT); the commanding officer retains the graphics display. The DMT is responsible for filtering tactical data and also for managing tactical and navigational computation.
- minimal configuration (Reshet TADS/Data Link), in which the processor and target-acquisition display share a common console. A separate computer manages the data link.

The tactical-display console (TDC) can be used as an independent, fully computerized, multifunction unit, showing maps, grids, zones, automatic update of own position, local processing of operator requests, definition of targets, and track histories.

This system is an extension of the earlier IAI-manufactured Gabriel target-acquisition and fire-control system, TADS. TADS consisted of an operator console incorporating a large CRT, fed by an automatic radar detector/tracker, the Automatic Tracking Computer (ATC). The CRT could display raw radar video as well as computer-generated symbology (synthetic video). Given its date of origin and its circular shape, it was almost certainly an analog unit with superimposed cursive symbology. The symbols showed target inputs from other sensors (optical and EW), but almost certainly not raw optical video.

There was also an alphanumeric display, surrounded by special-purpose keys, with a separate roller ball. The console could automatically track up to 20 targets simultaneously; alternatively, it could provide manual rate-aided tracking of up to 10 targets, the operator performing the usual CIC tasks of classifying and identifying radar targets. The system as a whole was intended to localize targets with an accuracy of 70 m in range and 0.5 deg in bearing. The operator communicated with the system by keypad and roller ball.

In the most compact version of the system, it appears that the fire-control radar is entirely unmanned, slewed onto its target on the basis of TADS commands. The TADS radar computer also provided all other system calculations, including those required for gun fire control; this is a highly centralized tactical data system.

Most of the Israeli missile boats also have a separate topside optical fire-control and manual tracking system, located on the bridge. Presumably, it can be coached onto a target designated by the TADS.

There is also a special, very compact Gabriel system, designed for the *Dvora* class and exported to Taiwan. This system requires 2 separate operators, 1 for the display control processing unit equivalent to the TADS, and 1 for a stabilized optical (periscopic) sight (OS). The optical sight is probably a periscope-based director developed by Kollmorgen, an American company, for a U.S. small-combatant program. This system also incorporates a vertical reference unit (VRU).

As of 1989, 110 Gabriel fire-control systems had reportedly been manufactured, 80 for export to customers such as Chile, Kenya, South Africa, and Taiwan. Reshet has probably been bought by Taiwan.

◆ Sa'ar V and Dolphin Systems

The new Sa'ar V corvettes are to have a fully distributed combat system, using Elta EL/S-9000 computers based on the Motorola 68020 microprocessor. Multifunction consoles will be connected with the ship's systems via multiple triple buses.

The Sa'ar V design includes a secondary (emergency) CIC aft, and the main CIC is buried in the hull for survivability. The combat system can also be operated, to some extent, from the bridge, although it appears that the CIC is the CO's battle station. The system can also accommodate a unit commander.

The *Dolphin*-class combat system was apparently designed along parallel lines; in contrast to earlier Israeli submarines, this one will have a separate CIC (with 5-14 operators, at 9 consoles, 8 for combat systems and 1 for radar).

The standard workstation console, both in the Sa'ar V and in the new *Dolphin*-class submarine, is the Operational Control Console (OCC) developed by Astronautics Corp. of America, Ltd., under Israeli navy contract. It incorporates a 19-in screen (1280 × 1024 pixels) plus either a second such screen or 2 × 9-in screens for 60-Hz raster-scan data. Each workstation is built around a VME bus carrying 3 processors: operator-machine interface, display, and a dual graphics engine; each graphics engine contains 3 processors operating in parallel to generate 6 million pixels/sec of random graphics. The workstation can accept 40-Hz digital data or analog video (e.g., raw radar video).

In a Sa'ar V, the main display includes the current tactical picture and alphanumeric data. One of the small displays carries information required to cooperate with other consoles or operators; the other carries system status information.

ITALY

◆ SADOc/IPN Series

SADOc (*Systema Dirizione della Operazioni di Combattimento*) was the general designation for the Italian version of NTDS. The same designation was extended to later Italian Navy tactical data systems. SADOc 1 was presumably equivalent to NTDS, with a single central computer. Later versions are federated; they combine 2 central computers (CP-7010 or -7020) served by a tape-cassette unit (TCU) with a series of consoles, each of which incorporates a microcomputer (typically an NDC 160/E). In at least 1 version, radar data are transmitted directly to the consoles (rather than to the main computers) via a radar central unit (RCU). The computers and the consoles are all connected to a dual serial bus (10 Mbit/sec on each bus), which is also connected to external equipment, such as guns. The main computers presumably carry the tactical picture.

Versions:

SADOc 1 is the U.S. NTDS adapted to the *Doria*-class missile cruisers.

SADOc 2 is a small-ship modular system, developed for the *Maestrale* and *Lupo* classes, that uses Italian equipment and ideas. It has been widely exported under the designation IPN-10. This Selenia-Elsag modular distributed system uses a 10-Mbit/sec data bus. There are 2 types of multifunction consoles, a single-operator vertical console with a 16-in CRT (SVC-16) and a 3-operator horizontal console with a 22-in console (MHC-22). There is still a dual central computer carrying the system data base, but each console contains its own NDC 160/E 16-bit minicomputer (replaced in newer installations by a MARA 286 computer, programmed in ADA). A version for a fast attack boat would have 1 SVC, and a corvette 2; an export frigate has 5 in all. Italian Navy *Lupos* and *Maestrale*s have 6, including 2 Selenia CDG-3032 (CP-7010) computers. The Italian Navy also has a 3-console mini-SADOc (*Minerva* class).

SVC-16 incorporates a keyboard and roller ball and can be used as an independent radar repeater. MHC-22 has 3 flat screens, at least 1 of which is used for alphanumeric, and 3 keyboards with roller balls; it incorporates an NDC-160E computer.

The system is tied together by a 10-Mbit/sec serial bus.

The latest version, under development since 1984, incorporates a MARA 286 computer (using an Intel 80286 processor) and is programmed using the same YMS operating system as the Digital VAX computers; the language is ADA. A new MAGICs console has been offered in place of the SVC-16; it has an embedded MARA 286 and twin 19-in, high-resolution, raster-scan screens (1024 lines $\times$ 1280 pixels) stacked vertically. This display is also incorporated in the Selenia NA-25 fire-control (and command/control) system and in Selenia's Submarine Integrated Combat System (SISC).

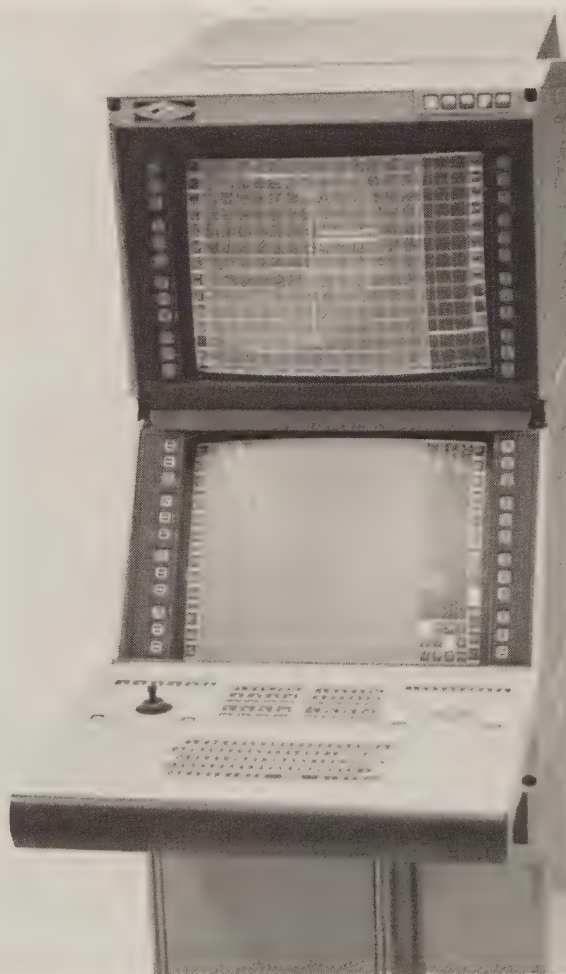
IPN-10 was exported to India for the carrier *Vikrant* and the *Godavari*-class frigate. The FPB version is installed aboard CNR 600-class corvettes such as the Ecuadorian *Esmeraldas*. It has also been reported in the Taiwanese *Lung Chiang*-class fast patrol boats. SADOc-2 is also installed on board the private-venture patrol boat *Saettia* and the new *Minerva*-class corvettes.

Selenia-Elsag offers a modernized version under the designation TBA (based on SEN-300).

SADOc 3 is the current large-ship system, exported as IPN-20. It is on board the carrier *Garibaldi*, the *Animoso* class, and the modernized *Audace*-class missile destroyers. In the carrier *Garibaldi*, this system incorporates 2 multioperator horizontal consoles (supervision, command/control) and 9 single-operator vertical consoles (EW, track management, air operations control). In this case SADOc 3 supports Links 1 (to NADGE, the NATO shore-based air-defense system), 11, 14, and 16; the NADGE link permits the ship to control shore-based aircraft. This version can handle 200 tracks.



The IPN series horizontal console shows the three data entry stations with their keypads and trackballs. (Selenia)



The IPN series vertical console, with its keyboard, keypads, and joystick. (Selenia)

SADOC replaces 2 earlier Selenia naval tactical data systems, SES, for missile cruisers (produced 1961–65) and SIDA (naval integrated defense system, 1963–66).

◆ IPN-S

IPN-S is the next-generation successor to the IPN series, which the Italian government proposed for the NATO frigate. Now that Italy has withdrawn from the NATO-frigate project, IPN-S will presumably end up on board the 2 new missile destroyers. No details have been released, except for the statement that this will be a distributed rather than a federated system, i.e., a radical break with past Italian combat-system architecture. However, official Italian statements also list Selenia as responsible for the central computer and the data bus, so the degree of decentralization may not be complete. The computer will be based on a Selenia multiprocessor architecture. Consoles will be by Selenia-Elsag, and software by Datamat. It is possible that the official statement has been poorly phrased and that each console will contain, or will be connected to, a Selenia computer.

◆ SEN Series

The Selenia-Elsag small-ship combat systems were announced in 1984.

SEN-100 is based on the Elsag NA18 optronic director, expanded to provide some command/control facilities. Intended for small craft of up to about 200 tons, SEN-100 controls 2 guns of different calibers. As of 1984 this system had been offered to Indonesia for use on board 4 projected fast patrol craft (it is presumed that they were the German Lurssen PB 57 type ordered in 1982, 2 of which were completed in 1985–86 and 2 of which have not yet been completed). The system is built around a single 1-operator vertical console, which normally shows radar PPI data but which can switch to a fire-control display.

The SEN-200 designation was reserved for ships of up to about 600 tons, but no such system was designed.

SEN-300 is intended for ships of up to about 1000 tons, to control a surface-to-air missile and 2 guns of different calibers. SEN-300 is based on Dardo E (an anti-aircraft fire-control system, described in the AAW section) and on the Selenia IPN-10 command/control system; the associated search radar will be based on the Orion RTN-30X electronics. The system uses 1 horizontal (tactical) and 1 vertical multipurpose console, thus requiring a minimum of 2 operators for all functions, including both active and passive surveillance.

◆ SER 100

SER 100 is Selenia's tactical data system, jointly developed with Racal in Britain. It will use the Racal 2459/1 radar integrated with NA-series optronic fire-control systems.

◆ TBA

The Selenia-Elsag combat system based on SEN-300, for larger ships (about 1000 tons and up), is effectively a modernized version of the *Maestrale/Lupo* system (SADOC 2/IPN-10).

◆ MAGICS

MAGICS is Selenia-Elsag's new Modular Architecture for Graphic and Imaging Console System workstation, used in SICS, in the NA-25 fire-control system, in the Italian version of FAMS, and in command/control systems. The standard console accommodates one or two 19-in color monitors (1280 × 1024 pixels), each driven by a MARA 286 computer. The MARA acts as display processor/controller, carrying application software and providing data to the internal graphic resources of the console. There are also a video processor and a graphics unit. The video processor accepts raw sensor data, to form radar (PPI, A-scope, B-scope) and sonar (B-scope) images and also provides an image memory. The separate graphics unit does geometric processing, produces geometric shapes (such as lines, cones, polygons), can transform sensor data from format to format, can

digitally mix 2 video channels (for windowing or mosaic-type image superposition), and provides an image memory. This unit can also function in other image formats, from 580 × 780 pixels interlaced (equivalent to 625-line European television) to 1280 × 1530 pixels (60 frames/sec).

MAGICS can function directly as a sensor display. It can accept radar data at a PRF of up to 16 kHz centered, or 8 kHz off centered. Radar video-sampling rate is up to 25 MHz, with 8 bits/sample (analog-to-digital conversion). Standard television and IR video can be accepted at 512–1024 lines/frame, and in this case video sampling rate is up to 40 MHz (6 bits/sample). Range scale can be 0.5–1024 km or nm. Time to change a pixel is 6 nanosec (0.006 microsec).

The basic MAGICS console also carries a magnetic-tape cartridge. There is also a tabletop configuration for limited space. The keyboard can have programmable flat panels, a joystick, or a trackball.

JAPAN

Japanese naval tactical data systems (CDSs) are designated in an OYQ series:

OYQ-2 was described as a Weapon Entry System (WES); it was fitted to the destroyer *Asakaze*. WES succeeded Weapons Direction Equipment (WDE) on board the first Japanese area-defense destroyer, *Amatsukaze*.

OYQ-3 was originally installed on board the *Haruna* but has now been replaced by OQS-6. OYQ-3 was described as a Tactical Data Processing System (TDPS).

OYQ-4 Mod 1 is found in the *Hatakaze*-class area (standard missile) air-defense ships. All air-defense sensors (radars and ESM) feed into the OYQ-4, which also receives Link 11 and Link 14 data directly. Only the sonar, OQS-4, bypasses OYQ-4, to feed directly into the underwater fire-control system (SFCS-6A), which controls ASROC and Type 68 12.75-in torpedo tubes. In contrast to U.S. systems, there is no WDS as such embedded in the tactical data system; the OYQ-4 communicates directly with the missile fire-control system (Mk 74 Mod 13). Earlier Japanese area-defense missile destroyers (*Tachikaze* and *Amatsukaze* classes) are not credited with tactical data systems, and in this sense correspond to the U.S. *Charles F. Adams* class. Presumably, OYQ-4 is approximately comparable to the German SATIR. OYQ-4 is described as a CDS.

OYQ-5 in the *Asagiri*, *Hatsuyuki*, and *Shirane* classes uses the U.S. UYK-20 computer. This system employs U.S. NTDS-type (OJ-194B) consoles; see the entry on NTDS for details. A block diagram of the *Asagiri* class's weapons system shows all the radars feeding into OYQ-5. However, sonar data are fed separately into an underwater fire-control system (SFCS-6B), which receives heading and gyro data from OYQ-5. Although the NOLR-6C ESM system feeds OYQ-5, the other major ESM sensor, OLR-9B, feeds directly into a jammer (OLT-3) and does not feed into the main combat system's computer at all. OYQ-5 controls guns and anti-aircraft missiles through their respective fire-control systems (FCS 2-21A and 2-12, respectively). The only associated data link is Link 14. However, the *Shirane* class has Link 11 as well as Link 14. OYQ-5 is described as a tactical data-processing system (TDPS).

OYQ-6 in the *Haruna* class, replacing OYQ-3, uses the U.S. UYK-20A computer. OYQ-6 is described as a CDS.

Tactical data systems are also designated in a Type series, so that, as modernized, the *Takatsuki*-class destroyer has TDS 3-2 with provision for Link 14.

Submarine combat data systems are designated in a ZYQ series.

NETHERLANDS

As of late 1990, Signaal is developing a new distributed combat system for frigates, competitive with the French TAVITAC.

◆ SEWACO/DAISY/FORESEE

These are Signaal's Sensor, Weapon, Control System (a designation applied by the Dutch Navy). Signaal distinguishes between SEWACO (which includes sensors and weapons) and DAISY (Digital Action Information System), which is the control system proper. At one time Signaal distinguished further and described DAISY as a computer plus its proprietary Combat Information Display System (CIDIS). FORESEE is the combination of DAISY hardware with the appropriate command/control software. The name is a pun on 4C: command, control, communication, and coordination. However, both the command/control system and the full-up combat system are generally denoted by the term SEWACO. Like NTDS, SEWACO is based on a single central computer, although later versions place considerable computing power in the consoles and so may be considered more federated than fully centralized.

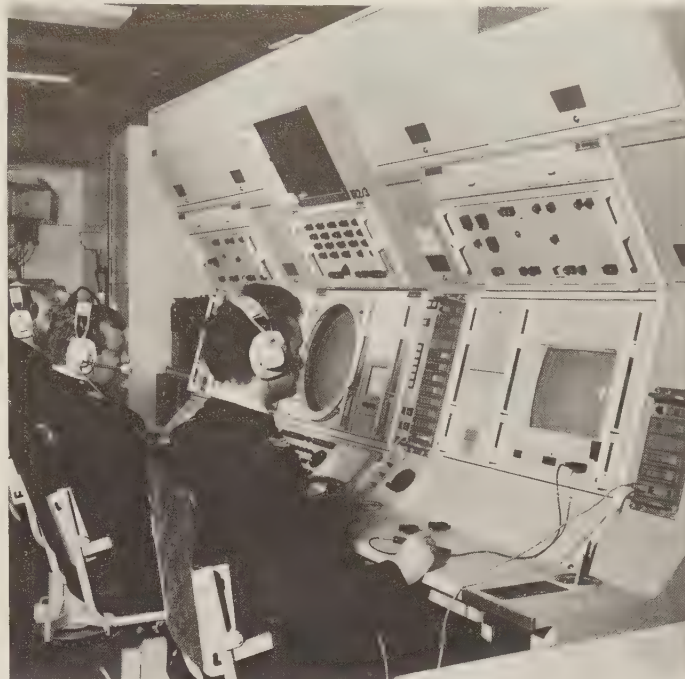
SEWACO was originally developed in the mid-1960s, entering service in 1975-76 on board the two *Tromp*-class missile destroyers, serving their elaborate 3D radars. Architecturally it was much like the contemporary U.S. NTDS, but the symbology and the program architecture were quite different. SEWACO uses alphanumeric track identifiers.

The detailed data that follow describe the original form of the system. SEWACO VII and the related STACOS use a later-generation SMR-4 computer and workstation consoles (SIGHT, Signaal general-purpose high-resolution tactical) incorporating some local processing capability in the form of 68000-series chips.

The standard computer is the Signaal SMR (the smaller but compatible SMR-S1 in some versions). At least in the original SEWACO, radar-video data were automatically extracted and inserted into the computer memory; early versions of SEWACO differed in the number of separate radar-video extractors and in the number of consoles. In some cases the system also served a DES electronic plotting table. Physically, the system is built around a data-handling cabinet and consoles. The cabinet contains the tactical computer, the sensor data distribution unit or SDDU (which feeds sensor data to the consoles), a computer data distribution unit or CDDU (which feeds synthetic video to the consoles), and 1 or more radar-video extractors. The video extractor takes radar information from the SDDU and feeds it to the computer via the CDDU. Up to 10 consoles can be served.



Standard Signaal horizontal display console (HDC) on board the Dutch air-defense frigate *Jacob van Heemskerck*. (Signaal)



Standard horizontal display consoles of the missile-control system on board a Dutch L-class air-defense frigate. (Signaal)

In all versions of SEWACO, the computer interfaces with both the weapons and the sensors, using 24-bit I/O channels.

The design concept was to build different systems around a common core, so that about 75% of the software modules and data-base (tactical-picture) elements of any version of DAISY would be identical. This modular programming concept made it relatively easy to develop new members of the family and to ensure their reliability and efficiency. Signaal also claimed that its modular programming approach made later modernization relatively simple. Such programming should, however, be relatively inefficient in terms of core usage.

The system carries 2 types of tracks: 225 point tracks (i.e., tracks of objects for which range and bearing are both known) and 30 bearing tracks (ESM, passive sonar, and visual bearings). Tracks can be automatic, manual, or dead reckoned. For air tracks, the system maintains a track history over the last 2½ min, and for surface and subsurface tracks over the last 40 min. In each case the track file includes course and speed (and height for an air target, depth and doppler for a subsurface target), as well as link status/correlation and ESM-bearing association data. Bearing tracks are characterized as ESM/ECM, ASW/torpedo, or visual.

Threats can be ranked in relation to own-ship, escorted high-value unit, or vital area center. Calculations are based on target hostility criteria, including category, identity, position, course, and speed; target identity can be derived from the target electronic signatures, IFF responses, or data from external sources. DAISY automatically computes the best pairing of targets with the highest threat rank with own-ship or own-force weapons (including missiles and fighters). Free-fire boundaries are entered manually, and some versions of the system can respond automatically within those limits. Up to 2 airborne weapons systems can be controlled locally by a DAISY system, the ship-board controller selecting the mode of attack (e.g., frontal, rear, up-and-over). A version of DAISY was developed for carrier use, presumably for the Dutch carrier *Karel Doorman*, but it seems not to have been installed. It included facilities for carrier-controlled approach.

DAISY is designed to operate with Link 10 or 11, incorporating manually set filters that restrict linked information to an area of interest and thus protect the system from overloading. Filter categories are the number of automatically accepted tracks, target category, and range. The software is designed to

accommodate up to 24 units in the data-link net. The system is also designed to format its own data for rebroadcast on Link 14 (teletype link); up to 45 tracks can be broadcast in this way.

There are 2 types of multifunction consoles, a vertical display console (VDC) and a horizontal type (HDC). Each carries a 16-in-diameter, labeled position display (CRT). The VDC also carries a 7-in alphanumeric display. The HDC can carry a 16–20-in PPI as an alternative to the labeled 16-in display, and there are one or two 7- or 15-in alphanumerics. Such a display normally accommodates a supervisor and 2 operators. These displays carry keyboards, programmable quick-action (i.e., special-function) keys, roller balls, and handwheels for communication with the system. Each console can be configured for any system task simply by changing the overlay (designation) of its special-function keys. There are 2 types of vertical display consoles, 1 for radar and 1 for sonar video. The HDC is a radar display console.

Signaal also describes the HDC as a tactical display console (TDC); it is an analog/cursive device (labeled plan display, LPD) capable of displaying video from 3 radars. Range scales are 2–256 nm. The VDC offers similar ranges.

Signaal currently offers a new general-purpose workstation, SIGHT (Signaal general-purpose high-resolution tactical) with raster scan. It can use laser disks to store maps, manuals, and procedures. SIGHT can have up to 4 system functions linked to it. It uses a multiple version of Ethernet with a total capacity of 40 Mbits/sec.

Versions of SEWACO: (Note: The Royal Netherlands Navy and some NATO versions are numbered, but there are also numerous export variants that are not listed.)

SEWACO I was for *Tromp*-class AAW destroyers and was ordered in 1971. Reportedly, the SEWACO project was started when a Dutch-British joint-development program, which included the SPS-01 radar, died with the cancellation of the British carrier CVA.01 in 1966. The radar had been planned for the *Bristol* (Type 82)-class missile destroyer and would have served a complementary ADAWS tactical data system. Instead, the Dutch decided to continue work on the advanced 3D SPS-01 radar and to develop their own suitable tactical data system. Thus, SEWACO almost certainly shares a common centralization concept with ADAWS and also shares the great weakness of the ADAWS systems, their inability to accommodate major system change and growth. It is possible that SEWACO VII solves part of the problem through greater modularity.

SEWACO II was for the Dutch "Standard"-class frigates (ASW version) and was ordered in 1975. There are 2 horizontal and 5 vertical radar displays, 1 vertical sonar display, separate WM25 and STIR (Signaal tracker/illuminator) weapons-control consoles, and a separate ESM-control console.

SEWACO III was an unsuccessful Signaal configuration, for a frigate similar to the "Standard" (ZW-06 and LW-08 radar, WM25 fire control, SQS-505 sonar, guns, Exocet, and Sea Sparrow). This system had 12 operator consoles: command/control, air- and surface-situation displays, EW/data-link control, weapons direction, helicopter control, ASW, hull sonar, VDS, sonar-signal injector, weapons control, and television.

SEWACO IV was for the Belgian *Westhinder*-class frigates and was ordered in 1974. There are 3 horizontal displays, a sonar display, and a radar plotting table (with true-motion indicator). There are separate fire-control consoles for missiles, guns, and ASW rockets.

SEWACO V was for the mid-life modernization of the Dutch *Van Speijk* class (now sold to Indonesia). There are 4 horizontal tactical displays and a plotting table. SEWACO V was ordered in 1976.

SEWACO VI is for Dutch "Standard"-class frigates (AAW version). There are 6 vertical consoles, 2 horizontal consoles, and a sonar display console. This version includes both primary and secondary radar-video extractors and was ordered in 1985.



General-purpose operator station (GOS) of an M-class (*Karel Doorman*-class) frigate. Several such stations are arranged side by side in the frigate's operations room. (Signaal)

SEWACO VII is for Dutch *Karel Doorman*-class (M-class) frigates. It is described as a next-generation system, with a higher degree of automation and integration. Since the new consoles are workstations (i.e., have some processing capability of their own), SEWACO VII is more a federated than a fully centralized system.

SEWACO VIII is for Dutch *Walrus*-class submarines and was ordered in 1979.

Other frigate installations include (order date in parentheses) Spanish *Descubierta* class (1974), Egyptian *El Suez* class (1978), Nigerian *Aradu* class (1978), Moroccan *Errhamani* class (1979), Argentine *Almirante Brown* class (1980), and Argentine *Espora* class (1980). Of these ships, the Spanish, Egyptian, and Moroccan ships are essentially sisters.

Unit cost of a current SEWACO is probably about \$2 million, based on extrapolation from the stated costs of equivalent systems rather than from Signaal published data.

◆ SINTACS

SINTACS is the Signaal combat data system proposed for the Australian–New Zealand frigates, in competition with the *Feranti 500* and the Swedish 9LV453 Mk 3. Although no details were published, SINTACS was probably a variant of the SEWACO VII system of the new M-class frigates. The Swedish system was chosen: it combined the command/control function with the weapons controls.

◆ STACOS

STACOS is the Signaal combat system for the Greek, Portuguese, and Turkish MEKO frigates. The Turkish MEKOs differ in that their Signaal combat-data systems are connected to Sea Guard point-defense systems (with associated Plessey short-range radar). The basic STACOS architecture is somewhat different from that of earlier DAISY/SEWACO systems. Data buses are employed. In a typical version, Mod II, a Signaal Data-Handling Cabinet is connected to 2 data buses: a dual combat-system bus and a dual display bus. Each of the vertical multi-purpose consoles (probably SIGHT units) is connected to both the video-distribution bus and the display bus. As in other Signaal combat systems, the data-handling cabinet contains a data-handling computer (DHC) with its interfaces, plus a sensor-data



Full-scale mock-up of the M-frigate operations room at the Netherlands Institute of Perception at Soesterberg, showing the new standard consoles in use. Note the video (the helicopter) displayed on the console in the foreground. The full CIC (operations room) contains 14 GOS consoles. (Signaal)

distribution unit (SDDU) for radar video. It also drives an SPL182 plotting table. STACOS Mod II incorporates 8 multifunction consoles (with 1 more optional).

The Turkish ships, the first of this generation to be completed, introduced the SMR-4 computer. Presumably, it is common to the other STACOS installations, for the Portuguese and Greek navies.

Signaal defines 5 separate tactical pictures that STACOS must compile and maintain: air, surface, subsurface, electromagnetic (i.e., ESM), and link (i.e., externally provided). The system as a whole provides command support in the form of threat evaluation, target designation (to AAW and antisurface fire-control channels, and to Harpoon missiles), ECM system monitoring, Link 11 message handling, and evasion advice upon torpedo or close contact detection. Helicopter and torpedo target designations are off line (i.e., via plotting table rather than automated). The system can vector a helicopter or maritime-patrol aircraft to attack a contact made by the ship (e.g., with a towed array) or to fly over a reference point, and the same vectoring function can also be used to recover the shipboard helicopter. There is also a tactical navigation function, which uses information from the ship's log and compass. Presumably, in the future a GPS receiver would be connected directly with the central system. Typical outputs are stationing calculation, CPA, and calculation of the ship's geographical position.

A Signaal block diagram of the overall system shows STACOS connected to 7 operational functions, which presumably match the consoles: track management (which might take up more than 1 console since the air and subsurface pictures would presumably be monitored separately), platform control, communications control, threat evaluation, resource monitoring, sensor control, and weapons control. Resource monitoring presents the status of own-ship and force weapons systems, as well as threat targets and current engagements.

Platform control means both own-ship control and the control of an associated helicopter or maritime-patrol aircraft, which the system handles as logical extensions of the ship. In each case, the track-handling software is the basis for control, which is exerted by display (STACOS does not steer the ship directly). Own-ship control includes steering advice for close contact evasion, torpedo evasion, chaff launching, torpedo launching, and helicopter recovery. Inputs include wind and drift as well as compass and log. One ship can control 2 auxiliary

platforms (helicopter or airplane), and auxiliary-platform control includes a ship-controlled approach (SCA) or a poor-visibility approach (PVA). As in the case of ship control, STACOS does not generate the actual commands. Instead, there is a display that is used to assist the controller talking to the pilot by radio.

The system as a whole can handle 512 tracks, which are carried in a separate track store. It divides tracks into 3 categories: sensor tracks (carried by a single sensor), system tracks (multisensor, own platform), and network tracks (based on data from other platforms, and of interest to a group of platforms). The system also carries special or reference points, which it handles like system tracks. They may include ESM fixes. As in earlier SEWACO systems, this one can use filters to match particular areas of interest and, so, to avoid overloading the track store. Filter operation is based on the number of automatically accepted tracks, track category, and range; the operator sets range filters for air and nonair targets. The total track capacity, however, is a system parameter that the operator cannot alter.

The key sensors are digital, and they create their own track files. System tracks are created by assigning such sensor tracks to system track numbers. Alternatively, the track manager can associate 1 or more sensor tracks to an existing system track, adding new data to it. The manager can also correlate a system track with data-link data and can shift responsibility for tracking from 1 sensor to another, e.g., from a long-range air-search radar to a shorter-range unit. Track files include the tracking source and an assessment of track quality, as well as engagement status, threat ranking (air tracks only), and time of last update (GMT).

Threat evaluation of air targets is automatic and can be computed with respect either to the ship or to a high-value target she escorts. Criteria include target category, identity, position, course, and speed. Identification is manual, based on data such as ESM and IFF, as well as data-link information. Thus, the STACOS form of TEWA is more sophisticated than that in, say, NTDS (which relies mainly on the ratio between closing rate and range). The ability to evaluate threats with respect to the nearby high-value target is important; in the Falklands, British Type 22 (Sea Wolf) ships escorting carriers were hampered by TEWA software that concentrated on targets heading directly for the ship, rather than for the unit she was protecting. STACOS displays the 8 most threatening air targets. The ship can engage only 2 at once, but the display is needed for rapid reengagement.

Weapons control includes monitoring. The system is decentralized in that the Sea Sparrow surface-to-air missile is autonomous. In this case STACOS designates targets, and the tell-backs from the system are used to update the overall situation picture. Harpoon firing data (e.g., way points, trajectory) are passed back into the overall tactical picture (to, among other reasons, avoid confusing the missile with an unknown air target). For the ship-launched lightweight torpedoes, STACOS shows danger areas, torpedo trajectories, and predicted hitting points, as well as course to steer, time to go (before impact), and duration. For a helicopter-dropped torpedo, STACOS presents a drop point and danger area, as well as data such as course to fly, range to go, etc. For the chaff launcher, STACOS presents wind direction and speed (from the navigational inputs) and advises which launcher to use and which course to steer. Actual launcher use (as well as actual course steered) is not controlled automatically. STACOS commands the APECS II jammer to start or stop operation against a target sent by the APECS system when it is in the automatic or semiautomatic mode. However, the jammer controls its own operation once it has been started.

In the Portuguese ships, STACOS employs a DA-08 long-range, digital, air-search radar; an MW-08 short-range, digital, 3D radar; an analog (Racal 2690) navigational radar; an analog IFF; a digital sonar; a digital APECS II EW system; a digital Dual Director Weapons-Control System (DDWCS, using two STIRs);

a Signaal VESTA helicopter digital data link; Link 11; Link 14 (which uses an analog modem); and Harpoon missiles (which are digital). The chaff launcher, torpedo tubes, and helicopter are all off line, not automatically controlled by STACOS. This division is probably typical of modern practice, and it is interesting to note how many essential elements are still not digital.

In the Greek ships, a weapons-control console is installed beside the two STIR consoles so that the STIRs can act as an independent, redundant, command/control unit.

In the Turkish version there are 3 vertical displays for tactical-picture compilation, a horizontal conference display for command decision making, and an automatic plotting table.

◆ Signaal Mini and Compact Combat Systems

These systems are extensions of the WM-series fire-control systems described in the Anti-air Warfare section. In a mini-combat system, a standard Signaal horizontal tactical display (described above under SEWACO) is connected to the weapons-control console, which contains the SMR-S1 computer (the same type as in the corresponding WM-series fire-control system). Signaal describes a compact system as one in which the computer feeds 2 or 3 horizontal consoles. In each case, the computer is installed in the standard Signaal weapons-control console.

Signaal mini-combat systems have been installed on board the Korean *An Yang Ho* (KCX) and the Thai *Ratanakosin*-class (PSMM Mk 16-type) corvettes. The corresponding fire-control systems are, respectively, WM-28 and WM-25.

No installations of the compact system have been reported.

NORWAY

◆ MSI-80S

MSI-80S is a fast attack (missile) boat tactical system, manufactured by NFT. It employs a single 3-operator tactical console (tactical operator, weapons-control operator, and passive-sensor operator); the officer in tactical control occupies a fourth position. The tactical operator initiates and controls target-data calculations and updates the tactical situation display. The system entered service in 1977 on board Norwegian *Hauk*-class fast attack boats.

The computer is a KS 500, using the Mary language. Some of the software is based on that developed for the MSI-70U submarine system (see the ASW section). The console itself incorporates a 23-in horizontal (main tactical) display that shows raw and synthetic video, plus a 12-in CRT. The latter normally shows alphanumeric but can act as a backup for the main display. Displays are manufactured by GEC Sensors.



MSI-80S on board the Norwegian fast attack boat *Hauk*. A smaller derivative is used on board Greek "La Combattante"-class fast attack boats. (NFT)

The associated sensors are twin Decca TM 1226 navigational radars and an electro-optical tracker (GEC V334 LLLTV camera, laser range-finder, IR scanner), optical sights, and ESM.

◆ MSI-3100

This combat system for the modernized *Oslo*-class frigates was first installed in February 1987. The contract was awarded in 1985. MSI-3100 incorporates two 2-operator KMC 9000 consoles, 1 for tactical control and 1 for weapons control. Tracking can be manual (via trackball) or automatic, the former mode permitting the operator to modify raw-video inputs. In the latter mode, radar data are inserted by an REX II radar plot extractor. As a whole, the system can handle up to 99 self-generated and 48 link-reported tracks. The 2 consoles communicate via a Budos data bus. There are no dedicated fire-control systems as such because all directors feed the weapons-control console, which in turn connects to the guns and missile launchers.



The first MSI-3100 system, in the operations room of HNMS *Trondheim*, September 1988. The console on the left is for weapons control (with one position for above-water warfare and the other for gun control); that on the right, for tactical control. The tactical-control console is responsible for surveillance and for target tracking (i.e., for evaluation of the tactical situation) and also for underwater warfare. Tracking can be manual (via a trackball) or automatic. Both consoles are connected by a data bus. Each screen is a 20-inch (diagonal) multicolor digital raster (television-like) display; the two to the left show a combination of raw and processed video. As a whole, the system can handle up to 99 self-generated and 48 link-reported tracks. (NFT)

Each console accommodates 2 KS 500 computers, 1 for general operation (256k) and 1 dedicated (128k). A KS 800 is used as a scan converter and display controller. In the weapons console, the dedicated computer is used for Terne (ASW mortar) fire control; in the tactical console, for air defense and antiship fire control. All use the Norwegian Mary computer language.

Taken together, the consoles amount to a federated system.

The same KMC 9000 multipurpose console is used in MSI-3100, in the MS-90U submarine system, in the NOAH ARCS control system for the improved Hawk missile, and in the FENRIS radar data-integration system.

◆ MSI-340/350

This development of MSI-3100 was announced in 1987. It employs the same KMC 9000 two-operator console, with either KS 500 or KS 900 processors. The software is written in either Mary, Pascal, or ADA. MSI-340 is a single-operator system with a 20-in CRT; it uses the NFT REX II radar plot extractor. MSI-350 is a 2-operator extension of -340. Generally, the console accommodates 1 weapons operator and 1 tactical (command/control) operator.

Reportedly, MSI-340/350 is the tactical command system envisaged for the next generation of Norwegian fast attack craft. Units intended for group command will have 2-console installations.

◆ NAVKIS

Kongsberg's (now NFT's) Navigation Command Control and Information System is installed in the *Nordkapp*-class coastal-patrol ships (EEZ enforcement ships). The system was ordered in November 1978. Priorities were (i) accurate navigation, so that the borders of the EEZ could be maintained; (ii) command/control; (iii) air surveillance and gun control. Each function is served by its own console (2 in the case of navigation: 1 in CIC and 1 on the bridge), and the consoles are connected by a data bus, which also receives sonar data directly.

The main console is the Command, Control, and Information System (CCIS), which can identify and automatically track 16 targets and identify and automatically plot up to 64 fixed points. It can display the air targets picked up by the air surveillance console, and it can define and display local geography (including fishery grid, oil block, and similar data). This console is also responsible for antisubmarine weapons control (sonar input, drop-point calculation and plotting for mining, and target-intercept calculation for torpedoes), and it provides a navigation backup (correlates data from the ship's sensors with known geographical points in the display of navigation data). The air-search radar feeds into the CCIS console, as does the ESM receiver.

Navigation was considered particularly important because radio-navigational-aid coverage of the Norwegian Sea is relatively poor. The ships, therefore, use 3-axis main gyros, 2-axis secondary gyros, a passive log, TRANSIT (satellite), Decca, Loran C, an echo-sounder, X-band navigational radars, and GPS. A navigational computer monitors the receivers and sensors, filtering their data to produce a best estimate of ship's position. The navigational computer also has access to surveillance radar, LLLTV, and optical-sight data normally fed to the CCIS console.

Finally, the air-surveillance and gun-control console directly controls air engagements and the ship's helicopter. Up to 8 air, surface, or subsurface targets can be tracked manually, and the air display includes IFF data. This console receives data from the air-search radar via a radar switchboard, which also feeds data to the CCIS.

The data bus is Budos, operating at about 30 MHz (bandwidth 10 MHz), with a capacity of 1–3 Mbits/sec.

SPAIN

◆ Alcor

Alcor is Bazan's small-ship combat system. Development reportedly began early in 1986, with shore trials early in 1988 and sea trials late that year. The initial-production version provides optronic fire control for 40-mm guns, but an expanded Alcor M is intended for corvettes and frigates. It incorporates a radar-video extractor and uses 2 parallel redundant data buses. The Alcor project is being funded largely to develop a combat system-architecture capability at Bazan.

The small-ship version consists of a COAR weapons console and a CONTAC tactical console; the current fire-control sensor is a stabilized television connected to a video tracker. The ship also carries navigation and surface-search radars, as well as an auxiliary optical target designator.

The system is tied together by a Cormonet data bus, which reportedly differs from the usual type in that it takes into account the priority of each user.

The CONTAC console contains 2 ruggedized IBM PC/AT-compatible computers, 1 carrying the tactical picture and the other providing the general-purpose computing power of the system. In this particular case, the second computer is responsible for gun fire control. The main tactical display, on the right hand side of the console, is a 20-in (diagonal), high-resolution

color monitor (1024 × 800 pixels); it is flanked by a 9-in monochrome display, presumably for raw sensor video. The operator communicates with the system by means of software-defined keys plus a standard keyboard and a roller ball. The programming language is Pascal 86.

The COAR console carries 2-monochrome monitors, 1 for alphanumeric and the other for video (e.g., television monitor video). Three separate keyboards control the video tracker, the configuration of the fire-control system, and data entry; the data-entry keys can be used to reconfigure the system, e.g., for stand-alone gun operation in the event that the system cannot obtain fire-control solutions from the tactical console. It seems unlikely that the COAR console has any local computing capability at all.

Alcor was developed as SPCVZ (*Sistema de Combate para Patrullero de Vigilancia de Zona*) for offshore patrol vessels; it was tested at sea, in partial form, in 1987. It will be the optronic FCS of the Spanish *Atrevido*-class patrol ships, entering service in 1991.

◆ Tritan-1

Tritan-1 is the Spanish navy's tactical data system, developed by the Spanish Naval Observatory at Cadiz. It was installed on board the carrier *Principe de Asturias* and the new *Santa Maria*-class frigates as built, and is being installed on board the *Baleares*-class frigates as part of their modernization. It is essentially NTDS plus Italian- and Spanish-built components. Selenia IPN-10 series consoles are provided to control the Meroka close-in weapons and to act as monitors for Selenia radars. There are also separate Elettronica ECM consoles. The main consoles are OJ-194/UYA-4s, built under license.

The *Principe de Asturias* has a UYK-7 central computer, supplemented by UYK-20s. She has 10 OJ-194 operations consoles; 2 OJ-197 command/control consoles; 4 Selenia IPN-10 consoles (for Meroka); 3 Elettronica consoles for that company's ESM, ECM, and ELINT systems; and communications consoles.

The *Baleares*-class frigates have a UYK-20 central processor, 5 OJ-194 consoles, 4 Selenia tactical and weapons-control consoles, a radar-data integrator (apparently broadly analogous to the U.S. SYS-1), and a Rockwell 2-way data link (presumably for at least Links 11 and 4). Modernization of the frigates is to be completed by 1991. The associated EW system is also new: it is Deneb, manufactured by Ceselsa.

SWEDEN

◆ Base HDA 101

Ericsson's new command/control system is presumably the successor to CCIS. Base HDA 101 was announced in 1989 and is contemporary with the BEAB Base 2000 series. HDA means High-Performance Distributed Architecture. As in the case of Base 2000, proposed applications include ground forces and land-based air defense. The word "base" is intended to suggest a basis or infrastructure upon which command/control systems can be erected. Again, as in Base 2000, the architecture is open to permit easy expansion and modernization. The associated computer is the Ericsson-developed APN 167 (which used the 68020 processor), in single and multiple arrangements. The nodes of the system are connected by an Ethernet LAN, and the nodes share a distributed data base. Unlike CCIS and Base 2000, this system has no separate picture-keeping computer and, therefore, no single- or dual-point failure mode. Programs are written in ADA or in a real-time version of Pascal.

Ericsson emphasizes the flexibility of its concept, to the extent that the software can run on alternative computers. Similarly, there can be many alternative displays. However, a typical system would consist of some combination of 5 types of nodes: a workstation node, a monitoring-and-control node, an I/O node, a data-base node, and a functional node. The data-base node carries large, semipermanent relational data bases and other functions stored in secondary memory; it is not a single repository of the system's dynamic data base. For example, in

a naval system the data-base node might carry maps as well as information on potential threats.

The workstation is the 1- or 2-operator console display. Ericsson envisages a 2-operator console with side-by-side, high-resolution, color, raster-scan screens, plus keypads and roller balls. One screen would normally be fed with scan-converted raw radar video. Ericsson currently offers a modular workstation designated DS 90. In a typical application, up to 4 radars would feed a common radar processor that in turn would feed a radar graphic processor (RGP) in the console. This processor would feed both the display screen and the system data bus. The screen is 1024×1280 pixels, displaying up to 256 colors simultaneously.

Running this sort of monitor (which is increasingly common) requires an enormous amount of data processing, in this case by 4 computers. They exemplify the sheer power involved in current raster-scan display systems. One is a raster converter that transforms incoming radar data from synchronous scanning (e.g., rotating beam) to raster-scan form. It carries out this transformation by feeding radar data into a memory equivalent to 8 bits/pixel/radar (i.e., about 1.25 Mbytes/radar; 4 sources of synchronous video can be accommodated), then stripping the same data out in raster-scan order. The same memory holds graphics that must be displayed with the radar data. Two sets of video can be mixed in a single pixel plane for display and processing together, e.g., when 2 radar pictures are being combined. A second computer generates graphics patterns (including text) for presentation. Its pixel memory provides 16 planes per pixel (i.e., 16 alternative monitor displays, each pixel being assigned both intensity and color). A third is a graphic processor. It is used to transform the video picture (e.g., to change scale or centering), to rotate or shift the picture. The latter alone requires four 25-MHz 68020 processors and up to 4 Mbytes of local RAM (expandable to 12 Mbytes).

The monitoring-and-control mode keeps the system operating.

The I/O node handles external communications. In a ship-board system, such nodes would handle information from ship sensors and from cooperating ships or shore stations.

The data-base node is a separate device handling relational data bases with large amounts of common functions such as recording and playback. It is not clear whether this node is envisaged as a means of maintaining the system data base when the system is not running.

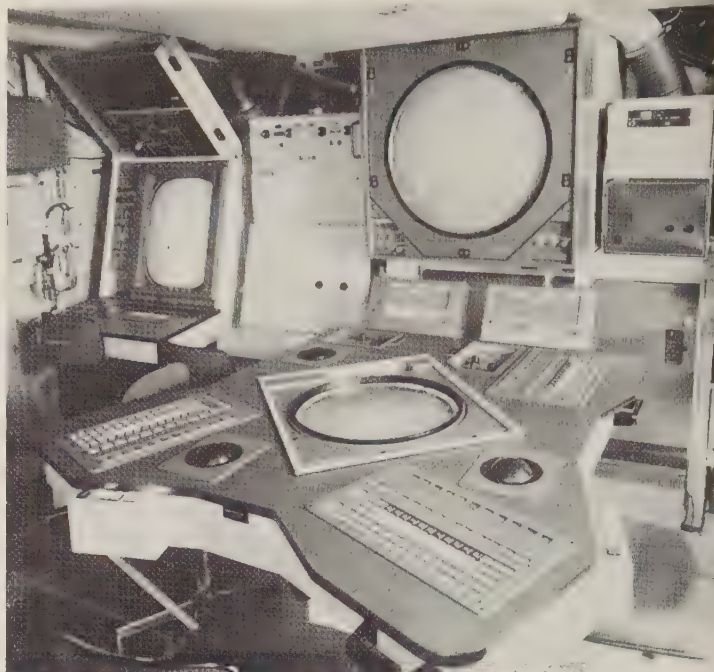
The functional node is a high-performance calculator for special functions such as radar-target detection and tracking.

◆ CCIS/CEPLO/MARIL/MARIS 880

CCIS (Command Control Information System) is a DataSAAB (now Ericsson) tactical system, for frigates, corvettes, and fast attack boats. It was designed for air defense and ATC, as well as for purely naval applications. In the Swedish Navy, CCIS replaced the Signaal M-22, which was used in the original *Spica* class.

The version of CCIS in Royal Swedish Navy service is MARIL; the *Stockholm* class is equipped with an extended version of MARIL 880. This system is based on the Censor 932E computer and can accept targeting data from helicopters and from a shore command center, via a data link, for OTH attacks. The display consoles are designated EPLO (Electronic Plotting System). The Royal Danish Navy's CEPLO (also called DEPLO, for Danish EPLO) is a version of CCIS. The Swedish *Hugin* class, which is generally credited with only a 9LV200 Mk 2, probably has a single (vertical) -console version of CCIS.

CCIS is based on the Censor 900E computer and the DS 86 graphic display system. The computer is used for both displays (picture keeping) and operational calculations (such as those required for fire control). Typically, CCIS is integrated with a 9LV-series weapons control system. For example, in a *Spica II*-class missile boat, MARIL is fed by ship sensors (the air-search and navigational radars, a communications ESM sensor, and an RWR), as well as by data links and by the ship's log and



A MARIL 880 missile-boat installation, showing the horizontal local-operations console and the vertical-screen general-operations plot (GOP) behind, above the 2 alphanumeric plasma displays. The screen in the background is a vertical operations console with a 21-in split-screen phosphor, to display synthetic video (a radar PPI) above alphanumeric. (Ericsson)

gyro. The single horizontal console, which in this version has a 16-in PPI, is manned by the tactical-picture compiler, the weapons officer, and the (antiship) missile-control officer. The weapons officer, in turn, assigns targets to up to 3 separate systems, which are themselves controlled by elements of the PEAB (now BEAB) 9LV200: the gun, the antiship missiles, and the torpedo tubes. Control of guns and torpedoes is exerted through separate single-operator PEAB vertical consoles. Antiship-missile orders are sent directly and automatically to the control panel for the RBS-15 missiles. See the Antiaircraft Warfare section for more details of 9LV200.

In the new *Goteborg*-class coastal corvettes, on the other hand, 3 standard CCIS consoles (2 horizontal LOPs [local-operations plot], 1 GOP [general-operations plot]) are connected to a system bus carrying 9LV Mk 3 operator consoles; the bus is also connected to the ship's weapons and sensors. In this case the combat-control system is described as a variant of 9LV Mk 3, rather than as CCIS controlling weapons, including those fed by 9LV200.

In the *Spica* class, then, the overall system is certainly best described as centralized, the operation suite (consoles and computers) receiving sensor data and designating targets for engagement. Such a system cannot normally survive the destruction of the central processor(s). However, MARIL also incorporates a ship system bus, and the bus can be used to work around individual system failures. Normally, raw radar video is fed directly into the radar plot extractor of the operations suite. The system bus is normally a means by which the operations suite can communicate with the weapons and fire-control devices. However, raw radar video can be fed instead into a plot extractor associated with the fire-control radar tracker, and thus into the combat-system bus. In this way the overall system can continue to operate, albeit with considerably diminished performance. The combat-system bus is largely concerned with the 9LV200 antiaircraft system, so in this degraded mode the ship operates as though 9LV200 is her combat-control system.

HDI 101 (above) and 9LV Mk 3 (below) are the next logical extensions of this idea.

The 16- or 23-in-diameter horizontal PPI display (LOP console) is used for target detection and tracking, 3 operators using their roller balls and keyboards. It includes 2 alphanumeric

plasma displays. There is also a single-operator, 21-in rectangular, LOP (PPI) display, in which the lower part of the screen (coated with a different phosphor) shows alphanumeric information, while the rest of the screen is reserved for raw video. This console also has a roller or joy ball and a keyboard. The 16- or 23-in vertical, command-decision display (GOP) shows only synthetic video. Tracking can be automatic or rate aided. The PPI area shown can be magnified by a factor of up to 128. Magnification is varied either continuously (using the roller ball) or discretely (using the keyboard). There is also a standard data-link terminal (DLT) with an alphanumeric screen and a keyboard.

In a medium ship (a missile attack boat), the 3 displays are typically combined into a 4-operator command center, the GOP standing above the flat LOP, with the 2 alphanumeric displays under it and the keyboard on 1 side. In a larger ship, the command center might consist of paired GOPs, with alphanumeric displays and keyboards between them, and paired LOPs (a total of 4) to either side. A small ship would be equipped with only a single vertical 1-operator console. All announced CCIS installations use either the single horizontal display or the combination of several LOP displays with two GOPs. However, as indicated above, the Swedish *Hugin* class (and others described as having only 9LV series Mk 1 or Mk 2 systems, without associated tactical data systems) probably have single-operator vertical LOPs.

CCIS uses 2 Censor 900 32-bit computers in parallel, each of which is sufficient to run a 2-console system. MARIL 880 substitutes the more powerful Censor 932E for the earlier Censor 900. Target positions are updated cyclically, every 2 min for 24 tracks, or every 30 sec for 6 tracks. In the semiautomatic (rate-aided-tracking) mode, the operator can correct the estimated target position by means of a trackball; the PPI then shows the new position plus a track history. All targets are generally shown with vectors (course and speed). EPLO is designed to accept data from both own-ship sensors and external digital data links. Charts used on the displays are built up of vector lines, typically 1000 of them. Several can be stored on a tape cartridge and called up as needed. In addition, the operators can use their keyboards and roller balls to mark areas of special interest (such as mine fields) onto the electronically stored maps.

Other system computer functions include TEWA, maintenance of a ship data library, weapons coordination and control, EW management, and torpedo fire control (replacing the stand-alone TORCI system of earlier Swedish attack craft). CCIS measures own-ship position by means of both navigational aids (such as Decca and Loran C) and the ship's own gyro and log. It integrates and filters these data to present the ship's position in latitude and longitude, and thus to help drive the tactical display. Other navigational functions are calculation of CPA; calculation of course, speed, and time to take up a designated station; calculation of time of arrival at weapon danger zones (and display of these zones); assistance in various maneuvers (presumably including maneuvering advice when firing chaff); and presentation of navigational patterns.

The ship's ESM system provides CCIS with emitter bearings, as well as with emitter identification data. CCIS sends search orders and bearings to the ESM sensors, jammers, and chaff launchers.

The architecture of the CCIS software reflects Swedish naval tactical concerns. Swedish fast attack craft operate inshore, often among the islands of the Stockholm Archipelago, and they are supported by an extensive shore-based command/control system. Therefore, the attack boat must work in the same coordinate system as the overall shore-based defensive network, rather than in a system of polar coordinates centered on the boat (which might be more natural in an open-ocean environment). In the Swedish case, the situation is simplified because boats operate over relatively short distances, so that a flat rectangular system of coordinates simulates the curved surface of the earth reasonably well. One axis of the system is aligned with a suitable meridian. Geographical features are mapped

using either a Gauss-Hannoverian or a slant stereographical projection.

The Danish CEPLO exists in 2 forms: a single (horizontal)-console version for fast attack craft (bought for the Danish *Willemoes* class in 1972; the ships were completed in 1976-78) and a 4-horizontal-console version (with 2 GOPs). CEPLO was installed on board the 2 *Peder Skram*-class frigates when they were modernized in 1977-79 and was initial equipment for the 3 *Nils Juels* class, completed in 1980-82. In the 4-console version, the horizontal multifunction displays are typically used for local air, surface, and subsurface plots and for weapons coordination and control. CEPLO is now being replaced by the Danish Terma TDS.

◆ 9LV Mk 3 Series/Base System 2000/Sea Viking

Base 2000 is a series of BEAB (formerly PEAB) multipurpose (naval and other defense applications) systems broadly comparable in concept to the new British SSCS. The 9LV designation refers to a fire-control system; the earlier 9LVs are fire-control systems that are part of a larger tactical command system. They are described in the Antiaircraft Warfare section. However, 9LV453 Mk 3, which was selected in 1989 for the new Australian/New Zealand ANZAC frigate is a fully integrated combat-data system, including CIC functions. The 9LV Mk 3 in the new Swedish *Goteborg*-class missile corvettes is an intermediate step between a full system and the earlier combinations of 9LV systems and the Ericsson CCIS. The boundaries between CCIS and Base System 2000 (as implemented in the *Goteborg* class) are not altogether clear, since drawings of the *Goteborg* combat system seem to show elements of CCIS or MARIL (2 standard horizontal displays, connected together, and a vertical command display (GOP), plus a pair of command computers like those typical of CCIS systems). In some cases, a naval version of Base System 2000 may be referred to as FS 2000, the FS being the Swedish acronym for Ship System.

The basis of all of these systems is a ship data bus (a dual Ethernet, each element of which can carry 10 Mbits/sec) which connects all of the sensors, weapons, consoles, and computers. In the *Goteborg* class, a combination of 2 horizontal EPLO consoles and the vertical EPLO GOP lies on the bus, together with the usual 2 CCIS computers. However, the bus also carries 6 standard 9LV Mk 3 workstations. It is connected to the radars (C- and X-band search), to the EW system (both sensors and chaff, with its own subprocessor), to the fire-control tracking system, to the guns (separate from the fire-control trackers; the guns take their orders from the bus), to the surface-attack and ASW system (which is separately fed by the sonar), to auxiliary systems, to a secondary data base, and to a video input. As in the U.S. H930, there is no physical connection between any particular operator station and the sensors and the weapons. Instead, stations produce and receive messages, and the routing of the messages determines which devices receive what. The 2 CCIS computers maintain the overall tactical picture, which is used by all of the consoles.

Each node on the bus has its own processor (CPU), in the form of a single circuit board. The microprocessor is the Motorola 68020, and it is associated with 4 Mbytes of RAM memory (as well as 256 kbytes of read-only EPROM memory carrying instructions for that node). These computers are the functional equivalents of the DCUs of the H930 system. As in the U.S. system, a distinction is made between the architecture of the processor within the node and the separate architecture of the system as a whole, which is presumably buffered from that of the node. As a consequence, the different nodes do not interact tightly, and the system is relatively easy to modify. For example, a great deal of the programming done for the *Goteborg* class could be modified for the Australian project that followed, even though the weapon and sensor fit of the Australian ships was radically different from that of the *Goteborgs*. This simplification reportedly greatly reduced the cost of the Australian system and must have been a major competitive advantage for BEAB.



The standard workstation of the 9LV Mk 3 system. (BEAB)

Programming is all in ADA, for easy transferability to other computers.

Computer functions developed for the *Goteborg* version of the system include the usual tactical-picture compilation, as well as threat assessment of air targets (with display of a threat priority table), and tactical navigation calculation (including intercept and formation calculations). The system is designed for data-link operation.

The modular architecture makes modernization, both within the nodes of the system and by the addition of nodes, relatively easy. The data bus itself can accommodate up to 100 users per segment. BEAB emphasizes the need to accommodate rapid changes in electronic devices, and also the need to modernize ships over their lifetimes. The open architecture of Base System 2000 (which is common to fully modular combat systems) seems comparable in concept to the open architectures of some modern personal computers. Just as in the computers, new devices and new capabilities can be added without major adjustment to the operating-system software, and also without interfering with systems already in place. For example, the *Goteborg*-class corvette is designed to accept later installation of a point-defense missile, such as the vertically launched Sea Sparrow.

The Australian 9LV453 Mk 3, which has been adopted for the ANZAC-frigate project (the Australian version of the MEKO 200), is an enlarged version of the *Goteborg* combat system. In this case there are no horizontal plotting tables at all, only 6 of the new standard 3-screen consoles described below, for the commanding officer/principal warfare officer (equivalent to the U.S. TAO), the surface-warfare coordinator (SWC), the ASW director (ASWD), the helicopter controller, the air-picture controller (APC), and the surface-picture controller (SPC). An additional console can be provided for the EW director (EWD). In addition, there is the usual pair of C2 data-base computers, carrying the tactical picture. The consoles and the computer occupy a command/control data bus, an LAN. It in turn is connected to 2 other buses, the combat-system data bus and a video bus (the latter, through 3 video distribution units). It also runs a plotting table. Compared to the *Goteborg* system, the ANZAC frigate requires 6 or 8 rather than 5 operators/controllers.

In the new units of the Finnish *Helsinki* class, 9LV Mk 3 employs 2 vertical consoles (SPL 85).

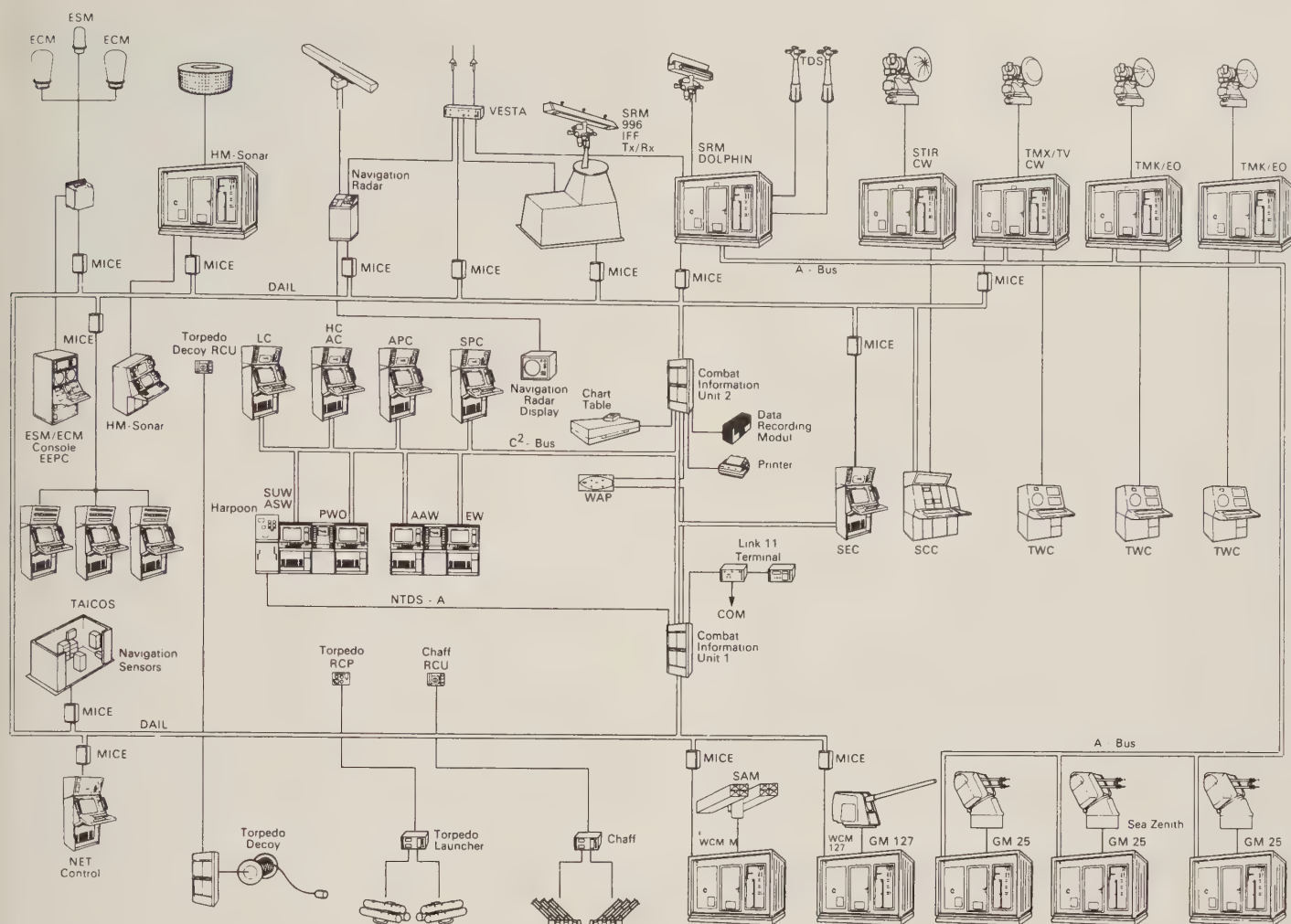
In the Danish Standard Flex 300, another application of 9LV Mk 3, the command consoles and their software were developed by Terma, the Danish company. The 9LV Mk 3 elements are the LAN bus and the fire-control system. This system has 3–7 vertical consoles, depending on the assigned role of the boat.

The 9LV Mk 3 family is the first implementation of the Base System 2000 concept, a modular approach broadly analogous to that represented by the U.S. H930 MCS. Computing power is distributed among the nodes of the system, although there are separate command/control data-base (i.e., picture-keeping) computers that represent single (dual) points of potential failure. All versions of Base System 2000 will use a standard single-operator vertical workstation (SPL 85) carrying 3 displays: a high-resolution, 20-in color or monochromatic, random-scan (cursive), display for synthetic video (on its left); a high-resolution, 12-in, raster-scan on its upper right, to display television, radar, graphics, and text; and a second, subsidiary, 12-in, raster-scan display on its lower right for television, A-scan radar data, or text. Operators call up functions by means of 2 touch input screens showing menus, and they also use keyboards and 1 or 2 roller balls. Each console carries its own central processing unit, with a 68020 processor and 4 Mbytes of memory. As a measure of system complexity, BEAB claims that it has produced a software library amounting to 1–2 million lines of code for the *Goteborg* (missile-corvette) installation.

In at least some versions, there may be 2 separate data buses, 1 for the command/control system and 1 for the combat system, the latter carrying sensor video to be distributed to the command/control system consoles.

These systems differ radically from earlier 9LV/MARIL systems, in which all of the computing power was concentrated in separate machines and in which there were special consoles for surface-gunners, air-surveillance, and antisubmarine operations. Moreover, the computers of the earlier systems were far less powerful than those of Base System 2000, carrying only 256 kbyte–1 Mbyte memory.

Sea Viking is a stand-alone subset of Base System 2000, comprising a tracker on a stabilized platform, a tracking-and-ballistic computer, and 1 or more GOCs. It can control surface-to-air missiles or several different weapons sequentially (e.g., SAM, then medium-caliber gun, then CIWS), selecting them in turn on the basis of an optimizing algorithm. The computers are



Cosys 200, as planned for the Turkish MEKO frigates, showing the array of standard Krupp Atlas consoles feeding a data bus, which in turn connects to the weapons system. Krupp Atlas is responsible for tactical data handling; the fire-control system is based on the Contraves Seaguard. MICE is the standard interface developed by Blohm & Voss for its MEKO Mk 3 frigates, and DAIL is the system bus installed in these ships. The main tactical data-handling consoles are in the center of the diagram, for the PWO and for the subordinate warfare officers (ASW, surface, AAW, and EW); the Harpoon-control console is alongside. The consoles above the C₂ bus are the inputs to the tactical system: 2 radar trackers and 2 track supervisors (compilers), the latter being APC (air-picture compiler) and SPC (surface-picture compiler). The hull sonar has its own console, shown to the left. The 2 combat-information units maintain copies of the current tactical picture, as well as archival data. TAICOS is a separate command system (shown at the left). On the right are the 4 consoles of the Seaguard system, 1 system-control console (SCC) and 3 fire-control consoles (TWC), 1 for each fire-control radar. (KAE)

powerful enough, according to BEAB, to evaluate threats (on the basis of ESM and radar inputs) and then choose a mix of hard- and soft-kill counters.

The 9LV Mk 3 series incorporate a variety of new sensors. See the 9LV entry in the Antiaircraft Warfare section for details.

SWITZERLAND

◆ Cosys 200

Cosys 200 is a collaborative effort among Contraves, Plessey, and KAE. The name suggests that Contraves is the lead company, and that the system is an outgrowth of that company's Seaguard ship point-defense system. Thus far the only application is the second series of Turkish MEKO 200 frigates. The

first series had a Seaguard point-defense system linked to a Signal SEWACO-type tactical data system. Seaguard itself has a distributed architecture, and Cosys presumably grows out of the Seaguard system.

KAE (Krupp-Atlas) is the system integrator, providing 8 or 9 standard German Navy consoles. The architecture is fully distributed, using a command bus and separate weapon and sensor buses, all fiber optic (DIAL, a Blohm & Voss shipwide data bus).

The Krupp MPR tactical-data-system consoles, which won a German navy competition in 1988, will appear for the first time in the Type 123 frigate. They are the usual multifunction raster-scan type with a 68020 processor (carrying 4 Mbytes of memory) in the console. Both the console processors and all other computers in the system are 32-bit units, and all software is written in ADA. A 32-bit 68030 can be substituted for the 68020. The Contraves C2003 console used in the Seaguard system itself is very similar and, thus, is broadly compatible with the Krupp main command/control console.

The Plessey part of the system is the search and target-acquisition radar, respectively the Royal Navy Type 996 and the Plessey Dolphin (AWS-6) normally associated with Seaguard.

USSR

◆ Soviet Combat-Direction Practice

A published report (1990) of a visit to the combat information center (CIC) of the *Sovremennyy*-class destroyer *Bezuprechny* provides some insight into Soviet combat-direction practice. The CIC is divided into functional sections that communicate by voice (presumably via headsets); CIC also communicates with the command post by voice. The term "command post" apparently refers to wherever the ship's commanding officer is located, and often that means the bridge. Recent Soviet naval literature includes a lively debate, reminiscent of one in the

U.S. Navy, over the proper place of the commander in battle, be it on the bridge or in CIC. Current Soviet practice is apparently to keep the commander on the bridge, CIC being supervised by a chief combat officer (i.e., a TAO). His tactical summary display is a pair of classical perspex boards in the center of CIC. The ASW module consists of a single passive/active sonar display (PREBOR 6) connected to a separate sonar room. There is also a separate navigational radar console. The AAW module does appear to be automated, with a circular horizontal console (S-170AM), a vertical console (S-170M), and a separate surface-to-air missile-control section (1 OK-10V situation display and 1 OE 3-1/5 target-engagement console). There are also EW and, according to the article, CW modules in CIC (the latter is probably defensive). The commanding officer, when working from CIC, uses an additional air picture console (S-170M), which can be used to direct friendly aircraft. Presumably, the 3 S-170Ms share a common tactical air picture. It is not clear from the published description whether air trackers manually input target data or the single main air-search radar automatically detects and tracks. It is also possible that the air consoles are merely radar repeaters and that tracking is done by grease pencil; the CIC was visited in port. The use of a separate situation-display console suggests that the air picture is automatically transmitted to the AAW controls.

Apart from the SA-N-7 missiles, the ship's weapons are controlled from other compartments. A control station for 4 SS-N-22 antiship missiles is located close to each group of missiles, on each side of the ship. Presumably, targets are selected and fire-control data are generated in CIC. Controls for the guns (130-mm and 30-mm) are local; it appears that their radars are not tied into the air picture in any way. Again presumably, targets are designated in CIC. Such an arrangement would satisfy the supposed Soviet requirement that a ship degrade gracefully in combat. It would correspond to Western World War II and early postwar practice. Similarly, the CIC contains no controls for the torpedoes and the RBUs. If the ship's sonar is indeed their fire control, then presumably they are fired from the sonar room.

There is also a secondary control position containing a ship's wheel and manual (grease-pencil) status boards, used primarily for damage control.

UNITED KINGDOM

In May 1990 the U.K. Ministry of Defence requested bids for the combat-management system (CMS) for the next-generation air-defense destroyers, which are to be bought following British withdrawal from the NATO frigate project.

◆ ADAWS/ADIMP

ADAWS is an Admiralty-designed combat system, based on a central computer and thus broadly analogous to the U.S. NTDS. ADAWS (Action Data Automation Weapons Systems) incorporated automatic radar detection (see below), though that did not generally entail radar data fusion. ADAWS included weapons control. Most installations (except for ADAWS 5) have 2 computers.

ADAWS 1 used a special Camper & Nicholson JGA display; all others use Plessey Mk 8 series vertical and horizontal displays. The standard vertical display is the LPD (labeled plan display), with a 12-in circular, monochrome CRT, for specific sensors and weapons. The JZ horizontal (tactical) display, used to create the merged tactical picture, is a 20-in-diameter, monochrome CRT with an attached 12-in vertical, alphanumeric display. Typically, there are 3 associated keypads and 3 roller balls. The Mk 8-series displays are analog types with digital injection (i.e., analogous to early U.S. NTDS). Most of these systems have 2 horizontal displays (ADAWS 6 and 10 have 4 each). The number of LPDs varies as noted below.

Early British systems differed from NTDS in using only alphanumerics and vectors, where NTDS uses standard symbols to distinguish between friendly, unknown, and enemy (and air, surface, and subsurface). In later versions, which have better



Standard ADAWS 2-operator vertical consoles. Note the use of the light pen for data entry. (Plessey)

symbol generators, ADAWS and other British command/control systems revive the earlier standard symbols (icons) for ship types, which had been used in manual plots at least since the late 1930s. Thus, current British tactical data systems provide the operator with both a vehicle (type) identification (e.g., a triangle for a cruiser) and a letter track identifier alongside it.

Although these systems are always credited with radar-plot extractors, in practice it appears that this option (which the British call plot auto-initiation) was rarely exercised. Instead, a human operator opened a track file by designating a target. The system then applied its automatic plot extractor to the area of the display immediately around this initial plot. This process was called local area extraction (LAX). Typically, an operator initiated a track by identifying a blip of interest (using a roller ball) and was alerted to resolve ambiguities, e.g., 2 tracks that seemed to merge. Once the computer was tracking, it placed a letter at the end of the track: P for track passing through a predicted position, M for a missed target (on that radar sweep), and C for a confused target (the computer followed the plot closest to the predicted position, unless otherwise instructed). The faster the target, and the smaller the probability of detection on a per-scan basis, the larger the local area and the greater the human input. Only in the upgraded systems (particularly those involving Sea Wolf) is there anything comparable to full ADT, as in U.S. systems. Generally, the operator or the system decides which radar to use for tracking; ADAWS does not allow for any form of radar fusion.

Depending upon plot quality, the system may automatically control weapons. Thus, with the advent of ADAWS, ships no longer have separate fire-control systems. Instead, at least in theory, all weapons control is exercised by the integrated control system.

Versions:

ADAWS 1 was for the County-class (second series) missile destroyers *Glamorgan*, *Fife*, *Norfolk*, and *Antrim* (late 1960s), employing 2 Ferranti Poseidon computers. Processed data were fed to the Sea Slug and Sea Cat missiles and to the 4.5-in guns. Computers also tested whether targets could be engaged by the missile system. There was an associated digital data link, so that sensor data and target allocation could be exchanged within a task force. There were 8 twin-display consoles. The digital computer passed target data to the analog fire-control devices, which actually directed fire. The associated plot extractor, SPADE (Special-Purpose Auto-Detection Equipment), was the first British digital device of its type. Earlier automatic detectors (in earlier ADA [Action Data Automation] systems) had been analog devices, comparing analog templates to the growth/decay curves of the radar returns. In these ships the central computer correlated tracks and, in theory, could fuse data from several sensors and also from IFF. The system was probably overly ambitious for its time since descriptions of later versions of ADAWS show substantially less sophistication.

Although the weapons were primarily controlled by ADAWS, all of them retained their older analog controls as backups. Unlike the earlier British ADA system installed on board the old carrier *Eagle*, this system included ASW contacts and was connected to EW receivers.

ADAWS 2, for the next-generation missile destroyer, HMS *Bristol*, employed 2 Ferranti FM 1600 computers (192 kwords). The central computer took over the entire fire-control task, a pattern of centralization followed by later ADAWS variants. In ADAWS 1, weapons control was still carried out by specialized analog machines. From this second version on, ADAWS incorporated 2 types of radar-plot extractors, LFX (limited-area/full extraction) and LAX (limited-area auto-extraction), with or without automatic initiation of radar tracks.

ADAWS 3 was an abortive version intended for the CVA.01 carrier, which was not built.

ADAWS 4, (virtually ADAWS 2 with the Ikara capability deleted) for Type 42 missile destroyers, controls both Sea Dart missiles and the 4.5-in gun. It employs Link 10. Development began in 1967. As modernized in 1988, this system adds a separate captain's console so that the captain no longer has to look over the PWO's shoulder. Software now provides a better threat evaluation in terms of the ratio between rate of approach and range. The ship can now transmit on 3 data links (presumably Links 4, 10, and 11) simultaneously.

ADAWS 5, for *Leander*-class frigates with Ikara ASW missiles, is a subset of ADAWS 2, using a single FM 1600 computer (64k memory, later increased to 128k). This system incorporates 6 LPDs. This version has only LAX with automatic tracking, plus special processing of ASW-helicopter transponder returns. The computer is designated computer outfit DAE-1.

ADAWS 6 is the *Invincible*-class system, using 2 FM 1600 computers. This system incorporates 32 LPDs. ADAWS 6 and 10 incorporate automatic radar detection and tracking.

ADAWS 7 is for Type 42 Batch 2 destroyers; it was developed in parallel with ADAWS 6. Improvements included a shift from Link 10 to Link 11.

ADAWS 8 is a modified ADAWS 7 for Type 42 Batch 3 destroyers; the principal change was to accommodate the Type 2016 sonar.

ADAWS 9 was not used; it had been designed for the abortive Type 43 missile destroyer.

ADAWS 10 is for HMS *Ark Royal*, the last *Invincible*-class light carrier. Presumably, this system will be incorporated in ships as they are rebuilt. This system incorporates 32 LPDs.

ADIMP, the ADAWS Improvement Program, was initiated with a contract to Ferranti in August 1988. Existing FM 1600 computers will be replaced by FM 2420s (for a 6-fold increase in computer power, presumably without major reprogramming). The LPDs will be fitted with raster-type alphanumeric displays in place of the current cursive units (using 68000-series processors and driven by a central Tote Engine), and the horizontal displays will be provided with additional alphanumeric displays. Scan compression will be provided to improve synthetic-video displays. Existing radar-plot extractors apply only to particular radars. However, the ships will be fitted with Thorn-EMI track combiners (comparable to the U.S. SYS series; the contract was let in January 1989). ADIMP applies to *Invincible*-class carriers and Type 42-class destroyers. It includes provisions for Sea Wolf and Goalkeeper and also for the 2050 sonar in Type 42 destroyers.

At the end of September 1989 the Royal Navy issued an invitation to tender (ITT) for captain's combat aid, a computer workstation-based system providing weapons status, target data, and target priorities to a ship's captain, as part of ADIMP. The ITT was originally released in 1988 but was later withdrawn. As of late 1989 the Ministry of Defence was expected

to award an initial development contract in March 1990, with full development following in 1991 and the system completed in 1992. The captain's combat aid seems somewhat analogous to the features promised for the U.S. ACDS, successor to NTDS.

ADIMP also includes a data-link preprocessor (DLPP), which allows a system designed for Link 10 to accept Link 11 and Link 16 messages. An RFP was issued in February 1989, and Thorn-EMI won the competition.

◆ CAAIS

The Computer-Aided Action Information System was conceived as a less expensive alternative to ADAWS. The central computer was retained to help the tactical picture, and processing was distributed as much as possible. The system is described as manually based but computer-assisted, which probably means that it is roughly comparable to the U.S. NTDS: plots are manually entered but are projected ahead by the central computer on a rate-aided basis. The system automatically processes IFF data and vectors an associated helicopter. The consoles do no data processing of their own, so this is not a federated system. The 1966 Naval Staff Requirement called for a unit cost of £100k.

Production began in 1969. Ferranti was prime contractor. Because CAAIS is essentially a computer system, the British designate it a computer outfit, DBA. The first 2 versions to enter service were DBA 1 and DBA 2.

CAAIS (DBA) entered service in 1974. In the first ship so fitted, the Type 21 frigate, the key element of distribution was to retain a separate fire-control system. The first CAAIS system used the FM 1600B computer and commercial Decca displays. FM 1600B was comparable in power to the Poseidon of the original British computer combat system (ADA) but cost about 10% as much. FM 1600B, in turn, has been succeeded by the more powerful but less expensive FM 1600D (which is also used in Nimrod aircraft and in some EW systems).

The main computer occupies a 3-cabinet suite. In the original system, data were presented on 6 Decca CA 1600 horizontal displays, developed from the commercial Deccascan. Each was a 2-operator unit with a 15.75-in, monochrome, analog PPI and 2 alphanumeric displays (16 characters each). It could show raw radar video with graphic overlays and had 8 range scales (1.5–144 nm). A range strobe (used to measure range accurately so that it could be entered into the computer) was adjustable between 100 yd and 60 nm. Each operator had a keyboard with special-purpose keys, as well as the standard alphanumeric set, and with a roller ball. One operator also had keys for synthetic-picture selection and for selection of a particular radar picture. A special console, CA 6001, was used for the search radar and also for primary and secondary IFF data.

Versions:

DBA 1 in *Leander* Batch 1 frigates (32k FM 1600B).

DBA 2 in Type 21 frigates. (DBA 1 and 2 were the initial-production versions). The corresponding weapons-control system is designated in a WSA series.

DBA 3 in HMS *Hermes* (carrier) as modernized (now the Indian *Viraat*).

DBA 4 in "Hunt"-class minehunters.

DBA 5 in *Leander* Batch 3 and Type 22 Batch 1 frigates, to control Sea Wolf missiles (GWS 25) and Type 2016 sonar; the computer is a 48k FM 1600B. As fitted to a Type 22 frigate, CAAIS reportedly can handle 60 tracks.

Ferranti subsequently developed a commercial version, CAAIS 400/450. CAAIS 400 was installed aboard Brazilian *Niteroi*-class frigates. The corresponding WCS is the WSA 400 series. An improved CAAIS 450 corresponds with the WSA 420 series. It provides for data-link operations, can control on-board ECM devices, and performs threat evaluation. CAAIS 450 has a new computer (1600E) and new vertical displays (12-in CRT

for the single console, 16-in for the command console, all monochromatic and incorporating keyboards and roller balls).

CAAIS export installations: *25 de Mayo* (Argentine carrier), *Almirante Williams*-class destroyers (Chile), *Viraat* (Indian carrier: DBA 3 version), *Nyayo* (Kenyan fast patrol boat; CAAIS 450 version), *Inahuma* class (Brazilian frigate: CAAIS 450 version), *Niteroi* (Brazilian frigate: CAAIS 400 version).

◆ CACS

The Computer-Assisted Command System was intended as the ADAWS successor but was rejected for its major planned installation, on board the new Type 23 ("Duke"-class) frigates. CACS was first proposed by Ferranti in 1977 as a replacement for the CAAIS system then installed aboard Type 21 frigates, but the concept was soon extended to the new (and much more demanding) Type 22. The NSR 7933A staff requirement was issued in January 1979. Unlike ADAWS, CACS was contractor developed; indeed, the contractor, Ferranti, was the first to get a full command/control-system contract. The first installation was aboard HMS *Boxer* (1982); the first trials were held in 1985. Development was somewhat delayed by the 1981 defense-spending moratorium.

Ultimately, CACS is probably a good example of the failure of a more or less centralized system under the effects of rapidly changing and growing requirements.

CACS is a partly federated system, its central computer(s) being a pair of FM 1600Es (1 is a running spare). They are linked by an ASWE Serial Highway (data bus) to several Plessey Mk 9 consoles, each containing 2 Argus M700/20 microprocessors. Updated versions have 3 M700/20 per console. In all, CACS 1 has 12 Argus M700 miniprocessors handling displays, sensors, and fire controls. CACS 4, intended for Type 23, included more than 20 M700s. There are also several F100L microprocessors.

There are 2 types of 2-operator consoles, A (command) and B (operator): A has 1 (shared) 16-in, monochrome, cursive main display and 1 Racal 7-in, raster-scan, alphanumeric input display (tote) for each operator. The latter can also be used for video data. The B console has 1 Racal 12-in, monochrome, cursive main display and 2 alphanumeric, 7-in, raster-scan displays per operator. In both, operators can interact with the system via keyboard, roller ball, dedicated keys, and light pens.

What is new, compared to ADAWS, is what Ferranti calls a prompt interface: console operators are presented with a series of prompts (choices) that can be activated by light pen or via the keyboard. This approach is equivalent to menu-driven software in civilian personal computers. As in the civilian case, it becomes practical as computer power increases. Ferranti developed its version as a private venture.

In 1985 CACS was described as capable of tracking over 500 targets simultaneously while conducting threat evaluation. The Type 22 Batch II installation (CACS 1) has 16 displays requiring 26 operators at action stations.

CACS was intended as the first major British system that would integrate passive sonar and ESM data into the action information system. However, that integration proved difficult, and CACS 1 (for Type 22 frigates) could not handle both air and towed-array-sonar pictures simultaneously. CACS 1 was installed in 1984-86, but as of 1989 it is still described officially as "not fully operational." Current forecasts of the date of completion run as late as 1991.

CACS 2 and CACS 3, intended for modernized Type 42 destroyers and their successor Type 43/44 destroyers, were canceled as part of the 1981 defence-review cuts, presumably as consequences of the cancellation of Sea Dart Mk 2.

CACS 4 was the version proposed by Ferranti for the Type 23 frigate and for the new replenishment ship (AOR); both are armed with vertically launched Sea Wolf missiles. Reportedly, CACS 4's development could not keep up with rapidly changing Royal Navy requirements, and ultimately it was dropped altogether in favor of a much more distributed system proposed by Dowty-SEMA. One way to look at the failure would be to note that a hardware producer (Ferranti) was dropped in favor of a

consortium dominated by a software firm (SEMA). MoD requested proposals for the CACS follow-on on 28 November 1986, and bids were due by 15 April 1987. Fifteen-month project-definition-study contracts were awarded on 12 August 1987.

The problem of CACS was probably that its central processor always lacked the capacity to accommodate rapidly changing software.

Ferranti regarded the basic architecture as unworkable and wanted to move instead to the "virtual architecture" of its System 500.

The only surviving new model in the CACS series is CACS 5, for Type 22 Batch 3 frigates (*Cornwall* class). It probably survives mainly because it was always considered a relatively simple modification of CACS 1.

In November 1987 Ferranti announced that it would offer the new FM 2420 computer to update CACS 1 and 5, and a contract to that effect was let in September 1988. A further contract followed on 24 January 1989; the total value of the upgrade is estimated as £30 million.

◆ CANE/DBE/DEA

The Decca (Racal) Computer-Aided Navigational System is a combat system for patrol craft and mincraft. The key is compilation of a current and accurate tactical picture; the system is essentially an automated plotting board. In its simplest form, it is no more than a spot of light projected upward onto the back of a chart to show the movement of a ship, with other lights showing other ships and important fixed points. The spot is controlled by a Decca automatic plotter fed by a Decca navigator and Loran C. Other ships are detected by radar or sonar and are automatically shown by other points of light; these contacts can easily be plotted on the chart. A track-management unit tracks up to 10 surface targets simultaneously, using rate-aided tracking. The operator initiates a track with the usual trackball and assigns a number through a keyboard; detailed track data can be seen on an adjacent display. Later versions have conventional CRT displays.

CANE I (DEA-1) was used on board British "Island"-class offshore-patrol vessels, and a modified version (DEA-2) was installed on board the hydrofoil *Speedy*. It could track 10 targets simultaneously, and it entered service in 1977. DEA-1 consisted of a chart table with an associated Kelvin-Hughes JUD display and an automatic plotter.

CANE II (DEA-3) can track 38 targets simultaneously and was installed on board the "Castle"-class offshore-patrol vessels. It also replaced CANE I on board the "Islands." This version used an automatic chart table, a processor, and 3 consoles. It was a simple central-computer system.

CANE 100/200 are export versions, announced in September 1981. CANE 100 (for fast attack craft) uses an integral Kongsberg KS 590 computer and a table-mounted control-and-display unit. It is a distributed system with a computer in each console. That is a less radical change than might be imagined since the original centralized system was really only the tactical-picture element of the usual combat-data system. The distributed versions add separate consoles for other functions, and the data bus carries the tactical picture among them. Cane 100 incorporates an automatic chart table and an automatic plotter.

CANE 200 is intended for corvettes and larger ships.

As currently (1990) offered, CANE is a distributed system built around a data bus with intelligent I/O nodes. Each tactical control console (TCC) is run by a 16-bit DS500 processor and has 1 Mbyte of internal memory. I/O is controlled by 68000-series chips. The interactive display carries a 12- or 16-in CRT, which can combine raw video with cursive characters (synthetic video); it also uses a 12 line × 40 character data screen. The consoles use resident bubble memory.

A 3-console form of CANE is installed aboard the British flying training ship RFA *Argus*. It is officially designated DBE(1). CANE is also installed on board RFA *Sir Galahad*.

CANE is currently in service or on order for Cameroon, Den-

mark, West Germany, Finland, Hong Kong, Indonesia, Jordan, Korea, Sweden, the United Kingdom, and Yugoslavia. The first CANE 100, for example, was installed on board the Cameroon fast attack craft *Bakassi*. In 1989 installation on board Jordanian "Hawk"-class fast patrol craft was announced. This system is also installed on board 2 new 450-ton Hong Kong police command launches, *Sea Panther* and *Sea Horse*. Racal is currently working on a successor system.

MAINS (Minehunting Information System) is a special-purpose version.

In contrast to the more combat-oriented systems, CANE is basically a surface-ship tracker designed to catch smugglers and poachers. Presumably, it ought to be attractive to small countries interested in protecting their EEZs. In such a role, it would have to be able to accept radar data from a radar-patrol airplane.

CANE exists in both single- and multiconsole versions. In the single-console version, it is very clearly a centralized tactical data system, the single computer feeding both the weapons and the automatic chart table. The multiconsole version shows 2 types of consoles, the control-and-display unit (CDU) and the operations display unit (ODU). The available documentation is somewhat obscure, suggesting both that the data base is replicated through the consoles and that only the CDU carries a processor (in which case the system is entirely centralized about the CDU). The consoles form an LAN that connects to a dual serial data bus. The bus is also connected to an automatic plotter and to an automatic chart table. The manufacturer, Racal, describes the consoles as autonomous, intelligent, tactical command consoles, much like those in, say, NAUTIS. Simple block diagrams suggest that the tactical command consoles occupy an LAN, which communicates with the weapons and sensors via the dual data bus.

The ODU carries a large PPI, either analog or scan-converted (raster-scan); it can also display synthetic video superimposed on raw video. The other standard console, the CDU, contains a processor, intelligent interfaces, data display (televisionlike CRT), and primary operator controls.

◆ RRASL

In August 1990 the Admiralty Research Establishment awarded Ferranti a contract for a demonstration command-decision aid embodying artificial intelligence, RRASL (reactive resource allocation—single ship level). RRASL is to assess a tactical situation and advise the captain and PWO of the consequences of alternative courses of action. It extends the Data Fusion Technology Demonstrator planned for trials in a Type 23 ("Duke"-class) frigate. RRASL is intended to take into account the potential for mutual interference between different defensive measures, both hard- and soft-kill, basing its recommendations on a library reflecting current tactical doctrine and system characteristics. RRASL is typical of several current attempts to apply artificial intelligence to choose between alternative (and interfering) defensive weapons (see the U.S. RAIDS in the Anti-aircraft Warfare section). Much of this problem is presented by the NAAWS program. Because it has to deal with a very rapidly changing situation, RRASL must present a single unambiguous decision, although the user can query its reasons and veto its recommendations. Ferranti claims that RRASL will be based in part on its experience in developing System 500 as the core of 1 of the alternative NAAWS systems.

◆ SSCS (SUCCESSOR)

The Surface-Ship Command System is for the Type 23 and the new replenishment ship (AOR), to replace the failed CACS. SSCS is manufactured by a Dowty-SEMA consortium, the names reflecting a series of industrial takeovers. Initially, the joint venture was described as Gresham-CAP, then Dowty-CAP, then Dowty-SEMA. SSCS is a fully distributed processing system that grew out of a generic distributed system, SUCCESSOR, which used a fiber-optic bus for its LAN. The first application was to a submarine command system; Dowty's proposal actually outperformed the requirement. It became SMCS



The next-generation British standard surface-ship command display, for the Type 23s' SSCS (surface ship command system). The same type of screen displays radar video at the left and sonar tracks on the right. (Racal)

("smacks," the Submarine Command System). There were some minor teething problems, but reportedly, the software proved extremely satisfactory. The next major competition was for the CACS 4 replacement. Plessey (NAUTIS) and Ferranti (System 500) received competitive contracts. Plessey dropped out because NAUTIS (which is fully distributed, without any command-bus LAN) did not correspond to the LAN system architecture that the Royal Navy wanted.

Plessey's place went to Dowty-SEMA, whose SSCS will be used in the Type 23 and the new AOR. It was part of the British proposal for the NATO frigate.

Individual consoles are linked up in an LAN by a fiber-optic bus, and the LAN is itself connected (as a unit) to the ship data bus. Each console contains a 20-in rectangular, high-resolution, raster-scan screen, with 2 plasma screens (totes) for alpha-numerics and a plasma touch panel (and mouse) for interaction between the operator and the system. There is no keyboard as such; the idea is that the operator should not have to take his or her eyes from the screen, except to jab a soft key (i.e., a software-defined key) on the plasma screen. Terminal development entailed design of a series of special processor cards. In theory, the architecture of the system as a whole is simplified by the sheer number of processors available: each processor can be dedicated to a special purpose. The console was originally developed for SMCS.

Two dedicated I/O nodes connecting the fiber-optic LAN to the sensors and weapons via the combat-system highway (bus), 1 to receive and 1 to transmit data. The nodes (with 80386-based microprocessors) do some preprocessing and hold master copies of the data base. They broadcast information into the consoles, which each hold copies of the data base. A hard disk holds permanent or slowly changing data, such as geography.

The Type 23 system employs 12 identical consoles, including separate ones for the captain and the PWO. In contrast, the submarine system uses 5. The surface-ship consoles differ from the submarine system in employing a "joyball" (a trackball with adjustable gearing) instead of a mouse, and an alphanumeric keyboard plus special-function keypads to supplement the plasma soft-key touch panel. A future development will probably have soft keys only, and it will eliminate the keypad altogether. As in other British command/control systems, this display is called an LPD (labeled plan display). Each console contains a full copy of the applications software, so that it can perform any system function.

The Type 23 system as a whole contains nearly 300 processors and over 1500 Mbytes of storage; these figures include the parallel processors (transputers). It appears that the system soft-

ware architecture is similar to that of the Ferranti System 500, programs running within a virtual environment (ADA operating system). Dowty-SEMA claims that the Type 23 command system can handle 1000+ tracks simultaneously.

◆ WSA 4/401/402/403 (GSA 4/GWS 22)

These WCSs are designed to work in conjunction with CAAIS. Typically, CAAIS integrates search-radar and data-link data and passes its tactical picture to the WSA console. The relevant CAAIS console operator can use the tactical picture to assign tracking radar(s) and weapons. Actual computation for gun ballistics or for missile tracking is done in the dedicated WSA console. Different designations apply to progressively more complex systems handling, e.g., ASW as well as surface and air weapons. From this series, Ferranti developed the commercial WSA 420 series. The higher-powered versions can function as full automated combat systems, maintaining track files.

WSA 4 (Weapon System Automation 4) controls the 4.5-in gun and the Sea Cat missile on board Type 21 frigates. WSA 4 is built around a single Ferranti FM 1600B computer, and all functions are centralized in the CIC (AIO in British parlance). There are 2 identical consoles, for gun and Sea Cat control, and both are linked to a 1-operator horizontal console of the CAAIS automated AIO, manned by the missile-and-gun director. This system is sometimes denoted GSA 4/GWS 22 for its separate gun and missile elements.

From the console, the single gun controller can track targets on 2 Type 912 (Orion RTN 10X) radars, see them on television, and fire as many as 20 rounds from the Mk 8 gun. The Sea Cat controller can fire as many as 4 Sea Cats (without reloading). Both are supervised by a missile-and-gun director at a CAAIS display a few feet away. CAAIS compiles the surface and air picture, and the director designates targets to WSA 4 using a tracker ball and marker. CAAIS also assigns the relevant tracking radar. The gun controller initiates the fire-control calculation and orders the gun or missile to aim and fire. Normally, the director receives the WSA 4 track data before fire begins, but in special cases the gun controller can open fire by closing the safety switch and pressing the firing pedal.

There are also emergency control (backup) operating modes for the gun and missile launcher. The 4.5-in gun is then directed by the lookout-and-aiming sight, and the Sea Cat by the pedestal-sight operator. Both would otherwise send their data to the WSA 4 computer rather than to the weapons.

The 2-operator WSA 4 console has 2 main electronic data displays (EDDs) with light pens, each showing data in graphical and alphanumeric form on a page-by-page basis. The correct page is chosen by light pen, using a list running along the bottom (TCD, WCD, NGSA, NGSB, WIND, SEACAT, for target-control display, weapons-control display, naval gunfire-support channel A and B, wind, and Sea Cat, respectively). TCD, for example, shows the status of the 2 trackers, the track number of the target, the weapons mode (e.g., GAA, for gun antiaircraft), and the target's heading, range, speed, and height.

The WSA 4 computer itself stabilizes the tracking radar antennas and also helps reduce tracking errors by predicting future target position. The computer considers all gun ballistics. Because the combination of computer and radars acts like a TWS radar, shifting from target to target while firing at both is relatively easy; and spotting corrections from both targets can be applied. In essence, the computer executes 2 fire-control solutions simultaneously. This technique takes advantage of the shell's 30–50-sec time of flight to provide the equivalent of 2 gunfire channels. Splash spotting is semiautomatic, with the gun controller entering splashes via a trackball applied to a B-scan scope. For indirect fire, the ship's and the target's coordinates are entered into the computer in metric grid form; and the computer automatically tracks the ship, using log and compass data and tidal data. During surface fire, if the director calls for antiaircraft fire, the system can shift over within a few seconds.

The computer permanently holds basic range tables, and in-



The operations room (CIC) of the Brazilian frigate *Liberal* (Vosper Mk 10), showing vertical consoles and a standard 2-operator horizontal display. This ship is equipped with 2 WSA 400-series systems and CAAIS 400. (Ferranti)

formation such as mean sea level pressure, mean equivalent winds, and muzzle velocity (gun wear/ammunition temperature) is entered by light pen.

The WSA 400 series is an expanded version, developed for the ASW version of the Brazilian *Niteroi*-class frigates. WSA 401 controls the Bofors 375-mm rocket launcher and the 4.5-in gun. WSA 402 controls the Ikara and Sea Cat missiles. Similar systems are used in the general-purpose version of the frigate. See also the WSA 420 below.

◆ NAUTIS

Plessey's decentralized command/control system (Naval Autonomous Information System) was based on a standard NAUTIC (Naval Autonomous Intelligent Console). NAUTIS was announced in 1983. Development of the first version, for the single-role minehunter (*Sandown* class) began in 1984. In these ships there are 2 monochrome displays in the CIC, plus a third on the bridge. Their NAUTIS-M version of the system integrates the navigational system, the minehunting sonar, and the control of the minehunting fish. The current U.S. mine-countermeasures ships (*Avenger* class) lack any similar integrator. About 1985–86 the U.S. Navy became interested in the *Sandown* system, which was tested under the Nunn Amendment program. The evaluation was successfully completed early in 1989. In August 1989 the U.S. Navy let a contract for a color version. It is to be integrated with the existing SSN-2 navigational system, in a program designated SSN-2(V) Phase 3.

The console employs iAPX-286 microprocessors, typically dual 80286s in a multibus. Additional iAPX-286s are used for intelligent interfaces to sensors and weapons. RAM is typically 4 Mbytes, expandable to at least 16 Mbytes, with additional nonvolatile memory for program and data-base retention (typically 2 Mbytes, expandable to at least 4 Mbytes). Presumably, the running tactical picture is periodically dumped into the bubble memory. The console can accept video from up to 3 separate radars, as well as up to 8 separate digital inputs, including IFF, helicopter transponder, and data-link plots and tracks. There is an RVP with scan conversion for the raster display. The console also includes a radar-plot extractor with multiple thresholds for constant false-alarm rate, clutter mapping, and windowing. Each console accommodates up to 54 double Eurocards (circuit boards).

Each standard console (workstation) accommodates either a 20-in, 1500 pixel × 1200 line, color raster (announced at RNEE in September 1989) or a 4096 × 4096-pixel, 16-in, cursive monochrome display. The new raster display can show raw radar video, graphics, or alphanumeric tables (totes); the cursive display is limited to synthetic video. The standard console can be supplemented by a separate tote display (alphanumerics) alongside; the enlarged console functions as a command/tacti-



NAUTIS-M tactical display during sonar search, showing the search plan, the history of the ship's track, and sonar coverage with sonar contacts. (Plessey)

cal suite. Each console has 32 software-defined special-function keys, as well as a standard keyboard and a tracker ball.

Consoles are connected to 2 data buses, a combat-system highway and a command-system highway, both 1553Bs or Ethernets.

The data base, replicated within the consoles, covers a 2000 × 2000-nm area (range scales 0.125–1000 nm) and includes radar and sonar tracks, route/search plans, user-designated tactical maps, and synthetic charts. Early system descriptions included a capacity for 6 user-designated tactical maps, 15 synthetic charts, 200 labeled reference points, 5000 underwater contacts, and 32 labeled bearing lines. The system can maintain at least 200 tracks (radar and sonar). In minimum configuration, it can automatically track 20 targets.

NAUTIS-L has been chosen for the refits of the 2 *Fearless*-class large British amphibious ships. They previously had no automated combat systems at all. Presumably, they can now function in part as amphibious flagships, a role that might otherwise have fallen to the British light carriers. This version employs 7 consoles. As of the fall of 1989, installation had been completed aboard HMS *Fearless*.

NAUTIS-P, the patrol-craft system, has been sold to the Royal Thai Navy, both for some new ASW corvettes and for fitting to 4 PRC-built frigates, the latter in 2-console form. The corvette version beat out a rival Signaal system. The Chinese-built frigates are to be stripped and entirely reequipped after delivery. This program is of interest because, once such a conversion has succeeded, many navies possessing similar ships (ex-Chinese or ex-Soviet, or copies) can apply it. A single console can provide radar surveillance, target tracking, target indication to weapons, navigation, and collision avoidance. It can also include optronic and EW control.

In mid-1989 NAUTIS was chosen for refits of 2 New Zealand *Leander*-class frigates, beating out RCA, Ferranti (System 500), Signaal, PEAB (9LV Mk 3), and Thomson-CSF. The system consists of 5 consoles, to control all surface and subsurface weapons and sensors. In all, 3 systems (1 for training) were sold, at a total cost of about £8 million, or about £2.7 million per 5-console system (£500,000 or more per console on this basis, which is much more than the per-console figure given below). These systems are to be installed by 1991.

NAUTIS forms the basis for a Raytheon proposal for an export

surface-ship combat system, and the company may ultimately manufacture it in the United States under license.

Versions:

NAUTIS-A assault ships and auxiliaries.

NAUTIS-D destroyers.

NAUTIS-F frigates. There would be 4 consoles (surface, air, ASW, and command summary). This system is reportedly being considered for the Taiwanese second series (which would be license produced by Raytheon) frigate program, as an alternative to the U.S. Hughes ACS.

NAUTIS-L amphibious warfare and logistics landing ships.

NAUTIS-M minehunters and minesweepers. There are up to 3 consoles (sonar, ship control, mine-disposal vehicle).

NAUTIS-P patrol vessels, strike craft, corvettes. There are 1 or 2 consoles.

NAUTIS-S. This version is a supplement to existing command systems. Typical enhancements include ASW, point-defense-system control, CIWS control, missile/gun-system control, ESM or ECM management, control of containerized systems, aircraft detection and control, command workstations, mine-counter-measures modernization, integrated communications, and data-link operation.

The great advantage of a fully modular system like this one is that it can be installed in a ship that was not designed for a large automated CIC. In the case of the ex-Chinese frigates, for example, Plessey claims that the system will fit in the existing bridge space. That fit is important because (again according to Plessey) adding a new deckhouse (as was done in U.S. NTDS installations) would exceed the strength limits of the existing hull, although it would not impose top-weight problems. Seeing a big derivative market in U.S. sealift ships, amphibious ships, etc., for which NTDS would be much too massive, Plessey has teamed with Raytheon Equipment Division, on a project-by-project basis.

Current cost per console is about £200,000 (about \$320,000).

Although NAUTIS is designed to operate as a modular system, with each console carrying the full tactical picture, at least one buyer has chosen to economize by deleting the full tactical processor from all but 1 console, in which case NAUTIS is effectively a central-computer system with outlying workstations, architecturally equivalent to ADAWS or NTDS. Later installation of the missing processor boards converts this centralized system back into a decentralized one. In this case the deciding factors were the requirements for computing power and reliability; there was no question of combat survivability since in either case all the consoles were concentrated in one restricted space.

NAUTIS can function either as a command data system or as a full combat system including weapons-control consoles; the degree of decentralization can vary radically in this way, as in the question of console content. A drawing of a typical possible NAUTIS-P installation shows that both the central system (2 consoles) and the 2 gun-control consoles would be connected to a common video bus, fed by the navigation and air-search radars and connected to the EW suite. However, the gun-control radar and the optronic director would have their own consoles, connected directly to the gun consoles rather than to the system bus. This arrangement is broadly equivalent to CAAIS.

◆ WAMS/CTC

Racal Marine Radar's Wartime Adaptation of Merchant Ships proposal for ships taken up from trade in an emergency (as in the Falklands) uses a new Command Tactical Console (CTC). CTC, in turn, is based on the Racal-Decca series of ARPA (automatic detection and tracking for surface targets) radars, introduced in 1983 and now mandatory in many merchant applications. CTC was announced in 1985, and at that time the company claimed that it had been installed for, or ordered by,

the Chilean, Chinese (PRC), Dutch, and Norwegian navies. CTC uses the standard Racal ARPA radar target-acquisition and automatic-tracking system, which uses local extraction. The advantage of local, as opposed to global, plot extraction is that radar gain (which determines the criterion by means of which the system decides a target is present) can be optimized separately for each portion of the space the radar sweeps, rather than being set constant for the entire area. The radar can, therefore, make special provisions to extract signals from areas of high clutter. Preprocessing for clutter reduction is by the Racal-Decca Clearscan technique, which is described in the Anti-aircraft Warfare section.

Target data are stored in true- rather than in relative-motion form. In theory, that mode should make it easier for a CTC-equipped ship to coordinate her data with those of other ships.

The system can maintain up to 20 target tracks, acquired either by joystick or automatically (in predesignated guard zones). Such targets can include aircraft at speeds of up to 600 kt. The console displays bearing, range, course, speed, and range and time to CPA in alphanumeric form; the ship's own speed and course can be displayed by designating a known fixed point as a reference. The variable gain in the system makes it possible to detect even small targets (Racal claims it can detect periscopes). Simple electronic maps can be entered into the system memory, superimposed on the radar picture. Targets can be entered into up to 3 separate weapons systems or transferred to other computers.

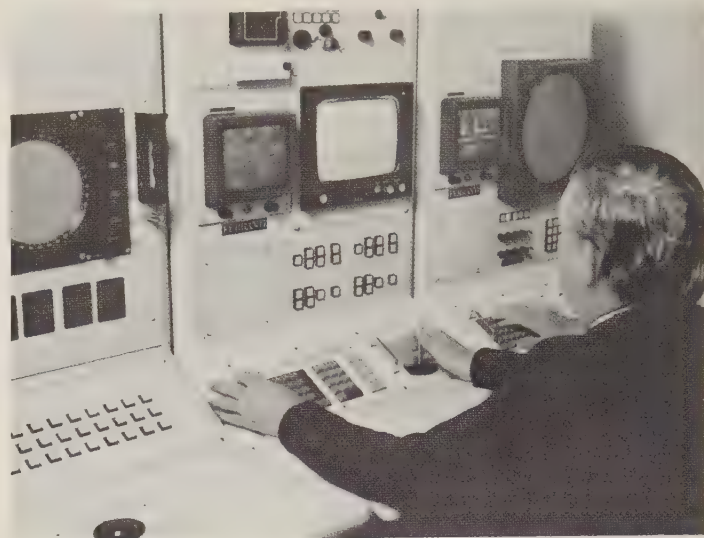
◆ WSA 420/CAAIS 450 Series

Ferranti's private-venture weapons-control and combat-direction systems are built on CAAIS and WSA 4 experience.

CAAIS 450 is Ferranti's automated AIO (CAAIS), corresponding to the WSA 420 series, providing for data-link operation, for presentation of a unified tactical picture (with indication of the most threatening target), for control of ECM, and for navigational assistance. CAAIS 450 is designed for Link Y operation, with Link 14 as an option. The minimum configuration consists of 2 consoles, each carrying a 16-in CRT, and a third carrying two 12-in CRTs. The first 1-CRT console is run by the command supervisor and the picture supervisor; the second, by the surface-picture supervisor and the EW/data-link supervisor. The 2-CRT console (2 single-operator consoles joined together) is run by the weapons director and the air-picture compiler. This 6-operator configuration can be expanded with 1- and 2-operator units to a total of 8 CRTs and 16 operators. Typical range scales are 4, 5, 8, 10, 16, 20, 32, 40, and 64 nm. The displays are refreshed 16 times/sec, and total system capacity is 120 tracks, 100 of them automatic.

Raw-radar tracking accuracy is improved by software filtering. The figures that follow are based on a search data rate of about 2.5 sec. Given an S-band search radar detecting a 30-kt target at 10 nm, the AIO tracker should maintain an accuracy of 8 min of arc in bearing, 55 m, 4 deg (in course), and 2 kt. Given an X-band navigational-radar detection of a surface target at 5 nm at 20 kt, corresponding figures are 8 min of arc in bearing, 15 m in range, 3 deg in course, and 1 kt in speed. A 350-kt air target at 10 nm should be tracked with an accuracy of 15 min of bearing in arc, 50 m in range, 2 deg in course, and 10 kt. A helicopter (90 kt), tracked by a transponder (RRA) at 7 nm, should be tracked with an accuracy of 10 min in bearing, 20 m in range, 4 deg in course, and 5 kt in speed. In effect, the AIO acts as the tracker of a TWS radar system. Net estimated accuracy is 0.3 deg in bearing and 100 m in range for a surface target (10 nm, 30 kt), or 0.5 deg and 150 m for an air target (5 nm, 600 kt). Both are within necessary target-indication limits for assignment to tracking radar (1 deg, 1000 m).

The simplest WCS, WSA 421, has 2 trackers, a radar (with coaxial television camera) and a visual sight (with laser range-finder) (and as an option a Decca range-only radar). Targets are indicated either by the radar (in search mode), by the visual sight, or by an external target-indication radar. The closed-circuit television monitors a target being tracked by the tracker



WSA 422 console, showing the video screen and the 2 flanking radar scopes.

radar. The computer can slew the visual sight (the optical fire director) onto the target, controlling it either in train or in train and in elevation. Alternatively, the operator can control the sight by joystick, either fully manually (emergency mode) or in stabilized mode. Two guns can be controlled. The system can maintain 2 independent tracks (radar and optical director), and it can also hold a manually indicated point in space at which to aim. A further track provided by the associated AIO can be held in memory; total capacity is 3 simultaneous tracks. One operator can run the system in cruising condition and 2 in action stations (4 for a double version). The system can easily be expanded to provide an extra visual director or an extra radar tracker; the latter requires an additional console.

The system can also fire guns indirectly, for shore bombardment; the grid position of the target is entered into the computer.

The standard weapons-control console carries a 12-in-diameter CRT on its left (TAU: target acquisition unit) side, and a 7-in-diagonal alphanumeric display (tote) and a closed-circuit television monitor on its right (gun controller's position). Displays are run by F-100L microprocessors, for flicker-free operation. They provide 128 stroke-written (cursive) standard characters and 16 programmable characters. The CRT on the left is used as a PPI (for air search), as a B-scan (for surface tracking and splash spotting), and as a split A/R-scope.

Ferranti offered WSA 421 in combination with a Selenia RTN-12X tracking radar with a coaxial television camera; RTN-12X was the monopulse successor to the RTN-10X used in WSA 4, the predecessor system, in Type 21 frigates. The WSA 421 software included special programs to overcome multipath effects in radar tracking of low-flying targets (within 1.5 deg of the horizon). There was also an optical director. Ferranti offered its own Type 901 laser and a Decca range-only radar. Type 901 is a 1.06-micron laser, with a pulse about 25 nanosec long (PRF 10 pps), and a 50% duty cycle. Beamwidth is 0.5 mrad (containing 85–95% of the total energy).

The Decca X-band, range-only radar uses a 17-in dish antenna; beamwidth is about 6 deg, and tracking range is provided in digital form. Peak power is 6 kW (850 pps, pulse width 0.75 microsec).

Typical acquisition time, from target indication with the tracking radar parked, to slew 90 deg to a target 10 deg above the horizon, would be about 4 sec. An initial gun fire-control solution would be available half a second after tracker acquisition, and the gun would be aimed at the target half a second later (albeit not fully accurately). Ferranti claimed significantly better gun accuracy than in earlier systems; a 4.5-in Mk 8 gun made 19 proximity-fuzed bursts out of 19 rounds fired at a Rush-

ton target closing from 7000–1500 yd (speed not given). The 4.5-in gun was the weapon controlled by the 2 predecessor systems, WSA 4 and WSA 400.

Ferranti offered 2 missiles as standard options, Sea Cat (already used in the WSA 4 and WSA 400 systems) and Aspide (in which case WSA 421 would pass target data to the missile subsystem). With additional consoles, the system could control torpedoes and antisubmarine rockets.

WSA 422 extends the 2-operator console, adding a 1-operator surveillance, tracking, and target-indication section, which can provide CIC services. It can accept search- and navigation-radar inputs and can provide manual rate-aided contact tracking. However, WSA 422 can be modified to extract radar data automatically for automatic tracking. The 1-operator surveillance section carries a 16-in-diameter CRT (labeled radar display) and a 7-in-diagonal alphanumeric display (tote). Typical range scales are 1, 2, 4, 5, 8, 10, 16, 20, and 32 nm. Tracks are labeled with a standard NTDS symbol, an indication of data-link status, an identifying letter or numeral, and a 4-digit (octal code) track number. A horizontal line through the NTDS symbol indicates that a weapon has been assigned, and velocity leaders (vectors) and track-history points can be provided. The display is refreshed at a rate of 16 times/sec. It can handle up to 60 tracks, although the weapons director's capacity is 10–12. Typical output accuracy is sufficient for target indication (1 deg in bearing, 1000 m in range).

Like WSA 421, WSA 422 can hold 3 gun-control-quality tracks simultaneously, 2 of them queued. However, because the AIO performs as a TWS radar, sufficient information is available to support surface-to-surface missiles separately.

Both WSA 421 and WSA 422 were built around FM 1600D computers, although later Ferranti offered versions incorporating the more powerful FM 1600E.

WSA 423, built around an FM 1600E computer, is WSA 422 plus a 2-operator CAAIS 450 command console, a more comprehensive CIC than WSA 422 provides. The third position in the WSA-series console is reserved for a separate weapons director. In this case both CRTs of the weapons-control console are 12 in in diameter. Gun-control-quality track capacity matches that of WSA 421 and 422.

As in CAAIS 450, the AIO subsystem can maintain 120 tracks, 100 of them automatic. Accuracy matches that of CAAIS 450, given above.

The command console provides designation directly to surface-to-surface missiles. The other weapons are controlled via interface cabinets fed by both the weapons-control console and the command console.

The standard WSA 423 consists of a 2-operator weapons-control console and a 3-operator AIO; a larger version would have double-headed weapons control (4 operators) and a 7-operator AIO. WSA 423 is designed for optional Link Y and Link 14 operation.

Ferranti also offered MCCS, a Mine-Countermeasures Control System based on CAAIS 450 consoles, singly or in pairs. MCCS was an export version of the "Hunt"-class CAAIS described above.

The new Brazilian *Inhauma*-class frigates have CAAIS 450, almost certainly with a WSA 420-series system; they are equipped with RTN-10X tracker radar. The earlier Brazilian frigates have CAAIS/WSA systems of earlier types, based on FM 1600B computers. The Egyptian *Ramadan* class have CAAIS AIOs and were probably the first ships to get WSA 423 (production began in 1980). Similar systems equip their near sisters, the Kenyan *Nyayo* class and the Omani *Al Sharqiyah* (the other Omani boats have 9LV300-series systems).

WSA 423 is built under license in South Korea by Samsung, to equip newer units of the frigate and corvette classes. In these ships the associated search radar is the Marconi S1810; the fire control radar is the Marconi ST1802, and the electro-optical director is the Radamec HK 409-029. WSA 423 supersedes the Signaal mini-combat systems installed on board earlier ships of these classes.

◆ WS500/CS500/MC500 (System 500)

Ferranti announced these combat systems in 1987, following 3 yr of development: WS500 for weapons control (to supersede the WSA 400 series), CS500 for command, and MC500 for mine countermeasures. All are built around distributed processors using a virtual system environment suite (VSE500).

The great virtue of VSE500 is that programs to run individual weapons and sensors can be inserted relatively easily so that it is unnecessary to build up a single massive program for a ship's command system, a program that is difficult to modify when changes are made in the associated hardware. Much of the effort of development has, therefore, gone into a new method of creating operating software, using the ADA language. The combination of hardware and software modularity should make it relatively easy to assemble a system optimized for any given collection of weapons and sensors. One might see in the modular command program a software parallel to the hardware modularity of the very successful German MEKO frigate, which caters to different navies' great differences in hardware choices.

Moreover, modular programming makes modification much easier and safer since changes in 1 module need not affect the others.

System 500 is designed to employ an FDDI 1 data bus (a fiber-optic LAN) and numerous (typically over 100) Motorola 68020 processors (68030 and 68040 can be substituted as they become available) in standard multirole consoles, each of which carries the full program load of the system, but 500 runs only those processors needed to perform a particular task. As in existing computers ashore, the CRTs of the consoles can be windowed to show several sensor or other device displays simultaneously, and the CRTs can also show closed-circuit television pictures, e.g., from the bridge or from a remotely piloted vehicle. In this sense these CRTs are equivalent to the multipurpose CRT displays of the new "glass cockpits" of aircraft.

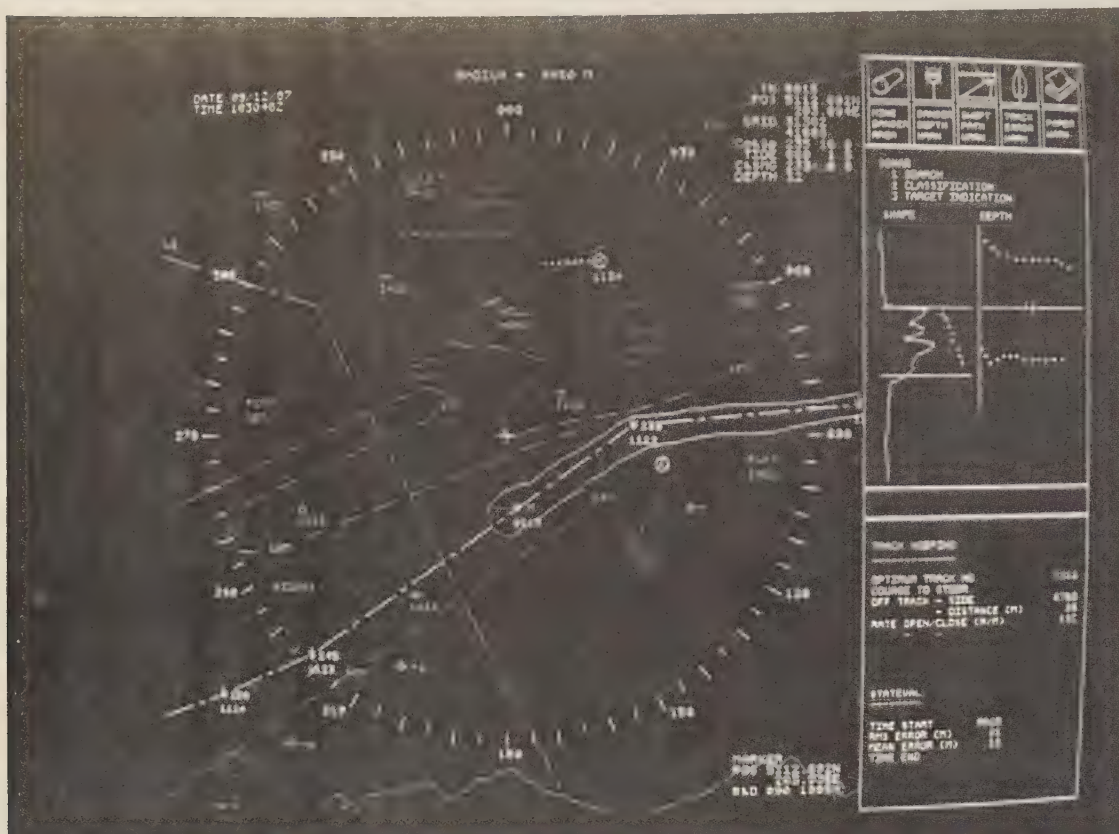
In CS500 the track table employed in earlier tactical data systems is replaced by a relational data base catering, in the larger versions of the system, to thousands of tracks. For each track the system carries a long-term history and comprehensive identity data, the latter making it possible to apply artificial intelligence techniques for tactical decision making. Because all the tracks are carried in comparable form, the system can correlate tracks from different sources to avoid duplication and clutter. This correlation is presumably equivalent to current U.S. measures to ensure gridlock (see ACDS and BGAAWC in the Anti-aircraft Warfare section). Moreover, because all radar tracks (taken from ADT sets) are carried together, the system can automatically select the best sensor track for each target; the operator does not shift, for example, between search radars. An associated multilink processor uses correlation techniques to reduce duplication among received tracks before these tracks are correlated with those produced by own-ship sensors.

The main track data base includes sonar and EW data.

Relational data-base techniques were used to achieve very fast reaction time, the Ferranti development team using a new solid-state relational processor (in effect, parallel processor), the first of its kind. Such a processor has the advantage of searching equally quickly through its data base for single or multiple attributes (e.g., looking for all incoming tracks that are at altitudes below 500 ft and at speeds of Mach 1 or more, a combination of 3 attributes that a normal processor would search out 1 by 1).

The program includes sufficient artificial intelligence for TEWA or countermeasures assignment, according to preselected rules. The program also provides maneuvering advice, which is important if the appropriate systems are to bear, and also if the ship is to present a minimum cross section to the approaching threat. Generally, the operator is provided with a veto and does not initiate action. Command-by-negation is necessary for short-range systems facing very high speed or pop-up threats.

The weapons-control applications of System 500 incorporate



Ferranti's System 500 synthetic video display shows the effect of windowing (sonar-performance parameters are shown on the same screen as the tactical situation). (Ferranti)

new types of prediction [software] based on target-profile matching, target-maneuver forecasting, and spread-fire techniques. Earlier systems, based on linear or simple curve prediction, did not have the information capacity to adjust their methods to particular targets, even though intelligence on the characteristic flight or ballistic paths of those targets might well be available in paper form. This type of direct application of intelligence data is possible in systems with really large memories and is likely to become increasingly common in the future.

Although the system is primarily software, Ferranti's favored application employs 20-in full-color CRTs with touch-sensitive screens, capable of rewriting a 1000-track picture within 80 msec; color provides the operator with much more information than a monochrome display. Menus are used to assist the operator in manual inputs. Each console can display both raw and processed video, and resolution is sufficiently good to display navigational charts. The standard console (workstation) carries a large CRT and 2 interchangeable electroluminescent panels, plus a trackball and keyboard. Ferranti also offers a simpler console (e.g., for damage control, hydrography, or a port headquarters) without the 2 electroluminescent panels.

Ferranti has offered a version of CS500 for the Royal Navy Type 23 command-system competition, employing 13 workstations (consoles). A variant, with 6 workstations, has been offered for the new AOR; presumably, both share the software needed to control vertically launched Sea Wolf missiles. Ferranti estimates that 40 workstations would be required for a carrier. As of late 1988, System 500 was being proposed for the Australian ANZAC frigate, for a proposed refit of New Zealand *Leander*-class frigates, and for the West German Type 123 program. Ferranti expects to employ a System 500-type open architecture as its contribution to 1 of the NATO AAW system proposals (see the Anti-aircraft Warfare section).

As of early 1990, 2 versions of System 500 had been sold: a mine-countermeasures variant (MC500, adopted as SATAM for

the new German Type 332 class) and GP 250, a fire-control predictor for the coast-defense batteries of the Royal Danish Navy. In the former case, MBB is the prime system contractor; in the latter, Terma is the prime system contractor.

◆ MINOS

This Marconi small-ship, distributed system uses autonomous multirole consoles connected by a data bus. Development was triggered by the advent of raster-scan displays (which could easily show both raw and processed video), by the appearance of displays suitable for daylight viewing (thus greatly simplifying installation in small ships without special enclosed combat information spaces), and by the availability of proprietary (commercial) computer cards. The last made it much simpler to assemble a tactical data system.

The console is built around a standard VME bus, chosen because cards for about 80% of system functions were already available commercially. Marconi, therefore, could concentrate on the front end, the plot extractor (automatic radar-target detector) and the radar-scan converter necessary to permit display of raw video on the raster-scan screen. Each console incorporates its own processor, and the consoles are connected as an LAN (Ethernet). This LAN, in turn, would be connected (gatewayed) onto the ship's combat-system (weapon/sensor) data bus (highway, in British parlance).

The monitor has 1000-line resolution, and each console can display up to 25 tracks (computing capacity suffices for about 100, but Marconi claims that so high a number would unduly clutter the screen). One Marconi brochure describes capacity per console as up to 20 autotracks and 8 manually controlled, rate-aided tracks, with range selectable from 5 to 160 nm. The existing software can form autotracks on any single plot, and such a track file induces continuous updating of that plot, for full automatic detection and tracking. In theory, the system can do sensor fusion, but that capability probably has not been implemented, as MINOS is intended for the small-ship market. MINOS is designed to support an interface with a data link.

A typical allocation of consoles would be: 1 to support the air-picture compiler, 1 for the surface-picture compiler, and 1 for the tactical position (command position); there could also

be a subsurface console taking sonar data. The track data base is replicated in all the consoles, and thus (as in any distributed system) it is preserved if any console goes out of action. The software is arranged so that lesser functions can be dropped automatically in the event of an overload.

This system was first announced at RNEE 1989 (September 1989). A display there showed two 1802 track consoles and 2 command consoles as typical. The 1802 panel can accommodate an electro-optical (television) display below the main raster-scan screen. It has a joystick. The command console has a keyboard and a roller ball, with an electro-luminescent tabular display under the main screen. The embedded computer is a 68020 on a standard card. Marconi contributed a plot extractor, a scan converter, and track processing software.

As of September 1989 Marconi was suggesting a price of about £100,000–150,000 per console, taking into account the cost of the radar distribution unit, system engineering, etc. That would be roughly similar to the cost of NAUTIS on a per-console basis.

MINOS was initially designated SSCS (Small-Ship Command System); it was, presumably, redesignated when the Dowty-SEMA SSCS was chosen for Type 23 frigates. As of July 1988, Marconi described SSCS as suited to fast attack craft 25–75 m long. A typical installation would comprise 2 or 3 consoles, with more for larger ships. The consoles could be connected to an automated plotting table and also to an event recorder, for recording and playback for later analysis and training.

One peculiarity of the system, at least as described in 1988, was that alongside the usual friend, unknown, and hostile symbols it also carried special symbols for neutrals; and besides the usual air, surface, and subsurface symbols it carried special symbols for hovering craft. In addition, targets would be color coded: unknown in orange, hostile in red, friendly in cyan-blue, and neutral in green. This graphic scheme probably well illustrates the potential inherent in a slight extension of the usual NTDS symbology. In this scheme all targets with speeds greater than 60 kt would generally be classified as aircraft, although such a processing scheme could be changed to cope with helicopters and VTOL aircraft. Targets would generally be identified explicitly as automatically or manually tracked, and they would also be identified with the number of the console responsible for tracking them.

UNITED STATES

◆ Aegis

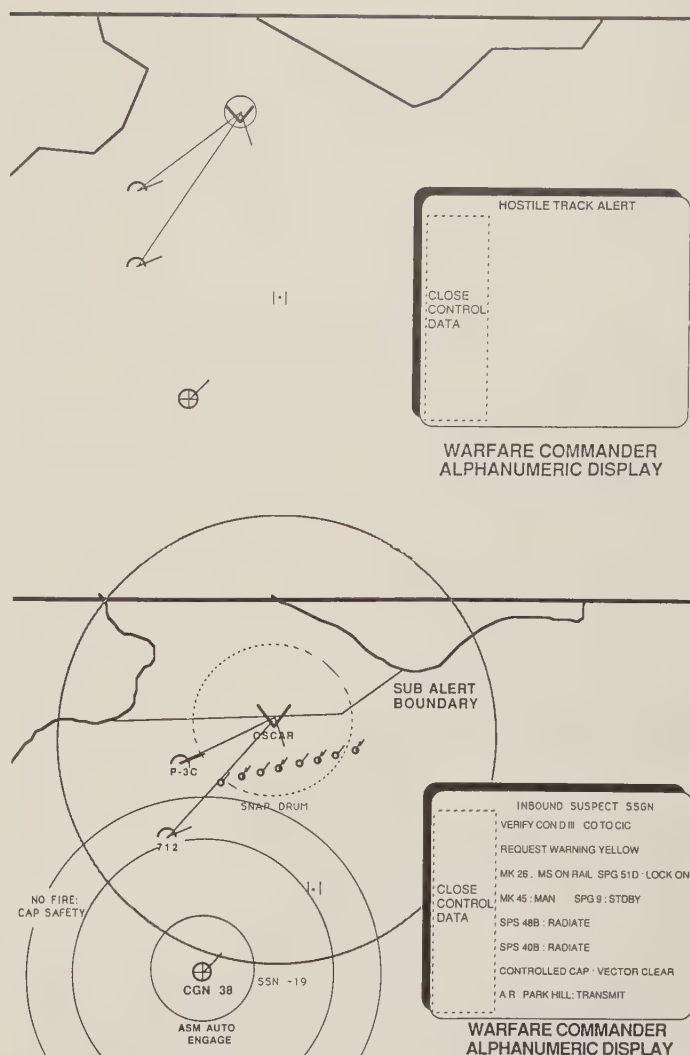
See Radar Integration in the Antiaircraft Warfare section.

◆ ACDS

Advanced Combat Direction System, the successor to NTDS (see below), uses Link 16 for data transmission and exploits the capabilities of the UYK-43 computer (which replaces the earlier UYK-7). ACDS Block 0, the interim system, covers installation of the new hardware, including the new UYQ-21 display. The associated software is a direct continuation of existing NTDS software, and Block 0, therefore, shows only modest improvements in capability compared to NTDS. ACDS Block 0's software is designated CDS Model 4, and the carrier and cruiser versions are quite different (the carrier is modular, the cruiser restructured). ACDS Block 1 uses CDS Model 5 software.

Block 0 begins a transition from AAW orientation in NTDS toward multiwarfare orientation; Block 1 is structured specifically to support composite warfare commanders (CWCs). This evolution is essential because the threat is no longer easily divisible into the traditional categories. For example, a missile-firing submarine may be tracked by ASW sensors, but it is really an AAW threat. Unless the portion of the combat system that is normally devoted to ASW recognizes a launcher's sound (a transient) as an AAW cue, the AAW part of the system will not be ready to look for a missile emerging from the water near the detected submarine.

Like NTDS, Block 0 is limited in track capacity, range, and "vocabulary" (the ability to describe tracks in greater detail than

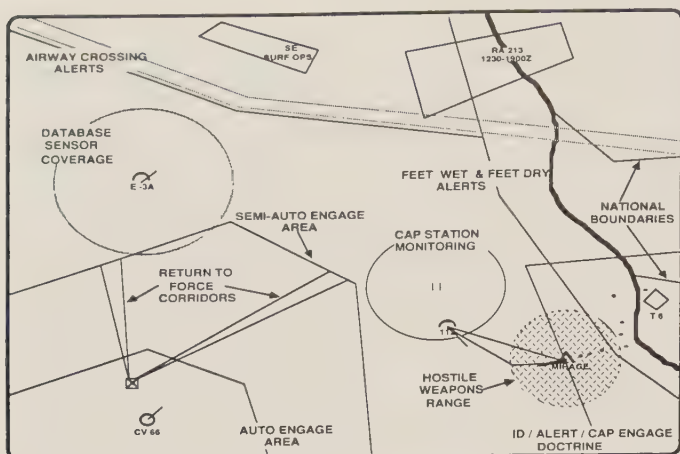


ACDS Block 0 and Block 1 pictures of the same tactical situation. Block 0 is equivalent to current NTDS; the diagram shows one hostile submarine (the "v") and two friendly aircraft (the semicircles), plus a ship (the circle) at the bottom. Interpretation is entirely the responsibility of the CIC personnel. Block 1 shows the effect of providing extensive on-line data bases, displaying weapons capabilities and threats. (Hughes)

air/surface/subsurface and friendly/unknown/enemy); Block 0's ability to gridlock is limited to self-correlation, and it has very limited capabilities to integrate ESM and ocean-surveillance data, even though those types of data are becoming much more important. Like NTDS, Block 0 is not designed to automate the decision to engage a target and, thus, does not really greatly reduce a ship's reaction time.

From a maintenance point of view, Block 0 shares the basic problems of NTDS: the program's logic is relatively inflexible, and system updates are difficult because the programming is not sufficiently modular. These problems in turn make it attractive to add stand-alone systems to ships, rather than to integrate the systems with the basic combat system. Such stand-alones, however, tend to be relatively ineffective because they cannot benefit from the ship's main sensors. Quick-reaction ECM systems suffered from that particular problem.

Block 1 marks a departure in system philosophy. NTDS was primarily a display system, the TAO using experience to add the information needed for decisions. In this sense NTDS is semiautomatic. For example, it shows but does not particularly highlight potential threats, and it is not intended to suggest appropriate courses of action. The sole current exception is the command-and-decision (C&D) processor in the Aegis system, which the ship's CO feeds with a series of doctrinal rules (including rules of engagement) and which does indeed suggest courses of action. For Aegis, the weapons-assignment role has



The effect of ACDS Block 1 zone processing. (Hughes)

been melded with the NTDS role to create something new, a combat-direction system (CDS). This change, from pure information coordination to combat direction, is reflected in a change from the existing CIC designation to a new CDC (combat-direction center) designation for the central command/control space of a ship.

Compared to NTDS, ACDS Block 1 offers expanded surveillance coverage, automated sensor processing, and expanded data exchange, both within a battle group and between the battle group and external sources of information.

Block 1 is already planned for all carriers (to enter service beginning in 1992) and may be extended to pre-Aegis cruisers (NTU ships) and to the major amphibious units. The lead ship is USS *Carl Vinson* (CVN 70), which is currently equipped with NTDS Model 4.0. Block 1 (Model 5.1) adds a second UYK-43 computer, plus entirely new software to fully exploit the new hardware. On board a carrier, ACDS Block 1 receives battle-force tactical data from the command/control processor (C2P, a third UYK-43), which receives the tactical data links (and, in the future, the remote satellite links, OTCIXS and TADIXS). ACDS receives all shipboard data directly: ESM data from SLQ-32 and from the Tactical Signals Exploitation System (TSES); SYS-2 radar tracks; beacon video; information from the ASW module; information from the TAS Mk 23 target-acquisition system; and information from the interim afloat correlation system/POST (which receives TADIXS B information from intelligence centers ashore). In the future it should also receive data from the big intelligence-processing systems, such as the Flag Data Display System (FDDS) in the TFCC (see above).

Compared to NTDS, Block 1 operates over 4 times the range (for 16 times the surveillance volume, maximum altitude being fixed). Block 1 can handle 4 times as many track files and adds auto-identification of tracks (7 levels, compared to 3 levels of manual track identification in NTDS). Link 16 provides 10 times the throughput of Link 11. Given much more data, it is possible to correlate tracks automatically and thus to maintain gridlock automatically. The only existing track correlator of this type is SGSAC, a manual system implemented in Aegis ships. On-board and remote ESM can be fully integrated because the system is fed by a highly secure data link (Link 16) that can carry ESM data. In contrast, NTDS ships have to rely on a separate secure data link (Park Hill), and their off-board ESM data are, therefore, processed outside the automated ship's combat system.

In particular, there is now enough information in the system to correlate ESM data for targeting. Such correlation requires special knowledge of individual sensor and emitter characteristics and exchange of data on emitter parameters among several ships, so that the correlator knows which ships are detecting the same emitter. The battle-group command system must, then, associate individual intercepts of what seems to be the same emitter to obtain positions good enough for targeting.

The most visible impact of ACDS Block 1 is in graphics, which are much more detailed than those of NTDS or Block 0. The improved graphics are supported by the second UYK-43, the decision support processor. As in NTDS, the first is primarily a track manager. Graphics are much more than simply a decision aid. Graphic processing, which is already quite common ashore, makes it easy to exploit the position of a point or a track in relation to a preassigned zone of the space in which the system works. For example, it is relatively easy to make the system reaction to a track depend on whether the track is or is not within a zone (say, the 12-mile limit) surrounding some coast. The alternative, to test the track against the entered zone boundary, is time-consuming and is probably outside the power of earlier combat-system computers. Zone processing complements the system architecture designed to accept doctrinal rules ("if . . . then" statements) and to present the operators and the TAO with the immediate operational implications of those rules.

This doctrinal processing can be used to create automatic combat-system checklists (ACSCLs). The CO and staff create the checklists to cover specific situations; each checklist is a series of actions and operating modes that should be optimum for that situation. Each list can also be reviewed and revised at will. All the checklists are carried as computer files, and the CDS automatically implements them when it detects the appropriate conditions. Its action includes display of the checklist itself so that the operator has, in effect, a veto in the event the system has somehow used an inappropriate ACSCL. This type of automation seems essential as threat-warning time shrinks and is an extended equivalent of the auto-engagement capability that is increasingly common.

Block 1 is the first CDS to incorporate an on-line intelligence data base; it can be used for realistic TEWA. In contrast, NTDS had to base its assessments entirely on target speed, course, and range (which, even so, was better than the situation before NTDS). This function seems like what Ferranti is now promising in its System 500 (see above) and will probably be characteristic of future tactical data systems using very powerful computers.

As an indication of the new level of data available on any particular track (i.e., detected target), one can compare data available from Block 0 (i.e., NTDS) and Block 1:

	Block 0	Block 1
Track Identifier	4 values	8 values
Track Category	4 values	8 values
Primary ID Amplifier	16 values	—
ID Amplifier	144 values	—
Platform	—	504 values
Platform Type	—	4095 values
Type Modifier	—	32 values
Nationality	—	country codes
Alliance	—	alliance codes
Unit	—	256 values/type

For example, the same ship might be described as:

Block 0	Block 1
Hostile	Hostile
Surface	Surface
Destroyer	Destroyer
Missile Platform	Krivak-II
	ASW/Targeting
	USSR/Warsaw Pact
	Hull No. 539

Given these specific data, the system evaluates the threat presented by the target (based on its known weapons characteristics, which are stored as a data base), provides alternative methods of engagement, and displays alternative engagement capabilities.

Link 16 is essential for this type of detailed processing because of its precision and its great information capacity. Thus,

the Block 1 program is being paralleled by programs to place Link 16 on board E-2Cs and F-14s.

Unlike NTDS, ACDS will have an integrated ESM interface because Link 16 is secure enough to carry intelligence and ESM data. Bearings can, therefore, be shared rapidly among ships for better targeting. NTDS had to use a separate ESM/intelligence facility using a dedicated, secure signals system, Park Hill. Moreover, because ESM data are integrated with other sensor data, the system as a whole can choose between ESM and weapon responses to particular threats.

One advantage of the much more powerful graphic processing capability is that the format in which information is presented can easily be changed. The data base is object-oriented, so screen data structures are easy to change without recompiling the basic computer code. This capability is important because users have such different desires (and needs) for interface formats. Given flexible formats, individual commanders can choose what they want, and the choice of format does not delay overall system development.

Automated status boards (ASTABs) complement the usual graphic displays, showing threat summary, task organization, and combat-system summary. All ASTABs can be displayed on either the dedicated ASTABs or on CRTs in the CDC, and the system operators can request ASTABs as desired. ASTABs can be defined as multipage electronic documents, 1 page being displayed at a time, but the overall computer system keeps the entire ASTAB up to date, to be called up as desired. There are 60 predefined formats (own-ship and force data) plus 20 user-defined formats. All of this information can be pulled from the full ACDS data base, including the track file and the intelligence data. For example, an operator might define an ASTAB listing ASW threats, giving for each threat platform its track number, its category (submarine, surface, air), its range, its ASW sensor, and its ASW weapon. Another page of the display (which could be called up as desired) might associate each threat with its lethal range. An ASTAB on force status might, for example, list the ships with the status of their ASW systems or their roles (e.g., picket, pouncer).

Hughes Ground Systems is responsible for ACDS Block 1. In contrast to recent modular command/control systems such as the Ferranti Series 500, Block 1 cannot be decentralized, partly because the data base is much too large to fit anything short of a very large central computer. In commercial terms, Block 1 corresponds to a system based on a mainframe with computer terminals, rather than to a decentralized LAN using individual workstations, each embodying the computing power of the system. Presumably, it will take at least a further generation of higher-density computers, and a much more capacious data bus, to permit the U.S. Navy to pass from a centralized NTDS-type system to something decentralized.

The new UYK-43 computer for ACDS supersedes the UYK-7 on which current versions of NTDS are based. The instruction set of the new computer includes the instructions of the UYK-7, so that UYK-43 can run UYK-7 programs: ACDS Block 0 is very similar to NTDS. ACDS Block 1 exploits the full capacity of the new computer. The Block 1 prototype is on board the carrier *Eisenhower*.

There is also a program for conversion of the CICs of existing major units from NTDS to ACDS. New features in a modernized CIC include provisions for Link 16 (JTIDS), the Aegis Tactical Executive System (ATES), Shipboard Gridlock (SGS)/Automatic Correlation (AC), and the Command/Control Processor (C2P). Late in 1988 the *Leahy*- and *Belknap*-class cruisers (CG 16/26 classes) were eliminated from this program.

The Hughes command/control processor (C2P) is intended to meet a requirement that CDSs quadruple their track capacity and effective surveillance range, and also increase their target insertion rate. C2P is a new computer program that mediates between data links and ACDS and the Aegis command-and-decision system. Presumably, C2P makes for faster processing by isolating the central tactical program from data link-handling tasks. C2P extracts information from the links,

forwards these data, and formats appropriate shipboard information for data-link transmission. It runs on a separate UYK-43 computer, outside the main combat-system computer, and uses a USQ-69 display terminal. The C2P operational requirement was issued in March 1982, and the first UYK-43 computers intended for operational evaluation of the Version O system were acquired under the FY88 program. Funding cuts in FY88/89 delayed some tests from FY90 to FY91, others from FY91 to FY92.

◆ FFISTS

Frigate integrated shipboard tactical system, a distributed combat system for *Knox*-class frigates using 4 DTC I computers, is in effect a poor man's NTDS. Like JOTS, this program was run by the Naval Ocean Systems Center (NOSC) at San Diego; it was conceived by a NOSC employee, Mike Pastore. One of the computers acts as a 2-way Link 11 terminal and as the track supervisor. It can accept processed radar data from a SPA-25G radar console. A second computer is responsible for data fusion. A third is responsible for the sonars: it is the interface with the active (SQS-26) and passive (SQR-18) sonars, conducting performance prediction and noise monitoring. The fourth computer conducts TMA for the towed array (the software is called automatic TMA for tactical commanders, ATTAC). The 4 computers are linked by their access to a Shared Resource Monitor (SRM), essentially a large hard disk, via Hewlett-Packard connectors (HP-IB links). The system can accept Link 14, intelligence, and OTCIXS messages, presumably via the data-fusion computer.

FFISTS appeared in the mid-1980s as a rapid-prototyping project; the first ship fitted with it was the USS *Harold E. Holt*. A total of 9 have been installed.

A second-generation FFISTS, using DTC II computers, is planned for 2 *Knox*-class frigates. JOTS will be used as the fusion computer, and the 2 acoustic computers will be replaced by one 2-screen DTC II workstation. The DTC II computers will be arranged in an LAN; they will not need an SRM.

The track supervisor is an expansion of a stand-alone low-cost 2-way Link 11 station, which may ultimately be installed on board the *Pegasus*-class hydrofoils.

◆ HYCATS (SSQ-87(V))

Hydrofoil collision avoidance and tracking system is actually the tactical data system of the *Pegasus*-class hydrofoils. It is used to target their Harpoon missiles. However, there is no provision for receiving Link 11, so they cannot automatically maintain a plot of OTH targets. The system was developed by UNISYS, and the computer is a UYK-44 (however, the lead ship, *Pegasus*, originally had a CP-901B). These ships were originally designed to a German Navy requirement, and the German version would have had the more elaborate AGIS system, with Link 11. Like the British CANE, HYCATS illustrates the convergence of purely navigational systems with combat-control systems, especially when the latter are used to target surface-to-surface missiles.

◆ JPTDS

Junior Participating Tactical Data System was a destroyer version of NTDS developed specifically for the *Adams* class; it was, in effect, equivalent to SATIR and SENIT 2. All of the *Adams* class was to have been fitted, but only 4 ships received JPTDS (DDGs 9, 12, 15, and 21). JPTDS was built around a single UYK-7 computer rather than the 2 (3, if SAMID improvements were incorporated) CP-642Bs of the cruisers. It has 8 UYA-4 consoles: 3 for detection and tracking, 1 for surface/subsurface, 2 for display/decision, 2 for weapons control. There is also a 3D radar console (in 1971, for SPS-39). The existing SPA-33 radar repeaters and WDE Mk 1 Mod 0 were removed. WDS Mk 13 displays target engageability rather than the fire-control solutions displayed by the earlier WDS Mk 11. Computer-aided target scheduling by the Mk 152 missile computer makes for better capability against multiple targets. Mk 13 can feed ship's pa-

rameters (heading, speed, roll, pitch) into JPTDS in the event that the normal sources of parameters fail. JPTDS's functions include radar tracking, weapons-system control, surface navigation, and automatic identification via a beacon video processor. The UYK-7 computer is connected directly to the missile and gun subsystems (the gun system via the missile system), and it is multiplexed to EW, chaff, and the underwater battery. JPTDS also incorporates Link 11. JPTDS's modernization includes the digital update to Tartar (now Standard Missile MR). In the event of a casualty to the UYK-7, and Mk 152 missile computer can be switched to the JPTDS signal generator to drive the FCSC (FCS Coordinator) and EC (Engagement Controller) consoles; the EC is then responsible for target tracking. As initially installed, the JPTDS UYK-7 had only 3 of its 16 available 16k modules. JPTDS was to have been extended to the remainder of the class (and also to the converted DDG 31 class), but that was never done. Installations in the 4 ships were completed early in 1973. The *Adams*-class modernization (including NTDS) was to have resumed under the FY80 program (beginning with DDG 3), but rising unit cost led first to a reduction to 10 units and then to cancellation of the program; 3 ships were modernized using operating funds (DDGs 19, 20, and 22).

◆ NTDS/CDS/MTDS

The U.S. Navy Tactical Data System is the oldest such system still in use, albeit greatly updated. NTDS was the world's first shipboard tactical data system based on programmable solid-state computers and using multiple computers in a distributed tactical data-processing system. It was also the first in the world to use automatic computer-to-computer data exchange, and the first naval implementation of an "expert" computer system in the form of a TEWA system.

NTDS was conceived as a means of automating the World War II-era vertical plot (the grease pencil, i.e., manual display of available radar data from all ship radars) to deal with the increasing number and speed of modern aircraft. After several experimental systems had been designed, a set of technical specifications was written in 1955. NTDS was conceived both as a single-ship system and as a means of exchanging information throughout a task force. NTDS was, therefore, based on standard computers, display terminals, and communications links; and although it was conceived initially for AAW, it was designed so that it could easily be extended to other warfare areas. Each ship would have data links connecting it to other

ships, to aircraft, and to a compatible Marine Corps system on shore. Each ship could control the entire NTDS net, so that on a fleetwide basis the system would degrade gracefully in the event of battle damage. The original NTDS concept also called for the use of programmable solid-state computers, to limit shipboard space requirements and to allow for future change. Some of these decisions were quite farsighted in 1955; for example, at that time it would have been much simpler to hardwire the computers than to make them programmable. Many contemporary systems did use special-purpose computers that, it turned out, froze system design much too early.

The data link chosen was phase-modulated HF (HF was chosen so that ships in the net could be widely dispersed, to minimize losses in the event of a nuclear attack). Message standards and protocols were first set by BuShips in July 1957 and later adopted by a Canadian-British-U.S. Tactical International Data Exchange (TIDE) Committee, and then by NATO as a whole. This message standard became Link 11. An alternative UHF link, Link C, was studied but rejected because of its limited range. The current system does use UHF links to nearby ships and to (and via) some aircraft.

All data had to be converted from analog to digital form. Two standards were imposed: on-line for such essential data as primary radars, gyros, and pit logs; and off-line (keyboard) for other sensors. However, the technology of radar-video extraction was relatively new at the time, and in 1955-57 it was considered impractical to provide RVPs for all the existing fleet radars. Therefore, NTDS was given a manual, rate-aided tracking capability. This manual data insertion was also available as a backup against the failure of those RVPs that were later installed, e.g., for SPS-33 on the nuclear ships *Enterprise* and *Long Beach* and more conventional radars on the carrier *Oriskany*. Only much more recently have RVPs become the rule, sometimes via an integration system such as SYS-1/2.

In the manual system, an operator (detector/tracker) detects a target (i.e., enters it into the computer) by moving a cursor over a blip; the computer acknowledges by superimposing track symbols on the indicated position. The detector/tracker then

⊕ Tentative track	☺ Subsurface friendly
☺ Air friendly	☹ Subsurface unknown
☹ Air unknown	☹ Subsurface hostile
☹ Air hostile	☹ Patrol/ASW aircraft
☹ Surface friendly	☹ Interceptor
☹ Surface unknown	☹ Downed friendly aircraft
☹ Surface hostile	☹ Aircraft carrier

Some standard NTDS symbols; this symbology is now standard throughout much of the West. The goal in symbology is to make the plot as vivid and as immediately meaningful as possible. NTDS seeks this end by using sharp symbols for enemy units and round (soft) ones for friendlies, and by using the upper part of the symbol for an air target, the lower part for a submarine, and the whole symbol (diamond, circle, or square) for a surface unit. Note also the "sea gull" symbol for an ASW airplane. These are warfighting symbols: there is nothing to represent a neutral. On the frigate *Stark*, the neutral Iraqi airplane that actually attacked the ship had to be classified as friendly, and that classification in turn made it impossible to engage automatically (the fire-control system could, however, track a dummy target following the same flight path). These are only a portion of the full NTDS repertoire. For example, the ACDS entry above shows the standard sonobuoy symbol as well as the own-ship symbol. (*Shipboard Weapon Systems* Vol. II, published by the U.S. Naval Academy, no date [late 1970s])



HF discone data-link antenna (AS-2865) for NTDS, USS *Mississippi*, June 1988. (Stefan Terzibaschitsch)

indicates the position associated with the same target on a later (hopefully, on the next) radar scan by moving a "ball tab," a small circle on the PPI, over that location. On each subsequent scan, the operator again corrects target position by ball tabbing the new blip (video) position and pressing a "position correction" button. After 3 such target confirmations, the computer begins to project the target's position, based on the target's course computed from the 3 positions. The operator is then responsible for checking whether the target does indeed follow this steady course and speed.

The action of the operator converts the raw analog video data into digital (position) data suitable for computer operation. In practice, the accuracy of the subsequent track projection is often reduced, as operators hit the "position correction" button 3 times for the same blip position, to be sure that it is entered into the computer as a valid target. Operators are likely to be particularly tempted to do so when targets are approaching at high speed at low altitude, and thus when they are first detected at fairly close range by a radar that may well take 4 sec or more to look again in their direction.

This rate-aided system projected a target's course and speed based entirely on the initial entry, without being able to check (except by operator intervention) whether the target continued at a steady course and speed. In theory, the operator would detect any changes by comparing the target's actual position with the projected position, but verification was not always practical when many targets were present.

Rate-aided projection was not a new idea; it was employed by several earlier systems. However, earlier rate-aided trackers were analog devices, in which a strobe could be positioned over a particular blip and then made to move to match the next appearance of the same target. Strobe position and rate of growth could be extracted from a radar console. In NTDS a digital computer compared successive target positions and generated an estimated target position, which it sent back up to the detector/tracker's screen. Thus, the detector/tracker could insert numerous targets, all of whose positions the computer would project ahead. The earlier analog trackers were limited to a single target.

With manual blip entry, many target detections were missed; and in many cases subsequent blips were missed, so that track files were not constructed or could not be maintained. Hence the importance of RVP (see Radar Integration in the Antiaircraft Warfare section).

Automation of combat data allowed for the passing of these data directly into the ship's combat system. Automation was first realized in the cruiser *Wainwright*, fitted with NTDS and WDS Mk 11 in 1966.

The original NTDS computer was the Univac CP-642, multiple units of which could be assembled in a USQ-20. The CP-642A computer of 1960 was replaced by CP-642B (USQ-20B) in 1963, and in 1971 the current UYK-7 was introduced. It is now being superseded by UYK-43. Early NTDS systems employed multiple CP-642s, 2 in a cruiser and 4 in a carrier (3 in the prototype installation on board USS *Oriskany* in 1961), but UYK-7 was so much more powerful that it could be employed singly, albeit in multibay form. These machines are all described in the separate computer section.

As of mid-1990, the following NTDS computers were in service on board surface combatants:

CP-642A *Belknap* class without NTU, and 1 *Leahy*-class cruiser.

CP-642B *Leahy* class without NTU; *Long Beach*; *Bainbridge*; *Truxtun*; *Mahan* class; and frigates *Koelsch* and *Voge* (now transferred).

UYK-7 *Belknap*; *Virginia* class; *Spruance* class; modernized *Adams* class (including JPTDS ships); *Tarawa* class; and *Perry*-class frigates.

UYK-43 New Threat Upgrade (NTU) ships: CGNs 36-37; CGs 16, 17, 19, 29, 30, 33, 34; DDGs 993-996; and *Wasp* (LHD 1).



NTDS consoles on board the missile cruiser *Wainwright*, 1968. Each console has a trackball that the operator uses to position a cursor over the blip he wants to enter into the system; one such ball is visible on the table in the foreground, and one is being manipulated by the second man from the right. (U.S. Navy)

A single UYK-43 in a *Kidd*-class destroyer replaces a 4-bay UYK-7.

The list does not include Aegis ships, for which the CDS is closely integrated with the weapons system.

The earliest remaining NTDS display is SYA-4; it was superseded by UYA-4 and then by the current UYQ-21. All 3 remain in service. They are described below.

The current version of NTDS is Model 4; model differences correspond to differences in Link 11. Thus the next version, Model 5, corresponds to Link Eleven Model Five (LEMF). Model 5 will also be able to use Link 16. Unfortunately, Link 16 uses the new NATO IFF categories for contacts, which do not match those of Link 11. As a consequence, the 2 systems cannot share quite the same software architecture. Moreover, the C2P, which is intended largely to translate between systems, cannot easily do that.

Typically, NTDS automatically incorporates information from a ship's own sensors and similar information inserted by other ships of a force into a computer data base in the form of a map of the space around the force. Electronic intercept data are collated separately (in special secure spaces), and a sanitized version is entered manually into the data base by keyboard. The basis of the system, then, is the detector/tracker at the CRT. An analogous role is played by a separate beacon video processor tracker, who uses the TACAN air navigation beacon and IFF transponders to track friendly aircraft.

The minimum NTDS installation, then, consists of 4 consoles: 2 for the detector/trackers (1 for air targets, the other for surface/subsurface targets), a summary console for the CIC supervisor, and a console for the weapons-control officer (WCO). The TAO who fights the ship from CIC (under the general orders of the CO) does not operate a console but has access to one, to gain an overview of the tactical situation. This minimum is acceptable only for a highly automated system, employing ADT radars. In most cases there is a considerable degree of track supervision, to ensure that the detector/trackers do not miss targets that deviate from the rate-aided projections the NTDS computer assigns to them. In general, too, there is at least 1 detector/tracker console per search radar. Radar data are merged (in the form of processed video) in the summary consoles, such as those for the WCO and the CIC supervisor.

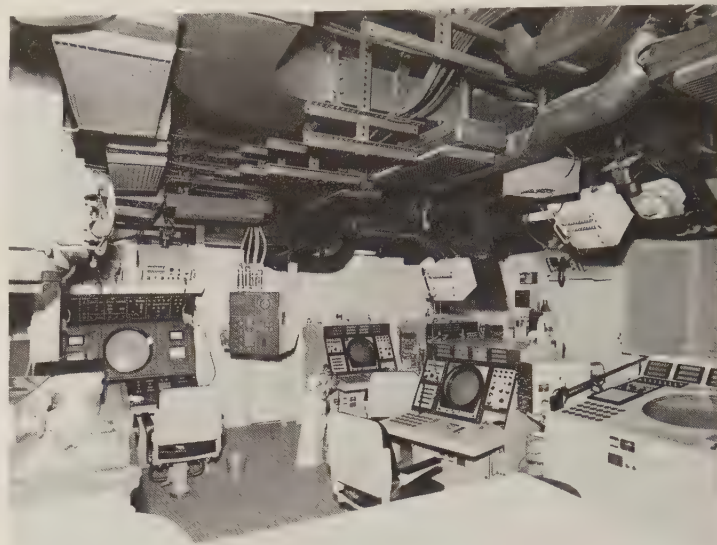
Generally, the surface tracker/detector is also responsible for inserting sonar data, which are not entered automatically. This split between radar and sonar data reflects the AAW origin of the NTDS system.

The TAO sets target priorities (generally by exception rather than positive direction). The WCO designates assigned targets to the WDS embedded in the NTDS. Ideally, the WDS compares target parameters with preset and entered thresholds and recommends an engagement sequence. The WCO actually selects weapons and fires them. In the *Perry* class the expectation was that some targets, such as pop-up missiles, would arrive too quickly for this sequence to work in time. The ship's NTDS was, therefore, designed for automatic engagement, the WCO having only a veto. However, that level of automation proved less than popular and was rarely, if ever, implemented. It may become more reliable as the frigate's radars are tied together using an SYS system (see the Anti-aircraft Warfare section) in an ongoing current program. One advantage of full integration is that there are many fewer false targets, so a ship's commander can have more confidence in a fully automatic engagement system.

A ship controlling aircraft will often have separate consoles for air controller(s) and for intercept controller(s), and 1 console will be devoted to IFF. There may also be multiple consoles for each of the roles listed. For example, in the minimum installation, the air detector/tracker has to compromise in the choice of range scale. In a larger installation, there may be separate long-range and short-range air detector/trackers.

NTDS development has been evolutionary, probably at least in part so as to avoid major software revision. Consequently, current versions do not take full advantage of the current computers. Hence the shift to ACDS (see above), which Hughes is developing.

Reportedly, NTDS suffers from limited track capacity, range, and vocabulary, the last limiting the system's ability to support decision making on-line. Targets are described as friend/unknown/enemy, which leaves out considerable ambiguity. For example, in the case of the *Stark*, the track of the Iraqi aircraft that actually attacked the ship was initiated by an AWACS aircraft that identified Iraqis as friendly, and the ship carried the track with that identifier. It took an extra effort for the TAO aboard the ship to keep in mind that the airplane was actually not U.S., and not privy to U.S. tactical data (e.g., could attack by mistake). The ship's combat system was so arranged that she



Another view of the standard frigate CIC (in this case, aboard USS *Estocin*) shows the 2-operator weapons-control console (WCC) to the left of the UYA-4 NTDS console. This picture was taken while the ship was fitting out in April 1980. (U.S. Navy)

could not normally attack a target identified as friendly (although that software limitation could be overcome by clever operation).

Limited system vocabulary may also have limited the detail in which the surrounding geography could be presented, and that restriction may explain why the tactical picture in the *Vincennes* showed only a single line rather than an airliner corridor (the single line was the centerline of the corridor). One lesson of the *Vincennes* incident may be that, in combat, decisions are taken on the basis of what the display shows, and that limitations in display tend to be overlooked or ignored.

Advertising for NTDS clones (SENIT, TAVITAC, IPN) tends to emphasize the richness of the tactical display (hundreds of lines, circles, etc.) but not any increase in on-line tactical information to support decision making. ACDS and perhaps System 500 may be the only exceptions.

CDS, the Combat-Direction System, is the successor to NTDS and is currently used onboard Aegis ships. In effect, CDS is the form of NTDS adapted to Aegis.

ACDS is the Advanced Combat-Direction System. Block 0 is a restructured NTDS with new software, entering service in FY87. Block 1 incorporates the Joint Tactical Information Data System (JTIDS) and has improved high-data-rate networking.

MTDS is the analogous Marine Tactical Data System. Its roles include bringing in fire support to protect marines in forward positions.

Perhaps the greatest problem of NTDS operation has been gridlock, the means of assuring that all ships in an NTDS net use the same coordinates to identify the same points in space, i.e., truly share a common grid. If the units do not, then the same target detected by 2 ships may be counted as 2 different targets, and thus assigned 2 (of a limited total number of) tracking and engagement channels. The gridlock problem has now, finally, apparently been solved, initially using Aegis hardware.

◆ H930/MCS

The Modular Combat System is the only U.S.-produced distributed combat system. It was developed by Honeywell and then sold (in 1988) to Hughes. Hughes has continued development and may also be working on a separate small-ship (fast-attack-boat) system, perhaps a mini-NTDS. No information on such a system has been forthcoming. Hughes is currently marketing an advanced version, MCS 2000, based on the H930 concept but using much more powerful processors. Five versions are cur-



The combat information center (CIC) of the newly completed frigate *Curtis* shows 2 standard OJ-194/UYA-4 consoles flanking the TAO (summary) console (OJ-197/UYA-4), with an SPA-25 radar repeater in the background. Not visible between the 2 status boards behind the consoles is a large backup vertical (manual) plot. The trackball of the console in the foreground has not yet been installed, but one is visible on the console on the right. (U.S. Navy)

rently in service: H930 Mods 0, 1, 2, and 3, and MCS (Modular Combat System).

Its developers claim that H930 is the only truly distributed system in current service, that systems described as distributed are really no more than multiprocessor types in which the separate processors are so tightly connected that the failure of any one will disable the system as a whole. The argument is that true distribution is much more a software than a hardware problem. Different combat-system tasks are normally interdependent, whether they are conducted by separate processors or, in sequence, by a single central machine. The key to the H930 architecture is that commands and changes to the tactical picture propagate as messages in a data bus. Any processor assigned to a given role can pick up messages relevant to its operation and can broadcast its own messages freely.

The first system of this type was the Honeywell Experimental Distributed Processing System (HXDP), a land-based system built under U.S. Navy contract, begun in 1972 and completed in 1974. Communications protocols and the data-bus hardware were developed at this stage. Some of the associated hardware was later tested on board the USS *Moosebrugger* (DD 980). As installed at San Diego, HXDP used an LN-66 radar, an E/O sensor/tracker, and a helmet-mounted visual target-acquisition system (VTAS), to control a GAU-8 Gatling gun. There were 3 modules: 1 for surface tracking (STM), 1 for air tracking (ATM), and 1 for weapons control (WCM), the last connected directly to the gun. The STM was fed by the LN-66, and it in turn fed a display/control console. The ATM was fed by the E/O tracker and the helmet sight. All were connected by a bus.

In 1975 Honeywell developed H930 Mod 0 for a fast patrol boat. Five were delivered. This system used 1 air-search radar (SPS-58), 1 surface-search radar (HC 75), 1 tracking radar (a Westinghouse W-120), and 1 Mk 35 optical director, with 2 system operators, to control one 76-mm gun, two 30-mm guns (in an Emerlec mount), and SSMs. The 2 radars were arranged for TWS operation. There were 2 minicomputers (for the 2 operator consoles) and 5 microprocessors. The 2 operator consoles are dedicated, respectively, to air and surface warfare, but either gun can engage any target. The 2 computers are programmed to be mutually supportive. This system became operational in November 1978, probably on board PSMM Mk 5 patrol boats of the South Korean Navy. Honeywell considered Mod 0 an extension of HXDP and thought it important mainly for gaining experience in console design. In this system primary operator switches and status indicators are multifunction, their meaning controlled by the computer program so that the operator's attention would be focused on the immediate task.

In 1976 Honeywell sold its first H930 Mod 1 system to Taiwan. This system was built around 5 UYK-19 minicomputers in 2 multicompartment consoles, connected by a combat-system data bus (LAN). The consoles in turn were connected to such elements of the ship system as guns and missiles. Mod 1 (January 1981) was installed on board 10 destroyers; it employed 1 dedicated air-search radar, 1 air/surface-search radar (SPS-10 and -58 sharing a common antenna), 1 dedicated surface-search radar (SPS-55), 2 tracking radars (HR-76), 1 Mk 35 optical director (with light enhancement), and an ESM intercept receiver. SPS-58 had a digital target extractor, and SPS-55 was a TWS radar. The 2 tracking radars were also programmed to conduct horizon search with automatic detection. At least in this version, the Mk 35 optical director incorporated light enhancement and an embedded television camera. There were 6 system operators to control two 5-in/38 gun mounts, one 76-mm gun, two 40-mm guns, and SAM and SSM (Hsiung Feng I) missiles. Support was provided by 5 UYK-19 minicomputers and 23 microprocessors. There were 2 command/control consoles, their responsibilities split so that the loss of either would not eliminate all capability.

Thus, Console 1 was fed by the ESM sensor, the Mk 35, and 1 of the 2 trackers. In turn, Console 1 was wired directly to the surface-to-surface missiles, to the 76-mm gun, and to 1 each of the two 5-in/38 and 40-mm mounts. Console 2 was fed by the air/surface-search radar and the second tracker, as well as the

heading/azimuth unit; it in turn was directly wired to the other twin 5-in/38 mount and the second 40-mm mount. The 2 consoles were wired together so that they could exchange information.

There were 3 gun-firing stations.

The Mod 1 system was designed so that it could be expanded to accommodate ASW weapons and sensors and so that it could accept a data link. This system was installed on board 13 ex-U.S. destroyers of the Taiwan Navy, rebuilt under Weapon-Improvement Program Phase I (*Wu-Jin I*).

Mod 2 (November 1980) is Mod 1 adapted to a 50-m patrol boat. Two were delivered, presumably for the 2 Taiwanese *Lung Chiang* (PSMM Mk 5) patrol boats. This system employed 1 air-search radar (SPS-58) and 1 surface-search radar (LN-66), 1 tracking radar (HR-76), and 1 Mk 35 optical director. Six operators controlled one 76-mm and one 40-mm gun and SSMs. Unlike Mod 0, Mod 2 employed ESM inputs. Mod 2 used 4 minicomputers and 19 microprocessors.

The associated Mod 3 was a land-based system. Five were delivered to Taiwan, beginning in March 1980, to control Hsiung Feng I SSMs. Mod 3 employed 1 surface-search radar, 1 HR-76 tracking radar, and 1 optical director. Three operators (at 1 tracking-and-control console) used 2 minicomputers and 11 microprocessors. This Mod 3 should not be confused with the Modular Combat System (MCS), which is part of the Taiwanese Weapon-Improvement Program III (see below).

This program forced Honeywell to adopt a modular architecture, because of both the overall complexity of the system and the fact that not all ships of the Taiwanese program had the same suites of sensors and weapons.

Modes 1 and 2 were modular, in the sense that each UYK-19 plus its associated sensors and weapons formed a separate building block (module), functionally independent of the others. However, the computers were physically concentrated and, thus, vulnerable. Moreover, particular computers were tied to particular system modules, so that the failure of any 1 computer would knock out an entire module. Reportedly, too, Mod 1 proved unreliable because its computers tended to overheat despite extensive air conditioning of the computer spaces. Overheating may have been exacerbated because all 5 UYK-19s were packaged in 2 consoles. This problem was cured in later versions of the system.

In the Mod 1 and Mod 2 versions, each module consists of a sensor, served by a distributed computing unit (DCU), and a weapon, similarly served, connected through a control console incorporating another DCU (physically, all the DCUs were concentrated in the 2 control consoles, but some of them were more closely associated with particular weapons or sensors).

Because SPS-58 can be set to detect targets automatically, the system can continuously evaluate air targets, processing highly threatening ones automatically. Given 1 target track, the computer typically takes 4 sec to evaluate a second report. If the second is more threatening, the computer takes 10–18 sec to slew onto that new target.

Typically, operators initiate tracking by marking the blip to be tracked on their PPIs; they can also initiate tracking by entering a target's coordinates, range, and speed (to enter a target visible only from some other platform). The tactical coordinator at the command console then assigns weapons. Four weapons-control positions are available: 1 at the optical director, 2 at the ASW/ASU console, and 1 at the AAW console. All of the guns may be controlled from either console, since commands can be transmitted back via the link between the command console and the 2 weapons consoles.

Against a low-flying target, with the HR-76 director initially centered in a 60-deg sector, reaction time from the arrival of the antenna at the designated position (0.75–2 sec after SPS-58 detection) is 6–12.5 sec (10 sec average).

Honeywell produced a third-generation modular combat system in 1978, using H930 Mod 1 hardware repackaged for better survivability and reduced cabling. This Advanced Development Model (ADM) was tested ashore and afloat by the U.S. Navy. It

consisted of 2 modules (control/sensor and weapon) connected by 3 redundant bus cables 300 m long. Later, a third module carrying a television/laser tracker/ranger was added. This is the system tested on board the USS *Moosebrugger*.

From Honeywell's point of view, the important advances in the ADM were the demonstration that physical separation, which would greatly improve survivability, was practical; the demonstration of multiple (again, survivable) data buses; and some advances in standardized packaging of electronics. As in the earlier H930 versions, controls were programmable.

ADM, in turn, was combined with new software for real-time synchronization, ADT, threat ranking, and engagement recommendation software, to form the basis of a fourth-generation system, the Modular Combat System (MCS). In Taiwanese service, H930 MCS has been applied to FRAM *Gearing*-class destroyers rebuilt under Weapon-Improvement Program Phase III (*Wu-jin III*).

In these ships MCS controls the full range of weapons: a 76-mm gun, 2 single 40-mm L70 guns, ASROC ASW missiles, lightweight ASW torpedoes, and SM-1 surface-to-air missiles. The sensors are the Dutch DA-08 air-search radar (with DA-05 antenna), the U.S.-supplied SPS-10/58A, the Westinghouse W-160 tracker radar, the Signaal STIR, a Honeywell-developed electro-optical sensor, a data link, ESM (derived from the Hughes SLQ-31), and a Krupp-Atlas DSQS-21 sonar. The ship



The standard console of the Modular Combat System. (Hughes Ground Systems)

carries a Phalanx close-in gun and supports a torpedo-carrying MD 500 helicopter. The tactical data system may also be adapted to control surface-to-surface missiles. ASW weapons are controlled through a Mk 114 (analog) fire-control system, which was supplied when the ships were transferred by the U.S. Navy.

In this system the control consoles were made physically independent of the weapons and sensors they served. Each console could, in theory, receive data from any sensor, limited only by the software for its own task. Each sensor or weapon had its own associated distributed computing unit (DCU), communicating with the system data bus. Some, but not all, of the DCUs are mounted in the operator consoles.

In such a system the DCUs must be able to function independently yet respond to commands from anywhere in the system. There can be no single controlling element, the failure of which would destroy the system. For example, there can be no single data-bus controller providing synchronizing pulses since it would represent a potential for single-point failure. From a programming or operational point of view, such an architecture permits the easy addition or deletion (e.g., because of battle damage or electronic failure) of any module. It also makes relatively simple the assembly of a system to meet a particular user's requirements. Moreover, since the consoles and sensors and weapons need not be cabled together, some of the consoles can be located relatively far from the others. This possibility was not realized in H930 MCS. However, in its second-flight (modified *Perry*-class) frigates, the Taiwan Navy is providing a secondary CIC in the form of a damage-control central. The damage-control space will be equipped with standard consoles and can, in theory, function as an alternative CIC in the event that the primary CIC is disabled. Presumably, this requirement was formulated as a result of satisfactory experience with H930 Mod 3.

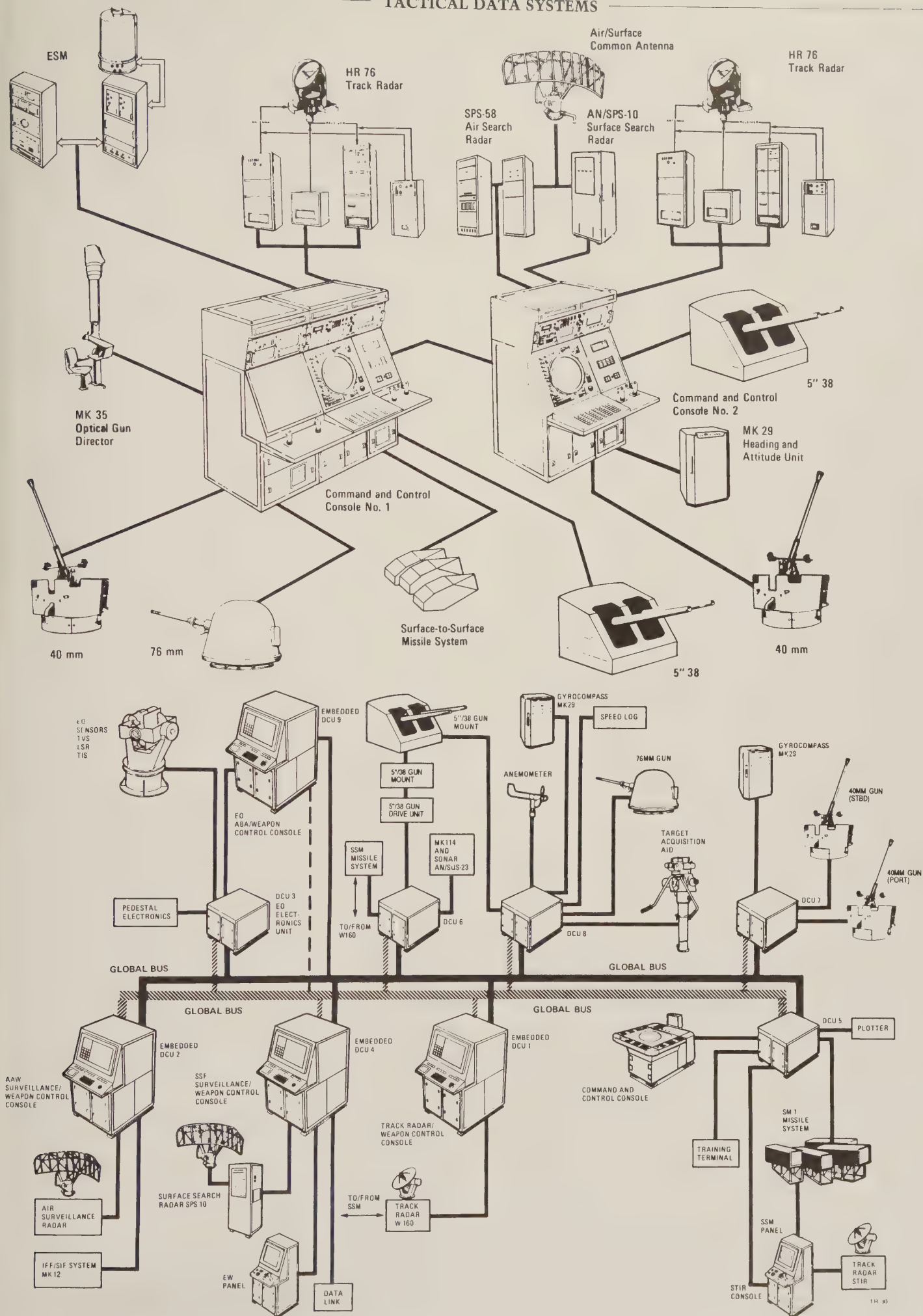
In H930 MCS there are 4 operator consoles (EO/weapons control, AAW/surveillance/weapons control, surface surveillance/weapons control, and track radar/weapons control), plus a horizontal command/control console and a computer-driven plotter. In some cases data are passed through the console into the global bus, but each console can execute any function. Thus, the air-search-radar data and the IFF data pass through the AAW console; EW, surface-search-radar, and data-link data pass through the surface console.

The architectural details that follow apply to all 3 main versions, but particularly to H930 MCS.

Each DCU contains both a resource computer (a UYK-19) and a separate I/O controller (IOC), a microcomputer. The IOC controls communication both with the devices (e.g., sensors or weapons) and with the system (global) bus that connects the DCUs. It periodically moves device data into the resource processor and retrieves computation results from it for processing into messages for the other DCUs. Because the IOC can access the resource computer's memory without the latter's intervention, the resource computer can be programmed with little or no concern for overall system operation. Its program is truly modular; thus, changes in the program have no effects on other parts of the overall system.

This feature had some attractive consequences. Software written for any application can be modified freely for another because such changes do not affect other portions of the system. For example, a standard ballistic program was written using a different set of coefficients for each gun. Such standardization greatly reduces the labor of programming, and it also makes programming errors much less likely. Moreover, changes to adapt to a new gun or a new type of ammunition require only revision of the table of coefficients. The tabular technique also makes it possible for operators to modify system operation relatively simply. For example, threat ranking can be modified by changing a table that weights various parameters describing a particular target. Such modification has no effect on the operation of other programs within the overall system, yet it can greatly change the way the ship reacts to a particular situation.

On a larger scale, modular design makes it easy for the system



Two versions of the H930 system illustrate the transition from distributed to fully modular operation: Mod 1 at top, Mod 4 at bottom. (Hughes Ground Systems)

as a whole to reject particular sources of data or decision. A controlling officer can always decide to vary the degree of automation with which the ship engages targets by affecting such decision-making programs as the threat ranker, whose features can be selectively enabled or disabled. This feature is broadly equivalent to the battle doctrine that the commander of an Aegis ship can insert into the computer system, yet it is probably much easier to change.

The IOC can be programmed in a fully standardized way, subject only to whatever special formats the device data arrive in. The main role of the IOC is to shuttle data within the DCU without overloading the resource computer. The IOC does this in part by maintaining a table of the names, addresses, data requirements, and status of all tasks and interfaces within the DCU. In some cases the IOC itself is used for application, as opposed to communication, tasks. Typically, it extrapolates gun orders to smooth ballistic-computer results into a form suitable for the gun servos. An IOC can also take over tasks from an overloaded resource computer.

Two separate buses, a parallel local bus inside the DCU and a series of serial global buses between DCUs, are used. The local bus is an extension of the internal data bus of the IOC itself. The effect of this architecture is that the IOC has, in effect, a dual-port memory connected simultaneously to the IOC processor and to the global bus. Messages awaiting transmission are stored in fixed positions in IOC memory, whence they can be read by the global-bus interface. Once a message has been read into the global bus, a flag in the message position is reset so that the IOC can enter a new message. Similarly, when the global bus interface senses a message addressed to the DCU, it can interrupt IOC operation. The IOC saves its present data and checks the special message location for a new message.

The designers accepted this degree of complexity to avoid overloading the resource computer. They sought to avoid direct computer-to-computer data transmission so as to avoid locking the DCUs into a rigid pattern susceptible to single-point failure. Hence the importance of the bus, into which each computer sends messages addressed to other computers, either for command or for weapons-control functions. The effect of the architecture is to isolate in each DCU those features particular to, say, a given sensor or weapon, so that what comes out is in a standard message format.

The system architecture avoided the use of any master data-bus controller, which would have represented a potential single point of system failure. Some degree of bus control is, however, essential because messages broadcast simultaneously would collide and become garbled. As in other bus systems, time is divided into slots, and the system has to be designed to provide only 1 message/time slot. However, division has to be done without providing any single master time standard.

In the case of the H930, each DCU is allowed a sequence number. Each message carries a sequence number. Each global-bus interface through which the message passes reads this number and adds to it; the interface has a table showing whether it is allowed to transmit in the next time slot. This arrangement is still not sufficient since a bus interface that fails will fail to increase the sequence number and, thus, will prevent another interface from transmitting. Each bus interface is, therefore, assigned a time-out period, the interval it waits before transmitting in the event the bus is quiet. Since the intervals are staggered, the unit with the shortest time-out period will automatically transmit (and restart the cycle) if several bus units cease to operate, or if the system is shut down and then restarted.

Each DCU is also provided with a real-time clock. Timing signals are important for many calculations, e.g., of target motion. Data sent to other DCUs must be timed because the purpose of the system is to provide useful dynamic data. The system clocks should, therefore, be synchronized. Again, no master clock can be provided. The solution adopted in the H930 is to include a clock time of transmission in each message. Upon receiving the message, a DCU resets its own clock to match.

Distances within the system are so short that transmission can be considered instantaneous.

Each message contains start and stop markers, a functional address (so a particular DCU can decide whether it wants to read the message, which is broadcast throughout the bus), an access vector, a word count, the data itself, a real-time clock value, and a cycle redundancy code. Message length is variable (hence the start and stop markers), up to 128 16-bit words.

Typically, 2 modules (a tracker and a missile launcher, plus 2 DCUs) can be connected to a third DCU in a common control console. In a more elaborate system, a surface-search radar, a Mk 35 optical director, and a hull-mounted sonar might all feed 1 control console, which might use their data to control antiship guns, torpedo tubes, and an antiship missile. Such a network would, in turn, be connected to a command/control console, which would be used for battle command. That console might simultaneously control another network, consisting of an air-search radar, a weapons-assignment console, an antiaircraft gun, and an antiaircraft missile. In principle, because all of the sensors feed data into all of the control consoles, any weapon can engage any target detected by any sensor. In theory, too, because much of the data generated by any sensor is processed at that sensor (by a DCU), reaction time should be very short.

Throughout, the driving philosophy was that the system should exploit the falling cost of computing, going from centralized to distributed architecture. Honeywell argued that, because the resource computers did not have to handle communications (bus) processing, overall system computing power increased in proportion to the number of the resource processors. A more tightly linked system devotes an increasing percentage of the power of each main computer to communication as it grows. In the H930 the bottleneck on system power is bus capacity. The system has 2 redundant global buses, each of which has a capacity of about 2.5 Mbits/sec. Special measures were taken to reduce message traffic, so as to remain inside this limit. Data on the bus are, in effect, filtered because much of the processing occurs in the DCUs located between sensors and bus. Typically, the global bus handles 20 messages/sec, and it is shielded from more than 100 messages/sec.

For example, radars deal with an enormous mass of information. However, an ADT radar reduces that mass of echoes to quite simple messages about the position and course of a given target. Tracking radars present special problems because in theory they generate data at about their PRF, which may be several thousand Hz. In this case radar data are transmitted directly into the appropriate resource processor, which generates the appropriate tracker-control signals digitally. The processor also smooths the corresponding pointing data, transmitting smoothed data to the system as a whole at the rate of 10–20 points/sec, a rate adequate for ballistic or missile-guidance calculation. The computations in turn are extrapolated (to a rate of 100/sec) to keep guns and missiles smoothly pointed. Admittedly, this smoothing adds complexity since the radar's processing computer could connect directly to the servos and provide quite sufficient data without any intermediate computation. However, the advantage of the modularity is so great, and the price of the additional computation so low, that it is acceptable. Presumably, it would become less acceptable were the system faced with much faster (and much more violently maneuvering) targets.

Mod 3 was designed to accommodate upgrades. Honeywell (and then Hughes) tested a 4-DCU system. The operating system as a whole has been rewritten to accommodate ADA software (it was originally written in ALGOL), and 1 ADA DCU was incorporated into the test system. In addition, 1 of the 4 DCUs had its processor replaced by the processor of the more powerful ROLM 1666 (the new processor is designated ROLM 1822). The new processor is about 5 times faster than the existing unit and has 16 times the memory capacity. Yet it occupies a circuit board compatible with those of the earlier Mod 3 system and, thus, can be used to upgrade existing ships.

As of late 1987 Honeywell planned to continue development

of MCS, to include several functions previously not completely integrated into the system:

- real-time data-link processing, for multiship operations
- separate operator stations for warfare area controllers, sensor supervisor, and emergency CIC backup
- integrated ASW capability with aircraft control, sonobuoy processing, complete underwater-situation display, and control of on-board ASW weapons (which at present are still controlled through the Mk 114)
- interactive automatic operation with IFF and ESM
- expanded capabilities for triangulation, navigation, and collision avoidance.

The current ACS (Advanced Combat System) or MCS 2000 effort goes further. It includes a new and much more powerful data bus, with a capacity of about 100 Mbit/sec, compared to the 10 Mbit/sec Ethernet standard in most systems.

◆ Litton System for Korea

In July 1989 Korea awarded the Litton Data Systems Division a contract for a naval tactical command/control system to provide automated contact between a shore command facility and a deployed patrol craft. The Korean subcontractor is Samsung, which already manufactures the Ferranti WAS 423 system. No details of the system are available, but it is apparently similar to a land-based command/control system, TYQ-23, which is used to control tactical aircraft. The marines will use it to replace the Marine Tactical Data System (MTDS), which in turn is compatible with NTDS. The current TYQ-23 computer is the 16-bit AYK-14 (2 are used in parallel), although Litton hopes to replace it with a 32-bit computer programmed in ADA, with 6 times the AYK-14 performance. Litton has an in-house project to add raster-scan (rather than cursive) displays.

The shipboard terminal of the Korean system is probably the Litton Tactical Display Console (TDC), which the company advertises for air, land, and sea applications. Because it was originally designed for applications such as the MTDS replacement, the TDC is designed to receive information on 1 link and transmit it on a different type of link (the marines must use both NTDS and land-oriented data). Thus, it can act as a gateway between link nets. The TDC achieves this type of performance by providing multiple track-reporting interfaces, the track picture itself being carried by the console computer (global memory).

The TDC has a 19-in color display incorporating a transparent touch panel (TTP). Such construction entirely eliminates the need for trackballs, joysticks, or light pens. Internally, the global memory and graphics controller feed into a VME bus, which in turn feeds the system-control and situation-control (i.e., data-filtering) processors and the interface- and link-control processors. Range scales are 2–2000 nm, and the console can carry 1024 tracks. The console is designed to grow to accept a 25-in color monitor.

The TYQ-23 contract was awarded in May 1987.

The first installations will be on board Korean frigates. The same Litton TDC, with its 19-in (1028 × 1028-pixel) display, is a TADIL-A (Link 11) receive-only terminal on board the battleship *Iowa*, where it also drives a large-screen display and 2 remote monitors.

DISPLAYS

◆ NTDS Displays

The current standard is the Hughes UYA-4, which replaced the earlier SYA-4; the UYA-4, in turn, is being superseded by the Hughes UYQ-21. UYQ-21 is also the standard display for several other systems.

SYA-4 was the first production NTDS console, designed about 1960. It employed discrete semiconductor technology. The first NTDS systems had switchboards that could address 15 SYA-4 terminals. The single-CRT console has a rotary switch for 22 operating modes. The basic console function is radar-target de-

tection. SYA-4 as a whole consists of the display consoles, special-purpose readouts, radar-azimuth-conversion equipment (the SYA-4 system converts ship-centered polar coordinates, in which radar targets are detected, into NTDS-oriented rectangular coordinates), a radar-data switchboard, a pulse amplifier, and a symbol generator. Each CRT console is accompanied by a separate console to display alphanumeric data (see below). System control (weapons coordination) requires a second type of console.

UYA-4 (designed about 1965) introduced integrated circuitry; only 1 type of console was required. The single console is designated OJ-194/UYA-4. Each console has 18 variable-action buttons (VABs) but also 6 fixed-action buttons, so that each VAB can adopt up to 48 labels. Similar variety on an SYA-4 console required entry of a function code by dialing. The OA-7079(V)10/UYA-4 console that immediately preceded OJ-194 has a roller mechanism, for 30 operating modes. OJ-194 has 45 operating modes. The system as a whole has 16 radio channels, compared to the 10 of the earlier SYA-4.

UYA-4 includes a large-screen (20-in) horizontal summary console, originally OA-7981 and then OJ-195/197. OA-7981 has an internal memory (4k 30-bit words). OJ-195 has an improved display, and OJ-197 has 18 VABs (48 labels) and 6 fixed-function buttons in place of the action entry panel and rollerball of the earlier console.

The system also employs an OA-7980 height-finding console, with 3 × 5-in CRTs (2 for height, 1 for raid size estimation). One CRT shows targets within selectable bearing gates (3, 6, 11, 22 deg), the other targets within selectable range gates of 4, 16, 32, and 64 nm. Each can call up a track by number and can show either full altitude scale (100,000 ft) or low altitude (30,000 ft). The raid-count CRT has selectable range gates (4, 8, 16 nm), azimuth lines (7, 15, 31, 63 deg), and bearing gates (3, 6, 11, 22 deg). Multiple CRTs are needed because the associated radar operates in 3 dimensions, not the 2 of a single CRT.

With the CIGARS (Console Internal Generation and Refresh System) field change, OJ-194 can create 1000 separate graphic symbols and also has much better ability to generate circles. The CRT is 12 in in diameter, and its minimum range scale is 1 nm.

Pre-CIGARS consoles have no internal memory capacity. In their case the UYA-4 system includes a refresh memory unit (RMU), which actually produces the successive screen images at a refresh rate of 15/sec, for flicker-free presentation, via a central pulse amplifier/symbol generator (CPA/SG). All UYA-4s include the CPA, which has 2 input and 2 output channels. Each channel can drive 15 consoles. Thus, 2 computers can drive 2 groups of up to 15 consoles each, and they can switch between the 2.

UYA-4 also includes a radar azimuth converter, CV-2095/UYA-4, for each radar, converting analog range and bearing data to digital form suitable for display on the digitally controlled consoles; the converters also produce the range marks used by the consoles.

A version of the OJ-194 console with CIGARS serves as the display of the SPS-48 and -52C radars. The display is computer driven, and it provides the operator with descriptions, such as land clutter or jamming, automatically selecting the best possible fix.

A full NTDS/WDS installation incorporates 2 separate types of operator console, 1 (with a single CRT) for data input or data utilization, and 1 (with 3 smaller CRTs in parallel) for height/size display. The latter, OA-7890/UYA-4, is used to evaluate and supply target height and raid size; 2 CRTs are range-height indicators, and the third is a size-analysis indicator. The main CRTs are PPIs with a maximum range of 512 nm. In early versions of UYA-4, as in SYA-4, each is associated with a separate readout console, carrying a square CRT and providing alphanumeric data on track number, IFF (SIF) code, track bearing and height, track range and speed, threat evaluation, interceptor data, and weapons recommendations. The OJ-194 console combines the 2 CRTs in 1.

Each single-CRT console can function in several data input modes:

Air Detector/Tracker (DET/TK) Each operator is assigned a specific sector, e.g., 60-deg wide, out to 128 nm; the operator detects (inputs into NTDS) all observed contacts and tracks them (monitors NTDS tracking). The number of consoles assigned to this role varies with the level of air activity. Friendly aircraft are automatically tracked by a Beacon Video Processor (BVP) using their Mode II IFF responses. In principle, a detector/tracker first enters a contact as a tentative plot (not transmitted to other ships via Link 11); the ID operator checks to see whether it is friendly. On a second radar sweep, the plot is refreshed, and the computer uses the 2 points to establish target course and speed. On the third update, the computer begins to carry the contact as an unknown; the track supervisor is responsible for ensuring that it is not a contact already carried by another ship in the group.

Surface Tracker (SURF) This tracker also sees the low-altitude air picture. The PPI is set on a shorter-range scale.

Identification Operator (ID) This operator assigns the identification symbol (friendly, unknown, enemy) to a track. The NTDS symbology makes no allowance for neutral targets.

ECM Supervisor (EC) This supervisor evaluates ECM raid reports, enters this information into the computer, and sends it via the data links.

Special Tracker (SPL-TK) This tracker provides high-precision data on a limited number of tracks for insertion into the associated WDS; the PPI is set on a 4-mile-range scale.

Track Supervisor (TK Sup) This supervisor monitors the system operators. The TK Sup assigns sectors to the detector trackers, supervises the height/size operator, corrects confused track situations, removes tracks when appropriate, supervises the communication keyset, ensures the accuracy of geographical position data, and can assist the ID operator. This role is equivalent to the "picture editor" in some Israeli systems.

Similarly, there are several data-utilization modes:

Ship's Weapons Coordinator (SWC) The SWC is the primary assistant to the Ship's Evaluator (the supervising officer in CIC). The SWC interrogates the NTDS computer to choose an optimum weapon, orders and initiates engagements, and orders hold-fire or cease-fire.

Intercept Controller (IC)

Air-Traffic Controller (ATC) The ATC is on carriers only.

Flag Mode on flagships This mode provides the embarked unit commander with a summary tactical plot.

Fire-Control Systems Coordinator (FCSC) The FCSC is for ships with embedded WDSs. The FCSC, the ship's fire-control officer, receives missile assignments from the SWC, decides which missile fire-control system to employ against a specific target, initiates interdirector designation, coordinates optical designation, and enters fire-control and weapons status into the NTDS computer. If a target is in the blind zone of a fire-control radar, the FCSC recommends a course to clear the director.

Engagement Controller (EC) The EC is for ships with embedded WDSs. The EC, the ship's missile officer, is under the FCSC and sends orders to the missile system (e.g., type of missile), ensuring that the target is not in the launcher's blind zone.

The full NTDS system also includes 4 keysets to input information into the computer: navigation (own-ship position), aircraft data (CAP data: e.g., type of aircraft, weapon load out, fuel state), ECCM (characteristics of intercepted transmissions, including bearings), and communications (identifies other ships in the Link nets, allows the TK Sup to send transmitting instructions to the NTDS computer).

A full NTDS/WDS includes a separate weapons-control panel, generally flanked by the FCS and EC consoles, providing the

means to observe and manually control data flow between the computer and the fire-control launching systems. There is also a casualty weapons-direction panel (CWDP) in the missile-director control room, providing backup in the event that the NTDS computer fails. The CWDP can select missile mode (AA or surface), can designate from director to director, and can warm up and fire missiles.

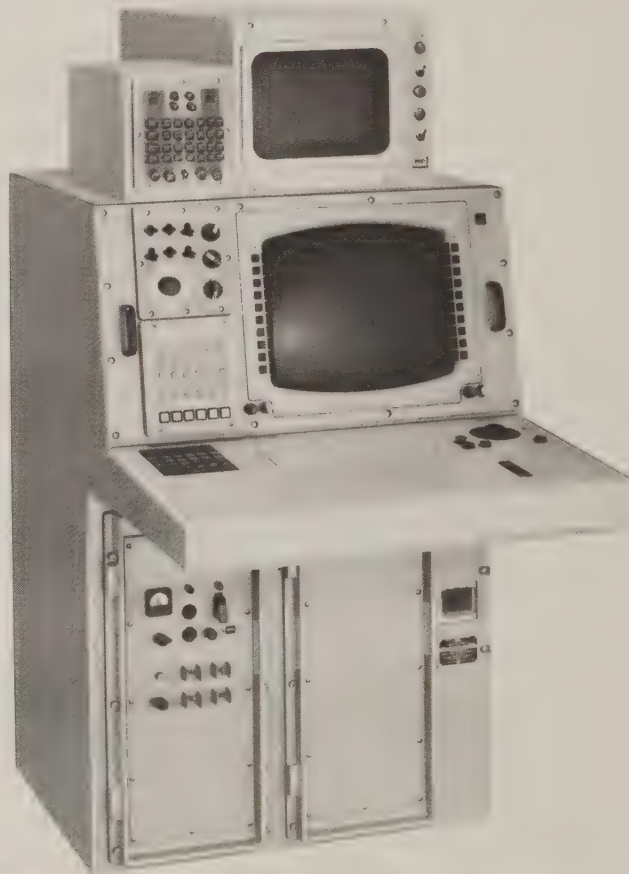
These modes of operation are typical of any pre-Aegis NTDS system.

UYQ-21 is the current multipurpose display system. Hughes consoles within the system are OJ-451/452 and OJ-535; see also the AVP (OJ-653), below. The system also includes the PT-525 liquid crystal projector described below, with an OJ-471 controller. UYQ-21 can display 256 unique shapes (64 alphanumeric, 128 tactical symbols, and 32 symbol modifiers, plus 32 computer-programmable symbols). Symbols can appear in multiple sizes and intensities, and they can be made to blink to emphasize them. Lines are point to point, velocity vectors, and connected segments. The system can also generate circles, ellipses, and arcs in any size or orientation.

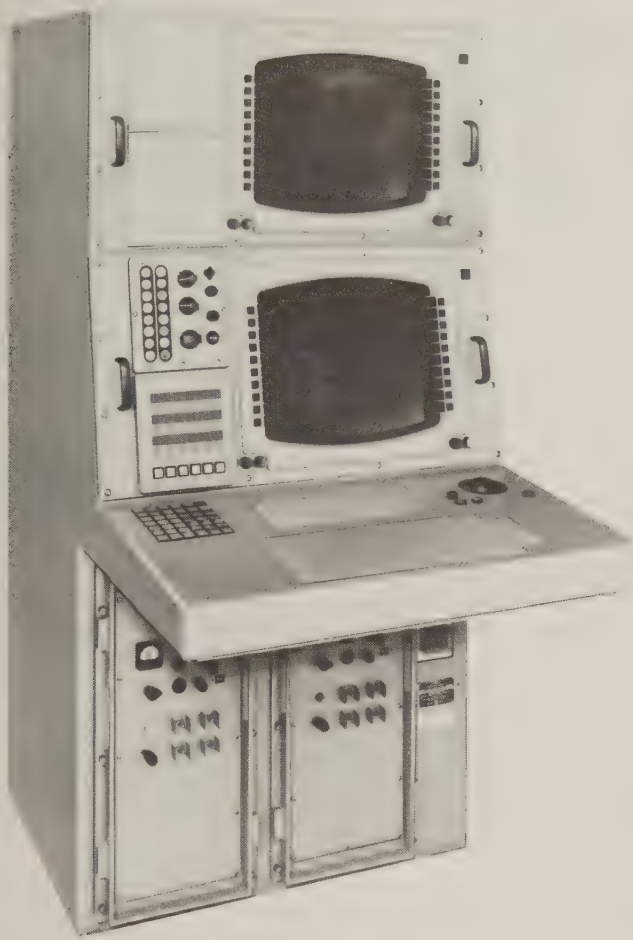
OJ-451 is a high-resolution stroke-writing (cursive) console. It is used to display synthetic video in systems employing a central data buffer. The console can also display raw video. An OJ-451 basic display unit (BDU) has a 13 × 11-in CRT (1024 × 800 or 1024 × 1024 pixels). Spot size is 0.010 in. Contrast ratio is 5:1 (3 bits/pixel).

OJ-451 is used in Aegis systems and in recent NTDS installations.

OJ-452 is a 2-screen acoustic console, displaying both synthetic video and raster-format video. Each CRT has its own acoustic display generator (ADG: CV-3550). The ADG can accommodate up to 2 Mbits of memory/CRT to refresh the acoustic data display. Contrast ratio is 12:1 (4 bits/pixel). Among



OJ-451 console with auxiliary monitor on top. Versions of this console can be used with either the UYA-4 or the UYQ-21 NTDS display systems. (Hughes Ground Systems)



OJ-452 acoustic console. (Hughes Ground Systems)

other ASW applications, OJ-452 is used in shipboard LAMPS installations.

OJ-535 is an alternative monitor, for systems employing digital-television (DTV) technology, which includes raster-scan radars. It is the high-resolution raster-scan (1280×1024 or 1024×1024 pixels, selectable on the front panel) display of the system, measuring 13×11 in. Minimum range scale is $\frac{1}{2}$ nm. Current consoles are monochrome, but 3-color units are replacing them. Up to 4000 characters can be displayed. The console has 5 input channels, 3 for composite video and 2 for composite or noncomposite video.

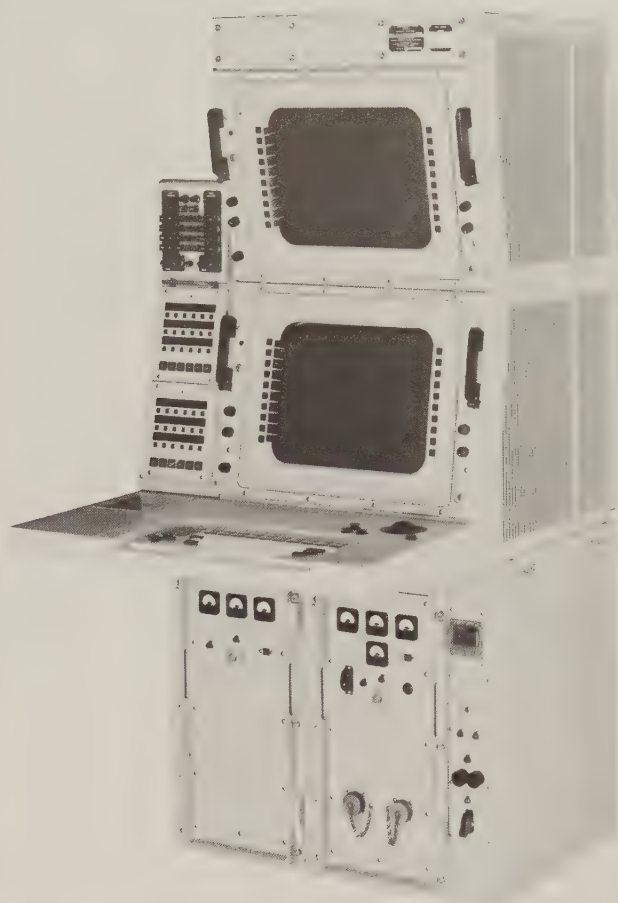
OJ-535 is used in cruiser and carrier CDSs (non-Aegis).

OJ-451 and OJ-535 exist both in single-screen versions and in versions with auxiliary CRTs (IP-1357) above the main screen. OJ-535 also exists in a dual-CRT version (the CRTs are stacked vertically). In this case the upper CRT is rotated 180° to provide the operator with an optimum viewing angle.

The 12-in auxiliary CRT is used for alphanumeric readout (2048 characters in a 64-character font); it can also display 525-line video.

The consoles are all equipped with keyboards, with trackballs, with a computer-controlled action entry panel (3×6 switches), with 20 variable function keys, and with a separate 6×7 array alongside the keyboard.

Aegis ships and some others now have large-screen projection displays, PT-525/UYQ-21, as part of their UYQ-21 display systems. Aegis cruisers have 4 projection displays; Aegis destroyers (Arleigh Burke class) each have 2. Large-screen displays are also being installed on board carriers, as part of their TFCCs (2 each), and on board some classes of NTDS ships: 1 each on board Leahy- and Belknap-class cruisers (but 2 on board the flagship, Belknap, for installation in FY93), 2 each on board the Virginia-



OJ-535(V)3 double-monitor console. (Hughes Ground Systems)

and California-class nuclear cruisers; 2 each on board Kidd-class missile destroyers (for installation in FY97-98); and 4 each on board Wasp-class amphibious carriers (LHDs). As of early 1990, installation had been completed on board the carriers Saratoga, Independence, Kitty Hawk, America, Nimitz, Dwight D.



OJ-535(V) single-monitor version. (Hughes Ground Systems)

Eisenhower, Theodore Roosevelt, and Abraham Lincoln and on board the cruiser *Richmond K. Turner*. The FY90 program calls for installation on board the cruisers *Gridley* and *Fox*. FY91 includes the cruisers *Reeves*, *Wainwright*, *William H. Standley*, and *California* and the carriers *Constellation* and *Carl Vinson*. FY92 installations are the cruisers *Josephus Daniels*, *Sterett*, and *South Carolina*.

Installation was scheduled for the battleships *Iowa* and *New Jersey* (for FY92), prior to the decision to lay them up, their screens will presumably go on board their sister ships.

The PT-525 liquid-crystal projector is driven by a digital television-signal generator, CV-3582, which processes computer output. One generator drawer suffices for 4 channels, as in Aegis cruisers. The generator provides 1024 × 1024 pixel resolution. Projection can be vertical or horizontal; in a CIC, the projector is generally located behind the large display screen. The typical image size is a 42-in square.

◆ Advanced Video Processor (AVP)(OJ-653/UYQ-21)

Developed by Diagnostic/Retrieval Systems, AVP is an addition to a UYQ-21 display system. The initial application is to the SQQ-89, but the manufacturer expects the AVP to become the standard U.S. Navy color display. Future versions may have single CRTs. The CRT is a 1280 pixel × 1024 line, color, raster display (30 frames/sec in interlaced mode, 60 frames/sec in a noninterlaced mode), expandable to over 2000 lines. Video bandwidth, which determines display information content, is 120 MHz. The current production version, for SQQ-89, has 2

CRTs mounted vertically. AVP can emulate the current UYQ-21 NTDS display but can also display specialized graphics.

The AVP is built around a standard VME bus. The embedded host processor uses a 32-bit 68020 chip with a 68881 coprocessor; memory is 1 Mbyte of ROM/PROM (for program software), 32 kbytes of fast read/write memory, and 4 Mbytes of data memory. The separate graphics processor has 256 preset characters, plus 512 software-defined characters, with 4 sizes/font. The graphic acoustics processor has a throughput of 5 Mflops (expandable), with a pipelined architecture; it provides 110,000 10-pixel vectors/sec/screen. The associated image memory is 8M pixels, in 256 colors and 256 shades of gray (24-bit planes). Claimed MTBF is 3000 hrs (15-min MTTR).

Full-scale engineering development of the AVP began under the FY88 program, with a production decision due in FY90.

◆ CWS (Color Workstation)(OJ-666(V)/USQ-88(V))

The Raytheon CWS is a "smart" display and, thus, halfway between an adjunct to a command/control system and a stand-alone data processor. CWS was the first high-performance color graphics workstation bought by the U.S. Navy, and its first planned application was to the Flag Display Data System (FDDS), part of the TFCC described above. However, the CWS contract for FDDS was canceled, and DTC 2 computers were bought instead. CWS is derived from Raytheon's experience with UYQ-31.

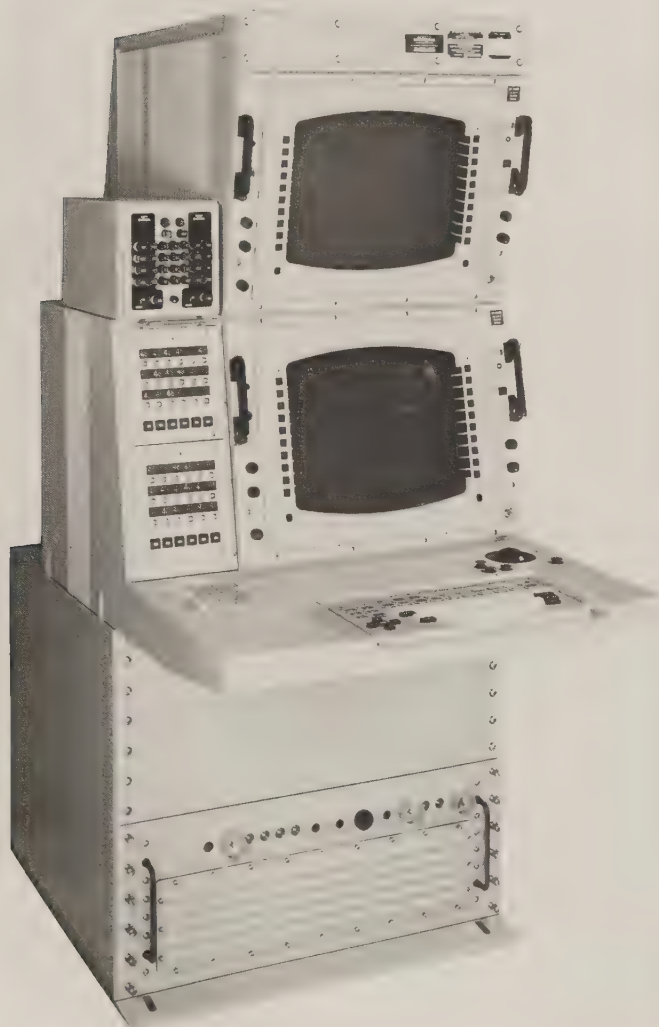
As of the spring of 1989, 108 units were on order, with options for another 159. Current applications include ATACMS and the JSIPS (Joint Services Imagery Processing System). CWS was ordered for TFCC but was rejected in favor of DTCs.

The standard CWS cabinet accommodates 2 color, 19-in, 1280 pixel × 1024 line, raster-scan monitors, driven by a Silicon Graphics IRIS geometry engine and a new variable-line-rate display controller. The same hardware can accommodate several alternative monitors: 20 × 20 in (2048 × 2048 pixels, used by the FAA for ATC), 13-in (diagonal: 1280 × 1024 pixels, a smaller version of the standard 19-in color display), 17-in diagonal monochrome (1280 × 1024 pixels, standard in the UYQ-21 series), and 10 × 10 in monochrome (1024 × 1024 pixels). Computer capacity suffices to drive a 2048 × 2048-pixel monitor at 60 frames/sec, i.e., more than 240M pixels/sec. Special software avoids the usual jagged edges of monitor images by modulating adjacent pixels, at a rate of up to 40M pixels/sec.

A 16-bit, local-display, processor bus provides intermodule command and diagnostic communications. A parallel high-speed data path connects the display processor, the geometry engine, the image-memory-update processor (IMUP), and the refresh-memory/video generators (RM/VG). The display processor, built around a 68020 chip, translates functions written in high-level language into data and control words for the remainder of the hardware. The display processor makes it possible for application programs to be written in terms of user-defined world coordinates. It also stores the external data display list and accommodates serial I/O ports.

The graphics engine translates and scales the user-defined "world" boundaries and coordinates into a form suitable for display in the pixels of the monitor(s); it also preprocesses data for the IMUP. The IMUP converts graphics instructions and data into address and data patterns required to plot every pixel into memory. For example, it fills in pixels between boundaries and between vector end points. Finally, the RM/VG stores 2 frames of video data (1 display, 1 refresh) for each monitor. It feeds directly into the display monitor, converting digital pixel data into analog data suitable for display and monitoring screen refreshment and synchronization. One RM/VG drives 1 monitor; the CWS can accommodate up to 8 of them, all on a high-capacity (30-Mbyte/sec), 64-bit, image-processing bus fed by the image generators (the IMUP and the geometry engine). Thus, the CWS can drive up to 8 monitors. Five RM/VGs can be fitted into the CWS backplane.

There are 3 types. A 2K RM/VG drives the highest-resolution display (2048 × 2048 pixels). The 1K version drives a 1280 ×



The Advanced Video Processor (AVP), OJ-653/UYQ-21. This example contains an acoustic video processor (behind the cooling vents) in its bottom. (Diagnostic Retrieval)

1240-pixel color monitor or two 1024 × 1024-pixel color monitors; the 0.5K version drives a 640 × 480-pixel display. The RM/VGs use 256k-image memory chips and store 8 bits/pixel. The video-generator portion of the RM/VG contains a 256 × 24-bit color look-up table and either three 8-bit 360-MHz (2K-version), three 8-bit 125-MHz (1K-version), or four 8-bit 64-MHz (0.5K-version) digital-to-analog converters. A total of 256 colors can be selected from a palette of 16 million.

The graphics engine has a large number of special-purpose VLSI chips to perform 2/3D geometric transformations, with a throughput of more than 80,000 floating-point coordinates/sec.

The display processor itself is fed by a 32-bit, 10-Mbyte/sec bus, to which are connected I/O modules, up to 3 separate (and parallel) application processors, a video formatter, and a digital scan converter. Each I/O module has its own 68020 local processor. As of 1990, CWS can accommodate NTDS E, MIL-STD-1553B, and ESDI disk I/O; the design can accommodate the new Safenet (see the entry on the NGCR computer system) and Mil-188C. The video formatter is used to receive and process digital raster-oriented radar or sonar data. It scrolls and waterfalls A-scan data and preprocesses A-scan data for display. The digital scan converter performs analogous processing of analog PPI radar signals; it offers variable range scales, offsets, target aging (i.e., it can store subsequent target positions), sweep correlation, and scan integration. Because analog radar video is converted into pixel form, graphics/texts can be superimposed on it.

The video formatter and the digital scan converter also connect directly to the image bus.

The application processor is built around a 68020 running at 16 MHz; it also contains 0.5 Mbytes of PROM, 12 Mbytes of read/write memory (RAM), 3 timers, a DMA controller, a floating-point math coprocessor, and 5 serial interfaces for external inputs.

Thus, the basic CWS accommodates four 68020 processors, 1 in the display processor and 3 in separate application processors. They run at a throughput of 2 MIPS. Each has 12 Mbytes of memory. An enhanced configuration uses dual 32-bit 68020s, each with 24 Mbytes of memory, with dual 160-Mbyte hard-disk drives. The 3 applications processors can be replaced by 15-MIPS RISC-based devices (using Motorola 88000 chips).

CWS was initially developed for the Federal Aviation Administration's Advanced Automation System, using a 2048 × 2048-pixel, high-resolution, color display (1984-85); meanwhile, Silicon Graphics developed a high-speed graphics processor and related software. Mil-spec packaging and display firmware were developed in 1986-88.

◆ ACWS/AMW/BSY-2 Console

Librascope's Advanced Color Work Station (ACWS) and Advanced Multifunction Workstation (AMW) were displayed at the U.S. Navy League show in April 1990. ACWS is the display of the Kollmorgen nonpenetrating periscope now under development. The 2 workstations are very similar; AMW is a growth version of ACWS. The periscope console has 2 CRTs and 2 image processors (forming 2 image channels for the 2 cameras of the periscope). The console includes image postprocessing. For example, the image produced by a FLIR in fog can be intensified using a pixel-by-pixel processor.

ACWS is available in both single- and dual-screen (vertically stacked) versions, in each case with 19-in (1280 × 1024 pixel, refreshed at 60 Hz) CRTs. It is built around a 32-bit VME bus, which normally carries a display processor (a Motorola 68020), a display memory, and a graphics engine feeding the screen(s). The bus can also carry a hard or optical disk, an applications processor (another 68020, which can be supplemented by an array processor), and a man-machine interface processor (a third 68020 handles input devices: keyboard, joystick, trackballs, electroluminescent touch screen, digitizing tablet, and audio inputs). The ACWS can digitize up to 3 separate analog video inputs, which enter via its graphics engine.

Each display/applications processor carries 4 Mbytes of memory and operates at 2 MIPS (100 kFLOPS).



The Librascope Advanced Color Workstation (ACWS). (Librascope)

The graphics engine uses a 68020 I/O processor, a 12-MIPS display list processor, and a 20-MFLOPS array processor; its image generator is a separate high-speed ASIC processor. It can calculate 1M (10 pixel) vectors/sec, 27M pixels/sec, 50,000 flat shaded polygons/sec, or 60,000 5 × 7 characters/sec. It can erase a full screen in 150 microsec, and it can support pan, zoom, and scroll functions on the screen at a rate of 24 frames/sec. There are 2 color (red-green-blue) output channels, each of which can have up to 12 bit planes (for overlays) and each of which can be drawn using a 4096-color palette (i.e., 12 bits/pixel). The engine can accommodate an optional shading processor. Radar and sonar sweep converters are available.

AMW is a growth version with an array processor, a real-time relational data-base manager, and an image processor (ACWS has only the image processor); the chassis can accommodate 3 processors. The array processor will provide sufficient capacity to display active sonar and radar data; to enhance active sonar, radar, and optronic data; and to generate 3D presentations of the acoustic environment (e.g., ray traces), mine fields, navigational aids, and weapons trajectories. AMW is also somewhat more application- (or engineering-) oriented than ACWS.

Like ACWS, AMW is built around a VME bus with 34 slots. Typically, it accommodates relational processor(s) with associated 28-Mbyte RAM, plus array processor(s) with their associated RAM, plus 150 Mbytes of hard disks. The relational processor can store and sort its 28 Mbytes 1000 times faster than a 68020-based software system. The array processor operates at 25 MFLOPS, for parallel processing of sonar, radar, or optronic data. These are in addition to application processor(s), each with 4 Mbytes of RAM, and a graphics processor.

The graphics processor is much more powerful than that of the ACWS. It consists of up to 6 types of elements, each of them connected both to the VME bus and to a separate picture element bus: frame grabber(s), a display list processor, a display list memory, hardware vector generator(s), and bit-map (frame-refresh) memories/display output processors. The latter interact with the two 1280 × 1024-pixel (60 frames/sec) touch-interactive (using IR with 1/8 the resolution of the monitor) color CRTs, which also connect with the applications processor. The optional frame grabbers convert standard composite video to 640 × 480 (8-bit monochrome or 12-bit color)-element images

for input to the display-refresh memories, which actually feed the monitors. Images are processed at 30 frames/sec. The bit maps have 4–16 planes/monitor, which can be overlaid with 4-bit plane/16 color transparent annotations.

CRT graphics capability is similar to that in the ACWS.

The operator panel provides fixed function keys, programmable keys, a typewriter keyboard, track marbles (trackballs), and a 512×256 -element electroluminescent touch screen.

The BSY-2 submarine combat system uses a simplified version of ACWS with only a single graphics engine. However, the chassis allows for later growth.

◆ MRCS

UNISYS's Militarized Reconfigurable Console System is its VME-based intelligent console, presumably based in part on experience gained with the *Kanaris* project (see the Antisubmarine Warfare section). The console has 12 slots for 68020/68881-based processors (up to 4 on the bus) and can accommodate 4–24 Mbytes of RAM. Processing speeds can be up to 6 MIPS. The bus can also accommodate up to four 68020-based I/O processors and up to 12 interfaces. The embedded graphics generator supports 2 independent monitor drivers (4 graphics planes, expandable to 8, per driver) with 16 colors (expandable to 256). It can generate 50,000 vectors and 5000 characters/sec, and the hardware incorporates a cursor generator. Resolutions: 768×1024 , 1024×1024 , and 1024×1280 . Dimensions (single monitor): $53 \times 26 \times 55$ in, 725 lb.

◆ Multifunction Workstation

The Rockwell (Autonetics Marine Division) workstation, announced in 1990, is an offshoot of the OJ-564 console used in the SOSUS system. It is included here (rather than under ASW) because it seems to fit the same basic requirement as the Raytheon CWS and the Librascope ACWS. The French Navy has ordered a half-height version and the associated cabinet. Like the other workstations described here, the Rockwell unit is built around a VME bus (backplane), which can accommodate standard cards for functions such as analog-to-digital conversion and video processing boards. The basic workstation contains a 1-channel processor but can accommodate a beam-former.

Although the workstation has 2 monitors, it can display 4 video channels simultaneously by windowing; it accommodates 2 separate video buses, each of which can be fed by 2 video channels. The graphics engines are Sun Windows with enhanced throughput (a polygon can be filled at the rate of about 25M pixels/sec, and 200,000+ vectors/sec can be generated). The video channels can accommodate 256 colors and have a bandwidth of more than 100 MHz; they produce 60 frames/sec without interlacing. Displays are 16 or 19 in (diagonal) or 20×20 in, with resolution of 1280×1024 , 2048×2048 , or 2048×1536 . They can be color or monochrome. Each monitor has 4, 8, or 24 memory planes.

A diagram of workstation architecture shows 4 main buses feeding the VME bus: a CPU bus, an array processor bus, and 2 video buses; the VME bus also carries RAM, an operator interface, and a controller with its own disk memory. The CPU (a 68020 with a 68881 coprocessor) carries 4 Mbytes of RAM, and the system can accommodate a 12-Mbyte RAM card. Available operator interfaces include a keyboard, a trackball, track marbles, a joystick, a stiff stick, a light pen, a mouse, hard and soft (programmable) function keys, and a flat touch panel. The console accepts up to 18 channels of RS-232 I/O, and it can accommodate a 344-Mbyte hard disk.

Dimensions: $75 \times 22 \times 48$ in (fits a 24-in hatch); weight is less than 500 lbs.

Rockwell offers a related single-monitor acoustic processor. One application is a specialized torpedo alert processor (TAS), which is fed by existing acoustic sensors and which provides an audible alarm as well as a CRT display. TAS shares unique software and special hardware (acoustic display, spectrum analyzer, and beam-former) with other Rockwell acoustic processors.

◆ SPA-25, SPA-50, and Other Radar Displays

SPA-25 and SPA-50 are the standard U.S. raw-video radar repeaters, superseding the earlier SPA-4. The earliest version dates from the mid-1960s. The chief current version is SPA-25F, a horizontal or vertical 10-in, digital, solid-state PPI. SPA-25G (see below) is a very different and much more capable replacement and, thus, merits separate treatment.

In SPA-25F displayed range is $\frac{1}{2}$ –300 nm, with $\frac{1}{4}$, $\frac{1}{2}$, 1, 2, 5, 10, 20, and 50 nm range rings. The range strobe can be used to read off ranges within 0.03%, and resolution is 10 yd below 50 nm and 0.1 nm above 50 nm. LED readouts show bearing and range of strobed targets (range in nm and yd). The display can accept radar signals at 10–5000 pps, with widths of 0.3–25 microsec and a scan rate of up to 60 rpm. This display can function either as a conventional PPI or as a range-height indicator for 3D radars. SPA-25 can be connected to a dead-reckoning unit that offsets its sweep (so that the radar shows something approximating true rather than relative motion). MTBF is 4000 hr (MTTR 20 min).

SPA-25 is often used alongside SPA-50, which is generally similar except that its CRT is about twice as large (22 in in diameter). SPA-25 accepts PRFs between 15 and 5000 pps. There is also a smaller-diameter PPI, SPA-18 (7-in screen, range scale 2–30 nm, PRFs 57–3000).

SPA-18, -25, and -50 were generally used with surface-search radars. They succeeded an earlier SPA-4 (10-in PPI, 140–3000 pps, range scale 1–300 nm). The contemporary air-search repeaters were SPA-8, -33, -34, -40, -41, -43, -59, and -66.

SPA-8 can show an off-centered display and can be used to display information. The electronic cursor and range sweeps or strobe and range sweeps can be time-shared. Range scale is continuously variable from 4 to 300 nm. Tracking cranks position the strobe or electronic cursor origin, and any target within 250 nm may be centered on the scope. The origin of the off-centered cursor and strobe may be controlled separately from the sweep itself. SPA-8A, -8B, and -8C are trackers. These PPIs have provision for DRT input.

SPA-33 and -59 are off-centered PPIs that can operate either as general-purpose PPIs or as part of an AEW system. They are similar to -8A, -8B, and -8C but have 2 joysticks in place of the range and bearing cranks, 1 for cursor origin and 1 for strobe and cursor bearing line. They have no provision for DRT input. Range limits are 300 and 400 nm, respectively.

SPA-34 combines -8 and -33 features and can function as a general-purpose off-centering PPI, an AEW-tracker indicator, or as an AEW repeater. It is too large for any ship smaller than a destroyer.

SPA-40 is a range-height indicator, with a maximum altitude of 150,000 ft and a maximum range of 300 nm. A joystick controls a height-line cursor or an angle-line cursor. Height is calculated by an analog computer and is accurate to within 200 ft. Errors due to earth curvature and refraction of radar signals are automatically corrected. The operator may select a delayed sweep to show a 30-nm segment between 0 and 150,000 ft, between 50,000 and 150,000 ft, or between 0 and 70,000 ft. The center of the range segment may be between 15 and 285 nm.

SPA-41 replaces SPA-40; it can display both height and angle simultaneously. The CRT is rectangular rather than circular.

SPA-43 is an intercept tracking-and-control computer.

SPA-66 is a more accurate replacement for SPA-34. In addition to the SPA-34 functions, SPA-66 can accept rectangular coordinate voltages to function as a range-height indicator for use with electronically scanned 3D radars, such as SPS-39/52. In the tracking mode, the operator sets the tracking strobe or the cursor origin to follow the position of any selected point on the display (e.g., own-ship or a selected target). The tracking information is displayed on counters, and it can be transmitted by synchro (i.e., by analog link). In the AEW-tracking mode, the reference point is own-ship position. In the AEW-repeat-indicator mode, the center of the display is displaced by an amount equal to, and opposite from, the offset provided by the tracking



An SPA-66 precision radar scope in use in the CIC of the frigate *T. C. Hart*, 1986. Note the fade chart under the sailor's right elbow: it shows the fading and reinforcement of the radar beam, probably that of an SPS-49, at different elevation angles, because of interference between the direct path and the path of a signal reflected off the sea. Such a fading chart can be used for a rough estimate of aircraft altitude; frigates like this one have no long-range 3D radar. (U.S. Navy)

set. The point of reference selected on the tracking set becomes the point of origin for the repeater. If own-ship is selected as the tracking point (i.e., if own-ship position is tracked on the radar picture provided by the airborne radar), then the repeater reads off ranges and bearings relative to own-ship; it provides a radar picture as though the AEW radar were part of the ship's fixed radar suite. As in other repeaters, SPA-66 shows fixed range rings and incorporates a variable-range strobe (to measure range accurately) and a movable cursor (to measure bearing). The cursor and range strobe can be centered on the sweep or unlocked and moved independently to set up air intercepts. The range strobe can also be used as a variable range ring, adjustable between 4 and 400 nm.

SPA-25G replaces virtually all of this equipment. It has a raster-scan display, uses radar digital scan conversion, and incorporates a 5-Mbit digital memory. SPA-25G can function as an electronic plotter and, thus, can form the basis of a very simple tactical data system on board a ship without such a system (or as a system backup). Although it is nominally a radar display, SPA-25G has some of the attributes of a simple tactical system such as CANE; it exemplifies the blending of display and data-system technology.

The 17-in rectangular screen shows both raw and processed video; the radar processor accepts 100–3600 pps, antenna rates of 0–60 rpm, and signals as short as 50 nanosec. Radar data are stored in digital form in three 1024×1024 -bit memory planes (to provide a gray-scale level of 8 shades, corresponding to 3 bits). The display itself is 1280×1024 pixels, the central 1024×1024 elements of which are dedicated to radar video (the rest are tabular). The CRT is raster scanned in 1125-line format (80 frames/sec, interlaced 2:1, i.e., a full 40 frames/sec). Resolution: 92 vertical lines/in.

Memory suffices to store, plot, and label 99 targets, 64 of which are target tracks. The system automatically calculates range, bearing, speed, and CPA and displays these data in a track-data-file block on the CRT; the data are also automatically made available to the data bus connected to the SPA-25G. Graphic images using up to 128 display lines can be created to show traffic lanes, harbors, marshaling areas, restricted zones, etc. Because radar data are held in a digital memory, the display need not fade (decay time is adjustable between 250 msec to no decay). Range scales are $\frac{1}{4}$ –250 nm or $\frac{1}{2}$ –500 nm; range rings are set at $\frac{1}{8}$, $\frac{1}{4}$, $\frac{1}{2}$, 1, 2, 5, 10, 20, and 50 nm (with 0.25% accuracy).

There is a special air-intercept mode, in which the processor calculates an intercept solution and displays alternatives for near-collision intercept and forward-quarter intercept. Outputs can be synchro or digital.

The associated executive controller is a 68000 16-bit chip, assisted by 8-bit microprocessors.

MTBF is 3000 hr (MTTR less than 30 min).

Both versions of SPA-25 are manufactured by ISC Cardion.

The new (1990) SPA-50G (made by Cardion) is intended to supplement SPA-25G. SPA-50G is intended as a tactical display, as a means of multisource data correlation and display, and as a real-time tactical decision aid. Because it incorporates considerable memory and computing power, it adds to the overall reliability of the CDS it serves. It can also be used for data link access, and it can be connected to a shipboard data bus network. For example, it can perform an electronic mailbox function.

SPA-50G uses scan-conversion techniques (i.e., raster scan) to display data from several sensors as well as graphic overlays. The cabinet is tied together by a VME bus. It incorporates 5 microprocessors (a 68020 system processor, a 68020 application processor, a 6809 operator-control processor, a 6809 for 1553 bus control, and a bit-slice graphics generator) with over 7 Mbits of digital bit-mapped memory for graphics, to accommodate 3 radar memory planes (i.e., video from 3 radars simultaneously) and 4 graphics memory planes (typically a status and designator plane, an own-ship plane, a graphics plane, and a map plane, each of which can be switched in and out of the display). There is also a radar-video integrator. The display is 1280×1024 pixels, refreshed at 40 or 80 Hz.

System processor memory capacity is 64 kwords of PROM and 64 kwords of RAM (expandable to 126k and 256k, respectively). The application processor memory is up to 8 Mbytes of RAM and 512 bytes of PROM, with further expansion capability. The application processor board can accommodate a 68020 (16.67-MHz clock rate), a 68881 math coprocessor, 4 Mbytes of dual-port dynamic RAM, up to 512 kbytes of EPROM, and up to 32 kbytes of static RAM. The graphics generator board uses



SPA-50G, a new-generation console, parallel in concept to SPA-25G. Such consoles include automatic radar target detectors and, thus, can be used to feed combat data systems such as FFISTS. (ISC Cardion)

a 125-nanosec instruction cycle and a 16-kword display list buffer. It has 2 standard character sets, large and small. The system runs at 16 MHz.

Further internal circuit boards can be added to expand SPA-50G capability.

As in the case of SPA-25G, this is another example of a display merging with combat system computers.

◆ UYQ-23

Motorola's smart interactive terminal is used for intelligence systems such as NIPS (SYQ-9) and BGPHEs (SLQ-50). It fits a standard 19-in rack; it incorporates a stroker display and can also display real-time or time-compressed video. The (V)3 and later versions have a split-screen display, and its keyboard includes a trackball. The (V)5 version has 2 trackballs. The (V)6 version has 3 split-screen displays. Internal memory varies with the version: 8k, 16k, 32k, or 128k 16-bit words. The digital interface is NTDS fast or RS-232C, depending on the version. The (V)1 version (8k memory) is part of OK-324/SYQ (NIPS terminal). (V)6 is part of OJ-557(V)/USQ-88(V) (TFCC).

Aircraft Tactical Data Systems

Just as with ships, aircraft can benefit from the integration of their sensors to form a coherent tactical picture. Large patrol aircraft are analogous to ships, with separate sensors served by individual operators. The tactical data system forms a single coherent picture out of the various pieces of data available on board to different operators. The first example of such integration was probably the Airborne Tactical Data System (ATDS) of the Grumman E-2, which is analogous to NTDS. Another very early example was the Lockheed P-3C (A-NEW). The integration of the E-2 is very similar to that of a shipboard CIC.

Single- or 2-seat aircraft are integrated on a very different level: the mechanism of integration has been the HUD, the single integrated tactical picture that a computer can form and superimpose over the pilot's view of the outside world. The first operational HUD, and the first tactical airborne digital computer, appeared together in the U.S. Navy Vigilante attack bomber of the 1960s. In such cases time pressure is probably a stronger driver than the sheer mass of information. As a consequence, the development of tactical aircraft data systems has gone more into display technology (i.e., into getting the information into the pilot's head in usable form) than into data handling per se, as in a maritime-patrol airplane.

The amount of data a pilot can process is inherently limited, and the computer can help by filtering (integrating) some of the relevant data, or by combining them in more usable form. By presenting them on the HUD, the system as a whole saves time since the pilot need not glance down periodically at the instruments (air data readouts) and tactical displays (e.g., radar, FLIR).

HUDs appeared at about the same time as aircraft data buses, including bus connections to the weapons pylons and bomb bays. In the past, aircraft were specifically wired to carry particular weapons. A pylon might be stressed for, say, 1000 lb, but its wiring, and the wiring of the aircraft fire-control system, determined just which 1000-lb stores it might accommodate. In addition, specific wiring carried specific arming and release messages (which might not be any more complicated than the release of a magnet) to the pylons. A bus, connected to a stores-control computer, can, in theory, accommodate a very wide variety of different weapons, perhaps the entire variety that a navy or air force uses. The only real remaining limit is aerodynamic; some shapes may not separate cleanly from particular aircraft. Moreover, the behavior of a particular shape, once it has separated, will depend in part on the aerodynamics of the dropping airplane. A ballistics (weapons-aiming) program will, therefore, have to be arranged for each combination of airplane and weapon. Hence the continuing need for integration testing; software and computers do not solve the problem completely, but they do greatly simplify it.

An airplane carries numerous air and tactical data sensors, and to display all of them would be to cover the HUD in symbols. HUDs are, therefore, designed to show only a fraction of the available data, the pilot selecting alternate programs (e.g., for cruise, for air-to-air combat, for particular bombing tactics).

The pilot must still look almost directly ahead to see the HUD superimposed on the sky. That must be distracting during violent maneuvers, as in close air-to-air combat. The ultimate HUD displays its data, not on a fixed screen in the cockpit, but on the pilot's helmet.

Pilot reactions still impose a time lag. The pilot sees a target and must move to react, e.g., to fire a weapon. No matter how perfectly coordinated the pilot is, hand movement will lag head and eye movements. One solution is to place sensors in the cockpit to pick up the pilot's head movement. The AH-64 ground-attack helicopter uses a simple form of this system. The concept would seem to have an important potential shipboard application by allowing quicker defensive reactions to lookout sightings, e.g., of incoming aircraft or missiles.

Besides the helmet HUD and the head sensor, it seems inevitable that the extent of integration, i.e., the extent to which the central tactical system combines different sensor outputs, will expand. Current aircraft generally still segregate ESM data from other tactical data; they are fitted with separate RWRs, for example. It seems likely that future tactical aircraft will have integrated EW suites (warning, identification, reaction).

The other likely future development is in the combination of information, which is now presented to the pilot via a HUD and displays, and the actual motion of the airplane. Many current tactical aircraft, such as the F/A-18, are flown by a computer, which provides the pilot with an artificially generated feel of the controls. However, the control circuit and the sensor circuit are entirely separate, just as, on board a ship, steering and engine orders are not controlled by the tactical data system. For an airplane, maneuver is intimately connected with air combat; the airplane itself is used to aim many of the weapons. Violent evasion triggered by ESM warnings is often necessary for survival. The next step, then, would seem to be to integrate existing fly-by-wire systems and existing computer-based air-combat systems. The pilot would still decide what to do, but the aircraft system would make many more of the implementing decisions. A pilot might, in theory, look at a distant enemy aircraft (indicated by radar on the helmet display) and order the airplane to engage. The airplane would then maneuver itself into an attacking position, and it would indicate to the pilot when to release weapons. A current U.S. DARPA program, the Pilot's Associate, makes much of this promise. One justification for more computer control is that a pilot may be unable to control an airplane through the really violent maneuvers that should be practicable in the near future.

This sort of integration already exists, in a limited way, in terrain-avoiding or ground-following systems, in which the aircraft radar directly instructs the flight-control system. Instruction may involve particular hydraulic actuators, or it may involve direct input into a fly-by-wire flight controller.

Helicopters are intermediate between the large multioperator aircraft and the tactical fighter or bomber. Typically, integration means that there are no longer any displays unique to any 1 sensor. Instead, the multifunction displays can be switched to any sensor, using an internal data bus.

CANADA

◆ HINPADS (AYW-501(V))

The Helicopter Integrated Processing and Display System for the Canadian version of the EH-101 (the New Shipboard Aircraft) is being developed by the NSA Mission Systems Consortium, led by CDC. The other members are Canadian Marconi and Litton Systems Canada. A published photograph of the mockup shows two 2-screen consoles side by side, each with 2 keyboards and a joystick.

FRANCE

◆ Atlantique Nouvelle Génération

The key difference between this version and the original Atlantic is the presence of an integrating computer, a 15M/125X (512 kwords). The associated acoustic processor is SADANG (*Système Acoustique d'Atlantique Nouvelle Génération*), the 2-position Thomson Sintra TSM 8200 (DSAX 1), sufficient to process 16 LOFAR or 4 directional active buoys. There are 2 identical stations, each with its own processor and display (a CRT with a 2-page refreshing memory, 8 channel displays, and 1 paper chart recorder with 4-channel display). SADANG processes omnidirectional LOFAR buoys in integrated ALI, HY-FIX, DEMON, and CODAR modes; DIFARS and VLAD in ALI-BFI and ABI modes; and also active buoys (omni and DICASS).

The architecture is semicentralized, with the central processor in charge of system management, communicating with peripheral computers running the signal processors and the data bus. The central computers carry the main tactical operational software. Each subsystem-management computer has its own tactical-and-management program so that its operator can process and filter incoming data and operate autonomously if the central computer fails.

The system is designed to function equally well against surface and submarine targets. Radar, ESM, and FLIR are the primary surface sensors, and the sonobuoys and MAD are the primary ASW sensors. The interior of the airplane is arranged so that the tactical operator (TACCO) can occupy either of 2 positions suited to these 2 roles, with 2 identical stations for the TACCO and the radar operator, each with a multipurpose display. A third multipurpose display is provided for the pilot. In the antiship role, the TACCO sits forward, near the ESM operator; in the ASW role, aft, near the acoustics processors. Each of the 2 identical TACCO/radar-operator stations has a bicolor multipurpose display to show raw video and the tactical situation, plus an alphanumeric display, a display selection panel, programmed action keyboards, and a trackball. These stations include the FLIR display. There are also alphanumeric displays for the navigator/communications operator and for the acoustic operator. An automatic plotting station (the aircraft's position is marked by a point of light) at the navigator/communications

station functions as a backup to the computer-driven tactical plot.

The basic combat-system crew (other than 2 pilots and a flight engineer) consists of the TACCO, the navigator/communications operator, the ESM-ECM-MAD operator, the radar operator, 2 acoustic operators, and a front observer; the airplane can carry 2 more observers as reliefs.

The normal load is 100 sonobuoys and 4 torpedoes or 2 Exocets, for an 8-hr mission on station at low altitude 600 nm from base. The buoys are carried in 4 reloadable launchers, plus four 18-buoy launchers; there is internal storage for 30 buoys. There are 4 hard points under the wings (two 750 kg, two 1000 kg). The bomb bay carries either 8 Mk 46 torpedoes, 12 depth charges, 9 mines, 2 AM 39, or 3 Mk 46 and 1 AM 39.

The earlier Atlantic was chosen in 1958 to meet a NATO specification; the last was delivered in July 1974. Design of the second-generation aircraft began in 1978, the prototype appearing in 1985. The first production airplane was handed over to the French Navy in October 1988. At that time the Atlantique Nouvelle Génération was described as the most complex aircraft yet developed in France.

The earlier Atlantic 1 is operated by France, Italy, Pakistan, and West Germany. It lacks any integrating computer system. The sonobuoy processor is the U.S. AQA-5; the radar is DRAA-2B; the MAD is DHAX-1; and the standard ESM set is ARAR-10B. French aircraft were later equipped with a Sparton demultiplexer and display for DIFAR buoys, TD-1135/A. The Dutch Atlantics have already been retired in favor of P-3Cs. The Italian aircraft are being upgraded by Dassault, with IGUANE radars, AQS-902 processors, and a U.S. tactical data system, probably ASN-150. The West German aircraft were modernized by Dornier and will probably be replaced by P-7As. These aircraft have Loral EW-1017 ESM sets.

◆ Super Étendard

Remanufactured Étendard strike fighters were fitted with a Thomson-CSF VE-120 HUD fed by a Kearfott UAT 40 central tactical computer built under license by SAGEM. The computer receives both radar (Agave) and inertial-navigation (a Kearfott UNI 40, built under license by SAGEM) data. Functions: navigation to a point stored in memory; bomb delivery, including automatic or manual release; and direction to a missile-firing point in space.

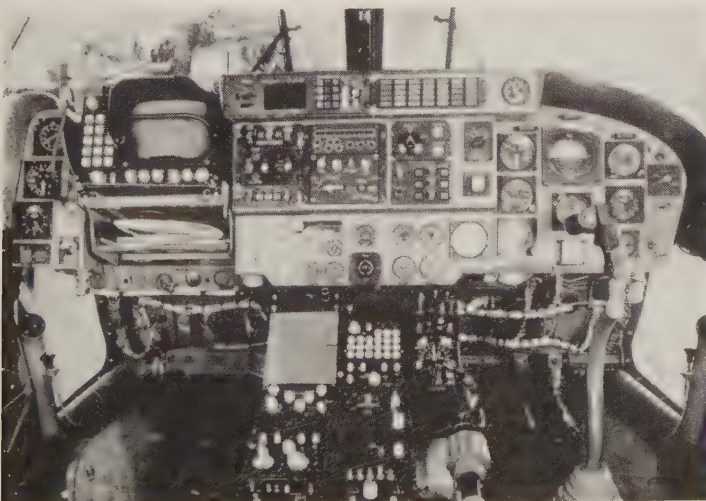
This program dates from 1974–77.

UNITED KINGDOM

◆ Central Tactical System

The tactical data system of the Nimrod MR.2 is built around a GEC 920 ATC computer; a separate Ferranti FM 1600D computer processes the data from the Searchwater radar. The associated acoustic processor is AQS-901, which uses twin 920

The Lynx cockpit illustrates the impact of computerization. The left photograph shows a Royal Navy Lynx, with its radar or electro-optics screen at the left. The right photo shows a similar cockpit with the central tactical system (CTS) installed. Numerous dials and switches are replaced by a pair of CDUs, and the space released has been filled by a tactical situation display. In the earlier cockpit, the integrating function of the display had to be carried out either in the heads of the pilot and copilot or on a manual plotting board. The situation display shows synthetic video, not the raw video of the radar or electro-optical sensor, which is still carried by the separate screen on the left. (Racal)



ATC computers; another 920 ATC serves the ESM system. The primary display for the tactical navigator (analogous to the U.S. TACCO) is a 24-in-circular CRT (summary plot). There is a separate navigational (track-keeping) plot.

The original Air Staff Requirement (ASR 381) for what became the Nimrod MR.1 was issued on 4 June 1964. The Comet airframe had been under consideration for the maritime-reconnaissance role as early as 1958, when it competed with the Breguet Atlantic for a NATO program. However, the system envisaged in 1964 was very different from the unintegrated systems of the 1950s. The first true Nimrod prototype flew in June 1968, and the first aircraft entered service on 2 October 1969. It used a 920B computer.

The MR.2 program began in 1975, and the first aircraft modified to this standard were delivered in 1979. New avionics included a better search radar (Searchwater in place of ASV.21D) and Loral ESM pods (in place of Thomson-CSF units). During the Falklands War, Nimrods were modified to carry Sidewinders, bombs, and Harpoon missiles. Modification was probably simplified because it involved software changes rather than re-wiring, the aircraft already having digital tactical data systems.

A Nimrod upgrade is now being considered; it includes Staff Requirement (Air) 909 for a new acoustic processor, SR(A) 910 for the central tactical system, and SR(A) 911 for systems integration. As of late 1989, RFPs were expected in the late spring or summer of 1990, but it was possible that they would be canceled in favor of British acquisition of U.S. P-7As. In the event RFPs were issued, project definition was expected to be quite short, suggesting an urgent need to replace the existing Nimrod avionics with existing, rather than future, equipment. The acoustics upgrade specification was written by GEC Avionics and RAE Farnborough; proposed system architecture is similar to that of the GEC Avionics AQS-903, already selected for the British Merlin (EH-101) helicopter. However, it uses more modern microprocessors (Motorola 68000 series) and will incorporate transputers and custom-designed integrated circuits (which suggests some application of Curtis-like processing; see the ASW section). Software will be written in ADA rather than in Coral 66.

As of early 1990, the series of avionics-update staff targets was being deferred, pending completion of an MoD study to determine whether it would be better to modify the existing airframes or to buy new ones (presumably P-7s with British equipment). There had been a report that severe corrosion problems would force the retirement of the existing Nimrods and, therefore, that no mid-life update would be worthwhile. Current plans call for the RAF to continue to operate its 36 Nimrod MR.2 and its 3 Nimrod R.1 ELINT aircraft through the year 2003. Eleven short-time airframes intended for the abortive Nimrod AEW program are in storage and could presumably be used either to replace badly corroded aircraft or for cannibalization.

◆ Escorter

MEL announced this small maritime-patrol-airplane tactical data system, which uses distributed processing, in 1989. Escorter has a series of identical consoles, each with a color raster display, a stiff-stick controller, a multifunction (i.e., software-configured) keyboard, and a tactical display processor. All are tied together by a 1553B bus. In the core configuration an additional video bus connects the search radar and the 2 consoles (TACCO and SENSO), feeding each with radar video. The main bus carries synthetic-radar-video, MAD, ESM, and processed acoustic data (the acoustic processor receives sonobuoy data directly, but these data are also fed into the bus). The acoustic processor is run from a separate acoustic operator (ACO) console, incorporating a display and a touch-sensitive keyboard. MEL offers 2 other options, an expanded (increased-performance) version and a reconfigurable system.

The expanded system adds a FLIR, a data link, and a capability for stores management (for attack as compared with surveillance alone). The stand-alone MAD and on-top position indicator (OTPI) of the core system are replaced by subsystems in-

tegrated with the 1553B bus, and the acoustic processor is expanded by the addition of a Barra side processor. The acoustic operator can control active buoys (DICASS). The consoles are provided with an auxiliary video channel so that they can be switched between FLIR, radar, tactical display, and acoustic display. Either operator can slew the FLIR using a stiff stick.

The reconfigurable version uses 3 identical consoles, any 1 of which can function as SENSO, TACCO, or ACO. This surveillance system uses a radar as its main sensor, lacking the expanded acoustic processor of the expanded version. Nor is there any MAD for a final preattack fix. However, there is an acoustic processor.

MEL describes Escorter as an ASV (surface-search) or ASW system and indicates the market it seeks by illustrating its brochure with a Dornier 228 and a Grumman S-2 Tracker. The brochure shows a variety of applications: synthetic radar video, raw radar video with ESM data and strobes, and ASW (sonobuoys and target track). In each case, the screen is divided into a graphic display on the left and a tabular display on the right.

The processor used in the system is not identified.

◆ RAMS

The Racial Avionics-Management System is the central tactical system (CTS) of Royal Navy Lynx (HAS 3 and later) helicopters, and the tactical data system for Royal Danish Navy Lynx helicopters. It is a partial glass cockpit, the main displays being 2 alphanumeric screens (control display units, or CDUs). RAMS 4000, the military version, employs 2 processor interface units (PIUs) containing up to 3 microprocessors, a data transfer device (DTD) to load initial data, and the 2 CDUs. The CDUs and PIUs are all connected to a dual 1553B bus, and the PIUs and DTD are also connected to a non-1553B internal aircraft equipment bus, for equipment not compatible with a 1553B. The Royal Navy version includes a 12-in programmable color tactical situation display (TSD). Further CDUs and PIUs can be added to the basic system, which can accommodate more than 1 TSD. RAMS uses nonvolatile mass memory (presumably bubble memory).

◆ Sea Harrier

The Sea Harrier FRS.1 has a Smiths Industries 6-50-series HUD served by a 20-kword Smiths Industries digital weapon-aiming computer (WAC) and an Ericsson SDS 80 air-data computer. The associated Ferranti inertial platform is controlled by an 8-kword computer. The HUD displays aircraft altitude and heading; other flight information selected by the pilot (IAS or Mach number, barometric or radar altitude, angle of attack, side force, vertical speed); navigational aids such as beacons; air-to-surface aiming data including a continuously computed impact-point (CCIP) or manually depressed line-of-sight (DSL) mode; air-to-air aiming solutions; air-to-air symbols; and an independent standby sight.

The HUD produced for the AV-8B, which is presumably similar to that of the Sea Harrier, has a 22-deg field of view. Presumably, the Sea Harrier system is not too different from that of the Tornado (5-50 series). The latter has a 9-kword memory; its inputs are 8 digital data channels and up to 32 discrete commands (e.g., ordering up an air-to-air rather than an air-to-surface program). Computer speed: add/subtract time, 3.75 microsec; multiply time, 8.63 microsec; divide time, 9.13 microsec. Accuracy: boresight, 0.05 mrad; symbol positioning, 0.22 mrad within 5 deg of dead ahead (0.32 mrad within 10 deg). Presumably, the Sea Harrier version has a larger memory because the Sea Harrier lacks the Tornado's 64k central computer.

Sea Harrier FRS.2 has a more integrated combat system tied together by a dual 1553B bus. As in other recent aircraft, an objective of the system is to permit the pilot to fly with little recourse to heads-down instruments or displays. In this version an eye-level up-front control panel (UFCP), just under the HUD, carries whatever critical weapons-system controls are not on the stick and the throttle. The earlier analog displays are replaced by a pair of multifunction displays (1 for the radar), leav-

ing only a few heads-down instruments. There is still a separate RWR, but its information is passed into the bus and, thus, should be available on the multifunction displays driven by the central computer. When the display shows raw radar video, it will be driven directly by the radar. Otherwise, synthetic video will be taken from the bus via a control-and-interface unit that is directly linked to the HUD/WAC. For example, a display can show threat data, target priority, and navigational information.

The bus does have some limitations. For example, the radar processor is too large to fit directly next to the radar transmitter-receiver, so it is located in the after avionics bay, near the tail. It is connected to the radar transmitter-receiver by a special fiber-optic link, whose bandwidth is needed to carry the raw radar data.

◆ TATTIX (ASN-902)

The GEC-Marconi tactical data system for a maritime-patrol aircraft incorporates the company's AQS-902 acoustic processor. TATTIX has been installed on board at least some Fokker Enforcers. The data bus is an ARINC 429 or a 1553B. The tactical plot (625 lines, 50-Hz frame rate) can accommodate up to 256 data entries and can show up to 64 tracks, up to 16 operator-defined circles or areas, and up to 16 annotated vectors. Range scales are 8, 16, 32, 64, 128, 256, and 512 nm. The same display can be used for ESM/radar to show a sonobuoy field, for localization within a sonobuoy field, and as a sonobuoy tote. The display can be monochrome or color.

Weights: tactical processing unit, 16.0 kg; tactical control unit, 4.5 kg; tactical display unit, 14.5 kg; cursor control device, 0.5 kg.

◆ TMS

GEC Avionics Tactical Mission System for Sea King 42B ASW helicopters for the Indian Navy, and also for modified British ASW Sea Kings. TMS incorporates the AQS-902B/C acoustic processor but can employ the Super Searcher radar, TANS navigation system, Hermes ESM, HS 12 dipping sonar (in the Indian helicopters), and Sea Eagle missiles. The microprocessors are 17 Z8000 and Z80 8-bit chips in 2 LRUs. Indian Sea Kings have 2 CRTs, each with its own keyboard.

UNITED STATES

◆ ASN-123

ASN-123 is the Teledyne Systems tactical data system for SH-3H Sea King (carrier inner-zone ASW) helicopters, operational in 1978. ASN-123 provides accurate automatic navigation, tactical situation displays, and flight-management and tactical aids, including multiple torpedo-attack solutions. The system was later upgraded with expanded computer memory and air-to-air and ship-to-air data links.

ASN-123 is also the tactical navigation/data system of the SH-2F LAMPS I helicopter; presumably, the SH-3H installation is an expanded version of the earlier LAMPS version.

ASN-123 is nominally a tactical navigation system. However, in the SH-3H it includes a panel on the sensor operator's console for entering sonar and sonobuoy data into the central TACNAV (ASN-123) computer. The main system display is in the cockpit, and the TACCO there has the main system-control panel. The dipping sonar (AQS-13E) incorporates a signal processor, which is also used to process sonobuoys the helicopter may lay; their data are displayed on the sonar CRT. The sonar processor is also used to send MAD data into the tactical data system.

In the SH-2F the system consists of a processor, a TACCO panel, a SENSOP panel, and a tactical navigation display. The automatic inputs are from a tactical navigation radar (ASN-182, to measure speed over the surface), a compass (ASN-50), a true-airspeed indicator, the sonobuoy receiver (ARR-75, to indicate which channels are active), and the sonobuoy launcher (to indicate which buoys were dropped). The on-board sensors monitored by the crew are the LN-66 surface-search radar, the ESM (ALR-66), and the MAD; sonobuoy data are processed exter-

nally, on the ship controlling the helicopter. MAD and radar data are entered manually through the SENSOP control panel; the radar has a separate display. Up to 20 radar contacts can be inserted into the system in this way. The TACCO monitors the ESM system and enters contacts manually into the central computer. The main system outputs are navigational: for example, true helicopter position and speed, navigational error (bias), base ship predicted position, course, and speed. Sonobuoy and torpedo splash points are predicted based on ballistics, using a manually entered aircraft altitude and manually entered or computed winds.

The computer holds data on a 512 × 512-nm area, with grid center specified by coordinates when the system is initialized before takeoff. Only a portion of the full area can be represented at any one time, but grid center is always the same (unless the computer is reset). There are 7 range scales.

◆ ASN-150

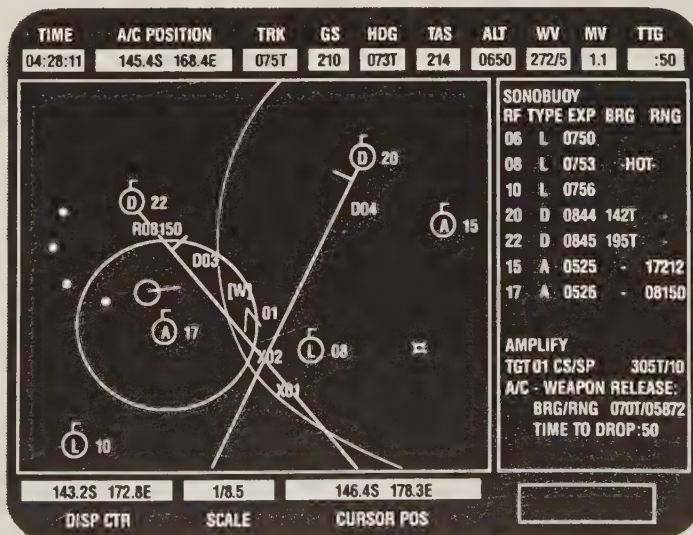
The Teledyne Systems ASW tactical data system is used in the modernized LAMPS I helicopter (SH-2G) and the SH-60F carrier inner-zone helicopter and is offered for export. The associated acoustic processor in the LAMPS I is UYS-503. ASN-150 was derived from the earlier ASN-123 described above.

The first version of ASN-150 was TDMS, the tactical data-management system of the SH-60F, the successor to the SH-3H; it is an outgrowth of ASN-123. The SH-60F has a crew of 4: pilot, copilot/TACCO, tactical (radar) -sensor operator (TSO), and acoustic-sensor operator (ASO). The TACCO and TSO each have a multifunction display; the pilot and ASO have horizontal situation displays. The system is tied together by a dual-redundant 1553B bus, and it is driven by dual tactical computers. TDMS also includes an armament-system controller (ASC).

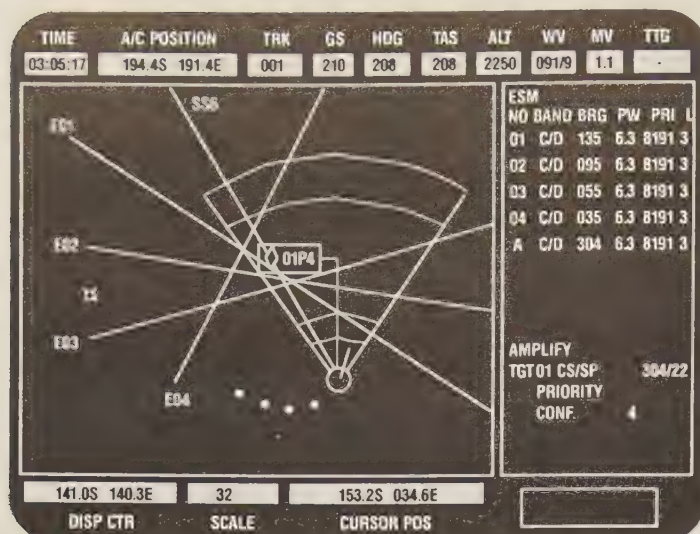
The helicopter operates both a sonar (AQS-13F) and sonobuoys; the same sonar-data computer (embedded in the AQS-13F) processes signals from both (4 sonobuoy channels) and displays the results on the multifunction displays.

The dual data processors are CP-1820/ASN-150, a military version of the Teledyne MECA 43 computer (described below).

A variant of the same data system, ASN-150(V), has been specified for the Fokker Maritime Enforcer Mk 2, currently in the proposal stage. Details below refer to this version, but they are probably not too far from the characteristics of the U.S. helicopter versions. The original Enforcer (17 of which were sold) had a GEC-Marconi ASN-902 as an option.



A typical ASN-150 display. The aircraft has dropped a mixture of LOFAR (L), DIFAR (D), and active (A) sonobuoys, and the computer is used to correlate the data they produce. The 2 circles are the ranges produced by the active buoys, on channels (RF) 15 and 17. The DIFAR buoys give bearings that place the target very close to one of the intersections of the range buoys. (Teledyne)



This type of ASN-150 display would be used to fire a Harpoon missile. A series of ESM bearings, all on C/D-band, is used to localize the target approximately. The missile is set to follow a dogleg path (with a left turn) to attack target 01. The arcs show the Harpoon's launch envelope. (Teledyne)

The Enforcer 2 sonobuoy processor is UYS-503; the radar is APS-140(V); the MAD is ASQ-504; and the ESM set is ALR-606(V)2; this system would also include a GEC-Avionics TICM II thermal imager. The Maritime Enforcer would have a 10-sonobuoy launcher, and it would use a BEAB BOP 300 chaff launcher. ASN-150 includes 2 stores-interface units (SIUs), each of which can control 4 weapons stations, for a total of 8. The system design includes provision for Link 11. The system is tied together by a 1553B bus. It employs 2 redundant tactical processors (CP-1820/ASN-150), driving 4 monochrome 15-in multifunction displays (MFD), 1 color 15-in multifunction display (MFD*), 1 color 6-in multifunction display (MFD), 7 control display units (CDU), and 4 display control panels (DCP). The principal operators are the TACCO, the ASO, and the NASO (nonacoustic-sensor operator); each has the following displays:

	ASO Station	TACCO	NASO	Cockpit
MFD	2	1*	2	6-in MFD (1)
CDU	1	2	1	2
DCP	1	1	1	1
Data Loader	—	1	—	—

Each MFD can display radar, FLIR, acoustics raster video, or stroke-written tactical-situation display. The CDUs are the primary operator interfaces with the system. The DCPs are extensions of the CDUs, providing extra display-oriented keys and a cursor control stick. The data loader is a small cartridge with 512 kbytes of RAM, which initializes the tactical data processors, and carries additional mission data.

System functions include navigation; automatic weapon pre-setting; target tracking; tactical aids, including assistance in 4 attack modes (intercept point, circle mode, snake mode, and vectored attack [vectac]); antiship surveillance and targetting; search and rescue; and fly-to points. Plotting aids are 15 vectors, 15 circles (fixed or expanding), an aircraft track history (10 dots), and a hook cursor. Scale is selectable between 0.5 and 128 nm/in. The system can carry 1 aircraft location, 1 datum, 30 sonobuoys, 30 DIFAR contacts, 15 range-only contacts, 30 DICASS contacts, 15 sonar contacts (entered through the data link), 15 target tracks, 15 surface ships, 30 radar tracks, 30 ESM contacts, 15 visual/manual contacts, 30 reference marks, 15 survivor locations (for search and rescue), 15 TACAN beacons, 30 fly-to points (fixed or moving), 1 intercept point, 1 weapons-release point, 1 snake-mode display, and 1 Harpoon launch envelope.

The data processor is the Teledyne MECA 43. Its arithmetic is arranged for 8-bit slices so that it can work with 16-, 24-, or 32-bit words. Memory options are magnetic core (18-mil cores, 16k 16-bit words, cycle time 1.0 microsec, or 13-mil cores, 16k 16- or 24-bit words, cycle time 0.8 microsec); CMOS RAM (2k or 4k 16-bit words, cycle time 0.2 microsec); bipolar RAM (2k 16-bit words, cycle time 0.05 microsec); or PROM (8k 16-bit words, cycle time 0.2 microsec). The central processor can address up to 64 kwords, expandable to 1M. Speed: fixed-point add/subtract, 1.625 microsec (floating-point, 7.531); fixed-point multiply, 4.375 microsec (floating-point, 12.531); fixed-point divide, 7.125 microsec (floating-point, 19.781). Floating-point numbers are represented by 16 or 32 (or 24 or 48) bits. This computer differs from most others in using only 2 parity bits for 24-bit words. There are 103 instructions (88 basic instructions).

The high-order language is JOVIAL J73/1.

In the version now advertised, the tactical processor contains 448k 16-bit words (384k of EEPROM program memory, 32k of core, and 32k of semiconductor RAM).

◆ A-6E/DIANE

The Grumman A-6 Intruder was the first U.S. naval airplane designed as an integrated weapons system. System architecture, laid down in 1957, has remained constant from the original A-6A through the current A-6E, although the original name, DIANE (Digital Integrated Attack and Navigation Equipment), has been dropped. The central computer, originally a Litton ASQ-61, communicates with the pilot via an 8-in Kaiser AVA-1 vertical display unit (VDI), whose synthetic video shows the route to fly. The computer does not fly the airplane during combat: in 1957 no one would have trusted a computer to do that. For example, no version of the A-6 has an automatic terrain-avoidance mode: the pilot flies to avoid the terrain displayed on the VDI. However, the computer can release bombs at a point it calculates, as the pilot flies the indicated path. There is no HUD. The computer does fly the airplane when it is not maneuvering, through an autopilot (automatic flight-control system, AFCS, designated ASW-16).

The second crew member, the bombardier-navigator (BN), designates targets to the computer via the main radar display (the AVA-2 direct-view radar indicator, DRVI). The pilot can designate targets via a bombsight. The BN selects weapons and chooses between salvo and train (sequenced) drop, the latter using an intervalometer adjusted either directly or via the computer.



The cockpit of an A-6E shows, on the left, the pilot's "road in the sky" display; on the right is the FLIR. The flat glass above the display is the pilot's optical sight. The missile panel is between the seats, showing what missiles the airplane is carrying (in this case, 2 HARMs). (Grumman History Center)

The VDI shows a synthetic-video "road map" called a contact-analog display (since it is analogous to what might be seen outside the cockpit) with artificial perspective. Aircraft attitude is shown by a ground-stabilized artificial horizon line, and "ground texture" and "cloud texture" symbols give the pilot a sense of motion toward the horizon. Horizontal lines above and below the horizon indicate pitch in units of 10 deg. A road on the ground indicates the desired flight path, and cloud symbols move to indicate changes in aircraft pitch and bearing. Numbers on the sky display are a heading "tape," giving the airplane's bearing. The tactical data system can superimpose attack information, including target symbol, steering symbol, release, and pull-up. The same CRT indicates the appropriate flight path during a carrier landing, based on ACLS signals.

Kaiser developed a solid-state radar-data scan converter, which allowed the VDI to show terrain elevations at 10 different ranges, out to 10 nm ahead, over a 60-deg sector. Each range contour is colored a different shade of gray to provide contrast, and terrain above the flight altitude is shown as above the horizon. A pilot can select 1 of 4 different ranges and code the terrain there with black vertical highlight bands. The pilot avoids this terrain by flying the (bomb) impact bar to the marked contour. Flight path and attack symbols can be superimposed over the converted radar data for low-level attacks.

The third stage in VDI development was provision to display FLIR and LLLTV images, for the A-6C (TRIM) and then for the A-6E (using TRAM).

The BN can enter up to 4 targets (or waypoints) into the computer. The VDI shows a target symbol for each in sequence, and the pilot flies toward it by keeping the symbol centered on the VDI. The symbol lights up when the airplane is 10 sec from the computed drop point. The VDI shows the effect of any evasive maneuver as a computed miss distance. Further targets are called up by pressing 1 of 3 buttons under the VDI. If they are outside the VDI field of view, it shows the appropriate road to take. Limits on the computer-VDI combination show in the requirement that the pilot bank into the new heading at exactly 30 deg.

The principal system sensors are a radar (originally a combination of APQ-88 and APQ-92, now APQ-148 or -156), a doppler navigational radar (APN-153, to measure speed over the ground), a radar altimeter (APN-141), an inertial navigation set (ASN-31, now ASN-92), and an electro-optical sensor (TRAM, introduced in the A-6E version; see below). Because the A-6 was designed largely for close air support, it had to be able to bomb targets with indistinct radar images, either designated from the ground or described in terms of offset aim points (the aim points being bright radar reflectors or the marines' TPQ-10 radar bombing beacon).

DIANE's development in service exemplifies the flexibility inherent in a digital computer. System capability was extended more through changes in software than in hardware aboard the airplane, as Programs P-1-P-8 appeared through the 1960s. The program originally supported straight-path weapons delivery (including straight dive or climb), dive toss, and high loft (for nuclear delivery). In 1967 an assisted automatic visual-bore sight mode was added: the pilot centered the target in the sight and pressed the bomb release to designate it. The radar measured the range, and the computer worked out the release point.

The computer was particularly useful in Shrike (ARM) delivery. Without a computer, an airplane pointed Shrike at the target radar after the missile seeker locked on. However, the computer made indirect attacks possible. Shrike could acquire (but not lock onto) a radar 40 nm away. Because the seeker had a narrow field of view, such acquisition indicated that the target was dead ahead, within a narrow cone. DIANE could store this indication as a datum. Once the datum had been entered, the pilot could make a long, slow turn to a different position, then again point at the emitter for another bearing; DIANE could triangulate since it continuously kept track of the airplane's position. Using that information, it could compute the appro-

priate airplane path to loft Shrike toward the target, the missile's seeker acquiring the target as it approached. The missile seeker had a large enough footprint to make up for the inaccuracy inherent in such an attack. The missile gained considerably in range. This approach was later applied to the AGM-78 (Standard ARM) missile under the designation passive angle tracking (PAT/ARM: 6 aircraft were modified). Six aircraft were fitted in 1970 with the APS-118 target identification and acquisition system (TIAS), in effect an extension of PAT/ARM. Although these particular systems are no longer in service, the tactical ideas they represent remain in the A-6E software. About 1980, 12 A-6Es were fitted with AWG-21, which could control Standard ARM missiles. Many aircraft now carry HARMs.

Avionics represented 43% of the cost of an A-6A (compared to 20% for the contemporary F-4B, which was considered highly automated). Available technology was not reliable enough: in 1968 the radars were credited with 40% attack reliability, and the total system with only 26%. Limitations in the electronics probably also limited performance when the system worked as designed. In 1968 it was estimated that an A-6A bombing a well-defined target from 1000-ft altitude could achieve a CEP of 900 ft (1500 ft from 3000 ft). Against a difficult radar target, however, CEP might easily grow to 4800 ft. These large CEPs were attributed largely to the sheer size of the radar beam, which could easily pick up the wrong aim point.

The solution (the A-6E system, proposed in 1967) was threefold: a more reliable radar (APQ-148, later upgraded to APQ-156), a faster and more capacious computer (ASQ-133), and ultimately a laser range-finder with a very narrow beam (working with the TRAM electro-optical sensor). Many A-6Es were reworked A-6As, initially fitted with the new radar and computer, for 21% improvement in operational readiness and 76% improvement in full systems capability. The A-6E itself was improved in stages. A-6E CAINS introduced a new standard inertial navigator (CAINS, ASN-92). The TRAM (AAS-33) electro-optical sensor was tested in 1974, and the first production A-6E TRAM flew in December 1978. The upgraded TRAM/DRS entered production in 1979. TRAM video appears on an 8-in CRT above the BN's DRVI. The FLIR can be slaved to the radar or to a stored aim point, and the laser is used for final ranging (reportedly it has 10 times the range accuracy of the radar, measuring target position to within 5 ft). The initial effect of the new computer and radar was to reduce radar CEP by 49% and visual CEP by 53%; CAINS reduced navigational CEP by 28%. TRAM made for further improvement, achieving 66% of the A-6E radar CEP (i.e., about 33% of the original A-6A radar CEP, or about 300 ft) and 71% of the A-6E visual CEP.

A fully digital ("glass") cockpit was planned for the abortive A-6F.

◆ A-7E

The A-7E system is a single-pilot equivalent of the A-6 system intended for day rather than night attack. The pilot designates the target and flies the airplane, using a HUD (through which the target can be seen) rather than a heads-down road-map display (and a separate designation display for the BN). The pilot designates a target defined by the HUD reticle, either aiming the airplane itself or slewing the reticle onto the target. The system radar (APQ-126) is slewed to the reticle. In an alternative radar bombing mode, the target is identified on the radar, and the reticle is slaved to the radar. The addition of a FLIR projected onto the HUD provides all-weather performance since the system can be used in what amounts to its visual mode. In each case, as in the A-6, the system radar (an APQ-126) measures range to the target. The system senses airplane motion and continuously computes the appropriate release point. The pilot follows HUD steering and solution cues. A pull-up symbol on the HUD warns the pilot that the plane has reached minimum safe pull-up distance. The system automatically releases weapons at the appropriate moment.

The continuous release-point calculation makes for flexibility: the pilot can change from tactic to tactic during an attack

without changing switches. There are 9 computed attack modes: normal, normal offset, radar, radar offset, navigation bombing (i.e., with reference to stored coordinates), gun mode, rocket mode, re-attack mode (second pass), and toss mode (presumably for nuclear delivery). In each case the pilot can choose to attack from a dive, level flight, climb, or over-the-shoulder. Analog systems allowed for only a limited repertoire of maneuvers; earlier A-7s had to approach their targets at a preset altitude and speed and perform a prescribed pull-up maneuver.

Data from sensors are refreshed about 25 times/sec; the computer refreshes the HUD 50 times/sec to avoid blurring and jitter. At this rate the display can follow aircraft maneuvers at rates as great as 200 deg/sec. The system measures winds (a major factor in bomb ballistics) by comparing doppler/inertial velocities with measured air data. As originally delivered, the system computer carried ballistics for more than 100 weapons. The computer (ASN-91) solves the trajectory equations (trajectories as such are not stored because the range of initial conditions is too great) to display bombing instructions on the HUD.

LTV, the aircraft manufacturer, claims that the computer-driven system makes for twice the accuracy of the earlier analog type, so A-7Es should require half as many sorties per target. Claimed accuracy: CEP 150–200 ft for level bombing, 8.1–9.6 mils for dive-toss delivery (15 mils for the previous analog system), 8.2–9.5 mils for strafing (rockets or 20-mm cannon).

IBM was system integrator, using a pair of 7094 computers to simulate the flight dynamics of an A-7.

◆ A-NEW (P-3C)

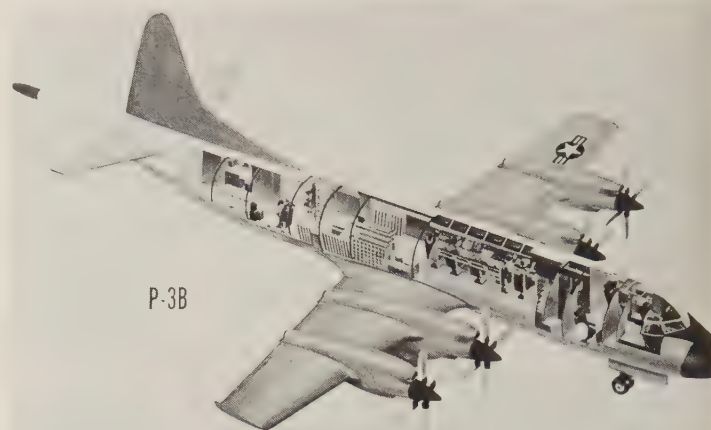
The P-3C was one of the first maritime-patrol aircraft to have a computerized tactical data system. It is analogous to a surface ship whose sensors and weapons are tied together by a central NTDS computer. Communication and coordination became much more efficient since information is transferred directly from console to console. Even in the initial version (Mod 1), the tactical coordinator (TACCO) could devote 85% of the time in the target area to tactical decisions, spending only 15% on coordination with the pilot and the sensor operators (SENSOs) and on mechanical manipulation, a reversal of the usual ratio.

The computer maintains a consistent tactical picture on board the airplane, using dual inertial navigators and a doppler radar. Automated navigation eliminates errors due to low-altitude high-G maneuvers, and its accuracy helps an airplane chasing fast submarines. Automated navigation eliminates the lengthy and mechanical calculations needed to determine relative sonobuoy positions. Navigation also includes prediction of the splash points of all the stores the airplane drops, including sonobuoys and torpedoes. However, unlike the later S-3, A-NEW did not track sonobuoys drifting in the water, so the airplane had to overfly their positions periodically to verify them. The TACCO can use the computer to estimate the likely results of alternative tactics. Such estimates were impractical in noncomputerized systems because each entailed so much computation, particularly of navigational data.

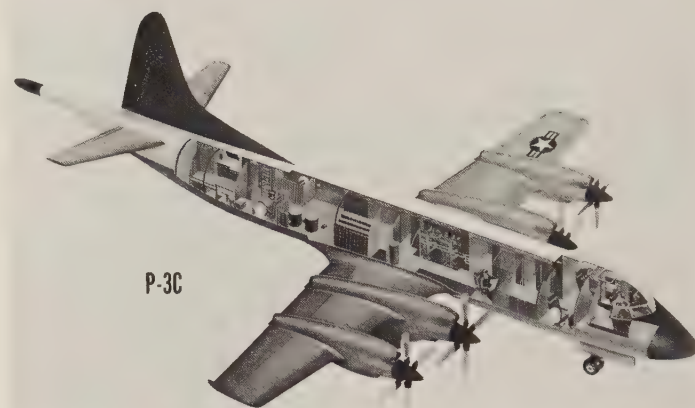
The automated navigation system is combined with a flight director (which replaces the 2-axis attitude indicator of the P-3B), providing the pilot with point-to-point steering commands calculated by the computer for, for example, greater precision in dropping sonobuoys or in executing a MAD search.

All information in the airplane was centralized, so it could be recorded (for later playback and analysis) and also transmitted (via Link 11) either to a surface ship or to an airplane relieving the one on station. Playback is important because targets missed in flight may be detected after an airplane lands, to be prosecuted on a later flight. Parallel with A-NEW, specialized ground or shipboard centers (ASWOCs, ASW operation centers) were developed for real-time or playback analysis. Typically, they have computers and gram printers equivalent to those on the airplane.

A-NEW meant, literally, a new ASW weapons system. It was conceived in July 1960 at the Naval Air Development Center



P-3B



P-3C

These drawings of the P-3B and -3C show 1 of the major effects of computerization. In the P-3B, all of the sensor operators are lined up facing 1 side of the airplane, so that the TACCO can look over their shoulders and integrate the data they produce. The airplane is far too narrow to allow for side-by-side seating facing forward or aft, which would be much more comfortable. In the P-3C, only the 2 acoustic operators face to the side, since only they use consoles too wide to be mounted athwartships, and the TACCO normally need not look over their shoulders, seeing what is needed on the TACCO display. In the P-3C, the TACCO seat is the one facing forward, on the right-hand side of the fuselage, just forward of the wing. (U.S. Navy)

(NADC) at Johnsville, Pennsylvania (the contract for P-3A production was not let until that October). Contracts for feasibility studies for computerization of airborne ASW were awarded in mid-1961 to North American (Autonetics), Hughes, Librascope, and Loral. A-NEW was approved in December 1962; the program was managed by NADC rather than by any single outside contractor. At that time the principal contractors were Dunlap & Associates, General Dynamics/Electronics, Grumman, Lockheed California, Loral, and Univac (Sperry), the last for the computer. As the manufacturer of the P-3C, Lockheed ultimately became system integrator (the company was displaced only with the advent of the Update IV version).

The first Mod 1 version was flight-tested on board a P-3A early in 1964. It was reportedly so successful that the fleet tried hard to bring this interim version into production. The next version, Mod 3, was flight-tested in 1966 (Mods 0 and 2 were ground versions). The final prototype system was Mod 3.2. The P-3C was approved for production in August 1967, and the first production prototype flew on 18 September 1968, roughly contemporary with the Nimrod, which also has a computerized tactical system. The P-3C entered service in 1969. By 1965 work on a second generation (Mod 4 ground prototype), compact enough to fit on board a carrier airplane, was beginning, with first contracts awarded during FY66. Mod 5 was the airborne

prototype. The result was the S-3A system described separately below.

Mod 1 doubled the rate at which a P-3 could prosecute a fast submarine, partly because the TACCO could handle twice as many sonobuoys. For the first time, too, the TACCO could use a variety of sonobuoy types simultaneously. Tactical navigational accuracy improved by an order of magnitude. Mod 3 introduced an improved TACCO console (50% more functions with about 30% fewer buttons, using VABs) and standardized multipurpose sensor displays to replace the earlier electro-mechanical ones (so that acoustic operators could, for example, monitor such nonacoustic sensors as the MAD). This version also introduced the Univac 1830 computer (CP-823/U), which had a maximum capacity of 32 kwords (in 4k increments), replacing an adapted air force missile-guidance computer. The P-3C entered service equipped with the more powerful Univac 1830A (CP-901), which was about twice as fast (1830 microsec cycle time was 4 microsec, and add/subtract time was 8 microsec) and had a 64k memory (plans originally called for 48k). In 1967 it was officially estimated that a P-3C would be 2-3 times as effective as a P-3B, essentially because of automation.

Automation also brought complexity: it was said that the electronics part count in 1 P-3C equalled that in all 144 P-3Bs. However, reliability did not suffer badly because the new electronics was generally solid-state.

The following description applies to the original P-3C (A-NEW) system; see the ASW section for details of improved versions (Updates).

The tactical coordinator (TACCO) is equivalent to a ship's TAO, supervising 2 acoustic sensor operators (SENSOs 1 and 2) and a nonacoustic operator (SENSO 3). Typically, a P-3C also carries 2 observers aft, plus a navigator-communicator and a flight-deck crew of 3. Compared to a P-3A or -3B, there are 2 fewer acoustic operators. However, a P-3C can continuously monitor 16 sonobuoys, compared to 8 for a P-3B or 4 for a P-3A, and the frequency spectrum covered is 10 times wider. These improvements all result from electronic, rather than electro-mechanical, data collection. A single operator can monitor 1 buoy or 1 narrow band visually while the system collects data from other buoys and other bands, then shift to those other data at will. Physically, the great change from past practice is to supplement the usual paper LOFAR recorders with CRTs. However, the expectation (in Mod 3) that all the SENSOs would have multifunction consoles has not been realized.

Compared to a P-3C, a P-3B has more specialized crew members. Navigation is a full-time job, so there is a separate radio operator. Sensor stations are specialized, so there are separate MAD/radar (equivalent to SENSO 1), Julie-ECM, and Jezebel stations. There are 3 observers, rather than the 2 on the P-3C, but the P-3C gains enormously in this respect by adding an LLLTV or FLIR (which SENSO 1 observes).

The central processor was conceived as part of a computer-aided human decision system. The tacit assumption was that the computer could not be expected to detect passive sonobuoy targets automatically. A SENSO decides that a LOFARgram indicates the presence of a submarine and passes that processed information (in the form of bearing lines or likely detection circles around particular buoys) into the central tactical computer by means of keysets on the SENSO 1 and 2 consoles.

The TACCO and SENSO 3 have ASA-70 summary tactical displays, whose 16-in CRTs can show synthetic-video symbols, scan-converted raw radar video, and LLLTV (later FLIR) video. A second CRT shows alphanumeric, such as radio channels and remaining sonobuoys. The TACCO calls up information from the SENSOs and from the central computer via a trackball and keyboards.

The pilot and copilot have ASA-66 tactical-data displays (with 7.5-in CRTs) showing sonobuoy positions, fly-to points, aircraft position and track, and predicted submarine track and position. These data are also available to the TACCO. The pilot can enter visual contacts directly into the display (and thence into the central computer).



An AQA-7 sensor station on board a P-3C shows both the CRT and the multichannel hard-copy recorder below it. The CRT is fed by a computer memory; operators can switch among buoys or among narrow bands without losing the data on the other buoys or the other bands. The hard-copy recorder, however, has no memory beyond what is on the paper, so it is very limited in the number of channels it can handle. (U.S. Navy)

In the computer-controlled mode, the airplane detects a submarine using passive LOFAR buoys, then drops command-activated buoys (e.g., SSQ-62), whose pinging is controlled directly by the central system computer, to localize the target. Then the plane flies directly over the predicted target position, using MAD for final confirmation before dropping a weapon.

Because buoys are selected through the computer (which is aware of the mix on board), the primary launchers on a P-3C are external: 48 unpressurized A-size preloaded chutes. They are supplemented by 3 reloadable A-size chutes (with 36 buoys stowed in launch containers) and 1 B-size chute. Earlier P-3s stowed all their buoys internally because they were manually selected: they used 9 chutes (and the airplane had to be depressurized to launch buoys through them).

Aside from the new acoustic processors, the P-3C introduced the APS-115 radar for full 360-deg sea-surface coverage and an LLLTV instead of a searchlight. The 43rd production P-3C introduced the ASQ-81 MAD. There was also a new automated ESM suite.

◆ ATDS

The Airborne Tactical Data System, the airborne equivalent of NTDS, is carried on board E-2 aircraft. Its air-to-air link to fighters is Link 4 (now Link 4A). ATDS was conceived roughly simultaneously with NTDS. The then Bureau of Aeronautics began to develop requirements for a carrier-based AEW/CIC airplane in 1955, but as yet there was no computer small enough to serve it. An interim contract was, therefore, given to Grumman for an interim nonautomated alternative, the E-1B (WF-2). The ATDS specification was issued in November 1955. Grumman received a contract for the E-2 on 5 March 1957, and the first fully equipped airplane flew in April 1961.

The E-1B carried 2 radar operators who could maintain 4-6 tracks and could control no more than 2 simultaneous intercepts using voice control. In 1960 it was estimated that an E-2A (not yet in service) could maintain 250 tracks and control 30 interceptions (via automatic data link). Newer versions have greater capacity. The crew consisted of 1 radar operator (instead of 2), an air controller, and a CIC operator. Each has an APA-172 console with a 10-in PPI and a 5-in alphanumeric display; targets are designated by light pen. The air-search radar automatically detects targets.

The system (picture-keeping) computer, a dual L-304, OL-77/ASQ, replaced an earlier hard-wired unit beginning in 1972. Originally, it had 8 kwords/module, but that capacity was doubled within a decade. A current project to buy a new computer had not been funded at the time of writing (mid-1990).

◆ LAMPS (SH-2 and SH-60B)

See the ASW section.

◆ S-3A

The S-3A tactical system was conceived as a smaller version of that of the P-3C, with some of the reduction in size balanced by better automation and a faster computer (AYK-10). There are only 3 crew members, in addition to the pilot: the copilot, responsible for nonacoustic sensors (radar and MAD) and communications; the sensor (acoustics) operator; and the tactical coordinator, who directs the weapons system as a whole.

Each has an ASA-82 multipurpose display (MPD). The pilot's smaller display is limited to the tactical plot; it guides the pilot during submarine-contact prosecution. The auxiliary readout unit, at the SENSO station, presents acoustic data only: the SENSO can simultaneously observe processed signals from 16 sonobuoys and monitor the tactical situation. Each MPD can display all mission data: acoustic (e.g., LOFAR) data, raw and scan-converted radar, FLIR pictures, ESM data, MAD data, and a tactical plot. The MPDs also present computer-generated cues (operational directions and suggestions) at the TACCO, COTAC/copilot, and SENSO stations, as well as alerts (system condition or failure messages).

FLIR and radar video are sent directly to the tactical displays; the acoustic-data processor (OL-82) feeds directly into the TACCO and SENSO displays and into the ARU. ESM, sonobuoy, and MAD signals are fed into the AYK-10 computer and thence into the displays. The computer (under TACCO control) normally controls sonobuoy dropping, although there is an alternative manual mode. Of the 60 sonobuoy chutes, 1 (chute P-2) is reserved for search and rescue.

The central computer automatically computes a splash point for each sonobuoy. It monitors sonobuoy drift through the water by locating all the buoys in the field. Passive buoys transmit radio signals continuously, and the sonobuoy reference system (SRS, designated ARS-2) locates them by passive interferometry, using 13-blade aerials distributed over the airplane's fuselage (i.e., by measuring phase differences between signals from the same buoy received at different aerials). Active buoys, which do not transmit continuously, are located by sending a modulated signal on their UHF command links and then measuring the same modulation as received on their VHF up-link. ARS-4 is a modified ARS-2 for the S-3B version of the Viking. The sonobuoy reference system was a major change from past practice, eliminating the requirement to overfly the buoys periodically, and permitting an airplane to remain at high altitude. A version of the S-3 sonobuoy reference system (ARS-3) was later incorporated into the Update II version of the P-3C.

The main (AYK-10) computer compares sonobuoy signatures with a library of stored signatures. The acoustic processor calculates target position when the airplane switches from passive detection to active localization, using active buoys. The acoustic processor was credited with a capability for automatic detection, though this may have been overstated. It integrates LOFAR signals over time to detect lines automatically, but in some cases such integration will not bring up a discontinuous

or changing line that might be evident from visual examination. The computer memory retains a record of the rise of different buoy signals; in theory, the sensor operator can use these data to trace the movement of a submarine through a buoy field.

The acoustic processor continuously records 28 channels of analog data, including 16 sonobuoy channels, raw and filtered digital MAD data, time codes, MAD cues, and commands from the AYK-10 computer. The SENSO and TACCO can listen directly to the signals heard by any particular buoy, e.g., in a directional audio mode.

Proposals for what became the S-3 were submitted in April 1968, and in August 1968 Lockheed and General Dynamics were asked to submit final versions. Lockheed was chosen in 1969. The S-3A first flew on 21 January 1972, and it formally entered service in February 1974.

The Canadian CP-140 Aurora has a modified version of the S-3A suite. Compared to a P-3C, it has a larger multipurpose display (MPD). The tactical compartment contains three 2-operator consoles, each with 2 MPDs and keysets to communicate with the AYK-502 (Univac 1832, i.e., AYK-10) central computer. The acoustic processor is OL-5004, similar to the OL-82 of the S-3A but with added vernier displays and ambient sea-noise measurement.

◆ TDS (RAN/RAWS)

The Collins Tactical Data System for helicopters was originally developed for the coast guard HU-65A and then modified for the RAN S70B Seahawk. The RAN version is called RAWS (Role Adaptable Weapon System). RAWS is quite different from the U.S. LAMPS; the RAN wanted the helicopter to be effectively independent of the frigate from which it flies. The model for RAWS, then, is the U.S. S-3 Viking.

TDS differs radically from earlier computer-based tactical data systems in its emphasis on the interaction between operator and display; it is designed so that the operator need not take his or her eyes from the display to use a keyboard. In a conventional system, the entry buttons must change function during operation, so touch-typing is impossible; the operator must be able to see what the buttons represent. The operator runs the TDS system by manipulating icons on the tactical display with a cursor driven by a joystick (a slew controller). The effect is much that of the Apple Macintosh computer. The manufacturer, Collins, emphasizes this view by calling the system computers Display Control Units.

Using RAWS, 3 operators can conduct a full ASW mission: a pilot, a TACCO, and a SENSO. The U.S. LAMPS III, which has much the same airframe, has 4 more crew members, aboard the parent ship, in the ship's operational cell (SOC).

The pilot and TACCO sit side by side facing forward, each with a navigational CRT (horizontal situation video display), with a larger (8 × 8-in) raster-scan tactical display between them. The navigational displays can show synthetic-video dial faces, radar video, synthetic-map data, map information overlaid on radar video, a hover display, and FLIR (when installed). The big raster-scan display shows the overall tactical situation in terms of NTDS and special symbols. The console between the pilot and TACCO carries dual keyboards and a slew controller.

The SENSO console in the rear of the helicopter contains a second tactical display, a third keyboard, and a second slew controller.

The central computer is provided with a data-loader cartridge carrying navigational data, sonobuoy loadout, initial search-pattern placement and orientation, contact/target information, and communications parameters (frequency selection and tuning). This form of initialization, data going directly into the controlling computer, makes for much quicker launch after contact, as little manual prelaunch setting is required. It also provides a natural pathway for in-flight updates via a data link. Data-loader capacity is 32 kwords.

The system is tied together by a dual-redundant 1553B bus, which has 22 terminals, 3 of which are reserved for future



The cockpit of an RAN Seahawk helicopter shows elements of the Rockwell Collins tactical data system. The cockpit panel is dominated by the 8 × 8-in tactical display unit (TDU). The smaller screens are MFD-80 navigational displays (horizontal situation displays), and the pilot and copilot each have CCD-810 control display units (on either side of the central console). The slew stick controller for the main display is visible on the left, at the lower edge of the CCD-810. (Rockwell)

growth (ESM, FLIR, and a dipping sonar); the current system uses 46% of bus capacity. The acoustic processor is a UYS-503 sonobuoy processor (which can handle 8 DIFAR buoys simultaneously). The helicopter carries 30 sonobuoys and 2 torpedoes or missiles. The SENSO chooses and launches sonobuoys via the tactical system, and the tactical display provides the necessary displays and alerts of contact. The system computes CPAs, doppler fixes, and hyperbolic fixes.

In the antiship role, the displays can show radar video, and the same navigational programs can set up a missile launch.

Each of 2 DGUs contains 3 advanced-architecture microprocessors (AAMPs): a system processor, a display processor, and an I/O processor. The AAMP is a single-chip 16-bit VLSI CMOS microprocessor, development of which began in 1979; it has been incorporated into numerous Rockwell projects, including the GPS satellite. The chip can execute double (32-bit) and triple (48-bit) -precision floating-point arithmetic and 16- and 32-bit fractional arithmetic. There are 3 versions. AAMP1, in production since 1986, has a peak performance of 1.7 MIPS (sustained 0.8 MIPS) at a clock rate of 20 MHz. It has also run at 30 MHz (2.4 MIPS) over a limited temperature range, and a

version using 1.6- and 1.2-micron rather than 2.0-micron technology has run at over 50 MHz. This chip contains about 74,000 devices. There is also a version fabricated using CMOS/SOS (silicon on sapphire) technology, for better resistance to radia-

#	B	RF	PROCESSING	T	L	S	SYSTEM PARAMETERS	
1	D	01	M1 V1 V2 DEMON	S	S	S	STATUS	S
2	L		M1 V1 V2 DEMON	S	S		TIME	01:40:37
3	R	02				S	TACT MOD	LOFNAR
4							SOUND SPD	1475
5	Z	01	M1 V1 V2 DEMON	S	S	S	AUDIO L	DIRECT 1
6			BEAM = 000 DP = 1				AUDIO R	DIRECT 2
7	T		SHALLOW CW 0.1 MAN			S	MVAR	M010
8	A							

BD	CF	BW	BD FROM	CF	BW
M1	320	640	B1	M1	320.0 30
M2	640	1280	B2	M2	640.0 30
V1	20	40	B3	V1	15.0 30
V2	60	40	B4	V1	45.0 30
V3	250	20			
V4	2310	40			
V5	150	10			
V6	300	10			
V7	55	10			
V8	25	5			

BD	CF	BW	TH	RK	ALERTS
1	2310.0	30	60		
2	150.0	10	60		
3	350.0	10	60		

BUOY TYPE		
1 LOFAR (L)	5 RANGE ONLY (R)	9 ANM (N)
2 DIFAR (D)	6 DICASS (A)	10 LOFAR DSOT (T)
3 VLA (V)	7 BATHY (B)	11 DICASS DSOT (T)
4 CODAR (C)	8 BARRA (Z)	12 BARRA DSOT (T)

Text (an acoustic set-up page) used by the Seahawk sensor operator (SENSO) to set up the acoustic processor and sonobuoy receivers. (Rockwell)



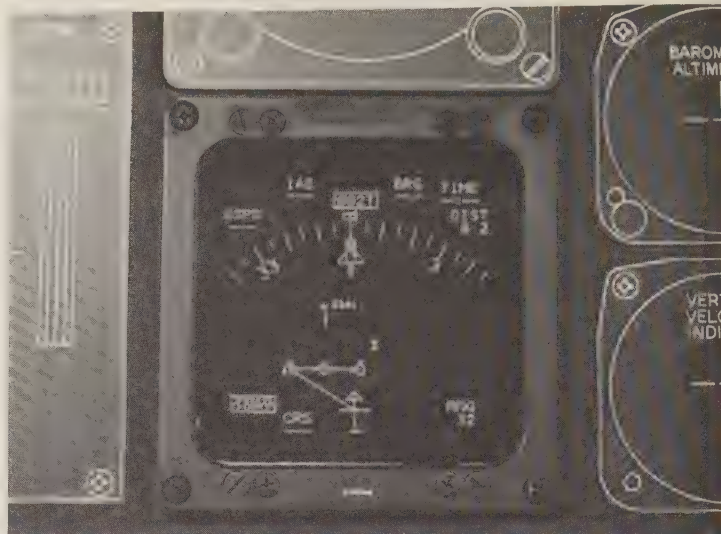
TACCO display of a sonobuoy operation on board an Australian Seahawk. The operator uses the slew stick controller to select from among a menu of icons shown at the left. The 3 buoys marked "B" are bathy-thermal, measuring the temperature (and, therefore, the sound velocity) profile. A line of passive buoys has been laid; the crossed symbol at the lower right indicates own aircraft (the triangle laid atop the left-most buoy indicates a fly-to point). The small triangles pointing to the left indicate visual contacts (stylized eyes). A hostile submarine contact, with course and speed (indicated by vector length) appears with its contact number, 2341, heading toward the buoy barrier. The small circle superimposed on the large one is the cursor; the circle at the bottom (above the word "fixed") is the active icon, with its meaning given. The letters "TACP" indicate the current display mode, with the display range scale, current time, display center point, alerts and annunciations, and bearing/range spread out along the lower border of the display. The hooked-item designator and strobe range/bearing from cursor can be displayed above the lower right-hand border. At the left, the upper left symbol indicates display mode selection. Modes are: TACP (tactical plot), R/TACP (radar tactical plot, i.e., radar display with tactical-plot symbology), R/TGT (radar display with radar tracked target symbology), Radar (video), and ACOUS (acoustic processor display video). Next to it is scale selection. Below are query (calls up an associated alphanumeric page) and move (repositions template and active selection display area to the other side of the display screen). The third line is the recenter command (selects display screen center) and suppression/restoration/deletion of designated targets. Fourth line: vector and strobe commands, the former displaying associated bearing and range. Fifth line: pointer (displays the pointer symbol) and circles (creates and modifies circles). Sixth line: create a track and track aid (update, reposition, modify, split, merge, sequence existing tracks; displays variable-length leaders and creates a target area of probability). Seventh line: tac aids (establishes and displays solutions for tactical and attack display aids) and fly-to (creates a fly-to point). Eighth line: transfer (displays designated targets on the horizontal situation displays) and data link (provides for designation of targets for data link transmission). Ninth line: special tactical markers (SPL) and fix designate (displays a tentative target symbol at the operator-designated location). Tenth line: patterns (creates manual-flight and sonobuoy-drop patterns) and stab (stabilizes sonobuoy plot and establishes data link gridlock). Eleventh line: hold (temporarily suppresses the display of all new [unacknowledged] PDIs) and radar center/scale (changes radar center/scale to that currently selected for the tactical plot display). (Rockwell)

tion. AAMP2 has 48-bit internal data paths for better performance and adds some instructions to the AAMP1 set. Performance: 2.3 MIPS peak, 1.6 MIPS sustained. Production began late in 1988. This chip contains about 117,000 devices. An SOS variant is planned. The current TDS uses the AAMP1 chip.

The current TDS uses 70% of the installed memory and 50% of the ultimate maximum memory capacity. There is a current reserve of about 40% of processor throughput.

◆ UDACS

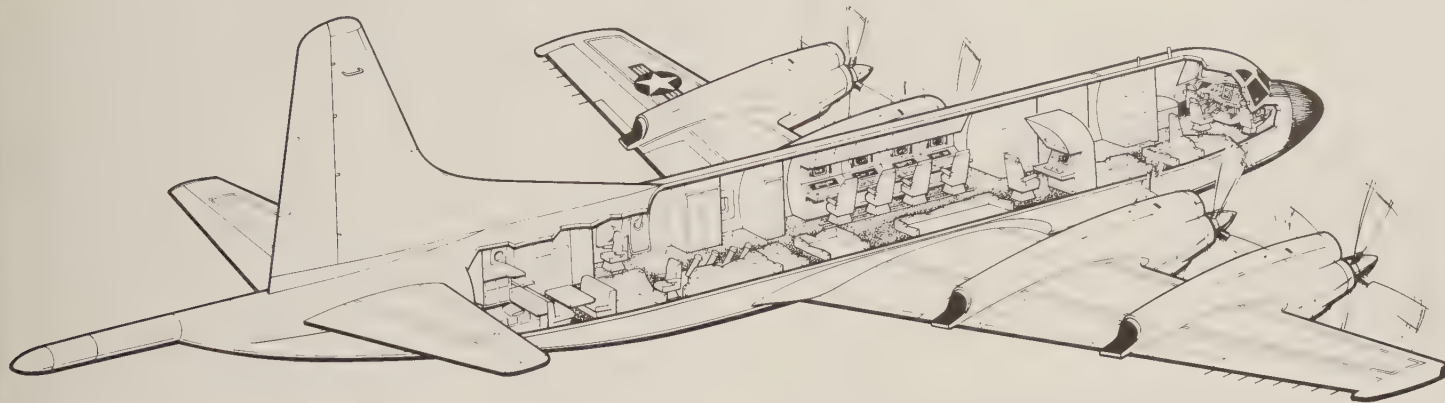
Boeing's Universal Display and Control System is the basis of the P-3C Update IV. The UDACS console was originally devel-



The horizontal (4 × 4-in) display of an Australian Seahawk shows, at the same time, navigational data and the tactical plot (at the center), with a fly-to point. (Rockwell)



UDACS is the next-generation U.S. maritime-patrol-aircraft system, replacing the centralized A-NEW of the P-3C and its 3 Updates with a distributed architecture using 68020 processors tied together by a 32-bit maxibus; burst mode throughput is 192 Mbytes/sec. In keeping with the distributed architecture, all the operators (including the TACCO) have identical workstations, whose screens can display any sensor's output, and which can combine sensor outputs using windowing. Conventional keyboards are replaced by plasma touch screens, which can change configuration in accordance with changes in workstation function. The upper picture shows windowing: a tactical plot is superimposed on LOFARGrams. The lower photo shows a sonobuoy tactical plot with a FLIR image windowed into its upper left corner. Note the keyboard in the console next to this one; recent UDACS photographs show only the plasma panel. (Boeing)



Update IV (UDACS) installed on board a P-3C. All 4 sensor-operator consoles are identical and lined up together. The TACCO console is forward, facing forward. (Boeing)

oped for the RNZAF P-3B update, and it is now offered for installation in a possible maritime-patrol version of the Boeing (Canada) Dash-8 airliner.

UDACS is a fully distributed system, without any central computer. The microprocessors are 68000-series chips.

NAVIGATIONAL SYSTEMS

FRANCE

◆ Syledis

Syledis is a precision hyperbolic navigation system used by French Tripartite Minehunters, operating at VHF frequency. See Decca (below) for an explanation of hyperbolic navigation. Syledis was developed specially for the Tripartite program. The minehunters were also fitted with Thomson-CSF TSM 5700 doppler sonars to measure velocity (both fore and aft and lateral) over the ground.

◆ Toran

Toran is a precision circular navigation system used by French Tripartite Minehunters, operating at HF frequency. Distances to 2 transponder beacons are compared, and position is found by triangulation. The Toran shore system is operated by the French lighthouse and navigational beacon authority.

◆ Trident III

Trident III is a 3-beacon position-fixing system developed by Thomson-CSF and installed on board some export mine-countermeasures craft.

USSR

There are 2 major satellite navigational systems, 1 comparable to the U.S. Transit and the other to the U.S. Global Position Satellite (GPS). The Transit equivalent consists of 6 satellites in 60-deg orbits and 6 in 30-deg orbits. GLONASS is reportedly comparable to GPS, the first 3 satellites having been orbited in October 1982.

There are also several surface systems. One of them, ALPHA, is similar to the U.S. Omega. It is not clear whether the designation is Soviet.

UNITED KINGDOM

◆ Decca

This navigational system was developed by the Admiralty Signals Establishment from 1937 on; Decca was first used to guide small craft and minesweepers during the Normandy Invasion in 1944. The Decca Navigator Company was founded to further

develop the system after the war, and to operate the associated system of transmitters. Although not as accurate as such higher-frequency systems as Hi-Fix/6, it is still used as a backup in mine countermeasures and would be available in wartime to guide merchant ships through cleared mine fields. Decca is effective at short and medium ranges; Loran and Omega are long-range systems.

Like Loran, Decca uses master and slave stations and measures position by forming a hyperbolic grid. All such systems are based on the geometric fact that all points for which the difference between the distances to 2 fixed points is the same form a hyperbola between them. A series of differences defines a series of hyperbolas, and in theory one can determine on which hyperbola one lies. A second pair of stations provides a second series of hyperbolas, and position is determined by the intersections between the 2 series.

Decca operates at low frequency, 70–130 kHz, with a nominal maximum range of 240 nm. Average maximum position errors at this range are 150 yd by day and 1200 yd by night; at 100 nm from the master station, the average errors are 30 and 100 yd, respectively. Typically, a chain consists of a master and 3 slave stations. The signals are all CW, distances being measured by comparison in phase between master and slave signals. Because phase changes are cyclic, position can be measured only within one 360-deg cycle, which is called a lane. Special supplementary signals are transmitted so that a receiver can determine in which lane it is located.

◆ Hi-Fix/6

Hi-Fix/6 is a Racal Marine Systems (formerly Decca) precise navigation system, operating at 2 MHz, essentially a higher-frequency equivalent of Decca. Hi-Fix/6 and the earlier Hi-Fix are used by some mine-countermeasures craft (such as Belgian and Dutch Tripartite Minehunters and by British craft). Hi-Fix/6 is now being superseded by Hyperfix (see below).

◆ Hyperfix

Hyperfix is a Racal Marine Systems precise navigation system, superseding the earlier Hi-Fix/6. Like Decca and Hi-Fix, Hyperfix uses phase comparison. The system operates at 2 MHz (actually the 1.5–3.5-MHz band), with a repeatable accuracy of 5 m at 250 km at night (500 km in daytime), described as 20 times better than earlier 2-MHz systems. Ranges as great as 700 km are available much of the time, depending on ionospheric conditions. Accuracy is often between 1 and 2 m.

Each station in the chain transmits signals at 2 frequencies about 1% apart. As in Decca and Hi-Fix, phase comparison is used to determine position within a lane. The lane is determined (within a group of about 100) by comparison between the phases of the 2 signals. At the frequency used, a lane is about 75 m wide at the baseline. Resolution is 0.001 lanes (but the display is not fine enough to fully exploit this accuracy).

Hyperfix has been deployed in chains of remotely controlled stations around Britain. The system has been adopted by Canada and at present is being supplied under contract to the U.S. Navy.

Twenty-four stations are being supplied in the Persian Gulf under Japanese contract.

◆ Micro-Fix

Micro-Fix is a new Racal 5-GHz line-of-sight system with an accuracy about 1 m out to 80 km. The ship transmits a signal that is returned from 2 or more portable shore stations for triangulation. Racal claims that this system is unique in being continuously self-compensating. The company is now developing a nonradiating hyperbolic variant.

UNITED STATES

◆ GPS (Navstar)

Global Positioning System will be completed by 1990. It will fix position within about 16 m (spherical accuracy), and velocity within 0.1 m/sec. With such accuracy, GPS becomes a means of guiding weapons against fixed targets, and several recent weapons, such as SLAM, are to incorporate GPS receivers.

A user automatically chooses the 4 most suitably located satellites and locks onto their navigation signals, obtaining a pseudorange (time difference) to each. These 4 pseudoranges in turn figure in 4 simultaneous equations, which the specialized Navstar computer solves for user position.

The first series, whose launchings began in February 1978, cover the continental United States and are intended primarily for test and validation. Ultimately, an 18-satellite constellation will provide global coverage. Satellites orbit at 10,898 nm, with a 12-hour period. Each weighs 1020 lb and is expected to last 5 yr (carrying 7 yr' worth of consumables, primarily booster fuel).

Including in-orbit spares, the total system consists of 28 satellites.

◆ Loran/Omega

Long Range Navigation system was originally devised during World War II and is now quite common on a worldwide scale. Omega is a variation. The basic unit consists of a "master" emitting timed pulses and a transponder ("slave") some distance (usually about 500 nm) away. A ship equipped with Loran listens for both master and slave pulses. The time difference between the 2 indicates the difference in path between the 2 stations, since the slave emits only after the master pulse has traveled the distance between master and slave stations. This time difference in turn defines a hyperbola on which the listener must be located. By listening to 2 pairs, the ship can locate itself on 2 intersecting hyperbolas (the system is often called hyperbolic navigation or hyperbolic fixing). Accuracy depends on the ratio of ship's distance from the baseline to baseline length; the longer the baseline, the better. Therefore, the tendency in Loran has been toward lower frequencies that propagate better over greater distances.

The original Loran-A operated at 1850–1950 kHz with a range of about 450–800 nm by day and 1400 nm by night, using ground-wave transmission. Loran-A was very widely deployed in the North Atlantic and North Pacific between 1955 and 1970. Loran-B was an abortive attempt to achieve greater range by reducing frequency. Stations proved difficult to synchronize, and the ground and sky waves interfered. Loran-C solved these problems by using synchronized pulses for both time-difference and phase comparison, and -C became operational in 1957. As coverage expanded, -C superseded Loran-A, which was largely abandoned in 1977. Loran-C operates at 90–110 kHz. Ground wave range is 1200 nm, but signals can also propagate by sky wave (range with 1 reflection from the ionosphere is about 2300 nm, and with 2 reflections about 4000 nm; the latter can be received only at night).

The purpose of the master/slave combination is to synchronize signals from the 2 stations of the hyperbolic pair. During the late 1960s, atomic time standards that made for simpler operation were developed. Pulses were synchronized by time standard. The secondary (formerly slave) station transmitted

upon receiving the master pulse but did not have to retransmit the original pulse. The system uses a form of pulse compression to achieve very long range and compares details of the pulse to avoid confusing ground and sky waves.

Omega operates at 10–14 kHz. At such very low frequencies, signals penetrate the sea surface and can be used by submarines operating at periscope depth. By using atomic time standards to synchronize very distant stations, Omega can exploit baselines as long as 5000–6000 nm; a total of 8 stations (the last of which, in Australia, entered service in 1982) cover the entire globe, 3 and usually 4 stations being usable from any position. As in Decca, phase difference is used for positioning, each lane being 8 nm wide on the baseline. Lane identification is by phase comparison of 3 auxiliary signals multiplexed with the basic 10.2-kHz signal. A ship finds her approximate position by some other means, to within about 50 nm, and then uses Omega to obtain a better fix. Once an initial fix is obtained, a receiver can count lanes crossed to maintain an accurate fix. Positions can be obtained within 1 or 2 nm.

◆ PINS (SSN-2)

The Magnavox PINS (Precise Integrated Navigation System) is installed on board the new U.S. *Avenger*-class minesweeper/hunters, following tests on board the older minesweeper *Pluck*. PINS was designed to operate with or without the assistance of shore-based fixed reference systems, and also in very deep water, integrating all available references: Loran-C, Raydist, Transit (and then GPS) navigational satellites, and a doppler bottom log effective to depths as great as 20,000 ft. The bottom log measures true ship's speed, so that position can be measured accurately between satellite passes. PINS is also used to record mine contacts and the ship's track through an area.

◆ Raydist

The Hastings Raydist "T" is a commercial hyperbolic (phase comparison) navigational system broadly comparable to Decca and its successors, originally adopted for the sweeping of Hanoi-Haiphong in 1973 and still in use as a U.S. alternative to other fixed systems. In 1972 the United States had no such system, and navigational accuracy was no better than 100–250 yd; a more precise system had been sought for a quarter century. Two ground networks and 33 receivers were purchased in October 1972 and installed on board the sweeping helicopters, the mine-clearance ship MSS 2, and 2 ocean sweepers. Each ground network consisted of 2 CW and 2 single-side-band (SSB) transmitters. During the 1973 clearance operation, average navigational error was reduced to 10–20 yd.

◆ SINS

SINS stands for Ship's Inertial Navigation System; it is presumed that the Soviets have an analog. SINS is the basic sensor of the U.S. Navy's ballistic-missile program (Polaris, Poseidon, Trident) since SINS is the nonemitting submarine position-and-motion indicator. In practice, SINS data are updated every so often by using Transit or some alternative navigational satellite, but any such update requires the submarine to put a detectable radio antenna through the surface. SINS's performance is measured in terms of the required reset interval to determine position to within a given error. Perhaps the major source of error is drag exerted on the main SINS gyro by its supporting structures.

Compared to the inertial sensor of a missile, SINS must function over much longer periods at much lower velocities. Otherwise, it is identical in concept: measured submarine acceleration is integrated to provide submarine velocity and then integrated again to provide submarine position. The missile's fire-control system requires not only the absolute position of the submarine (latitude and longitude) but also its heading, speed (north and east components), roll, pitch, and vertical velocity (heave), a total of 8 parameters.

Work on SINS began in 1954, based on the research done for the inertial navigation system of the air force's Navaho cruise

missile. The first unit, installed in the USS *Compass Island* and *Nautilus*, was a modified missile N6A, with a gas spin gyro bearing. Mk 2 Mod 0 was introduced in the *George Washington*-class ballistic-missile submarines, with a total of 56 being built (3 per submarine). Installation of a new stable platform housing with fewer temperature gradients and airflow variations converted these units to Mod 4. A new SINS, Mod 2, was introduced to support the longer-range Polaris A-3. It incorporated a new gyro with greater angular momentum (i.e., less affected by unwanted torques). Mod 2 was installed in the *James Madison* class. Mod 3 introduced an additional monitor gyro, identical to the main gyro, that compensated for drift in the 2 leveling gyros. Mod 3 was installed in all ballistic-missile submarines but the *George Washington* class. For Poseidon, with its greater range (2600 nm), Mod 3 was modified to a new Mod 6 configuration.

A new electrostatic-gyro-support technology was developed for Trident submarines, although early units have the earlier Mk 2 SINS.

SINS is installed on board carriers, where it provides initial data to aircraft navigation systems (CAINS).

◆ TACAN

Tactical Air Navigation system is a transponder that provides aircraft with accurate distance and heading information. The antenna rotates within a radome, producing a series of coded pulses: bearing relative to magnetic north, beacon identification, and beacon distance. Equipment on board the aircraft processes these pulses to provide location data. Because

TACAN is a transponder, it is somewhat more discreet than the earlier beacons, which emitted whether or not they were required. Current U.S. TACANs operate on 252 channels (evenly divided for reception and transmission) in L-band (1025–1150 MHz for reception, 962–1024 and 1151–1213 MHz for transmission). TACANs can communicate with up to 100 aircraft within a 300-mile radius. Ships generally carry a single TACAN antenna, mounted at the masthead. There are 4 standard antennas, URN-20, URN-25, SRN-6, and SRN-15, all of which provide the same type of pulse train.

The Soviet equivalents are Top Knot, in the *Kiev*-class carriers, and various versions of Round House, which are always mounted in pairs, either fore and aft or athwartships.

◆ Transit

Transit was the first U.S. satellite navigation system, developed by the Applied Physics Laboratory (APL) to exploit the doppler effects of passing emitting satellites like the first Soviet Sputnik. APL used doppler data to measure the Sputnik's orbit but then realized that, given a known orbit, doppler data could be used to measure position on the ground. Transit was proposed in 1958, primarily to support the Polaris submarine program, and was placed in full-time service in 1964, becoming the first U.S. operational satellite system. It was made available for commercial use in 1967.

The current Transit system consists of six 100-lb solar-powered satellites in 600-nm orbits, each carrying a precise crystal clock and emitting orbital signals. Accuracy at a fixed site is about 100 ft.

STRATEGIC STRIKE SYSTEMS

CHINA (PRC)

◆ C-SS-N-3

Dimensions: approx 1.5 × 10 m [60 in × 33 ft]

Weight: approx 14,000 kg [30,000 lb]

Warhead: 1 (reports vary on yield)

Range: est 2700–3600 km [1750–2300 nm]



A C-SS-N-3 missile being loaded on board a Chinese Xia-class submarine. (*Ships of the World*)



C-SS-N-3 missiles. (*Ships of the World*)



A Xia-class missile submarine. (*Ships of the World*)

The first submerged launch was carried out on 12 October 1982 by the single Golf-class trials submarine, at a range of 1600 km. The missile has 2 solid-propellant stages. Twelve missiles can be carried by Xia-class submarines; in 1988, 2 such submarines had been completed and 2 were under construction. Reportedly this weapon was developed in part from the CSS-2 (DF-3) land-based ballistic missile, which has a range of 2700 km and which carries a single 1–3-MT warhead (and, in its newer version, 3 MRVs, 50–100 kT each). This missile was first fired by a Xia-class submarine during July 1988. The Chinese designation is Ju Lang 1 (JL-1).

An improved C-SS-NX-4 is currently under development; reportedly this improved version carries a 2-MT warhead.

FRANCE

Submarine-launched ballistic missiles are ejected from their tubes by pressurized air, stowed in bottles (M20), or by gas generators (later weapons).

◆ M20

Dimensions: 1.5 × 10.4 m (5.2 m first stage, 2.6 m second stage) [59 in × 34.1 ft; 17.1 ft, 8.5 ft]

Weight: 21,000 kg [46,300 lb]

Warhead: megaton range (TN-60); later replaced by an improved TN-61

Propulsion: solid-fuel rocket: Type 904 first stage, Rita IIP6 second stage. Burn duration: first stage 50 sec (45,000-kg thrust); second stage 52 sec (32,000-kg thrust). [99,200/70,500-lb thrust]

Range: 3000 km [1900 nm]

M20 was the second-generation French naval ballistic missile, succeeding the original M1 and the longer-range M2. M20 is an M2 with a megaton warhead accompanied by penetration aids (decoys); it is intended specifically to penetrate the missile defense around Moscow. The thermonuclear warhead is hardened against ballistic-missile defenses, presumably such radiation effects as neutrons and EMP. This missile may also be designed to use a steep energy-inefficient trajectory that limits exposure to defensive radars by reducing time spent in their beams.

The M20 missile is cold-launched by compressed air and is aerodynamically unstable. The second stage and the warhead are the same as those of the S3 ground-launched strategic missile. M20 became operational in 1977 (on board the submarine *Indomptable*). Only 1 submarine, *Le Redoutable*, still carries this missile; all of the other submarines have been converted to fire the newer M4.

◆ M4

Dimensions: 1.93 × 11.05 m [76.0 in × 36.2 ft]

Weight: 35,000 kg [77,140 lb]

Warhead: six 150-kT TN-70 (MIRVs)

Propulsion: 2-stage rocket with powered MIRV bus. First stage: Type 401(P10), 71,000-kg thrust; second stage: Type 402(P6), 30,000-kg thrust; third stage: Type 403, 7000-kg thrust. [156,500/66,100/15,400-lb thrust]

Range: 4500 km [2900 nm]

M4 is the MIRV successor to M20. Almost twice as heavy as M20, M4 is designed to fit the launch tubes of existing French strategic submarines. Exploiting French research into small thermonuclear warheads, the French government decided to proceed with M4 in December 1974. Compared to M20, M4 is an all-new missile with new first- (401), second- (402), and third- (403) stage motors. The last powers the warhead-dispensing bus.

The M4 missile is launched by a powder charge; M4 can be fired at greater depths than M20 and can be fired in closer sequence than the earlier weapon. The 6 TN-70 warheads are spread over a 150 × 350-km [97 × 227-nm] area.

M4 was first fired at sea on 10 March 1982 and became operational in 1985 on board the submarine *L'Inflexible*. M4 now arms all earlier strategic submarines except the *Le Redoutable*; conversion of that ship would have required the installation of new (rather than modified) launch tubes.

Delays in M5 development have led to a new program for an interim weapon, M45, which is to enter service in 1994 on board the submarine *Le Triomphant*, the first of a new generation. M45 can carry a TN-71 warhead to a nominal range of 5000 km [3200 nm]; however, an M45 carrying a single warhead reached 6000 km on 4 March 1986. Operational M45s will carry 6 new TN-76 "stealth" warheads, presumably to evade Soviet ballistic-missile defenses.

◆ M5

The M5 missile is under development for projected second-generation strategic submarines (the first missiles will go to sea in the third submarine of the class). Design requirements include a range of 3240 nm and 8–12 TN-75 MIRV warheads; radar signature may be reduced, and penetration aids added, to counter Soviet ballistic-missile defenses. This weapon was initially described as M4C.

◆ ASMP

Dimensions: 0.30 m × 5.38 × 0.96 m over fins [11.8 × 211.8 × 37.8 in]

Weight: 840 kg [1851 lb] **Warhead:** 300-kT

Propulsion: integral rocket-ramjet; maximum speed Mach 3.5

Range: 80+ km at Mach 2, low altitude; 250+ km at Mach 3, high altitude [52 and 162 nm]

A medium-range nuclear standoff missile, ASMP (*Air-Sol Moyenne Portée*) is designed for use against both tactical and



The French submarine-launched ballistic missile M5 emerging from the water. (Armées d'aujourd'hui—SIRPA)



ASMP under the wing of a Super-Étendard. (Aerospatiale)

strategic targets. ASMP is carried by 24 (of a total of 55) Super Étendard carrier attack aircraft as well as by French land-based tactical (Mirage 2000N) and strategic (Mirage IVP) aircraft. In French official parlance the word "tactical" was changed to "prestrategic" before the ASMP went into service, to emphasize French reliance on deterrence through the threat of escalation. In the case of the Super Étendard, ASMP replaces a standard nuclear gravity bomb (the 60-kT AN-52, first deployed in 1977). This program began in March 1978 after a government decision to proceed with an aircraft-carried standoff weapon for attacking hardened targets. ASMP was, therefore, primarily a way of extending the usefulness of the French strategic air arm.

The carrier *Foch* was refitted in 1987–88 to carry ASMP in place of the earlier AN-52 bombs. However, her sister, the *Clemenceau*, is not being refitted because she is to be replaced by the new nuclear carrier *Richelieu* about 1996. It is reported that the French Navy wanted a lower-yield version for antiship attack, but finances precluded development of 2 versions of the basic weapon.

The size of the missile was limited so that it could be carried by a Mirage 2000N. The missile design has some stealth features, including some radar absorbing material. In addition, ASMP is hardened against EMP.

ASMP's aerodynamic design is unusual, having 2 prominent angled air intakes, whose fairings lead back to the after end, but no wings as such. At very high speeds, the intakes and fairings provide sufficient lift, and the only special aerodynamic surfaces are the 4 fins at the tail. The intake fairings carry such auxiliary

equipment as the actuators for the fins. The air intakes are modeled on those of the Concorde airliner.

There are 3 alternative flight modes: high-altitude/terminal dive, low-altitude terrain following, or low-altitude with terminal pop-up for air burst (against naval targets). In the last case, the missile would attack from relatively short range (effective range is limited to about 60 km [39 nm] by the radar horizon of a low-flying attack aircraft). All 3 flight modes include preprogrammed evasive maneuvers.

The engine is probably the most interesting feature of the missile. The initial choice, a solid-fuel rocket, was rejected because it would have been much too heavy, resulting in an unacceptable 3–4-ton missile. Instead, a solid-fuel booster is used to accelerate the missile to Mach 2, at which speed the main ramjet is efficient. The rocket burns out in about 5 sec, and about 1/20 sec later the nozzle is ejected. The burnt-out booster becomes the combustion chamber, a "swirl type" developed since 1972. There can be no conventional flame holder (since all the volume of the chamber is occupied by the solid booster), so the flame is stabilized by the 2 jets of air from the air intakes, forming what amounts to a fluid flameholder. The fuel is conventional kerosene rather than the denser Shellodyne used in U.S. cruise missiles, the former fuel being much better known in France when ASMP was designed. However, a second-generation cruise missile will use denser fuel.

ASMP first flew on 23 June 1983 and was the first European missile to shift automatically from rocket to ramjet mode. The missile became operational on 1 May 1986 on board Mirage IVP bombers of the FAS (*Forces Aériennes Stratégiques*). Total planned production is about 100 weapons.

USSR

Reportedly, Soviet liquid-fueled missiles are floated up from their launch tubes before being ignited at the surface. If that is true, then they cannot be surface launched (they cannot be ignited in their launch tubes). The disadvantage is that they cannot be fired by surfaced submarines in the Arctic. On the other hand, a submarine could escape before her missiles, floating at the surface, ignited, thus not disclosing her position to possible counterattack. The denser solid-fueled rockets (SS-N-17 and -20) are, again reportedly, launched from their tubes by gas generators, as in U.S. service. They are, therefore, suitable for surface firing, e.g., in the Arctic. A DoD painting shows a Delta-IV-class submarine surfaced in the Arctic, firing her SS-N-23 missile. Presumably, then, this class uses a gas generator to eject its weapon.

◆ SS-N-3 Shaddock

See the Strike/Surface Warfare section for the strategic version of this tactical missile.

◆ SS-N-5 Sark (R-21)

With the retirement of the Golf-class submarines, this missile is extinct. See the first edition of this book for details.

◆ SS-N-6 Serb

Dimensions: 72 × 390 in **Weight:** 41,600 lb
Warhead: one 1-MT in Mod 2, two 350-kT RV in Mod 3
Throw weights: 700 kg for Mod 2, 2350 kg for Mod 3
Propulsion: 2-stage liquid rocket
Range: 1300 nm (Mod 1); 1600 nm (Mod 2); 1600 nm (Mod 3)
CEP: 1640 yd

SS-N-6 was the first modern Soviet naval ballistic missile, carried on board Yankee-I-class submarines. It is reported that about 1000 were built. Because range was only 1300 nm at first, submarines carrying Serb had to approach the U.S. coast to fire. That range reflected the secondary role assigned to Soviet naval forces when the weapon was conceived (probably about 1960) and deployed (1968). Official doctrine then was that submarines would remain in reserve while the land-based strategic rocket force engaged targets in North America; the submarines would be used either for terminal bargaining or for a second-phase



SS-N-6 was the first modern Soviet sea-launched ballistic missile, enough smaller than SS-N-4/5 that a useful number (16) could be carried by 1 submarine. This ship, a Yankee-class submarine, was designed to carry SS-N-6. From 1967 until the advent of Typhoon in the 1980s, all Soviet ballistic-missile submarines were direct developments of the Yankee. SS-N-6 could be carried in numbers because it was so much shorter than SS-N-5, which filled not only the depth of the submarine hull but also the height of its sail. SS-N-6 required only a small protrusion above the submarine hull. (U.S. Navy)

attack. The surge requirement explains the Western assumption that the contemporary Victor-class ASW submarine was conceived as a Yankee escort.

In practice, Yankees patrolled off the U.S. coast during the 1970s and 1980s; some analysts assumed that the assigned role of these submarines was to destroy key U.S. command/control facilities at the outbreak of war. The Soviets would certainly not have expected these boats to survive very long after the outbreak of war, in waters dominated by the U.S. Navy. By 1988 the Yankees had been withdrawn to European waters, perhaps to replace the SS-20 land-based missiles scrapped under the new INF treaty. Yankees returned to the U.S. east coast during the summer of 1988, after the treaty had been ratified.

SS-N-6 is liquid-fueled, the fuel being replaced periodically and the missile refurbished. Possibly because of problems with missile fuel, a Yankee-class submarine suffered a missile tube explosion in the Atlantic, ultimately sinking on 6 October 1986 off Bermuda. It is difficult to avoid concluding that these weapons are deteriorating despite maintenance and, therefore, that the force as a whole may be losing its effectiveness.

All operational missiles are SS-N-6 Mod 3, carrying 2 MRVs.

SS-N-6 was reportedly designed by the Chelomei bureau, which was also responsible for some cruise missiles. This missile reportedly shared some characteristics of the earlier land-based SS-11, which Chelomei also designed, and was reportedly developed as part of Khrushchev's 7-year plan (1959–65), the tactical-technical requirement having been drafted in 1958. According to a former Soviet naval officer involved in missile development, the original requirement was for a single-stage underwater-launched missile 180×1000 cm [71×394 in], i.e., 4 m [157 in] shorter than the existing SS-N-4, with a maximum weight of 19 metric tons, a range of 2400 km [1300 nm], and a CEP of 1 km [0.54 nm]; the missile would carry a single 0.7-MT reentry vehicle. The rival Yangel bureau had just completed work on the SS-N-5 (1300-km [700-nm] range) and was concentrating on land-based missiles (SS-9). SS-N-6 was first flight-tested in 1966, and it entered service in 1968. Mod 2 was an interim longer-range version, developed by the Chelomei bureau while work proceeded on SS-N-8; Mod 2 provided 550 km [300 nm] more range, partly by reducing warhead weight (to 650-kT yield).

◆ SS-N-8 Sawfly

Dimensions: 65 × 504 in **Weight:** 30,000 kg [66,000 lb]
Warhead: one 800-kT (Mod 1) or two 500-kT (Mod 2)
Propulsion: liquid-fuel rockets
Range: 4240 nm (Mod 1); 4950 nm (Mod 2)
CEP: 0.84 nm (Mod 2)

SS-N-8 symbolized a shift in Soviet strategic doctrine: the navy achieved parity with the strategic rocket force. Submarines had to be able to fire at any time after the outbreak of war. This missile, therefore, was given sufficient range for it to be fired from its peacetime operating area, i.e., from a sanctuary (basin) area dominated by the Soviet Navy. SS-N-8 incorporated



Delta, carrying the SS-N-8 missile, is essentially a Yankee (SS-N-6) with longer missile tubes. The original Delta, shown here, even retained the lower after end of the missile tube section, and the difference in height is a measure of the difference in missile length. (U.S. Navy)

stellar-inertial guidance, in hopes of achieving useful accuracy even from the bastions. Reportedly, the stellar-inertial system was not always reliable, and initial reports of spectacular accuracy were exaggerated. The maximum range achieved during testing has been 9200 km, which is the longest of any current naval strategic missile.

Sawfly is carried by Delta-I- and -II-class submarines and by the sole Hotel-III, which was 1 of 2 test ships, along with a Golf-III. The Golf-III was discarded in 1987. SS-N-8 entered service in 1973. This missile's design is reportedly based on that of SS-N-6.

◆ SS-N-17 Snipe

Dimensions: 1.7 × 10.6 m [66.9 × 413 in]
Weight: 20,290 kg [44,700 lb]
Warhead: one 800-kT or two 500-kT
Propulsion: solid-fuel rocket **Range:** 2100 nm
CEP: 1400 m [1500 yd]

Snipe was the first Soviet solid-fueled naval ballistic missile, and also the first with a postboost vehicle (i.e., with MIRV potential). It is carried by a single Yankee-II-class submarine, apparently a system test ship. SS-N-17 was first tested in 1975, and it became operational in 1980. Design probably began in 1969. This missile reportedly uses some SS-16/20 technology (the missiles all have similar postboost buses) and itself led to SS-N-20. There was speculation that SS-N-17 was intended as a direct replacement for SS-N-6 (hence its appearance on board a modified Yankee), but that it was not deployed because of its limited range, difficulties with its rocket motor, and SALT I numerical limitations.

◆ SS-N-18 Stingray (RSM 50)

Dimensions: 1.7 × 13.6 m [66.9 × 535 in]
Warhead: three 200-kT MIRV (Mod 1), or one 450-kT (Mod 2), or seven 200-kT MIRV (Mod 3)
Propulsion: liquid-fuel rockets (2 stages)
Range: 3530 nm (Mod 1 or Mod 3) or 4350 nm (Mod 2)
CEP: reported as 875 or 1200 yd

SS-N-18 was the first Soviet naval MIRV missile, using storable liquid propellant as in SS-N-6/8. Like SS-N-8, SS-N-18 has stellar-inertial guidance, reportedly improved by the ability to take multiple star sights. Design work probably began in 1964, with R&D and tests in 1970–75. Mod 1 first flew in 1975 (first flight from a submarine was in November 1978). Mod 2 flew in 1977 and entered service in 1979. Mod 3 first flew in 1981–82. SS-N-18 is carried on board Delta-III-class submarines. When it entered service, it was the largest naval strategic missile in the world.



The height of the missile section of this Delta-III is a measure of the great length of its SS-N-18 missile; the sail proper, at the forward end of the missile section, is the same height as that of a Yankee. (U.S. Navy)

◆ SS-N-20 Sturgeon (RSM 52)

Dimensions: 2.17 × 14.7 m [85.4 × 579 in]
Warhead: six-nine 100-kT MIRV
Propulsion: solid-fuel (3 stages)
Range: 4300 nm **CEP:** 550–650 yd

SS-N-20 is carried by Typhoon-class submarines. It was first tested, unsuccessfully, in January 1980 (1 source gives a 1979 date), but successful tests were reported in 1981, and 4 were launched by a submerged submarine in October 1982. The system was considered operational as of 1983. A single Golf-V submarine in the Black Sea was modified to test SS-N-20. In March 1986, SS-N-20 was the only Soviet SLBM in series production. Design work probably began in 1972; in 1974 Leonid Brezhnev told then-President Ford that unless the United States abandoned its Trident program, Typhoon would go ahead. Reportedly, problems with this weapon delayed the Typhoon program, the submarine being ready well before the missile had become sufficiently reliable.

Although previously credited with 6–9 RVs, SS-N-20 is counted with 10 under the START treaty rules.

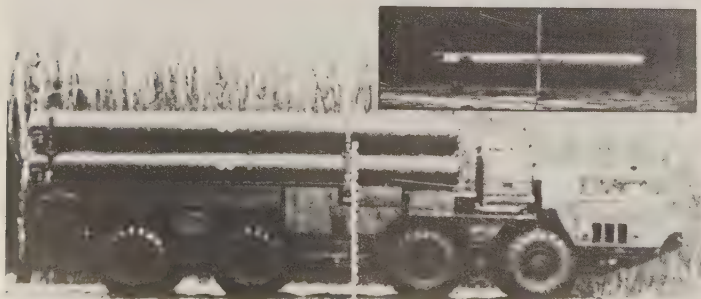
This missile reportedly embodies SS-N-17 technology.

A modified version of SS-N-20 (Mod 2) was probably tested in 1988, and a completely new SLBM (presumably to be designated SS-N-26) is reported under development.

◆ SS-N-21

Dimensions: 51 cm × 8.09 m (canister: 65 cm × 8.39 m) (span approx 300 cm) [20.1 × 318.5/25.6 × 330.3 in]
Weight: 1700 kg (2440 kg with canister) [3747/5378 lb]
Propulsion: turbojet with rocket booster **Range:** 1600 nm

SS-N-21 is the Soviet equivalent of the U.S. Tomahawk strategic cruise missile. There are 2 other versions: the land-based SS-C-X-4 and the air-launched AS-15 (KENT). Details were



No photo of SS-N-21 has been released, but in connection with the Intermediate-Range Nuclear Forces Treaty the Soviets did release this photograph of its land-based version, SS-C-4. (Department of Defense)

taken from the Soviet description of SS-C-X-4, released as part of the INF treaty. SS-C-X-4 is carried in a 65-cm canister; it seems likely that the naval version is carried similarly. It follows that the weapon can be fired only from a 65-cm torpedo tube. Reported speed is Mach 0.7. SS-N-21 follows a low-altitude (approx 190–200-m altitude, [600–650 ft] flight path).

Yankee-class submarines are being converted to carry this missile, in a new midships section with horizontal launching tubes. The estimated capacity is 20–40 missiles.

The Soviet designation of the associated land-based weapon (SS-C-4) is RK-55.

◆ SS-N-23 Skiff

Dimensions: 1.8 × 14 m [70.9 × 551 in] **Weight:** 40,000 kg (88,000 lb)
Warhead: 7 MIRV
Propulsion: liquid-fuel rockets (3 stages)
Range: 5000 nm **CEP:** estimated 500 m [550 yd]

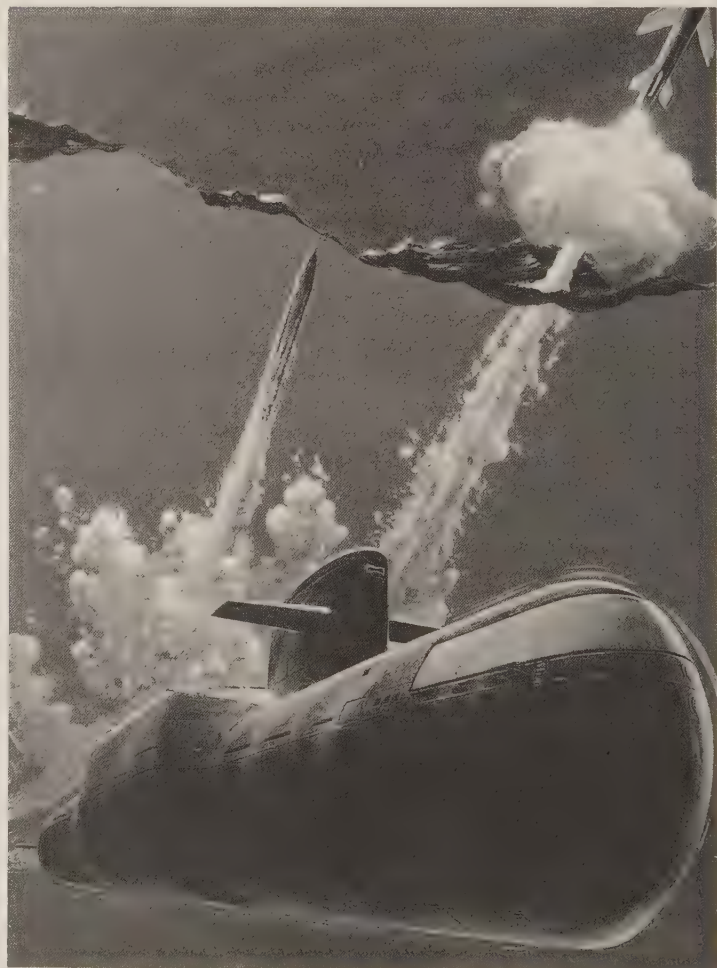
SS-N-23 is carried by Delta-IV-class submarines and may later be retrofitted to Delta-IIIs. It is similar in size to SS-N-18 but has greater throw weight and is more accurate. Flight tests began in June 1983, and the missile entered operational service about 1987; it was not yet in series production as late as March 1986. There were apparently early reliability problems.

For treaty purposes, SS-N-23 is now credited with 4 RVs, although as many as 10 have been reported in the past. A modified version of this missile probably completed sea testing in 1988.

◆ SS-N-24

Dimensions: approx 1.25 × 12 m; span 5.9 m [49 × 472 × 232 in]
Propulsion: jet, Mach 3.0 **Range:** 1600 nm

SS-N-24 is a very large, new cruise missile; range estimates are as great as 4000 nm. This missile may correspond to



SS-N-24 cruise missiles being fired by a converted Yankee-class submarine. (Department of Defense)

SS-N-21 as SS-N-8 corresponds to SS-N-6, i.e., SS-N-24 may be a strategic cruise missile that can be fired from within a bastion. The only published sketch suggests that this missile is launched without any canister, spreading its wings after emerging from the water. The only launch platform to date is a modified Yankee-class submarine.

A ground-launched version, SSC-X-5, under development, was canceled because of the INF treaty. Development began before 1983.

UNITED STATES

U.S. naval ballistic missiles are fired using gas generators; the missiles are ignited when they reach the surface. They can, therefore, be fired by a surfaced submarine. However, reportedly, a Trident I (C-4) cannot be surface launched without some risk of damage to the firing submarine.

♦ Polaris (UGM-27C)

Dimensions: 54 in × 387.5 in **Weight:** 35,000 lb

Warhead: six 150-kT (three 200-kT in U.S. version)

Propulsion: solid-fuel rocket (first-stage thrust, 36,000 kg)

Range: 2500 nm

Although no Polaris missiles remain in U.S. service, this weapon equips the 4 British strategic submarines, under the 1962 Nassau Agreement. Britain maintains a facility capable of manufacturing and servicing Polaris missiles, and the weapons are armed with a British multiple warhead, Chevaline. Chevaline was developed as a penetration aid, and it is described as a compromise between the multiple (but cotargeted) warheads of

U.S. Polaris missiles and the fully independently targeted warheads of Poseidons. The 6 warheads are carried on a maneuvering penetration aid carrier (PAC), which incorporates a computer-controlled stable platform; it also carries decoys. Reportedly, the warheads can hit points as much as 40 nm apart.

The original A-3 missile fired 3 warheads, but their distribution could not be adjusted to attack different targets. They were ejected from the missile's second stage by rockets, which also imparted some spin to improve accuracy as they fell. Presumably, the PAC can maneuver to a very limited degree to aim the warheads independently. A full postboost vehicle (PBV) would provide a wider spread, achieved by maneuvering for a longer period or through larger angles. The distinction may be that the PAC can change only the overall pattern of warhead distribution, whereas a PBV can maneuver to drop each warhead separately.

Chevaline was developed from a U.S. penetration aid system, Antelope, which used a modified (Mk 2 Mod 1) guidance system. An Antelope missile could be fired into a special lofted (steeply falling) trajectory, to minimize exposure to a ballistic-missile defense system's radar. The Antelope computer was also specially hardened against EMP pulses from the explosions of defending nuclear missiles. It had special metallic gaskets. In addition, the Mod 1 computer periodically stores its data content in a protected module. It was assumed that the main effect of an EMP pulse would be to corrupt current data; such corruption was detected by a special circuit, the current data discarded, and the stored data returned to main memory. That response still made for some inaccuracy since the stored data were at least 1 computer-storage-cycle old.

Chevaline flight tests from ground pads began in September 1977, and sea trials in November 1980; the last development launches were made in February 1982. A remotoring program was conducted in 1981–86, as the original motors were deteriorating. The A3 missile itself was a radical redesign of the original Polaris single-warhead weapon, maximum range increasing by two-thirds. The secretary of defense approved development in September 1960, the project was funded in October, and the first missile was launched on 26 October 1963.

The first U.S. Polaris submarines carried a Mk 80 fire-control system; the versions controlling the A3 missile were Mod 2 in the original *George Washington* class and Mod 3 in the *Ethan Allan* (SSBN 608) class. Mk 84 was installed in the *Lafayette* class, which were later converted to Poseidon operation. Mk 84 is also the fire-control system of British Polaris submarines. Details below apply to the original U.S. Mk 80 system.

Missile flight parameters were calculated for a specific launch point and for nominal flight conditions. These data were punched into computer cards, together with the proportional or interpolation constants and the coefficients used to correct these values for the actual launch point (as measured by the submarine navigational system) and for the actual flight conditions. The submarine patrol area was divided into launch squares, each small enough that the interpolation constants were accurate enough (20' in latitude × 20' in longitude), and a separate card produced for a launch reference point in each square. Nine launch squares formed a launch complex 1 deg in latitude × 1 deg in longitude. The launch squares were small enough that a launch reference point remained valid for a submarine 5 min into the adjacent square, so a card remained valid for a useful period of time, as the submarine moved through the water.

The cards were punched out on board the submarine but before the sub reached a particular firing area. The specialized dual Polaris Target Card computer system had paper tape input for both program and targets (targets could also be input directly, by typewriter at the computer console). At this stage of computer development, the calculations involved were far too complex to be carried out in real time; the digital-computer element of the system was off-line. This system in turn replaced the earliest technique, which was to punch out the cards ashore, at Dahlgren. Presumably, the increased range of the A3 missile,



Polaris A-3, as currently used by the Royal Navy. (U.S. Navy)

which greatly expanded the possible submarine patrol area, made it less practical to prepunch cards for stowage aboard the submarine.

Mk 84 incorporated a digital computer, but it is not clear whether the computer allowed real-time operation. The next system, Mk 88 (for Poseidon), eliminated this step, using a much faster computer (see the Poseidon entry below).

The effect of the punched-card system shows in the sequence of submarine operational conditions. A submarine in the patrol area could operate in condition 3SQ, i.e., at 2 hrs' notice after targets had been designated. Presumably, 2 hr were required to align the missiles but also (and at least as importantly) to prepare the requisite punched cards. In the next readiness condition, 2SQ, which could be held for 60 days, the submarine was at 15 mins' readiness, with her targets in range and designated, i.e., with punched cards set up. 2SQ was the normal patrol condition. In condition 1SQ, the first missile could be fired at 1 min's notice.

The Mk 80 fire-control system constantly monitored submarine position to ensure that the appropriate card was used. It computed the appropriate bearing, toward which the missile was aimed. This calculation included the effect of the rotation of the earth. It also took into account estimated wind affecting the reentry body near the target, when the body is no longer under positive control. The fire-control system could take into account not only submarine movement but also target displacement from the original position estimate. Thus, the system could, in theory, attack a semimobile target, or a target that had been incorrectly located when the target cards were prepared. Target ballistic wind was periodically received and updated, presumably on the basis of satellite data. Corrections due to submarine roll, pitch, and yaw were also entered into the target data system.

Mk 80 could provide data for 8 targets at a time; typically 2 missiles were assigned to each target. However, each target-data-input unit could provide data to up to 4 missiles, all of which would be aimed at 1 target. The basic system could fire a missile either for a ground burst or for an air burst (at 1 of 3 alternative heights) over the target; the air-burst trajectory was somewhat longer since it had to pass over the target.

The basic missile sensor is the set of gyros and accelerometers on the stable platform in the nose. Before launch, the stable platform is lined up with a vertical axis, a horizontal axis pointing to the target, and a cross-range axis. The gyros measure missile yaw, pitch, and roll relative to the stable platform. There are also 3 accelerometers measuring motion along the 3 axes; the hard-wired digital computer in the missile measures velocity and position from the accelerometers and gyros. The outputs are pitch and yaw steering commands, and velocity yet to be gained before the motor is cut off (the solid-fuel motor cannot be throttled). All of this requires a stable time reference, which is provided by the computer clock (crystal-controlled oscillator).

Alignment is critical to the operation of the system since the missile steers in relation to the aiming axis pointing toward the target.

Missiles are stowed in the tubes with their stable platforms aligned as closely as possible with the axes of the submarine, but there is always a small misalignment, due both to errors in placing the missile in its tube and also to the slight motion of the missile while the submarine moves. Before the missile can be fired, the stable platform must be aligned with the submarine axes so that it can be turned toward the target (target bearing is measured relative to the submarine). The target bearing fed into the missile takes into account the roll and pitch of the submarine, i.e., the difference between its axes and axes set in the earth.

Alignment with the submarine axes is accomplished using optics since light travels in straight lines, and deviation from a path is relatively easy to measure. Each missile has an optical window, and each tube has a corresponding window. The missile also contains a prism on its outer stable platform gimbal, which would point along the ship's axes were it properly

aligned. The gimbal angle is converted into an angle between 2 beams of light, 1 incident on it and 1 reflected from it and then turned through 90 deg (by a prism on a trolley running down the missile bay); the distances are such that even a very small angle produces a noticeable difference between the 2 beams.

The missiles in a Polaris submarine are lined up in 2 rows adjacent to the missile-control center because each missile must be accessible to the optical path from the fire-control system. That arrangement is an important submarine design consideration: the reactor cannot be amidships, as in an attack submarine, but must instead be abaft the missile bay.

Normally, the stable platform is caged (secured). When a missile is prepared for firing, it must be erected, i.e., it must be stabilized with respect to gravity. Once the platform has been aligned with the submarine's axes, the fire-control system can erect it (set the vertical) and aim it (set its horizontal axis in the direction of flight). Erection involves separating out submarine motion components (coarse erection) and separating out the motion of the earth (fine erection); in space, the missile measures its motion with respect to a nonrotating set of coordinates, rather than with respect to the rotating earth.

This stabilization takes time, about 1 min to spin up the gyros, then 1 min for coarse alignment and erection, and about 6½ min for fine erection. During stabilization the optical alignment trolley is used to measure missile misalignment angle, which is an additional input to the alignment angle calculated by the fire-control system.

The Polaris first stage steers by rotating its 4 nozzles to control pitch, yaw, and roll. The second stage steers by injecting liquid freon downstream into the single nozzle. As the freon passes across the line of thrust, it causes an oblique shock wave, which in turn deflects the thrust; the angle of deflection is proportional to the amount of liquid injected. Six openings (connected to 2 ports) are distributed around the nozzle, and they can be used either singly or in combination.

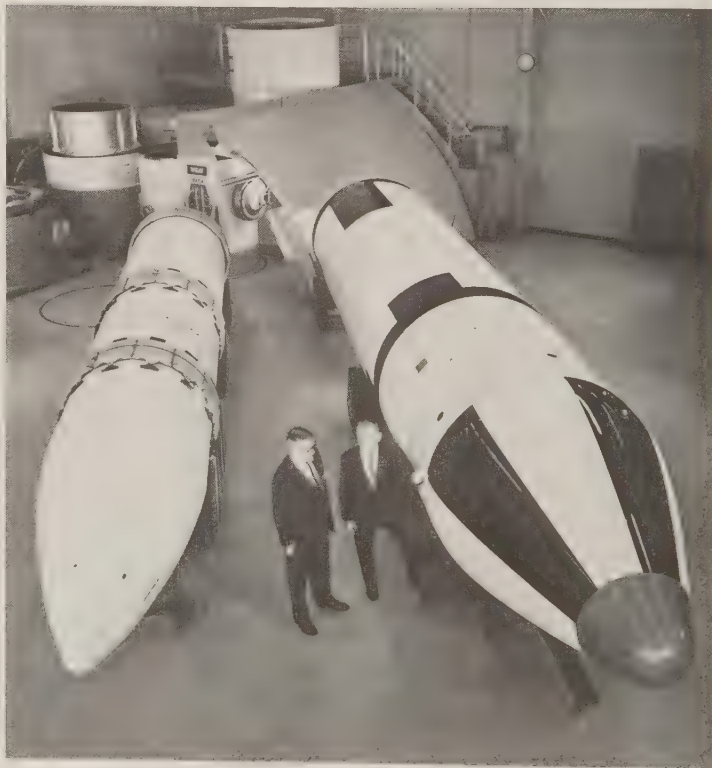
Except for the warhead description, the data are for the U.S. version, Polaris A-3.

◆ Poseidon C-3 (UGM-73A)

Dimensions: 74 × 408 in **Weight:** 65,000 lb

Warhead: up to 14 MIRV to 2500 nm or ten 50-kT RV (Mk 3) to 3200 nm **Propulsion:** 2-stage solid-fuel rocket

Range: 2500 or 3200 nm



Poseidon C-3 (right) compared to Polaris A-3. (Lockheed)

This Lockheed weapon was the second-generation U.S. submarine-launched strategic missile. In 12 *Lafayette*- and *Benjamin Franklin*-class submarines, it was replaced by Trident C-4, which fits the same launch tube. This replacement program was completed in December 1982. Some remaining Poseidons are being "uploaded" with more powerful warheads.

Like Polaris, Poseidon is a 2-stage missile. It ignites 90 ft from the launch tube, before leaving the water; the main stage burns for about 50 sec. Second-stage burn time will vary with targeting, but it is nearly the same as nose-fairing ejection time, which can be set at 22.08 or 33.28 sec.

Unlike Polaris, Poseidon has a powered postboost vehicle (called the equipment platform) carrying its reentry vehicles (RVs) in 1 of 4 alternate configurations. The equipment section maneuvers using a gas generator and 8 two-way thrusters. They can be used either to position the platform between RV firings (to hit several targets in sequence) or to add distance along the line of flight (downrange distance). Four of them provide pitch, yaw, and thrust along the missile's longitudinal axis; the other 4 provide roll control and thrust along the 2 perpendicular axes.

Poseidon uses a Mk 3 guidance system (Mk 2 was Polaris A-3). As in Polaris, Mk 3 continuously calculates the remaining velocity-to-be-gained needed to reach its target, and steering commands are generated to drive that velocity to 0 (i.e., to motor cutoff, which is the only available motor command). The digital Poseidon guidance computer (PGC) has a capacity of 1k 24-bit ROM (wire braid memory) and 1k 96-bit running memory; the long words are used to achieve high precision in arithmetic. Characters are 6 bits in length. Clock rate is 3.9 MHz.

Guidance is more flexible than that of Polaris, allowing for variable loft angles and variable range between 500 and 3500 nm. Unlike Polaris, Poseidon uses thrust vectoring for control in both its first and second stages, in both cases with a single nozzle.

Unlike Mk 80, which uses a hybrid digital-analog computer, Mk 88 is wholly digital, using a general-purpose digital control computer (DCC). One DCC can provide guidance inputs for 16 missiles; each submarine has duplicate systems for reliability. Normally they operate in parallel, each controlling 8 missiles. Each DCC has 16 kwords (24-bit word) of magnetic-core memory, with 4 input and 4 output channels. There are 44 instructions. The 2 DCCs share a 2.25-Mword mass store (magnetic disk pack or file, consisting of 20 recordable surfaces; read rate is 28 kwords/sec), containing all the tactical, test, and maintenance programs and all the target data. Guidance constants for each missile are provided on a punched Mylar tape, compiled before patrol, which can be read into the mass memory. These data might include, for example, the gyro drift rate of the particular missile. The DCC generates launch-bearing, fuze-set, and guidance data; there is no need to define launch squares or to precompute before entering a launch area.

The DCC drives a command-slew subsystem (CSSS), an alignment subsystem (ALNSS), and an erection subsystem (ESS), which control the stable platform in the missile. Command slew is the initial, quick (15-sec), coarse adjustment of the stable platform, signals being sent directly to the gimbal torque motors (bypassing the inertial gyros, which are much slower because they have to measure angles very precisely).

The 2 DCCs are part of the digital geoballistic computer (DGBBC), which also serves the submarine's Mk 113 underwater fire-control system (a new Mod of this system was associated with conversion to Poseidon, i.e., with installation of the computer). The system includes 2 magnetic disk files, which can be manually switched between the 2 DCCs.

As in Polaris, the missiles are aligned optically.

Poseidon grew out of work on an enlarged (74-in- rather than 54-in-diameter), single-target missile, provisionally designated B3, and also out of navy interest in the ongoing air force MIRV program of the time. There was some interest, too, in adopting the air force Mk 12 or Mk 17 reentry vehicle, although ultimately Poseidon used a much smaller Mk 3. C3 was a MIRV version of B3, and it was first announced on 18 January 1965,

President Johnson choosing to use a new missile name despite its strong connection to earlier versions of Polaris. The MIRV development was formally approved on 13 January 1966, and flight testing began in January 1968. The first submarine to deploy with Poseidon was the USS *James Madison*.

Poseidon is credited with 8 times the effectiveness of A3. Reported CEP is 600 yd, although the missile was more commonly regarded as a relatively inaccurate soft-target killer. The hard- vs. soft-target issue became quite heated in the 1970s, when an inability to hit hard targets was equated with arms-control stability (a hard-target killer could be construed as a first-strike weapon since it could disable enemy missiles before launch). By this time the navy was already working on improved accuracy and yield, the CNO first having announced his interest in hard-target-killing capability in October 1962. Initial evaluation of a stellar-inertial guidance system followed early in 1966, and work on a Mk 4 stellar-inertial system began in 1968. Congress later expressly prohibited the navy from deploying either the guidance system or a new high-yield warhead; both decisions were reversed in the development of Trident.

Although 14 RVs can be carried, the usual load is 10. The missiles can be ripple-fired. In a test, the USS *James Madison* took 56.3 sec/missile, a total of about 15 min for all 16.

♦ Trident C-4 (UGM-96A)

Dimensions: 74 × 408 in **Weight:** 70,000 lb

Warhead: eight 100-kT Mk 4 MIRV **Propulsion:** solid-fuel rocket
Range: 4350 nm **CEP:** 1500 ft

Trident I is Poseidon's successor, designed to fit existing tubes and to achieve 4000-nm range without losing the accuracy of the predecessor. Its postboost vehicle (MIRV bus) incorporates a stellar sensor for positional corrections, thus achieving greater accuracy. This missile became operational in 1978.

Compared to Poseidon, Trident I was conceived as a longer-range missile with about the same throw weight. Trident I achieves greater range partly by increasing its effective length, extending an aerospike at launch. The spike is credited with



Trident C-4 (right) compared to Trident D-5 (left). Note the aerospikes. (Lockheed)



Trident C-4 launching, with the aerospike extended. (U.S. Navy)

reducing frontal drag by 50%, i.e., with adding 300 nm to the missile's range. The aerospike also made it possible to use a very blunt nose that could accommodate a third rocket stage together with the warheads. C-4 also benefits from advances in propellant chemistry, making fuller use of its fuel. Instead of blowing open ports (and thus neutralizing thrust) at a precalculated point in second-stage flight, it burns all its fuel and then calculates the appropriate third-stage trajectory. The new high-energy fuel is credited with about 40% of the range improvement, another 35% being credited to the use of improved chamber material (Kevlar), which allows increased propellant loading and higher operating pressures.

C-4 uses the stellar-inertial-update guidance proposed for Poseidon to help overcome the effects of uncertainty in a submarine's position. The missile is credited with a CEP of 500 yd (8 Mk 4 RVs with W76 100-kT warheads), and in 1982 it was stated that improvements in guidance optics could reduce CEP to 250 yd. The Mk 500 Evader MARV, carrying a 100-kT weapon, was developed by Lockheed as an alternative warhead but has not been procured.

The guidance system, Mk 5, can function in all-inertial or stellar-inertial modes. Two proposed versions of C-4 were dropped because D-5 development was accelerated: C-4U, with improved guidance, and Long C-4 TFS (44 ft long, i.e., as long as D-5, with a Terminal Fix System for improved CEP). There was also a proposed "flat deck" version in which the third-stage motor was eliminated in favor of more RVs, reportedly up to 10 Mk 12A.

C-4 development was approved on 14 September 1971.

Lockheed received the C-4 contract in 1974, and the first missile was launched in January 1977. The *Francis Scott Key* was the trials ship, beginning her first Trident patrol in October 1979. The entire 12-ship Poseidon-to-Trident conversion program was completed in March 1982. The C-4 procurement objective was 570; procurement ended in FY84 (72 in FY83, 52 in FY84).

◆ Trident II (D-5)

Dimensions: 83 × 528 in **Weight:** 130,000 lb

Warhead: 8–12 Mk 5 RV (300–475-kT warheads) or fourteen 150-kT MIRV or seven 300-kT MARV; initially D-5 will use the Mk 12A RV of the Minuteman and MX land-based missiles (475-kT)

Propulsion: 3-stage solid-fuel rocket; burn time about 65 sec for each of 2 lower stages, and 40 sec for the third stage
Range: 6000 nm **CEP:** 400 ft

The fire-control system on the submarine matches that of Trident I but adds a gravity sensor and a new navigation sonar. The missile itself uses a new epoxy case for all 3 stages and a new high-energy propellant similar to that of the land-based MX. As of early 1988, the first full system tests (submarine launches) were scheduled for March 1989.

Production of the first 21 missiles was authorized under the FY87 program (66 under each of FY88/89); the total objective (1988) is 845 missiles (for 19 SSBNs, with 30 missiles for testing). Alternative loads: 10–15 MIRV, or 11–13 Mk 4 RVs, or 6–9 Mk 5 RVs. Guidance is stellar-inertial, for a reported CEP of 400 ft (1500 ft for Trident I). The Mk 5 vehicle/W87 combination was selected in October 1982. All missile tests up to September 1987 used 8 warheads; in September 1987 a D-5 was tested with 10 smaller warheads. However, in December 1987 President Reagan and the Soviet General Secretary Mikhail Gorbachev agreed that, for arms-control purposes, the missile would be credited with no more than 8 warheads.

The first sea test (21 March 1989, from the USS *Tennessee*) was a failure; the missile pinwheeled. D-5 flew successfully on 2 August 1989, but it failed again on 15 August. The missile then flew successfully in December 1989. The effect of the failures was to push initial deployment back from late 1989 to March 1990. The failures were apparently caused by damage to rocket nozzles by the column of water that rises with the missile. This water surge is much larger than in earlier Trident, Poseidon, and Polaris missiles and was not allowed for in the D-5 tail design. The solution was reportedly a mesh cover for the rocket nozzle that keeps water out while the missile is rising; the cover is blown out by missile ignition.

This program was accelerated in 1982 by Secretary of the Navy John Lehman, the object being to introduce the missile as early as possible so as to avoid the cost of refitting submarines completed to carry the earlier C-4. The planned introduction date of 1989 (on board the *Tennessee*) was 3 yr earlier than originally projected. At the same time, the planned number of D-5 submarines was increased to about 20. Full-scale engineering development of the D-5 (UGM-133A) missile began in October 1983, in parallel with its new W87 warhead (300–475-kT yield), the latter to deal with superhardened silos and similar targets, invulnerable to existing warheads.

The FY90 program includes 63 missiles, with 52 in FY91; unit cost is \$28.4M in FY90.

Britain has chosen Trident D-5 for the next-generation *Vanguard*-class strategic submarines. They will carry British warheads; but the missile bodies will be maintained by a U.S. facility, the Royal Navy turning missiles in for maintenance and drawing refurbished ones (which the British will then arm with their own warheads). Critics of the British Trident program have derided this practice as "rent a missile." The Anglo-American agreement was signed on 14–15 July 1980; 80 missiles will be acquired (16 per submarine plus enough spares to fill another submarine).

◆ Tomahawk (including nonnuclear versions)

Dimensions: 20.9 × 252 in **Weight:** 3181 lb

Warhead: 200-kT (W80 warhead)

Propulsion: F-107 turbojet sustainer

Range: 1350 nm (250 nm for TASM, 675 nm for the conventional land-attack weapon, and 472 nm for the land-attack submunition weapon)

Tomahawk was conceived as a weapon not covered by existing arms-control treaties and, therefore, as an initiative the United States could take to counter growing Soviet strategic forces. The initial DoD cruise-missile studies were ordered in 1973, and it is reported that then-Secretary of State Henry Kissinger favored the weapon as a bargaining chip in SALT II negotiations. Tomahawk then acquired a life of its own, and critics of arms procurement have cited cruise missiles as examples of



Tomahawk programmed conventional air burst over a revetted bomber, demonstrating the ability to attack large aircraft. (General Dynamics)

how a bargaining chip can become a permanent fixture of military forces. The Carter Administration resisted deploying this strategic cruise missile for fear that it would breach the observability requirement built into the SALT II treaty. Late in 1980, however, the decision to deploy the tactical version of Tomahawk opened the way to deployment of the strategic version.

The navy had been very interested in a small and easily deployed strategic weapon before 1973 as a way of spreading U.S. strategic firepower over a much larger number of platforms. One advantage of such dispersal for the U.S. is that the Soviets, preoccupied with nuclear weapons, must dissipate their own efforts by targeting (hence tracking) a much larger number of U.S. ships and submarines. This U.S. strategy is a form of jujitsu: if the war is unlikely to turn nuclear, it is a way of using the existence of nuclear weapons to gain decidedly nonnuclear ends (greater survivability of individual valuable ships, such as aircraft carriers). The idea of reversing the significance of nuclear forces can also be seen in more recent maritime strategic approaches to Soviet bastions: threatening Soviet nuclear forces there will, it is hoped, concentrate Soviet naval attention away from the sea lines of communication, at least early in a war.

Tomahawk can be dated to a 1971 internal navy study of basing options for a future U.S. sea-based cruise missile. The 2 alternatives studied at the time were a 2000-nm weapon, 6 of which could fit a standard Poseidon tube (and which could be ejected together), and a 1500-nm torpedo tube-launched weapon. The latter was adopted, and the SLCM program was formally approved on 2 June 1972. On 6 November the SLCM

project was merged with a program for a 300-nm submarine-launched tactical (antiship) missile, STAM, which had originally been conceived as an extended-range Harpoon.

General Dynamics won a fly-off against LTV's ZBGM-110; more recently, McDonnell Douglas has been selected as a second source, for competitive annual bidding. The first guided Tomahawk flight was in December 1976.

Missile diameter is slightly less than the 21 in usually quoted: the missile in its canister fits the standard 21-in torpedo tube. The data above, except for range, are for the strategic version. Quoted ranges differ widely, figures as great as 2000 nm being claimed for the strategic missile and 400 nm for the tactical version armed with a Bullpup warhead.

Both strategic and tactical versions are in service. Under the INF treaty, land-based Tomahawks in Europe (operated by the U.S. Air Force) are being destroyed. This does not affect the naval versions. Air-launched versions, both long- and medium-range, have been proposed, but they have not entered service. Soon, then, Tomahawk will exist only in surface-ship and submarine versions. The planned total naval procurement is 3994. Surface ships carry Tomahawk in 4-missile armored box launchers and in the Mk 41 vertical launcher. Submarines carry Tomahawk either in torpedo tubes or in special vertical tubes.

The effective range of the antiship version is limited by the need to search for the target at the end of what may be a lengthy flight. Land-attack range is limited by the weight of the warhead. Guidance is by terrain-matching (TERCOM) and inertial navigation, a system designated TAINS (TERCOM-Aided Inertial Navigation System). Unlike a ballistic missile, a TERCOM-guided cruise missile can attack only over suitable (and suitably mapped) territory, and that requirement in turn may somewhat limit Tomahawk operations. Tactical versions use DSMAC (Digital Scene-Matching Correlation), in which the scene viewed optically is compared to an on-board digital map. In a 24 April 1988 night test, the optical viewer was assisted by a strobe light. The antiship version of Tomahawk incorporates Passive Identification/Passive Direction Finding (PI/DF) equipment intended to enable the missile to discriminate among potential targets, presumably on the basis of their characteristic emissions. The 4 antennas are flush-mounted on the missile skin, feeding a microwave receiver.

Versions (navy procurement goal in parentheses): BGM-109A, nuclear land attack (758); BGM-109B, antiship (593); BGM-109C, conventional land attack (2643, of which 1486 are Block IIA with Bullpup unitary warheads and 1157 are Block IIB with bomblet warheads); BGM-109D, land attack with bomblets (0); BGM-109E, antiship (0); BGM-109F, land attack, antiairfield (560); BGM-109G, ground-to-ground nuclear, with variable yield (0). AGM-109C was the abortive medium-range air-to-surface (MRASM) terrain-following missile; AGM-109I was a proposed MRASM with an infrared seeker, and AGM-109J was a proposed MRASM carrying bomblets. The Tomahawk land-attack missile with a nuclear warhead is sometimes denoted TLAM-N; the Tomahawk antiship missile is TASM; and the Tomahawk conventional land-attack missiles are often denoted TLAM-C (unitary conventional warhead) and TLAM-D (bomblet dispenser).

TLAM-C Block IIA, which carries out an optional terminal maneuver (pop-up and dive), was approved for production during FY86. The terminal maneuver is selectable before flight. Other improvements are provisions for a mobile launch point and for alternative selection of over-water waypoints. A programmable warhead detonation (PWD) for this version has been tested.

TLAM-C Block IIB is the bomblet version, tested in FY86. It carries 166 Aerojet Ordnance BLU-97/B combined-effect bomblets in 24 packages, 22 of them holding 7 bomblets each (6 each in the other 2). Each bomblet (2.5 × 6.6 in, 3.4 lb) carries an incendiary fuze, a fragmenting case, and a shaped charge. The missile can eject bomblets to hit several targets per pass; in a November 1987 test, a submarine-launched Tomahawk dropped bomblets on 3 targets and dove on the fourth. The bomblet version became operational in FY88.



Tomahawk attacking multiple targets using submunitions. (General Dynamics)

An Improved Sea-Skimming Variant (ISSV) was operationally tested in December 1985 through May 1986.

A Block 3 Improvement Program, now in development, will enter production in FY91. Changes include an improved turbofan engine (19% more thrust, 3% less fuel consumption), GPS, an improved form of DSMAC, and improvements for better coordination with tactical air strikes.

The supporting weapons system is Mk 36/37 (submarine/surface-ship vertical launcher). It is being modified (Block II) to accept data from fleet intelligence sources and sensors, presumably as an outgrowth of Outlaw Shark (see OSIS and TFCC under Surveillance and Control).

Late in April 1988 the navy briefed contractors on requirements for a stealthier next-generation SLCM, with better accuracy and greater range.

Late in 1988 the U.S. Navy awarded a contract to McDonnell Douglas Astronautics for an extended-range Tomahawk, for completion in 1992. The contract includes the use of the GPS satellites, time-of-arrival software (so that different missiles can make a near-simultaneous attack, to saturate terminal defenses), an improved version of DIGISMAL, and an insensitive-munitions/extended-range payload section. The changes are to be such that older missiles can be modified to the new standard when they arrive for maintenance every 3 or 4 yr; no additional missile purchase is involved.

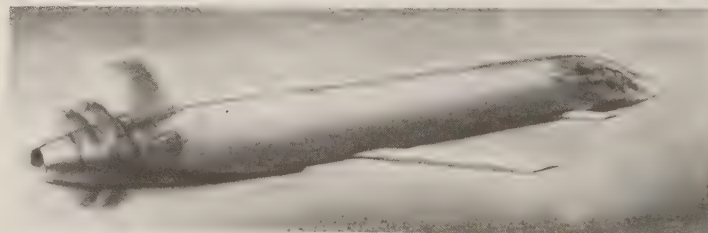
Early in 1990, when the cancellation of the Sea Lance ASW missile was announced, some funds were transferred from that weapon to Tomahawk. There was an official suggestion that Sea Lance might be replaced by a Tomahawk variant carrying a Mk 50 torpedo. It is not clear just how serious these suggestions were; Tomahawk is much slower than Sea Lance. It could, however, be a credible replacement for the *surface-launched*



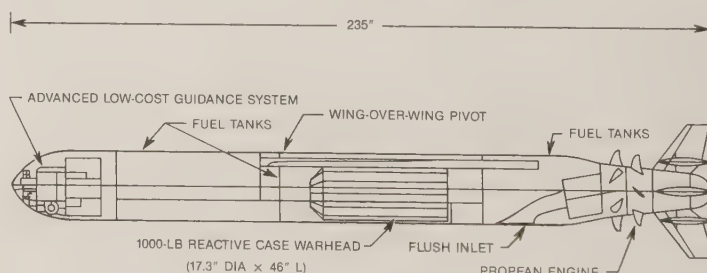
version, provided that the missile's target could be updated after launch by a data link either from the launching ship or from a helicopter prosecuting the contact. A Tomahawk variant, equipped with sonobuoys, was an unsuccessful contender for the original Sea Lance contract in 1980.

◆ Excalibur (LRCSW)

Excalibur is a navy project for a long-range highly accurate cruise missile, a Tomahawk successor, which might be used to deliver nonnuclear warheads. The missile will presumably exploit new high-accuracy technology that was first publicly described in the summer of 1987 and that may use lasers for very accurate map-reading. Some have suggested that long-range



General Dynamics's version of LRCSW. (General Dynamics)



McDonnell Douglas's version of LRCSW. (McDonnell Douglas)

conventional cruise missiles can take over some roles currently reserved for strategic nuclear weapons and that, therefore, such missiles may have a revolutionary impact on future warfare. In particular, in 1987 both the Blue Ribbon panel on a new U.S. national strategy (which conceived the concept of "discriminant deterrence") and a Defense Science Board study of Strategic Nonnuclear Capabilities (SNNC) pushed for the development of what they called Long-Range Conventional Cruise Missiles (LRCCM). The air force requested \$50 million to begin development in FY89. Ultimately the program was moved into the Joint (i.e., air force and navy) Stand-Off Weapons program, which also includes the AIWS and MSOW described in the Strike/Surface Warfare section.

Excalibur is a navy LRCCM program proposed as an alternative to the JSOW weapon; the navy proposal for development during FY90-94 reportedly includes ship-, submarine-, and air-launched versions. The key difference between a navy-developed LRCCM and an air force-oriented weapon would almost certainly be the navy requirement that the weapon fit a standard submarine torpedo tube, whereas the dimensions of the air force weapon would probably be limited by those of the standard bomber rotary launcher. Because of just these requirements, Tomahawk is so different from the contemporary air force ALCM.

The U.S. Navy established a Tentative Operational Requirement (TOR) for an advanced sea-launched cruise missile (ASLCM) on 9 March 1988; the U.S. Air Force established a Statement of Need (SON) for a conventional cruise missile (CCM) on 28 February 1989. The Joint Chiefs of Staff had already issued a Joint Mission Needs Statement in November 1988, and concept development formally began on 22 September 1989. In December 1988 the navy was made the lead service in a joint navy/air force program, the navy term being LRCSW and the air force term LRCCM. The air force is responsible for propulsion, in a program located at Wright-Patterson Air Force Base.

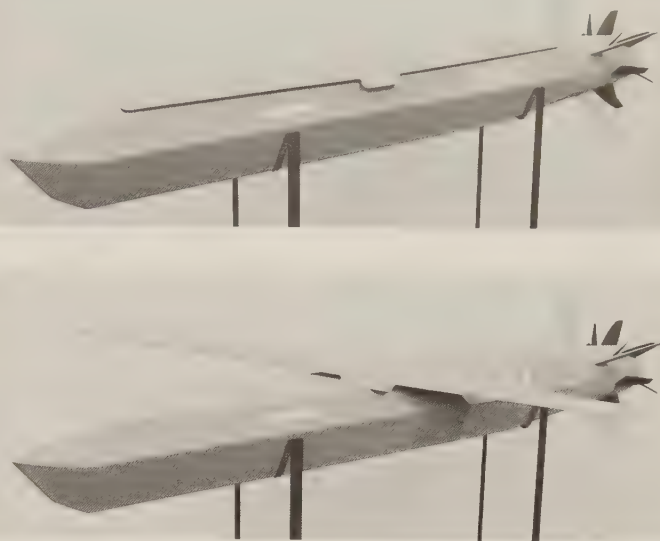
As of early 1990, there are to be 2 versions, for long and short (one-quarter of long) ranges, both carrying 1000-lb warheads. Unit cost limits are, respectively, \$1.5 million and \$900,000 (goals are \$750,000 and \$500,000). Maximum weights are, respectively, 3600 and 2250 lb.

In November 1988 the Naval Air Systems Command awarded Lockheed Missiles and Space Company a contract to study guidance, mission planning, and survivability for an Advanced Sea-Launched Cruise Missile (ASLCM) to replace Tomahawk. The ASLCM is to have a greater range. The Lockheed study will concentrate on the surface-launched version. Lockheed suggested that the contract might lead to hardware design and construction and then to demonstration validation flights.

Three companies exhibited alternative long-range conventional cruise missiles at the U.S. Navy League show in March 1989: Boeing, General Dynamics, and McDonnell Douglas. Each missile was powered by an unducted-fan (propfan) jet at its tail, driving contra-rotating propellers of the type also proposed for full-scale aircraft. The program is entering the concept-definition stage, and the navy is expected to request bids during FY90. At this writing the final designation of the program is uncertain. Excalibur is a name used within the navy. The original ASLCM designation was succeeded by LRCCM, then by LRCSOW (long-range conventional standoff weapon), and then by LRCSW (long-range conventional standoff weapon).

The versions shown at the U.S. Navy League show in April 1990 all had sharp noses and chined (faceted) bodies, to reduce radar cross section by reflecting radar signals away from the transmitter.

At least 3 alternative guidance techniques are being investigated: laser radar scene-matching (CMAG, cruise missile advanced guidance, developed as an air force program since about 1983), imaging infrared, and a synthetic-aperture radar (SAR). Loral exhibited its own SAR at the 1989 show. Besides the terrain comparison navigation used by the current Tomahawk, a very precise future cruise missile might employ feature navigation



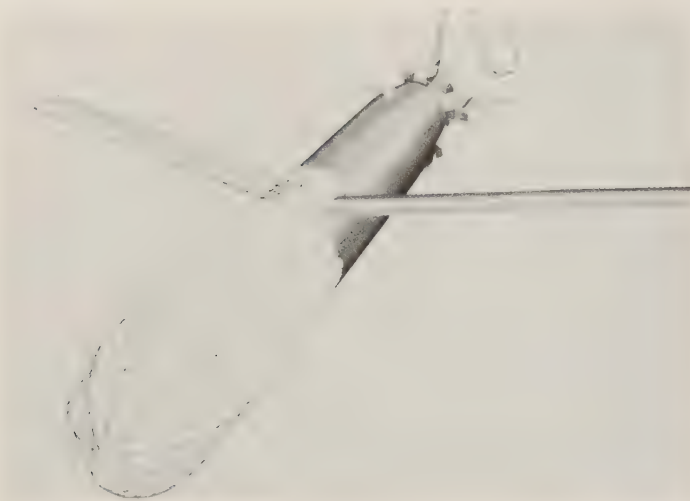
The Boeing version of LRCSW, in its folded and unfolded configurations. The wing is oblique. (Boeing)

gation (i.e., comparison with the relative positions of features on the surface, such as crossroads, rather than with the absolute height of terrain). In theory, feature-navigation data might be derived from conventional maps and so might permit the use of long-range missiles against targets for which special terrain-contour maps had not been prepared.

Loral displayed its autonomous SAR seeker at the Navy League show; this device is probably typical of those being considered for LRCSW guidance. It is 15 in in diameter and 23 in long, weighs 74 lb, and requires 392 W of power. This seeker employs a conventional-looking flat plate array antenna, which can swivel to the side (for SAR) or can look straight ahead. The seeker can, therefore, be used for conventional terrain avoidance and even terrain height matching as well as for scene matching by imaging. Typically the radar would be used for at least 1 mid-course match with some prominent terrain feature and then would produce a series of target images of successively finer resolution as the missile approached. Compared to the current height-matching system, a SAR is much easier to program since it needs only a series of images of terrain. Loral claims that missions can be planned (i.e., weapons programmed) in minutes rather than hours at the squadron level.

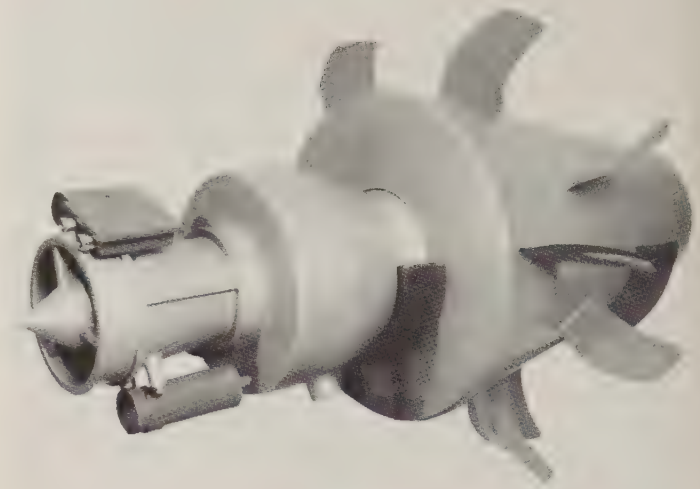


The General Dynamics version of LRCSW. It has an unducted-fan engine, which is not visible here. The wings and tail are swept forward at a small angle, and the vertical fin extends below the missile. (General Dynamics)



The McDonnell Douglas version of LRCWS, showing the shape of its nose and body. Note the small flip-out fins forward of the unducted fan. (McDonnell Douglas)

The 3 proposed weapons differ in configuration. Boeing showed a missile with a single wing pivoted along its upper surface; after firing, the wing would turn into an oblique position. General Dynamics showed 2 forward-swept wings, carried internally, that would pop out after firing; its missile also showed small canard foresurfaces. McDonnell Douglas showed 2 pivoting wings (carried 1 over the other) below the upper surface of the missile; these wings would also pop out after firing. McDonnell Douglas's and Boeing's configurations leave considerable space under the wing for a submunition-dispensing warhead (although McDonnell Douglas's sketch showed a 1000-lb unitary reactive case warhead, 17.3 in in diameter and 46 in long). Boeing emphasized commonality between different LRCWS versions, for vertical launch, torpedo-tube launch, and air launch; Boeing had already conducted a study of a propfan derivative of its air force air-launched strategic cruise missile (AGM-86B).



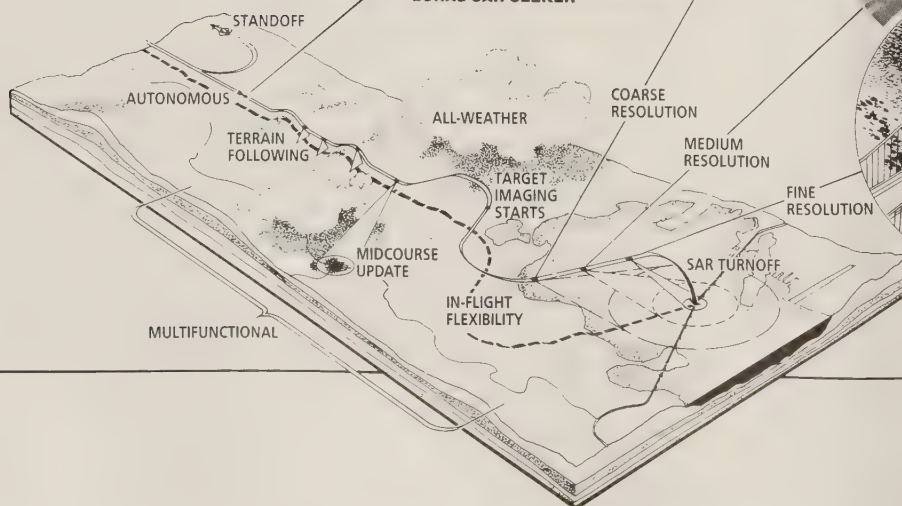
A possible Excalibur power plant is this new propfan engine by Teledyne-CAE. Total length is 35.53 in, and diameter, with the blades folded, is only 16 in. The entire engine weighs 150 lbs. In comparison, the Harpoon missile's J402-CA-400 sustainer, which was the first to be designed for "wooden round" use, weighs 101.5 lbs and is 29.2 in long, with a maximum diameter of 12.5 in. Teledyne also offers a bypass turbojet for next-generation cruise missiles, presumably a rival to the propjet. This turbojet would weigh 135 lbs, with a diameter of 13.2 in, and would produce a thrust of 1100 lbs (compared to 660 for the Harpoon engine), with a specific fuel consumption of 0.9 lbs/hr/lb-thrust (compared to 1.2 for the Harpoon engine). (Teledyne-CAE)

Since a major LRCWS application is submarine launch, the missile is probably limited by the torpedo tube's dimensions, which include a 21-in maximum diameter. McDonnell Douglas showed a length of 235 in, which is presumably the maximum allowable.

LORAL
Defense Systems - Arizona



LORAL SAR SEEKER



A synthetic-aperture seeker for advanced cruise missiles. (Loral)

LRCSW will almost certainly be propelled by an unducted fan; the blades must fold (for tube stowage), and they must also be stealthy. On the other hand, the missile is launched at nearly Mach 0.75, the speed at which it flies to its target, so there is no need for variable pitch. A half-scale engine is to be tested late in 1990. The current competitors are: Teledyne/GE, Allison/Hamilton Standard, Garrett (folding propfan blade technology), Williams International (improved version of current F107). The first 2 are concentrating on complete engines. Allison plans a development version of its Model 250-C30 as the core of a future engine. Teledyne is looking at an engine derived from the GE 36 engine demonstrated on a 727 airliner. The company is also working on a private-venture 700-1000-lb core engine specifically designed for propfans.

Several of these companies displayed prospective LRCSW engines at the 1989 Navy League show. All should be more economical than current turbofan cruise-missile engines, providing either more range with current warheads or larger warheads. The existing Tomahawk makes its long range only in its nuclear version, and in that case the warhead weighs less than 300 lb. Tomahawks carrying substantial nonnuclear warheads cannot carry enough fuel to go nearly as far, yet the hope of the LRCSW is that it can reach full Tomahawk ranges and still carry large conventional warheads (and achieve virtually zero CEP).

The LRCSW engine is conceived as a possible modular-engine replacement for the Tomahawk turbofan.

STRIKE/ SURFACE WARFARE

This section includes all weapons and fire-control systems intended primarily for antiship or ground attack. The 2 applications are often extremely difficult to distinguish, as many weapons, such as cluster bombs, intended primarily for use against land targets have important antiship applications. For example, during the fighting in the Persian Gulf in 1988, U.S. A-6 Intruders used Paveway laser-guided bombs to attack Iranian ships, while cluster bombs were used during attacks on Libyan ships in March 1986. The Maverick ground-attack missile has reportedly been used by Iran to attack tankers, and indeed the U.S. Navy uses a special antiship version of Maverick.

From a missile's point of view, ships and land targets all move relatively slowly; therefore, they impose very similar loads on propulsion and aerodynamics: hence, the dual-purpose weapons. However, a ship almost always presents great contrast to its surroundings and, therefore, is a relatively easy target for a fire-and-forget weapon. Most land targets show much less contrast with their surroundings and, therefore, must be identified by eye, at least at present. In some cases, there is sufficient contrast for an autonomous seeker, but in most an artificial signature must be imposed. Hence, the widespread current use of laser designators and the considerable interest in imaging infrared seekers (which allow an operator to designate a target for a missile or guided bomb). The great drawback of the laser is that its designation platform must remain in position while the weapon is in flight. Even in the case of ships, the situation may not be very simple. The target ship may well be part of a formation, and other, lower-value parts of the formation may be larger radar targets.

Weapons' characteristics largely shape attack tactics. The issue for the designer is how best to penetrate terminal defenses. The techniques, very broadly, are speed, saturation, and stealth. Very high speed penetrates by limiting the number of shots a defense can fire while the attacker passes through that defense's effective-range band. Examples include most recent Soviet antiship missiles, which fly at about Mach 2.0. Alternatively, an attacker may fire numerous weapons at the target, preferably from many different directions. Several recent antiship missiles, such as current versions of Harpoon, incorporate programming for way points. The missile is fired along a course away from the target and then turns sharply into the target. This maneuvering has 2 effects. First, it limits the value of early-warning since the missile does not remain on its initial course long enough to be engaged. Second, the maneuver enables a single attacker to execute a coordinated multidirectional strike, with missiles appearing on target from several angles at once. Waypointing may allow an attacker to overwhelm the limited number of defensive channels that most ships have. Finally, there is stealth, the best-known example of which is the use of sea-skimming trajectories that limit detection time (as long as the defender has no airborne radar). The desire for stealth affects the choice of missile seeker (e.g., IR rather than radar, or 1 type of radar rather than another) and of targeting device (the presence of a radar platform may warn a target that it is about to be attacked, even when the attack itself is stealthy). Generally, stealth limits the defense's reaction time.

These techniques work not only for attacks on shipping but also for other forms of strike warfare. For example, a pilot attacking a concentration of vehicles on land can probably make a single successful pass if the approach is at very low altitude because there would be the advantage of surprise—in effect, the benefit of stealth. However, if that pass is used merely to decide which vehicle to hit, the pilot may well die on the second pass, when the defense is alerted: hence, the advantages claimed for current single-pass/multiple-shot systems (e.g., for Maverick). Similarly, modern attack tactics often envisage several aircraft suddenly appearing on radically different bearings, a single formation having split up beyond the target's radar horizon. That is saturation. As a target's defensive capacity increases (in terms of the number of defensive channels), the attacker is forced to allocate more weapons per attack, in turn reducing the lethality of those weapons that do penetrate. Similarly, an attacker forced

to use faster weapons may not be able to fly those weapons at very low altitude, and the weapons themselves may emit so much infrared radiation that the target enjoys earlier warning.

This section includes airborne surface-search radars, although some of them are intended primarily to detect submarines. This section does not include standard shipboard surface-search and navigational radars. They are described in the Antiaircraft Warfare section. Some of the radars listed are intended primarily to help enforce EEZ, particularly in the Third World. Such radars, because they can detect and locate small surface craft (such as those used by smugglers), have an important potential either for direct targeting or for directing other missile-bearing aircraft. In the Falklands War, for example, an Argentine Neptune with a long-range APS-20 radar reportedly directed Exocet-carrying Super Étendard fighters, which had only to pop up briefly to fire and could thus avoid extended exposure to British detection. The standard U.S. AEW radar (APS-120 series) has the same capability but is listed in this book under AAW because air-to-air detection is that radar's primary role.

Probably the most important current antiship-sensor development is inverse synthetic aperture radar (ISAR). An airborne synthetic aperture radar (SAR) achieves its very high resolution (sufficient for imaging) from the motion of the airplane along a straight and level course. High resolution would normally require a very large antenna. A conventional radar scans as it moves, so that by the time it has moved a significant distance, the radar is no longer looking at the same scene. In contrast, a SAR does not scan. Since it is constantly staring in the same direction, pulses emitted at any point along the SAR's path and received later on contribute to the overall radar picture. A SAR's effective aperture (antenna size) is the distance the radar travels while those pulses build up, the product of the aircraft's speed (along the straight flight path) and the period of time during which pulses build up in a coherent way (the integration time). The latter depends in part on the amount of memory built into the SAR system, since the radar has to remember earlier echoes to compare them with later ones, taken further along the flight path. A SAR can achieve very impressive resolution but can look only to the side. Targets are more often straight ahead.

ISAR solves this problem by using the motion of the target (roll, yaw, or pitch) rather than that of the airplane. The resulting image generally lacks the quality associated with SAR but may suffice for crude ship recognition and for attack assessment (comparison of before and after images). The radar may be able to measure target course relative to the radar, reassembling what amounts to a target silhouette; and crude recognition may be automated. In this form ISAR may be applicable to future antiship missiles.

The key is that the angular velocity of the target as a whole equates to different linear velocities (e.g., in ft/sec) at different distances from the distant radar. Each such linear velocity (in the direction of the radar) causes a doppler shift in reflected radar echoes. Thus different doppler shifts are associated with different distances from the line about which the target is moving (for example, its centerline in the case of rolling motion). The line about which the target moves becomes a reference line, and an image of distances can be built up. In the case of roll, with the radar abeam, a plan image of a ship results. Similarly, the doppler frequencies associated with the pitching of a ship give the heights of points along its length, so that a series of measurements by a radar pointing bow to stern gives a target silhouette. Since the target is unlikely to be either directly in line with the radar or directly abeam of it, the ISAR should be able to produce a nearly 3D image.

This section also includes infrared detectors. They fly on board all ASW aircraft and on board many attack aircraft; some are intended primarily to detect hot snorkel exhausts, and others are primarily for land attack. All have some capability to detect and image (and hence to help classify) surface targets; therefore, they are included here.

The central distinction in classifying weapons, whether they are attacking fixed or moving targets, is between point-attack

and area-attack weapons. Improved technology makes it possible for weapons to be delivered with extremely small errors (CEPs, or circular errors probable, of 10 ft or less are now quite common). Some analysts have, therefore, suggested that the future of munitions lies with relatively small numbers of essentially zero-CEP devices, some of them perhaps deliverable from extreme distances. However, the efficacy of such weapons depends in turn upon how well the targets can be located. Therefore, this section also includes some tactical reconnaissance systems. The ones listed should be taken as typical rather than comprehensive; but the reader should be aware that, no matter how precise the weapon, it cannot reach a valuable target unless that target can be located in the first place. That makes it difficult, for example, to attack individuals who may not be home when the missiles arrive to greet them.

The alternative is to cover a suspected target area with large numbers of relatively imprecise weapons. Area-attack has certainly been the approach in the past, and at present this approach is represented by bomblet-dispensing munitions such as the U.S. Rockeye and, presumably, also by fuel-air explosives. Area-attack is useful not only because targets may not be precisely located but also because the targets themselves may be spread out over a considerable area. For example, it may be impossible to fire a separate long-range weapon at each of numerous troops dug-in around a target area; however, area-attacks on the troops may kill many of them and may so demoralize the rest as to make them ineffective.

It is common, then, to distinguish between "dumb," "smart," and "brilliant" weapons. A "dumb" weapon is entirely unguided after release; all the intelligence in the system is concentrated in the launch vehicle, be that an airplane or a ship. A "smart" bomb attacks a target designated by the launcher, homing on some element of the target's signature picked out in advance or on a signature, such as a laser spot, imposed by the launch vehicle or by some cooperating platform. Finally, a "brilliant" weapon will choose its own target. No "brilliant" weapons are currently in service, but many analysts have suggested that these weapons are the future of guided munitions.

There are several major ground-target categories. In amphibious operations, it is essential to neutralize troops and coast-defense weapons (such as truck-borne antiship missiles) dug-in at the objective area. There is some hope that modern high-mobility amphibious forces can evade such fixed defenses altogether, although evasion may not be possible when geography clearly dictates the choice of landing zone. Generally, it will be important to disable opposing enemy air forces and air defenses. Once amphibious forces have landed, an enemy will try to counter them with mechanized troops, tanks, and perhaps attack helicopters. Thus, antiarmor/antivehicle weapons are extremely important. Naval forces may also be called upon to execute classical, deep air strikes, e.g., at enemy industrial targets, air bases, roads, highways, and bridges, as in Vietnam. Given sufficient lifting capacity, the naval air-to-ground arsenal is not so different from that available to the land-based tactical air force, and many of the weapons listed here are air force types.

The major problem in ground attack is that the targets (which may be both small and camouflaged) must be distinguished from considerable ground clutter and then must be designated to a bomb or other munition. The pilot's eye is likely to be more effective than any automated system, but the pilot may be subject to antiaircraft fire as the targets are chosen. The longer the pilot takes to decide, the more vulnerable the pilot is. In theory, a pilot can designate a target to a purely ballistic system. However, a bomb, rocket, or cannon shell that is unguided after launch will probably miss because of such random factors as windage between release and impact. The closer the pilot is to the ground at the time of release, the more accurate the delivery, but also the greater the danger to the airplane.

The next step, then, is to provide some sort of post-release guidance. A bomb can be made to home on a laser spot on the designated target, and the laser can be manipulated either by the pilot or by someone on the ground. An alternative is to

direct the bomb to home on some feature of the target as it is seen from the airplane, using either optical or infrared wavelengths, so that the pilot need not wait for the bomb to hit; but the target may have insufficient contrast for homing. In both cases, homing must be continuous after the bomb begins to approach its target, and experience shows that homing may be thrown off completely by the dust and debris thrown up by an earlier bomb, by clouds, or by smoke. If laser homing is used, an enemy who is aware of which laser wavelengths are in use may be able to provide alternative targets.

Moreover, the attacking pilot has to keep a laser on the target during the missile's flight, so must remain within the target area, and that is quite dangerous. However, few ground targets show sufficient contrast for autonomous television (electro-optical) homing.

A variation on these themes is to provide the missile with an optical or infrared seeker and a data link to the launch airplane. The missile can then be fired at a target that the pilot cannot see but that can be designated via the data link once the missile spots the target. The U.S. Navy developed just such a weapon, Condor (AGM-53); but the jam-resistant data link proved extremely expensive, and the project had to be abandoned. More recent (and less ambitious) data-link projects have, however, survived, as in the case of Walleye. As with laser designation, the data-linker must remain in a restricted air space and, thus, may itself be vulnerable to enemy attack. On the other hand, it is further from the enemy than it would have been had it fired a lock-on-before-launch missile. This situation is not very different from that of a Soviet submarine or surface ship firing an SS-N-3 or SS-N-12 antiship missile. Indeed, it is sometimes suggested that the latest Soviet air-launched antiship missiles incorporate data links that permit them to lock the missiles on after, rather than before, they are launched.

One other possibility that has recently arisen is inertial guidance: the pilot designates the target as a point in space, and the bomb or missile flies itself into that point, without reference to the ground. In principle, this is precisely what a long-range ballistic missile (which is, after all, a ground-attack weapon) does, but in this case over a much shorter distance and a much shorter time.

Another important near-term improvement is millimeter-wave (MMW) homing. Millimeter-length radiation is at the long-wave end of the infrared spectrum, short enough to provide some imaging, but long enough to cut through such natural obstacles as smoke. Millimeter-length radiation can also be generated by extremely high frequency radar techniques. There is some hope that MMW will make direct (fire-and-forget) homing on tanks and other vehicles possible. At present there is no really effective means of homing on such objects, unless they are generating considerable heat against a cool background. Most "brilliant" antiarmor submunitions (weapons intended to be carried within larger warheads) now under development in the United States seem to use some type of millimeter-wave homing. In the absence of such techniques, antiarmor munitions depend either on continuous guidance by the operator (e.g., wire guidance, as in the TOW missile) or on a percentage chance of hitting (as in bomblets).

Somewhat further in the future are imaging techniques using artificial intelligence (AI) to enable an incoming weapon to decide for itself which target to hit. These techniques are unlikely to end the story because, just like a human eye, a mechanical sensor can be misled by clever forms of camouflage and decoying. It is not at all clear, either, whether future "smart" or "brilliant" antiarmor weapons will be cheap enough to apply on a large scale.

All of these techniques are applicable to shells, and laser-guided artillery shells now exist.

For simplicity of reference, torpedoes are all included under ASW weapons, although in many cases torpedoes are intended for use against only surface targets. Similarly, antiship mines are listed separately in the Mine Warfare section. Guns are all

listed in the AAW section; in some cases their antiaircraft capability may be marginal.

RECONNAISSANCE SYSTEMS

Aircraft-Carried Sensors

UNITED STATES

◆ ATARS

The joint-service Advanced Tactical Air Reconnaissance System will be the first airborne reconnaissance system to replace film with electronic data storage (as currently used in satellites) so that information can be data-linked back to base while the ATARS platform is still airborne. Because there is no need to store large quantities of film, the system can fit in an RPV. Reportedly, the greatest technical challenge in the project is the very-high-data-rate digital recorder required.

The sensors will all, therefore, be electro-optical: as in TARPS (see below), 2 visual for daylight (low-altitude/wide field of view and medium altitude/stand-off) and 1 IR (night).

This program is air force led, and the first application will be to existing RF-4Cs. The initial navy application will be to the mid-range RPV (MR-RPV), and the marines will use ATARS on board F/A-18Ds. ATARS will also replace TARPS pods on board F-14Ds.

Bids were submitted in July 1987, and Control Data Corporation was chosen as manufacturer in May 1988. Initial flight tests, on an air force RF-4C, are scheduled for the fall of 1990. ATARS-equipped RPVs will also be used.

◆ TARPS

Tactical Air Reconnaissance Pods can be carried by F-14 and F/A-18 fighters. Currently, 2 F-14As in each carrier air wing are fitted to accept these pods, and 3 aircrew are trained to use TARPS. All new F-14Ds will be wired to accept TARPS.

TARPS replaces the specialized equipment built into such aircraft as the RF-8 and RA-5C and was bought as an alternative to a new specialized reconnaissance airplane, which would have been a modified F-4 Phantom (the marines did buy a specialized RF-4B). The pod is conceived primarily as a strike-planning and battle-damage-assessment system, and TARPS was widely used during the operations off Lebanon in 1983-84.

The pod carries 2 cameras (Fairchild KA-99 low-altitude panoramic, with 9-in focal length; and CAI KS-87B frame camera, with 12-in focal length) and an infrared line scanner (Honeywell AAD-5A, with both wide and narrow fields of view). Total weight is 1700 lb.

TARPS was developed by the Naval Air Development Center and is produced by the Naval Avionics Center. The system is to be replaced by the new ATARS.

The marines have not followed the same development path. Instead, they are developing an internal reconnaissance pallet for 2-seat F/A-18D fighters, about one-third of which will be wired to accept the pallet. Installation of the pallet requires removal of the internal 20-mm cannon of the F/A-18, and the pallet can accept any 2 of the 3 TARPS cameras.

◆ UPD-4/9

UPD-4 is a Goodyear SAR, used on Marine Corps RF-4Bs. When these aircraft retire, their F/A-18 successors will carry a podded UPD-9, similar to the air force UPD-8. UPD-9 adds a data link so that the radar image can be received on the ground before the airplane returns. Data-link range is about 200-250 nm; radar range is about 50 nm. The pod, which can be carried by the F/A-18D, weighs less than 1500 lb and is cooled by ram air. At least some of the new marine pods are repackaged UPD-4s. The pods are about the same size as the standard 330-gallon center-line fuel tank and weigh about 1500 lb each.

Production development of the pod began in July 1987; by that time the prototype had already flown on board an RF-4.

UAVs

This section has been renamed UAVs (unmanned air vehicles) instead of RPVs (remotely piloted vehicles) because many UAVs operate autonomously. The earlier designation is still widely used, even for autonomous craft.

CANADA

◆ CL-227 Sentinel

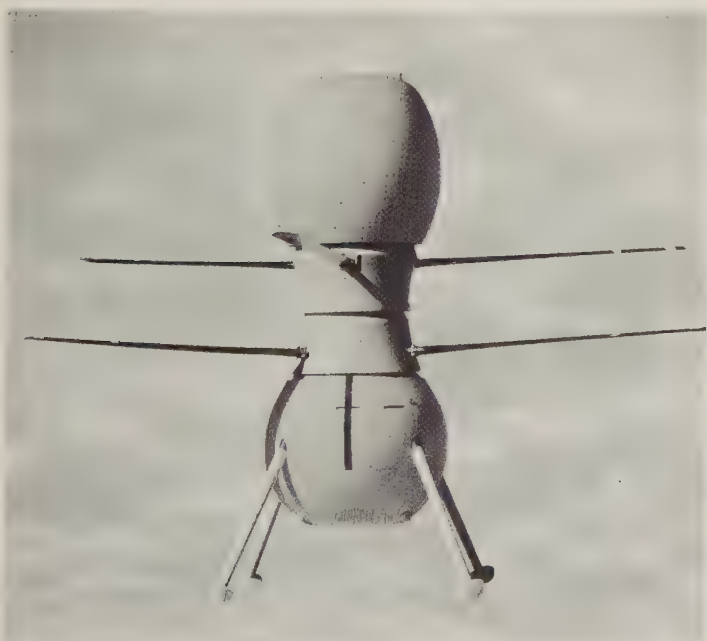
Engineering development of this small helicopter RPV began in 1977, with the first systems-test vehicle flying in 1980. In 1985 the Canadian government agreed to support the final development phase, so that fully militarized aircraft were available from late 1987 onward. CL-227 consists of a pair of turbine-driven contraprops with bodies above and below; guidance is based on a strapdown inertial sensor. Sentinel can fly at the end of a 200-m [655-ft] tether; powered by a Wankel engine, the prototype made its first flight on a tether on 25 August 1978. Most of the flight experience has been gathered with a slightly enlarged Phase 2 RPV powered by a 32-HP Williams International WR34-15-2 engine, which first flew untethered on 14 December 1981. The current Phase 3 version is slightly larger yet (details below).

The Sparton dwarf buoys (described in the ASW section) and their related seeder magazine were intended specifically for the Sentinel RPV. The magazine, 50 × 36 cm [30 kg], carries 20 miniature LOFAR omnidirectional buoys, or 4 DIFARs, or 4 SSQ-529 DICANCASS buoys. The DICANCASS transducer would be lowered into the water while the RPV hovered, functioning as a miniature dipping sonar.

Dimensions: rotor diameter 2.80 m [9 ft 2.25 in]; height, including landing gear 1.64 m [5 ft 4.5 in]; maximum take-off weight 190 kg [419 lb], including 88 kg [194 lb] payload (up to 54 kg [119 lb] fuel and up to 45 kg [99 lb] disposable payload).

Performance: maximum air speed 130 km/hr [84 kt], ceiling 3000 m [9840 ft], climb rate 3 m/sec at 1500 m [9.8 ft/sec at 4920 ft], endurance 4 hr at 1000 m [3280 ft].

The CL-227 program began in 1964 and was substantially reoriented in 1968. Customer flight trials began in 1980. The current \$60-million program, including production of 10 vehicles, is supported in part by the Canadian government (agreement announced 7 May 1985) and began in 1986. The first full production prototype flew on 20 November 1987.



The Canadair CL-227 Sentinel RPV. (Texas Instruments)

The NATO Group 11 demonstration planned for the summer of 1988 was canceled, but in August and September 1989 a CL-227 successfully flew 9 missions from the U.S. Army vessel *Jan Tide* off Point Mugu. The UAV used a real-time data link to direct it to find and intercept a target ship, and it used its own sensors to provide visual identification and target classification. At this time CL-227 was a candidate for the U.S. close-range RPV requirement.

◆ CL-289 (AN/USD-502)

A surveillance RPV designed initially for land use but proposed for the U.S. MR-RPV (see below), CL-289 was derived from CL-89, a joint Canadian-German project begun in 1961 and first flown in 1964. Production of CL-89 began in 1967, and as of 1987 more than 500 had been delivered to the British, German, French, and Italian armies. CL-289 was conceived as a corps-commander support-device, i.e., for area surveillance over ranges greater than those achieved by CL-89. CL-289 is a joint Canadian-German project; work began in July 1976, and France joined the program in March 1977. CL-289 first flew on 3 March 1980, and full-scale production began in 1987, initially for the French and German armies. The RPV is powered by a KHD T117 (240-lb thrust) turbojet. Speed is described as considerably more than that of CL-89, which achieves 400 kt. Dimensions: 1 ft 3 in × 11 ft 6.5 in (plus 3 ft 9.5 in booster); span is 4 ft 4 in.

GERMANY

◆ Geamos/Seamos

This Dornier private-venture helicopter UAV was announced early in 1989; the names indicate the mission (ground or maritime reconnaissance). It has an 80-km [44-nm] radius of action and can operate either autonomously or under remote control. It uses U.S. DASH (QH-50D) rotors and dynamic controls, with Dornier avionics, electronics, and system integration. The power plant is a 330-SHP Boeing T50-BO-12 turboshaft. The payload is supplied by LCTAR (Thomson-CSF). The GEAMOS UAV was successfully tested in August 1989. Dornier hopes to demonstrate the SEAMOS shipboard version in 1991.

◆ Submarine-Launched RPV

As of 1989, the German Navy is considering a submarine-launched RPV. Working with fast attack craft, it would provide both OTH target acquisition and target data relay. As of 1989, the tactical concept was being developed by the NATO Naval Armament Group. The planned technical demonstration had to be postponed by 2 years. CL-289 is the most likely candidate, but the group is also considering 2 U.S. models and the Dornier SEAMOS.

INTERNATIONAL

A NATO study group on RPVs for small ships was formed in December 1986 to establish a 2-year program to develop requirements because an earlier study (1985) had shown that there were no funded national programs for maritime-suitable RPVs. The U.S. Navy is chairing the group, which includes representatives of Canada, France, Italy, Spain, West Germany, and the United Kingdom. Four ship categories are involved: 500-ton fast patrol boats (as in the German Navy); corvettes; frigates; and 5000–8000-ton surface warships. RPVs had to be operable in 85% of weather conditions, which meant launch/recovery at: (figures for frigates, with FPBs in parentheses) pitch 4 (5) deg, roll 10 (15) deg, acceleration at the bow 9 (5) m/sec. The required radius of action was 35 nm for a fast patrol boat and 75 nm (100 nm desired) for a larger ship. Fuel had to be compatible with the host ship (JP-5 preferred), and the controlling data link had to be difficult to jam and to intercept.

Typical missions included

Early detection of an air threat along a known axis, using

ESM, focal planar array, IR search-and-track: endurance 1 hr, radius 40–60 nm.

OTH area reconnaissance/missile damage assessment, day/night imaging system: endurance 1 hr, radius 75–100 nm.

Gunfire-support targeting, day/night imaging plus laser range-finder/designator: endurance 3 hr, radius 30 nm.

EW, ESM, active/passive ECM, decoys: endurance 2 hr, radius 75–90 nm.

Communications Relay, 2 VHF/UHF radios back to back: endurance 3 hr, radius 80 nm.

ASW, sonobuoys and/or dipping sonar: endurance 3 hr, radius 60 nm.

Initially, the greatest interest was shown in vertical take-off RPVs such as the Canadair CL-227 Sentinel, the British Sprite, and the U.S. Pointer (now named Tracer). There was also a Dornier design study, SEAMOS.

As of mid-1988, Canadair was scheduled to demonstrate its CL-227 on board a frigate in September 1988. M. L. Aviation (Great Britain) was scheduled to demonstrate its Sprite RPV helicopter from a "Castle"-class OPV in November 1988, and there were tentative plans for a demonstration on board a German fast patrol boat. The Bell-Boeing Tracer tilt-rotor RPV was scheduled for demonstration on board a U.S. ship by the NATO group's December 1988 deadline.

ISRAEL

◆ Helstar

This helicopter UAV, using the rotors and transmission of the old U.S. Navy DASH (QH-50), was announced in the fall of 1989. In Israeli Navy service it will be carried by *Reshef*- and *Aliyah*-class fast attack boats. The latter already carry Kiowa and Dauphin helicopters. The only photograph thus far released shows Helstar with a FLIR ball and a belly radome, for 360-deg scan. IAI hopes to achieve a radar range of 40+ nm from Helstar. The power plant is a 420-SHP Allison 250C-20B. The rotor's

diameter is 20 ft, and height is 10 ft. Maximum take-off weight is 2450 lb (payload 450 lb, plus 900 lb of fuel, for 6-hr endurance). The unit cost is about \$4 million. Helstar first flew on 18 July 1990.

◆ Pioneer

The U.S. Navy bought this Israeli RPV to satisfy a requirement, stated in mid-1984, for a mini-RPV, for both the marines and for naval gunfire support (spotting). The RPV was probably based in part on experience with an Israeli RPV, Mastiff (a design predecessor of Pioneer), which was bought by the United States in January 1984 to support the marines in Lebanon. Mastiff was flown on board the helicopter carrier *Guam* on 26 March 1984. In July 1984 Secretary of the Navy John Lehman directed the Naval Air Systems Command to achieve a minimum operational capability as soon as possible, i.e., to buy an existing RPV. He was later credited with having accelerated the program by at least 2–3 years. The navy, therefore, opened the competition to any manufacturer that could participate in a fly-off by the spring of 1986, the winner to provide 3 years of technical-support services. Only Lockheed and Mazlat could be ready in time, and in 1985 Lockheed withdrew from the competition, leaving only the Mazlat Pioneer. Canadair, which demonstrated its CL-227 to the U.S. Navy in 1984, could not be ready in time. The navy bought 3 Pioneer systems in 1986 (2 shipboard and 1 Marine Corps, ordered 7 January 1986, with options for 2 more, exercised in February 1987), and 4 more in FY88. Successful tests during 1987 led to a decision to seek full-scale production under the FY89 program. In June 1988 the U.S. Navy ordered 4 more Pioneer systems, each including several RPVs. The ultimate navy requirement is 43 RPV systems, each consisting of 8 aircraft and a control unit.

The manufacturer, Mazlat, is a subsidiary of Tadiran/IAI, and the U.S. agent for Pioneer is AAI.

Pioneer was tested on board an LHA in June 1986 and became operational on board the battleship *Iowa* in December 1986 (installed June–December), carrying out reconnaissance over Central America. Pioneer was rocket-launched by the battleship and recovered in a net; the guidance transmitter was in a radome on the second funnel of the ship. Teething troubles caused the loss of 4 of the first 5, 3 to crashes on the ship and 1 to engine failure. The 2 major problems in the RPV itself were insufficient data-link range and an unreliable engine. The required 100-nm range could not be met, but range did increase from 50–67 km [32–43 nm] during tests. A ground-based version could be controlled at 165 km [107 nm], presumably by using a taller antenna.



Pioneer. (AAI)



Pioneer control antenna (at the forward end of the funnel, in the radome), USS *Iowa*, 1988. (A. Raven)

Pioneer is powered by a 26-HP Sachs gasoline engine, and the U.S. Navy wants to replace this engine with one running on JP-5, the standard (and considerably safer) navy-wide gas-turbine fuel. The sensor is a television camera.

In April 1988 it was reported that Pioneers had flown without mishap for 207 hr (70 sorties) from the battleship *Iowa*, during a Mediterranean and Gulf of Oman deployment.

Dimensions: span 5.15 m $\times$ 4.26 m length overall $\times$ 1 m height [16 ft 10.75 in $\times$ 13 ft 11.75 in $\times$ 3 ft 3.25 in]; maximum payload 45 kg [99 lb]; maximum take-off weight 195 kg [430 lb]. Maximum level speed is 48–70 kt; ceiling is 4575 m [15,000 ft], radius 100 nm, and endurance 6–9 hr. Fuel capacity is 11.1 U.S. gallons.

In June 1988 Mazlat announced that it was designing a VTOL RPV for small ships but would not undertake full-scale development until finding either a foreign partner or a launch customer.

In mid-1989 Mazlat was reportedly working on an improved Pioneer, called Searcher, which would be closer to the U.S. SR-UAV requirement. Maximum take-off weight is 700 lb, and endurance is 10½ hr. Searcher is to carry a day/night television sensor and a laser designator; the avionics used in it are compatible with those of the 430-lb Pioneer and the 1000-lb Impact.

◆ Impact

IAI's Impact is a competitor for the U.S. SR-UAV program. It has twin propellers (push-pull configuration) and an underbody sensor. This vehicle is powered by 2 TCM Thrust 45-HP engines and cruises at 60 kt; maximum speed is 110 kt. Rate of climb is 1000 ft/min, and service ceiling is 18,000 ft. Endurance is up to 12 hr. Gross weight is 1250 lb, including 150 lb of useful load and 200 lb of fuel. Wing span is 26 ft, length is 20 ft, and height is 6 ft. Impact has been under operational evaluation since 1988. It is a proposed competitor for the U.S. UAV-SR requirement, offered by a consortium of IAI and TRW Defense Systems Group. As part of this package, IAI is offering a stabilized modular optronics platform, MOSP (multimission optronics stabilized payload). An improved miniaturized version, IMOSP, is being developed for the U.S. Navy under the Nunn program.

The SR-UAV version, offered jointly with TRW, is JIMPACS (Joint Improved Multimission Payload Aerial Surveillance Combat Survivable System). The system as a whole includes 10 aircraft. Span in this version is 26.2–29.2 ft, maximum take-off weight is 1250 lb, payload is up to 250 lb, maximum speed is 120 kt, and endurance (with a 200-lb load) is 12 hr. JIMPACS will be launched from a runway or a zero-length launcher (using a rocket booster); recovery is via an arrested landing, with a parachute for emergency recovery.



IAI's Impact, a competitor for the U.S. SR-UAV program, is shown on display at the Paris Air Show, 1989. (Author)

ITALY

◆ Mirach

Mirach is a family of RPVs manufactured by the Meteor company. The propeller-driven Mirach 20 (carrying either an IR sensor, with a range of 32 km, or a radar) was proposed for the U.S. Navy's short-range RPV (Pioneer was chosen). Mirach 20 was displayed at the Italian naval exhibition, *Mostra Navale*, in 1986. Mirach 20 is powered by a 26-HP Herbrandson Dyad 2-stroke flat-twin engine, and the airframe is built mainly of Kevlar. Dimensions: span 3.83 m, length 3.62 m [12.5 $\times$ 11.9 ft]; weight 95 kg empty, 197 kg max at launch [210/434 lb]; maximum internal combat load 20 kg [44 lb]. Maximum level speed is 108 kt, and maximum endurance is 3 hr. Maximum rate of climb at 1000 m is 240 m/sec [3280 ft: 787 ft/sec].

There is also a larger Mirach 100, proposed for the MR-RPV, powered by a 400-lb-thrust NPT 401 turbojet. Mirach 100 is currently in production, over 150 having been built by early 1987. Users include Libya and Iraq, so that Mirach may well have seen combat service. Mirach is built under license in Argentina as MQ-2 (Bigua). In the U.S. MR-RPV contest, Mirach was offered with a Pacific Aerosystems Mizar data link. Dimensions: 1.8 m span $\times$ 3.94 m [71 $\times$ 155 in]; weight 210 kg empty, 310 kg loaded, internal combat load 70 kg [463/683/154 lb]; maximum level speed 458 kt (Mach 0.92); maximum endurance 1 hr. The normal 1-way penetration range is 485 nm. Mirach can be preprogrammed, e.g., to loiter over a battle area.

UNITED KINGDOM

◆ Raven 200

Flight Refueling, Ltd.'s ultra-light UAV, offered for U.S. evaluation, was derived from the earlier Raven 1. It is 33% larger (60 kg [132 lb] rather than 15 kg [33 lb] weight). Endurance is 4 hr, and radius is 40 km [22 nm]. Raven is essentially a sophisticated model airplane, launched from a rubber-band (bungee) catapult. Span is 3.6 m [142 in], and length is 2.6 m [102 in]; a 12-HP 2-stroke engine drives it at 35–90 kt, with a ceiling of 10,000 ft. Raven either is flown by a remote pilot (who orders heading and altitude) or can be programmed to fly over an area of interest. It can carry day or night sensors, transmitting their imagery back to a ground station. All of the ground equipment can be carried by a single Land Rover.

◆ Sprite

M.L. Aviation demonstrated this helicopter RPV to the U.S. DoD in May 1985. In British tests, Sprite has successfully landed on a rolling platform in gusty winds of up to 20 kt. Overall weight is 88 lb [40 kg], and endurance (depending on payload) is over 2 hr. Rotor diameter 1.6 m, body diameter 0.65 m [5 ft 3 in/2 ft 1.5 in]. Payload is 12 kg, typically 6 kg of fuel and 6 kg of sensors [26/13/13 lb]. The power plant is two 6-BHP Kolbo D238 2-cycle gasoline engines, or two 7-BHP Piper 2/80 2-cycle gasoline engines. Cruise speed is 60 kt, and climb rate (at 45 kt) is 1200 ft/min. Normal operating altitude is 250–500 m, ceiling 3000 m [820–1640, 9800 ft].

The typical payload consists of a thermal imager, a CCD color television camera, or a monochrome LLLTV. These sensors can be steered through 110 deg in elevation, and they can be scanned in bearing by spinning the vehicle on its axis (a capability that is not affected by flight direction). The manufacturer hopes that a future version will be programmable for sector scanning.

Sprite's radar cross section, currently about 0.5 m², is to be reduced to 0.3 in a proposed production version (a cowling will smooth its shape). The manufacturer claims that this vehicle cannot be seen beyond 800 m. The acoustic signature is reduced by venting exhaust gases from the top of the vehicle, to be mixed with cold air in the rotor down wash.

Sprite was developed as a private venture and first flew in January 1983. As of 1989, Sprite was 1 of 2 remotely piloted helicopters (RPH) scheduled for evaluation by the U.S. military,

the other being the Canadian CL-227. The U.S. Navy is considering Sprite for small-ship use, 1 role being communications relay (the "poor man's satellite"). The present variant is an advanced prototype rather than a production version.

UNITED STATES

◆ RPV Master Plan

U.S. UAV development is now being conducted by a JPO (Joint Project Office) established in mid-1988. Congress demanded that the different services' UAV programs be merged after the army's Aquila (MQM-105) program was abandoned in 1987, after 14 yr (and \$1 billion). Congress, therefore, froze FY88 money for nonlethal UAVs pending establishment of a joint program. A JPO was established within NAVAIR, attached to the joint cruise missile office. The JPO produced 2 class requirements: short range (200 km beyond the forward line of own troops [FLOT] and mid-range (JSCAMPS): SR-UAV and MR-UAV. Two more were later established: close-range (over the hill) and long endurance.

A UAV Master Plan submitted to Congress in June 1988 called for 3 categories: short range, medium range, and long endurance. RFPs for the baseline family of RPVs are due in 1990, with evaluation and testing to begin in FY92. There was some fear of duplication of effort between the UAVs and standoff (but loiter) munitions; Tacit Rainbow falls into the gray area between a classical UAV and a standoff missile.

There has been some concern, both in Congress and in DoD, that the delay involved in restarting the program after FY88-89 funds were frozen (in August 1988) would be excessive. This freeze was not the first restructuring of the program. Secretary of the Navy John Lehman significantly accelerated the navy program late in FY85, and in FY87 Congress demanded increased use of RPVs, probably as a reaction to the loss of an airplane and its crew during the Libyan raid. Secretary Lehman's directive was to use, wherever possible, existing equipment. The navy requirement was broken down into short range (Pioneer), medium range (MR-RPV), and long range (high altitude, in combination with the army and DARPA). A reconnaissance version of the existing BQM-74C Chukar target drone was tested during FY86.

The U.S. medium-range UAV is to be designated BQM-129. It is now known as JSCAMPS (Joint Service Common Airframe Multiple Purpose System). As of about March 1989, projected procurement (during FY89-94) was 775, including 230 (150 air force and 80 navy) reconnaissance aircraft equipped with ATARS, 120 non-ATARS reconnaissance aircraft, and 425 targets. Teledyne won the medium-range competition with its Model 350, defeating Northrop and Martin Marietta/Beech.

The version of ATARS to be carried by JSCAMPS will be more compact than that planned for tactical aircraft. The latter carry both electro-optical cameras and an infrared line scanner; the RPV will be designed to carry one or the other.

Early in 1989 the JPO split the short-range requirement in 2, creating a new close-range (CR-UAV) requirement. The SR-UAV is to operate 150 km beyond the FLOT, with 300 km desired. Minimum payload volume is 500 in³, the vehicle to execute 2 separate missions simultaneously (choosing among EW, ELINT, SIGINT, other forms of intelligence collection, and communications relay).

The SR-UAV RFP was issued in March 1989 after industry had objected to an earlier draft. Planned procurement (FY89-94) is 4 prototypes plus 38 systems, each including 8 air vehicles, with a mixture of payloads. Estimated unit cost of a system is \$500-600M. Most are to be bought during FY93-94.

Five offers were submitted by May 1989: GEC with Phoenix; IBM with Heron UAV and MIZAR avionics; IAI/TRW with the Impact vehicle and JIMPACS (Joint Improved Multimission Payload Aerial Surveillance Combat Survivable System); the McDonnell Douglas/DSC Skyeye R4E-50; and the Leading Sys-

tems Amber 450B. In mid-September Phase I contracts were awarded to McDonnell Douglas/DSC and IAI/TRW for, respectively, \$43.1 and \$18.5 million. Evaluation of the 2 alternatives should be conducted between March and October 1991, with a prime contract award early in 1992.

Of the UAVs listed, only Skyeye is currently operational, having entered service with Egypt at the end of 1988. It has also been bought by several other countries. It is also the only U.S.-designed short-range UAV currently under active development. R4E-50 is larger than earlier versions and can carry a combined SIGINT/imaging payload. It is powered by a Teledyne Continental rotary engine and uses a parafoil recovery system (25 kt controlled approach, with a soft landing; it can make a second approach if the first must be aborted).

Current plans call for 3 versions of SR-UAV: Blocks 0, 1, and 2. Block 0 is a baseline system for the army and marines, with a day/night imaging payload. Block 1 is adapted for naval use. Block 2 is to be an improved version, with automatic track/search features, greater survivability, and an engine burning a heavy fuel such as JP-5. Reportedly, the main issue in Block 1 is shipboard handling (which proved difficult with Pioneer); it is estimated that the vehicle itself will account for only 10-15% of the overall system cost. That makes a VTOL such as the Bell Pointer attractive for Block 1. However, to choose such a vehicle would be to reject the congressional desire for a high degree of commonality among all versions of the RPV.

As of early 1989, 36 Pioneers were on hand, with 28 more scheduled for delivery during 1989. Pioneer, originally a navy system, is to replace the army's more expensive Aquila. As of early 1989, 8 Aquilas were on hand, with 8 more scheduled for delivery during the year.

The close-range UAV is defined by a range of 30 km [16.4 nm], an endurance of 1-6 hr, and a speed of 100 kt; it is to be particularly simple to operate. The different services have very different roles in mind. The navy seeks a "flying crow's nest" for small warships; the army and marines want a "view over the next hill"; the air force wants base security and the ability to assess postattack damage to its own airfields. The JPO is conducting 3 Foreign Weapons Evaluations (FWEs) in this category: the CL-227, Sprite, and the Raven 200. It is also considering the Sandia Labs AROD (Airborne Remote Observation Device), which is being evaluated by the marines, and infantry-portable UAVs. As of early 1989, the marines had tested one low-cost device, the Aero-Vironment Pointer. The marines and the army have bought a longer-range very low cost vehicle, the Brandebury Exdrone (Expendable Drone), which has a range of 565 miles and a 7-hr endurance.

A Mission Need Statement (MNS) for the CR-UAV was scheduled for completion early in 1990, with contract award scheduled for FY92, and production and testing for FY94.

Both the SR-UAV and the CR-UAV may carry the Israeli-developed IMOSP (Improved Multi-Optronic Stabilized Platform); it integrates a laser designator with either a FLIR or an electro-optical sensor.

At the other end of the scale, an RFP for a long-endurance vehicle is expected during FY91. The only long-endurance RPV in current U.S. service is the Leading Systems Amber, 6 of which were on hand early in 1989. Four more were delivered during 1989. This figure covers all the services, whose requirements for (and definitions of) high endurance vary. For example, the army's concept of a long-endurance RPV or UAV calls for an endurance of about 36 hr and for operation out to about 300-km range. On 7-8 June 1988 an Amber set what its manufacturer called a world record for UAV endurance by remaining in the air for 38 hr and 27 min. This is still far short of the several days' endurance that a useful long-loiter naval UAV would require. The Amber payload is code-named Skydancer.

As of 1989, full-scale development of the E-UAV was expected in FY93. Competitors probably included an unmanned version of the E-Systems/Garret/Grob Egrett, now being developed for the West German government.

◆ AAV

Martin Marietta's Autonomous Air Vehicle (AAV) was developed for DARPA. AAV is primarily an experiment to see whether enough intelligence could be built into an unmanned vehicle for it to find hidden targets (using a FLIR and a millimeter-wave radar), attack them with smart submunitions, evaluate damage, and reattack if necessary. The end product was a captive flight in October 1989, after a 4-month program.

AAV was, then, primarily an exercise in image processing. Martin Marietta hoped that the vehicle's image of an area could be scanned automatically to show the places most likely to contain targets, e.g., trees in which tanks may take cover. The AAV would loiter near such areas, waiting until targets appeared; it could also seek out soft secondary targets such as aircraft on airfields. The loiter capability would tend to deter an enemy from unmasking its force, i.e., from moving, just as Tacit Rainbow is intended to deter an enemy from turning on its radar. Even if it did not attack directly, the loitering smart AAV could provide such a deterrent when operating in a reconnaissance mode since its information could cue attacks. The original impetus was the need to attack strategic relocatable targets, such as mobile ballistic missiles, but AAV has a major tactical value.

For Martin Marietta, the key to AAV is the company's Geometric Arithmetic Parallel Processor (GAPP), which can analyze thousands of pixels simultaneously. On a terrain board it was able to recognize targets in less than 0.2 sec, compared to several minutes for a conventional serial computer working pixel by pixel. GAPP was developed originally for night-vision systems.

Texas Instruments has a competing development-and-demonstration contract.

◆ Amber

This long-endurance reconnaissance RPV was developed as a classified program by DARPA. Amber is propeller-driven (pusher engine), and the fuselage's length can range from 13 to nearly 20 ft (payload volume 5–15 ft³, capacity 150–300 lb). It was announced in May 1988 that the U.S. Navy planned to buy 96 Ambers, which are suited to ship or ground launch, for radio relay, surveillance, and signals intelligence. At that time 10 had been turned over to the navy. Operational trials were scheduled for late 1989, and the system could become operational in 1990.

As of early 1988, Amber had flown continuously for 31 hr, at altitudes of up to 23,000 ft. In the basic high-altitude Amber 1 configuration (450A45), the power plant is a 65-HP pusher (KH-800) engine, length is 14.3 ft, wing span is 28.4 ft, and gross take-off weight is 750 lb (empty weight 280 lb). Speed is 250–300 kt. Two alternative payloads are being developed: one for radio relay, the other with an electro-optical sensor (as in Pioneer) and a signals intelligence package.

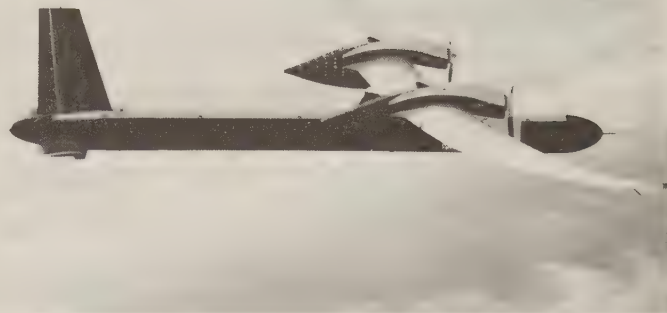
The manufacturer, Leading Systems, was formed in 1983 specifically to develop a high-tech, high-performance UAV. The company is currently producing 10 "maturation" Ambers to test payloads and operational concepts. Leading Systems is currently working on an Amber IV, with a 19-m (62.3-ft) span and a 65-HP KH-800T liquid-cooled 4-cylinder engine. The company is developing a KH-1200TD 3-cylinder 2-stroke diesel, with opposed pistons to reduce vibration, as its next-generation power plant.

As of 1990, 1 Amber system (6 UAVs) had been delivered, but the vehicles were all in storage.

Amber was conceived as a successor to the air force's manned TR-1 and is separate from the HALE program of the Naval Air Development Center.

◆ Condor

Boeing Advanced Systems built this very long endurance UAV for DARPA. Condor was rolled out late in March 1986 but did not fly until October 1988. Delays were caused by difficulties with propulsion, as well as a ground-handling accident, which



The Condor high-altitude long-endurance UAV. (Boeing)

presumably resulted from the light weight (hence flimsiness) of the very long span vehicle. Condor is the air element of the DARPA Fennel program, reportedly designed to carry a large-aperture active-array radar, in support of air defense against cruise missiles. Boeing is seeking support for other missions such as ESM and drug interdiction. To achieve extremely long endurance, Condor uses a very light all-composite structure (its wing weighs only 2 lb/ft²), a sailplanelike very high aspect ratio wing (200-ft span, aspect ratio 36.7:1), and low-powered engines (two 170-HP liquid-cooled turbo-supercharged Teledyne Continental engines, driving 16-ft propellers). It takes off from a dolly and underwing outriggers and lands on a centerline skid. Control is fly-by-wire, presumably to reduce flight loads on the lightweight structure.

Condor has demonstrated an endurance of 60 hr and has reached 67,028 ft.

Early in 1990 DARPA announced an experiment, planned for 1991, to demonstrate the use of a long-endurance UAV, such as Condor, to support submarine AAW. The UAV would act as the system radar platform, and it would communicate with the submarine by means of a 2-way blue-green laser. In theory, this sort of system would permit a submarine, submerged in the Norwegian Sea, to ambush Soviet bombers flying south to attack a carrier battle group. (In practice the bombers might well fly elsewhere, and the blue-green laser uplink might be less than fully covert.)

◆ HALE Projects

HALE is an acronym for High Altitude Long Endurance, and there are persistent reports of U.S. Navy interest in such devices, Amber (above) being a case in point. HALE reconnaissance vehicles were successfully used in Vietnam, and the new technologies of very lightweight aircraft construction and also of lightweight sensors make HALE vehicles quite attractive. The current definition of long endurance seems to be about a week, so that a few HALE could support a deployed surface action group without requiring integrated launch-and-recovery facilities. The current HALE program is described as an investigation of a large unmanned aircraft of extremely long endurance.

In December 1986 the Naval Air Development Center issued an RFP for a HALE for wide-area surveillance and OTH-T; responses were due by 6 February 1987. Requirements included an endurance of 120 hr at a cruising speed of 116–161 kt, and a service ceiling of 65,000–90,000 ft. The required payload was 7500 lb, and wingspan could exceed 61 ft. The RPVs described here are generic HALEs and were not specific responses to this

RFP. They indicate the sort of capabilities that are now available.

In 1983 Lockheed-California announced a twin-engine HALE powered by 2 turbofan/turboshaft engines (driving 14.3-m-diameter propellers, which would be locked for take-off), with a wingspan of 84.1 m. Endurance was 24 hr at 27,400 m.

About 1985 Teledyne Ryan announced Spirit, with an endurance of 80 hr at an altitude of 15,850 m to 160 hr at an altitude of 6100 m. Span was 85 ft and overall length about 40 ft (depending on payload); height at the tail was 14 ft (propeller diameter 20 ft). Weight was 4500 lb, and payload 300–1200 lb (depending in part on fuel load, which could be as much as about 900 lb). Cruising speed was 130 kt, and operating altitude 52,000 ft (absolute ceiling 75,000 ft). The power plant was a single flat-6 pusher engine. Spirit probably flew in 1986.

At about this time, too, E-Systems tested L450F, based on a Schweitzer sailplane and powered by a Pratt & Whitney PT6A engine.

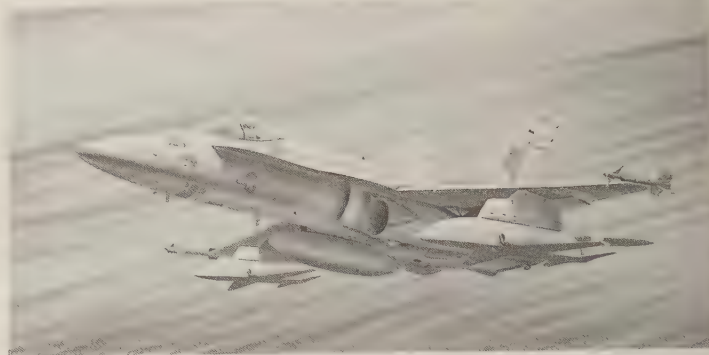
The first high-endurance UAV was apparently the Teledyne-Ryan Compass Arrow (AQM-91A), used for reconnaissance during Vietnam (and capable of 24-hr endurance at 50,000 ft). Surviving examples were placed in storage in 1973. NSA and the Air Force began Compass Cope, effectively an unmanned U-2, in 1972 (55,000 ft, 30 hr); Boeing won the competition, but the program ended in July 1977. At about this time the Naval Air Development Center began its own HALE program, HISPOT (high surveillance platform for OTH targeting); contracts went to Teledyne-Ryan and, in 1987, to Boeing and Northrop (reportedly for a stealthy flying wing). DARPA began its own UAV program, Teal Rain, in the early 1980s, with contracts to Leading Systems (Amber) and to Boeing (Condor).

◆ MR-RPV (JSCAMPS)

The RFP for a medium-range RPV with a target variant was issued in August 1986, and 1 of 2 finalists was to be chosen late in 1988, with production to begin in 1989. The program was restructured as a navy–air force program in 1988, new RFPs being scheduled for April of that year. At that time the navy planned to buy 31 mid-range systems, each including 5–8 RPVs. Funds were frozen in March 1988, pending creation of a joint-service RPV office, to comply with a congressional directive. Industry meetings were held in August 1988 to discuss the restructured program, and at that time it was not clear just when money would be available or just how well the program would be supported; reportedly, there was some official skepticism about the value of such long-range RPVs. The program was renamed JSCAMPS (Joint-Service Common-Airframe Multiple-Purpose System). The new multiple-purpose designator covers alternative use as a target drone. The new request for proposals was issued by the Naval Air Systems Command on 28 June 1988; proposals were due 60 days later.

As of 1986, the specified operating radius of the MR-RPV was 350 nm. Other reported requirements were 2-hr endurance with a 250-lb payload, a speed of at least Mach 0.90, ceiling of at least 40,000 ft, and maximum weight of 2000 lb. The baseline missions were:

- Air launch from an A-6E/G, to fly over an airfield 350 nm away, determining the type, number, and location of aircraft there. The notional field is assumed to be defended by ZSU-23 cannon, with SA-6 and SA-9 missiles nearby. Image data must be available to the battle-group commander within 2 hr. The RPV data link might be jammed in the target area. The RPV would be recovered from the water by helicopters, or directly by a destroyer with a landing device.
- Deck launch by a destroyer, to locate a 3-ship surface action group about 175 nm (accuracy of location assumed to be 15 nm) away, finding type, course, and speed of each enemy ship. Target data would be transmitted to friendly forces, and the RPV would remain in the target area to conduct damage assessment. The RPV would be recovered from the water.



An artist's concept of an F/A-18 fighter carrying 2 BQM-145A (Ryan Model 350) medium-range UAVs. (Teledyne Ryan)

- Ground launch by a marine field unit, to provide images for strike planning against 3 widely separated, defended targets (e.g., bridges, fuel-storage areas, truck/tank parks), 150 nm from the launcher; total flight would be 450 nm. A similar air force mission would involve a target 350 nm away, data to be transmitted in real-time by data link (see ATARS above).

- Air launch by an RF-4C or F-16, for the 350-nm mission.

The MR-RPV ground station must be compatible with that used by the shorter-range Pioneer, which the new RPV will complement.

The original competitors included the Canadair CL-289, the Meteor Mirach (see above), a Martin Marietta/Beechcraft RPV based on the BQM-126, the Northrop NV-144, and the Teledyne-Ryan Model 324 Scarab.

In August 1988 Ryan displayed Model 350, a candidate for the reopened MR-RPV competition, based on Model 324. It is 44 in shorter than Scarab, with an overall length of 16.3 ft and an 11-ft wingspan, and with a weight of 1400–1800 lb. The proof-of-concept prototype is powered by a Teledyne CAE 373-8C (970-lb thrust) engine, and the airframe is built entirely of fiberglass-epoxy composites. Estimated cruising radius is 450 nm. Maximum speed is Mach 0.91, and ceiling is 45,000 ft. Carrying a 307-lb payload, Model 350 weighs 1825 lb and has a cruising endurance of 2.5 hr and a range of 1000 miles. The Model 350 prototype flew for the first time on 22 October 1988, being launched by an F-4C at 15,000 ft. The flight lasted half an hour, the RPV reaching 27,500 ft and Mach 0.75. It was recovered by parachute.

Prototype contracts were awarded to Martin Marietta and Northrop in September 1987 for a 14-month prototype construction phase. In 1989 Teledyne-Ryan won the competition for the restructured program with its Model 350, now designated BQM-145A.

Current (1990) characteristics: span 126 in, length 216 in, maximum weight 1910 lb, cruising range 700 nm.

◆ Cypher

This Sikorsky UAV was announced in June 1990; a smaller proof-of-concept vehicle flew in July 1988. Cypher employs a ducted coaxial (advancing blade) rotor; the duct adds lift to that generated directly by the blades. A version currently under development will have a 130-lb payload (total weight 325 lb), a 65-HP engine, a cruising speed of 80 kt, an endurance of 3–4 hr, and a ceiling of 8000 ft. Dimensions: diameter 5.75 ft, height 1.80 ft. The proof-of-concept vehicle weighed 43 lb and had a 4-HP motor; it was 5 ft in diameter.

Cypher is being developed as a potential SR-UAV, and a version is being built to meet a current U.S. Army Laboratory Command requirement for a target-acquisition system, to view targets up to 20 km [22,000 yd] from a battalion-level command post. The company hopes to sell a naval version, arguing that its small footprint and vertical takeoff and landing peculiarly suit it for naval operations. Sikorsky also argues that the shroud



Sikorsky's proof-of-concept ducted-fan vehicle. (Sikorsky Aircraft)



An artist's concept of a naval version of the Sikorsky Cypher UAV. (Sikorsky Aircraft)

surrounding the propeller should make Cypher safer than a conventional UAV helicopter.

◆ Tracer (formerly Pointer)

Bell-Boeing's tilt-rotor RPV is essentially a miniature V-22 Osprey. Pointer flew for the first time in 1988. The short-range version has a maximum speed of 160 kt and can loiter at 70 kt; ceiling is 25,000 ft and range is 220 nm (endurance 5 hr). Dimensions: 13 ft 5 in length, rotor diameter 7 ft 9 in; empty weight 395 lb (655 lb loaded, including 160 lb of fuel and 100 lb of sensors). The power plant is a 95-SHP Williams International turboshaft.

◆ Skyeye

Skyeye is 1 of the 2 alternatives for the U.S. SR-UAV requirement. It is based on, but not identical to, the existing R4E-50: span has been increased from 20–24 ft, maximum launch weight from 730 to at least 1000 lb, and propeller diameter from 0.99 to 1.22 m. There will also be a new engine more powerful than the original 46-HP Teledyne Continental GR-18. The configuration is twin booms, a fuselage pod, and a pusher propeller. Cruise speed is 100+ mph, and endurance is 8+ hr. Skyeye is catapult-launched and parafoil-recovered (descent speed is 25 kt).

Skyeye lost to IAI in a 1985 U.S. Navy competition because a test model was not available in time for a China Lake flyoff.

AIRBORNE SENSORS

CANADA

◆ APS-503

Band: X (9.2–9.4 GHz) **Beam:** 4×5 deg

Peak Power: 50 kW **Gain:** 30 dB

Pulse Width: 0.5 microsec **PRF:** 400

Scan Rate: 30 rpm **Antenna Dimensions:** 24×18 in

Antenna Weight: total weight 45 kg [100 lb]

APS-503 is the sea-search radar of Canadian Sea King helicopters and is manufactured by Eaton and by Litton of Canada. The antenna is stabilized in pitch and roll and can be tilted through 8 deg up or down. The display is a B-scope.

LASR-2 is a commercial version with twice the power (100 kW peak), 2 pulse widths, 4 alternative PRFs, and 3 alternative scan rates. LASR-2 is broadly comparable to the APS-504.

◆ APS-504/APS-140

Band: X (8.9–9.4 GHz) **Beam:** 2.3×5 deg

Peak Power: 100 kW **Pulse Width:** (i) 0.5 (ii) 2.4 microsec

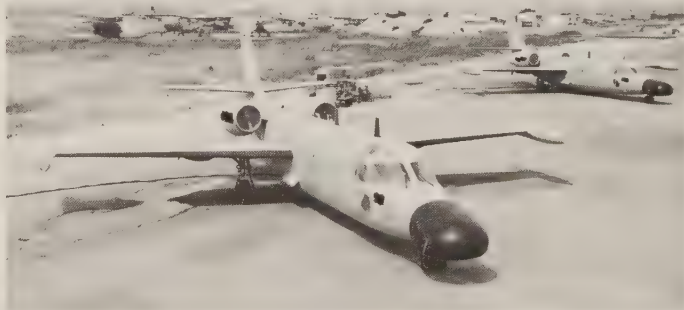
PRF: 1600, 1200, 400, 200 pps (range scales 20, 50, 100, 250 nm)

Scan Rate: 30 or 12 rpm (or 72 deg/sec sector scan)

Antenna Dimensions: 112×33 cm (stabilized)

Antenna Weight: under 72 kg total

APS-504 is the maritime-surveillance radar developed from APS-503 by Eaton and by Litton of Canada. The (V)3 version incorporates a scan converter so that its video can be displayed on a standard 875-line high-resolution television, and so that it can be recorded by a standard television cassette recorder. It is stabilized in pitch and roll, and it can operate in variable-width sector-scan mode.



Two Israeli Westwind 1124N maritime-reconnaissance aircraft show their APS-504(V)2 nose radars. All markings have been blacked out by the censor. (Embassy of Israel)

The basic version is (V)2; (V)3 has digital processing and a high-definition raster display. The (V)5 version is a pulse-compression radar with a TWT transmitter (8-kW peak power). Typical maximum range is 370 km. In 1987 Litton Canada received contracts for a (V)5 upgrade, which could be used on board Canadian S-2 Trackers. As of 1989, these aircraft are to be retired, but the radar is presumably a candidate to upgrade the many Trackers still in service elsewhere.

APS-504 is standard in Fokker maritime-patrol aircraft, which are operated by Angola, the Netherlands, Peru, the Philippines, Spain, and Thailand. Other users: Australia (GAF Searchmaster L), China (Harbin Y-8), Egypt (Navy Beech 1900), Iceland (Coast Guard Twin Otter), Indonesia (GAF Searchmaster L), Nigeria (Twin Otter), Thailand (Grumman S-2), and the United States (Customs Service GAF Nomad, Navy Beech 1900 for range safety).

The Litton APS-140(V) is a derivative of APS-504, incorporating coherent TWT, pulse compression, frequency agility, and scan-to-scan integration. The IRIS reconnaissance radar is a synthetic-aperture derivative; as of 1989, 6 were in service, with 3 more in production. Imagery is stored on board the aircraft, down-linked as needed. IRIS can operate in either wide-swath (18×18 -m resolution) or high-resolution (3×3 -m resolution) modes.

◆ LN-66

See shipboard radars and fire-control systems (under Antiaircraft Warfare section).

◆ ASP

Computing Devices Co. is conducting full-scale engineering development of an Airborne Signal Processor (ASP) for an SAR planned for Canadian CP-140 Aurora maritime-patrol aircraft.

FRANCE

◆ DRAA-2A

Band: X **Pulse Width:** (i) 0.5 (ii) 2 microsec

PRF: (i) 1300 (ii) 400 pps

Scan Rate: 6 or 8 rpm (provision for 30-deg sector scan)

The stabilized radar of the Alizé carrier-based ASW aircraft and of the Atlantique Mk 1 (DRAA-2B) has a maximum instrumented range of 60 or 200 nm (reflected in PRFs above). This radar is being superseded by IGUANE.

Although this radar is principally a means of detecting surface ships and snorkels, DRAA-2A can also function as a low-altitude AEW set, like the British Searchwater and the U.S. APS-20 (which, after all, was originally conceived as an AEW set). Within a French battle group, the combination of this radar and the shipboard higher-altitude sets should give effective radar early-warning out to a radius of about 100–150 nm.

Many details are not available, but the first prototype Alizés had U.S.-supplied APS-33s, which presumably approximated DRAA-2A's dimensions and performance. APS-33 was intended for large ASW aircraft such as the Neptune. APS-33 operated in X-band and had a 3.6-deg fan beam and, with 52 kW peak power (pulse widths 0.5 and 5 microsec, PRFs 800 and 200), could detect a surfaced submarine at 65 nm and a snorkel at 20 nm. Maximum range was 200 nm, minimum 200 yd.

A 1957 proposal to equip some Alizés with APS-20 radars for dedicated AEW was rejected. Presumably, a combination of separate AEW and ASW aircraft would have displaced so many strike aircraft that the small French carriers would no longer have been viable.

◆ Agave

The multimode X-band monopulse radar of the Super Étendard strike fighter is used to target Exocet antiship missiles, among other weapons. Scan limits are 140×60 deg, and the radar can detect an airplane at 18–28 km or a patrol boat at 40–55 km. In the search mode, the radar scans over 140 deg horizontally, and over 6–12 deg vertically, the position of the horizontal bar being selectable through 60 deg up or down. Typically, vertical cover is limited to a single 6-deg bar to reject low-altitude clutter; at higher elevation angles, 2 bars (12 deg) are used because the single narrow bar may miss a fast target. In the autotrack (monopulse) mode, the radar can transmit data either to a missile or to a HUD. Range gates can be set at 5–85 nm.

Agave is a 1-operator radar, and its controls (antenna elevation, bearing and range markers, lock-on for autotrack) are all

on a single hand grip. The antenna is an inverted Cassegrain. Total weight is 65 kg.

Agave was proposed in 1974, derived from the earlier RH 370 helicopter radar. Passing its trials in 1975, Agave entered service in 1978. Over 170 had been ordered by 1986. They have been installed on Jaguar, Mirage F1, and Mirage 50 aircraft. The Jaguar version uses a raster scan display rather than the usual PPI. Agave is to be replaced by the new Anemone radar on French Navy Super Étendards.

The original RH 370 had a peak power of 90 kW and used a 51-cm Cassegrain dish, stabilized in roll and pitch. RH 370 could detect a patrol boat at 35 nm, with an accuracy of 1 deg in bearing and 0.1 nm in range. RH 370 reached the initial evaluation stage in June 1971.

◆ AGRION 15/IGUANE/VARAN

Band: X (9.1 GHz) **Peak Power:** 108 kW

Pulse Width: 0.25 or 1.5 microsec **PRF:** 1200, 600, 300 pps

Scan Rate: 12, 24 rpm **Weight:** 110 kg (total)

Data above apply to Varan (TMV 118B).

These systems are X-band frequency-agile pulse-compression surface-search radars. Pulse compression is used partly to reduce peak power, thus making the radars less detectable. In 1982 Thomson-CSF claimed that pulse compression made for an effective pulse width only a tenth that of magnetron radars, with 35 times the equivalent peak power, and that VARAN was 6–8 times lighter, 3–9 times more difficult to detect, and 6 times more discrete than any other pulse-compression radar on the market.

These radars use 2 pulse lengths, long (tenths of a microsecond) for long-range detection of large targets and short (thou-



An Atlantique Nouvelle Generation (Atlantique Mk 2) displays its IGUANE radar and its ESM systems in the wingtips. Any radar pushed out into the airstream creates drag, but that offset from the main airframe is the only way a single reflector can cover anything approaching 360 deg. Offset was the solution in aircraft such as the Alizé, the P-2, and the S-2. The alternative is to use 2 reflectors (as in the P-3) or to accept 180-deg scanning (as in the S-3, which has a nose radar). The bulge under the transparent nose contains a gyro-stabilized high-resolution thermal imaging camera, Tango, with a switchable $6.45 \times 4.30/2.15 \times 1.43$ deg field of view (the turret can turn to 110 deg to either side of the airplane, and its elevation limits are $+15/-45$ deg. The output is a 625-line television signal, 50.5 frames/sec. (U.S. Naval Institute)

sandths of a microsecond) for small targets in a rough sea. The long compressed pulse provides sufficient energy for long range. The short pulse is needed in a rough sea to limit the size of the resolution cell, so that the target stands out against the surrounding noise.

The basic unit is IGUANE, the radar for the Atlantique 2 and for the modernized Alizé. The program began in 1974, and technical evaluation began in January 1979; IGUANE first flew in May 1981. Claimed performance: 28 nm on a snorkel, 60 nm on a fast attack boat, 130 nm on a medium-sized ship, all in sea-state 3 or 4. For target classification, the antenna is locked with its beam pointing sideways, functioning as a synthetic-aperture system, while a special unit (Anaconda) forms the image. The antennas used in the Alizé and Atlantique are identical to those already in use. Total weight is 75 kg in an Alizé and about 130 kg in an Atlantique.

AGRION 15, which is used to target AS 15TT missiles, adds a monopulse tracking unit and a matched boresight-stabilized 1.3-m cheese antenna. AGRION 15 has 2 scan speeds and a TWS mode. This radar is used on board the Dauphin helicopters exported to Saudi Arabia. It has also been bought by Iraq and Chile.

VARAN is an IGUANE with a smaller antenna, for medium maritime-patrol aircraft to use for sea search and OTH-T. VARAN equips French Navy Guardian maritime-surveillance aircraft.

Thomson-CSF, the manufacturer, credits all 3 radars with the ability to detect a lifeboat or a snorkel at 30 nm, a fast patrol boat at 60 nm, and a freighter at 120 nm.

The names of all 3 radars are acronyms: IGUANE is *Instrument de Guet pour Avion Navale Embarqué*; AGRION is *Appareil de Guet de Recherche et d'Identification d'Objectif Na-*

vale; VARAN is *Veille Aéroportée Anti-Navire*. Work on IGUANE began in 1975, and the first production radars were delivered in 1980.

◆ Anemone

Anemone is the replacement for Agave, to be used in French Navy Super Étendards now being modernized. Anemone is primarily an air-to-surface radar but also has useful air-to-air performance. Modes are: linear scan search, continuous track, single target track, track while search, ground map, and ranging. The manufacturer is Electronique Serge Dassault (ESD).

◆ Ocean Master

The next-generation maritime-patrol-aircraft radar now under development, Ocean Master, is derived from technology originally developed for the RDX/RDY fighter radars, both of which have programmable signal processors (for variable waveforms). It is expected to enter service in 1995-96.

Like the current French maritime-patrol-aircraft radars, Ocean Master employs pulse compression. It will also use scan-to-scan and pulse-to-pulse integration to detect periscopes in sea clutter; it will incorporate ISAR; and it will be capable of tracking numerous targets while scanning. A SAR capability is under development. The radar's RDX/RDY ancestry will provide it with significant air-to-air performance, to provide a degree of AEW. As in the fighter radars, the antenna is electronically scanned (the customer can specify either an active or a passive array).

The scan-to-scan and pulse-to-pulse integration and digital-processing features are now being tested on board an Atlantique 2 aircraft.

◆ ORB 31 (Heracles I)

Band: X (9335-9415 MHz)

Beam: (a) 4×7.5 (b) 3.2×6 (c) 4.8×7.5 deg

Peak Power: 12 or 30 kW

Gain: (a) 29.2 dB (b) 30.5 dB (c) 28 dB

Pulse Width: (i) 0.2 (ii) 0.5 (iii) 4 microsec

PRF: (i) 1600 (ii) 800 (iii) 400 pps

Antenna Dimensions: (a) 608×308 mm (b) 728×368 mm (c) 460×308 mm

Antenna Weight: (a) 1.1 (b) 1.3 (c) 0.8 kg (ORB 31D combines reflector (c) with 30-kW transmitters) (ORB 31W combines reflector (a) with 30-kW transmitters)

The Omera-Segid helicopter sea-search radar is used in its ORB 31D version on board Super Frélon helicopters to target the AM 39 Exocet. This radar also exists in an ORB 31W configuration, for French Navy Lynx helicopters, and in an ORB 31AS antisubmarine version, carried by Alouette-IIIs. These radars all scan through 180 deg in bearing.

The ORB 31D and 31W versions use 2 transceivers, one for long range and another for short range and high resolution (and for clutter rejection). Range on a ship (1000 m^2) is 80 km (ORB 31D) or 50 nm (ORB 31W), and total weight is 75 kg (ORB 31D) or 61 kg (ORB 31W).

ORB-31 was derived from ORB-3, which is a license-built Ekco weather radar.

◆ ORB 32 (Heracles II)

Band: X (8500-9600 MHz or 9100-9500 MHz)

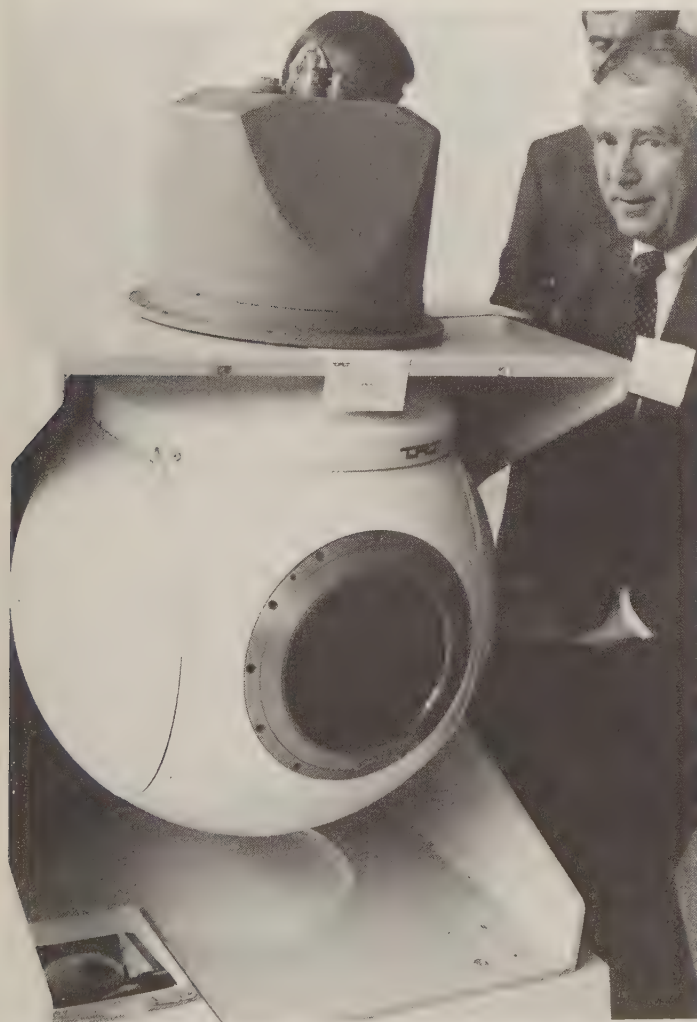
Beam: 2.6×6.2 deg **Peak Power:** 80 kW

Gain: 32 dB **Pulse Width:** 0.25 or 2.0 microsec

PRF: 1200, 600, or 300 pps **Antenna Dimensions:** 72×36 cm

Antenna Weight: total weight 129 kg

The modular Omera radar for small maritime-patrol aircraft was announced in 1979. ORB 32 was developed from the ORB 31-series. Each radar consists of 5 main elements: an antenna (1 of 7 parabolic reflectors, with major axes 46-85 cm and minor axes 30 or 36 cm, with front or rear illumination, gains of 28.5-32 dB and beams of $2.6-4.8 \times 6.2-7.5$ deg); a pedestal (1- or 2-axis stabilization, full or sector scan at 20 and 40 rpm); a junction box; a transmitter-receiver (4 types covering both bandwidths above, all with the same peak power, PRFs, and



The TANGO IR turret of the Atlantique-2 maritime-patrol aircraft, at the Paris Air Show, 1989. (Author)

pulse widths, but fixed, tunable, coded jump, or frequency-agile); and a PPI display. Sectors are 60, 120, 180, or 240 deg; and all of these radars can scan the full 360 deg. Range is 90 km on a 500-m² target.

Data apply to the ORB 32WAS version for the SA 321 Super Frélon helicopter. This radar was adopted by China (PRC) for its SA321J helicopters. There is also a similar ORB 32WD reconnaissance and target-designation radar, capable of tracking 2 ships. The Swedish government plans to buy a combined AS/WD version, ORB 32ASD.

◆ RDX

The Thomson-CSF pulse-doppler radar for the new Rafale fighter is to be operated by both the French Air Force and the French Navy. The air force requires simultaneous air-to-air and air-to-ground operation, including terrain-following. The navy emphasizes air-to-air detection at maximum range, for fleet air defense. The air force requirement is to be met by an electronically scanned antenna, which flew in 1987 and which will be able to generate multiple beams either simultaneously or in rapid succession. Because multiple-beam forming wastes some radar energy, the ideal navy solution would have been a mechanically scanned antenna. Since both versions of Rafale will probably have to carry the same radar, RDX will instead add radar power to make up for the scanning losses. To meet the requirement for operations at a wide variety of ranges, RDX will operate at high, medium, and low PRF, the peak power being matched to PRF (and varying by a factor of up to 10). The transmitter will be a dual-peak-power TWT. RDX will also use a programmable signal processor capable of about 1 Mflop within relatively small dimensions, requiring the development of new 0.8-micron (versus the current 1.2-micron) integrated-circuit technology.

Range will exceed that of the current RDI, i.e., beyond 50 nm. Rafale is also to have an optronic air-to-air fire-control system, with a range of 30+ nm. RDX is necessarily a multimode radar, since it must be suited to fleet air defense, deep strike, and ground attack. In the air-to-surface mode, it is optimized for antiship attack, entailing long-range target search, multitarget tracking, target assessment, and control of smart weapons.

Search modes are: look-up/look-down, velocity search (VS), and range while scan (RWS). Raid assessment is automatic; the system chooses the 8 highest-priority targets, displaying their ranges and closing speeds. The pilot can change priority. Tracking modes: TWS and single target track (STT). TWS is intended for firing MICA missiles fitted with active seekers; STT is optimized for semiactive missiles. Selection among close combat modes is controlled by the pilot from the stick. In the air-ground mode, the HUD superimposes a radar map on the real landscape, in a suitable scale. The system can also automatically terrain-follow while in the air-to-air mode ("expanded visibility"). RDX can also radar-map with high resolution for navigational update, target designation, search and tracking of both fixed and moving targets, and air-to-ground ranging.

RDX will use a new Radant (RBG) antenna, developed by Thomson-CSF ($\frac{2}{3}$ share) and by ESD ($\frac{1}{3}$ share), collaborating as a GIE (*Groupeement d'Intérêt Economique*); RBG means *Radar de Bord du GIE*. It is a passive scanner because the deadline for service entry was too short for development of an active array.

RBG is a patented Thomson-CSF design; there are 2 tandem lenses, each consisting of a stack of phase-shifter channels and each polarized at right angles to the other, with a 90-deg polarizer between them. Each steers the beam in 1 dimension by phase shifting. The lenses are illuminated from behind by a flat-plane array that produces the focused beam turned by the phase shifters.

In April 1989 the French government (DGA) awarded the consortium a contract for contract definition and for development prototypes. The first prototype is to be delivered in 1991; it will fly during the second half of the year aboard a Mystère 20. It will first fly on board a Rafale in 1993, production beginning in mid-1995.

◆ RDY

This new radar for Mirage 2000 fighters incorporates an air-to-sea mode for Exocet and Kormoran missile control. They are primarily air-to-air radars and also have low-altitude penetration modes (for ground avoidance and contour mapping). As in RDX, the key to multiple operation is a programmable signal processor. Variable waveforms include multiple-range gate high PRF, medium PRF, and low PRF. The flat-plate antenna scans a 60-deg cone; it may later be replaced by an electronically scanned antenna. The transmitter has 2 alternative peak powers, corresponding to different PRFs. This radar is scheduled to enter production in 1991.

ITALY

◆ APS-705/707/APQ-706

Band: X (dual frequency)

Beam: 2×7 deg (AB 212); 1.5×10 deg (SH-3D)

Peak Power: 25 kW (option: 75 kW)

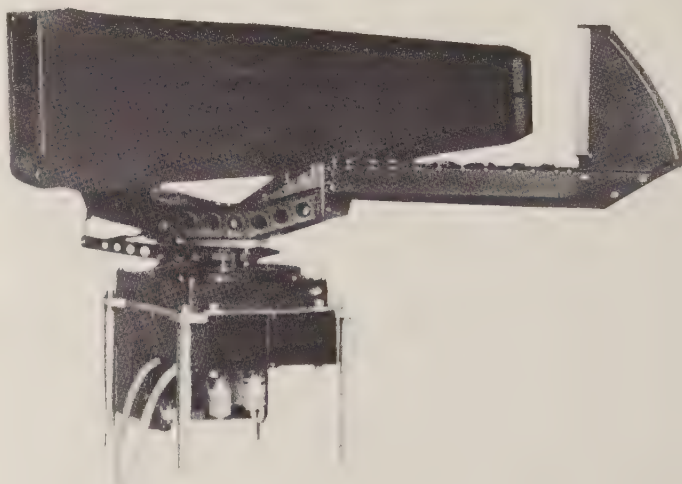
Pulse Width: (i) 0.05 (ii) 0.15 (iii) 0.5 (iv) 1.5 microsec

PRF: (i) 1600 (ii) 1300 (iii) 1300 (iv) 650 pps

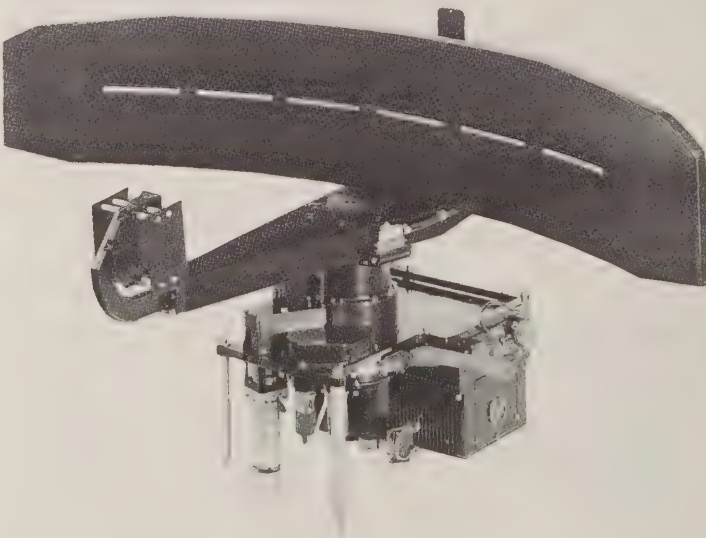
Scan Rate: 20 and 40 rpm

Antenna Dimensions: 1.2-m aperture (AB 212) or 1.6-m aperture (SH-3D) **Antenna Weight:** total system weight 87 kg

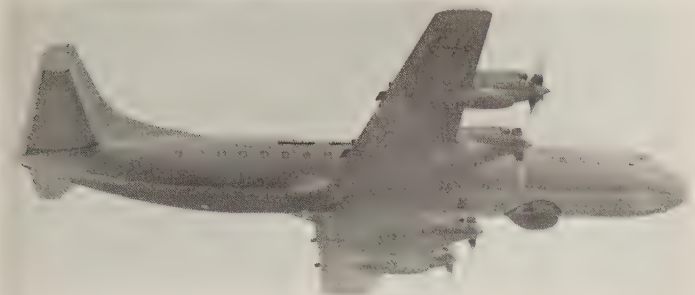
The SMA TWS radar for Italian Navy AB 212 and SH-3D helicopters (surface search, periscope detection, and tracking) employs two 25-kW transceivers (1 antenna) for frequency di-



APS-705 antenna, line-of-sight stabilized in roll and pitch. This radar is also offered in a prodded version, to provide aircraft with an antiship capability, in association with the Marte missile. APS-705 operates in X-band, with peak power of 20 kW. (SMA)



APS-707 antenna, designed to operate at a peak power of 90 kW. (SMA)



APS-707 installed on board an Argentine Electra airliner converted for use in maritime patrol. The U.S.-built Orion (P-3) shares much the same airframe. (SMA)

versity. The antenna is stabilized in line of sight and can be tilted 20 deg up or down.

APS-707 is a more austere version of APS-705. 707 is a single-channel fixed-frequency lightweight set (one 20-kW transmitter). There is also a high-powered version, using a 90-kW transmitter, which has been adopted by the Argentine Navy to replace existing APS-20 radars on board SP-2H Neptune maritime-patrol aircraft. APS-707 is frequency agile and has other ECCM features.

APQ-706 is a double-antenna radar (back to back) used to guide the Marte antiship missile (carried on board Italian Navy SH-3D Sea Kings). 706 uses 2 channels, 1 of fixed frequency and 1 with frequency agility, the latter to detect small high-speed targets. The fixed-frequency channel is used for navigation and periscope detection. The transmitter is the 75-kW frequency-agile unit available as an option in APS-705. The antenna is line-of-sight stabilized.

◆ APS-784

The SMA/FIAR X-band radar for Italian EH-101 helicopters will probably serve both for surface search (including attack against surface ships) and for some degree of AEW. The antenna will scan through 360 deg. The transmitter will be a TWT, and pulses will be compressed. For antiship operation (such as missile target designation), APS-784 will be capable of TWS operation. APS-784 will be a compact radar, using only 4 line-replaceable units.

SMA has offered a scaled-down version for the NATO NH.90 helicopter.

◆ Grifetto (PA-2801) and SCP-01

Grifetto is the FIAR radar proposed for the antiship version of the Italian-Brazilian AM-X fighter; some of this technology may be incorporated in the APS-784 radar of the EH-101 helicopter. Grifetto is part of a privately developed Grifo series of X-band radars. The simplest, PA-2801, is a small (50-kg) magnetron radar limited to antiship and close-air-support missions. It is designed to detect a frigate at a range of 55 nm. Aeritalia considers Grifetto the standard radar for the antiship version of the AM-X.

The antiship version of Grifo is currently designated Grifo-ASV. It operates in the lower part of X-band, using a low-PRF 100-kW magnetron, with a 41×34 -cm flat-plate monopulse antenna. The main operating modes are air-to-sea (including TWS on seaborne targets) and air-to-air (including single-target tracking). Ground tests were completed in 1988, and late in 1989 Grifo-ASV was being tested on board a PD 808. Integration with AM-X was then scheduled to begin mid-1990.

However, a more advanced radar in the same family, Grifo X, may be adopted for Italian Air Force strike versions of the AM-X. Grifo X weighs about 70 kg (165 lb), has a 16-in antenna, and should have useful air-to-air performance.

The most advanced radar of the series, Grifo, uses a TWS transmitter and weighs about 90 kg (about 200 lb). The antenna is a 24-in flat plate, and a frigate can be detected at 80 nm in sea-state 4. This radar is intended to replace existing radars on aircraft such as Mirages and Soviet- and Chinese-built fighters.



Members of the Grifo radar family show the range of antenna sizes envisaged. The radar in the background is the antiship version (P2801); the multimode P2800 is in the foreground. (Author)

The prototype was tested in 1988. Bandwidth is up to 200 MHz, with both low- and medium-PRF waveforms. Average power is up to 120 kW (up to 4% duty cycle).

In 1988 SMA announced an alternative AM-X radar, SCP-01 (Scipio), which SMA was developing in cooperation with a Brazilian company, Tecna, using Brazilian Air Force research and development funds. SMA will be responsible for signal processing. SCP-01 will presumably equip Brazilian AM-X strike fighters. Total weight will be about 80 kg; the antenna diameter is about 16 in, and average power will be about 120 W. Estimated range on a frigate is 60 nm.

SWEDEN

◆ HERA (9HCI 100)

The BEAB-Omera frequency-agile periscope-detection and surface-search radar appeared on refurbished KV-107 ASW helicopters in 1986. HERA can detect a snorkel at 25 nm in sea-state 5, or a frigate at 100 nm, and can be used to find targets for the RBS 15 missile. A transponder allows 2 helicopters to coordinate their attacks.

9HCI 100 is the export designation (9HCI 200 with torpedo fire control included).

◆ SLAR

Ericsson's side-looking airborne radar is used by the Swedish Coast Guard and offered for export as an austere AEW unit. It has been carried aboard a Metro III airliner for coast-surveillance trials. As of 1989, it was in service with several countries.

The antenna pod is 3 m long and operates in X-band. Total weight is less than 70 kg. Radar images are displayed on a television and can be recorded. Range is up to 100 km, and the data can be filtered for moving targets.

USSR

◆ Big Bulge

The Bear-D X-band surface-search radar is used to target SS-N-3 and -12 missiles. This radar, with a smaller radome, is also fitted to Hormone-A helicopters. Reported PRFs for the Hormone version are 414–418 and 621–628 pps.

◆ Down Beat

The Blinder and Backfire missile-guidance radar appeared in 1959. Down Beat is associated with the AS-4 and AS-6 missiles, and it is frequency-agile, with variable PRF.

◆ Mushroom

This X-band surface-search radar is installed in Ka-25 ASW helicopters.



Big Bulge radar under a Bear-D bomber, 1989. (U.S. Navy)



This Hormone helicopter carries a smaller version of Big Bulge, for missile targeting. (U.S. Navy)



Down Beat nose radar on board a Badger. (U.S. Naval Institute)

◆ Puff Ball

The navigation/attack radar on Badger-C is used to target AS-2 and AS-6 missiles. Puff Ball is also carried by Badger-D, -E, -F, and -J. Puff Ball operates at X-band, with PRFs of 410 and 620 pps.

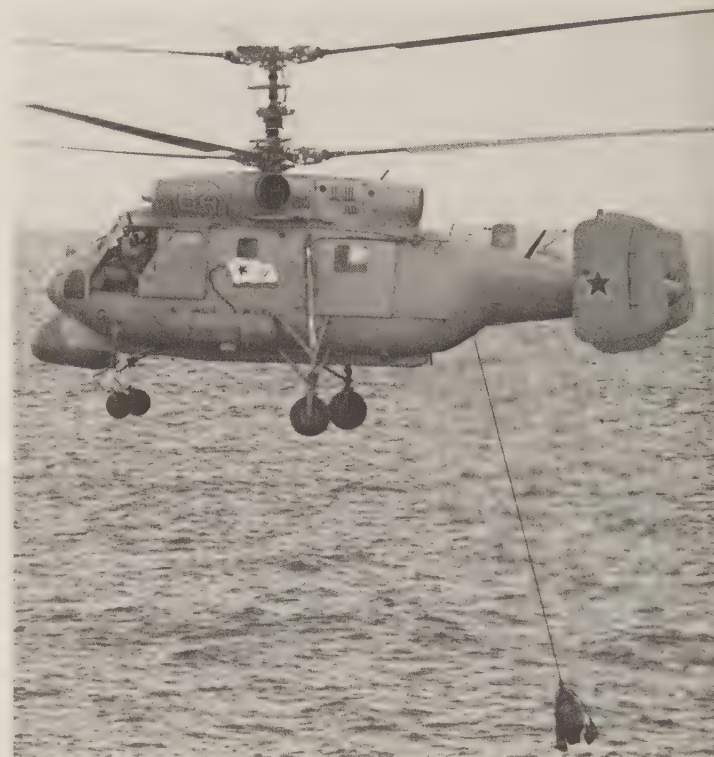
◆ Short Horn

Short Horn is a Ka-band (14–15 GHz) bombing radar and is the chin (sea-search) radar on the Bear-D. This radar is also carried

by Badger-G (AS-5 and AS-6 missiles). Short Horn is frequency-agile and has both circular and sector scan. Reported characteristics: pulse width (i) 1–1.8 (ii) 0.5–1.4 (iii) 0.4–1.3 (iv) 0.01–0.9 microsec; PRF (i) 313–316 (ii) 496–504 (iii) 624–626 (iv) 1249–1253 pps.

◆ Wet Eye

The surface-search radar of May and Bear-F ASW aircraft is associated with the BM-1 and, presumably, later sonobuoy systems.



Wet Eye radar under the nose of a Hormone ASW helicopter, which is dipping its sonar. (U.S. Naval Institute)



Wet Eye radar as carried by an IL-38 MAY. (U.S. Naval Institute)

UNITED KINGDOM

◆ ARI 5955/MAREC/MAREC II

Band: X Peak Power: 15 kW
Pulse Width: 0.5 PRF: 400 pps

The Sea King X-band search radar was introduced in 1968 and has been replaced since 1982 by the MEL Sea Searcher. ARI's effective range is 50 nm, compared to 100+ nm for the Sea

Searcher. ARI 5955 was originally a German Ekco radar. X-band was chosen because S- or C-band would have given insufficient definition, and Ka- and Ku-band would have been excessively affected by weather. This and later MEL radars are all associated with big horizontal plotting tables incorporating backlit radar displays.

MAREC (Maritime-Reconnaissance Radar) is a developed form of ARI 5955, with a higher peak power (65 kW) and antenna gain (34.5 dB), 2 pulse lengths (0.5 and 2.5 microsec), and 2 PRFs (200 and 400 pps). In a proposed installation on board the British Aerospace HS 748, MAREC used a 36-in stabilized antenna (2.5-deg beam) in an under-fuselage radome. Alternative antennas were 24–48 × 12–21 in.

MAREC was not sold successfully, but MAREC II was selected for Indian Coast Guard Do 228 aircraft and also for the Dornier Do 128 used by the Cameroons. MAREC II operates in X-band (peak power 80 kW); pulse widths are 0.4 and 2.5 microsec (PRFs, respectively, are 400 and 200). Maximum range is about 250 nm (maximum instrumented range is 219 nm). The Indian sets are being produced under license by Hindustan Aeronautics.

◆ Blue Fox

The Ferranti multimode monopulse X-band radar for Royal Navy Sea Harriers was developed from the private-venture Blue Falcon core radar of the mid-1970s. Reportedly, Blue Fox is also related to Seaspray. The antenna is a flat roll-stabilized slotted array. It incorporates an IFF interrogator.

Radar modes: (i) air-to-air/air-to-surface scanning in azimuth and/or elevation; (ii) lock-on track (1 target); (iii) visual acquisition (through the HUD); (iv) air-to-surface ranging (the radar locks on the aim point to provide range data); (v) ground mapping (for navigation).

The transmitter is a spin-tuned magnetron, hopping frequency on a pulse-to-pulse basis for ECCM, for clutter rejection (the clutter characteristics vary from frequency to frequency, hence can be reduced if successive pulses are integrated), for glint reduction (again, the reflecting characteristics of a complex target will vary with the frequency, and thus can be smoothed out by frequency hopping), and also for reduction of STA errors due to detection of large reflectors (such as land masses) at a distance.

Blue Fox was optimized for mid- to high-altitude targets; the Sea Harrier was originally intended to intercept Bear-Ds providing targeting data for ships and submarines armed with SS-N-3 missiles. As a consequence, Sea Harriers in the Falklands had no look-down capability, and pilots often had to acquire their targets visually.

This radar is to be replaced by Blue Vixen, which can look down, in Sea Harrier FRS.2.

◆ Blue Kestrel

This X(I)-band radar for British EH-101 and Sea King helicopters covers 360 deg. Blue Kestrel is a TWS radar, and its transmitter is coherent (with pulse-compression); it is also frequency-agile. This radar was derived from Seaspray (below). Scan rate is 12 or 24 rpm, and a small target can be detected at 25 nm. Blue Kestrel was first installed for tests (on board a Sea King) late in 1985, for flight trials in the spring of 1986. Development models were delivered by January 1989.

◆ Blue Vixen

Ferranti's multimode coherent pulse-doppler radar for modernized Royal Navy Sea Harrier (FRS.2) is derived from the earlier Blue Fox and from Ferranti's private venture Blue Falcon core-radar project. Blue Falcon is also the basis for Ferranti's proposals for aircraft such as EFA. Blue Vixen is a response to some of the Falklands lessons and is designed to be compatible with the AMRAAM medium-range air-to-air missile.

The radar automatically selects the appropriate air-to-air mode, from among low PRF, high PRF (velocity search or range while scan), and medium PRF. It also automatically initiates

TWS, presenting synthetic-video track histories to the pilot. On detection of a target within a specific short-range zone, the radar automatically selects single-target-track (STT) mode. There are 2 air-to-sea modes (both with TWS, Sea 2 with a decluttered display for tracking small targets in high sea-states). A real-beam-mapping (RBM) mode provides ground mapping and can incorporate TWS. The other air-to-surface modes are air-to-surface ranging (for weapons delivery), precision velocity update (for navigation), and beacon interrogation. Growth options are doppler beam sharpening (DBS) and ground moving-target indication (GMTI). Special covertness features are the ability to retain radar data after reception (transmit/freeze mode), single-sweep transmission (data update), spread-spectrum transmission, and sector search. The manufacturer also lists the narrow-sidelobe antenna and the TWS capability as covertness features.

Total weight is 141.5 kg, of which 102.5 kg is in the nose and 25 kg (the programmable signal processor) is in a rear bay, connected to the nose equipment by a 1553B bus.

The development contract for this radar was let in July 1983, and a prototype, which flew in a BAC 111, was delivered late in 1985 (flying in mid-1986). Limited finances forced deletion of provisions for JTIDS, although space and weight are still reserved for later installation.

Red Fox is a repackaged version offered for other aircraft.

◆ Sea Searcher/Super Searcher

Compared to the earlier ARI 5955, the MEL X-band search radar for Sea King helicopters is credited with twice the range. Sea Searcher is a TWS radar that can sector-scan. There are 2 alternative (selectable) pulse widths, for operation in various sea-states. The antenna is enlarged: sizes from 107–610 mm in horizontal aperture [42–240 in] are available.

Peak power is 85 kW, and scan rate is 30 rpm.

Super Searcher is a development announced in 1982 that uses a 42 × 16-in dish, or a 48 × 10-in planar array, or a 30 × 10-in planar array antenna, and has greater detection, tracking, and missile-guidance performance. All arrays are stabilized within ±20 deg. A new color CRT replaces the earlier monochrome PPI. There are 3 selectable pulse lengths, including an ultrashort pulse for high definition in bad weather, and 4 alternate PRFs. Scanning is by sector or over the full 360 deg. The 14-in raster-scan (625-line) CRT display has freeze frame and memory storage (and MTI). Range scales: 4, 8, 16, 32, 64, 128, 256 nm. This radar has TWS capability. Signal processing options are within-beam integration, scan-to-scan integration, pattern enhancement, and CFAR. Super Searcher is the radar of the Indian Navy Sea King Mk 42B helicopter and also of the RAN S-70B Seahawk; it was also selected for Brazilian EMB-111 patrol aircraft.

In 1988 MEL announced Super Searcher PC (pulse compression), which was proposed for the Canadian New Shipborne



Super Searcher PC components. (MEL)

Aircraft (NSA) helicopter. This version uses a TWT transmitter; it has 3 alternate pulse widths (2 compressed, 1 uncompressed), and 5 alternate PRFs.

The Royal Navy planned to install a new 360-deg-scan Super Searcher Skua (Triple S) in rebuilt Lynx helicopters, but this requirement was canceled because of cost in 1988.

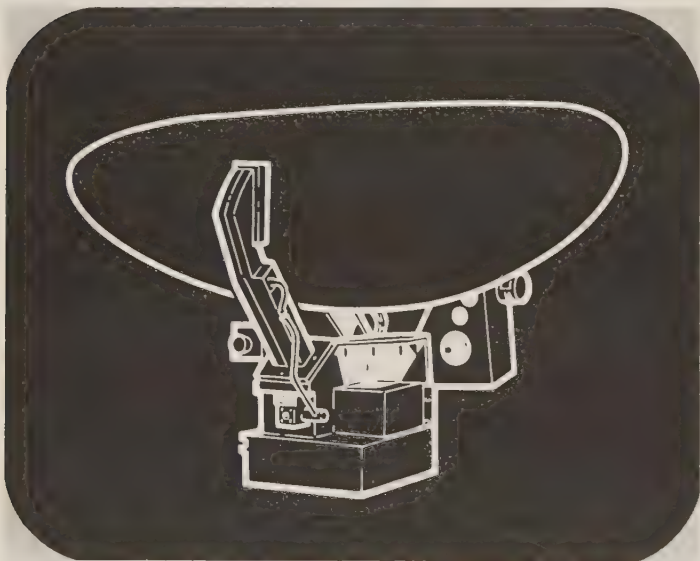
◆ Seaspray

Band: X **Antenna Dimensions:** 27 in × 10 in (deep)
Antenna Weight: total weight 65 kg

Ferranti's sea-search radar for the Lynx helicopter uses a Philips frequency-agile (spin-tuned magnetron) transmitter. Seaspray is intended primarily to detect and track small fast craft, such as fast patrol boats, and can be used to guide Sea Skua missiles. It can also be used as a periscope detector. Tracking is monopulse. There are 4 selectable PRFs.

Ferranti announced Mk 2 and 3 in August 1982. Mk 2 had a new processor, and Mk 3 was a TWS version with a full 360-deg scan. Compared to Seaspray Mk 1, Mk 3 has full 360-deg coverage and TWS performance. The display is a television-type raster showing processed video, and the picture can be frozen if necessary. Total weight is about 140 lb.

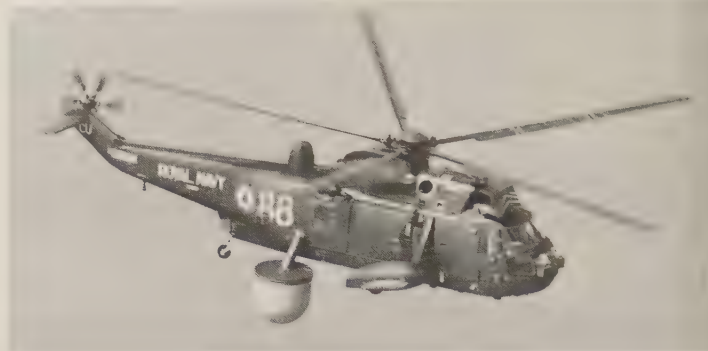
By early 1985 over 250 Mk 1s had been ordered, users including the Royal Netherlands Navy, the Royal Danish Navy, Argentina, and Brazil. In 1984 the German Navy selected Seaspray Mk 3 for the Sea King Mk 41 helicopters, to replace their existing MEL ARI 5955 radars, which could not be used to illuminate targets for Sea Skua missile engagement. Mk 3 was also chosen for South Korean Super Lynx Mk 99 helicopters, which are being equipped with Sea Skua missiles. In November 1984 a further version, Seaspray Mk 4, was chosen to equip Bell 212 ASW helicopters for Turkey.



Seaspray antenna (686 mm wide). (Ferranti)

◆ Searchwater (ARI 5980)

Searchwater is Thorn-EMI's Nimrod MR.2 X-band pulse-compression surface-search radar; Searchwater also serves as an AEW radar on board British and Spanish Sea King helicopters. This radar was the major improvement over the MR.1 version, using both a narrow beam and a short pulse to limit the patch of sea clutter surrounding a target. Pulse-to-pulse frequency agility helps eliminate sea returns, which are frequency dependent. The radar integrates all pulses in any beamwidth during 1 scan and can also integrate from scan to scan. The detection threshold is controlled to maintain a constant false-alarm rate; the associated computer produces processed video, which is what the PPI shows. Searchwater is credited with a target-



Searchwater in its AEW form, as carried by Sea King helicopters. (Westland)

classification capability based on target size and aspect. The antenna is pitch- and roll-stabilized, with controllable tilt and automatic sector scan.

The operator has A-scope, B-scope, and raster-scanned PPI displays, the A-scope being used for what appears to be ISAR.

In 1985 Thorn-EMI was awarded a contract for a color display, with which processed video could be overlaid on raw video (in the monochrome version only processed video could be displayed). That was expected to improve anticollision performance, as well as detectability of targets.

Claimed performance: 28+ nm on a snorkel, 60+ nm on a fast attack boat, and 130+ nm on a medium-sized ship.

Searchwater development began in 1972, initial tests following in 1973; the first production Nimrod 2 was delivered in August 1979.

The associated IFF is the Cossor Jubilee Guardsman.

Thorn-EMI's helicopter-borne early-warning version of Searchwater was initially developed in response to the experience of the Falklands War. The patrol version, intended for sea search, uses a fan beam; the AEW version uses a pencil beam with circular polarization provided as an alternative to the vertical and horizontal polarization of the Nimrod (patrol) version.

The AEW version has 2 alternative scan rates (faster to track faster-moving targets, slower for better detection at longer range) and 4 range scales (i.e., PRFs; pulse widths are adjusted to match range scales, presumably to maintain the same average power output). There are alternative warning and search modes optimized, respectively, for aircraft and ship detection. The antenna can also be tilted to scan for weather features, and a separate A-scope is used to assist in target classification; presumably the blips displayed on it show some structure related to the target's shape and aspect.

Targets are detected by the operator, who manually designates them on the PPI. In the warning mode, the PPI is arranged to brighten fast-moving targets. Once designated, targets can be automatically tracked. Any position of the PPI can be displayed in expanded form on a B-scope (bearing vs. range) for more accurate positioning of the target designator, a feature presumably valuable if there are many targets close together. The associated computer provides both target track data and computed range and intercept-vector data for fighters. A Sea King equipped with Searchwater controls fighters directly (as does the much more powerful E-2C) rather than merely handing target data down to a ship (as in early U.S. and all previous British AEW aircraft).

The system can track up to 16 air targets in manual control and can direct up to 6 simultaneous interceptions. There are 2 operator stations, side by side, with the tactical coordinator (in contact with the senior warfare officer on board the carrier) on the right. The tactical coordinator can track up to 40 surface targets, the helicopter providing OTH-T support for surface ships. The officer at the left-hand display is responsible for air targets. The system is reportedly being developed to interchange data between the 2 displays so that fighters can be directed against designated surface targets. Work is also proceeding to increase computer capacity so that more air targets can be han-

dled. The system currently lacks the air-to-surface data link associated with many earlier AEW aircraft (which did not themselves control fighters); reportedly, Searchwater also suffers from clutter when tracking low-flying air targets. Introduction of a coherent transmitter (as in the related Skymaster surface-search radar) would help solve the latter problem, as target doppler would be easier to extract.

Searchwater is described as noncoherent, but its manufacturer also credits the system with the capability of extracting doppler data from its pulse-compressed signals. That capability suggests that pulses are internally coded by phase rather than by frequency.

Thorn-EMI had proposed an AEW adaptation of Searchwater before the Falklands War, but this project had been rejected on the grounds that the Royal Navy would, in the future, fight only in the North Sea and eastern North Atlantic, i.e., always under the cover of long-range shore-based aircraft such as AWACS. The Falklands War demonstrated that other contingencies were very possible, and on 5 May 1982 Thorn-EMI revived its idea. The study was officially approved on 13 May, and 2 Sea King helicopter prototypes were ordered on 24 May; the first flew on 23 July 1982, and the prototype Sea King AEW helicopters embarked on board HMS *Illustrious* on 2 August 1982. The project survived the end of the war, and production AEW helicopters became operational in 1986. British carriers now embark a flight of 3 AEW helicopters. In addition, 2 ASW Sea Kings are fitted for, but not with, the Searchwater radar, as potential spare airframes. In mid-1989 the Royal Navy ordered 2 more Searchwaters, to equip the 2 Sea Kings fitted for but not with the radar, so that each carrier will have 4 rather than 3 AEW Sea Kings. These radars will be delivered in mid-1991.

This system is also employed by the Spanish Navy.

Thorn-EMI is developing a next-generation series of radars, Skymaster (for AEW) and Searchwater 2/Searchwater NH. Skymaster is currently being offered for installation on board a Britten-Norman Defender, but the manufacturer believes that it can be carried by a Lynx frigate helicopter. Skymaster is a pulse-doppler radar capable of detecting a low-flying fighter at 140 km (77 nm) and of tracking more than 50 targets (with more than 250 held on file). Like Searchwater AEW, it normally requires 2 operators.

Searchwater 2 offers Searchwater performance at about half the weight and also provides AEW. It is intended for maritime-patrol aircraft such as the P-3, Fokker Maritime Enforcer Mk 2, and the CN235. Searchwater NH is a variant intended for the NATO frigate helicopter now under development.

◆ ANR 360 (Navigator)

Decca's maritime-surveillance radar was developed in Norway and first flew in a Cessna 337 in mid-1979. Navigator is a standard Decca X-band (3-cm) solid-state marine radar with a 25-kW transmitter. The antenna is limited to 18-cm depth to fit under the chin of a helicopter. In the Mk 1 fitted in the Cessna, the antenna is in a standard cargo pack attached to the underside of the fuselage, using a fiberglass radome. Mk 3, planned for the Sea King helicopter, will use a chin radome for 360-deg scanning. Maximum instrumented range is 95 nm, with 8 range scales from 0.5 nm up.

This radar was originally developed to meet a Norwegian requirement for a periscope detection unit, to deal with submarines in fjords. As fitted in Sea Kings, the radar will have a data link to control attacks by fast patrol boats hidden behind islands.

◆ ASR 360

Band: X (9.1 GHz) **Beam:** 3×27 deg
Peak Power: 25 kW **Gain:** 25 dB
Pulse Width: 0.05, 0.25, and 1.0 microsec
PRF: 825 pps minimum **Scan Rate:** 32 rpm
Antenna Dimensions: 30-in slotted waveguide

ASR 360 is Racal-Decca's surface-search marine radar, adapted for small maritime-patrol aircraft, such as converted

Short Skyvans (Sultan of Oman Air Force, which bought 15 in January 1984). As of 1984, ASR 360 had also been selected by British Aerospace for a modified Jetstream 31EZ. ASR 360 was originally developed for the Royal Norwegian Navy in 1979, to be flown on board a single- or twin-engined Cessna (the first installation was a Royal Norwegian Navy Cessna 337).

◆ Sea Owl (PID)

GEC-Marconi's stabilized long-range FLIR for Royal Navy Lynx helicopters is also designated Passive Identification Device (PID). The stabilized FLIR uses standard TICM II modules, and the associated signal processor automatically searches for, detects, and tracks surface targets. The turret slews at up to 60 deg/sec, over ± 120 deg in azimuth; elevation limits are $+20/-30$ deg. Magnifications are $5\times$ and $30\times$ (fields of view 12×8 and 2×1.33 deg). The IR sensor uses 8 parallel CMT SPRITE detectors and feeds a 625- or 525-line monitor. Turret weight is 66 kg. There are also a 17-kg signal processor and a 16-kg target tracker for automatic search, detection, and tracking of surface targets. The system is designed to connect to a 1553B bus.

GEC-Marconi has proposed the related multirole FLIR turret for the projected Super Lynx helicopter. This turret slews at up to 110 deg/sec and is stabilized to within 88 microrad. The telescope zooms continuously between 2.5 and 10 magnification; fields of view are 24×16 down to 6×4 deg with 625-line (50 frames/sec) video, or 19.4×13 down to 4.9×3.3 deg with 525-line (60 frames/sec) video. Resolution in the narrow field of view is typically 0.227 mrad vertical and 0.182 mrad horizontal. The TICM II module uses 8 parallel SPRITE detectors working in the 8–13 micron band. Total weight is 35 kg, and the turret is 380 mm (15 in) in diameter.



Sea Owl, on display at RNEE, 1989. (Author)

UNITED STATES

◆ AAR-42

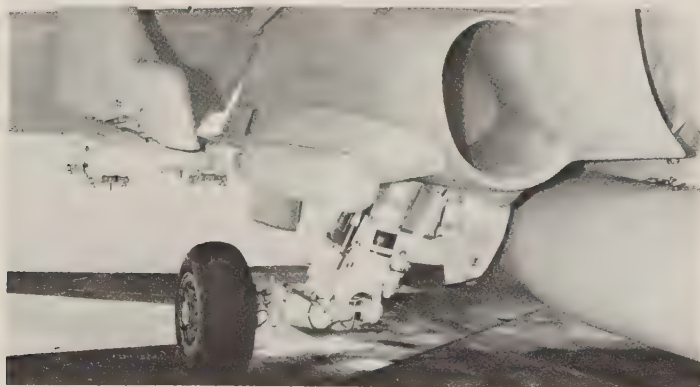
AAR-42 is Texas Instruments's pod-mounted FLIR detector for A-7 attack aircraft. AAR-42 is gimballed and provides a night window/bombsight; as of 1988, over 100 had entered U.S. Navy service. Early in 1985 work began on an upgrade for the Air National Guard, to include a wide-field-of-view navigation mode, DC-restored video, and a capability for hands-off operation (automatic gain/level). These improvements will be available for possible navy upgrades.

The stabilized FLIR image is displayed on the pilot's HUD. Coverage: ± 20 deg in azimuth, $+5/-35$ deg in elevation. The lens zooms from wide ($1\times$ magnification) to narrow field of view ($4\times$ magnification), the former for navigation and the latter for target identification and weapons delivery. By 1985 claimed MTBF was 390 hr.

Work began in 1973, with operational evaluation in October 1976, first production delivery in September 1978, and approval for service use in March 1979. Pod dimensions: 21×193 in (720 lb). AAR-42 will ultimately be replaced by the new Low Altitude Night Attack (LANA).

◆ AAR-50/AAQ-16

Hughes's system, AAR-50 is a navigation set, TINS (thermal imaging navigation set), for the F/A-18, derived from the earlier AAQ-16. AAR-50 provides a pilot with an image (on the HUD) of the approaching terrain, in either black-is-hot or white-is-hot form (the latter looks something like a conventional television image). TINS has a fixed 20×20 -deg field of view (and thus cannot be used for target-following), occupying a pod (10×78 in, 175 lb) on a stub pod adapter on the starboard side of the airplane. Hughes claims that MTBF is greater than 410 hr (MTTR is 17 min, using standard WRA components). Five prototypes have been delivered; as of early 1989, first production deliveries were scheduled for that year.



TINS (AAR-50) mounted on an F/A-18. (Hughes)

The earlier AAQ-16 is intended for both the U.S. V-22 Osprey and the Anglo-Italian EH-101; it was deployed to the Persian Gulf on board U.S. SH-2s (see below). AAQ-16 is a turret-mounted FLIR, slewing at 130 deg/sec, with azimuth limits of ± 210 deg and elevation limits of $+85/-180$ deg. It has 2 magnifications, $1\times$ and $6\times$ (corresponding fields of view are 30×40 and 5×6.7 deg). Video is 875 or 525 lines. The turret is controlled by a joystick. The turret weighs 45 lb and is 12 in in diameter (14 in deep). Hughes claims MTBF is 400 hr.

In 1988 AAQ-16s (in production for the army and the Customs Service since 1985) were mounted on board LAMPS I helicopters operating in the Persian Gulf. On these aircraft the turret is in the nose, on the right-hand side, just forward of the radome. The AAQ-16 image can be down-linked to the ship operating the helicopter.

◆ AAS-33 (DRS)/TRAM

AAS-33 is the A-6E detection-and-ranging set (DRS), part of the airplane's TRAM (Target Recognition and Attack Multisensor) system. TRAM employs a stabilized turret carrying a FLIR, a laser rangefinder/designator, and a laser receiver (to pick up targets designated on the ground), all within a 20-in dome. The FLIR has a zoom (up to 13-power) lens. The main technical problem in development was packaging everything within the very small dome. The sensors can be slaved to the aircraft radar, and when not in use the dome rotates to protect the FLIR and laser windows. Hughes is the manufacturer.

Reportedly, pilots credit TRAM with quadrupling their capability and with increasing bombing accuracy tenfold. Because the turret can be turned 180 deg, TRAM can be used to assess bomb damage on the first run, without making a second pass.

DRS and TRAM were part of the project for an enhanced all-weather A-6A, begun in 1972. The prototype was test flown in 1976, and TRAM was approved for service use in March 1980. Conversions of existing A-6s began in 1978, and installations in new aircraft under the FY85 program.

Northrop received a contract from Grumman in May 1985 to develop an IR video automatic tracker (IRVAT) for the A-6E. The tracker could keep lock on targets while the airplane maneuvered. The FY86 program included funds to begin engineering design to integrate AV-8B/F-18 night-attack electro-optics into the A-6E. This project includes a passive night navigation system. The Naval Air Systems Command issued an RFP for a follow-on DRS in April 1987.

◆ AAS-36/37

AAS-36 is the Texas Instruments infrared detecting set (IRDS) for P-3 Orions. IRDS provides a thermal image of the target on



An AAS-36 turret under the nose of a P-3 Orion. (Naval Reserve Association)

a television set, and the detector is inertially stabilized against target motion. The passive tracker can be locked onto a target of interest. The set is carried in a small turret under the nose of the airplane.

AAS-36 is broadly similar to the AAS-33 DRS used on the A-6E. FLIR fields of view are 15×20 and 5×6.7 deg. Slew rate is 1 rad/sec (about 57 deg/sec), and azimuth limits are ± 200 deg. The turret is stabilized to within 0.125 mrad. It weighs 301 lb. MTBF is 300 hr (MTTR 30 min).

AAS-36 replaces the KA-74 camera originally installed on board P-3A and -3B aircraft. A program to replace the LLLTV originally installed on board the P-3C began about when the airplane entered production, and competitive procurement of a FLIR turret began in 1971. The navy temporarily bought 11 Hughes AAR-37 and 4 Texas Instruments AAR-40 FLIRs before awarding the AAS-36 contract to Texas Instruments in 1972 as part of the P-3C Update II. Texas Instruments began work late in 1974, the first production award following in mid-1977. AAS-37 was initially installed on board P-3C Update II aircraft, but was later extended to -3As and -3Bs.

The AAS-36 infrared receiver is incorporated in the AAQ-15 infrared detecting-and-tracking set used on board air force HH-60 helicopters and C-130 gunships. In that application 3 simultaneous fields of view are presented, and there is an automatic video tracker.

The AAS-37 IRDS (IR detecting-and-ranging set) is a derivative, used on board marine OV-10Ds. AAS-37 provides automatic target tracking and laser illumination for weapons such as Paveway. The project was originally designated OV-10D Night Observation Gunship (NOGS); it was canceled, then revived in 1978 as the Night Observation System (NOS). The IRDS development contract was awarded in June 1976, with the first flight test following in November 1977. Technical and operational evaluations were completed in July 1978, and delivery of 23 units began in February 1979 and was completed that August.

◆ AAS-40 (Seehawk)

This lightweight Northrop FLIR was developed for the U.S. Coast Guard's HH-65 Dolphin helicopters but was not adopted; it has been included in the S-2 Tracker modernization project for Taiwan. Seehawk uses standard DoD FLIR components. The 39-kg turret-mounted FLIR has 3 magnifications, $1 \times$, $2 \times$, and $6 \times$ (corresponding fields of view are 30×40 , 15×20 , and 6.5×5 deg). The turret slews at up to 180 deg/sec; azimuth limits are ± 190 deg, and elevation limits are $+30/-105$ deg.

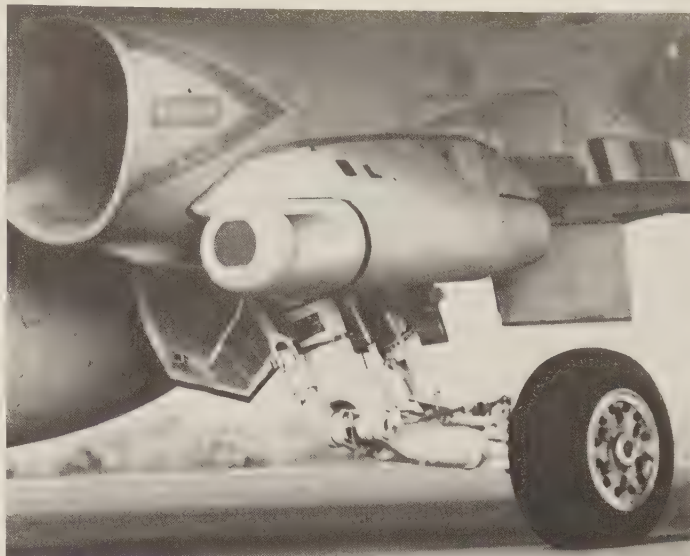
◆ AAS-38

AAS-38 is the Texas Instruments/Ford Aerospace FLIR for F/A-18 Hornet fighter-bombers and is used primarily for attack against land targets. The system is pod-mounted and ultimately will control a laser target designator/ranger. This FLIR incorporates an automatic target tracker and automatic gain/level control for hands-off operation. The system as a whole employs 10 Weapons Replaceable Assemblies (WRAs); mean time to replace 1 is less than 12 min.

The pod is 13×72 in and weighs 347 lb. It is typically mounted on the lower left of the aircraft fuselage and provides the pilot with a 3×3 - or 12×12 -deg field of view. The pilot can move the line of sight from -150 to $+30$ deg, with 540 deg of roll freedom in either direction. Targets can be tracked at 75 deg/sec.

AAS-38 was the first navy FLIR designed for supersonic operation. This system entered service in February 1985, after more than 175 successful test flights between 1980 and 1983, a 170-flight program at NWC China Lake and NAS Patuxent River in 1984, and an operational evaluation at Patuxent River in 1985. Full-scale development of the laser tracker began in 1983, and it is scheduled for incorporation in pods delivered from 1989 onward.

Dimensions: 13×72 in; weight 370 lb (including laser



AAS-38 FLIR pod mounted on an F/A-18 (Hughes)

ranger). Ford claims an MTBF of 80 hr for the full FLIR/laser ranger (MTTR 15 min).

Three major improvements are currently in production: pod boresight G-load compensation software; filtered inertial-to-sightline coordinate transformation (CSI) for better targeting accuracy; and air-to-air automatic tracking. A multifunction autotracker and an advanced air-to-air capability are under development. The multifunction autotracker automatically selects 1 of several possible air-to-air tracking methods (algorithms) to lock onto another airplane. The autotracker can conduct a search for an airborne target, automatically detecting it and locking on; alternatively, the autotracker can track several targets simultaneously (a FLIR equivalent of radar TWS performance).

During the Gulf War an AAS-38 pod was carried on the port stores station of 1 SH-60B LAMPS III helicopter of HSL-44. The pod's 875-line video was interlaced so that it could be displayed on the 525-line monitor on board the helicopter. This image could not be data-linked down to the ship. Six more production pods will have the data-link capability, and the FLIR may be slaved to the helicopter's radar. The SH-60B cockpit could not be modified for night operations, so the crews were provided with hand-held, army-type, Texas Instruments TAS-6A FLIRs. Crews were also provided with Fujinon stabilized binoculars to identify distant surface contacts detected by the search radar. However, in the absence of a zoom-lens FLIR, such identification brings the helicopter well within the range of hand-held missiles. Hence the importance of the FLIR pod.

In all, 25 SH-60s were modified for the Persian Gulf mission (Earnest Will).

Reportedly, current production AAS-38s incorporate a laser target designator/ranger, for which space was provided in the original design. The laser can perform some radar functions when the airplane is operating in radar silence.

◆ S-3 FLIRs (OR-89/AA)

The FLIRs installed in S-3s do not have separate AN designations because the FLIRs are integral elements of a larger weapons system. The first version, OR-89/AA, was also the first FLIR to be designed simultaneously with the overall airframe. The OR-89/AA is also installed on board many P-3Bs and Canadian CP-140 Auroras (as OR-5008/AA). Existing OR-89C/AAs are now (1988) being upgraded to OR-263/AA configuration, incorporating DoD Common Modules. The OR-263 can be operated off-line as an independent FLIR.

Both OR-89 and OR-263 are manufactured by Texas Instruments.

OR-89/AA was developed from the AAD-4 and AAS-28 FLIRs used in Vietnam. Lockheed contracted with Texas Instruments directly in August 1969, and the first prototype was delivered in March 1971. The FLIR is turret-mounted under the airplane, just abaft the cockpit. The field of view is 5×6.67 or 15×20 deg, with azimuth coverage of 200 deg in either direction and elevation coverage of 0 to -84 deg. Output is an 875-line television picture. About 1982 the specified MTBF, which had been demonstrated in service, was 345 hr. Turret diameter is 20.5 in.

The AAQ-10 (Pave Low III) of the HH-53 helicopter is a derivative. This device is also installed on board Israeli Navy Westwind reconnaissance aircraft, in a special high-speed turret. The full Pave Low installation includes an APQ-158 radar.

◆ APG-65

See the Anti-aircraft Warfare section; APG-65 is a dual-purpose radar.

◆ APQ-126

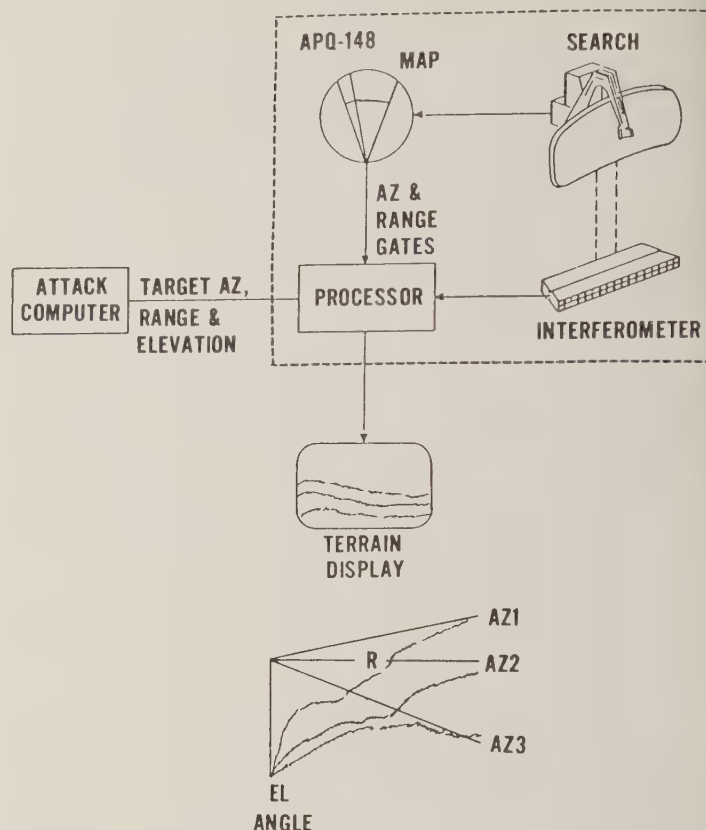
Band: Ku (7 selectable frequencies, 600-MHz band)
Beam: 2.5×18.4 deg (antenna tilts to cover $45 \times +70/-30$ deg)
Peak Power: 60 kW **Gain:** 28.5 dB
Pulse Width: (i) 0.2 (ii) 1 (iii) 2 microsec
PRF: (i) 3600 (ii) 720 (iii) 360 pps
Scan Rate: 90, 120, 180 deg/sec (horizontal); 150 deg/sec (vertical)
Antenna Dimensions: 19.5×13 in
Antenna Weight: 45 lb (230 lb total)

APQ-126 is Texas Instruments's radar for the A-7E Corsair II attack bomber. Compared to the earlier APQ-116, 126 added a third pulse mode and a terrain-avoidance mode, in addition to ground ranging, ground mapping for navigation, and blind bombing. Frequency agility (over a 30-MHz range at a switching rate of 100 Hz) is used to improve ranging accuracy and to achieve long-range target detection. APQ-139 is a later version with AMTI.

◆ APQ-148/156/APS-130

Band: Ku (16–17 GHz) **Beam:** $1.4 \times 35-50$ deg
Peak Power: 100 kW **Gain:** 39.2 dB
Pulse Width: (i) 0.4 (ii) 1.25 (iii) 3.0 microsec
PRF: (i) 2400 (ii) 800 (iii) 300 pps
Scan Rate: 100, 50, or 25 deg/sec sector scan
Antenna Dimensions: 36×17 in
Antenna Weight: 138 lb

Data above apply to APQ-92, the radar superseded by APQ-148; they give an indication of its characteristics, although the details of the newer radar will be somewhat different. Total coverage in the radar described above is 120 deg in the horizontal, and vertical coverage limits are $+20/-40$ deg, depending on tilt. Total weight was 490 lb. The associated monopulse target tracker, APQ-112, used a 14-in circular parabolic dish (gain 30 dB, weight 75 lb, beam 3.8 deg). It operated in Ku-band



This diagram illustrates the principle of the APQ-148 and -156 radars. The interferometer associates an elevation angle with each combination of range and azimuth; the processor picks out the particular combinations corresponding to each point observed by the main radar, using azimuth and range gates around those points. The result is a terrain display. (Norden Systems)

(15.8–17 GHz), with a peak power of 60 kW (0.4 microsec pulses, PRF 2400 pps). The beam could scan over 90 deg in the horizontal, and between $+15$ and -45 deg in the vertical. Scan rate was 50 deg/sec in the vertical, to find the elevation of a target detected by the main APQ-92, and sector scan rate was 60 deg/sec. Total weight was 300 lb.

APQ-148 and -156 (a modified -148) are the A-6E radars. APQ-148 operates in Ku-band, with peak power about 60 kW; the antenna is 24×18 in (originally 36×18 in). Total APQ-148 weight is about 500 lb. In the APQ-156 version (total weight 450 lb) it has 3 alternate PRFs and 4 alternate pulse widths. These radars have the same video processor as APQ-92 but have new antennas (AS-2604) and frequency-agile transmitters. Both -148 and -156 have TWS capability. The manufacturer (Norden) claims that the receiver design maximizes azimuth resolution, achieving about half the value that would be calculated based on antenna size (hence the use of a significantly smaller antenna in the newer radar). That suggests that these radars use some form of monopulse processing. They are frequency-agile, primarily to reduce ground clutter and scintillation.

These semi-3D radars replace the earlier combination of the 2D APQ-92 and the pencil-beam (monopulse target tracker) APQ-88 or -112. APQ-92 used AMTI processing to detect significant moving ground targets. APQ-88 or -112 locked onto a target designated by the BN on a display generated by the main radar. It was used primarily to provide target elevation to the central computer. The target tracker also provided a supplemental terrain map, presented on the pilot's radar CRT beneath the vertical display.

The combination of 2 separate radars was a major maintenance problem. In 1969 the A-6 system was modified so that the target-tracker radar, which was essential for elevation data, could also provide some search data, in a redundant-target-tracking (RTT) mode. However, the main radar could not be



An APQ-156 antenna, showing the phase interferometer below the main reflector. (Norden Systems)



An APS-130 antenna for the EA-6B. This radar is essentially APQ-156 without the interferometer. (Norden Systems)

discarded because its fan beam was needed to achieve a sufficient search rate.

The solution was to replace the second (pencil-beam) radar with an interferometer consisting of 2 rows of 32 horns each, 24 in wide, moving with the main dish in azimuth. The difference in time of arrival of a signal in the upper and lower rows of horns measures the elevation angle to a target picked up by the 2D reflector. The interferometer produces a continuous elevation-range profile for terrain avoidance.

The combination of conventional dish and interferometer, with a single transmitter, is APQ-148.

Radar operating modes are search (basic mode), beacon, airborne moving target indicator (AMTI), and terrain clearance for low-level flight. Radar range modes include displays at up to 150 nm as well as much more detailed ones out to 75 nm. Minimum PPI range is 5 nm. Targets may be detected in the PPI mode using AMTI, which operates at short ranges (limits are 18, 22, and 27.5 nm depending on the display mode). There are also 2 special sector modes, ARE-60 (automatic range expansion—60 deg) and ARE-30, B-scans between ± 30 and ± 15 deg, primarily for attack. The depressed-center PPI mode (azimuth sector 20–110 deg) is primarily for navigation.

There are 2 displays, a 6-in direct-view radar indicator (DRVI) for the BN and a 5-in storage tube for the pilot (which can retain a radar picture when the radar scans only once, then shuts down, for stealth). The APQ-156 version has only a DRVI. In addition, terrain data are displayed for the pilot, for terrain avoidance, on the horizontal display, gray shades giving range information, and height giving elevation data. The terrain win-

dow on the vertical display is 26 deg wide (in terms of real azimuth); this is search-radar-terrain-avoidance (SRTC) data.

Norden received a contract to convert existing APQ-92 radars to TWS operation in August 1969. The first 13 APQ-148 radars were ordered in 1970 (total cost \$5.946 million, the first being delivered in 1971), with about 200 being delivered by the end of 1975. Six preproduction AMTI modification kits (MX-9736/APQ video processors) were ordered in 1976, followed by an order for 18 in 1978, and a contract for 295 more in 1980.

At that time work also began on updating the APQ-148 to -156 configuration. An analog signal-converter unit is replaced by a digital unit. The BN control box is replaced by 2 panels, an updated control box and a separate built-in test panel. The moving-target indicator is replaced by a more advanced unit. Reportedly, this modification is associated with TRAM, and the digital signal converters may be needed to process TRAM video for presentation on the radar scopes. Reportedly, Norden is developing an ISAR modification for APQ-156, and a version of this radar has been installed in B-52s as part of their offensive-avionics-system (OAS) upgrade.

Early in 1985 Norden received a Grumman order for the A-6 upgrade radar, which became APQ-173 (see below).

APS-130 was a simplified version of APQ-148 for the EA-6B Prowler, but it has been superseded by APQ-156C (first ordered in 1987), this radar now being standard in all versions of the A-6.

◆ APQ-168/174

APQ-168 is the Texas Instruments radar selected for air force and navy versions of the Bell-Vertol V-22. APQ-168 is intended primarily for navigation and terrain avoidance and is derived from a radar developed for the LANTIRN low-level attack sensor. Flight trials on board an HH-60 helicopter began in 1988.

APQ-174 is another derivative of the same LANTIRN radar, intended specifically for combat search and rescue.

◆ APQ-173

APQ-173 was the projected radar for the canceled A-6F Intruder and was intended to replace the APQ-156 of the earlier version. The contract award to Norden was announced in 1985. The future of this radar is in doubt, given the cancellation of the A-6F and uncertainty over the A-6G (which was intended to have most of the avionics planned for the -6F, but not some other improvements). This radar may have been derived from a multimode radar developed by Norden for Israel.

APQ-173 uses doppler beam sharpening for ground mapping and has an ISAR mode for ship classification. Reportedly, APQ-173 can acquire and track tactical targets at more than twice the range of the earlier APQ-156.

APQ-173 is a growth version of APQ-156 with ISAR, increased (reportedly more than doubled) range, sharper resolution (using doppler sharpening), and an air-to-air mode suitable for AMRAAM use. Increased range was considered crucial because the new generation of standoff weapons exceeds current radar range. With the cancellation of the A-6F for which it was designed, APQ-173 was to have been installed on board the new A-12. However, Norden was dropped by the A-12 systems integrator (GE), and at this writing the radar is the subject of a lawsuit.

The A-6F would have combined APQ-173 with dual AYK-14 mission computers (for redundancy), and its combat system would have been tied together by a 1553B bus. Other major features would have been the IR Video Automatic Tracking (IRVAT) system, ALQ-165, ALR-67, and NAVSTAR GPS.

◆ APQ-183

APQ-183 is Westinghouse's multifunction radar (MFR) for the A-12. The first was delivered in August 1990. APQ-183 includes elements of the B-1B and F-16 (APG-66) radars and, reportedly, also reflects some of the experience gained in developing the earlier APQ-173, canceled in April 1989. Reportedly, APQ-183 is a modular radar, including SAR and ISAR elements.

◆ APS-20

Band: S (2820 MHz) **Beam:** 3.5×8 deg
Peak Power: 2 MW **Gain:** 32 dB
Pulse Width: (i) 0.67 (ii) 2 microsec **PRF:** (i) 900 (ii) 300 pps
Scan Rate: 2, 4, 6, or 15 rpm; sector scan 20–50 deg/min
Antenna Dimensions: 8×3 ft, parabola
Antenna Weight: 180 lb

These data apply to APS-20F. This radar was originally developed late in World War II for AEW and was carried by a variety of single-engine aircraft, including the British Gannet. APS-20 also proved very effective at snorkel detection and for that reason equipped the P-2 Neptune ASW aircraft. During the Falklands War, Argentine P-2s used their APS-20 radars to target British warships for Super Étendards carrying Exocet missiles.

◆ APS-80A

Band: X (8.5–9.6 GHz)
Beam: 2.4×3.5 deg (3.6-deg pencil beam; 18-deg csc²) (coverage: $45 \times +10/-20$ deg)
Peak Power: 143 kW **Gain:** 35 dB
Pulse Width: 2.4 microsec **PRF:** 400 pps
Scan Rate: 6 rpm (sector scan 48 scans/min)
Antenna Dimensions: 42×24 in
Antenna Weight: total weight 380 lb

APS-80 is the radar installed on board P-3A and P-3B patrol aircraft, replaced in P-3C updates by APS-116.

◆ APS-88

Band: X (8.5–9.6 GHz)
Beam: 2.6×5.0 or 3.2×18.0 csc² deg (coverage: $40 \times +10/-25$ deg)
Peak Power: 45 kW **Gain:** 33.5 dB
Pulse Width: (i) 0.35 (ii) 0.8 (iii) 4.5 microsec
PRF: (i) 2000 (ii) 1025 (iii) 200 pps
Scan Rate: 6 or 28 rpm; sector scan 36 deg/sec
Antenna Dimensions: 42×20 in
Antenna Weight: 61 lb (total 228 lb)

APS-88 is the periscope-detection and surface-search radar of S-2 Trackers.

◆ APS-115

Band: X **Beam:** 2.4×3.6 deg
Peak Power: 143 kW **Gain:** 34 dB
Pulse Width: (i) 2.5 (ii) 0.5 microsec **PRF:** (i) 400 (ii) 1600 pps
Scan Rate: 6 or 12 rpm; sector scan 36 or 72 deg/sec
Antenna Dimensions: 3.5 ft
Antenna Weight: 84 lb (each); total system weight 523 lb

APS-115 is the sea-search radar of the P-3 Orion. This radar is unusual because it uses 2 antennas, 1 in the nose and 1 beneath the tail, to achieve 360-deg coverage, without disturbing overall streamlining.

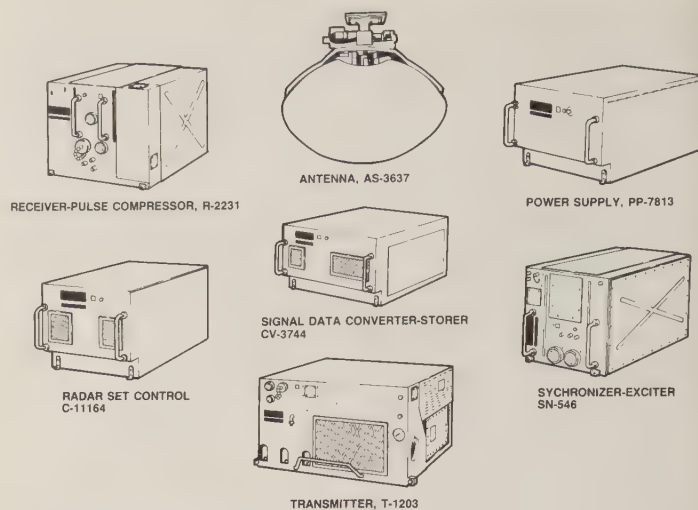
◆ APS-116/134/137

Band: X (9.5–10.0 GHz) **Beam:** 2.4×4.0 deg
Peak Power: 500 kW **Gain:** 34 dB
Pulse Width: (compressed) (i) .0025 (ii) 0.5 (iii) .012 (iv) .012 microsec (all pulses are transmitted at 0.5 microsec duration) (compression ratio 250:1)
PRF: (i) 2000 (ii) 400 (iii) 400 (iv) 400/2000 pps
Scan Rate: (i) 300 (ii) 6 (iii) 60 (iv) searchlight, for ISAR
Antenna Weight: total system weight is 472 lb

These data apply to APS-137.

APS-116 is the surface-search radar of the S-3A Viking, of the German version of the Atlantic, and of the Canadian CP-140 Aurora. Manufactured by Texas Instruments, APS-116 is a coherent (MTI) high-resolution (short-pulse) radar. For periscope detection amid the clutter of rough water, or for high-altitude surveillance, this radar rejects clutter by using pulse compression and fast-scan processing. APS-116 has TWS capability but can also operate in a searchlight mode, tracking a single small target. Modes are (i) periscope and small-target detection, (ii) navigation and weather avoidance, (iii) long-range maritime surveillance, and (iv) ISAR imaging.

Performance in test: 26-nm range on a snorkel (aircraft at



APS-137(V)1. (Texas Instruments)

1500 ft), 33-nm on a fast attack craft (from 5000 ft), 75-nm on a destroyer (8000–10,000 ft). These are maximum ranges in sea-state 3/4, and mean ranges were shorter. For example, the average range on a snorkel was 15.5 nm. Minimum resolution is 1.5 ft.

APS-134 is the "international successor" to APS-116, incorporating the latter's less sensitive improvements. Peak power is 500 kW, with a fast-scan antenna. Modes are

- (i) periscope detection in clutter, with high resolution (1.5 ft): 2000 pps, 150 rpm, 32-nm display, adjustable false alarm rate;
- (ii) long-range search/navigation, with medium resolution: 500 pps, 6 rpm, 150-nm scale;
- (iii) maritime surveillance, with high resolution (short pulses): 500 pps, 40 rpm, 150-nm scale. This radar was chosen for the U.S. Coast Guard HC-130.

APS-137(V) is a modified APS-116 incorporating ISAR, for the S-3B Viking; 137(V) supports the Harpoon antiship missile. In ISAR mode, the aircraft antenna does not scan the ship but points in searchlight mode, examining the different doppler shifts as the target moves.

APS-137 will replace APS-115 on some P-3s.

In 1989 an APS-137 was mounted experimentally on board the hydrofoil *Hercules* (PHM 2), currently used primarily for anti-drug-smuggling surveillance. In the frequent surface-ducting conditions of the Caribbean, it can often see well beyond the ship's nominal radar horizon, and its ISAR feature is used



APS-137 was mounted experimentally on board the hydrofoil missile boat *Hercules*, to provide OTH ship identification, using ducting and the ISAR capability of the radar. It occupies the mast radome. (Texas Instruments)

to identify potential targets, separating them from the dense shipping traffic. In one exercise *Hercules* was able to distinguish a missile destroyer from surrounding shipping and, thus, to cue in other hydrofoils for a simulated attack.

◆ APS-120/125/138/139/145

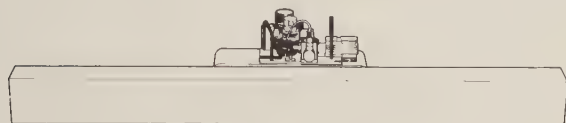
See the Anti-aircraft Warfare section.

◆ APS-124

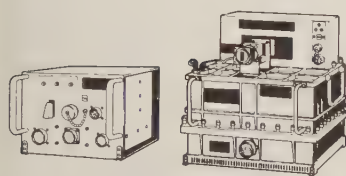
Band: X **Beam:** 1.2×20 deg
Peak Power: 350 kW **Pulse Width:** (i) 0.5 (ii) 2 (iii) 1 microsec
PRF: (i) 1885 (ii) 940 (iii) 470 (16-period staggered PRF) pps
Scan Rate: (i) 120 (for weather) (ii) 6 (iii) 12 rpm
Antenna Dimensions: 72×12 in planar array
Antenna Weight: total system weight is 208 lb

APS-124 is the sea-search radar of the LAMPS III (SH-60) helicopter. Small targets are detected in the midst of sea clutter by sea-clutter decorrelation (fast scanning and scan-to-scan integration). With a low profile, the antenna can be slung under the helicopter, for full 360-deg coverage. The short-pulse rapid-scan mode is for weather. Estimated range on a 1-m^2 target is 16 nm, compared to 20 nm for APS-115 or -116.

The antenna is AS-4035.



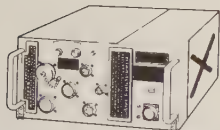
ANTENNA, AS-4035/APS-124



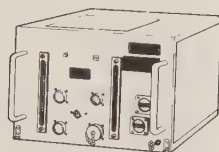
TRANSMITTER UNITS
T-1308/APS-124
C-9889/APS-124



SIGNAL DATA CONVERTER CV-3204/A



CONVERTER CONTROL C-9643/A



RECEIVER/SYNCHRONIZER
R-1979/APS-124

APS-124. (Texas Instruments)

◆ APS-127

Band: X **Beam:** 5×6 deg
Peak Power: 200 kW **Pulse Width:** (i) 2 (ii) 0.5 microsec
PRF: (i) 400 (ii) 1600 pps **Antenna Dimensions:** 2×2.6 ft
Antenna Weight: total weight 295 lb

APS-127 is Texas Instruments's surface-search radar for small maritime-patrol aircraft, such as Danish Gulfstream IIIs. Estimated range on a 1-m^2 target is 18 nm. This radar is carried by U.S. Coast Guard HU-25A aircraft. APS-127 is unusual in using a stabilized antenna. It integrates successive scans by using a direct-view storage-tube display for both plot and surveillance information.

◆ APS-128

Band: X (9375 MHz) **Beam:** 2.4×9 deg
Peak Power: 100 kW **Gain:** 32 dB
Pulse Width: (i) 2.4 (ii) 0.5 microsec **PRF:** (i) 400 (ii) 1600 pps
Scan Rate: 15 or 60 rpm **Antenna Dimensions:** 42×11 in

Eaton's sea-surveillance radar is for light aircraft, particularly for antismuggling and EEZ enforcement. Users are Brazil, Chile, and Gabon on Brazilian-built Embraer EMB-111 aircraft; the

Japanese Maritime Self-Defense Agency on Beech 200Ts; the Royal Malaysian Air Force and Indonesian Air Force on C-130MPs; Spain and Uruguay on CASA C-212s; Spain on retrofitted C-130s; NASA on the Short Skyvan; and the U.S. Customs Service on an ILC Aerostat (balloon).

The flat-plate array antenna is compensated for pitch and roll up to 20 deg and can be tilted up to 15 deg up or down. The transmitter is frequency agile (85 MHz peak-to-peak). Claimed mean time between failure is 442 hr in long-term use.

Unlike most radars, this one uses a television-type (raster-scan) display. The radar signal is converted into a digital signal before display, and the bright 8-in (diagonal) tube can be shifted to display the outputs of other sensors, such as FLIRs. The display is bright enough to have signal-processing features, including target enhancement and scan-to-scan integration, so that target tracks can be generated. The radar is also fully integrated with inertial, Omega, or other navigational systems, and the display can be switched to other sensors, such as infrared.

Claimed performance: 30 nm range on a snorkel or a small fishing vessel (10 m^2) in sea-state 3; 60 nm on a trawler (150 m^2) in sea-state 5; 100 nm on a freighter (500 m^2) in sea-state 5; 120 nm on a tanker (1000 m^2) in sea-state 5.

There is a pulse-compression version for small-target detection; the manufacturer claims that resolution is 5 times better than that of standard maritime radars. Frequency is selectable between 9.2 and 9.5 GHz in 20-MHz steps, and there is 100-MHz pulse-to-pulse frequency agility. Peak power is 8 kW minimum (10 kW nominal) but equivalent to 500 kW (50:1 compression ratio), for 5-microsec pulses (compressed to 0.1 microsec). PRFs are 2000, 1500, 800, and 400 Hz.

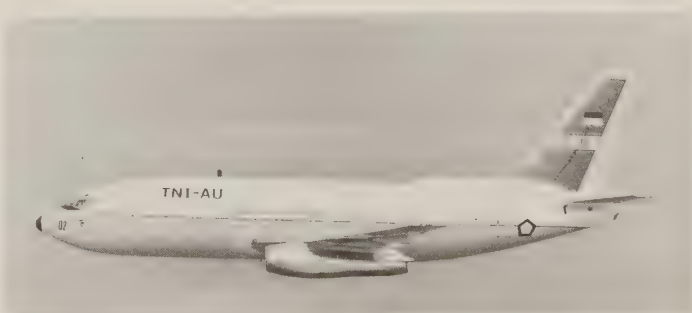
The current manufacturer, the Telephonics Corp., offers DTACS, the Digital Tactical System, an APS-128 plus added sensor capacity, with tactical-navigation and sensor-plot data displayed on the radar screen via microprocessor control. DTACS is installed on Puerto Rican police Beech 200T aircraft and has been offered as an S-2E or helicopter system.

◆ APS-131/135/SLAMMR

These are Motorola X-band, side-looking, SAR radars. APS-131 and -135 are used by the U.S. Coast Guard to detect ships and boats as well as oil slicks. SLAMMR (side-looking airborne modular multimission radar) is a commercial version sold to Indonesia and carried on board modified Boeing 737s (the antennas are on the upper aft fuselage). APS-131 uses two 8-ft slotted arrays mounted back to back in a stabilized pod carried under the belly of an HU-25A aircraft. There are 4 range settings: 13.5, 27, 54, and 108 nm. APS-131 has a peak power of 200 kW (0.2-microsec pulses, PRF 677 or 1477 pps) and produces a 1-deg beam. APS-135 is a similar radar carried by Coast Guard HC-130s. Its two 16-ft antennas are mounted on the sides of the fuselage. The fan beam is 0.5 deg wide (csc² fan). In both cases, the output of the radar is a film image analogous to a strip map.

Eight of these radars were delivered to the U.S. Coast Guard in 1982.

Indonesia uses 16-ft antennas for the SLAMMRs in its Boeing 737 surveillance aircraft; there is also a version with 8-ft anten-



SLAMMR radar occupies the dorsal strake, aft, on this Indonesian Boeing 737. (Motorola)



APS-135 in a side pod on the fuselage of a Coast Guard HC-130 (above the landing-gear fairing). (Motorola)

nas. The 16-ft antenna gives 0.5-deg resolution in azimuth. Peak power is 200 kW (generated by a magnetron; a 0.2-microsec pulse makes for 30-m range resolution). Despite the noncoherent design, there is very good pulse-to-pulse stability for moving-target indication; the optional MTI processor uses an FFT, to detect targets simultaneously from 0 to 80 nm. Flying at 30,000 ft, SLAMMR can detect a 100-m² target out to 100 nm (for maritime surveillance), depending on ocean conditions and aircraft speed and altitude. It can detect a 1-m² target out to 35 nm. With the MTI processor, it can detect small targets moving at 5 mph at 50 nm and larger and faster targets at 80 nm. The single operator station uses either a dry film display or a color CRT. Current upgrades include a high-resolution digital recorder.

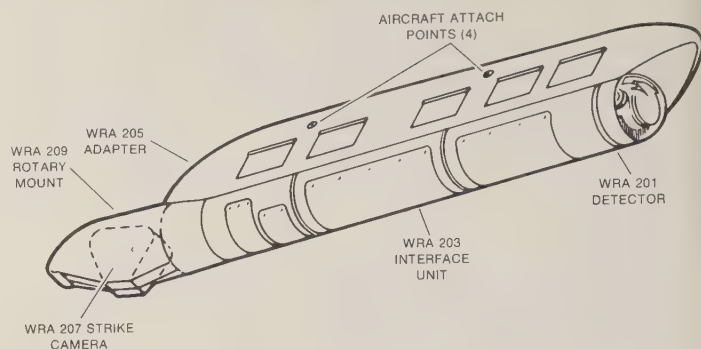
◆ APS-143

Band: X (9.2–9.5 GHz, agile over 200 MHz)
Peak Power: 8 kW **Gain:** 31–33 dB typical
Pulse Width: 5 or 17 microsec, compressed to 0.1 microsec (compression ratio 70:1, 240:1)
PRF: 2500, 1500, 800, 400 pps

This Telephonics small-aircraft sea-search radar is presumably a potential successor to APS-128. (V)1 is in coast guard service on shipboard aerostats (balloons). (V)2 has been selected by the U.S. Air Force for range surveillance and safety. (V)3 has been selected for the Sikorsky S-70C(M)1 ASW helicopter and for the NATO frigate helicopter (NH 90). All versions use a TWT transmitter and a flat-plate stabilized antenna. Claimed performance: detects a 1-m² target at 37 km in sea-state 3 from low altitude. Azimuth accuracy is 0.5 deg, and range resolution is 46 m. Total weight is 81.8 kg. The radar can be fitted for TWS and MTI and for missile guidance; it can interface with ESM or IFF. Maximum range is 370 km. The display is a digital raster-scan unit; memory is 512 × 512 × 3 pixels for video, and 512 × 512 × 1 for overlay graphics. APS-143 combines APS-128 technology with a compressive receiver similar to that in the B-1B. Telephonics describes it as the lightest, least expensive pulse-compression radar of its type in existence. Total system weight (APS-143) is 180 lb.

◆ ASQ-173

The pod-mounted F/A-18 Laser Spot-Tracker/Strike Camera (LST/SCAM) is manufactured by Martin Marietta. The stabilized laser spot-tracker occupies the forward end of the pod. The system picks up a target designated by a ground- or air-based laser, feeding digital target data into the F/A-18 fire-control system and indicating target position on the HUD. The target is acquired at maximum standoff range on the first pass, reducing aircraft vulnerability; and communication between the attack pilot and the forward air controller or ground target designator is minimized. The 35-mm strike camera at the after end of the pod is gimballed so that the target can be photographed while the attacking airplane maneuvers. Dimensions: 8 × 90 in, weight 155 lb, required MTBF at least 333 hr. This pod occupies



F/A-18 laser spot tracker/strike camera (LST/SCAM, or AN/ASQ-173). (Martin Marietta)

the space on the starboard side of the F/A-18 body otherwise occupied by a Sparrow missile.

◆ HARPSS

Texas Instruments High-Altitude Remote-Platform Surveillance System is a large-aperture IRST system to be tested on board a P-3C in 1991. It is to be tested through the end of FY91, with production scheduled for FY96. HARPSS has an 8-in aperture and shows greatly improved clutter rejection; it covers 360 deg. The same IRST system will be modified as an airborne-early-warning sensor.

◆ Integrated IR Search and Track/Laser Rangefinder Sensor Demonstration

In November 1989 Hughes received a 27-month contract to demonstrate the operation of an IR sensor and a CO₂ laser through a single aperture. Such a device would greatly reduce the surface area of the sensor; the main technical problem is to shield the IR sensor from the laser. The ground test was scheduled for August 1990 and the airborne test for late 1991.

◆ A-6E System Weapons Improvement Program (SWIP)

SWIP began in January 1988 as an interim improvement program for A-6Es, pending the production of the A-6F. With the cancellation of the A-6F and then of the more austere A-6G, it became a means of maintaining the A-6 fleet pending the introduction of enough A-12s. SWIP has encountered some funding difficulties but will presumably benefit from any slowdown in the A-12 program. It addresses the major limitations of the current A-6E: the lack of any passive night-attack capability, limited ECM, analog displays and controls, a slow (and saturated) computer, no ISAR radar, marginal engine thrust, and marginal bringback (i.e., capability to return to a carrier without dropping fuel and expensive weapons; current bringback, including fuel, is 6000 lb). The same list of defects was used to justify the A-6F; presumably, the ultimate goal of SWIP is not too far from the canceled project. However, in order to be affordable, SWIP proceeds in blocks. Block I is now underway, and Block II is being funded. Late in 1989 the Senate rejected Block III in favor of Block II for FY90. Block III is to be requested under the FY91 budget.

Block I provides Harpoon IC, HARM, and Maverick capability, as well as survivability upgrades and the new Boeing wing.

SWIP Block IA was begun under the FY90 program. It includes a new mission computer (as yet undetermined) driving a HUD, a standard central air-data computer on the 1553 bus, the new IDAP defensive package, improved navigation systems (GPS, with software installed in the ASN-139 inertial-navigation system), and a new TACAN (ARN-118 rather than ARN-84). The existing ALQ-126 countermeasure is retained, with new antennas in a modified wing fillet. The first SWIP Block IA airplane should begin flight tests in about May 1991. Eventually, a total of 110 aircraft are to be updated.

IDAP, the integrated defense avionics program for the A-6E, is being installed in conjunction with SWIP Block 1A but is separately funded. It is to be installed beginning in 1993.

Block II provides Cats Eyes/NVG for passive night attack, the AWW-13 data-link pod for the SLAM missile, weapons-control-system wiring upgrades, and safety improvements such as a better flight director (TADS, the tactical-attitude direction system).

IDAP employs an S-band active warning radar, covering both forward and rear hemispheres, which triggers chaff, IR decoys, and a new towed active decoy. It also advises the pilot to take the best possible evasive course. Grumman claims the towed decoy is the first operational one of its kind. Developed by China Lake, it has already completed flight and development tests. An A-6E carries 3 towed decoys deployed from a belly position well abaft the wing, near the chaff dispensers. IDAP also provides the pilot with night (FLIR) imagery in the main display.

◆ Harrier Night Attack (Cheap Night)/Real Night

From late 1989 on, Marine Corps Harriers (AV-8B) will be equipped with a special austere night-attack system, comprised of a narrow-field FLIR camera in the nose and a pair of NVGs for the pilot. The FLIR image, with a 22-deg field of view, is presented on the pilot's HUD (at 1:1 scale) and can also be shown on a cockpit CRT. The goggles allow the pilot to see to the side, and they expand the field of view at minimum cost (and minimum space and weight penalty). Although the view through the goggles is not as sharp as that presented by the FLIR, pilots have found no difficulty in integrating the two. The result is much simpler and less expensive than the air force's LAN-TIRN, partly because the field of view of the FLIR is fixed (pointing ahead). Pilots look into a turn with their goggles, rather than slew the FLIR, which is mounted in the nose above the angle-rate bombing system. Unit flyaway cost is estimated at \$1.2 million.

The goggle concept, code-named Cheap Night, evolved in 1984–85 from a proposal, presented at the navy/marine strike school, for an inexpensive night-vision device to expand Harrier capabilities. GEC Avionics was chosen to supply the Cat's Eye goggles. Cat's Eye was developed as part of a continuing British program, Night Bird, begun in 1978.

The U.S. Navy conducted a series of foreign weapons evaluation (FWE) projects: Cheap Night, Quick Night, Real Night, and also USN Fleet Quick Night. The Cheap Night program began in April 1984, using a TA-7C at China Lake to develop a night visual attack capability, balancing capability against cost and using existing technology. Using goggles, a pilot could fly at 450 kt at 200 ft, then pop up and bomb.

The next program, Quick Night (1985–86), used an A-6E at NATC Patuxent River. This time the crew used Cat's Eyes goggles and the navigational FLIR of the A-6E. The crew found the FLIR field of view too narrow (the airplane had no HUD), but they liked the goggles and the combination of filtered cockpit lighting and the FLIR. A 12-month Fleet Quick Night program was then conducted, using an Atlantic Fleet A-6, to further define night-system requirements.

The current A-6E program is Real Night, again using GEC equipment. This time the A-6 is equipped with a CO₂ laser-scanning and obstacle-warning pod (the British-built GEC LOCWS) to paint unseen obstacles on the HUD projecting a FLIR image. The pod scans an 8-deg box (2 deg up, 6 down, 4 across) in a near-vertical sinusoidal pattern at 50 kHz, building up a full frame every 1–1.5 sec. Once obstacles have been detected, they are stored and continue to be displayed even after they have moved out of the 8-deg box. Locus is designed to detect a 1-cm cable at 1.5 km in heavy rain. The first test flights were in 1986, using an A-6 carrying a FLIR with a thermal target-cuing device in an underwing pod.

As of May 1988, the U.S. DoD planned to buy 600 Laser Obstacle and Cable Warning Systems (LOCWS) and 2000 NVGs (part of Cheap Night).

Night attack F/A-18Cs and Ds are to receive a related system using a 20-deg HUD.

The marine order for Cat's Eyes goggles was the first major sale of the system. An operational A-6E squadron began using them in 1987, and 83 were initially ordered, with an option for 245 more. They have combiner eye pieces underneath the actual image intensifier, giving the user an unrestricted view when looking down toward the HUD or instrument panel. Other goggles require the user to view the HUD or instruments through the tubes, giving a poor view. When the pilot looks outside, a light-intensified image is projected onto the combiner eye pieces. An IR beam points up from the instrument panel, switching the goggles off automatically when the pilot looks down inside. An Integrated Night-Vision System (INVS) was begun late in 1987, to develop a lightweight, integrated, night-vision-goggle helmet that would be balanced to eliminate the torque and strain caused by unbalanced goggle weight during high-G maneuvers.

◆ ARBS (AN/ASB-19)

Hughes's Angle Rate Bombing Set was developed for the Marine Corps, to improve the accuracy of visual bombing. ARBS automatically tracks ground targets and automatically acquires spots designated by ground-based lasers. The tracker provides the bombing (weapons-delivery) computer, an IBM System 4/Pi, with both the line-of-sight angle to the target and the rate of change of that angle. The air-data computer provides true air speed and altitude; and the weapons-delivery computer solves for the ballistic path of the bombs, providing the pilot with an appropriate course displayed on the HUD and releasing the bombs at the appropriate moment. No range measurement is required (it is implicit in the combination of altitude and line-of-sight angle). Targets are tracked by a dual-mode television/laser tracker. The weapons-data computer stores all appropriate weapons ballistic data.

Nine preproduction models were built in 1975, and tests began in the summer of 1976. ARBS was initially installed in A-4M attack bombers, which had no elaborate radar system, and was also compatible with the AV-8 Harrier, which ARBS now equips. In an AV-8B, ARBS consists of a dual-mode tracker (DMT) in the nose, a weapons-delivery computer (WDC), and control units (CUs). The DMT acquires and tracks laser-designated targets; in daytime, the pilot can also designate and track using a television. Because the television camera is located next to the laser tracker, transition from mode to mode is very easy; the airplane can also acquire (and then track) targets designated by lasers on board other aircraft or on the ground. In addition, because the airplane is provided with an inertial navigation system, a target position can be predesignated, and the laser set to point it out when the airplane comes within range. The WDC computes weapon trajectory and filters DMT data, delivering them to the aircraft general-purpose computer, which actually flies the airplane and drops the bombs. Tracker slew angle and target designation are controlled from the aircraft stick (the AV-8B has a HOTAS cockpit); target data are presented on the HUD.

Typical television acquisition range is 15 km (8.2 nm) for a 3-m target with 10% contrast. A typical target designation laser 1 km from a target can be detected at 15 km under similar conditions. The optics can slew to compensate for 450 deg of rolling motion, covering +10/–70 deg in elevation and ±37 deg in azimuth. The system computer is designated CP-1278; it is an IBM System/4 Pi SP-1, with 32k 16-bit words (17 bits including parity check), operating at 440 KOPS. Total system weight is 59 kg [130 lb], and estimated cost, about 1987, was \$210,000.

This system was originally the Improved Weapon Delivery System (IWDS) for the A-4M.

◆ RDR-1300

Band: X (9305–9385 MHz) **Peak Power:** 10 kW
Pulse Width: (i) 0.5 (ii) 2.35 microsec
PRF: (i) 800 (ii) 200 pps
Scan Rate: 12 or 36 looks/min (scan angle 120 or 40 deg)
Antenna Dimensions: 10, 12, or 18 in flat plate

This Bendix radar, also made by FIAR, is standard in the Hughes/McDonnell 500 Defender, which many navies use as a lightweight ASW helicopter. The U.S. Army designates it APN-215 (V). It is also widely used commercially. RDR-1300 can be used both in the radar mode and in a beacon reception mode (9310 MHz).

The antenna is stabilized in line-of-sight within 1 deg. Range accuracy is 1%, and minimum tracking range is 600 yd. Data are held digitally in the radar memory, and the display is a 4.34×3.33 -in high-contrast CRT. Range marks (for, respectively, the long/short range modes) are 2.5/0.5, 5/1, 10/2, 20/4, 40/10, 80/20, 160/40, and 240/60 nm.

RDR-1400 is a related helicopter navigation and beacon radar, used on the Italian navy's utility version of the Sea King helicopter. The 1400C version incorporates a sea-surveillance mode, with clutter rejection to detect small boats, buoys, etc.

The RTR-1401B receiver-transmitter operates at the same peak power but with different PRFs, 720 and 240 pps. Maximum range: 185 nm with the 10-in antenna, 240 nm with the 12-in, and 322 nm with the 18-in.

◆ RDR-1500

Band: X (9370–9380 MHz; 9305–9315 MHz for beacon)

Beam: 2.6 or 3.4×10.5 deg **Peak Power:** 10 kW

Pulse Width: (i) 0.1 (ii) 2.35 microsec

PRF: (i) 800 (ii) 200 pps

Antenna Dimensions: 99.06 or 73.66 $\times$ 22.86 cm flat plate [39.0 or 29.0 $\times$ 9.0 in]

This Bendix-FIAR radar is derived from the RDR-1300C and carried on board coast guard HH-65A Dauphins. It has a high-resolution mode for sea search and terrain mapping and a long-range mode for weather avoidance. Maximum range is 300 km [164 nm].

◆ TNR

Texas Instruments' Ku-band pulse-compression Tornado Nose Radar equips German naval strike Tornado aircraft (the British nonnaval air-defense version uses a different radar). There is no official designation; TNR is commonly used. The Tornado system might be imagined as a more elaborate and more automated version of the A-6E described in the Surveillance and Control section, using a 64k central computer, with TNR as its main sensor. The main navigational sensors are an inertial platform and a doppler radar. The main computer can store planned targets for preset attack (using dive or loft bombing, air-to-surface missiles, or guns). Bombs can also be dropped on targets of opportunity, using a continuously computed impact line (CCIL) displayed on the HUD, or using laser target marking.

TNR consists of 2 separate elements sharing a common mounting, power supply, and computer/processor, the TFR (terrain-following radar) and the GMR (ground-mapping radar). The former is used for high-speed approach and escape, the latter for weapons control. TFR is limited to a terrain-following mode. GMR has mapping, air-to-surface ranging, air-to-air tracking, land/sea target lock-on, and beacon-homing modes. There is also a home-on-jam mode. The radar image is digitally scan converted for HUD display. ECCM features include PRF jitter and frequency agility. The main GMR display is the combined display (CRT) in front of the rear seat; radar data can also be displayed on the pilot's HUD. GMR employs a conventional, stabilized dish antenna and operates at moderate PRF. It has a fairly narrow beam in both azimuth and elevation since it can be maneuvered in azimuth and in elevation for the air-to-surface ranging mode, the outputs from which are slant range, range rate, and pointing angles to the target.

The TFR antenna is a 2-lobe, monopulse, phased array mounted below the GMR antenna; the central system computer integrates its output with other navigational sensor data. In straight flight it performs a 2-bar box scan (± 8 deg in azimuth, $+10$ to -20 deg in elevation); when the airplane turns, those parameters open up, the scan being steered into the turn. At a

high rate of turn, the scan becomes a figure-8 (total scan about 15 deg in azimuth; the antenna is steered as much as 7 deg into the turn). The antenna thus looks ahead into the direction the airplane is about to take. The associated computer lays down a "ski-toe" contour ahead of the airplane, the rise in the toe being set for a given level of pilot comfort (maximum push-over varied in minus 0.95-G increments for the hard ride, and minus 0.5-G in soft ride). The system climbs the airplane whenever a terrain feature is detected penetrating the set contour. TFR operates at high PRF.

TNR has a height-finding mode in which the angle to an identified surface target is measured as a datum.

The radar is built under license by Ferranti/GEC Avionics, AEG/Telefunken/Siemens, and FIAR. A Phase I improvement (1985) went into production in 1987; it provides the radar with a faster computer.

TNS was chosen about 1970, winning out over a proposal for a 3-part radar, using X-band for ground mapping, Ku-band for operation near the target, and a laser for final ranging. There was also an unsuccessful Autonetics proposal for a single phased array.

AIR-LAUNCHED MISSILES AND GUIDED BOMBS

ARGENTINA

◆ Martin Pescador

Dimensions: 21.85 m $\times$ 2.95 m (span 73 cm) [8.6 $\times$ 116.1 $\times$ 28.7 in]

Weight: 140 kg [309 lb] **Warhead:** 40 kg [88 lb]

Propulsion: rocket **Speed:** Mach 2.3 (impacts at Mach 1.1)

Range: 2.5–9 km [2700–9800 yd]



Martin Pescador, as displayed in Argentina, 1982. (Dr. R. S. Scheina)

This radio-command-guided antiship missile was developed by the *Instituto de Investigaciones Científicas y Técnicas de las Fuerzas Armadas* (CITEFA); the name means Kingfisher (which suggests its role). It is sometimes described as a Bullpup derivative. The guidance operator follows the missile, using the tail flare. Martin Pescador can be launched from an airplane at up to Mach 0.5, or from a low-speed helicopter (in which case its effective range is 4.3 km).

Development was completed in 1979, and the missile entered service in 1982. Two or three were used, unsuccessfully, during the Falklands War. A total of 68 were reportedly manufactured between 1981 and 1984, to replace AS 11 and AS 12 missiles in Argentine service.

CHINA (PRC)

◆ HY-4, C601

See Silkworm (ship-launched version).

FRANCE

◆ Exocet (AM 39)

See ship-launched versions.



Exocet AM 39. (Author)

◆ ANL

ANL is the projected Aerospatiale-MBB aircraft- and helicopter-launched antiship missile (*anti-navire légère*): 200 kg (50-kg warhead), with solid-fuel ramjet propulsion (for speed greater than Mach 2) and 30-km range. Guidance will be mid-course inertial and terminal active radar.

This weapon began with a German Navy requirement for a missile for helicopters, combat aircraft, maritime-patrol aircraft, and even ships operating in narrow waters. However, ANL would also fill a potential French requirement for an AS-15TT replacement. MBB will probably collaborate with Aerospatiale on this project.

◆ ANS

See ship- and ground-launched antiship missiles.

◆ ARMAT

Dimensions: 40 cm × 4.15 m (span 120 cm) [15.8 × 163.4 × 47.2 in]

Weight: 550 kg [1213 lb] **Warhead:** 160 kg [353 lb]

Propulsion: solid-fuel rocket

Speed: Mach 0.9 (supersonic in a dive)

Range: 40–120 km [43,700–131,200 yd]

This antiradar missile, carried by the Atlantique maritime-patrol aircraft, replaces AS 37 (and uses much the same airframe). ARMAT has much the same configuration as AS 37; but the motor has a much greater impulse, and ARMAT has a new seeker. This missile has been used by the Iraqi Air Force in the Gulf War (reportedly in 1984). ARMAT will be replaced by the lighter-weight STAR.

◆ AS 12

This wire-guided missile is carried by French Navy and Royal Navy WG-13 (Lynx) helicopters. See also the surface-to-surface version, SS 12M.

◆ AS 15TT

Dimensions: 18.4 cm × 2.16 m (53 cm wing span) [7.2 × 85.0 × 21 in]

Weight: 96 kg [211.6 lb] **Warhead:** 29.7 kg [65.5 lb]

Propulsion: rocket (boost-sustain; burn time 45.2 sec)

Speed: 280 m/sec [919 ft/sec] **Range:** 15+ km [8+ nm]

This helicopter-fired missile first appeared in the mid-1970s as a replacement for the existing AS 11/12. AS 15TT is a sea-skimmer (altitude about 15 m, radio altimeter equipped) and radar-beam command-guidance replaces the wire guidance of the earlier missiles. The manufacturer claims that AS 15TT is difficult to jam because it receives signals by means of a rear-facing antenna. The guidance radar, a Thomson-CSF AGRION 15 (X-band, pulse-compression), tracks both target and missile



AS 15 TT, as carried by a Dauphin 2 helicopter, with AGRION 15 radar. (Aerospatiale)

and computes the error in range and bearing between missile and target.

The impact-fuzed warhead is derived from that of the AS 12.

Current users: French navy, Bahreini navy (from a helicopter on board the Lurssen fast patrol boat), Saudi Arabia (helicopters flying from *Al Madinah*-class frigates). The development program was financed as part of the Saudi program; first deliveries were in March 1985.

In 1989 Iraq became the second customer for the Dauphin/AS 15TT antiship system, Saudi Arabia having been the first.

Reportedly, the system suffers from very short effective range (2–3 nm); the missile-guidance link cannot function at the design range of about 7 or 8 nm. Reportedly, the explosive launch technique thrusts many missiles out of the capture beam.

AS 15TT is the end result of a series of missiles beginning with the AS 12 developed in 1955–57 by Nord. AS 12/SS 12 (see SS 12M, below) was a version of the earlier SS-10/11 antitank missile with a warhead 4 times as heavy, for use against ships or fortifications. Like the earlier missiles, it is wire-guided, the operator tracking the tail flare and applying course corrections manually. Thus AS 12, whose trials began in 1960, is a daylight system. The next version, AM 10 Lasso (Léger Air/Surface Semi-Automatique Optique), used semiautomatic IR guidance similar in principle to that of the TOW missile, the operator tracking the target and the system tracking the flare in the tail of the missile. The warhead was the same as that of AS 12. The program was announced in 1977, but it was soon superseded by AS 15, which was originally to have had radio command guidance in place of the wire guidance of the earlier missiles. Compared to AM 10, AS 15 has a slimmer body with flip-out tail fins. The TT suffix in AS 15TT indicates *tous-temps* (all weather), the missile being tracked by radar rather than by a tail flare.

A surface version, MM 15, was proposed for coast defense in 1979 and was shown as a ship-launched weapon in September 1984. No sales had been announced as of late 1988.

◆ AS 30

Dimensions: 34.2 cm × 3.65 m; 1.0 m span [13.5 × 143.7 × 39.4 in]

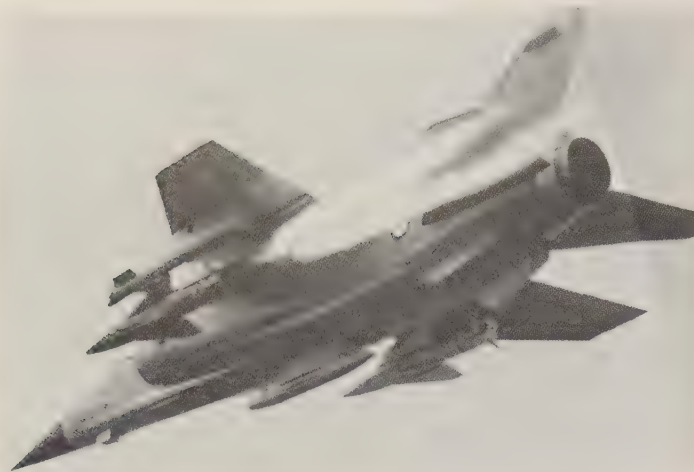
Weight: 520 kg [1146 lb] **Warhead:** 240 kg [529 lb]

Propulsion: solid-fuel rocket (boost-sustain)

Speed: 450 m/sec on sustainer, after 2-sec boost [1476 ft/sec]

Range: 10 km; flight time to impact approx. 21 sec; minimum range about 3 km [10,900/3,300 yd]

Data apply to the AS 30L laser-guided version of the basic weapon. The original AS 30 (semiautomatic-command line-of-sight guidance) was begun in 1958 and was delivered in 1964. Work on the laser-guided version began in 1974, the ATLIS designator running its trials in 1977. The laser-guided missile first



An AS 30L is fired; the laser illumination pod is outboard on the same wing. (Aerospatiale)

flew on 4 April 1980, production beginning in 1984 (first delivered June 1984). The target is designated on the basis of a television image, the laser and television being slaved together so that the pilot can drop the weapon and break away at 4 Gs. The television automatically tracks the target during and after the break.

This weapon is in service on board French Navy Super Étendards and on board French Air Force Jaguars equipped with a Thomson-CSF laser designator pod, for use against both ships and fixed land targets. AS 30 has also been exported to Egypt and to Iraq; Iraq reports having used it during the Gulf War.

Production: 538 were on order by early 1987, 223 having been delivered. Reportedly more AS 30Ls have been manufactured for export than for French service. Over 4000 of the earlier AS 30 were manufactured, for at least 7 countries. Estimated unit price in 1986 was \$275,000.

◆ AS 37 Martel

Dimensions: 40 cm × 4.122 m (span 1.192 m) [15.8 × 162.3 × 46.9 in]

Weight: 550 kg [1212 lb] **Warhead:** 150 kg [331 lb]

Propulsion: dual-thrust solid-fuel rocket

Speed: about Mach 1

Range: 30–60 km [32,800–65,600 yd]

This Missile Anti-Radar Television was an Anglo-French project, originally an antiradar weapon. Separate studies conducted by Hawker Siddely Dynamics and by Matra during 1960–63 were merged in 1964. Matra was responsible for the antiradar Martel (AS 37). Hawker Siddely developed a television-guided version to meet RAF Staff Requirement AJ.168. Only the antiradar version remains in service, with the French Navy (Atlantique Mk 1) and with RAF antishipping Buccaneers.



AS 37 Martel television-guided missiles carried by an RAF Buccaneer maritime-attack bomber. [U.S. Naval Institute]

The airframe is similar to that of AS 30. The antiradar seeker is steerable.

In 1982 Martel was considered for action against Argentine radar in the Falklands, but the U.S. Shrike was chosen instead, reportedly because of skepticism that the missile could survive the very long flight from Ascension to the target. The missile was used by the French Air Force in Chad in 1987.

◆ STAR

In 1986 Engins Matra announced that it was working on a new antiradar missile, STAR (*Supersonique Tactique Anti-Radiation*). STAR is described as a 250-kg [551-lb] ramjet with a range of 150 km [164,000 yd], designed to open penetration corridors for naval attack aircraft and also to attack heavily defended targets such as high-value warships. STAR will incorporate experience with Martel and also with the ARMAT missile, manufactured since 1984. The latter is too heavy to be carried by anything short of an Atlantique maritime-patrol bomber, whereas a Super Étendard would be able to carry 4 STARs.

At the Bourget Navale show in 1988 Matra described STAR as the first of a family of lightweight Mach 2.3 air-to-surface missiles, the second of which would be an antiship missile, a competitor to the Aerospatiale ANL.

Germany (West)

◆ Kormoran (AS 34)

Dimensions: 34.4 cm × 4.4 m; 100 cm span [13.6 × 173.2; 39.4 in]

Weight: 600 kg [1320 lb]

Warhead: 160 kg; 55-kg HE [353/121 lb]

Propulsion: boost-sustain rocket

Speed: M 0.9 **Range:** 30+ km [33,000+ yd]

Kormoran was conceived as an antiship missile that could be fired by a low-flying aircraft, popping up briefly to fire, against ships moving at up to 40 kt. Kormoran, therefore, uses inertial mid-course guidance and an active terminal seeker, approaching the target at a height of 2–5 m. Guidance modes are radar lock-on (RLO), radar acquisition (ACQ), and visual (VIS). In the RLO and ACQ modes, the missile is fired either without any use of the aircraft's radar or with a brief pop-up for acquisition. The visual mode allows firing even if the fighter's radar fails, but this mode entails considerably greater danger to the launching pilot.

The missile uses a delayed-action fuze to penetrate the target, the warhead consisting of 55 kg of high explosive surrounded by 16 projectile charges, each of which can penetrate 70–90 mm of steel. The explosive is formulated to provide an especially rapid explosion, so that the pressure wave is particularly destructive.

Kormoran firings began in 1967 with a series of booster tests from F-104G fighters. Test firings were completed in 1974 with approval for service use. At that time MBB was awarded a contract for 10 preseries and 350 production weapons. Of 7 test shots July–September 1977, all were hits. The first production missiles were delivered in December 1977.

Kormoran 2 has an improved (220-kg) warhead, increased range (55+ km), and improved ECM resistance and is designed for better target selection and for multiple launches. The missile weighs 630 kg and flies at Mach 0.95.

Kormoran began with an MBB study in 1962, a development contract following in October 1967. The design was reportedly influenced by experience in several abortive Franco-German missile projects of the 1960s; development was by Nord (now Aerospatiale) and Bolkow (now part of MBB). Drop tests were made in 1969, and a 50-round test program was completed in 1973. The production contract, for 356 missiles and 56 installations, was let in November 1976. The missile made 7 hits out of 7 shots during German naval tests in December 1977. Italy ordered Kormoran to arm its antiship Tornados in 1980, and about 450 have been delivered to date.

The Kormoran 2 program began with a 1983 development contract, and deliveries to the German Navy (*Marineflieger*)



Kormoran missiles carried by a German Navy Tornado. (Messerschmitt-Bölkow-Blohm GmbH)

were expected in 1988–89. Late in 1987 Kormoran 2 was successful in its second test flight (Sardinia range). Total production will probably be about 180, excluding export sales.

In 1987 estimated unit cost was \$450,000 for Kormoran 1 and \$575,000 for Kormoran 2.

INDIA

Hindustan Aeronautics Ltd. is reportedly developing a Mach 4 air-to-surface missile for air force and navy use, with a 100-km (109,000-yd) range and a 35-kg [77-lb] payload. The missile is to be launchable from 30,000-ft altitude.

INTERNATIONAL

◆ MSOW

The MSOW program collapsed in mid-September 1989 when the U.S. Air Force withdrew in favor of a hitherto-secret competing system, probably the Have Slick described below. Northrop was reportedly tasked to resurrect a standoff weapon proposal, originally formulated under the U.S. Air Force–Army JTACMS program, to compete with MSOW-B (the long-range version). The United States also withdrew from a program to develop ISAS (Intelligent Shelter Attack Submunition), a smart KE penetrator using IR, mm-wave, or dual-mode seeker, which was to have been carried by the MSOW bus.

The Rockwell team was selected shortly before the program collapsed.

MSOW details can be found in the previous edition of this book.

ISRAEL

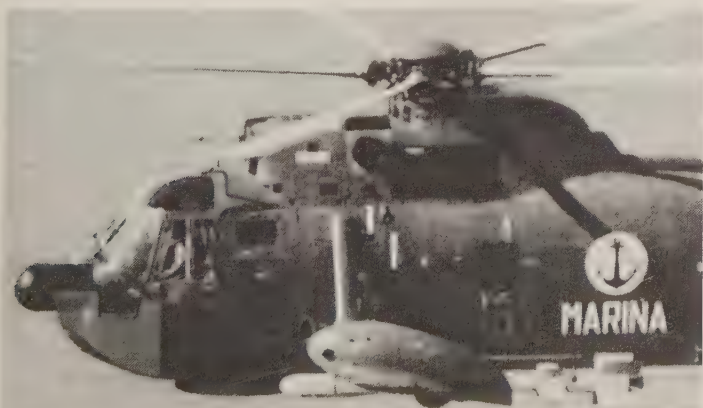
◆ Gabriel III A/S

See ship-launched version.

ITALY

◆ Marte

See Sea Killer (ship- and ground-launched antiship missiles).

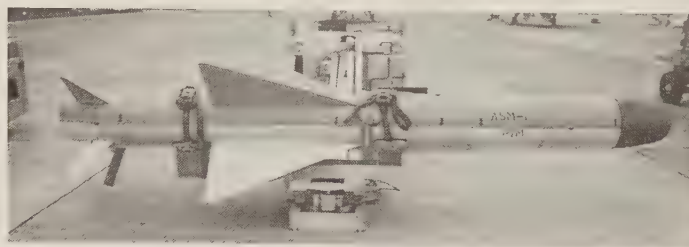


Marte Mk 2 carried by a Sea King helicopter. (OTO-Melara)

JAPAN

◆ ASM-1

Dimensions: 35 cm × 3.95 m; 120 cm span [13.8 × 156.8; 47 in]
Weight: 610 kg [1344 lb] **Warhead:** 250 kg [550 lb]
Propulsion: solid-fuel rocket **Speed:** Mach 0.9
Range: 50 km [54,680 yd]



ASM-1. (*Ships of the World*)

Mitsubishi is the prime contractor, selected in November 1973, for this Japanese Type 80 antiship missile. The missile was tested in 1977–79 (first unguided flights were December 1977), and production began in 1980. ASM-1 was announced for coastal defense in 1981 and entered service in 1982 (F-1 fighter). This missile employs inertial mid-course guidance and an active terminal seeker and approaches the target at low altitude.

Platforms: F-1, F-4EJ, F-15, F-16, and P-3; all but the F-16 (2 missiles) carry 4 each. In the case of the F-1, a J/ASQ-1 fire-control system is required. Estimated unit price (1987) is \$425,000. An ASM-1C version for P-3 Orions is being bought under the 1987–90 Four-Year Defense Plan.

The Japanese FY88 budget included funds for a successor ASM-2 using an imaging infrared seeker and powered by a turbojet. The ASM-2 will be the primary antiship weapon of the new FS-X (F-16 derivative). ASM-2, based on the Type 87 surface-to-surface missile, has a range of more than 150 km. The first prototype is scheduled for completion in the fall of 1990.

Reportedly, a new version of ASM-1 (perhaps ASM-2) incorporates ferrite-based, radar-absorbing-material (RAM) wing surfaces in place of the light alloy surfaces of ASM-1.

The SSM-1 surface-to-surface missile is a turbojet-powered version. In 1988 it was reported that Mitsubishi was beginning development of a new long-range antiradar missile specially intended to attack ships.

XGCS-1 is Mitsubishi's strap-on, passive-IR guidance system for 225-kg and 340-kg bombs. Flight tests (for initial use by F-1 fighters) began in mid-1988.

NORWAY

◆ Penguin

See ship-launched version.

SWEDEN

◆ Rb 04E

Dimensions: 50 cm × 4.45 m × 200 cm span [19.7 × 175.2 × 78.7 in]
Weight: 600 kg [1322 lb] **Warhead:** 300-kg HE [661 lb]
Propulsion: single-stage solid rocket
Speed: about Mach 0.9 **Range:** up to 32 km [35,000 yd]

Guidance for this missile is by active terminal radar following an autopilot-controlled flight. This weapon, the first Swedish air-launched antiship missile, is manufactured by Saab-Scania. Rb 04 was originally designed to meet a 1949 requirement for an antiship standoff missile, the prototype being launched on 11 February 1955; Rb 04 became operational in 1959. Rb 04D became operational in 1972 and was followed by the current Rb 04E, which has a reduced wingspan, modernized structure, better guidance, and a new rocket motor. The contract for its development was signed in 1969. Rb 04E can be launched at

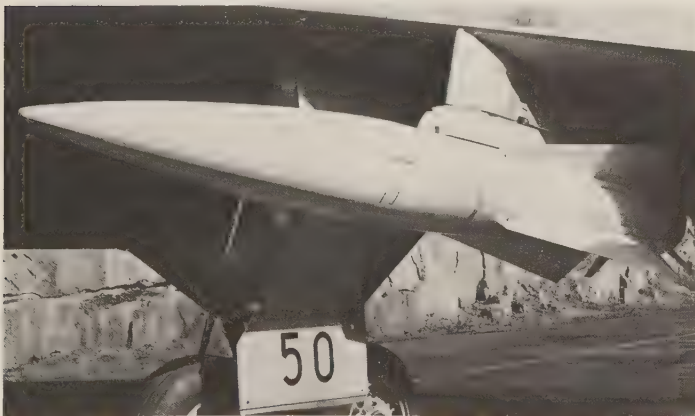


A Viggen attack fighter with 2 Rb 04E missiles underwing. (Swedish Navy)

near-sonic speed and is carried by the AJ 37 Viggen fighter. The missile attacks at low altitude, after a programmed descent. Production ended in 1977. Rb 04E experience was exploited in the RBS 15 program (see ship-launched missiles).

◆ Rb 05A

Dimensions: 30 cm × 3.6 m × 80 cm span [11.8 × 141.7 × 31.5 in]
Weight: 305 kg [672 lb] **Propulsion:** liquid-propellant rocket
Speed: supersonic **Range:** 9 km [9800 yd]



The Rb 05A antiship missile, as carried by a Viggen attack fighter. (Swedish Navy)

This missile is radio-command guided, the operator using a joystick to line up a tracking flare in the missile's tail with the target. The Rb 05A development contract was let in 1960, followed by a production contract in 1970; production ended in 1977.

◆ Rb 15

See ship- and ground-launched antiship missiles.

USSR

Details of guidance are given for many of the Soviet air- and surface-launched missiles. The reader is cautioned that these are old data (from about 1973). The Soviets may well have re-

placed some or all of their conical-scan radars with monopulse units much more resistant to countermeasures (as the PRC did with its Styx derivatives). The demise of the British masthead repeater conical-scan countermeasure suggests that this development occurred in the early 1980s.

◆ AS-1/SS-C-2 Kennel/Salish (Komet)

Dimensions: 115 cm × 7.9 m; span 4.9 m [45.3 in × 25.9 ft; span 16.1 ft]
Weight: 3100 kg [6800 lb] **Propulsion:** RD-500K turbojet
Speed: 510 kt **Range:** 55 nm [13.5 nm for coast defense]



AS-1 being moved to its Badger bomber. (U.S. Navy)

AS-1 was the earliest Soviet air-to-surface antiship missile; SS-C-2 is the coast-defense version. The Soviet name is Samlet. SS-C-2 has been widely exported. It was initially deployed only in concrete bunkers on the Black Sea coast; in the mid-1960s a mobile system was tested. In the early 1970s these weapons were replaced, in Soviet service, by SS-C-3 (the coast-defense version of the SS-N-2). Reportedly, SS-C-2 is still used by Bulgaria, Cuba, Egypt, Poland, Romania, and North Korea. The air-to-surface version is no longer in Soviet service, but a few may remain in Egypt and Indonesia, for launching from Tu-16 bombers.

The Soviet Navy initially experimented with ex-German V-1 cruise missiles, but in 1947 the MiG fighter design bureau was ordered to begin work on a new antiship missile, Komet, using a combination of beam-riding mid-course guidance and semiactive terminal guidance. The radar was a modified RPB-1 X-band bombing/navigation radar, Komet III (NATO code name Mushroom). This weapon became operational in 1958. It was limited in effective range because the bomber had to provide sufficient terminal illumination. Moreover, because the bomber had to remain near the target throughout the flight of the missile, the attack could be disrupted up to the time of impact by the destruction of the bomber. The combination of tail bulb (to receive the guidance beam) and nose radome (for semiactive terminal homing) provided evidence that the system had both beam-riding and semiactive guidance. AS-1 was typically dropped at 16,000 ft at 250 kt, to dive at about 3 deg.

The normal warhead weight was 600 kg, but reportedly it could be increased to as much as 1000 kg.

The missile generally resembles (and reportedly is based on) the MiG-15 jet fighter, and reportedly AS-1 used MiG-15 jet engines with more than 5 hr of running time remaining (so that the engine could be run up and tested annually without exhausting its lifetime before operational use). Running time was 6 min before flight, with a flying endurance of 15 min.

The beam-riding guidance technique limits surface-to-surface range to line of sight. This missile was installed on board the

cruiser *Admiral Nakhimov* in 1956–57, and several missiles were launched successfully. However, the system was abandoned because of the size and inefficiency of the weapon. Several Komets were reportedly test fired before Marshal Tito on the Soviet naval test range at Cape Feolent in 1958.

A coast-defense (land-based) version entered development in 1952, differing from the air-launched version by having a smaller rearward-pointing antenna. Presumably that decrease was acceptable because the range was quite limited, to about 25 km, so that the missile needed less gain to receive the guidance beam at extreme range. Tests began in 1956 at Cape Feolent, and the first missiles were deployed at Balaklava, and then at Kildin Island, in 1958 as a replacement for the existing 130-mm coast-defense gun. Missiles were fired from semifixed rails in reinforced underground bunkers, the missile rising to a preprogrammed cruise altitude of 400 m before coming under radar control. The bunkers were expensive, and they were soon replaced by a mobile launcher, a truck-borne rail. This device in turn was derived from a zero-length launcher that the MiG bureau had developed in 1956 for the SM-30 (MiG-19 derivative) interceptor. The Soviets deployed their first mobile launchers at Poti in the early 1960s. Ultimately, the Soviet Navy deployed about 19 missile battalions (3 Northern Fleet, 6 Pacific Fleet, 5 Black Sea Fleet, and 5 Pacific Fleet), but these figures probably include SS-C-1 (land-based SS-N-3) missiles. A typical mobile battalion consisted of 3 batteries, each with 6 launchers. The earlier fixed battalions had been only about half as large, with 2 or 3 launchers per battery.

Exports began in the early 1960s. The Polish Navy received 3 battalions, the East Germans 1, and the Rumanians and Bulgarians 1 or more batteries each; the missile is still in service in the latter 2 countries. This missile was also exported to Cuba, Egypt, and Syria, with Cuba receiving about 50 launchers.

There was also an army version.

In the late 1970s the Soviets began to replace SS-C-2 with a land-based version of SS-N-2 (Styx).

The Soviet designation of the air-launched version is KS-1 (industrial number 4K87, popular name Komet). The designation of the coast-defense version is S-2 (Sopka).

◆ AS-2 Kipper (K-10)

Dimensions: 35 in × 31 ft, span 16 ft **Weight:** 9250 lb
Warhead: 1000-kg [2200-lb] HE or nuclear
Propulsion: turbojet **Speed:** Mach 1.4–1.6
Range: 115 nm high trajectory; 54 nm low trajectory

Kipper is a turbojet antiship missile with active radar seeker or inertial guidance (nuclear version); one missile is carried by a Badger-C. Kipper entered service in 1961. Like the later AS-4 and AS-6, AS-2 locks its radar on before launch: hence the need to fly at relatively high altitude until fairly close to the target. This method of operation is ultimately limited by the launch platform's altitude; at 40,000 ft the radar horizon is about 300 nm. A missile that can lock on after launch can be fired to a greater distance. For example, if the missile climbs to 80,000 ft and then scans (and locks on by data link), the radar horizon is about 480 nm.

AS-2 is typically launched at about 36,000 ft at 400 kt, cruising level for the first 40 nm, then diving at 8–10 deg until it reaches a point about 75 nm from the expected target position. The missile then flies level or dives at an angle of less than 3 deg. Minimum range is about 30 nm. The seeker (I-band, conical scan on receive only at a scan rate of 60–80 Hz) is activated 60–40 nm from the expected target position. Total flight time from a range of 100 nm is 7.5 min. The missile carries a beacon, so the launching bomber can track it in flight, and its inertial mid-course guidance has provision for command override. These tactical data date from late 1973.

AS-3 (Soviet designation: K-20), a fighter-sized missile carrying a large thermonuclear bomb, is almost certainly limited to strategic attack and so is not described here. AS-3 is being replaced by the slower (but much longer-ranged) AS-15, an air-launched version of SS-N-21.

◆ AS-4

Dimensions: 35 in × 37 ft, span 11 ft **Weight:** 14,300 lb
Warhead: 2200-lb HE or nuclear
Propulsion: liquid-fuel rocket
Speed: Mach 2.5–3.5 [1850–2590 mph]
Range: 250 nm high flight profile; 150 nm low altitude

This weapon was apparently designed specifically for the Blinder bomber, itself intended as the successor to the Badger. Kitchen was first seen in 1961 under a Soviet Air Force Blinder-B, during the Tushino air display, and was later adapted for strategic bombers (Backfire-B and Bear-B and -C). AS-4 has not been seen under Soviet naval Blinders but is carried by Backfire-Bs, entering service in 1967.

AS-4 is launched at about 36,000 ft but climbs after launch to an operational altitude of about 80,000 ft. Its J-band terminal seeker is activated about 80 nm from the expected target position, and it begins its 3-deg dive shortly afterward. Terminal velocity is Mach 1.1 (cruise velocity is about Mach 3.5). Minimum range is 70 nm. Time of flight from a typical operational range of 150 nm is 9.4 min. Mid-course guidance is by a pre-programmed autopilot. These tactical data date from late 1973, when it was not known whether the missile had a mid-course command-override feature.

The associated radar is Down Beat.

AS-4 is a very difficult target to engage because, thanks to its rocket motor, it cruises at extreme altitude before diving steeply at its target. The antiship version uses active radar guidance, but nuclear-armed versions probably are inertially guided; in this latter form AS-4 may replace the huge AS-3 (which is essentially a jet fighter's body carrying a large thermonuclear bomb). In the nuclear antiship version, AS-4 presents a particularly difficult problem: because the missile may be intercepted only as it dives, a conventional missile kill may leave the tumbling bomb intact. This problem has made for considerable U.S. Navy interest in defensive nuclear SAMs in recent years.

There is also an antiradar version, reported in 1981.

The Soviet name is Burya.

◆ AS-5 Kelt

Dimensions: 35 in × 28 ft, span 15.7 ft **Weight:** 10,350 lb
Warhead: 2200-lb HE **Propulsion:** liquid-fuel rocket
Speed: Mach 0.9–1.2
Range: 175 nm high-altitude flight profile; 90 nm low-altitude flight profile

AS-5 is a faster, one-for-one replacement for AS-1 (the Soviet Komet) and was introduced in 1965. Two can be carried underwing by Badger-C and -G bombers. J-band terminal-phase active radar homing replaces the beam-riding guidance of the earlier missile, and AS-5 has about twice the range of the AS-1. The warhead is 1000 kg [2204 lb] of HE. Wings and tail surfaces resemble those of AS-1; the nose is similar to that of Styx (SS-N-2).

AS-5 probably has a minimum range of 60 nm and an operational range of 60–80 nm. Minimum range is the range at which the seeker must be turned on to control the missile effectively. Typically, then, the missile would be launched at about 70 nm at 36,000 ft, locked on immediately, and set into a 6-deg dive. At this range the radar horizon is at 10,000 ft, and a launch at this altitude would reduce the dive angle to less than 3 deg. Total flight time would be 6.7 min. Alternatively, the missile can be launched at extreme range and its terminal homer activated when its estimated range to the target is about 60 nm; at that point it begins to dive. The initial dive, to about 8000 ft at 40 nm from the target, is steep, followed by a shallower (less than 3 deg) dive into the target. Total flight time in this case is about 11 min. These tactical data date from late 1973.

The associated radars are Short Horn and Puff Ball.

Antiradar AS-5s were fired at Israeli targets during the 1973 October War. Of 25 missiles fired, 20 were shot down by fighters or by ground antiaircraft guns. The remaining 5 destroyed 2

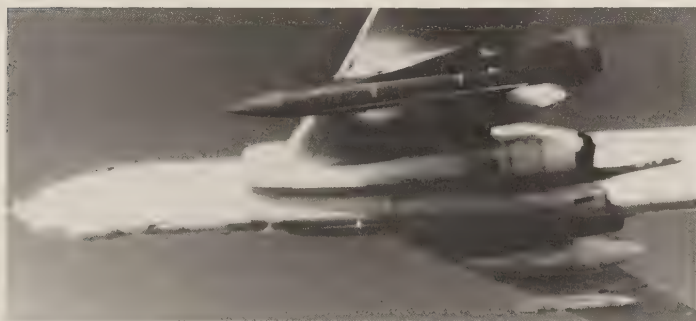
radars and a supply depot, demonstrating the antiradar capability of the seeker.

◆ AS-6 Kingfish

Dimensions: (approx) 35 in × 34.4 ft; span 8 ft
Weight: 10,800 lb
Warhead: 1000-kg [2200-lb] conventional or 350-kT nuclear
Propulsion: liquid-fuel rocket **Speed:** Mach 2.5–3.5 (at 60,000 ft)
Range: 350 nm high-altitude profile; 160 nm low-altitude

Carried by Badger and Backfire bombers, AS-6 probably embodies some AS-4 technology. Guidance is reportedly similar. AS-6 probably has a considerably higher speed but a similar flight profile (high-altitude cruise, reportedly at about 18,000 m [59,000 ft], and a steep terminal dive). First reported about 1972, Kingfish entered service about 1977.

The long range quoted recently and unofficially for the high-altitude profile would suggest that this missile can lock on after launch (LOAL). Whether Soviet air-launched weapons have this capability has long been the subject of debate, as LOAL would greatly change Soviet antiship tactics. For example, a bomber carrying a LOAL missile could approach at relatively low level before firing its weapon in a pop-up trajectory, basing the launch point on data supplied externally (e.g., by satellite). Maximum range may actually be closer to 250 nm if this weapon is not locked-on after launch.



AS-6 carried by a Badger bomber. Note the absence of a big targeting radome: this missile is probably an inertially guided land-attack version. (U.S. Navy)

◆ AS-7 Kerry

Dimensions: 275 × 3525 mm; span 785 mm [10.8 × 139; 30.9 in]
Weight: 287 kg at launch, 222 kg at burn-out [633/489 lb]
Warhead: 111 kg [245 lb] **Propulsion:** solid-fuel rocket
Speed: 600–750 m/sec [1165–1456 kt]
Range: 2–10 km [2200–10,900 yd]

AS-7 is a standard Soviet tactical missile, carried by Forger VTOL fighters and also presumably by other aircraft, including naval Fitters. Introduced in the late 1970s, it is roughly equivalent to the U.S. Bullpup. The missile is manufactured under license by Rumania, under the designation A921; the data above and the notes below apply to this version as displayed at Baghdad in 1989. Yugoslavia also manufactures a version of AS-7. The missile shown in 1989 is about twice as fast as originally described, somewhat slimmer (11 rather than 12 in in diameter), and with a shorter wingspan (30.9 rather than 37.4 in); the earlier data apparently referred to an earlier test version.

The missile is manually guided to line of sight (via a radio command link), 3 radio correction points being provided in its flight pattern. In the version shown at Baghdad, it had an HE antitank warhead with an impact fuze.

AS-7 can be launched at 80–5000 m [750–16,400 ft] altitude. Minimum launching altitude at a diving speed of 600–1000 km/hr [330–550 kt] is 3–5 km [10,000–16,400 ft]. Maximum G-load at launch is 4.6.

The Soviet name is Grom. Other users are Bulgaria, India, Iraq, and Poland.

AS-8 was the designation temporarily applied to the AT-6 helicopter-borne antitank missile.

◆ AS-9 Kyle

Dimensions: 50 cm × 6.0 m; span 2.0 m [19.7 × 236; 78.8 in]
Weight: 750 kg [1653 lb]
Warhead: 200 kg [440 lb]; also reported as 150 kg
Propulsion: liquid-fuel rocket **Speed:** Mach 3.0
Range: 90 km [49 nm; also given as 60 nm]

This defense suppression (antiradar) missile, carried by Badger, Backfire, Fencer, and Fitter-C and -D, was introduced in the mid 1970s. AS-9 may be the antiradar missile supplied by the Soviets to the Iraqis during the Gulf War under the designation X23. An Iraqi version displayed at Baghdad in 1989 was designated Nissan-28 and was reported to have 3 different seeker heads, for 3 different bands (for ground and naval radars).

Configuration is similar to that of the much larger AS-6.

◆ AS-10 Karen

Dimensions: 305 mm × 3.5 m [12 × 137.8 in]
Weight: about 400 kg [882 lb] **Warhead:** 100 kg [220 lb]
Propulsion: solid-fuel rocket
Speed: Mach 0.9 **Range:** 6 nm

The AS-10 is an electro-optically guided tactical missile, derived from AS-7. Karen is carried by land-based naval Fitter-D fighter bombers. It is broadly comparable to the U.S. Maverick.

◆ AS-11 Kilter

Dimensions: 42 cm × 4.9 m; span 1.45 m [16.5 × 193; 57 in]
Weight: 780 kg [1719 lb] **Warhead:** 170 kg [375 lb]
Propulsion: solid-fuel rocket **Range:** 55 km [30 nm]

AS-11 is an antiradar missile carried by defense-suppression aircraft such as the Su-24 Fencer and MiG-25 Foxbat F; presumably it could also be carried by the large carrier-based fighters.

◆ AS-12 Kegler

Dimensions: length 3.8 m; span 90 m [150; 35.4 in]
Weight: 350 kg [771 lb] **Range:** 34 km [37,000 yd]

Reportedly, this antiradiation missile is a lighter weight successor to AS-9, for the Su-24 Fencer, Su-25 Frogfoot, and Tu-22M Backfire.

During 1989 there was increased interest in the threat of Soviet antiradar missiles, some members of Congress asking whether the Aegis system could contend with the threat. This interest was apparently caused by a CIA study of Soviet ARM potential, perhaps involving one or more new air-to-surface missiles.

◆ AS-13 Kingbolt

This is an air-to-surface missile carried by the Su-24; no other information has been released.

◆ AS-14 Kedge

Dimensions: 40 cm × 3.9 m; span 1.0 m [15.9 × 154; 39.4 in]
Weight: 630 kg [1389 lb] **Warhead:** 250 kg [551 lb]
Propulsion: solid-fuel rocket **Range:** 6–8 km [6600–8700 yd]

AS-14 is a laser- or electro-optically guided missile, with 4 fixed rear fins and 4 canards. Kedge-A is the laser-guided version, to which the range above applies. Kedge-B is an electro-optically guided version equivalent to the U.S. Maverick. Aerodynamic range is variously reported as 30 or even 40 km [44,000 yd], and the disparity with effective range given here suggests that the missile can be used in an alternative ground-designated mode, the airplane dropping it beyond defensive range. AS-14 is similar to AS-10 and can be used against shipping.

AS-14 is carried by the Fencer-D (Su-24), Fitter (Su-20/22), Flogger (MiG-23/27), and Frogfoot (Su-25) in Soviet service. At least with the Flogger, AS-14 is controlled by a laser designation pod. The Soviet designation is X-29L. The industrial designation 9M721 has also been reported.

AS-14 has been exported to Iraq; a Mirage F1EQ-5 carries 2

underwing and uses a French Thomson-CSF ATLIS laser designator pod in place of the Soviet equipment. ATLIS was developed for the 10-km AS-30L and can guide AS-14 out to a range of 12–15 km, compared to the normal range of 6–8 km.

AS-15 is a strategic missile, the air-launched equivalent of SS-N-21 (RK-55); AS-16 is a short-range strategic ballistic missile equivalent to the U.S. SRAM. AS-19 is reportedly a long-range strategic cruise missile. Presumably, AS-17 and -18 are next-generation tactical weapons.

The Soviets have laser-guided versions of their standard 500-, 750-, and 1000-kg bombs; it is not certain whether these versions are in naval service.

UNITED KINGDOM

◆ ALARM

Dimensions: approx 23 cm × 4.24 m; span 73 cm [9 × 166.9 × 28.8 in]

Weight: about 200 kg [441 lb]



ALARM antiradar missiles carried by an RAF Tornado. (British Aerospace)

ALARM (Air-Launched Antiradar Missile) is currently being developed for the RAF; ALARM, should it enter service, will probably also be carried by Royal Navy Sea Harrier fighters. The manufacturer, British Aerospace, claims that maritime use on board RAF antiship Buccaneers is currently (1988) being studied.

ALARM differs from earlier antiradar missiles in that it can loiter above a radar, forcing its operator to shut down. The missile uses a boost-sustain motor, flying to a preset altitude and then diving or gliding. In theory, because the motor is shut down well away from the target, ALARM should not provide much of an infrared signature. The seeker is turned on soon after launch; the missile is guided toward an emitter if one is found. Published sketches of ALARM's trajectory suggest that it follows a ballistic (up and over) path rather than a direct homing path and, therefore, that the missile can function despite emitter shut-down (after launch). If the preselected target does not emit when the missile is fired, the missile hangs from a parachute over the target area, deterring an enemy operator from turning on his or her set.

Unfortunately, trials in the United States had to be canceled because of failures of the Nuthatch motor, and in November 1987 a new motor, developed by Bayern Chemie of West Germany, was selected. Early in 1988 there were reports that the British Ministry of Defence was considering buying U.S. HARM missiles and canceling ALARM. However, the missile flew successfully at China Lake in November 1988.

◆ Sea Eagle (P3T)

Dimensions: 40 cm × 4.14 m; span 1.2 m [15.8 × 163 × 47.3 in]

Weight: 600 kg [1325 lb]

Warhead: approx 230 kg, aluminized RDX-TNT [about 500 lb]

Propulsion: Microturbo/Toulouse TRI-60-1-607 turbojet engine

Speed: Mach 0.85 (cruise) **Range:** 110+ km [120,000 yd]

Sea Eagle was developed to meet British Air Staff Requirement 1226 for a replacement for both the television-guided AJ 168 and the antiradar AS 37 versions of Martel. Sea Eagle is essentially a Martel with a turbojet and a new seeker.

Sea Eagle uses inertial mid-course and active terminal-phase radar guidance and can distinguish a preferred target from



Sea Eagles on board an Advanced Sea King helicopter, 1985. (Westland)



A Sea Eagle missile, with a French cluster bomb (Belouga) in the foreground. (Author)

among a target array (e.g., a task force or convoy). Selected target-signature data are stored in the missile's computer before flight. Reportedly, the seeker head is capable of homing on jam or homing on a specific radar emitter. The manufacturer is British Aerospace Dynamics.

The missile is designed to hit a target at or just below the waterline. The front face of the warhead is specially dished to ensure penetration at shallow grazing angles, recalling dished faces fitted to World War II air-dropped depth charges so that they would not skid on hitting the water. This warhead was developed at RARDE (Royal Armaments Research and Development Establishment) for the abortive Under-Sea Guided Weapon development of Martel.

Sea Eagle is carried by British Sea Harrier, Tornado, and Buccaneer aircraft, and it is operational with both the Royal Navy and the Royal Air Force; the missile has also been sold to the Indian Navy (to be carried by Sea King helicopters). Reportedly, Sea Eagle will also be exported to Saudi Arabia, to be carried by Saudi Tornado strike aircraft. There are reports that India may buy Sea Eagle for Jaguar fighter-bombers. Sea Eagle has been tested on board the Chilean CASA/Embraer T-36 trainer (2 can be carried by the A-36 attack version) and on board the Tornado.

Sea Eagle was first fired in 1981. Development of a projected Mk 2 was abandoned.

A ship-launched version, P5T, was proposed in 1981. British Aerospace claimed that 3 could be carried for every 2 MM 40

Exocets. However, the Royal Navy chose the U.S. Harpoon in place of both for the Type 22 Batch 3 and the Type 23 frigates. At that time, the major development item was the strap-on booster. However, British Aerospace had to develop the booster anyway so that Sea Eagle could be fired by Indian Navy Sea King helicopters. Thus, British Aerospace was able to develop the surface-launched version of the missile with very little additional effort. P5T was first launched in March 1987. As of 1988 no sales had been reported.

◆ Sea Skua (CL 834)

Dimensions: 25 m × 2.5 m; 0.72 m span [9.8 × 98.5 × 28.5 in]

Weight: 145 kg [325 lb] **Warhead:** 30 kg (9 kg RDX) [66/19 lb]

Propulsion: boost-sustain solid-propellant rocket (boost burn-time 2 sec)

Speed: Mach 0.8 **Range:** 15 km [16,400 yd]



Sea Skuas carried by a Lynx helicopter, 1984. (Westland)

Sea Skua is a helicopter-launched antiship missile, conceived primarily as a counter to fast missile-armed patrol boats. The range was chosen so that Sea Skua could be fired from outside the lethal envelope of a Soviet SA-N-4 anti-aircraft missile (located, e.g., on board a *Nanuchka*).

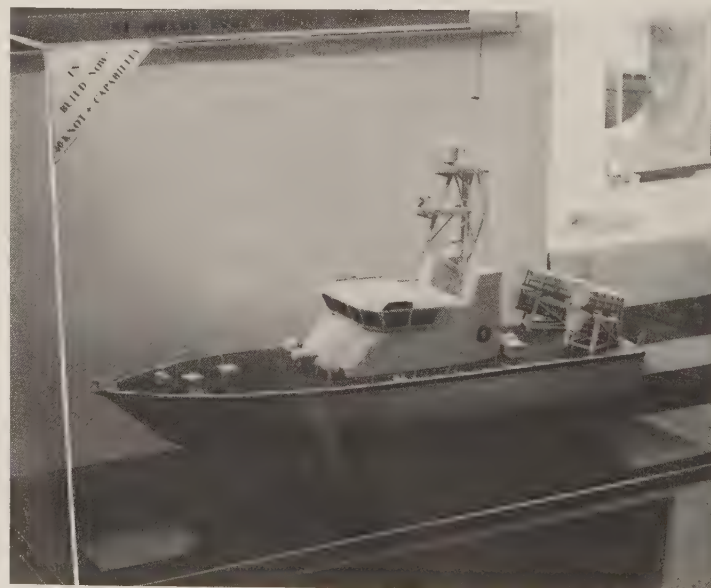
Guidance is by semiactive radar, typically using emissions by a surface-search set such as the Seaspray on board Lynx helicopters. The flight path is preprogrammed, with a choice of 4 approach altitudes (choice based on sea-state and type of target). Approach height is maintained by a radar altimeter. Typically, a Lynx shipboard helicopter carries 2 or 4 Sea Skuas.

Sea Skua replaces the French AS 12 in British service and is broadly equivalent to the French AS 15TT. AS 12 had been bought as an interim weapon that could be fired by a Wasp helicopter, and Sea Skua was inspired by evidence, e.g., in Exercise Northern Merger (1974), that such a helicopter could easily locate and attack surface ships. The Lynx, then in development, was expected to locate and identify hostile ships by both Seaspray radar and ESM. Missile weight was fixed by the requirement that 3 missiles and their associated equipment (but not the Seaspray radar) weigh no more than 580 kg. Frigates' space constraints limited the length of the stowage frame to 2.65 m, and wings and fins had to be detachable. The intended target set the type of warhead (30-kg SAP, for penetration).

Project definition for Sea Skua began in April 1972, and BAC formally proposed the missile in 1974. British government funds were provided in 1975 to complete the program and produce missiles. The first airborne firing of a fully guided round came in November 1979. This missile was ordered by the West German Navy in May 1984 for use on board Sea King helicopters, which are being equipped with Ferranti Seaspray 3 radars in dorsal radomes. This program is being completed in 1989. Turkey has adopted Sea Skua for use on board its projected fleet of



Sea Eagle compared to Sea Skua, at RNEE 1989. (Author)



The Sea Skua boat now under construction; this model was displayed at RNEE in 1989. (Author)

Agusta-Bell AB.212 helicopters, using a radar mounted above their cockpits; and Brazil plans to deploy the missile on board its Lynx helicopters.

Current work concentrates on the ship-launched (SL) version. Reportedly, several Southeast Asian and Latin American navies have shown interest, although no orders had been announced as of the fall of 1988. British Aerospace installed Sea Skua on board a Hymatic 21 fast patrol boat, for demonstration firings (the first was on 25 June 1990). It carries 8 missiles and a Seaspray Mk 3 radar. There is also a proposed coast-defense version, using a 4-missile box launcher. British Aerospace carried out the first successful firing of the SL version in December 1988.

The first Sea Skua fired from the boat (*Verifier*) off Aberporth at a range of 12 km [6 nm] missed a buoy target by 0.4 m. The guidance radar is a 360-deg scanning Seaspray Mk 3 radar, normally mounted on board a helicopter. The missile can engage targets 15–20 deg to each side of the axis of the launch canister and can be programmed to fly at any 1 of 4 heights. Missiles can be ripple-fired and can fly at preset vertical as well as lateral separations. The ship-launched version is nearly identical to the air-launched type, but the signal processor in the radar is more sophisticated.

UNITED STATES

◆ AIWS

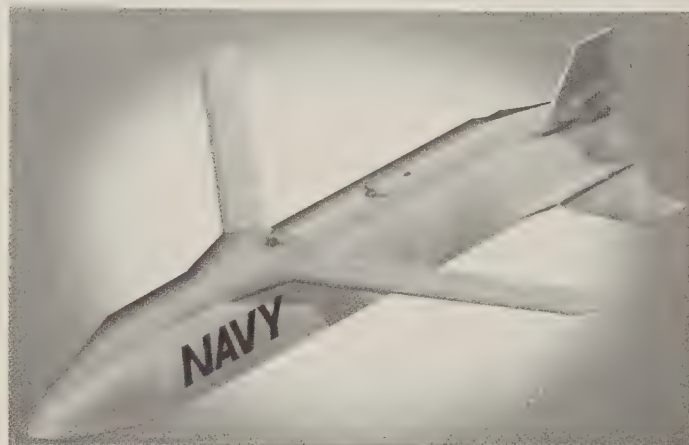
AIWS is a navy program for a short-range Advanced Interdiction Weapon System, to engage land targets and to replace laser-guided weapons such as Paveway, Skipper, and Maverick. These 3 subject the launching airplane to too great a threat; AIWS will be fire-and-forget. AIWS was 1 of 2 new air-weapon starts of the FY87 program; the other was SLAM. The program also envisaged an additional new weapon, ASWS, for use at greater ranges. ASWS and AIWS were formally proposed in February 1985 as future affordable ("bronze bullet") standoff weapons; the interim SLAM will be extremely expensive.

AIWS was conceived as a low-cost weapon with a range of somewhat over 5 nm and with a maximum weight of 2250 lb, to carry 3 alternative warheads: 1000- or 2000-lb unitary warheads or a cluster of bomblets. Guidance will initially be inertial (see IAM below), although satellite navigation (GPS) may later be incorporated. Reportedly, the required baseline navigational performance is a drift of no more than 10 deg/hr, but the new ring laser gyro technology may make 1 deg/hr practicable. Press releases suggest that the "bronze bullet" concept may later be relaxed to allow for such exotica as an Israeli-developed fire-and-forget IR-imaging (as in Popeye 2) or millimeter-wave guidance, and fiber-optic-wire guidance by the launching airplane. The baseline remains a fire-and-forget weapon.

AIWS resulted from the Naval Strike Warfare Master Plan of 1985, and the RFP, originally scheduled for December 1986, was



Boeing's version of AIWS. (Boeing)



McDonnell Douglas's version of AIWS. (McDonnell Douglas)

approved in March 1987 after a long study of performance vs. cost. Then Secretary of the Navy John Lehman ordered the cost limit of \$50,000 just before he left office; the original expected unit cost had been \$70,000 to \$120,000. The production decision will probably be made about 1992, AIWS entering service about 2000.

The AIWS program was approved by the Deputy Secretary of Defense in December 1985, to make up for the lack of any true standoff naval attack weapon other than the obsolescent Wall-eye. The only other general-purpose naval attack weapons are general-purpose bombs (including such laser-guided variants as Skipper) and cluster weapons (Rockeye and APAM). Even guided weapons such as Skipper must be launched by a pilot who has the target in view and who is, therefore, vulnerable to anti-aircraft fire.

AIWS's characteristics were developed at a May 1986 conference at NSWC. They were much affected by lessons learned both in Lebanon and in the Libyan raid. The conferees wanted a low-altitude standoff range greater than that possible with Walleye, Skipper, and LGBs; the launch itself should not reveal the aircraft's location; the weapon should be difficult to detect en route to its target; the weapon should make multiple kills per pass; and the aircrew should be provided with "last frame assurance" that the intended target had been neutralized or destroyed, so that subsequent attackers could be assured that the target was no longer a threat, and so could avoid wasting weapons on it.

The key requirement was the demand that the pilot not have to lock the missile onto the target before firing. Pilots cannot stand off at low (safe) altitude if they must have the target in sight at the moment of missile launch. The usual solution has been to provide the missile with a data link to the airplane, locking on only after the target has been detected, while the pilot looks on from a safe distance. However, long-range antijam data links are expensive, and a pilot loitering, even at a distance, to decide which of several targets in the seeker's field of view to attack may be in danger.



The Texas Instruments/LTV version of AIWS, which they call Shadow. (Texas Instruments)

The AIWS solution is to allow the pilot to specify the precise location of a target during a brief pop-up at a safe distance. Target location is fed into the memory of the missile, which can, in theory, navigate to the designated target after popping up at much shorter range. "Last frame assurance" required a combination of some kind of imaging sensor and a data link, but that link would be needed for only a short time, just before the missile hit. The link could, therefore, be simpler than that used in earlier missiles, for which pilots had to use their imaging sensors to find the targets in the first place.

Quiet launch required aerodynamic performance superior to that of existing weapons, so that even when launched at low altitude the missile could coast for a time before its motor ignited (if power was required at all). Multiple kills per pass required a cluster munition. The missile could provide CEPs, at 5-nm range, of 5–7 ft. Long range suggested GPS-aided inertial guidance. The system could be either completely prebriefed, the missile flying to a predetermined target position; or the missile could be flown to a target located by the airplane. In either case, accuracy would depend on the accuracy of the aircraft's navigation. In the second case, the aircraft's survivability would depend upon how quickly the target could be located once the airplane was nearby. It would have to pop up to sight the target, and pop-up altitude would depend on terrain features.

Unfortunately, studies soon showed that within the \$50,000 ceiling the weapon could not have a terminal seeker, data link, or propulsion. AIWS characteristics were, therefore, revised; the weapon would achieve a minimum operationally acceptable standoff range, a low-cost inertial guidance system (estimated guidance costs were \$14,000–\$21,000), a cluster payload, and capacity for future growth to meet the initial requirements.

There were still some design problems, particularly in providing an unusually high lift-to-drag ratio (as much as 13:1). In 1988 it was estimated that the airframe would probably cost \$12,000–\$20,000 (perhaps as little as \$10,000 in a future automated factory). AIWS is reportedly conceived as a stealthy weapon. That characteristic is probably important for 2 reasons. First, unless the missile is stealthy, its appearance near the target will give away the presence of the launching airplane. Second, AIWS will enter service at about the same time as the new stealthy naval attack aircraft, the A-12 (the Advanced Tactical Aircraft). In theory, a stealthy missile could be slung from a stealthy airplane without compromising the latter's low observability, whereas conventional munitions would add enormously to the overall radar cross section of such an airplane.

Development of AIWS began in mid-April 1987. The competitors are Boeing, Grumman, McDonnell Douglas/Hughes Aircraft, and Texas Instruments/LTV. Boeing is already under contract to build 10 Recoverable Test Vehicles (RTVs), which will be used to test elements that may be integrated into AIWS; the first RTV was delivered to the Naval Weapons Center in January 1988. Grumman was dropped from the program early in 1989.

Current plans (1990) are for 16,000 units ("bronze bullets") for delivery through 2002, to replace Walleye, Skipper, and Laser Maverick. They will initially be armed with a cluster warhead and later will have a unitary warhead from the advanced bomb series now under development for the navy, or with an air force earth penetrator.

◆ ASWS

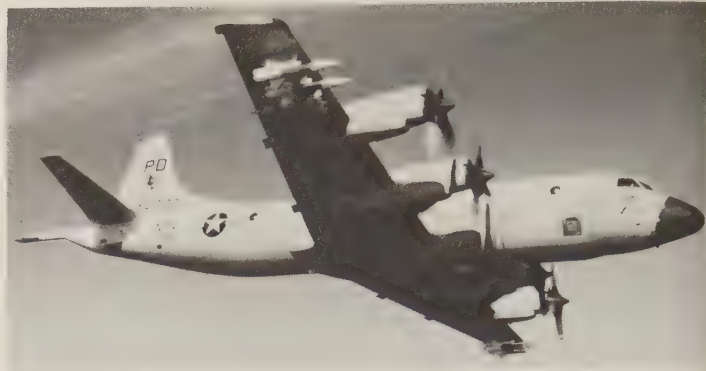
The navy's Advanced Stand-off Weapons System was conceived as the long-range complement to AIWS (SLAM successor). No details have been released.

◆ Bullpup (AGM-12)

Dimensions: 18 × 163 in; span 48 in **Weight:** 1785 lb
Warhead: 1000 lb **Propulsion:** storable liquid-fuel rocket
Speed: Mach 1.8 **Range:** 10 nm

Data are for Bullpup B (AGM-12C), typical of most versions.

Bullpup is radio-command guided into its target, the operator visually tracking a flare in the missile's tail. The original Bull-



Bullpups carried by a P-3B Orion, 1970. This missile was carried to attack surfaced submarines; it has now been superseded by Harpoon. (U.S. Navy)

pup A was designed in the early 1950s, entering fleet service in 1959. Bullpup B and later versions carried the heavier warhead listed above. Huge numbers of Bullpup were built, both in the United States and in Europe, and they were carried by ASW aircraft (such as the P-3) as a means of dealing with surfaced submarines (e.g., providing mid-course guidance to missiles) and with small warships. In French service Bullpup was replaced by AS-12.

Although this weapon has been superseded in U.S. service by "smart" (i.e., self-guided) standoff weapons, Bullpup is probably still in large-scale service elsewhere. The Bullpup warhead is incorporated in the Tomahawk missile and in the Norwegian Penguin and was also used in an abortive surface-to-surface derivative of Tartar developed for (but not used by) the West German Navy.

◆ Electro-Optic Bombs

The current standard U.S. Navy electro-optic weapon is Walleye. However, as stocks of Walleye are expended, the service can also use the standard series of electro-optically guided air force glide bombs described below. The original version was Pavé Strike (HOBOS, the homing bomb system), developed for the Vietnam War. The primary type, GBU-8/B, was a Mk 84 bomb fitted with a seeker, body strakes, and controllable fins. The data link connected it to the weapons-system operator (WSO) in the back seat of the attacking airplane. The successor weapon is the Rockwell GBU-15 cruciform wing weapon (CWW), for a Mk 84 or M118 (3000-lb) unitary bomb or an SUU-54 cluster weapon. The seeker can use television or an imaging IR camera. CWW can be steered toward a target area at low altitude, then made to climb and dive in. It can be steered all the way or else locked on. Development began in 1973 and tests in 1978, including over 60 launches. GBU-15 entered service in 1980. Unit cost at that time was \$127,000, including the data-link pod.

AGM-130 is a powered version, deleted from the FY88 and FY89 budgets in favor of the SLAM missile. However, the air force plans to start a production line under the FY90 budget and to begin procurement under the FY91 budget. AGM-130A is a modified Mk 84 bomb; AGM-130B is an SUU-54/B carrying BLU-106B runway-cratering munitions and HB876 area-denial munitions.

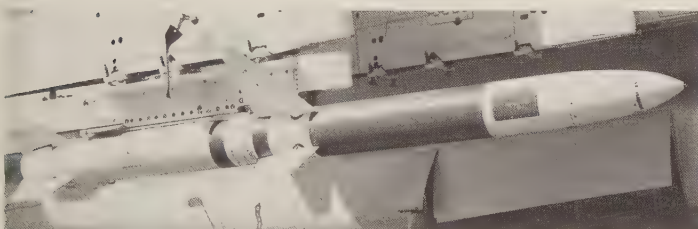
The guided bomb series (laser and electro-optic) consists of:

- | | |
|-------|---|
| GBU-1 | Rockeye II cluster bomb with KMU-420 guidance kit |
| GBU-2 | Pave Storm I, CBU-75 with KMU-351 guidance kit |
| GBU-3 | CBU-74 with KMU-422 guidance kit |
| GBU-4 | BLU-89 blast-fragmentation bomb with KMU-353 kit |
| GBU-5 | BLU-90 penetration bomb with KMU-353A kit |
| GBU-6 | Pave Storm I, CBU-79 with KMU-351 kit |

GBU-7	Pave Storm I, CBU-80 with KMU-351 kit
GBU-8	EOGB-1, Mk 84 bomb with KMU-353A kit (HOBOS). Also KMU-390 image-contrast, and KMU-359 IR. Both KMU-353 and -359 can be used with Mk 84; only KMU-390 can be used with the M118 3000-lb bomb. CEP is 20 ft.
GBU-9	M118E1 bomb with KMU-390C kit
GBU-10A	Paveway I, Mk 84 bomb with KMU-351B kit
GBU-10D	Paveway II, Mk 84 bomb with KMU-351E kit
GBU-10E	Paveway II, Mk 84 bomb
GBU-10F	Paveway II, Mk 84 bomb
GBU-11	M118 bomb
GBU-12	Paveway II, Mk 82 with KMU-388 kit
GBU-13	SUU-51 dispenser
GBU-15	Current guided bomb (modular guided weapon). Versions: GBU-15(V)1 day only, with AXQ-14 data link GBU-15(V)2 all weather, with IIR seeker
GBU-16	Paveway II (LGB-83), Mk 83 bomb with KMU-455 kit
GBU-17	hard-structure munition
GBU-20	Planar Wing Weapon, canceled 1980 in favor of GBU-15
GBU-22	Paveway III penetrator
GBU-24	Paveway III with Mk 84 bomb

♦ HARM (AGM-88)

Dimensions: 10 in × 13 ft 7 in × 44 in wingspan
Weight: 798 lb **Warhead:** 146 lb
Range: depends on launch speed/altitude
Propulsion: dual-thrust rocket motor (Mach 2+)



A HARM (AGM-88A) missile. (U.S. Navy)

HARM, the High-Speed Anti-Radar Missile, is the current standard U.S. antiradar missile. It is supersonic (as its name implies) and enjoys a very long range and, it is claimed, low detectability. Performance objectives were a broad frequency range, an increased sensitivity, a countermeasures resistance, and a smokeless motor (for low detectability). HARM is important both as a strike-protection weapon and as an antiship weapon; HARMs could be launched as precursors of an antiship-missile attack, forcing an enemy to turn off its defensive radars before the heavier (and slower) Harpoons or Tomahawks arrive.

The missile can be fired in any 1 of 3 modes: prebriefed, self-protection, or target-of-opportunity. In the prebriefed mode, the target can be acquired by the missile after it is launched (the missile seeks out an expected signature), and the attack can be conducted from very long range. Alternatively, an attacking aircraft can fire HARM automatically on the basis of information processed by an RWR. Finally, HARM can be fired at targets of opportunity, using the missile itself as the radar-search receiver, the weapon being fired manually.

The guidance system incorporates a strapdown inertial system; reportedly HARM can continue to fly toward a threat radar even after the radar has shut down. This capability predates the missile, having been introduced in Standard ARM during the Vietnam War.

Current tactics reportedly require that the missile be programmed with target range, bearing, and frequency before being fired. Given a preset range, the missile seeker can be set to activate 7–10 nm from the expected target position, to protect

the missile from distraction by other emitters resembling the target. Current HARMs must be pointed to within 15 deg of the direction of the target (i.e., the airplane must be pointed to within 7.5 deg of the target at the moment of firing).

Missile range is generally described as greater than 25 nm. In 1974, when HARM was first being developed, the desired maximum range was given as 100 nm. In 1988 it was reported that maximum range is 80 nm. Missiles are usually fired at 35–55 nm to ensure that their seekers acquire the targets.

HARM originated in the navy's Tactical Air Armament Study of 1969, which outlined the limitations of the existing Shrike and Standard ARM. Studies began in FY70, and a Proposed Technical Approach was published in FY71. After FY72 tests, Decision Coordinating Paper 92 of June 1972 approved development. Texas Instruments was selected on 24 May 1974. The air force joined the program in 1975. However, development proved difficult. Although 25 advanced-development missiles were tested, a DSARC II review in January 1977 ordered that the weapon stay in advanced development until demonstrating expanded frequency coverage and sufficient maneuverability. After that demonstration, full-scale engineering development was authorized in February 1978; and in November 1980 a navy SAR recommended low-rate production (80 weapons) for FY81. Operational evaluation, using 40 missiles, was begun in November 1981. It was successful, and full-scale production was approved on 20 April 1983. HARM was first deployed on board the carrier *Kitty Hawk* (carried by A-7s) on 13 January 1984 and first saw combat during the April 1986 Libyan raids, when 40 HARMs, some of which had been on hand for up to 3½ yr, very successfully destroyed Libyan radars.

HARM is manufactured by Texas Instruments and is employed on board U.S. naval aircraft: the A-7 Corsair II, the F/A-18 Hornet, the A-6 Intruder, and the EA-6B Prowler (first deployed August 1986). The missile would also be compatible with F-14 Tomcat fighters, although they do not currently carry it.

HARM platforms vary widely in capability. An A-7 or F/A-18 pilot will generally respond only to a preprogrammed threat. The pilot can manually reprogram the missile, but without a sophisticated threat receiver such as the ALQ-99 of the EA-6B, the pilot cannot expect to detect an unexpected threat. Until the mid-1980s, however, installation of HARM on board EA-6Bs was resisted, partly for fear that the missile might home on the airplane's active jammers. Installation became necessary when the navy experimented with all-Grumman (F-14, A-6, and EA-6B) air wings, since the new air wings did not include the usual HARM platforms, the A-7 and the F/A-18. It turned out that the missile could not home on the host airplane because the seeker was not turned on until well clear.

The great advantage of the EA-6B is that, using its ALQ-99, it can detect, locate, and verify a threat, reprogramming its missile to suit. A Block 86 upgrade to the EA-6B will remove the requirement that the aircraft point at the target and will also add a range-unknown firing mode. The first improvement is important for the EA-6B because otherwise it must interrupt jamming to fly toward the target before firing. Block 86 also allows the EA-6B to reprogram HARM in flight for threats not included in its preset threat library (prepared before flight by TEAMS, the Tactical EA-6B Mission Planning System). TEAMS prepares mission tapes for the ALQ-99, telling it which signals to seek. Using TEAMS, the airplane can be quickly reprogrammed on the ground to meet unexpected threats.

As of late 1988, only 5 EA-6B squadrons (in the all-Grumman air wings) have deployed with HARM. The navy expects to extend HARM capability to all other EA-6Bs. The bottleneck is missile-control panels, only 16 of which were available as of late 1988. Texas Instruments was to have begun delivery of 129 new panels (6 per month) beginning in November 1988.

Production of AGM-88A will continue through FY 89/90, to meet a requirement for about 15,500 missiles (7672 for the U.S. Navy and 7821 for the U.S. Air Force, down from 8054 and 9006 as stated in 1985). Procurement: FY83, 160; FY84, 381; FY85,

813; FY86, 904; FY87, 766 (total 1078 for both services, against a request for 1177); FY88, 766; FY89 (request), 1307; FY90 (plan) 200; FY91 (plan), 400. As of 1987, unit cost was about \$285,000. The thousandth missile was delivered on 26 August 1986, and the 5000th missile was delivered in September 1988.

A low-cost seeker (LCS) was developed by China Lake (1986). There are 2 alternatives. One is a seeker developed originally for the army's advanced radar projectile (ARP) (which would have to be modified to match the frequency coverage of the China Lake seeker). Because the seeker accounts for about half the overall cost of the missile, there is some hope that the new seeker will cut cost by about 20%. The LCS may also be installed in an alternative airframe, perhaps a Sparrow; the Senate Armed Services Committee has asked that the seeker be made generic rather than specialized for HARM. For a time, the navy was considering a low-cost ARM seeker for Skipper, the bombs to be used to saturate enemy radars. Congress has required that at least 800 of the FY89 HARMs, and at least 1200 of the FY90 missiles, incorporate low-cost seekers. HARMs with the low-cost seeker will be designated AGM-88B. Ford Instrument delivered the first 6 production low-cost seekers in 1987 for evaluation. The low-cost seeker was expected to be the basis of a projected joint-service advanced ARM. However, the program was terminated as part of the 1989 budget cuts.

A proposed dual-role ARM (DRARM) would have used LCS (ARP) technology and a gimbal seeker for both air-to-air and air-to-surface attack, using a Sparrow or AMRAAM airframe. DRARM was a new start scheduled for FY89, based on brass-board work under the earlier ERASE program (with initial planning in FY86).

AGM-88B shows several major improvements. It has a programmable memory (using EPROM, electrically programmable and erasable memory chips) so that the missile can easily be adapted to changing threats, even in the air. The new warhead contains thousands of 3/16-in tungsten-alloy cubes, 3 times the density of the replaced steel cubes. This warhead can now do substantial structural damage to a radar station, not merely to the radar antenna proper, cutting through half-inch mild steel or quarter-inch armor. The current flyaway cost, about \$200,000, is less than one-fifth the price of the original FY81 missiles, and MTBF greatly exceeds the original requirement of 200 hr. The next major hardware change, scheduled for FY89, is an engine that can better withstand flight-deck fires. It will be painted with a thermal insulation layer except for a narrow stripe. When the missile cooks off, only the stripe will ignite, and the motor will fall apart instead of exploding.

The next version, AGM-88C, will have a new seeker to deal with more sophisticated radars. Originally a new LCS was to have been developed as an alternative to the Texas Instruments seeker. Instead, both Texas Instruments and the alternate contractor, Ford Aerospace, are developing functionally equivalent high-end seekers for missiles designated AGM-88C-1 and -88C-2. Development of the Block IV (AGM-88C-1) missile was completed in 1989, and the missile entered service early in 1990.

The LCS was a response to congressional criticism made early in 1985; at that time early production missiles were failing (7 of 8 misses in 1984-85), and even so were expected to be quite expensive. Ford Aerospace and Raytheon were selected as LCS competitors. Texas Instruments responded by proposing partial redesign to cut cost and improve capability. DoD refused to pay \$30M for this Block-4 design, having committed \$350M for the LCS. Eventually the services agreed to pay \$17M for 13 new seekers; Texas Instruments invested \$38M. In the new C-1 design, a single antenna replaces the 2 previously used to cover the missile's wide spectrum (0.5-20 GHz), and the new signal processor is several times more powerful than its predecessor. Even so, more than half of the new missile's plug-in boards are identical to earlier ones.

In September 1989 Ford was expected to conduct pilot production under the FY90 program, with an option for limited production in FY91, and with the production contract evenly

divided with Texas Instruments in FY92. Missiles produced from FY90 on will have a more lethal warhead, to enable the missile to damage a ship's bridge as well as destroy its radar (the steel cubes now used will be replaced with high-density tungsten that can penetrate 0.5-in armor).

The current MTBF is 300 hr, compared to 125 specified. HARM is now so reliable that the airplane carrying it can use its seeker for electronic intelligence, its guidance system detecting emissions from shipboard radars and identifying the ships based on their signature. The 1989 unit price was slightly over \$200k, about 10% less than 1988.

As of 1989, the next-generation ARM was visualized as a dual mode weapon to frustrate countermeasures, e.g., passive radar plus IIR; radar emissions would be used to enable the IIR to locate its target in the background scene, and the IIR would provide guidance if the radar shuts down. Active mm-wave radar is an alternative to the IIR.

AGM-88B is being sold to Germany. The first letter of offer (5 April 1984) was for 866 missiles; the offer was revised in September 1985, for 944. Reportedly, West Germany wants to license-produce the weapon, requiring as many as 9000, to be carried by Tornados. A sale to Japan was announced in January 1987, and a sale to Spain is expected. Australia and Italy have also expressed interest, partly inspired by the missile's performance in the Libyan raids.

The U.S. budget request, as of January 1989, was for 1307 missiles in FY89, 1162 in FY90, and 1400 in FY91.

◆ Harpoon (AGM-84)

See ship-launched version.

◆ Have Slick

This is an air force program to develop a new generation of stealthy bomblet dispensers for the next generation of tactical aircraft. It will presumably be used by the navy's A-12, and it was probably the occasion for the U.S. withdrawal from the MSOW program. Flight tests are scheduled for 1990.

Have Slick is intended to blend into an airplane's shape during flight and, thus, is a direct descendant of work on conformal stores, such as fuel tanks, designed for aircraft such as the F-15. The current 2000-lb low-drag bomb contributes 25% to F-15 drag, but the goal of Have Slick is 2.5%, to be achieved by eliminating the blunt shape and the pylon. Two can be carried by an F-16, or 4 by an F-15. Individual weapons are to be launched by pistons. Because there are no pylons, the weapon has to be pushed clear of the air stream around the airplane; piston launch is preferable to explosive launch because it imposes a lesser load on the weapon and thus requires a less robust (lighter) structure, which can be made out of radar-absorbing or radar-transparent material.

Have Slick is a 2 × 14-ft "complex shape" with four 7-in fins. It has a composite (presumably radar-absorbing) skin and carries about 1200 lb of munitions (50% more than current cluster bombs and dispensers). This capacity is possible because the epoxy structure of the weapon is so light; only the spine (10% of the structure) is metal, to take the shock of piston launch. Examples of loads: 306 antipersonnel bomblets, 45 antitank weapons, or 24 antirunway devices. These munitions would be ejected from the weapon's tail. Have Slick would run in toward its target area at supersonic speed, over a distance of about 20 miles. It would then slow to plant munitions, making several high-speed passes around a battlefield. A mock-up has been installed on an F-111, and it is expected to fly at Mach 1.2, beginning in March 1990. Current estimated airframe cost is \$30,000, and the program goal is \$27,000 (which does not include payload or electronics, by far the major costs).

◆ IAM

Inertially Aided Munitions, a generic U.S. program for a new type of guided bomb, was revealed in 1988. IAM began about 1984-85. A low-cost inertial sensor (strapdown gyroscope and accelerometers) is used to provide the bomb with a precise

measurement of its path through space so that, even if lofted by an airplane below the radar horizon, the bomb can guide itself into a target designated by the attacking pilot. The inertial system cancels the usual delivery errors and is expected to improve CEP by at least an order of magnitude. The bomb trajectory can be tailored to conditions, such as terminal defenses, and the sensor should be immune to countermeasures. Moreover, each of several bombs dropped simultaneously by an airplane can be aimed at a different objective. Because IAM does not emit any signals, it would seem to be an ideal complement to future stealthy attack aircraft.

The IAM communicates with and receives alignment data from the aircraft inertial-navigation system through the standard bomb data bus (MIL-STD 1760 architecture). Predesigned target coordinates are stored in the bomb's inertial reference unit (IRU), the unit being updated via the data bus during flight. The IRU in turn controls the bomb's tail fins. In this form, bombs must be pretargeted before the airplane takes off. However, an airplane equipped with a mapping radar or a laser range-finder could presumably compute target coordinates just before the moment of release, and IAM could attack targets of opportunity, as long as they did not move very much during the bomb's flight. On the other hand, a bomb aimed at a set of coordinates cannot be jammed or fooled by camouflage, as long as the airplane can bring the target within the footprint of the bomb's fall. Similarly, an IAM weapon can attack targets that are virtually invisible, such as bridges or command posts, or very small targets such as aircraft in revetments.

Captive-carry tests have demonstrated a 12–14-ft CEP for 20-sec time of flight (low-altitude delivery) and 40-ft CEP for high-altitude delivery (50,000 ft, 60-sec flight). There is some expectation that these figures can be improved by adding satellite (GPS) navigation to the airplane and, perhaps, to the bomb. Analysis suggests that kill probability may be improved by a factor of 5 or 10 because of the much improved IAM CEP. Of course, a great deal depends on just how accurately target position has been determined before attack.

Northrop (Precision Products Division) and Boeing are the contractors. As of April 1988, Northrop had built 22 Mk 82 IAM bombs.

The technology-demonstration phase of the IAM program should have been completed by December 1988. The navy included an IAM full-scale engineering-development line in its FY89 program; the air force plans to begin such development in FY90.

◆ Maverick

Dimensions: 12 in × 98 in × 28.5 in (span)

Weight: 635 lb **Warhead:** 300 lb

Propulsion: Thiokol TX-481 dual-thrust solid-fuel rocket

Speed: supersonic **Range:** about 14 nm

Data are for the AGM-65F navy IIR version.

The Hughes Maverick is now the standard U.S. short-range tactical standoff missile; AIWS is the planned successor. Reported average CEP is less than 4 ft; and of 100 known combat launches to date (AGM-65D version), 87 hits have been achieved. This missile has been very widely exported, combat use including both South Vietnam and the Iran-Iraq War (by Iran). By the end of 1977 a total of 5666 had been exported to 7 countries: Iran (2500), Israel (600), Turkey (100), Sweden (500), Saudi Arabia (1666), South Korea (200), and Greece (100). Mav-

erick has since been exported to Egypt, Germany (West), Jordan, Morocco, Pakistan, Singapore, Taiwan (GRC), and Yugoslavia. A European consortium, led by Selenia, manufactures the missile for Belgium, Denmark, Italy, the Netherlands, and Turkey.

Development began in 1965, the prime contractor (Hughes) being selected in 1968. The missile first flew in 1969, and procurement began in 1971; Maverick entered service with the air force in January 1973. The IIR version was approved (DSARC II) in September 1976, the first successful firing being on 18 November 1975.

Versions are: AGM-65A, the original television-guided missile; -65B, the extended-range television version with scene magnification; -65C, a laser-guided version (-65E produced instead); -65D, the air force IIR version, with a 125-lb warhead; -65E, the Marine Corps laser-guided version with a 300-lb blast/penetrating warhead and a reduced-smoke motor; -65F, the navy IIR version with the -65E warhead and motor, for day/night attack against ship or shore targets; and -65G, the air force IIR version with the 300-lb warhead. AGM-65G has an improved seeker that the attacking pilot can use to aim the missile at a specific portion of a large target. The A- and B-versions weigh 462 lb; the D-version, 485 lb; and the E-version, 645 lb.

The navy's purchase of laser Maverick in FY88 will keep the production line open through 1990. The FY89 budget includes only IIR Maverick.

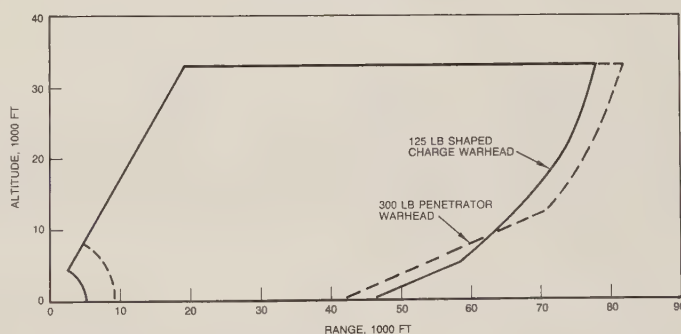
Procurement to date: over 30,000 AGM-65A/B; 60,697 AGM-65D; 5306 AGM-65E; 7000 AGM-65F; 1800 AGM-65G.

Unit cost: AGM-65A/B, \$50,000 in FY80 dollars (production ended May 1978); AGM-65D, \$124,000 in FY85, \$119,700 in FY86, \$88,343 with competition in FY88; AGM-65E, \$140,000 in FY84. Recent procurement:

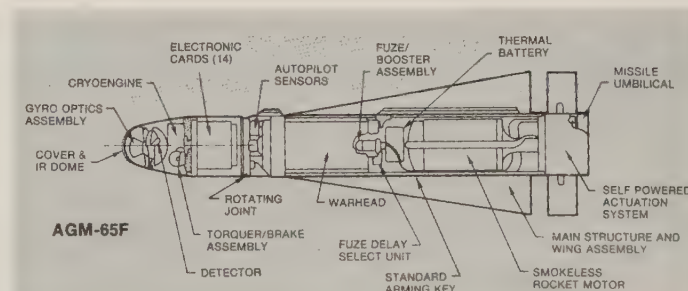
	FY84	FY85	FY86	FY87	FY88	FY89
Air Force IIR	1980	2600	2240	3224	2700	2931
Navy IIR	—	—	195	248	425	731
Navy Laser	185	600	1500	—	1300	(732 requested)

Rapid cost escalation explains the reduction in procurement, costs later falling because of dual-sourcing and also because of the implicit threat to cut Maverick further by substituting Skipper. Navy laser-Maverick production was suspended in FY87 so

MAVERICK LAUNCH ENVELOPE
(MACH = 0.9)



Maverick launch envelope. (Hughes)



Maverick (AGM-65F) internal profile. (Raytheon)



AGM-65F Mavericks under the wing of an A-6. (Grumman Aerospace)

that a new fuze could be incorporated. In September 1987 the total U.S. objective was stated as 60,697 missiles.

Other versions have been suggested. Hughes and the air force proposed Have Wedge, a dual-mode weapon (ARM in AGM-65A television missiles). The television would have allowed the weapon to remain on course to the target even if the radar transmitter shut down. An August 1984 test produced a direct hit, but the program was not carried through to production. This concept might be applicable to SLAM, which uses a Maverick IIR seeker.

In April 1988 Hughes announced a new IR Maverick fire-control system, Rapid Fire. It automatically scans a target area and chooses likely targets, displaying them in the cockpit (and aiming up to 6 missiles for engagements). The pilot can, therefore, engage several targets during a first pass, which is all that is likely before defensive guns are engaged. Rapid Fire uses 1 of the Maverick IR seekers as a sensor, so no additional aircraft sensor is needed; the system selects targets on the basis of their shape and size. The pilot can override the system's target selections. Hughes claims that Rapid Fire can fire 4 Mavericks in less time than 1 can be fired manually. Although the program is administered by the air force, Rapid Fire is applicable to navy and marine aircraft carrying this weapon. The target discriminating logic may also be applicable to other imaging IR weapons.

As of March 1989, Hughes and Raytheon, the 2 Maverick manufacturers, were competing for a contract to develop an Improved Maverick missile. An award was expected in the summer of 1989, leading to an 18-month demonstration-validation phase. The weapon, which is intended as a gap-filler pending the appearance of AIWS, would enter service in FY93 (the baseline AIWS, expected to enter service in FY95, will not match Improved Maverick capabilities). Improved Maverick is a short-range standoff weapon incorporating a data link (for lock-on after launch) and a new motor with more sustainer thrust (the current missile is boosted for the first half second, then the sustainer fires for 3½ sec, the missile reaching Mach 1.3 before coasting). The range is expected to double, perhaps even to triple.

This program was inspired by the demonstrated ability of the missile sensor to lock onto a target beyond the missile's flight range, e.g., an F/A-18 was able to lock onto a Septar target boat at a range of about 18 nm. Plans called for the sacrifice of 1400 of about 6600 newly built Mavericks in the FY91-92 program, the money going into a few extended-range prototypes for a demonstration/validation program. Existing missiles would later be retrofitted. The future of this program is now in question because Maverick production was eliminated from the FY91 defense program.

There is also an experimental mm-wave-seeker program, initially for the air force, paid for out of the balanced technology initiative (BTI). Four prototypes are to be built and test fired. The seeker is that originally built for the earlier Wasp missile, enlarged to 9-in diameter and otherwise improved, to find "special targets" (presumably command/control posts).

As of early 1990, Maverick has been test fired by a P-3, and a current operational evaluation is determining whether P-3 Maverick capability is worthwhile. Illustrations of the new P-7 maritime-patrol airplane sometimes show Mavericks at the wing tips.

As of March 1989, Hughes is proposing a helicopter-launched version for LAMPS helicopters, with a shaped-charge warhead, as a shorter-range alternative to Penguin at about a sixth the cost. With an IIR seeker and a shaped-charge (125-lb) warhead, Maverick could reach about 6 nm from a 100-kt helicopter, and 4.5-5 nm from a hover. Use of the heavy 300-lb warhead would roughly halve these figures. Hughes argues that the shaped charge will suffice against most ships; in static tests, it cut through 45 ft of hull when exploded at a 70-deg oblique angle, generating a 4-atmosphere overpressure (and temperatures of 700 deg C) in the area adjacent to the trajectory.

Hughes also expects to propose a Maverick using a fiber-optic

data link, similar to that in the army's FOG-M lightweight missile. As of early 1989, China Lake was testing a fiber-optic guided Walleye, and the second firing, conducted while the launch airplane maneuvered freely, had been successful. Hughes uses a dual payout system (1 reel in the missile, 1 in the airplane) analogous to that of a wire-guided torpedo. This method has been demonstrated at supersonic speed at ranges as great as 100 km and is complemented by a new proprietary method of high-speed fiber-optic inspection (by laser) for quick and inexpensive fiber winding.

The Israeli Popeye 2, which is to be carried by U.S. Air Force B-52 bombers, is reportedly derived from Maverick.

The U.S. budget request, as of January 1989, was for 731 missiles in FY89, 560 in FY90, and 2135 in FY91.

◆ Paveway

Paveway is the standard U.S. laser-guided bomb, manufactured by Texas Instruments. Paveway I was the original version. Paveway II is now in service. Paveway III is a new development, intended for low-level delivery, that will use a mid-course autopilot and a very sensitive seeker. Paveway is also designated LLLGB (low-level laser-guided bomb) and is a generic seeker/wing combination, applicable to all of the Mk 80 series bombs. All of the Paveway-series bombs use a NdYAG laser operating at 1.064 microns (as in the U.S. Pave Knife or Pave Tack). The standard NATO laser designator operates at this wavelength using a 10-20 pps code.

The original Paveway was selected for accelerated development in 1965 by the U.S. Air Force Armament Development and Test Center as the laser-guided system of choice. Feasibility demonstration, using an M117 bomb with a KMU-342 guidance kit, began in December 1965, and development began in July 1967. Paveway entered service in December 1968. Texas Instruments beat out North American Autonetics for the contract (1966).

Paveway I uses a 4-quadrant silicon detector array, which drives the 4 control fins to keep the bomb pointed at the target laser spot. The kits fitted to the U.S. Mk 82, 83, and 84 bombs are designated KMU-388, 421, and 351. Paveway I has been exported to 17 countries; the United Kingdom uses it with 1000-lb bombs (designated Mk 13 or Mk 17). Pave Storm was Paveway I applied to an SUU-54B cluster bomb. Paveway I lacked standoff range and had limited performance in mist and fog. Early bombs were controlled entirely by their forward fins.

Paveway I development began in May 1969, and the weapon entered service in December 1970.

The Paveway II engineering prototype was ordered in December 1974, and the weapon entered production in 1977 (FY76 program). It has upgraded electronics and more sensitive airfoils, and is less expensive (it uses some plastic parts). The Paveway II bombs are GBU-10E/B (Mk 84), GBU-12D/B (Mk 82), and GBU-16B/B (Mk 83); Skipper is a powered version of GBU-16B/B. Britain uses a version applied to its Mk 13/18 1000-lb bomb family, with KMU-351E guidance kits.

Unit prices: FY81, \$8372; FY83, \$17,643; FY85, \$30,139; FY86, (air force) \$40,262, (navy) \$33,972.

Naval procurement: FY84, 350; FY85, 2752; FY86, 2109; FY87, 243; FY88, 222; FY89, none.

Paveway III has a rocket booster. It incorporates microprocessor control, a digital autopilot, and flip-out wings; and it can be delivered in a dive, from level flight, or by toss-bombing. The seeker has an enlarged field of view and greater sensitivity for laser acquisition in poor (e.g., European) weather. Warheads were primarily Mk 82 and 84, although it could also accommodate Mk 83 and the Hard-Structure Munition warhead. The laser seeker could be replaced by an mm-wave or passive IR seeker. All of this turned out to be far too expensive. By about 1985, moreover, the air force, the program sponsor, was more interested in an autonomous weapon to attack high-value (and hotly defended) targets; the laser-designation mission was becoming far too dangerous. Hence the shift to projects like MSOW and Have Slick.

Paveway III began full-scale engineering development in 1980. By 1985 the air force planned to continue to buy Paveway II and III through FY92. It awarded Texas Instruments a contract for 2448 Paveway III bombs (with Mk 84 warheads) in December 1984, only to cancel the contract the following February because the unit price had escalated to \$34,900. Texas Instruments then offered a 5-year program at a unit price of \$25,100. In fact, the air force bought 1407 Paveway III in September 1985 but had to pay \$40,000 each. The service then withdrew its request for further production for FY86. However, testing and development continued. In September 1986 Texas Instruments announced new software to control the angle of attack and of bomb impact, which would be important for a hard target penetrator. Paveway III was tested through 1986.

Paveway III's standoff range is probably about 3–5 nm, compared to 1–3 nm for Paveway II.

In 1988 Texas Instruments claimed that 2 Paveway III bombs were equivalent to 7 Paveway II and to 1014 unguided bombs of the same type, so that destruction of a given target would cost \$470,000 using Paveway III, \$2.08 million using Paveway II, or \$171 million using conventional weapons. It is not clear to what extent these figures included estimated aircraft losses.

The advantage of Paveway III is that it can be delivered below the flight envelopes of most surface-to-air missiles and outside anti-aircraft-gun range. Texas Instruments claims that the bomb automatically compensates for varying release conditions, so that the pilot has merely to place the target in the middle of the HUD, minimizing exposure to enemy fire. The mid-course guidance allows for considerable offset from the airplane's flight path, and the bomb is designed for steep terminal trajectory. Inertial control is required for mid-course guidance, the bomb homing on a laser spot only at the end of the trajectory. Guidance is by 4 short wings attached to the seeker on the nose of the bomb; 4 big wings at the tail make for a 5:1 glide ratio to the target.

◆ Shrike (AGM-45)

Dimensions: 8 × 120 in; wingspan 36 in
Weight: 400 lb **Warhead:** 145-lb blast-fragmentation
Propulsion: solid-fuel rocket
Speed: Mach 2 **Range:** 25 nm

The first U.S. antiradar missile, Shrike is obsolescent but remains in service (1990). Based on the Sparrow air-to-air missile airframe, Shrike was developed by the Naval Weapons Station at China Lake. The main design limitations are that the seeker must be pretuned to a set frequency (a total of 13 different seekers have reportedly been produced) and that the seeker is rigidly mounted in the missile, so that the carrying aircraft must dive at the target, warning the radar operators to shut down. The missile then goes ballistic, as it has no memory circuits. Even so, Shrike has been widely used, in Vietnam, in the Middle East, in the Falklands, and probably in the Libyan raids of 1986, always as an interim weapon pending provision of sufficient HARMs.

A series of accidental Shrike attacks on ships in Vietnam in 1972 (most notably USS *Worden*) demonstrated that small weapons could destroy combat capability by wrecking topside antennas. Antiradar missiles were thereafter considered effective antiship weapons, with the potential for "cheap kills." Partial protection, in the form of Kevlar wrapped around some waveguides, was later provided, at least in the U.S. Navy.

Development of Shrike began in 1958, and production in 1963. About 18,500 were made. Variants included AGM-45A-1, A-1A, and A-2 (1963–66, G- to lower J-bands); A-3, A-3A, A-3B (1963–68, wider-band seekers); A-7 (lower frequencies; May 1967); A-9 and A-10 (USAF only); and AGM-45C (Shrike currently carried by air force F-4Gs, to suppress SA-6 guidance radars).

As of 1989, Shrike antiradar missiles are reportedly no longer carried aboard aircraft carriers. They presumably survive as war reserves.

◆ Sidearm (AGM-122A)

Dimensions: 5 × 113 in; span 24.8 in **Weight:** 195 lb
Warhead: 10-lb blast-fragmentation
Propulsion: single-stage rocket **Speed:** Mach 2.3
Range: about 18,000 yd (high-altitude delivery)



Sidearm carried by an attack helicopter. (U.S. Navy)

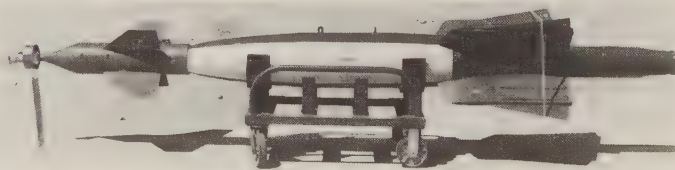
Sidearm is a low-cost self-protection antiradar missile, to be carried by Marine Corps helicopters and Harriers. A converted AIM-9C (semiautonomous radar-homing version of Sidewinder), Sidearm was developed by the Naval Weapons Center (China Lake), which modified the original narrow-band passive seeker to broader-band purely passive operation and also modified the original target detection device for air-to-ground operation. The original rocket motor and wings were retained, but the canard fins were modified. Sidearm executes a programmed pitch-up shortly after launch, so that the missile can be carried by a very low-flying airplane.

Procurement: FY86, 885; FY87, 256; FY88, 276; none in FY89 (although continued production had been requested). As of September 1988, Sidearm was being operationally evaluated, and a production decision was expected early in 1989. On 25 April 1988 a Sidearm successfully attacked an armored vehicle.

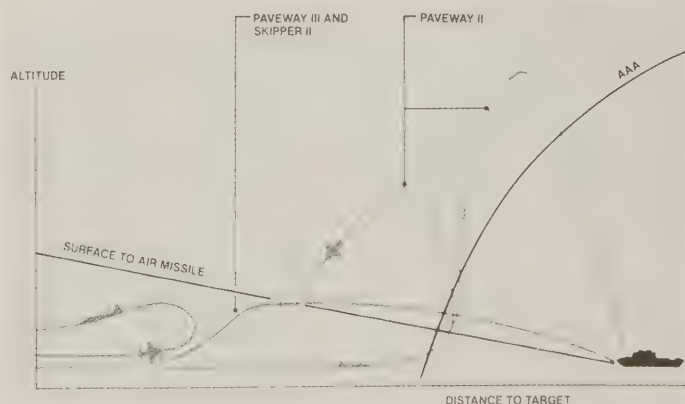
As of 1989, the navy was seeking funding to extend frequency coverage up from surface radars to those used by airborne types, and also to extend the seeker antenna's field of view. This projected AGM-122B version was canceled because of a lack of funds.

◆ Skipper II (AGM-123A)

Dimensions: 14 × 169 in; span 63 in
Weight: 1280 lb **Warhead:** Mk 83-5 1000-lb bomb
Propulsion: Shrike solid-fuel rocket (Mk 78-0; WPU-5/B)
Speed: transonic **Range:** 7–9 nm



Skipper II. (U.S. Navy)



Skipper and Paveway attack trajectories. (Emerson Electric)

Skipper II was conceived as an inexpensive air-to-surface standoff missile, consisting of a Paveway II (GBU-16) laser-guided bomb with a Shrike rocket motor. Skipper, although it could not match Maverick performance, cost only about a quarter or half as much. Therefore, Skipper could be deployed in large numbers very quickly; it was certainly superior to an unguided bomb or a laser glide bomb. Because Skipper was a viable alternative to Maverick, the navy could effectively pressure the Maverick manufacturer to reduce its costs. (Cost reduction was also the effect of opening a second-source Maverick production line [Raytheon].) Skipper is much slower, unable to duplicate Maverick's performance. Even so, Skipper can still follow a moving target.

Skipper was conceived in the late 1970s at the Naval Weapons Station, China Lake, but did not attract official attention until 1981. An airfoil-motor trade-off study was conducted in FY82. Prototypes were operationally evaluated in January 1983 (over 25 were launched), and FY84 funds were reprogrammed to support the weapon. The production RFP was issued on 7 December 1983. Aerojet was awarded the motor contract on 24 July 1984, and Emerson received the missile contract on 5 March 1985; first deliveries followed in July 1985. Unit cost was \$24,324 (FY88). Procurement: 500 in FY85, 995 in FY86, 1600 in FY87, and 1334 (2556 requested) in FY88. The FY89 POM included 1550, but the budget request deleted this weapon. The stated navy requirement had been 12,000 missiles and 15,000 bomb-modification kits (\$10,000 each, for Paveway II bombs; the motor costs \$5000).

There were reportedly some problems with the quality control of the Emerson guidance-and-control package, and the navy asked Texas Instruments to improve the Skipper seeker.

The navy proposed conversion of the entire air force Paveway III stock, to replace the projected Paveway III bomb (unit cost \$142,000 when canceled), but the air force did not consider any of its bombs surplus for conversion.

A Skipper with a low-cost antiradar seeker was suggested by the navy as an alternative to, or complement to, HARM. A cluster-bomb version has also been suggested.

In FY86 Congress directed development of 2 Skipper versions, a low-cost laser-guided training bomb and a fiber-optic technology demonstration (FOG-S; see the account of Fiber-Optic Weapons, below).

◆ SLAM

See Harpoon (ship-launched).

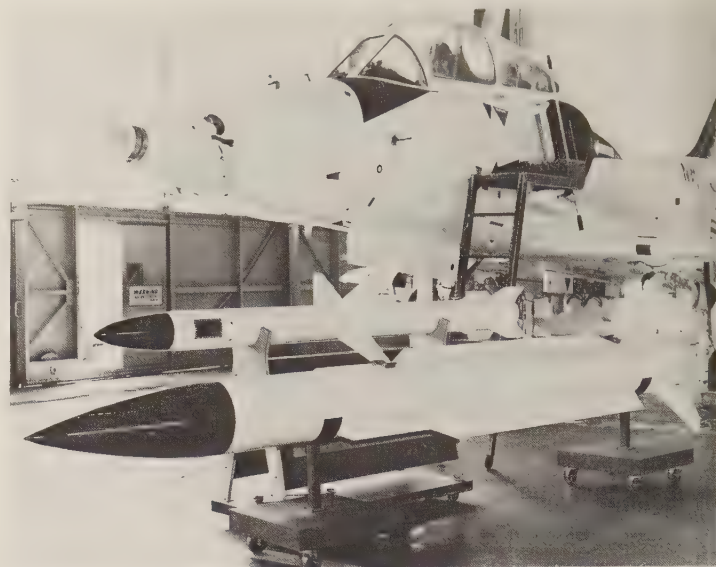
◆ Standard ARM (AGM-78)

Dimensions: 13.5 × 180 in; wingspan 42 in
Weight: 1356 lb **Warhead:** 219-lb blast-fragmentation
Propulsion: dual-thrust rocket
Speed: Mach 2.5 **Range:** 60+ nm

Standard ARM is an antiradar derivative of the Standard Missile surface-to-air weapon and is designed for greater versatility than Shrike. Standard ARM can continue to home on a radar that has shut down during the missile's approach. No longer in production, Standard ARM remains in service (1988).

Standard ARM was ordered in September 1966 as an emergency replacement for Shrike, initially using the Shrike AGM-45A-3A seeker (Mod 0) but then being fitted with a Maxson broad-band seeker (Mod 1: AGM-78B) that did not have to be retuned and that was gimballed to allow for a wider range of airplane maneuvers. There was also an impact marker, to permit follow-up attacks on a concealed target. Major variants: AGM-78A-2 (red phosphorous smoke marker), A-4 (improved seeker to counter specific early-warning and GCI radars), B (seekers for E-G- and I-bands), B-2 (unified seeker covering all bands), C-2 (more sensitive seeker, modified fuze, and rocket motor), D (General Dynamics seeker), and D-2 (final production).

Production of AGM-78A began in FY68, and the last AGM-78D-2s were delivered in August 1976, about 3000 missiles having been manufactured. General Dynamics proposed a further

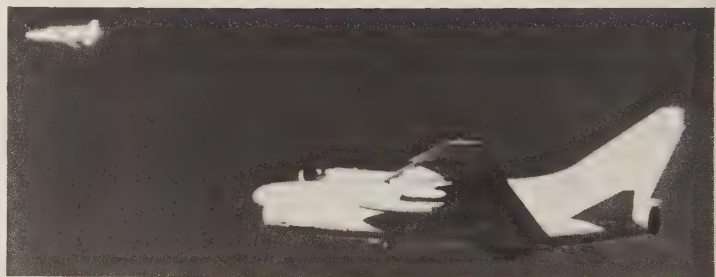


The 2 ARMs developed during the Vietnam War, and still in service: Standard ARM (foreground) and Shrike (background). (U.S. Navy)

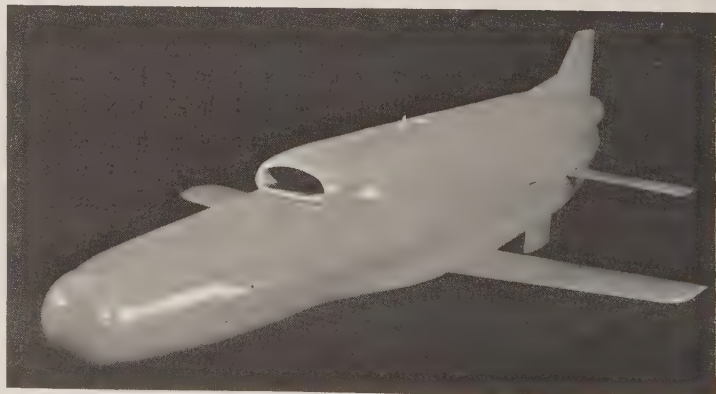
lightweight version, as an interim HARM, but it was rejected. In July 1986 the Israel Defence Forces released a photograph of a Purple Fist antiradar missile very similar in configuration to Standard ARM but with a reshaped nose.

◆ Tacit Rainbow (AGM-136A)

Dimensions: 27 × 100 in; span 61.4 in
Weight: about 1270 lb **Warhead:** 40 lb (WDU-30B)
Propulsion: Williams International WR36-1 turbofan
Range: reported about 100,000 yd (endurance at least 80 min)



Tacit Rainbow fired by an A-7. (Northrop)



Tacit Rainbow. (Northrop)

A new type of antiradar missile developed by the Northrop Ventura Division, Tacit Rainbow can loiter in the area of a suspected (but shut-down) radar, waiting for it to be turned on. Tacit Rainbow should, then, deter the operator and, thus, turn off enemy air defenses. Conventional antiradar missiles, such as HARM, cannot loiter, and thus a radar turned off to avoid them can come back up after they have passed. Some current

missiles, such as HARM, are credited with a capability to hit a threat radar even if it is turned off during their flight, but they are probably unable to deal with multiple threats. Because the operators of the several radars could not know which one(s) Tacit Rainbow had targeted, the operators would be less likely to turn their sets back on when the missile was in their area. Details have not been released, but presumably the missile can select any of a variety of threat radars for attack, automatically setting priorities, and it would appear that flight path and loiter time are preset. The missile was developed as a classified program, first revealed in 1987.

Full-scale development began in November 1981 with an Air Force contract to Northrop; Tacit Rainbow was selected by the DRB (Defense Resources Board) as a triservice program in November 1984.

The first successful flight against an emitter was made on 10 December 1984. The first successful launch from a navy A-7 (against an emitter) was on 27 November 1985. It appears that the first successful full-up flight, in which the missile loitered, then automatically sought out and identified an emitter (which had been shut down when the missile appeared), and then attacked and destroyed that emitter, was made on 12 April 1988. It is not clear whether some of the 1984-85 flights were made with preprototypes since recent press releases refer to flight tests beginning in 1987.

The missile is stowed with its surfaces folded, the 61.5-in wing swinging out shortly after launch.

Tacit Rainbow suffered from severe cost escalation. In 1986 a 300% cost overrun forced the air force to cap the development contract. Because of test problems, the House Armed Services Committee recommended a \$60M cut in FY89 funding, leaving \$55M (including \$11.9M to start second-source production).

In June 1989 a delay of at least a year (to June 1990) in completion of the 25 developmental/operational test flights was announced, the program already running 18 months late. In August 1989 the House Appropriations Committee tried to terminate the program, claiming a 253% overrun. The air force successfully protested that the cost data were misleading, comparing estimates for a large buy to a much smaller purchase planned for FY90. FY90 production was eliminated, but Tacit Rainbow remained in the FY91 budget. Thus the program survived, but at so high a unit cost that in December 1989 the navy

was forced to withdraw from production. The service did remain in the full-scale development program and thus can later deploy the missile on board A-6s. At present only air force B-52Gs are scheduled to carry it. Clearly the missile was still needed, but by that time the overall budget was too tight to accommodate it. The Senate was particularly anxious to keep the navy in, transferring funds from the SLBM Warning System to Tacit Rainbow.

It seems likely that navy withdrawal from Tacit Rainbow was justified in part on the theory that stealthy A-12 attack aircraft would need less in the way of penetration aids. Should budget cuts and high unit costs slow or kill the A-12 program, leaving the A-6E Intruder or some successor version as the only principal attack bomber for much longer, the Tacit Rainbow decision will probably be reversed.

At this writing, work is proceeding on a ground-launched version for the army.

◆ Tomahawk

See the Strategic Strike Systems section.

◆ Walleye I and II (AGM-62)

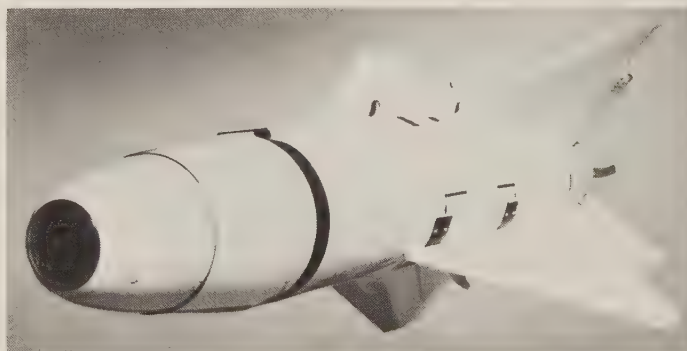
Dimensions: 18 × 159 in; span 51 in

Weight: 2340 lb **Warhead:** 2000 lb

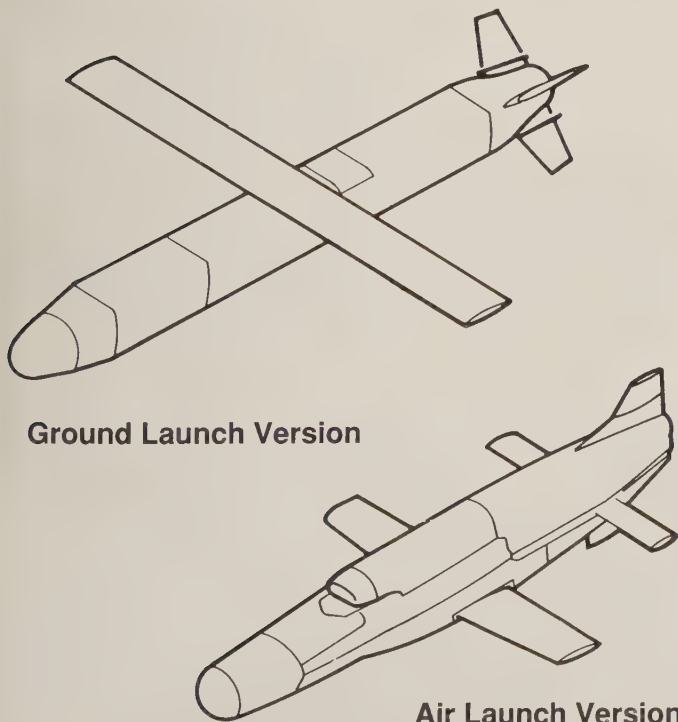
Speed: glide bomb **Range:** maximum 20 nm (minimum 1 nm)



Walleye. Note the television nose (covered until flight) and the wind-mill generator at the tail. (U.S. Navy)



Walleye. (U.S. Navy)



Ground Launch Version

Air Launch Version

Air- and ground-launched versions of Tacit Rainbow, the latter still under development. (McDonnell Douglas)

Data are for Walleye II. Walleye I, 1100 lb, is 12.5 × 136 in (span 45.5 in), with a maximum range of 16 nm.

This electro-optical (television) homing glide bomb by Martin Marietta was employed during the Vietnam War. No longer in production, Walleyes remain in storage.

The specific operational requirement for this homing glide bomb was issued in August 1962, and Walleye I entered production in 1966 and service in 1967 (production ended in 1970, 4531 having been built). Walleye I could be carried at up to Mach 1.9, and from 35,000 ft it could glide 10 nm. This version carried an 825-lb linear shaped-charge warhead. Hughes converted 1481 Walleye I to Walleye II, with a heavier warhead and a more accurate seeker, and reportedly built 529 new Walleye IIs. Walleye II enjoyed a much greater glide range. To exploit it, a better data link (extended-range data link, ERDL) was developed, so that the bomb could be locked on after launch. Most or all remaining Walleyes have been converted to Walleye II.

There was also a nuclear version, but it was acquired only by the air force.

Walleye versions were designated guided weapons of various Marks. Many were practice or exercise versions. Mk 5 was Walleye II, with the large warhead. EX-10 was the experimental data-link version. Mk 12 was Walleye II with a new 2-band link. Mk 13 was Walleye II with a 5-channel command data link (for retargeting after launch) and with larger wings for extended glide range. Mk 21 (1977) was Walleye I ERDL (extended-range data link) using Channel A; Mk 22 was similar (using Channel C in Mod 2, Channel E in Mod 4). Mk 23 was Walleye II ERDL (1975). Mk 24 (1974) was Walleye II, but its guidance lacked a ground bore-sight adjustment, cager retainer, or narrow field of view. Mk 25 was similar. EX-29 (1979) was an experimental Walleye I ERDL with a new differential-phase-shift-keyed (DPSK) data link, presumably jam resistant. These features were implemented in Mk 30 (1983). Mk 34 (1986) was Walleye I with a Phase II (antijam) data link (Mod 2 had an improved television camera tube). Mk 35 (1987) was a CRAB (caging, retaining, and bore sighting) version of Walleye I, without any data link. Mk 36 (1987) was an ERDL version of Walleye I. The last weapon version, Mk 37, was a 2080-lb ERDL missile with the Phase II antijam data link (Mk 38 was a captive practice round).

SHIP- AND GROUND-LAUNCHED ANTISHIP MISSILES

BRAZIL

◆ Barracuda

Dimensions: 32 cm × 5.2 m; 1.2 m span [12.6 × 205; 47.2 in]
Speed: Mach 0.9 **Propulsion:** rocket sustainer
Range: 70 km [77,000 yd]

This missile is under development by Avibras Industria Aeronautica in both ship-mounted (MM-70) and truck-mounted (SM-70) forms; MM means Mar-Mar, SM means Superficie-Mar, and the number is the range in km. An air-launched version is also projected. Barracuda was to have equipped the projected 7th–16th Brazilian ocean-patrol frigates to be built by Verolme do Brasil at Puerto Alegre, replacing Exocet MM 40. Work began in 1986, and the project was reported canceled in the 1987 Brazilian defense cuts. However, an artist's sketch was displayed at the 1989 Paris Air Show, and the missile was reported once more under development, with a first flight expected in mid-1991. At that time work effort was concentrated on the coastal-defense version. A battery would include 3 launcher vehicles, each with four 580-kg launch containers. The target-acquisition radar might be the Swedish Giraffe or the Italian Pluto. The shipboard version is now proposed to replace Exocets on board existing Brazilian frigates, using the same launch containers.

The missile itself has a cruciform tail and low-aspect wings. Development of the Avibras SIS strapdown inertial mid-course-guidance sensor is complete, but as of mid-1989 work was only beginning on the active-radar seeker, and the warhead was only 20% developed.

Barracuda is also known as Astros II/Ms. Astros II is an unguided bombardment rocket (Artillery Saturation Rocket System), using SS-30 (127 mm, 30 km), SS-40 (180 mm, 35 km), or SS-60 (300 mm, 60 km) rockets. Presumably, SS-70 denoted a guided weapon with a 70-km range, launchable from the standard Astros truck. The existing rockets are all derived from space sounding (research) vehicles, and the launcher is modular so that rockets can be interchanged very easily.

CHINA (PRC)

CATIC (FL and SY) and CPMIEC (HY) market similar missiles under different designations, presumably indicating different design bureaus; the manufacturer (the Nanchang Aircraft Factory) may be the same. However, FL-4 is described as a ship-launched version of HY-4.

◆ HY-1

A modified Styx, HY-1 was initially developed by the Nanchang Aircraft Factory as a coast-defense weapon. Work began about 1963, the factory submitting a development plan in December 1964; the preliminary design was reviewed in April 1965. Small-scale production began in 1966, but the shock of booster ignition apparently caused 3 failures, that year and the next. Acceptance tests finally succeeded in May 1972, and the missile was certified in 1974.

Work on a shipboard version began in 1967. Unlike Styx/SY-1, which is fired from a launcher fixed to the deck of a ship or attack boat, HY-1 was intended for a trainable launcher; it would be fired across the deck. Presumably, such firing makes very different demands on the guidance system's gyros. Two simulation launches late in 1968 showed that it could be launched transversely from a moving ship, and 2 dummy missiles were successfully fired from a Chinese missile destroyer in September 1971. The same ship made the first successful live firings in September 1973 (4 hits out of 4 shots). The missile was certified for production in January 1976. Batch production had already begun in 1975.

Initially the shipboard and coast-defense versions differed; they operated in different environments, and the shipboard version required some modifications to its radar and autopilot. However, a common version was developed, production beginning in 1978. HY-1 is carried on board Chinese Luda-class destroyers, and Jianghu- and Riga-class frigates. It may have replaced SY-1 on board fast missile attack boats.

Work on a modified HY-1A began in 1983; the main changes were better ECCM, lower flight altitude, and longer range. Flight tests were conducted July–September 1985 (4 hits out of 4 shots), and production began in October 1986 (deliveries began in 1987).

The HY designation stands for Hai Ying, meaning Sea Hawk.

Both this missile and HY-2 are described as Silkworm (CSS-N-2).

◆ Silkworm (HY-2, HY-4, C601, C201)

	HY-2	HY-4	C601
Diameter	—	0.76 m [29.9 in]	—
Length	7.36 m [290 in]	7.36 m [290 in]	7.38 m [291 in]
Span	2.75 m [108 in]	—	2.4 m [95 in]
Weight	2998 kg [6608 lb]	2000 kg ^a [4408/3834 lb]	2440 kg [5378 lb]
Warhead	513 kg [1131 lb]	500 kg [1102 lb]	513 kg [1131 lb]
Speed	M 0.9	M 0.8–0.85	—
Range ^b	95 km [104 kyd]	150 km [164 kyd]	95–100 km [104–109 kyd]

a. 1740 kg, air-to-surface.

b. Effective range 35–135 km [38–138 kyd].

Silkworm (CSS-N-2) is derived from the Soviet Styx, via SY-1 and, probably, HY-1. The official history of the Chinese aircraft industry, which describes SY-1 and HY-1 evolution in some detail, does not mention HY-2 at all, but the designation appears in numerous Chinese brochures.

HY-2 is produced by the China Precision Machinery Import and Export Co. (CPMIEC) and probably first appeared in the early 1980s. Egypt was the first recipient of FL-1 and HY-2 missiles (1984–85). These weapons may also have been exported to Bangladesh, North Korea, and Pakistan, although in each case it is not certain which missiles have been transferred (e.g., Pakistan has missile boats, but they may be armed with SY-1, HY-1, or FL-1, all of which use much the same airframe).

HY-2 is apparently exclusively a coast-defense missile. HY-4 exists in both surface- and air-launched versions, the latter being lighter (as shown above). C601 is an air-launched version carried by Chinese-built Badger bombers (1 or 2 per airplane).



Chinese missiles manufactured by CPMIEC on display at ASIINDEX 1988. From the top, they are M-1B, C301, C101, C802, C201, M-1, and HQ-61 (SAM). M-1 and M-1B are army artillery rockets fired from multiple launchers; -1B is heavier and achieves a greater range. (CPMIEC)

The HY-2 warhead is somewhat smaller than that of Styx, so Silkworm can carry more fuel for greater range. HY-2 and -4 use active-radar seekers; C601 has an active monopulse seeker. HY-2A uses an IR seeker. HY-2G has a more precise radar altimeter, so it can cruise at a lower altitude.

HY-4 flies at 200 m (330 ft) during cruise and at 70 m (230 ft) while homing; the missile dives steeply into its target. HY-2G flies at lower altitude, 30 or 50 m [98 or 164 ft], using a precision radar altimeter. The other weapons in this series cruise at 100 m [330 ft] height.



Chinese HY-2 (Silkworm) coast-defense missiles. (U.S. Naval Institute)



Silkworm being launched by a Chinese Osa-class attack boat. (Naval & Merchant Ships Publishing House)

HY-2 is powered by a liquid-fuel rocket, with a solid-fuel booster. A modified HY-2, HY-4 uses a turbojet power plant, with its intake under the fuselage (rather than a liquid-fuel rocket), with a solid booster for launch, C601, which is slightly more powerful than HY-2, uses a liquid-fuel rocket.

C201 is a revised HY-4 with better electronics. It was first displayed at ASIINDEX 1988 (November 1988).

Reportedly, this missile is manufactured under license in North Korea, using Chinese- rather than Soviet-supplied technology. Reported exports: Albania, Egypt, and Pakistan. Reportedly, the Silkworms fired by Iran in the Persian Gulf (from April 1987 on) had been manufactured in North Korea; the PRC denied having provided them and announced that sales would be stopped. Reportedly, Zaire may use HY-2 as a coast-defense missile.

◆ HY-3/C101/C301

Dimensions: 54 cm × 5.6 m [21.3 × 220 in]

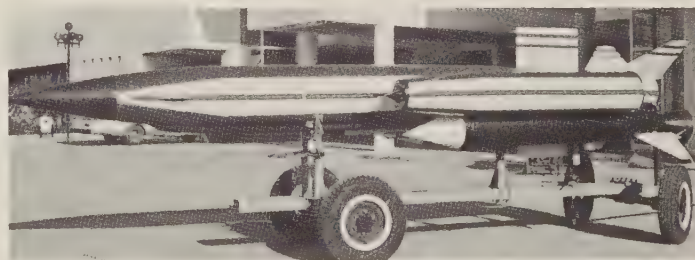
Propulsion: 2 ramjets (and 2 solid-fuel boosters)

Speed: supersonic **Range:** 50 km [27 nm]

C101, which resembles the British Bloodhound surface-to-air missile in configuration, was announced in 1985 and will probably enter service about 1990. C101A is a proposed air-launched version. The manufacturer is CPMIEC. Length is also sometimes listed as 7.2 m [283 in] and range as 70–80 km.

HY-3 (C301) is a heavier and longer-range version of C101, launched using 4 boosters. Approximate dimensions are 76-cm diameter and 9-m length [29.9 × 354 in], and range is 100 km [109,000 yd]. This missile was first displayed as C301 at ASIINDEX 1988 in Beijing (November 1988).

Both missiles attain a speed of about Mach 2, running in to the target at a preset altitude of 7–50 m. A photograph displayed at the Paris Air Show in 1989 shows a missile hitting at a height of about 3 m [10 ft]. Both use active radar guidance, and each can be preset to execute a single terminal maneuver to evade close-in defenses.



C101 antiship missile, showing ramjets and boosters. (CPMIEC)

◆ FL-1/SY-1

FL-1 is a winged missile similar in configuration to HY-2. After launch, FL-1 rises to 100–300 m [328–984 ft], but then it descends to 30 m [98 ft], maintaining altitude with a radar altimeter. The missile has a new monopulse radar seeker, apparently operating at a higher frequency than that of the HY-2 series, and carries a 513-kg warhead. The seeker was probably derived from that of the SY-2 (C801); it is considerably smaller than that of the HY-2.

The FL designation stands for Feilung, meaning Flying Dragon.

◆ FL-2

Dimensions: 54 cm × 6 m; span 1.705 m [21.3 × 236 × 67.1 in]

Weight: 1300 kg without booster [2865 lb]

Warhead: 365-kg shaped-charge [804 lb]

Propulsion: solid-fuel rocket

Speed: Mach 0.9 **Range:** 50 km [55,000 yd]

This ground-launched sea-skimming antiship missile was first shown at the 1987 Paris Air Show. Externally, FL-2 broadly resembles Silkworm, but FL-2 uses solid propergol fuel; there is also a jettisonable booster.

The manufacturer describes the seeker as an antijam type, and the radio altimeter is said to be accurate to within 0.6 m, for sea-skimming flight.

◆ FL-4

FL-4 is the ship-launched version of HY-4.

◆ FL-7

Dimensions: 54 cm × 6.6 m [21.3 × 259.8 in]

Weight: approx 1800 kg [3967 lb]

Warhead: shaped-charge

Propulsion: liquid-fuel sustainer; solid booster

Speed: Mach 1.4 **Range:** 32 km [35,000 yd]

The manufacturer is CATIC. Externally, FL-7 appears to be a stretched FL-1/HY-2. FL-7 is described as an alternative to C801. Cruise height is 50–100 m [164–328 ft]. CATIC claims a hit probability of 75% and states that the guidance system has ECCM features. Reportedly, this missile is intended to replace FL-1/HY-2 (Styx).

In 1988 it was reported that Iran had received about 100 FL-7s.

◆ SY-1

SY-1 was a direct copy of the Soviet SS-N-2A Styx (NATO designation CSS-N-1). SY means Strive Upstream, and the missile is used both on shipboard and for coast defense.

The Chinese acquired a manufacturing license in 1959. Preparation for production began in March 1960. The first 3 ground-launched missiles were tested in November–December 1964, with shipboard simulation missiles following August–November 1965. Presumably, these were all ballistic shots since a Chinese account states that telemetry tests occurred only April–July 1966. The certification test was completed in November 1966, with 8 missiles hitting out of 9 fired (the requirement was that 6 out of 9 hit). Refitted SY-1s, tested July–August 1982, achieved the same results. Missiles were manufactured by the Nanchang Aircraft Factory. Some minor improvements, such as a better radome, were introduced.

The Chinese considered the missile defective because it used an aneroid barometer (hence could not fly at low level, since response would be too coarse and too slow) and because it used a conical-scan (on receive only) seeker, which was relatively easy to counter. The missile was initially modified to fly at a preset altitude before diving into the target; 3 hits were achieved out of 3 shots (probably about 1970).

In 1974 the Defense Industry Office of the State Council formally ordered modifications: a solid-state microwave monopulse seeker and a vertical speed sensor with a radio altimeter; the new version was designated SY-1A. Low-altitude tests using the new height controller (3 hits out of 5 shots) were successful in 1975, but 3 design certification tests (1977–80) failed, and the new version was not certified until December 1983, after a successful test in the fourth quarter of 1982.

Meanwhile, the manufacturer developed an additional improvement, the "second lowering height"; in this version the missile descends from its normal relatively low altitude to sea-skimming height near the target. This modification was successfully tested in 1980.

In its coast-defense role, SY-1 has been seen on the chassis of a T-63 amphibious tank.

◆ C801/C802/SY-2

Dimensions: 0.36 × 5.814 m; span 1.18 m [14.2 × 228.9 × 46.5 in]

Weight: 815 kg [1794 lb]

Warhead: 165 kg, semi-armor piercing [364 lb]

Propulsion: boost-sustain rocket (2 motors) **Speed:** Mach 0.9

Range: 8–40 km ship to ship; 10–50 km air to ship [8700–44,000 yd/10,900–55,000 yd]

SY-2 is an indigenous Chinese development, as compared to the earlier Soviet-derived antiship missiles. The design requirements were light weight, supersonic speed, and countermeasures resistance. Work on a liquid-fueled version began in 1970;



C801 being launched by a submarine. (CPMIEC)



C801 antiship missile, with booster. (CPMIEC)

the Chinese have written that development was badly delayed by the Cultural Revolution. The first ground test was completed only in 1975, and the test of the ground telemetry missile in 1980. Meanwhile, the liquid-fuel project was canceled in 1976 in favor of a solid-fuel alternative, at the navy's request. The Chinese account states that "results were gained from scientific research in this respect" by 1986, which presumably means that the missile had been test flown by that time.

SY-2 is also designated C801.

This weapon is also called "Yinji" (Hawk Attack). It is similar in configuration to Exocet and uses a similar box launcher, but these missiles probably are not related. The missile climbs after launch then dives to cruise altitude (20 or 30 m). Diving again to 5 or 7 m, C801 turns on its active monopulse radar seeker and then dives into the target.

C801 is carried by at least one E5SG-class submarine (6 missiles in tubes, fired on the surface) and Jianghu-III-class frigates. C801 has been offered for export on board a modified Hoku class missile boat (4 C801 in place of 2 HY-2; the boat is a steel-hulled version of the Soviet Komar). At least 1 Luda-class destroyer is reportedly being refitted with C801 missiles (but reports may actually reflect a Chinese proposal to build ships so armed for export), and this weapon is also being placed on board existing Chinese fast attack boats. An A-5 attack aircraft can carry 2 underwing.

C802 is an upgraded C801, first displayed at the Asiadex exhibition in the fall of 1988. Propulsion is by turbojet (with a rocket booster), for a speed of Mach 0.8–0.9, a maximum range of 120 km [65.6 nm] and a minimum range of 15 km [8.2 nm]. Cruising altitude is 20–30 m, and the missile descends to 5–7 m for terminal homing. Dimensions: 360 mm × 6.392 m [14.2 × 252 in]; weight is 715 kg [1576 lb]. The missile is manufactured by CPMIEC.

C801 has reportedly been supplied to several Middle Eastern countries, including Iran. C801 was supplied to Thailand on board new Jianghu-V-class frigates. Reported unit price (1990) was \$780,000. It was reported in mid-1990 that some PRC Luda-class destroyers would be rearmed with quadruple C801 launchers in place of their current FL-2s.

FRANCE

◆ Exocet

	VERSIONS			
	MM 38	AM 39	SM 39	MM 40
Diameter	34.8 cm [13.7 in] all versions			
Length	520 cm [205 in]	469 cm [185 in]	580 cm [228 in]	580 cm [228 in]
Span	100 cm	110 cm	113.5 cm	113.5 cm
Weight ^a	[39.4 in] 750 kg [1653 lb]	[43.3 in] 655 kg [1444 lb]	[44.7 in] 666 kg [1468 lb]	[44.7 in] 855 kg [1884 lb]
Warhead ^b	165 kg [364 lb] all versions			
Speed	Mach 0.93 all versions			
Range	42 km [46 kyd] ^c	50–70 km [55–77 kyd]	50 km [55 kyd]	65 km [71 kyd]

^a1345 kg [2964 lb] with capsule.

^bHexolite blast-fragmentation with a delayed impact fuze for SAP action. Explosive weight 132 lb.

^cMinimum range 4440 yd.

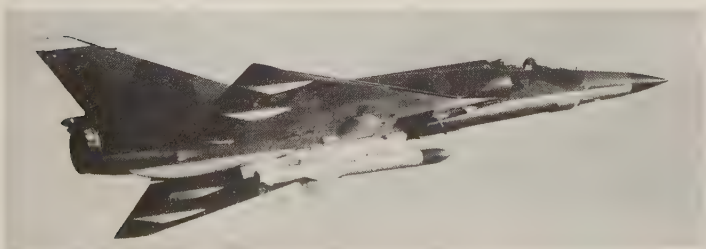
Perhaps the best-known Western ship-launched antiship missile, the Aerospatiale Exocet sank the British destroyer *Sheffield* and the container ship *Atlantic Conveyor* in the Falklands. Exocet has also been used by Iraq in the Gulf War, severely damaging the U.S. frigate *Stark* and hitting numerous tankers. Exocet exists in ship-launched (MM 38 and MM 40), air-launched (AM 39), and submarine-launched (SM 39) versions, all of them fueled by a solid rocket, and all sea-skimmers with active-radar homing. The ANS is the projected replacement.

The operational requirement was to disable the target, the designers arguing that to guarantee sinking they would have to provide so heavy a weapon as to preclude carrying it on board anything but a large ship. They also argued that even a relatively small (700–800-kg) missile penetrating a ship at Mach 0.9 or more while carrying a 160-kg warhead would have a devastating effect on a large ship. Some have compared this missile to a 13.5-in semi-armor-piercing (i.e., battleship) shell. In practice, when Exocets have failed to explode after impact, their unexpected solid fuel has started major fires. Because the fuel includes its own oxidizer, such fires can be impossible to smother, and the extreme temperatures generated can start fires in nearby compartments. This incendiary effect seems to have been entirely unexpected. A substantial number of duds was reported during both the Falklands War (for example, the *Sheffield* succumbed to the effects of the rocket-fuel fire, the warhead never exploding) and the Gulf War; but this problem has apparently been cured.

Range is relatively short, the designers arguing that a missile launched at very great range has to search a relatively large area of uncertainty around the target, and that the radiation of the seeker is likely to be the first warning of the missile's approach.



Exocet MM 38, the original version. (U.S. Naval Institute)



Exocet AM 39 carried by a Mirage 50 fighter. (Aerospatiale)

On this basis, the original MM 38 was designed for a range of only 40 km [44,000 yd], corresponding to the radar horizon of the medium-sized warship that would be firing the missile. At so short a range, flight time is very limited, and the target cannot move very far while the weapon is in flight, i.e., there is little uncertainty. However, a shipborne helicopter can do better, and the current MM 40 has a range of 70 km. The helicopter links its data to the launch ship; the missile still operates on a fire-and-forget basis. The air-launched AM 39 has a range of 50–70 km, depending on platform speed.

Rocket propulsion makes for shorter range than a turbojet, but the designers claim that it is unnecessary to boost an Exocet to anything like the initial altitude of a turbojet missile such as a Harpoon. The surface-launched version is fired from a fixed launcher (elevated to 12 deg), and the 2-sec boost brings the missile to a maximum altitude of 30–70 m [98–229 ft]. The missile then cruises at 9–15 m [30–49 ft] in altitude. At a distance of 12–15 km [13–16 kyd] from the predicted target position, the missile descends to attack altitude (normally 8 m [26 ft], but as low as 2.5 m [8.2 ft] in a calm sea). The seeker is turned on at this point, and altitude is maintained by radar altimeter.

System reaction time is about 60 sec (time required to warm up the seeker radar's magnetron). Prefiring information is target range and bearing, own-ship heading, own-ship speed, and vertical reference, plus manual inputs for seeker angle search, seeker turn-on range, terminal altitude, and proximity function selection (impact or pseudoproximity). There is no proximity fuze as such, but the radar altimeter can be set to burst the missile as it passes over a target. The pseudoproximity fuze works through the seeker, which calculates a "should-hit" time from the range, and detonates the weapon about 0.015 sec after it should have hit. The missile is, therefore, vulnerable to chaff: the pseudoproximity fuze can be activated by the chaff, causing the missile to explode after entering a chaff cloud, instead of seeking a real target after passing through the cloud. Missiles can also be set to begin a target-search routine after passing through a chaff cloud without detonating and without detecting an object above the sea's surface. Aerospatiale now offers a Super ADAC seeker (with better ECCM) for backfit.

AM 39 has modified control surfaces so that it can be carried at supersonic speeds, and it has a light-steel rather than an alloy motor casing. The motor provides more thrust for greater range. The SM 39 version, which is carried by French attack and strategic submarines, is launched via a buoyant capsule (fired from the tube by a gas generator and powered underwater by a solid-fuel motor, which boosts the missile clear of the water). This version uses a waterproofed MM 40 digital computerized seeker. The capsule is powered so that it can break the surface some distance from the launching submarine, reducing the risk of detection for the submarine. Boosting from underwater also reduces the maximum altitude the missile reaches and, thus, its detectability (50 m rather than the reported 600 m of Sub-Harpoon).

MM 40 is a longer-range version in a more compact canister (possible because the wings fold; total weight is 1150 rather than the 1750 kg of MM 38, and typically 2 MM40s can be carried for every MM 38). MM 40 is suitable for coast defense because this version can take a gyro angle as great as 90 deg (MM 38 can turn only 30 deg).

Exocet was first announced in October 1968, with an order from the French Navy. Greece followed in December (first firing July 1970), then Germany (West) in December 1970 (first firing June 1971), and the Royal Navy in June 1971 (trials, HMS *Norfolk*, April 1974). AM 39 was first tested in 1972. SM 39 was announced in 1979 and first fired by the submarine *Agosta* in mid-1981. Series production of MM 40 began in January 1981. The thousandth Exocet was delivered in October 1980. First reports of combat use in the Persian Gulf were in 1984.

Britain uses the MM 38 version of this missile, in a British system called Excalibur, to defend Gibraltar. The associated radar is Type 1006. The British naval designation for the Exocet

system is GWS.50. Qatar uses the MM 40 version for coast defense.

Estimated unit costs as of 1986 (export price in parentheses): MM 38, \$350,000 (\$450,000); AM 39, \$525,000 (\$650,000); SM 39, \$850,000 (this weapon is not available for export); MM 40, \$490,000 (\$600,000).

Production: total deliveries as of 1986 (total orders in parentheses): MM 38, 1262 (1575); AM 39, 714 (809); SM 39, 24 (62); MM 40, 399 (470). Orders in 1986 amounted to MM 38, 2; AM 39, 3; SM 39, 11; and MM 40, 31.

China (PRC) reportedly obtained some of these missiles in April 1985 via a third party, possibly using Exocet as a basis for its own C801 missile, and there have been reports of Brazilian production under license. A torpedo-carrying version (as a future French ASW standoff missile) was proposed, but the MILAS missile was adopted instead.

◆ ANS (Anti-Navire Supersonique)

Dimensions: 35 cm × 5.7 m [13.8 × 224 in]

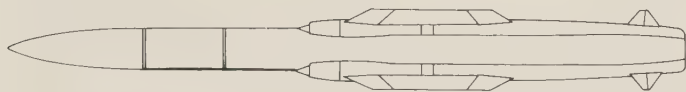
Weight: estimated 850 kg [1873 lb]

Warhead: about 180-kg SAP [397-lb] **Propulsion:** rocket-ramjet

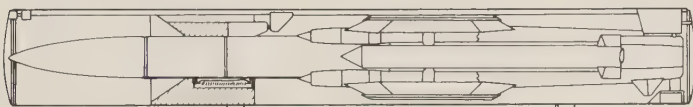
Speed: Mach 2 cruise, Mach 2.5 at high altitude

Range: 180 km [97 nm]

- AIR LAUNCH MISSILE



- SHIP LAUNCH AMMUNITION



ANS. (Aerospatiale)



An ANS prototype in flight. (Aerospatiale)

This projected replacement for the Exocet is currently under development by a consortium of Aerospatiale and MBB (Messerschmidt-Bolkow-Blohm). ANS is designed to make maximum use of existing Exocet fire-control (fire-and-forget) and

launch facilities and will be compatible with MM 40 launchers. However, ANS is intended to reach supersonic speed (Mach 2.0) and should be able to go as far as 180 nm by flying at high altitude. Normally, ANS will fly most of the way to the target at high altitude (hence at high speed, without excessive fuel consumption), descending to sea-skimming altitude about 30 km from the predicted target position and weaving at high speed (up to 10 Gs) to avoid defensive measures. The surface-launched version will have a rocket booster; the air-launched version will use no booster at all and thus may avoid detection (at the moment of launch) by passive IR scanners.

ANS was conceived about 1974 as an Exocet replacement, MM 100, which was intended to fly its entire flight path at sea-skimming altitude. The project then became the French/British/German ASSM/ASEM. That project collapsed in 1981, the British having withdrawn. ANS was announced in May 1981. ANS incorporates many projected ASSM features, including the ramjet with solid booster, the inertial navigation system, and the active-radar (Serge Dassault Super ADAC) seeker. There are 2 alternative power plants: a liquid-fuel ramjet with solid booster derived from that of the ASMP strategic missile (see the Strategic Warfare section), tested in 1985; or a boron solid-propellant rocket-ramjet proposed by MBB. In 1988 it was reported that the boron-hydride motor had been chosen.

The French-German MoU was signed in 1983, and development was completed in 1986, with the first ballistic test flight at the CEM test center in the Mediterranean on 21 May 1987. At that time the choice of propulsion had not yet been made. In 1988 it was expected that series production would begin in 1992-93 and that missiles would enter service in 1994 on board ships and from 1997 on board aircraft. However, funding cuts in 1989 stretched out this schedule, so that expected service introduction was delayed to 1998 in the French Navy and 1999 in the German. Unit price will probably be about \$1-\$1.5 million.

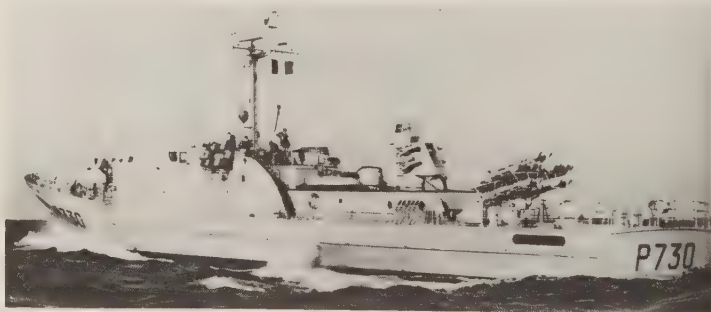
◆ SS 12M

Dimensions: 7.1 × 73.7 × 25.6 in **Weight:** 165 lb

Warhead: 62.5 lb. Several types, including OP3C, an SAP with a bulbous shape to aid fragmentation (actuates about 6 ft after penetration), containing about 13 lb of TNT/RDX mixture.

Range: 6580 yd (670 yd minimum)

Speed: 580 ft/sec (flight time 34 sec maximum)



SS 12M missiles on board the French patrol boat *La Combattante*, on the side of the turreted launcher amidships (the much larger launcher aft carries flares). These missiles are no longer carried by French patrol craft but survive in small numbers in some other navies. (U.S. Naval Institute)

SS 12M is a naval version of a widely used army missile; the naval users are Greece (*Kelefstis Stamou* class), Libya (*Susa*-class fast attack boats), and Tunisia (P 48-class patrol boats). The launching system was developed by Vosper (the Libyan boats' builder) and Nord Aviation. The launcher fires up to 8 prepackaged missiles in succession, all the missiles occupying forward-facing fixed racks. The attack boat, therefore, has to turn toward the target at the moment of firing. The missile aimer occupies a turret with a gyro-stabilized APX.260 sight.

The operator uses a joy-stick to guide the missiles in flight, this optical control limiting their use to visible targets. This system is extremely difficult to use from a moving ship or boat.

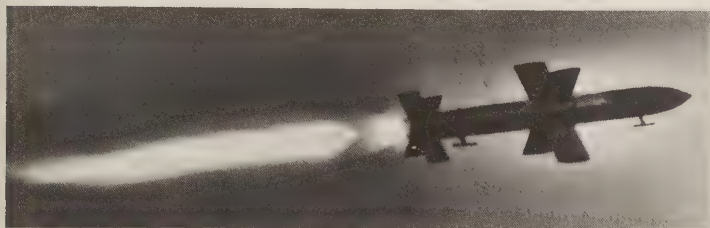
Trials began in 1958, and SS 12 production began in 1959, AS 12 following in 1960. SS 12M was first demonstrated in 1966.

Sweden used the earlier SS 11 (as RB 52) in coast defense; it is now being replaced by the U.S.-supplied Rockwell Hellfire (see RBS 17, below). See the last edition for details.

ISRAEL

◆ Gabriel

Gabriel was developed by IAI in 1966–68 as a direct counter to the Styx missiles supplied to the Arab states; and Gabriel entered service in 1972, proving successful during the October 1973 Mid-East war. Although having a much shorter range than Styx, Gabriel could lock onto a smaller target (i.e., a missile boat) and apparently could be fired much more easily.



Gabriel in flight. The 2 dipoles visible below the missile are presumably part of its radar altimeter. (U.S. Navy)

The original concept was to use semiactive guidance, the firing boat providing illumination. In theory, such guidance uses the intelligence of the shipboard operator to overcome jamming and sea clutter. Gabriel I also has a backup pure radio-command mode, in which the missile is steered with the aid of an optical sight, the operator tracking 4 tail flares. Gabriel II uses semiactive guidance, though in a more sophisticated form, and has an upgraded sustainer motor. During the 1973 war several missiles broke lock on their relatively small targets after picking up

larger commercial ships. In 1980, therefore, work began on an active seeker (incorporated in Gabriel III) for better discrimination. Current Israeli tactics reportedly favor fire-and-update and mixed attacks (e.g., 1 active-seeker Harpoon and 2 semiactive Gabriels) to complicate target ECM.

Gabriel I climbs to about 100 m [328 ft] after launch, then at an estimated range (from the target) of 7.5 km [8200 yd], descends slowly to 20 m [66 ft]. The missile can then be command-guided in azimuth. At a range of 1.2 km [1300 yd] from the target, Gabriel I descends to 3 m [9.8 ft], using either radio-command or semiactive-radar guidance. Later versions rise to only about 35 m [115 ft], and cruise at 17–20 m [56–66 ft].

The associated fire control is the Selenia Orion 250 (RTN-10), later replaced in at least some cases by the Israeli-built EL/M 2221.

Gabriel III has a new frequency-agile active seeker (for greater operational range) and an updated guidance computer. The missile can be fired either in fire-and-forget or in fire-and-update (mid-course data-link update) mode. The aircraft-launched III A/S version has no booster. Typically, the aircraft TWS radar is used to aim III A/S; the TWS radar can cut search area by as much as 40:1, and the missile seeker can be turned on much closer to the target. This missile can be launched at 300–30,000 ft altitude by F-4, Mirage, Kfir, or A-4 aircraft. Gabriel III was announced in 1979, and development was completed in March 1980.

Gabriel IV is a new swept-wing missile, powered by an 810-lb thrust Bet Shemesh Sorec 4 turbojet. Its operational status remained uncertain as of 1990.

After the 1973 Middle East war Gabriel I was widely exported, in characteristic sealed shipping/launching containers with a shelf life reported as 2 yr. Known customers include Taiwan (1978), Kenya (37.5-m boats, 1979), Ecuador (1980), Chile, Singapore, Thailand, and South Africa. Brazilian plans to acquire Gabriel (1982) were canceled to avoid problems with the Arab states buying Brazilian weapons. Reportedly, about 2500–3000 Gabriels have been manufactured. Estimated unit prices (1987) were Gabriel I/II, \$400,000; Gabriel III, \$450,000; Gabriel III A/S, \$550,000; Gabriel IV, \$675,000. In 1971 the quoted Gabriel I price was \$85,000–\$95,000 or a total of \$2.5 million for 6 missiles plus radar and fire control.

The South African Skorpioen is a Gabriel II derivative, built under license. However, the Taiwanese (GRC) Hsiung Feng I is an unlicensed copy.

VERSIONS

	I	II	III	IIIA/S	IV
Diameter	32.5 cm [12.8 in]	35 cm [13.8 in]	34 cm [13.4 in]	34 cm [13.4 in]	43 cm [16.9 in]
Length	3.35 m [132 in]	3.35 m [132 in]	3.8 m [150 in]	3.85 m [152 in]	4.7 m [185 in]
Span	1.385 m [54.5 in]	1.385 m [54.5 in]	1.35 m [53.1 in]	1.1 m [43.3 in]	1.6 m [63.0 in]
Weight	400 kg ^a [882 lb]	500 kg [1102 lb]	560 kg [1234 lb]	600 kg [1322 lb]	960 kg [2116 lb]
Warhead	180 kg ^b [397 lb]	180 kg [397 lb]	150 kg [331 lb]	150 kg [331 lb]	est 150–200 kg [est 331–441 lb]
Boost Thrust	3600/3	3600/3	— (lb thrust/duration)	—	—
Sustain	100 sec	200 sec	— (duration)	—	—
Speed	M 0.65	M 0.65	M 0.65	M 0.73	M 0.85
Range	20+ km ^c [22+ kyd]	36–40 km [39–44 kyd]	36 km [39 kyd]	60+ km [66+ kyd]	200 km [220 kyd]
Attack Altitude	4.5–6 m [14.9–19.7 ft]	2.5 m [8.2 ft]	1.5/2.5/4 m [4.9/8.2/13.1 ft]	—	—

^aGabriel I in launcher/container: 600 kg [1322 lb].

^bExplosive weight in Gabriel I: 154 lb, with delayed-action fuze.

^cMinimum range for Gabriel I: 5500 yd.

ITALY

◆ Otomat

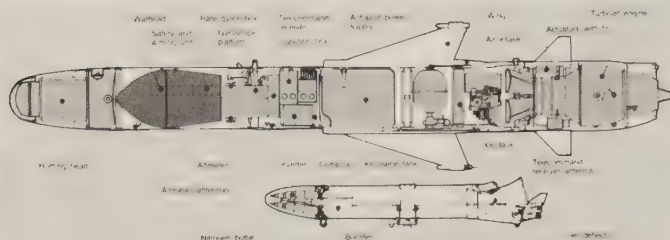
Dimensions: 46 cm × 4.46 m; 1.35-m span [18.1 × 189.8 × 49.1 in]

Weight: 770 kg at launch; 660 kg in flight [1697/1455 lb]

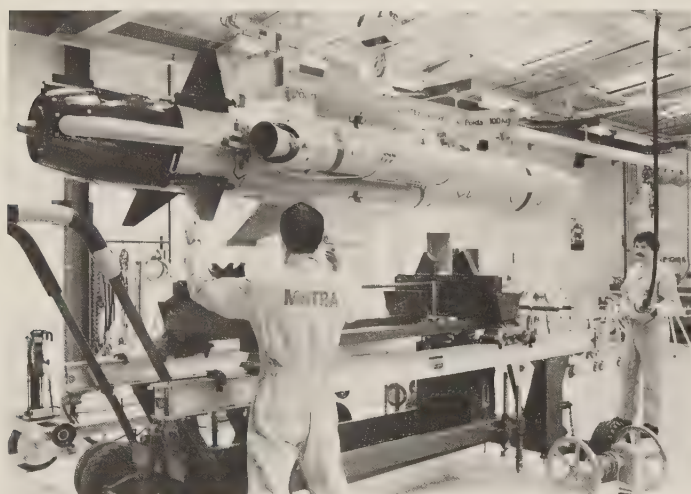
Warhead: 210-kg [463-lb] Herotol blast [132-lb explosive]

Propulsion: Turbomeca Arbizon III turbojet and 2 solid-fuel boosters **Speed:** Mach 0.9

Range: 6–60 km, Mk 1; 100–180 km, Mk 2 [6.6–66 kyd/109–197 kyd]. Minimum range for Mk 1 is 6600 yd; maximum effective range is 64 kyd; maximum flight range is 88 kyd.



Otomat missile. (Matra)



Otomat. (Matra)

Otomat is a collaborative French-Italian project (OTO Melara and Matra); missiles are manufactured in both countries. Otomat uses inertial mid-course guidance and an X-band active terminal seeker. The launcher is fixed at an elevation of 12 or 18 deg. The rocket booster carries Otomat to an altitude of 80 m [262 ft] and a sustainable speed of Mach 0.9. The missile switches on its seeker at an expected range of about 12 km [13.1 kyd]. The missile climbs to 175 m [574 ft] at a range of 4 km [4400 yd] from the target then, at 2-km [2200-yd] range, dives at 7 deg. That dive increases the chance of penetrating deep into a target ship but exposes the missile to hostile fire for an estimated 12 sec. Otomat Mk 2 is, therefore, designed to sea-skim throughout its flight.

Mk 1 receives its launch data (true target bearing, own-ship heading, time of flight, and vertical reference) from the launch ship. The initial missile course can be as much as 200 deg away from the angle of the launcher. Warm-up time is 30 sec (gyro spin-up time). It appears that the original missile could not accept mid-course updates, but that limitation does not apply to production Mk 1s.

The French version of Mk 1 (which was apparently not successfully exported) uses the Clio fire-control system, and all Mk 1s use a 3-axis Thomson-CSF Col Vert terminal seeker that scans in elevation and to 20 deg to either side of the missile. Italian-made Mk 2s have an Italian-made SMA single-axis active seeker.

Mk 2 is designed to accept mid-course guidance from a helicopter closer to the target. There are 2 forms. In the Italian Tesco system, the helicopter orders the turn toward the target, so the missile is initially directed toward the helicopter. Thus, the missile flies at low altitude all the way to the target, not needing to be high enough to receive mid-course guidance from a ship. However, because the missile must fly directly to the helicopter, the system as a whole cannot engage more than 1 target (or a few targets very close together) at a time. Moreover, the effect of the system is to increase flight time, as the missile must follow an angled path. For example, a missile fired by a Venezuelan *Lupo*-class frigate hit a target 131.5 km [144 kyd] away, but that engagement entailed a flight leg of 85.8 km [93.8 kyd] to the helicopter, and another of 51.9 km [56.8 kyd] to the target. Typical mid-course guidance platforms are AB 212 and Sea King helicopters.

In the French ERATO (Extended Range Targeting of Otomat), mid-course corrections are transmitted directly by the launching ship. The missile must, therefore, climb to 900 m [2952 ft] altitude to remain within range of the shipboard data link. The ship tracks the helicopter, which in turn detects and tracks the target. The missile descends to 20 m [66 ft] cruise altitude after receiving final instructions by ship data link, at a maximum range of about 80–100 km (the ship's radar horizon for the helicopter). A final pop-up maneuver is possible. Maximum total range is 166 km. The helicopter need not fly near the missile's flight path, and the system as a whole can engage several targets simultaneously (up to 16 missiles at 6 targets with 6 simultaneous mid-course updates). This flexibility makes it possible for the missiles to approach 1 target from several different directions more or less simultaneously. Typically, this system employs an ORB 31 or 32 or AGRION helicopter-borne radar.

Mk 2 is also designated Otomat Compact; it has folding wings for more compact stowage. The original box was 1.36 m in diameter and 4.7 m long, with a weight of 850 kg empty. Otomat Compact uses an elliptical-section container with the same width, but only 0.84 m high and weighing only 595 kg. As in the case of Exocet (MM 38/MM 40), the change in launcher allows 2 missiles to be carried in the space (and very nearly with the weight) formerly allowed for 1.

OTO Melara and Engins Matra conceived Otomat as a private venture and began studies in 1967 and development in 1969. The first unguided launching was in 1971, the first successful guided flight following in February 1972. Mark 2 trials began in January 1974. A proposed air-to-surface version was abandoned in 1976.

Otomat is in Italian Navy service and has been exported to Egypt, Iraq, Kenya (on board 2 Vosper-Thornycroft 56-m attack boats), Libya, Nigeria, Peru, Saudi Arabia, and Venezuela. About 830 Otomats had been ordered by the end of 1986, and unit cost was about \$350,000–\$400,000. As of January 1982, 402 Otomats had been reported deployed on board 83 ships.

Egypt and Saudi Arabia use Otomat for coast defense. As of 1988, Otomat production was to continue, to be followed by a successor, the supersonic Otomach. Because the Otomach program has encountered difficulties, as of 1990, an Otomat improvement program is planned, including replacement of existing analog circuitry by digital alternatives, better ECCM, greater stealth, and provision for a terminal maneuver (not previously available). An ASW version (see the Antisubmarine Warfare section) was announced in October 1986: MILAS.

◆ Sea Killer/Marte

Dimensions: Marte Mk 2: 31.6 cm in diameter; Mk 2: 20.6 cm in diameter [12.5 and 8 in, respectively]. Marte Mk 2: 4.84 m in overall length, including 1.09-m booster [191/43 in]; Mk 2: 4.7 m in overall length, or 3.64 m without booster [185/155 in]. Marte Mk 2, 98.4 cm in span [38.7 in]; Mk 2: 99.9 cm in span [39.3 in]

Weight: Marte: 330 kg [727 lb]; Mk 2: 300 kg [661 lb]. Marte in shipping container: 1056 lb. Marte Mk 2 weighs 345 kg [760 lb].

Warhead: Sea Killer Mk 2: 70-kg [154 -lb] Tritolal blast SAP with impact fuze; Mk 1: 75-lb HE-fragmentation, including 35-lb HE

Propulsion: boost: 1.7-sec burn, to 250 m/sec [820 ft/sec]; sustain: 75-sec burn

Speed: Marte: 300 m/sec [984 ft/sec]; Mk 2: Mach 1.9

Range: Marte and Mk 2: 20–25 km [22–27 kyd; minimum range 6 kyd; Mk 1: minimum range 3250 yd, maximum 11 kyd]

The missile is Sea Killer, the ship system is Mariner, and the helicopter system is Marte. Sea Killer can also be carried by a fixed-wing airplane, in which case the missile needs no booster (and is, therefore, 84 kg lighter). These missiles were manufactured by Sistel.

Mark 1 (Nettuno) is a surface-to-surface version of the Contraves Sea Indigo surface-to-air missile (slightly longer, with a larger diameter and greater weight). Sea Indigo was never placed in service by any navy, but Sea Killer Mk 1 was bought by Italy for fast patrol boats (installed only in the now-stricken *Saetta*). Mk 1 is no longer in service. Work was begun by Contraves Italiana SpA in 1963, the first prototype flying in 1966, and the weapon entering service in 1969; that year the missile was taken over by Sistel SpA (which was formed around the Contraves missile division).

Nettuno was designed for use with the Contraves Sea Hunter Mk 2 fire-control system. It is command guided, either beam riding or by direct radar command based on optical target tracking. In either case, the missile maintains sea-skimming altitude (6.5–33 ft) by means of a radio altimeter. This missile was fired from a trainable quintuple launcher (total weight about 10,000 lb).

Sea Killer Mk 2 (Vulcano) is an entirely new 2-stage missile designed to use the same guidance and construction techniques as its predecessor. The associated fire-control system is Sea Hunter 4. The missile is commanded into the line of sight of the fire-control system, then rides a radar beam. Corrections, a reference signal, and event commands (e.g., warhead arming signal) are sent via a command link at a frequency well removed from that of the guidance radar. Initial launch information includes roll, pitch, and own-ship speed. Flight time is input either manually or through the fire-control computer, and maximum range corresponds to about 120 sec. The system's reaction time is about 30 sec (to warm up the radio altimeter). The missile flies a sea-skimming (3-m altitude) course by radio altimeter; altitude can be adjusted in flight by command from the launching ship or from a helicopter. Like Mk 1, Mk 2 can also be radio-command guided (via the command link mentioned above) using an optical target tracker; the missile is made to fly down the optical axis of the tracker.

In a typical ship installation, the target-tracking radar is a Selenia RTN or a radome-mounted SPQ-711 (part of the Contraves Sea Hunter system). The bridge carries an optical tracker.

Sea Killer Mk 2 was bought by Iran (in a trainable quintuple launcher on board Vosper Mk 5 frigates). In these ships the fire-control radar is the Contraves Sea Hunter.

The first 2 successful Mk 2 launches were reported in October 1971.

In the Marte Mk 1 system, a Sea King helicopter with SMA APQ-706 radar carries 2 Sea Killer Mk 2 missiles. The APQ-706 radar uses 2 back-to-back antennas and 2 radar transceivers: a frequency-agile unit and a unit linked to a PPI. When the radar locks onto the target, the missile can be fired. Like Sea Killer, it is a beam-rider flying at a set altitude (3.4–5 m) above the sea.

Marte Mk 2 has a larger-diameter nose containing an Otomat active seeker for fire-and-forget operation. Reports indicate that the warhead is no heavier than that of Sea Killer Mk 2 or Marte Mk 1. The airframe and booster aft of the nose section duplicate those of Marte Mk 1. There is also a version of Marte Mk 2 intended for use by fast aircraft; it has no booster and weighs 260 kg [573 lb].

The corresponding ship system, which has not found any buyers, would carry 6 missiles in tubes good for 6 months without maintenance.

Sea Killer began as a private-venture project in 1965, the first tests coming in 1969, and the first operational installation, on board Iranian Navy frigates, in 1971/72. The first Marte Mk 1 was delivered to the Italian Navy in 1977, and the Italian Navy selected the Mariner system in July 1979. However, no ship installations were made. Marte Mk 2 was announced in mid-1983, and the first Marte Mk 2 test was a shot from a ground launcher against a trawler at a range of 18.8 km, 23 March 1984. Marte Mk 2 entered Italian Navy service in 1987.

In 1988 AerMacchi announced plans to integrate Marte with the MB339 trainer/light attack aircraft, and this missile will probably be carried by the Italian/Brazilian AMX fighter/attack airplane (using an FIAR/ECTA Pointer radar or an SMA/Tech-nasa Scipio for the Brazilian version, or the FIAR Grifo for the dedicated antiship version).

JAPAN

◆ SSM-1

Dimensions: 35 cm × 5 m; 116 cm span [13.8 × 197 × 45.7 in]

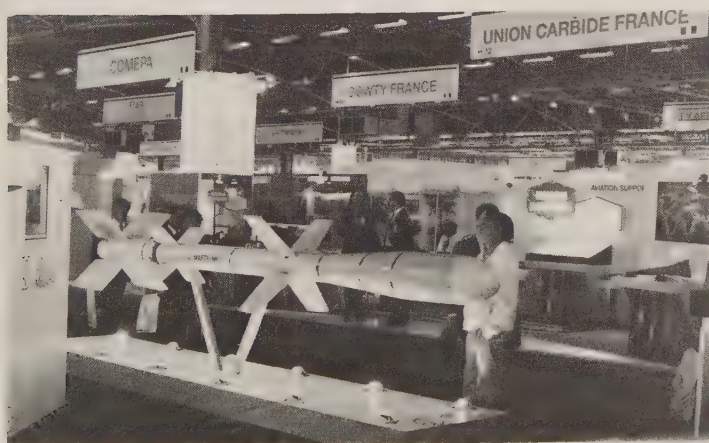
Weight: 661 kg [1457 lb] **Warhead:** 225 kg [496 lb]

Propulsion: Mitsubishi TJM-2 turbojet, 2 boosters

Speed: subsonic **Range:** 150 km [164 kyd]



SSM-1. (Sea Power)



Marte Mk 2 at the Paris Air Show, 1989. (Author)

At present SSM-1 is a truck-mounted antiship missile, for coastal defense. However, the missile is probably suitable for ship mounting. The Japanese FY88 budget included the first six 6-tube truck-mounted launchers for the Ground Self-Defense Force, out of a planned total of 56 (total 384 missiles). SSM-1 is derived from the ASM-1 (see Air-Launched Missiles), with a turbojet instead of a rocket power plant. Reportedly, the ASM-2 air-launched missile will be derived from SSM-1.

SSM-1 was proposed in 1981, and development began in 1982. The prototype was completed in 1983. Japan has no test range of its own, so the first prototype SSM-1 was dropped by a T-2 over the Sea of Japan in July 1986; missiles were also test-fired at Point Mugu, California, in June 1987.

In February 1988 Kawasaki received a contract for a feasibility study of an air-launched version, to be carried by P-3C Orions.

A new ship-launched antiship missile, SSM-B (presumably SSM-1B), is to replace Harpoon in Japanese service; first trials

were reportedly scheduled for 1988. Procurement was to begin in FY90. SSM-1B or a derivative (sometimes described as SSM-2) is to arm the new Japanese hydrofoil missile boats.

When SSM-1 was originally proposed, unit cost was to have been \$385,000 (FY78 dollars), based on a purchase of 150 missiles. The purchase was increased to 250 missiles, but the current unit-price estimate is \$697,000 (FY87 dollars); the prototypes cost \$728,000 each (FY87).

NORWAY

◆ Penguin (AGM-119)

Dimensions: 28 cm × 2.95 m × 1.42 m span [11 in × 118 in × 55.5 in span]; Mk 2 length 2.96 m [117 in]; Mk 3: 28 cm × 3.20 m × 2.00 m span [11 in × 10 ft 5 in × 3 ft 3 in]

Weight: Mk 1: 330 kg; Mk 2: 340 kg; Mk 3: 350 kg, 400 kg with launcher [Mk 1: 741 lb; Mk 2: 749 lb; Mk 3: 771/882 lb]. Mk 3 weight has also been given officially as 820 lb with a 265-lb warhead.

Warhead: 250-lb SAP [Bullpup Mk 19] **Propulsion:** solid rocket

Speed: Mach 0.7 [Mk 2 and Mk 3: Mach 0.8]

Range: Mk 1: 20 km; Mk 2: 27 km; Mk 3: 40+ km [22/29.5/44 kyd] (Minimum range is 2750 yd in the Mk 1 version.)



Penguin being test fired by a U.S. 65-ft Patrol Boat Mk 3, 1982. (U.S. Navy)



Penguin Mk 2 Mod 7 on board a LAMPS helicopter (Grumman Aerospace)

Penguin was the first IR guided antiship missile (indeed, the first modern NATO antiship missile). It is boosted to an altitude of 80 m, cruising at 66 ft; the IR seeker is activated at a preset range. The designers chose IR homing because the prospective users, the Norwegian and Swedish navies, operate in areas of strong radar clutter dealing, respectively, with fjords and the Stockholm archipelago. IR homing also provides a target with less warning than an active-radar seeker, although requiring the missile to fly at a greater altitude. Prior to launch, the missile is provided with target bearing, target relative speed perpendicular to the line of fire, range to IR-seeker activation, and gyro-platform compensation data. Maximum flight time (Mk 1) is about 85 sec. Total reaction time, from the off condition to

firing, is about 2 min but can be cut to 7 sec if seeker cooling is maintained.

The altimeter is a pulsed laser.

The warhead is a U.S. Bullpup Mk 19 with a U.S. Mk 312-2 contact fuze (delay changed from 8 to 10 msec, to allow some penetration of the target). Total explosive weight is 103 lb.

Mk 1 is carried in the fiberglass shipping container (43.3 × 43.3 × 122 in, 396 lb) from which the missile is launched.

Mk 2 is a longer-range ship-launched version using a new launcher. However, the U.S. Navy plans to adopt Mk 2 Mod 7, a helicopter-launched version, for the LAMPS helicopters (see below).

Mk 3 (AGM-119) is an air-to-surface version that flies a pre-selected search pattern. The missile can be launched at altitudes of 150–30,000 ft and at speeds of up to Mach 1.2. The pilot can launch Mk 3 at up to 50 deg off boresight. There are 4 trajectory options: altitude hold "on" (missile flies either at maximum cruise altitude or at launch altitude, whichever is lower, up to the waypoint); altitude hold "off" (missile descends to preset mid-course altitude); mid-course altitude high (about 300 ft); and mid-course altitude low (sea-skimming). The pilot also selects the search pattern (wide, normal, asymmetrical) before launch.

In Norwegian service the associated fire-control system is MSI-80S, incorporating twin Decca TM 1226 radars, a Marconi-Elliott LLLTV camera/tracker, a laser range-finder, an IR scanner, and ESM. In Swedish service the missile interfaces with the PEAB 9V200 fire-control system; the Greek Navy uses Penguin with the Thomson-CSF Vega 2.

Penguin was developed in 1962–70 by the Norwegian Ministry of Defense and Kongsberg Vapenfabrikk, with some U.S. Navy financing (which is why Penguin uses a Bullpup warhead, and why the U.S. Navy has certain rights to the missile; it has been evaluated several times in the United States). Test flights were completed in 1971, and Penguin entered service in 1972 in the Greek, Norwegian, Swedish, and Turkish navies, on board fast patrol craft and, later, on board Norwegian frigates.

The U.S. Navy evaluated Penguin on board a 65-ft patrol boat (completed April 1982). The missile seemed too heavy for that hull but was chosen for the larger special-warfare craft (SWCM, Sea Viking). Penguin was successfully tested on board the air-cushion landing craft JEFF B in October 1983 in response to a House Armed Services Committee recommendation that alternative missions be sought for the landing craft. For this test the missiles were loaded on a flatbed truck. The U.S. surface-launched Penguin program died with Sea Viking.

By 1983 the fleet had proposed both a helicopter-launched antiship missile (HLASM) and a short-range surface-to-surface missile (SRSSM). A 1983 study rejected SRSSM (for carriers, amphibious ships, and service-force ships) but did show that the combination of LAMPS III and HLASM would be worthwhile. Penguin was the leading HLASM candidate, and in April 1984 the Mk 2 Mod 7 version, with folding wings and with an improved IR sensor, was formally chosen. The program then called for 272 missiles. In 1985 \$14.6 million was provided to evaluate the missile in this role, but rising unit cost led to a reduction from 272 to 192 missiles. In July 1986 the Senate Armed Services Committee objected that Penguin was too expensive, that it would equip only 33 ships (and a total of only 28 helicopters), and that it had a range of only 20 nm.

Production funds were dropped from the FY89 budget, but they were restored in FY90; a contract for 64 Penguin Mk 2 Mod 7s, to be carried by U.S. Navy LAMPS helicopters, was let in October 1989. Another 65 missiles have been requested for FY91. The missile has been proposed to both Korea and Greece, to be carried by adapted SH-2 helicopters. The U.S. designation is AGM-119B (-119A is Penguin Mk 3).

As of 1990, Norwegian Penguins are being upgraded to Mk 2 Mod 5 standard. Penguin Mk 3 was selected by the Royal Norwegian Air Force in 1980 to arm its F-16A/B fighters. Operational evaluation was completed in 1988, and the missile was formally accepted for service on 12 May 1989. Turkey is re-

portedly showing interest in purchasing it, and the U.S. Air Force is testing it as part of the system integration evaluation of the F-16A/B Operational Capability Upgrade program.

NFT is reportedly considering a surface-launched version of Mk 3.

As of 1988, estimated unit cost was \$220,000 for Mk 1 or Mk 2, or \$500,000–\$550,000 for Mk 2 Mod 7 or Mk 3.

SOUTH AFRICA

◆ Skorpioen

See Gabriel (Israel).

SWEDEN

◆ Rb 08A

Dimensions: 65 cm × 5.7 m; span 3.6 m [26.1 × 224 × 142 in]

Weight: empty 1720 lb [launched at 2645.5 lb]

Warhead: 250-kg [551-lb] blast-fragmentation

Propulsion: turbomeca Marbore IID jet [882-lb thrust] with solid-fuel booster

Speed: about Mach 0.65 **Range:** 135 nm

This antiship cruise missile was derived from the French (Nord Aviation) CT-20 target drone and developed by Nord and CSF (later part of Thomson-CSF) under the designation M20, specifically for the Swedish Navy. Work began in 1959, and Rb 08A entered production (by Saab) in 1966; 98 were manufactured, and production ended in 1970. The missile was formerly carried by 2 Swedish destroyers and is now used for coast defense.

No speed data on Rb 08 were ever released; the figure above is characteristic of the similar R 20 battlefield-surveillance drone. The CT 20 target, which was lighter than Rb 08 but of about the same size, was credited with a speed of 900 km/hr at 10,000 m [486 kt at 32,800 ft].

◆ Rb 12

Rb 12 is the Swedish designation for the Norwegian Penguin Mk 2 (see above).

◆ RBS 15

Dimensions: 50 cm × 4.35 m; span 85 cm folded/1.4 m spread [19.7 × 171 × 33.5/55.1 in]

Weight: 598 kg (780 with boosters) [1318/1719 lb]

Warhead: estimated 250-kg [551-lb] semi-armor piercing (a modified, heavier warhead is under development)

Propulsion: Microturbo TRI 60-1-077 [370-kg thrust] with rocket boosters

Speed: Mach 0.9 (to Mach 0.7 by 3-sec booster burn)

Range: 70 km [77 kyd]; 150 km for air-launched version

RBS 15 is a fire-and-forget weapon with an active-radar (frequency-agile) seeker. Flight parameters, such as the search pattern, are automatically selectable by the fire-control system. The mid-course inertial system can be updated by data link. PEAB claims that frequency agility in the seeker reduces glint by a factor of 2–4 and increases target-detection range by more than 50%. Frequency agility is also said to eliminate target fading during lock-on, to reduce sea clutter, and to obviate any requirement to allocate different frequencies to the different missiles of a salvo. The seeker is designed to provide home-on-jam as an option, and the missile can also be modified to maneuver evasively (using memory tracking to remain locked-on).

The seeker is designated 9GR400; it is built around the same type of PEAB spin-tuned X- or Ku-band magnetron used in the 9LV200 fire-control system. Typical pulse width is 0.2–1.0 microsec, with a jittered PRF of 1000–4000, a peak power of 65–100 kW, and search limits of 30 deg either side in azimuth and 15 deg up or down in elevation.

Reportedly the RBS 15 airframe is derived from that of the earlier RB04E air-launched missile; the use of components of the earlier weapon drastically cut development time. Reportedly, too, the missile was developed at the urgent recommendation of the Swedish Aircraft Industry Committee to maintain missile design and production capability. The Swedish defense



RBS 15. (Saab)



RB 15 missile being fired from a coast-defense launcher. (Swedish Navy)

forces disagreed (presumably on grounds of cost) but were overruled: RBS 15 was chosen instead of the U.S. Harpoon or the French Exocet.

The development contract was let to Saab in June 1979, and the design was frozen in mid-1980. The first live firing was in July 1981. Initial Swedish Navy deliveries were completed in 1985. Finland ordered RBS 15 (15M version) in March 1983, and the missile entered service on 7 June 1984; Finland also uses the missile for coast defense (first delivered in April 1988). This weapon has been ordered by Yugoslavia to replace existing Soviet-supplied SS-C-3 Styx coast-defense missiles and may also be carried by new *Kobra*-class missile boats. Estimated unit cost is \$479,000 (FY87).

There is also an air-launched version, RBS 15F, for use by Swedish Air Force Viggen fighters. A projected submarine-launched version was rejected by the Royal Swedish Navy, on the grounds that long-range wire-guided torpedoes were preferable.

◆ Hellfire (RBS 17)

See U.S. section.



Hellfire (RBS 17) being fired from its coast-defense launcher. (Swedish Navy)

TAIWAN (ROC)

◆ Hsiung Feng I/II

Hsiung Feng I is an unlicensed copy of the Israeli Gabriel; the name originally meant Male Bee, but was changed to Proud (or Brave) Wind in 1980/81 in line with a general redesignation of new Taiwanese (ROC) systems with "Wind" names. Reportedly, the developers experienced problems with the rocket motor and with the copied guidance system. The warhead is a 70-kg blast-fragmentation type. This missile is used both on board ship and in coastal batteries. Hsiung Feng may not be a true sea-skimmer, since at least some films show it flying well above the sea and then diving steeply into its target.

The associated fire-control radar is SPG-24.

Reportedly, work on the Hsiung Feng I fire-control system began in the 1970s. The missile project was completed in 1977 (it was first reported in January 1977). The initial test firings were conducted on board the former torpedo boat *PT 1*. Israeli-supplied Gabriels had been mounted on board some ROC destroyers as early as 1974. In the absence of any Israeli radar, these missiles may have relied on radio-command guidance, which is a backup control system for Gabriel I.

Hsiung Feng II resembles the U.S. Harpoon but is reportedly powered by a license-produced Turbomeca Arbizon IV turbojet, which has a somewhat greater diameter than the U.S. engine (but develops 10% more thrust). Film footage of the initial trial shows folding wings, and the missile appears to approach its target at very low altitude (5–7 m), using an active-radar seeker. Reports indicate that the missile can accept mid-course guidance data, e.g., from a helicopter. The data link involved is probably similar to that of Hsiung Feng I. Unlike Harpoon, Hsiung Feng II incorporates an IR sensor, officially described as Automatic Target Recognition Image Tracking Module Mk 2. The missile is carried in a fairing above the main (radar) seeker. Presumably, the combination of radar and IR will defeat the relatively simple countermeasures currently employed on board PRC ships.

Film of test launches, shown in February 1988, appears to show a modernized *Fletcher*-class destroyer (Wu-Jin I or Weapons Improvement Mk I) launch platform. Reportedly, the Taiwan Navy will employ Hsiung Feng I and II side by side, as the Israeli Navy employs Gabriel and Harpoon. The land-based version of Hsiung Feng I is deployed in a triple towed trailer. A land-based version of Hsiung Feng II exists, and an air-launched version is planned, for use with the new Ching-Kuo fighter and also possibly with the AT-3 trainer. Reportedly, a submarine-launched version is also under development.



Hsiung Feng being fired by a Taiwanese destroyer. (*Defense Technology*)



A Hsiung Feng I missile on parade in Taiwan. (Fu S. Mei)



Hsiung Feng I being fired from a Taiwanese destroyer. Note the command-guidance director in the foreground. The unmanned director is a U.S.-type Mk 51 controlling the twin 40-mm gun mount visible below the director to the right. (Fu S. Mei)



Hsiung Feng I being fired by a Taiwanese PSMM Mk-5 class (*Lung Chiang*-class) fast attack boat. She carries an OTO-Melara 76-mm gun forward, and the main air-search radar is the stand-alone version of the U.S. SPS-58, which is unique to the Taiwanese (ROC) Navy. The radome presumably covers a Hsiung Feng control radar of unidentified type. (Fu S. Mei)



Hsiung Feng II missiles on parade in Taiwan. The fairing above the nose carries the IR sensor. (Fu S. Mei)

USSR

Many Soviet naval missiles have alternative nuclear warheads, as noted below. Many may also have chemical warheads; certainly chemical weapons are very common in Soviet land forces. No detailed information on naval chemical weapons has been published, and it is sometimes argued that a fleet subject to a chemical attack could steam out of the chemical cloud, relying on short-term measures such as citadels. Another view is that, since the Soviets themselves class chemical weapons with nuclear weapons as "means of mass destruction," nuclear deterrence would also deter them from using chemicals.

One can imagine an attack in which explosives or bomblets were used to open ships for follow-up chemical attack. Gas attack was taken very seriously before World War II, and no realistic solution was found at that time (in one internal U.S. document, experts suggested that a gassed battleship might as well be scuttled, since it could not be decontaminated). Western consciousness of Soviet chemical-warfare potential has increased enormously over the last few years, and numerous reports of the chemical-security measures that the Soviet Navy has taken

have been adduced to suggest that the Soviets do indeed possess naval chemical weapons. Perhaps the most important antigas devices that Western navies currently use are the gas detectors, most of which use lasers to detect poisonous chemicals in the surrounding atmosphere.

◆ SS-C-2 Salish

See AS-1/SS-C-2 under air-launched weapons.

◆ SS-N-2 Styx (and SS-C-3)

Dimensions: 30 in × 21.3 ft; span 9 ft (SS-N-2C: 31-in diameter)

Weight: 5070 lb (SS-N-2A)

Warhead: 500 kg [1100 lb]; somewhat heavier in SS-N-2C

Propulsion: liquid-fuel rocket (solid booster)

Speed: Mach 0.9 [666 mph]

Range: 25 nm (effective to 16 nm); SS-N-2C: 45 nm



An SS-N-2 being loaded. (Siegfried Breyer)



An SS-N-2 missile being checked before loading. (Sovfoto)

SS-N-2 was the first Soviet sea-based antiship missile to enter large-scale service. Intended to replace the torpedoes of small fast attack craft, SS-N-2 is a radar- or IR-homing fire-and-forget weapon. Styx was the first antiship missile to sink a ship in combat, Egyptian Komar-type missile boats sinking the Israeli destroyer *Eilat* in 1967. Styx was also fired successfully during the Indo-Pakistani War of 1971, by the Chinese (PRC) Navy in the Paracel Islands in 1974, and, reportedly, by the Iraqi Navy during the Iran-Iraq War (1980). In 1988 Iran began to use a land-based version of the Chinese (PRC) equivalent, Silkworm (HY-2 and derivatives), against shipping in the Persian Gulf. Styx was also used, unsuccessfully, during the October War (Israel-Arab) of 1973. At that time the reported reason for the weapon's failure was the excessive time required to run up the missile's gyros before firing: the Arab missile boat crews, under attack, tended to fire before their weapons were ready. In addition, be-

cause the missile had been designed to attack large warships, its seeker could not always distinguish the small Israeli missile boats, parts of whose superstructures had been covered in radar-absorbing material.

SS-N-2 A and B (introduced 1958 and 1964, respectively) are I-band active-radar homers, the B-versions having alternative IR homing. SS-N-2B (Osa-II-class missile boats) also has folding wings and, reportedly, sea-skims on its final approach to the target. These weapons are carried by Osa- and Komar-type missile boats. SS-N-2C (originally designated SS-N-11) has a maximum range of 45 nm. Both radar and IR homing versions are in service. A forward observer is needed to take advantage of the increased range; presumably, larger ships can accommodate the necessary communications and plotting facilities. Therefore, this weapon, introduced in 1967, is carried by Modified Kashin- and Kildin-class destroyers, by Tarantul-class missile corvettes, and by export Nanuchkas (Soviet Nanuchkas fire SS-N-9 missiles). All versions of the missile have been widely exported.

The Soviet designation is P-15 (industrial index number 4K40); SS-N-2C is P-20 and P-21. The coast-defense version, SS-C-3, is P-20/21. The Finnish designation for this missile (SS-N-2B) is MTO-66; it is used both afloat and for coast defense (in the latter role, together with the French SS 11).

Development began in 1954. Although Styx-armed missile boats entered service in 1958 or 1959, final testing (in the Northern Fleet, by two Osa-IIs) was not completed until 1960–61. Reportedly, the liquid-fuel rocket was chosen over a turbojet for quick acceleration, and the weapon was not provided with a nuclear warhead because of its short range (initially 13 nm): the firing platform might have suffered damage. Initial Soviet estimates were that 2 hits were needed to sink a destroyer (as in the case of the *Eilat*), and that 12 missiles (3 boats) had to be fired to achieve them. Boats were, therefore, organized in units of 3, and standard doctrine called for the dispatch of 2 units to ensure that 1 would reach the target area. Missile installation and arming initially took 15 hr, but that period was later reduced to 12 hr, and by 1962 an Osa could be fitted with her 4 missiles in 4–6 hr.

Missiles are loaded with storable liquid propellant, which gradually corrodes the missile body. Weapons, therefore, tend to be expended in large numbers, the usual lifetime being about 2 yr.

The Square Tie targeting radar of an Osa or Komar can detect a destroyer at up to 22 nm under favorable conditions (maximum theoretical radar range is 48 nm), and fast patrol boats can be detected at about 10 nm. The operator sets a range gate around the expected target position, and data for firing the missile can be computed for ranges of 3–15 nm. For longer ranges, at least in the original version, the appropriate firing range must be calculated manually, by plotting board, and that significantly reduces hit probability. The missile-firing platform must turn into the direction of fire. The missile is launched at a 15-deg angle to the horizon, then climbs at 45 deg to an altitude of about 450 ft. The seeker, operating on 1 of 6 preset frequencies, is switched on at about 6 nm from the calculated impact point. At least in early versions, the seeker cannot distinguish fixed from moving targets and chooses the one with the strongest echo. The seeker is, therefore, quite vulnerable to deception by chaff. Altitude is preset at 100, 150, 200, 250, or 300 m [330, 500, 660, 825, or 1000 ft]. Reportedly, the initial design of the missile included provisions for mid-course guidance, the weapon flying at 400 m [1300 ft] until it neared the target.

As of 1973, Styx's minimum range was 4.5 nm, and estimated effective operational range was 12–18 nm (for -2A and -2B versions). Most firings to that date had been at altitudes of 500 ft or less. The terminal radar seeker in SS-N-2A was a conical scan (on receive only) radar, and the use of such a seeker (in Styx as well as in contemporary Soviet air-launched antiship weapons) explains British interest in the masthead reflector countermeasure. In a maximum-range attack, the Styx seeker would be activated at an estimated range to the target of 6 nm, but in a

minimum-range attack it could be activated at an estimated range of 2.5 nm. In each case, the missile approached its target at a glide angle of 1–2 deg. The SS-N-2C terminal radar activates at an estimated range of 15 nm from the target, allowing the launch platform much more freedom of maneuver during launch (but also providing the target with much better warning).

The warhead is a large shaped charge, carried just abaft the fuel tank. In theory, then, the effect of a hit is to blast a hole deep into the target while filling it with burning fuel. Soviet doctrine is to fire 7–8 missiles at a cruiser, or 4 against a destroyer. Because hit probability against a fast patrol boat is limited (because of its small radar cross section), the doctrine in this case is to fire 2–4.

Some major limitations in the original SS-N-2 were the minimum range of 5 nm (the homing and arming mechanisms are not activated until the missile has flown that far) and the inability to seek out the preferred target among a group of ships. Nor can targets be attacked from seaward within 4 nm of the shore, because of radar clutter. At least in its original form, SS-N-2 cannot be fired if the air temperature is below 4 deg F or above 101 deg F.

Although the Soviets considered SS-N-2 strictly an antiship missile, the Indian Navy very successfully used this missile against shore installations, such as refineries (which are strong radar reflectors) during the 1971 Indo-Pakistani War.

The coast-defense version, SS-C-3, was developed in the late 1970s to replace the much larger SS-C-1 (coast-defense version of SS-N-3). Meanwhile the Chinese were using essentially the same Styx missile for coast defense. However, the standard Soviet transporter carries 2 Styxes and a Plank Shave fire-control radar, plus a control cabin, whereas the standard Chinese launcher is a single rail. Thus, each Soviet launcher truck is, in effect, an independent fire unit, even though Soviet doctrine calls for several such units to attack most warships. Effective engagement range is limited by the performance of the truck-mounted Plank Shave, which can probably detect a target at about 35 km [38,000 yd] at maximum elevation.

Exports of this missile began in 1983–84, initially to East Germany and then to Yugoslavia, followed by Soviet clients in the Middle East. As in the case of SS-C-2, the standard organization is a 3-battery battalion, each battery consisting of 6 launchers.

Iraq manufactures the SSC-3 version of Styx under the designations Faw-70, -150, and -200. The numbers probably indicate the maximum range in km, Faw-70 being a locally built SSC-3, and Faw-150 and -200 having enlarged fuel tanks. All were advertised for export at the Baghdad exhibition in 1989.

◆ SS-N-3 Shaddock (and SS-C-1)

Dimensions: 38.3 in × approx 33 ft (SS-N-3C: 39 ft); span is about 16.8 ft **Weight:** 11,900 lb

Warhead: 1000 kg [2200 lb; nuclear version reportedly 350 kT]

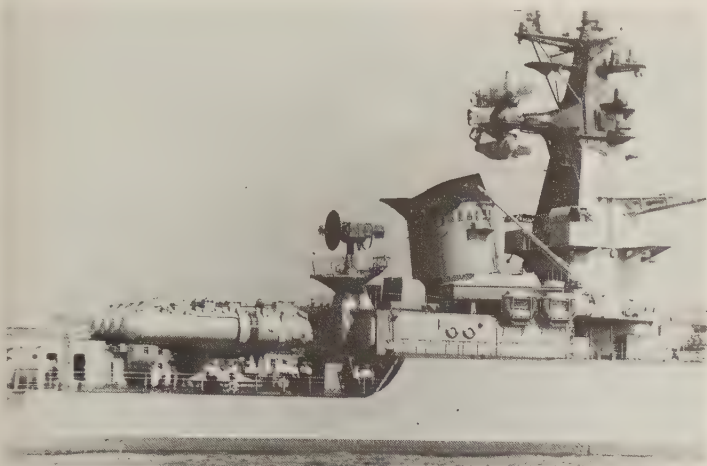
Propulsion: liquid-fuel rocket **Speed:** Mach 1.4 [1040 mph]

Range: 250 nm (400 nm for SS-N-3C)

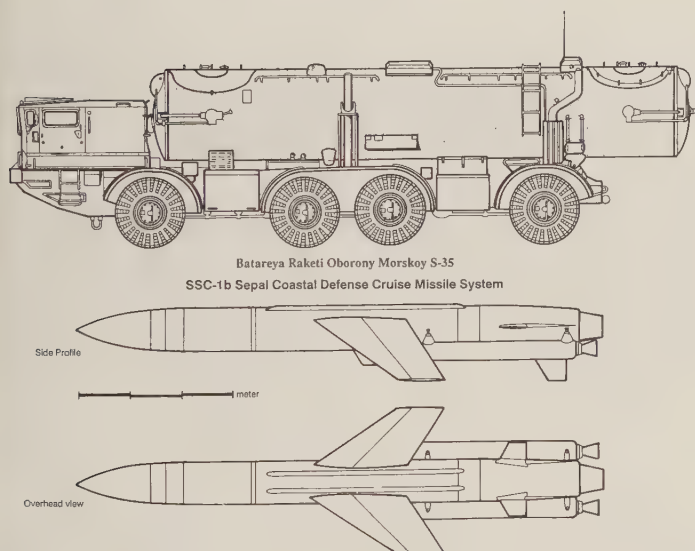
Shaddock was the first Soviet OTH ship-launched anticarrier missile. It seems to have originated as a strategic cruise missile but is listed under antiship weapons because all of the platforms (Echo-I-class submarines and Whiskey-class conversions) de-



SS-N-3 missiles in their launch tubes on board a Juliett-class submarine, being raised for firing. (U.S. Navy)



SS-N-3 launch tubes and the control device, Scoop Pair, on the after side of the mast above. There are 2 independent antennas, so the ship can presumably engage 2 targets using this director. The radomes on the side of the mast are for electronic countermeasures: the big radome is a Top Hat jammer (another pair is on the tower foremast). Above and below the jammer are smaller Bell-series radomes and the squatter, broader-diameter radome of Guard Dog. Presumably, the latter is a wide-open detector, whereas the Bells contain spinning antennas for accurate direction-finding and, therefore, for directing the jammers in the Top Hats. (C. P. Lemieux)



The SS-N-3 missile and the transporter for its coast-defense version, SSC-C-1b. (Steven Zaloga)



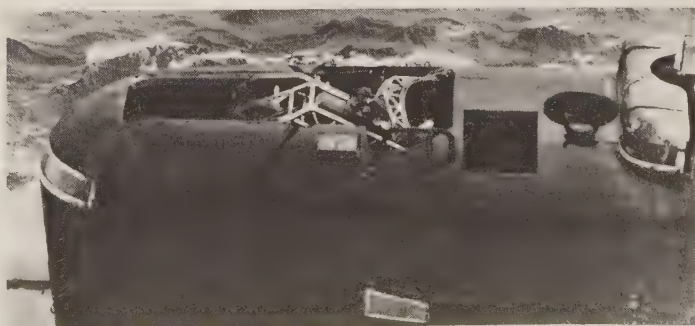
SS-N-3 (Shaddock) soon after launch, with the booster still burning.

signed to use the missile solely in the strategic role have been converted to other uses or discarded. However, the nuclear-armed nonhoming strategic version remains in service. This version might also be usable against moving formations, depending upon the details of the targeting technique.

Because the homing version of SS-N-3 flies so far, i.e., spends so long in flight, the missile requires mid-course assistance to ensure that it hits the right ship within the target formation. That help generally involves a Bear-D radar-reconnaissance aircraft, which provides the firing submarine or surface ship with a radar picture of the target formation. This picture is matched against that provided by the missile itself. Hormone-B helicopters also carry an appropriate targeting radar. The firing platform uses a radar tracker/transponder: Front Door/Front Piece in submarines (Juliatt and Echo-II classes), Scoop Pair in a Kynda- or Kresta-I-class missile cruiser. Some missile cruisers also have Plinth Net antennas (probably passive) clearly associated with this missile system; they appear to be receivers for targeting data derived from the missile seeker.

The targeting technique can be upset by the destruction of the radar platform or by an attack on the launching platform before it has locked the missile(s) onto the desired target. The high-altitude radar search by the missile itself can provide a target with useful warning. The Soviets are well aware of these weaknesses, the much faster SS-N-19 providing the ultimate solution. An interim solution would be to accept a much shorter engagement range, hence a much shorter flight time, and then to use the weapon in a fire-and-forget mode. The efficacy of such a tactic would depend upon the quality of prefiring data and upon the speed of the missile (i.e., upon flight time). The better the pretargeting data, the closer to the target the missile could turn on its seeker, hence the shorter the effective warning time.

SS-N-3 typically climbs from its launcher at an angle of 15–20 deg, attaining a maximum (cruise) altitude of about 13,000 ft. The terminal homer is activated at an estimated range from the target of about 70 nm; once it locks on, the missile dives at 20 deg, leveling off for a terminal run-in. In a typical attack at a range of 150 nm, the missile would attain maximum altitude about 100 nm from launch and would begin its dive about 50 nm from the target. Total flight time in such an attack would be 14.2 min. When these figures were compiled, minimum range was estimated as about 12 nm, but it seems unlikely that attack from so short a range was ever practiced or contemplated. The seeker scanned conically (at 60 Hz) on receive only, in I-band. These data were compiled in 1971–73, at which time the missile was credited with a speed of Mach 1.2–1.4, with a maximum range of 220 nm and an operational range of 150–170 nm. A submarine firing SS-N-3s would launch them in pairs. Apparently, because the Front Door/Front Piece could not track 2 salvos simultaneously, the submarine could not fire a second salvo until the first had locked on, so the salvo interval was about 15 min. This limitation may explain the installation of a



A Soviet submarine's missile-guidance antennas, Front Door/Front Piece, folded down inside the sail. The front and side of the sail hinge to expose the antennas. The glassy strip on the front of the sail (at left) covers a sonar; the windshield at right indicates the forward part of the manned portion of the sail.

secondary antenna, Plinth Net, on board some surface ships armed with SS-N-3; the additional antenna might be used to communicate with distant missiles while the main guidance radar (Scoop Pair) handled a second pair of missiles, closer to the ship.

SS-N-3C, the inertially guided version, was probably actually the first developed. It appeared in 1960. SS-N-3A, fired by submarines (Juliatt and Echo-II), entered service in 1962, contemporary with SS-N-3B, for surface ships (Kynda and Kresta-I).

The Soviet designation for the original strategic weapon is P-5, P-5D being an improved version with a doppler altimeter. It appears that P-6 and possibly P-7 were the submarine-launched nuclear-armed anticarrier versions, and that P-35 was the surface-ship version. S-35 is the coast-defense version. All were designed by the Chelomei bureau.

SS-C-1 is the Western designation for the coast-defense cruise-missile version.

This weapon evolved into SS-N-12 and SS-N-19.

◆ SS-N-7 Starbright

Dimensions: approx 21–22 in × 23 ft **Weight:** 7440 lb
Warhead: approx 1100-lb [500-kg] HE
Propulsion: liquid-fuel rocket
Speed: Mach 0.9 **Range:** 35 nm

SS-N-7 is an underwater-launched analog of SS-N-2, i.e., a replacement for previous submarine antiship torpedoes. Starbright is carried by Charlie-class nuclear attack submarines and, like SS-N-2, is a fire-and-forget weapon. SS-N-7 appears to exist only in a conventional version.

Charlie was apparently not a very successful submarine, and there is some question as to whether the Soviets consider the short-range fire-and-forget submarine missile a dead end. If that is true, then the 65-cm torpedo (see the Antisubmarine Warfare section) may be this missile's true successor, in effect functioning as an underwater cruise missile. Alternatively, the new 65-cm tube may provide sufficient volume for a new antiship cruise missile.

In 1971–73 the U.S. Navy credited SS-N-7 with a maximum range of 30 nm and a minimum range of 4–5 nm; probable operational range was 25 nm. The missile could be launched at depths down to 150 ft, and cruised at 100–300 ft. The terminal seeker was activated at an estimated range from the target of 25 nm, after which the missile dove toward its target at an angle of 3 deg or less. The seeker was a J-band conical scanner (on receive only, at 200 Hz) with sector scan switches to limit its FoR. Total flight time from 30 nm was 3.2 min at a speed of Mach 0.95.

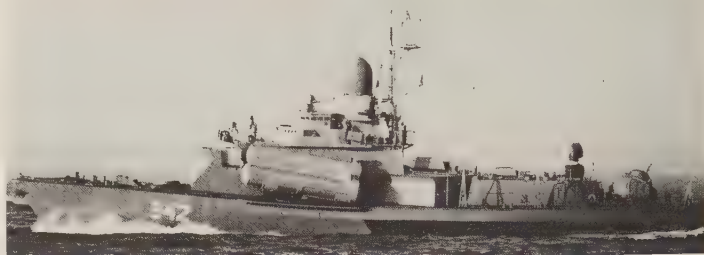
From a Western point of view, SS-N-7 was particularly frightening when it appeared in 1968 because, unlike previous longer-range Soviet antiship missiles, it would provide very little warning. It would pop out of the water only about 2 or 3 min before hitting a ship. Even though it would fly high enough to be detected, such detection might not occur early enough for defenses to be activated. SS-N-7 thus inspired a variety of countermeasures, including the British Sea Wolf missile, the U.S. New Threat Upgrade (IADT), and the U.S. decision to provide the *Perry*-class frigate with a highly automated anti-aircraft fire-control system, in principle capable of initiating fire against a pop-up missile. All of these measures were partly inspired by the threat of the Styx missile, which had just demonstrated its efficacy against the Israeli *Eilat*, but it seems more likely that SS-N-7, which could appear anywhere on the world ocean, was the terrifying new threat against which NTU was designed.

The missile itself is essentially a longer-range equivalent of Styx (SS-N-2) and physically may be somewhat similar to some of the Chinese Styx derivatives. SS-N-7 in turn gave way to the dual-purpose (surface- and submarine-launched) SS-N-9. When the Charlie-class submarine first appeared, it was evaluated as firing, not a winged cruise weapon, but rather an antiship equivalent of the U.S. SUBROC ASW missile—which would have been an even more difficult target for anti-aircraft defenses.

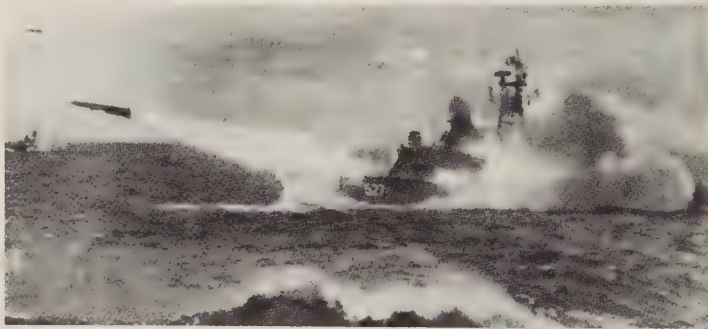
There appears to be no antiship version of the SS-N-21 torpedo-tube cruise missile (see the Strategic Strike Systems section) presumably because the Soviets demand a combination of high speed and large warhead, to overcome target defenses and to damage large warships.

◆ SS-N-9 Siren

Dimensions: length 8.84 m [348 in] **Weight:** 6500 lb [2950 kg]
Warhead: 1100-lb HE **Propulsion:** liquid-fuel rocket
Speed: Mach 0.8 **Range:** 58–65 nm



SS-N-9 launch tubes on board a Nanuchka-class missile corvette. The big radome, Band Stand, probably contains a surface-search radar and a data-link receiver that allows the ship to attack targets beyond her horizon. The gun aft is a twin 57-mm controlled by a Muff Cob director, and the back-to-back surface-search radar in front of Band Stand is Peel Pair. Forward of it is the Pop Group director of the SA-N-4 missile launcher that is located forward of the superstructure. (U.S. Navy)



Nanuchkas firing SS-N-9 missiles.

Carried on board Nanuchka-class missile boats and Charlie-II-class nuclear attack submarines, SS-N-9 is a longer-range equivalent of SS-N-2. Siren may have originated in a 1961 project for a 50–70-km patrol-boat missile. Effective targeting at the ranges possible with this missile requires third-party assistance, presumably directly to the firing platform. The missile system is associated with the Band Stand radar (actually, with the radome; it is not certain that the same equipment always occupies it). The radome may contain a radar receiver for down-linked third-party data.

This weapon has not been exported; Nanuchkas produced for Soviet client states are armed instead with SS-N-2C. That circumstance may reflect the security of the down-link or of the inertial guidance required for long-range flight before the active seeker is switched on.

There may be a nuclear version (200 kT), as at extreme range the missile is far enough away not to damage the firing platform.

SS-N-22 is the successor weapon.

◆ SS-N-12 Sandbox

Dimensions: ca. 90 cm × 11.7 m with span 260 cm [35.4 × 461 × 102 in]
Weight: about 11,000 lb **Warhead:** 2200-lb HE or nuclear
Propulsion: liquid-fuel rocket
Speed: Mach 2.5 [1850 mph] **Range:** 300 nm



SS-N-12 missile launchers on board the cruiser *Slava*, 1984. Their tracker/data-link radar, Front Door/Front Piece, is on the forward side of the foremast, below the big air-search radar. Below it is a Kite Screech fire-control radar for the twin 130-mm gun forward. The air-search radar on the foremast is Top Steer; the larger back-to-back radar farther aft is Top Pair. The large fire-control radar aft is Top Dome. The small guns abaft the 130-mm turret are 30-mm Gatlings, controlled by Bass Tilt directors. (HMS *Excellent*)



The Front Door/Front Piece missile transponder tracker (for SS-N-12 control) on board the *Slava*-class missile cruiser *Marshal Ustinov*, which visited Norfolk in 1989. Above the tracker is a Palm Frond surface-search radar, and below is a Kite Screech fire-control radar. (S. Zaloga)

Sandbox is a faster successor to SS-N-3; like the earlier missile, SS-N-12 presumably exists in both nuclear and conventional versions. Like SS-N-3, SS-N-12 requires mid-course correction.

These weapons are carried on board Echo-II-class submarines and on board *Kiev*- and *Slava*-class cruisers.

◆ SS-N-19 Shipwreck

Weight: about 10,000 lb

Propulsion: liquid rocket **Range:** 300 nm



Punch Bowl, the targeting satellite data-link antenna, on board the *Slava*-class cruiser *Marshal Ustinov*, in Norfolk in 1989. (S. Zaloga)

To date, Shipwreck is the ultimate development of the SS-N-3 concept. SS-N-19 is so fast that it needs no mid-course guidance. An Oscar-class missile submarine can, therefore, fire the missile submerged, on the basis of information provided by a radar satellite via the Punch Bowl down-link antenna. This weapon is also carried by *Kirov*-class missile cruisers.

◆ SS-N-22 Sunburn

Dimensions: length about 30 ft **Warhead:** 1000-lb HE

Propulsion: liquid rocket **Speed:** Mach 2.5

Range: 55–68 nm

SS-N-22 is the larger, faster, and lower-flying successor to SS-N-9 and thus the ultimate current expression of the Styx concept. Sunburn is similar in concept but should be more difficult to counter, although, given its sheer size, SS-N-22 probably cannot fly as low as Western sea-skimmers. At present *Sovremenny*-class missile destroyers and *Tarantul*-III-class missile boats are the only platforms, although it is possible that this missile will form the battery of a Charlie successor.

Light Bulb is the antenna of the associated data link system, presumably connecting the firing ship to an OTH sensor, such as an aircraft radar.



SS-N-22 missiles in their launch tubes on board the missile destroyer *Otchayanny*. The Band Stand radome is like that on board a Nanuchka-class corvette. Above the radome is a Kite Screech director, controlling the twin 130-mm gun forward; note the hole in the dish for a television camera. The enclosed radome to one side of the foremast is Front Dome, to control the SA-N-7 anti-aircraft missile (whose single-arm launcher is visible forward of the bridge), and the big air-search radar is Top Steer. The 3 surface-search radars are Palm Fronds. Note the IFF array atop the 3D radar. (U.S. Navy)



Light Bulb (the radome alongside the funnel), the targeting data-link antenna associated with the SS-N-22 missile, on board the *Sovremennyy*-class destroyer *Otlichnyy*, which visited Norfolk in 1989. (S. Zaloga)

◆ SS-NX-25

Late in 1988 a new East German fast attack craft, about 52 m long, tentatively code-named BAL-COM-10, was observed on her sea trials. She carried 8 missile canisters, similar in size to those used for Western Harpoon or Exocet (MM 40) missiles. Presumably each canister holds a new Soviet antiship missile. The new weapon would seem to be a considerable departure from previous Soviet practice, seeming unable to carry anything remotely like the current standard 500- or 1000-kg warhead. On the other hand, a boat carrying 8 such missiles can present a Western antimissile defense system with a degree of saturation that, in the past, would have required either several boats firing together or else a large surface combatant like a *Slava*.



Balcom 10 shows the new SS-NX-25 missile in its canister launcher. (West German Ministry of Defense)

There are several possible explanations for this development. One is that, in the Baltic, the Soviets will generally face relatively small Western warships and, therefore, will not really need the massive warheads adopted in the past to attack carriers and other major warships. Another is that the Soviets realize that they cannot achieve much more in the way of penetrating terminal defenses unless they adopt smaller and more numerous weapons. For example, it is unlikely that a big supersonic missile like SS-N-22 can really sea-skim.

Much depends on the details of the new weapon. If it is a rocket, like Exocet, then it can saturate defenses by sea-skimming and streaming in, but it cannot execute elaborate way-point maneuvers. If the weapon uses a small turbojet, like Harpoon, it can sea-skim and then attack from many directions by using way points.

Soviet willingness to adopt smaller warheads might also point to a decision to buy smaller air-launched antiship weapons (i.e., those that might be carried internally) and perhaps to adopt a 53-cm torpedo tube-launched antiship weapon (the salvo effect could be achieved by firing such weapons from several tubes, in rapid succession).

SS-N-25 was first tested in 1987, on board a Soviet Nanuchka III.

UNITED KINGDOM

◆ Sea Eagle

See Air-Launched Missiles above.

◆ Sea Skua

See Air-Launched Missiles above.

UNITED STATES

◆ Harpoon (AGM-84/RGM-84/UGM-84) and SLAM (AGM-84E)

Dimensions: 13.5 × 182.2 in (151.5 in long for air launch) (SLAM is 177 in long)

Weight: 1145 lb (air launch), 1439 lb (ASROC launcher), 1500 lb (SAM launcher), 1503 lb (capsule/canister launcher), 1385 lb (SLAM version)

Warhead: 488.5-lb HE (blast; semi-armor piercing)

Propulsion: J402-CA-400 Turbojet (cruise) (600-lb thrust) with solid-fuel booster (12,000-lb thrust for 2.9 sec) for ship or submarine launch **Fuel:** 100 lb **Speed:** Mach 0.85

Range: 75–80 nm surface-launched, 120 nm air-launched

Harpoon is probably the most widely deployed of all modern Western antiship missiles; it is used by 19 navies (including 9 NATO navies). Originally developed for air-to-surface use, Harpoon also exists in surface- and submarine-launched versions, the latter employing a buoyant capsule for launch. The object was to develop a weapon that could be carried on board virtually all naval platforms. That requirement in turn limited Harpoon's dimensions to approximately those of the Standard Missile (Surface-to-Air) so that Harpoon could be fired from the usual surface-ship launchers. Even so, most Harpoons on board surface ships are carried in canisters that, incidentally, can only be replaced in harbor.

Harpoon was originally a P-3 weapon. It is also carried by standard U.S. and foreign naval attack aircraft, and the first launch from an F/A-18 was in the summer of 1986. The U.S. Air Force currently carries Harpoon antiship missiles on board B-52G bombers (12 internal, up to 8 external) to support its maritime warfare MoU with the navy; the first operational air force launch was in the Caribbean, 20 April 1986.

McDonnell Douglas, the manufacturer, has proposed Harpoon as a coast-defense weapon, analogous to an existing form of Exocet.

Harpoon first saw combat on 24–25 March 1986, when A-6Es used the missile to sink 2 Libyan ships. Harpoon was also successfully used during the Persian Gulf engagement in April 1988.

Harpoon was conceived in 1965 by the Naval Air Systems Command as a longer-range (25 nm) follow-on to Bullpup, to be carried by ASW aircraft attacking surfaced submarines (i.e., a harpoon to kill whales). That mission was later expanded to include antiship attack (e.g., attacks against Soviet missile-bearing fast patrol boats), and the missile was being considered for ship mounting even before the *Eilat* incident of 1967 publicized the potential of antiship missiles. The project began formally in 1968, an RFP being released in 1970. McDonnell Douglas, whose in-house studies of long-range antiship missiles began about when NAVAIR became interested, was chosen as prime



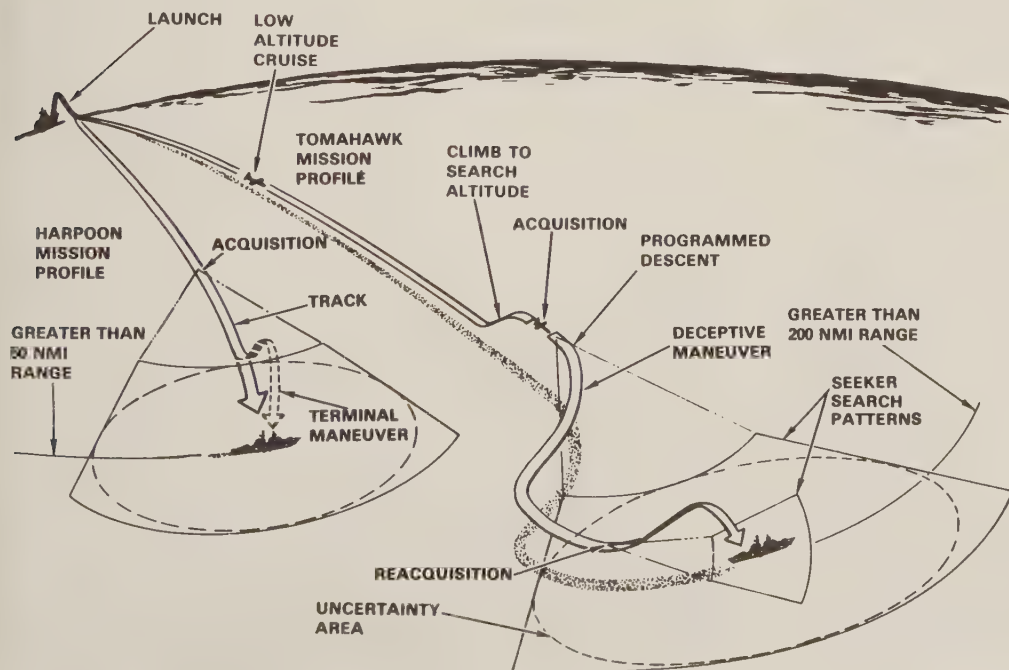
Harpoon is fired from the ASROC launcher of USS *Knox* (FF-1052). (U.S. Navy)

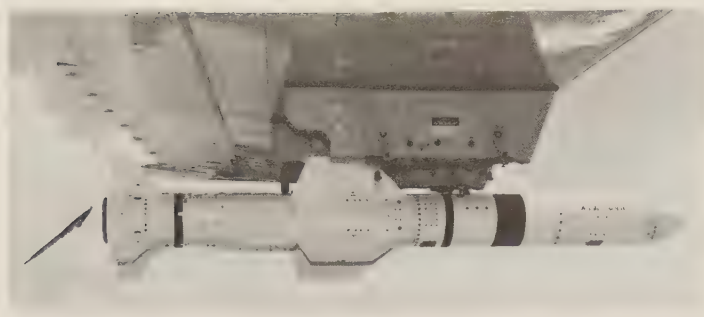
contractor in June 1971, flying the first missile on 17 October 1972. The requirement for long (over 50 nm) range was imposed after McDonnell Douglas was chosen, a small turbojet being substituted for the rocket envisaged in early studies. Production began in 1975, and Harpoon entered service in 1977. Overall, demonstrated flight reliability has been about 93% in 374 launches (100% since 1982).

All versions home using a Texas Instruments active Ku-band frequency-agile radar (fire-and-forget). A strapdown-inertial system is used to maintain course until the missile reaches a preset position where radar homing is turned on. Alternatively, the missile can be fired as a bearing rider, with the radar on throughout flight, to attack a target whose range is not known. Warning of the approach of the relatively small missile should be primarily by detecting its radar emission; the better the initial target position, the shorter the time the radar seeker need be switched on. Early versions flew directly toward the intended target, but later types (Blocks IB and IC) may incorporate waypoints, the missile flying an indirect course and perhaps switching the radar on intermittently. It is also possible to select either a nearly horizontal approach to the target or a terminal pop-up (steep climb and then dive) that may frustrate many types of terminal defense.

As originally designed, the missile (when launched by a ship or submarine) was boosted ballistically to 1300 ft before diving

Typical mission profiles for Harpoon (left) and TASM (Tomahawk Antiship Missile). (McDonnell Douglas)





Air-launched Harpoon, as carried by a P-3. (McDonnell Douglas)

into its cruise path. That profile would clear nearby ships, but it would also expose the missile to radar detection. In particular, submarine operators feared that the column of smoke and water coming out of the sea would disclose their position, and some versions apparently provide much less of a tell-tale signature.

The warhead is designed to survive penetration of a submarine's pressure hull or of a surface ship's hull. Reportedly, 1 hit should suffice to kill anything the size of a *Nanuchka* or smaller; 2 should disable a frigate (e.g., a *Krivak*), and 4, a missile cruiser; 5 should disable a *Kiev*. That estimation of effectiveness does not take missile reliability and terminal defenses into account. Most warships carry 8 Harpoons in 2 clusters of 4 canisters each.

Block IB incorporated an advanced guidance package, for the Royal Navy, which wanted a sea-skimming terminal phase for submarine-launched Harpoons. Deliveries to the U.S. Navy began in June 1982.

Block IC shows increased range and selectable terminal trajectory. It can also fly several doglegs to the target (way-pointing), concealing the position of the firing ship. A ship equipped with a Harpoon fire-control computer (SWG-1) can use way-pointing to arrange for several Harpoons to arrive simultaneously from different directions. IC is the current (1988) production version. Earlier versions can be upgraded to IC standard at a unit cost of about \$20,000. The Royal Navy is having this work done in the United Kingdom.

McDonnell Douglas expects to produce a Block II for the 1990s, with a range of 100+ nm, with variable mission profiles, and with improved discrimination between targets and nontargets. Range can be improved by about 15% by replacing the current JP-5 fuel with JP-10, and a greater improvement is possible if the fuel tank section of the basic airframe is lengthened. There is also continued interest in better target discrimination; for example, in future it may be possible to set the radar to seek out smaller high-priority targets instead of larger low-priority ones. McDonnell Douglas has reportedly proposed modifying the overall system to feed target-signature data to the weapon before launch.

As of the fall of 1988, Block II was described as a combination of Block IC features with a new Dash-4 seeker.

McDonnell Douglas received a contract to develop a new version, probably to be designated Block ID, in September 1989. It is about 2 ft longer and 150 lb heavier than earlier Harpoons, to achieve about twice the aerodynamic range, and it can re-attack a target not detected on the first pass by flying cloverleaf-shaped search patterns. The missile needs the re-attack capability to exploit its additional fly-out range, as it lacks any means of mid-course update. Reportedly Block ID will incorporate more radar absorbing material in its structure for better stealth. The FY91 U.S. Navy budget request includes 126 of these Improved Harpoons, which should become available about 1991. Reportedly, McDonnell Douglas is also working on a supersonic Harpoon successor with twice the range of the current missile.

The navy requested, but failed to obtain, FY87 funds to start work on an extended-range Harpoon with increased maneuvering capacity. The missile would have been lengthened, the fu-

selage plug adding a fuel tank to double the range; minor increases in skin friction would have been more than made up for by the additional fuel.

An FY90 research project to improve missile lethality by detonating unexpended fuel presumably applies to Harpoon. Design work is to begin under the FY91 program.

The standard stand-alone shipboard launcher is a quartet of Mk 141 canisters, ships typically carrying 2 sets (although the battleships have 4). The canisters cannot be reloaded at sea, and typically they are replaced rather than reloaded in port. There is no current vertically launched version, although some years ago effort in that direction was reported; the new cruisers and destroyers equipped with vertical launching systems carry canisters. As of late 1988, an armored canister was being developed. Harpoon can also be fired from the standard Mk 11/13 and Mk 26 Tartar/Standard launcher and from the standard ASROC "pepperbox," as well as from standard submarine torpedo tubes (60% of the U.S. attack submarine fleet was equipped to fire Harpoon as of the end of 1988). Some export customers use truck-mounted Harpoon as a coast-defense weapon.

Several countries reportedly use Harpoon for coast defense: Egypt (with Otomat), Spain, and at least one Asian country, probably South Korea. From the early 1990s on, Denmark plans to use Harpoons from the discarded *Peder Skram*-class frigates as part of its coast defenses.

The original Harpoon ship terminal was SWG-1. The Block IC missile uses the much more sophisticated SWG-1A, which contains a graphic display unit and is updated. In SWG-1, the operator makes 1 or 2 engagement decisions. SWG-1A is much more versatile. It takes into account NTDS data, including the identities of background ships near the target. The terminal automatically generates missile flight plans with waypoints to optimize angles of approach for the highest probability of acquiring and hitting the target while avoiding being shot down. SWG-1A calculates time on target so that several missiles can be fired together to arrive together, saturating target defenses. It can also calculate from a designated time on target, so that weapons from its ship arrive with those from others.

Early in 1989 it was announced that U.S. Air Force F-16 fighters based at Misawa in Japan would be modified to carry Harpoons. This was the first time that Harpoon was integrated with the F-16 (it is already integrated with the F/A-18).

The air force has requested a longer-range version for B-52s, with a range of over 120 nm. McDonnell Douglas has test-flown a missile with a 13-in plug (extra fuel tankage) that reportedly almost doubled the range.

The ship-launched version was bought for the Australian, British, Danish, Dutch, German, Greek, Iranian, Israeli, Japanese, Korean, Norwegian, Pakistani, Portuguese, Saudi, Singaporean, Spanish, Thai, Turkish, and Venezuelan Navies (a Yugoslav request was turned down in 1984). The submarine-launched version is in service in the Australian, British, Dutch, Israeli, Japanese, and Pakistani Navies. Indonesia, as well as many of the navies listed above, operates the air-launched version. Although Iran ordered 222 air-launched Harpoons, only a very few had been delivered at the time the United States imposed an arms embargo, and 85 of these weapons were bought in FY85 for the Air Force B-52G program, 30 aircraft being modified.

Current (1988) inventory goal is 4023, with production scheduled to continue through 1992. The 4000th missile was delivered on 17 December 1986, at which time 4800 had been ordered. The 5000th missile was delivered on 2 December 1988, by which time more than 5400 had been ordered. As of 1988, 40% of production was for foreign sales. Recent U.S. procurement: FY83, 221; FY84, 315; FY85, 354; FY86, 395; FY87, 96; FY88, 124; FY89, 138. Missiles procured from FY88 onward will have an improved ("Dash-4") seeker and guidance package.

SLAM (AGM-84E) is a modified Harpoon (120-nm range) for long-range precision ground attack, in effect a replacement for the long-dead Condor. SLAM incorporates a Maverick IIR seeker with a Walleye II data link and a GPS satellite-navigation re-

ceiver for mid-course guidance. Condor's problem was that the jam-resistant data link was extremely complex and expensive. Presumably SLAM will fly almost all the way on inertial/GPS instructions, turning on its data link only at the last possible moment, and so avoiding jamming or interception. Although employing off-the-shelf components, SLAM is likely to be quite expensive, and it is being bought only as an interim weapon until the new ASWS (see Air-Launched Missiles above) appears. McDonnell Douglas was awarded a contract for 14 SLAMs on 1 February 1988. As of 1988, procurement of only 290 missiles was planned. The first production SLAM was delivered on 3 November 1988. SLAM was successfully fired from shipboard for the first time on 26 June 1990; a LAMPS III helicopter controlled it near the target. The navy is deciding whether to proceed with development of a shipboard version of the missile.



SLAM land-attack missile. (McDonnell Douglas)



SLAM under the wing of an A-6. Note the nose window for its electro-optical sensor. (McDonnell Douglas)

SLAM was the outgrowth of a long series of IIR Harpoon experiments. In 1981 it was reported that versions of the missile had been flown carrying both the electro-optical seeker originally developed for Condor and 2 types of IIR seeker built by Ford Aerospace. One of the latter used a data link, the operator on the ship designating the target; the other had on-board processing. SLAM could, therefore, be delivered in fire-and-forget fashion by an A-6. In 1 test, the missile successfully identified its target in a harbor, commanded a 360-deg turn, and flew over the ship's funnel. Reportedly, this type of seeker could even distinguish between one ship and others, of a different type, nearby.

SLAM operation requires an advanced data-link pod (AWW-13); operational evaluation of SLAM/AWW-13 began in FY90. It is applicable to both the A-6E and the F/A-18.

SLAM was selected over the air force's AGM-130 in the tri-service Standoff-Weapons Master Plan of 1988. As of early 1990, the FY90/91 requests for SLAM were 48 and 58 missiles, respectively.

Total Harpoon procurement in FY89 was 119 missiles; as of January 1989, the budget called for 190 in FY90 and 215 (rather than the 184 forecast in January 1989) in FY91.

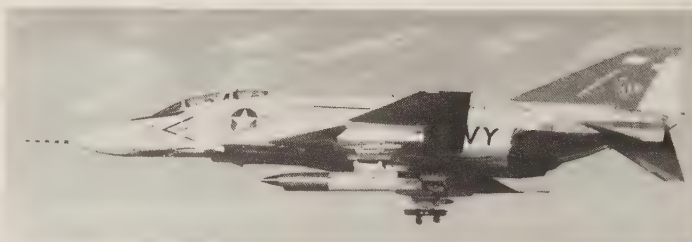
◆ Harpoon II

Reportedly, Martin Marietta has proposed a surface-to-surface version of its Supersonic Low-Altitude Target (SLAT: BQM-127A) as a follow-on to Harpoon, with the unofficial name Har-

poon II. The missile is powered by an integral rocket-ramjet; its design is based on the ASALM (Advanced Strategic Air-Launched Missile) flight-tested in 1979. As currently (1987) conceived, this missile would be dropped by an airplane at an altitude of about 1000 ft, 55 nm from the target. Descending to about 30 ft in the first 10 nm, the missile would cruise at that altitude for 45 nm at Mach 2.5, popping up over the target. The full-scale engineering-development program will also seek a capability for Mach 3 flight at altitudes over 30,000 ft. Flight tests began in the latter half of 1987.

The unique Martin-developed engine combines a solid booster with a liquid-fuel ramjet. The solid booster case becomes the combustion chamber of the ramjet once the solid fuel has been consumed; the booster accelerates the missile to Mach 2.1 in about 6 sec, after which the ramjet accelerates the missile to Mach 2.5.

The SLAT full-scale engineering-development contract was awarded in September 1984; it covered 15 flight-test missiles, with navy options for 330 more. The navy has indicated a requirement for a total of 1000 operational missiles. SLAT presumably simulates the Soviet SS-N-22 missile and, therefore, would seem a natural starting point for a future U.S. supersonic antiship weapon. SLAT dimensions are 21.2 × 218.2 in (launch weight 2445 lb).



SLAT carried by an F-4. (Martin Marietta)



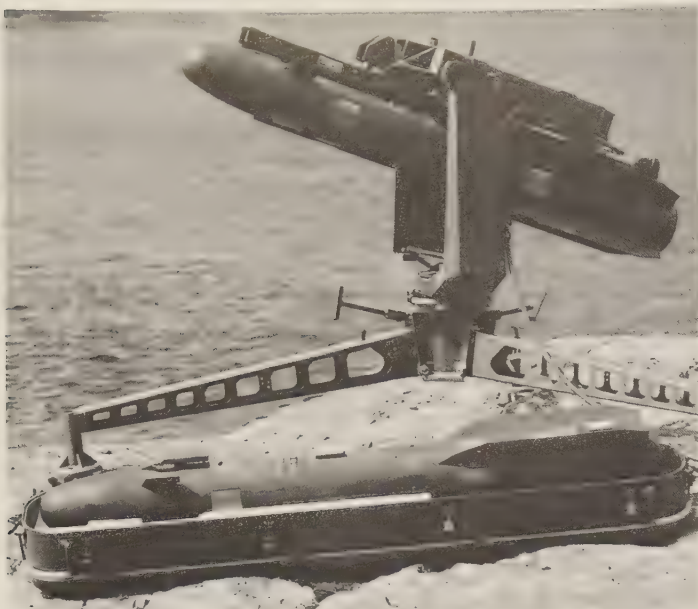
SLAT in action. (Martin Marietta)

◆ Hellfire (RBS 17; AGM-114A)

Dimensions: 7 × 64 in; span 14.25 in
Weight: 108.5 lb (compared to 99.6 lb antitank)
Warhead: approx 20 lb **Propulsion:** solid-fuel rocket
Speed: Mach 1+ **Range:** 3+ nm

This U.S. Army weapon, built by Rockwell, has been adapted for coast defense by the Swedish Navy. The missile is laser-guided (semiactive homing). As of 1988, 25 battalions were scheduled for formation, to replace 32 battalions firing French SS 11 wire-guided missiles (1989–95). The first 700 missiles were ordered in June 1987. The air-launched version, which has 2 shaped-charge warheads in tandem (for follow-through attack against, e.g., reactive armor) is the primary armament of army AH-64 attack helicopters and of Marine Corps AH-1W and AH-1J attack helicopters. The Swedish version has an antiship warhead (Bofors blast-fragmentation, downward-pointing) and a modified autopilot. It is fired from a portable launcher.

The missile is designed as a combination of 4 modules: seeker, warhead, autopilot, and motor. The standard army version uses a semiactive laser seeker, an analog autopilot, a



Hellfire (RBS 17) in its coast-defense version. The missile weighs 48 kg (with its container, 71 kg). (Bofors)

shaped-charge warhead, and a minimum-smoke motor. Rockwell offers some other options: IIR, RF/IR, or mm-wave seekers; a digital autopilot; a multipurpose warhead; and an extended-range (pulsed) motor.

The Swedish designation is RBS 17, and in Swedish service the laser designator is the El-Op PAL (portable advanced laser). Hellfire made 4 hits out of 4 shots at a range of 5 km in initial Swedish tests in September 1989. The laser designator has an effective range of 8 km. Reportedly, the Norwegian Navy is interested in buying Hellfire for coast defense.

The U.S. Navy already buys Hellfire for Marine Corps helicopters and in 1987 tested it as a possible SEAL-boat weapon. In 1989 it was again tested by the U.S. Navy, 4 being fired from an LTV Crossbow launcher on board the SES-200 surface-effect ship, and 3 being fired from a Crossbow ashore. In the shipboard tests, 1 hit a "billboard" target and another a 56-ft target boat, at a range of about 3000 yd. Two others missed a smaller target boat. The missile is being considered for a projected class of coastal patrol boats.

Hellfire entered U.S. Army service in January 1985.

The basic missile is being improved, probably with a tandem warhead (to defeat reactive armor) and a multipulse motor (for longer range). Two new passive (fire-and-forget) seekers are under development, a joint services 3-5 micron focal-plane IIR array (Ford Aerospace/Texas Instruments) and a mm-wave seeker. The latter is being developed by Martin Marietta/Westinghouse under the U.S. Army Airborne Adverse Weather Weapon System program (Longbow). Marconi is developing an active mm-wave seeker (in a Hellfire version called Brimstone) to meet an RAF Staff Requirement (SR(Air) 1238) for a fire-and-forget weapon to attack second-echelon tanks. Flight tests of rounds with digital autopilots began in early 1988. Missiles so fitted can use more maneuvering power, can dive more steeply, and can be launched from high-speed fixed-wing aircraft.

The army contract for the conceptual design of the optimized missile was let in June 1989. Goals were reduced weight, length, and unit cost, as well as hardening of the laser seeker against countermeasures. This program includes work on the future seekers described above.

◆ Crossbow

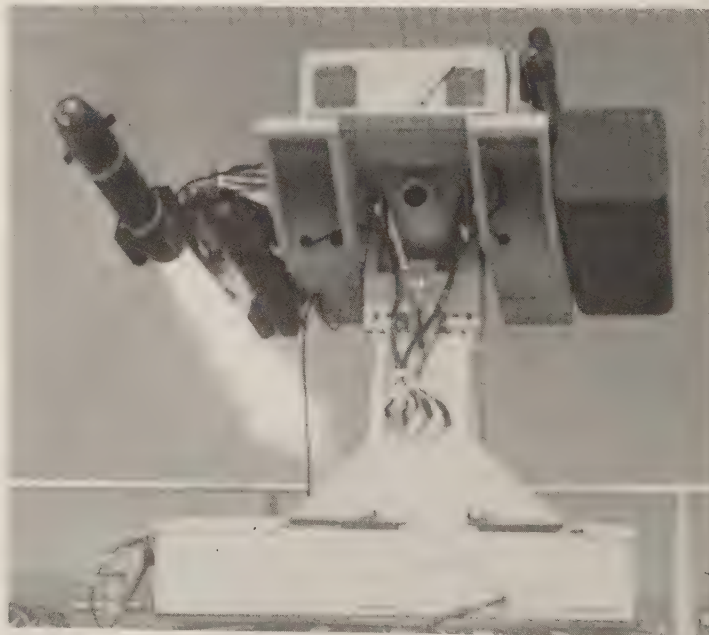
LTV's Crossbow is a stabilized pedestal-mounted stand-alone weapons platform suitable for fast attack craft. Crossbow is included in this section because its most likely application is to carry small antiship missiles on board craft in the same class

as the current 65-ft Patrol Boat Mk 3 and 4. The platform has also been demonstrated on board trucks and on board wheeled and tracked personnel carriers. Crossbow carries a television camera and can accommodate a FLIR and a laser designator or range-finder. The system is designed for automatic target acquisition and tracking while the off-mount operator identifies the target, selects the weapons, and (according to LTV) optimizes the firing. The latter phrasing suggests some form of computer threat evaluation and even weapon assignment. The system automatically leads the target.

Elevation limits are $+75/-10$ deg, and total weight, including up to 1500 lb of weapons and sensors, is less than 3000 lb. LTV lists a wide variety of missiles and guns suitable for the Crossbow pedestal, including Hellfire, the British Starstreak, TOW, the French Mistral, the U.S. Stinger, the Swedish RBS 70, a variety of unguided rockets, 0.30- and 0.50-caliber machine guns, the Oerlikon KAA 20-mm cannon, the Mauser 25-mm cannon, and the Bushmaster (Mk 38) cannon. There is an associated fire-control console incorporating a gripstick.

Acquisition and tracking tests were conducted on board the surface-effect landing craft LACV-30 at Patuxent River, as part of a PMS 300 Foreign Weapons Evaluation effort (the weapon in question was the Bofors-modified version of the Rockwell Hellfire, its foreign feature providing the occasion for evaluation). The tests are a collaborative NAVAIR/NAVSEA effort, and NAVSEA is paying for further evaluation for a near-term application to Special Warfare (i.e., to craft like the 65-footer). The Crossbow on LACV-30 managed to track surface and air targets, such as Cobra helicopters and Septar fast surface targets, in a simulated firing mode. The laser could not be demonstrated in the LACV-30 tests because of range safety limitations. The next test stage was a series of 3 unguided missile firings at Huntsville, Alabama, to test the ability of the launcher to overcome transient firing motions, so that its laser designator can be held on the target. Early in April 1989 Crossbow was to be tested at Yuma, firing guided weapons from a Hummer truck. A seagoing mount was tested on board the SES-200 surface-effect craft late in September 1989.

At the U.S. Navy League show in March 1989, LTV displayed a model of Crossbow carrying a pair of Hellfires on one side, a 2.75-in rocket pod on the other, and a 0.50-caliber machine gun.



Crossbow launches a Hellfire missile during a shipboard test, 1989. During other at-sea tests, Crossbow has successfully launched RBS 70 missiles and 2.75-in rockets and has fired a 0.50-cal machine gun and the 25-mm automatic cannon. The window (with wiper) visible above the launcher carries the system sensor, a military-rated television camera. (LTV)

◆ Sea Ray

Dimensions: 8 × 118 in **Weight:** 400 lb
Warhead: 150-lb fragmentation
Propulsion: Mk 78 solid-fuel rocket motor
Speed: subsonic **Range:** ca 7 km [7700 yd]

Texas Instruments announced in 1985 that it was developing this missile for an unnamed foreign customer, most likely South Korea. The missile can be fired from shipboard, from a helicopter, or from an airplane. Sea Ray uses many existing components: the Paveway III laser and guidance unit and the Shrike Mk 78 motor. The missile flies a ballistic path until the laser designator is switched on, about 10 sec before expected impact. Texas Instruments stated that during sea trials on board the customer's ships, a round hit the target at 7-km range within 9 in of the nominal aim point.

Development began in 1981, and Sea Ray may have entered service in 1987. Sea Ray is also the name of a fiber-optic guided-naval-missile program under development at the Naval Ocean Systems Center in Hawaii (see below).

◆ Fiber-Optic Weapons/Sea Ray

There are several ongoing programs for fiber-optically guided missiles. Such weapons exploit the high-data capacity of an optical fiber, sending back to the operator an image of the scene they observe. The link is unjammable and, in theory, undetectable. It should also be quite inexpensive, as the only sensor aboard the missile is a simple television camera. Such missiles should also be stealthy since they do not use emitting sensors. Fiber-optics might be seen as a way to achieve the advantages of an imaging sensor without the great cost of automatic interpretation inside the missile. The first project of this type was the army FOG-M, now defunct; Boeing is now trying to sell the army a fiber-optically guided mortar round (FOMP).

As of early 1989, a ship-launched antiship weapon, Sea Ray, was under development at the Naval Ocean Systems Center, Hawaii. No details were available. Meanwhile, China Lake was testing a fiber-optic link for Walleye. Skipper is being developed in fiber-optic form (at the specific behest of Congress, using FOG-M technology; it is called FOG-S and is a technology-demonstration program). The FOG-S project began in FY88, and the FY89 program included completion of the demonstration of the fiber-optic data link as paid out from a single pylon, using a FOG-M missile. That year's program also included initial work on longer-range payouts from an alternative air vehicle (e.g., Recoverable Test Vehicle) and/or steps toward exploring issues in powered Paveway vehicles (interaction between the missile exhaust and the fiber) and advanced seekers.

The FY88 Advanced Technology Transition program (which develops technology for near-term application to specific systems) included work on an ultra-low-loss, coated fluoride fiber, work on Sea Ray, and also work on an all-optical towed array. The FY89 program included a 10-km test of advanced fiber-optics technology and a demonstration of Sea Ray. At that time Sea Ray was scheduled to transition to development during FY90.

There is also a Fiber-Optic Technology program. Hughes has developed a range of fiber-optic missile links. Up to 100 km of fiber has been wound on a spool 0.3 m in diameter × 0.6 m long, and Hughes hopes ultimately for ranges up to 400 km.

See also the Franco-German Polypheme-SM.

◆ Standard Missile

See Antiaircraft Warfare section.

◆ Tomahawk (BGM-109)

See the Strategic Strike Systems section.

UNGUIDED BOMBS AND AIR-LAUNCHED ROCKETS

FRANCE

◆ Bombs



An Étendard attack fighter displays the standard French guided and unguided weapons, including the standard rocket pods and AS 30 missiles and DEFA 552A guns. (ECP Armées)

Super Étendards carry 250- or 400-kg [551- or 882-lb] free-fall or retarded bombs. Typical dimensions are 273 × 2253 mm [10.75 × 88.7 in] or 324 × 2121 mm [12.75 × 83.5 in] for 250 kg, and 403 × 2195 mm [15.9 × 86.4 in] for 400 kg.

The standard French laser-guided bomb is the BLG 400 or BLG 1000 (400 kg and 1000 kg, respectively). It uses a Thomson-CSF seeker. Development began in 1978, and trials (BLG 400) began in 1984, with deliveries (including export orders for Iraq and at least 1 other customer) beginning in 1985. Standoff range is 2–8 km. BLG 400 is specifically described as having an antiship capability. BLG 1000 has a dual-charge warhead to penetrate heavy structures; it entered service in 1988. A BLG 250 is now being developed.

◆ Dispenser

The Super Étendard can carry an Alkan 530 bomblet dispenser carrying 2 blocks, each with twenty 74-mm [2.9-in] Thomson-Brandt grenades or cartridges in tubes facing sideways. Each cartridge is 74 × 214 mm [2.9 × 8.4 in] and weighs 2 kg [4.4 lb]; each grenade is 70 × 190 mm [2.76 × 7.5 in] and weighs 1.6 kg [3.5 lb]. Cartridges carry chaff and IR flares. Grenades are parachute-retarded antiarmor bomblets, which can penetrate 200 mm of armor.

◆ Durandal/CBU-15

This French (Matra) antirunway bomb is in service with 10 nations. It was nearly adopted by the United States but was rejected in favor of the U.S. Air Force's developmental hard-structures munition. In the absence of such a bomb, it takes an enormous, perhaps prohibitive, number of sorties to achieve any reasonable chance of putting a concrete runway out of action. Given the immature state of hard-structures munition development, Durandal may yet become attractive to the U.S. Navy. The U.S. designation is CBU-15.

The bomb can be dropped at altitudes down to 200 ft and at speeds of 400–625 mph. It is braked by a double parachute, and an internal rocket fires when it reaches a 20–30-deg down-angle. At a terminal velocity of about 850 ft/sec, its forged steel nose penetrates up to 16 in of concrete. A 1-sec delay fuze bursts it under the runway to form a crater about 6.5 ft deep and 16 ft in diameter, with a lip pushed up out to a radius of about 23 ft, and concrete fractured farther out.

The standard tactic is to drop Durandal from triple ejector racks; 6, 9, or 10 such bombs (which can be delivered by 2 aircraft) being considered sufficient to disable a typical runway. Dimensions: 223 mm × 2700 mm [8.8 × 106.3 in]; fin span

430 mm [16.9 in]; weight 219 kg [483 lb]. The warhead weighs 100 kg [202 lb]. Durandal entered service in 1977.

◆ Nuclear Weapons

The standard bomb carried by the Super Étendard is the AN.52; it is now being retired in favor of the ASMP standoff missile. Reportedly, there are 2 versions of the bomb, with yields of 25 kT (elsewhere reported as 15 kT) and 6–8 kT. The bomb weighs about 1300 lb.

◆ Rockets

Super Étendards carry Matra 155 pods (eighteen 68-mm [2.68-in] rockets). This pod can also be carried by British Sea Harriers. There are 2 types: first-generation rockets with unitary warheads (shaped-charge, blast-fragmentation, or chaff); and second generation multidart warheads (antiarmor or illumination). Typical dimensions are 68 × 910 mm [2.68 × 35.8 in], 5 or 6.2 kg [11 or 13.7 lb] for first generation; 68 × 1380 mm [2.68 × 54.3 in], 8.3 kg [18.3 lb] for second generation. Range is 1000–4000 m [1095–4375 yd].

USSR

◆ Bombs

Soviet naval aircraft carry gravity bombs as well as missiles. For example, naval Badgers dropped bombs in Afghanistan. The Yak-38 Forger VTOL fighter can carry 250- and 500-kg [551- and 1102-lb] free-fall bombs of various types. Reportedly, there are over a thousand different Warsaw Pact bombs, but that number may include numerous obsolete types.

Published designations consist of a prefix indicating the bomb type and then the weight in kilograms. Standard types include:

General-purpose Bombs (FAB Series): Both high-drag (World War II) and low-drag (equivalent to U.S. Mk 80 series) configurations. One published photograph shows a low-drag bomb being retarded by the Soviet equivalent of the U.S. ballute. The high-drag series are: FAB-8, -10, -15, -20, -25, -50, -110, -500, and -1000. Low-drag: FAB-100, -250, -500, -750, -1000.

Low-drag Blast-fragmentation: OFAB-250, -500.

Demolition (Thin-case): 100, 250, 750, 1100 kg.

Concrete Penetrators (Retarded): BETAB-250 and -500. There is also an M62 penetration bomb (500 kg; also exists in a 250-kg version).

Napalm (low drag): PLAB-250, -500. PLAB-150L is a reported designation for a 150-liter napalm bomb.

Incendiary (low drag): ZAB-100, -250, -500, -750, -1000; there is also a ZAP-200 incendiary container weapon.

Cluster Bombs: RBK-180 and -250; there is also an RAB-120 carrying fragmentation bomblets. RRAB (no weight given) contains incendiary bomblets. An RBK-250 carries 60 antipersonnel or 30 antitank bomblets. The former are AO-2.5-2, and each is about as effective as a single 81-mm mortar round. The shaped charge bomblets (number indicates weight of bomblet) are PTAB-1.5, -2, -5, and -5/1. There are also fragmentation bomblets (RAP-2.5, -3.5, -16). AK-2 is a dispenser for 240 1-kg chemical bomblets (mustard and Lewisite). DPT-150 is a reported cluster-bomb designation (54 PTAB-1.5, 44 RAP-2.5, or 34 RAP-3.5).

Dispensers: PKPE-1 contains twenty-nine 70-mm tubes, each containing 2 or 3 submunitions, launched laterally by a small charge; the submunitions are either blast-fragmentation grenades or shaped-charges (similar to the RPG-7 warhead). A helicopter or ground-attack airplane typically carries 2, firing to each side.

Chemical weapons: The Soviets have displayed high-drag bombs of World War II vintage and presumably have developed modern low-drag equivalents. VAP-200 is a container bomb;

VAP-1000 (BATT) is a dispenser (700 liters of hydrogen cyanide for low-altitude spraying); and KhAB-500 is filled with 180 kg of phosgene. VAP is probably a general dispenser designation, and newer weapons include an NOV-AB series of bombs containing nonpersistent toxic agents and an SOV-AB series containing persistent toxic agents.

It is not clear to what extent the designations quoted are of Western, rather than Soviet, origin.

◆ Nuclear Weapons

Reportedly, there are at least 14 types of tactical nuclear weapons. The current standard weapon is reportedly a 1000-kg bomb with a 350-kT yield, and a 700-kg bomb with a 250-kT yield is being introduced. Presumably, the Soviet nuclear depth bomb has a much smaller yield, on the order of tens of kT.

◆ Rockets

The Yak-38 Forger VTOL fighter can carry pods: UB 16-57 and UB 32-57 with, respectively, sixteen and thirty-two 55-mm S-5 series folding-fin rockets. The "57" refers to tube diameter. There are 9 warheads, including HEAT, high explosive, fragmentation, and chaff. Typical burnout speed is 620 m/sec [2034 ft/sec].

UNITED KINGDOM

◆ Bombs

The standard Sea Harrier load is 3 British Mk 13/18 or U.S. Mk 83 1000-lb bombs. During the Falklands War, Sea Harriers also delivered U.S.-supplied Paveway laser-guided bombs, reportedly using hand-held laser target-designators. Mk 13/18 is considerably fatter than the U.S. low-drag bombs but has a fairing for streamlining. Mk 13/18 can be fitted with a parachute retarder.

◆ Carrier Bomb Light Stores

Sea Harriers carry BL 755 bomblet dispensers (419 × 2451 mm [16.5 × 96.5 in], 277 kg [611 lb] loaded), which carry 21 shaped-charge/fragmentation bomblets in each of 7 compartments.

◆ Rockets

The standard Royal Navy rocket pod carries nineteen 2-in rockets; Sea Harriers also carry the French Matra 155 pod and the U.S. LAU-69/A (2.75-in FFAR).

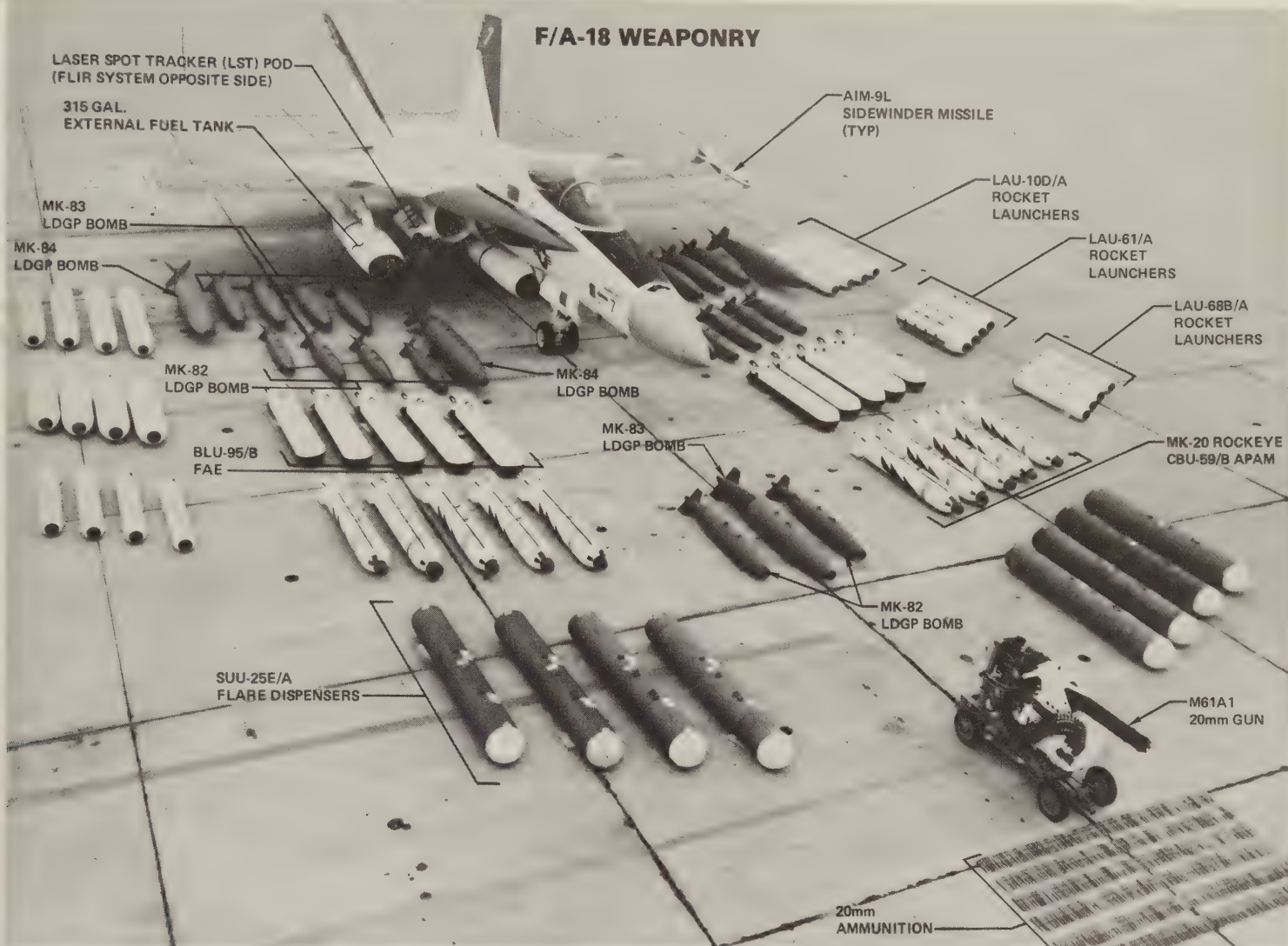
◆ Nuclear Weapons

Sea Harriers aboard the 3 light carriers are equipped to deliver tactical nuclear weapons. These probably are 200–400-kT WE-177A/B bombs of the type also carried by RAF aircraft, including the shore-based Buccaneers and Tornados assigned to maritime missions. The Royal Navy also uses a reduced-yield WE-177C nuclear depth bomb, the airframe of which may be related to that of the U.S. B57 (which British aircraft, such as the Nimrod, can carry). Shipboard Sea King and Lynx helicopters and shore-based Nimrods carry the depth bombs. An unofficial estimate credits Britain with a total of 180–200 WE-177s, of which 155–175 are A/B versions. All 3 versions use the same "physics package." Presumably, the versions correspond to the different yields of the U.S. "dial-a-yield" bombs, except that in the British case the yields are preset.

UNITED STATES

◆ Bigeye

Bigeye is a new binary chemical bomb, developed about 1985 but not yet deployed. The binary weapon is safer to handle than unitary munitions since its components are not lethal until they mix in the air. They mix only after release, to produce VX nerve gas, which the bomb sprays from its nose. Critics of this program have suggested that the mixing process is so lengthy that the bomb must be released either at high altitude or in a toss maneuver; both releases increase the vulnerability of the launching aircraft. In 1986 Congress repealed a 16-yr morato-



An F/A-18 can carry all the standard U.S. unguided weapons, which are shown here. LDGPs are low-drag (i.e., streamlined or "slick") general-purpose bombs; FAE is fuel-air explosive. (McDonnell Douglas)

rium on U.S. production of chemical weapons, but only for army 155-mm shells and not for Bigeye.

In 1986 the Grumman A-6 was validated for Bigeye delivery.

◆ Fuel-Air Explosives

Fuel-air explosives (FAE) are not currently in service, but several types have been developed, and presumably, they can easily be deployed. The only type used in battle in significant quantities was the BLU-73/B, containing 72 lb of ethylene oxide, 3 of which were carried by the CBU-55/B cluster bomb. CBU-55/B was tested in 1969-70 and standardized in 1971 for mine-field or landing-strip clearance. Each bomblet forms a fuel-air cloud about 15 m [about 50 ft] in diameter and about 2.5 m [about 8.5 ft] thick; in Vietnam such a cloud could clear a jungle area 30 m [about 100 ft] in diameter. The bombs also proved very effective against area targets since the blast wave was not stopped by buildings or small land features, such as hillocks.

CBU-72 was an improved version intended for delivery from fast aircraft.

Work on a second generation naval FAE, concentrated on an FAE glide bomb, began in 1973; the McNulty test was intended to simulate a near miss by such a weapon. Reportedly, there was also interest in underwater detonation of FAE as an ASW weapon, FAE warheads being exploded at simulated depths of 1500-2300 ft. Presumably, in these cases the warhead carries a compressed oxidant that is released together with the fuel; the

objective is a strong underwater shock wave. None of these weapons appears to have been adopted.

There was also a parallel U.S. Air Force program, begun in 1967, to develop a 2500-lb retarded FAE bomb (Pave Pat). An FAE cluster bomb, BLU-76, was designed specifically for delivery by the F-4 Phantom. Reportedly, the major difference between air force and navy FAE weapons was the fuze delay, more than 4 sec for the air force and 125 msec for the navy.

The most recent weapons are BLU-95 (XCL-1)/B and BLU-96 (XCL-1)/B, originally known as FAE-I and -II (500 and 2000 lb). Other types developed but not deployed included FAESHED, MADFAE, SLUFAE, HFS-I, and HFS-II. The CATFAE mine-clearance device is now under development. Work was already underway at China Lake as early as 1960.

FAEs are interesting as an attempt to get more explosive effect out of a given weight and volume, since weight and volume are strictly limited for any airborne weapon. The fuel carried by the bomb is mixed with the surrounding air to form an explosive mixture, then detonated when it reaches an appropriate density. The bomb, then, need not carry its own oxidant, whereas much of the weight of any conventional explosive is oxygen. For example, 100 kg of TNT contains 42 kg of oxygen in its molecules. On the other hand, 100 kg of propylene oxide takes 69 kg of oxygen from the air when it burns. For Decane, the ratio is 100:34; for aluminum powder, 100:89. In some cases, a conventional explosive, dispersed as a powder, reacts with air like an FAE; FAE and such powders are grouped with other high-impulse explosives under the name EBM (enhanced-blast munitions). Weight for weight, propylene oxide and aluminum release 7.9 and 7.4 times as much energy as TNT. Decane releases



The effect of a fuel-air explosion, shown in a sequence of 1972 photographs of a simulated near miss on the former destroyer escort *McNulty*. Note the dispersion of the cloud before the detonators are fired into it. The second and third photos show how the cloud envelops the ship and then goes off (note the shock wave in the water). (U.S. Navy)

10.3 times as much energy as TNT. These figures are not quite so encouraging for volume, but they are still impressive.

There are 2 problems. First, FAE is a pure-blast explosive. Most weapons combine blast and fragmentation, and the latter effect is often the most devastating. The burst of an FAE is quite dramatic, but often the structure being attacked is only lightly damaged. The ship illustrated here did eventually sink, but quite slowly. FAE is most effective against soft targets such as aircraft, communications antennas, missiles, unarmored vehicles, and troops. For a soft target, the FAE's lethal radius is generally far greater than that for TNT. Impulse (integrated pressure) can be as much as 100 times that for TNT, although peak pressure is less, and by no means comparable with nuclear effects.

Second, it is not easy to ensure that the FAE will detonate

properly. The fuel must be distributed just right, and the detonators must be distributed within the fuel cloud (and fired) just right. Wind, temperature, even humidity can ruin the effect.

◆ Low-Drag Bombs/Snakeye/Ballute

The Mk 80 series are the primary U.S. Navy bombs, developed in the late 1940s at the suggestion of Douglas Aircraft. All have the same aerodynamic shape (aspect ratio 8.5), the Mark number indicating the weight: Mk 81, 250 lb (9 × 76.1 in); Mk 82, 500 lb (10.8 × 90.9 in); Mk 83, 1000 lb (14 × 110.9 in); and Mk 84, 2000 lb (18 × 154 in). Ninety percent of navy bombs dropped in Vietnam were Mk 82s, with Mk 83s accounting for most of the rest.

The 2 main developments have been retarders and anticook-off casings. Retarders make low-level delivery practical (so the bombs will not explode directly under the airplane). The major current retarder is a set of 4 pop-out fins (Snakeye); but they are not always reliable, and accidents have occurred. Goodyear developed an alternative, the inflatable Ballute. Snakeyes may be designated with an R suffix, as in Mk 82R.

Anticook-off bomb casings reduce the risk inherent in flight-deck fires. A conventional Mk 82 in a fuel fire will cook off in about 4 min. A coated Mk 82 will last 9 min and will then burn rather than explode, so that it can be tossed off the flight deck.

After Vietnam an advanced general-purpose bomb (AGPB) program was begun, to produce improved 500-, 1000-, and 2000-lb weapons. The 500-pounder was a blast-fragmentation type for close air support, fuzed for either instantaneous or delayed explosion or for air burst. The medium bomb was designed for moderate penetration (e.g., against buried ammunition). The heavy bomb was a demolition weapon for attacking bridges, roads, and deep tunnels. AGPB never received very much funding, partly because the Mk 80 series had been manufactured in such great numbers during Vietnam, and partly because of a general belief that guided bombs had made unguided weapons obsolete.

◆ ABF

The new Advanced Bomb Family is to be compatible with the stealthy A-12 attack bomber; presumably, these are low-observable weapons that can be carried externally without compromising the stealth of the airplane. The bomb's stealth is more likely to be achieved by material than by shape.

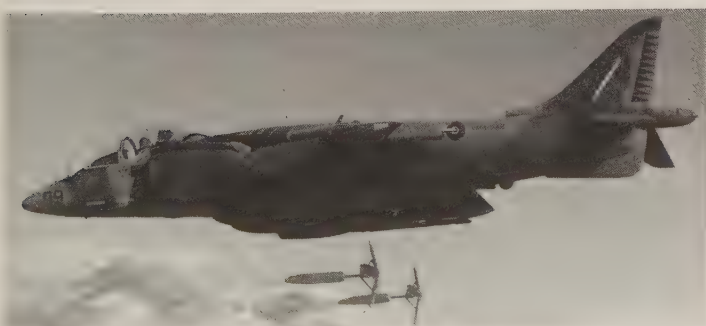
Lockheed exhibited its version of the ABF at the U.S. Navy League show in April 1990. The 500- and 1000-lb bombs are both cylindrical, differing only in length. Each is an all-up round, ready for flight in its shipping container. Fuze and retarder (parachute or ballute) are already in place. The fins fold to wrap around the bomb body, so they do not require preflight assembly. Fuzing option is selected in flight. The 500-lb version, replacing Mk 83, is a blast-fragmentation bomb; the 1000-lb version, replacing Mk 84, is a hard-target warhead capable of penetrating at least 1 ft of concrete. The all-up round configuration is attractive because it can drastically reduce turn-around time between sorties. The common fuze, to be developed as part of the program, will have settings for delivery mode (high/low drag), safe aircraft separation time, and bomb-burst time delay following impact. It will also incorporate an extended time (random delay) antitamper feature and an air-burst proximity sensor. The fuze will be able to accept signals from a future underwater mine adapter, so the bomb will be adaptable as a future Quickstrike bottom mine.

Some (25–40%) of the 1000-lb bombs produced will have inertial guidance systems with movable tail fins.

The Lockheed designs are only tentative since the RFP has not yet been issued (as of April 1990 it was expected in February 1991). The ABF Tentative Operational Requirement (TOR) was issued in 1983, and the OR in 1989. A formal Industry Briefing was scheduled for May 1990, with contract award in the first quarter of 1992 and production go-ahead late in 1995. Unit cost targets are \$3900 for the 500-lb version and \$5900 for the 1000-lb version.



Two Lockheed ABF bombs, the 500-pounder at left and the 1000-pounder, with fins unfolded, at right. The cutaway section shows the fuze and the retarding mechanism. (Lockheed)



An AV-8B Harrier II drops Snakeye (Mk 82) retarded bombs; note the fins opening. (McDonnell Douglas)

◆ Napalm

The current standard weapon is BLU-27 (750 lb, filled with 100 gal of Napalm-B).

◆ Nuclear Bombs

The current standard strike bomb is B61. However, there is also a version of the B57 nuclear depth bomb rated as a lay-down weapon. B57 is now quite old, and it is to be replaced by a dual-purpose nuclear depth bomb/nuclear strike bomb (NDB/NSB), B90, for which 1 candidate is a modified B61. The advantage of the dual-purpose weapon is that it limits the carrier magazine space that must be devoted to nuclear weapons. The B61 "dial-a-yield" bomb is the current standard air force/navy weapon. Development began in 1963, and B61 was fielded in 1967. The current Mod 5 entered service in 1977; the other current naval versions are Mods 0, 1, and 2. A new Mod 6, with improved safety and command features (presumably, a better permissive-action link), should enter service in 1991. The yields of these bombs can be adjusted ("dialed") without any modification of the internal physics package. The reported maximum yields vary with the version, 1 unofficial claim being 10–100 kT for Mod 0/2, 345 kT for Mods 3/5, and 900 kT for Mod 1. The minimum yield may be as low as 1 kT. Dimensions are typically 13.4 in × 10 ft 11 in. There is also an earlier high-yield nuclear bomb, B43 (18 in × 13 ft 8.5 in, 2060 lb). In 1990 the U.S. stockpile included 350 B43s, 1600 B57s, and 3025 B61s of various versions. An unofficial estimate credits the navy with 250 B43s, 475 B57s, and 625 B61s.

◆ Rockets

The 2 primary U.S. air-launched rockets are the 2.75-in folding-fin aircraft rocket (FFAR) and the 5-in folding-fin Zuni. Both are normally carried in pods.

FFAR ("Mighty Mouse") was conceived as an air-to-air weapon. It is 47.85 in long and weighs about 18 lb. The original 2.75-in rocket developed through motors Mk 1 through 4; the final version, Mk 4, developed 750 lb of thrust for 1.2–1.4 sec, accelerating the rocket to 2300 ft/sec [1570 mph]. Improvements over earlier versions increased warhead weight from 6 lb to 10 lb by the mid-1960s, and by that time range was 550–6500 yd (3750 yd effective). Mk 40 was a new motor for a helicopter-borne version. Because the helicopter is a slow platform, the nozzle is arranged to impart greater stabilizing spin.

The most common warheads of these versions of FFAR are M151 (10-lb HE, white phosphorus, or fragmentation), M156 (10-lb chemical), M229 (17-lb HE, white phosphorus, or fragmentation), and WDU-4A (flechettes). M151 is considered equivalent to an 81-mm mortar round, M229 to a 4.2-in mortar round. The flechette antipersonnel round developed from a program for improved artillery ammunition. There are also shaped-charge antitank warheads.

These rockets are typically carried in expendable 7-rocket (Aero 6, then LAU-32) or 19-rocket (Aero 7, LAU-3 and LAU-69) launchers. FFAR is sometimes carried by marine attack helicopters, and it was used against Iranian attack boats in the Persian Gulf.

Zuni replaces the earlier fixed-fin high-velocity aircraft rocket (HVAR), which may survive in some navies. It is 110 in long, weighs 107 lb, and reaches 2370 ft/sec, about 1400 kt. It is typically carried in a 4-rocket LAU-10 pod and has either a general-purpose or a shaped-charge warhead. During the Vietnam War ship-launched Zunis were used to disperse chaff (see the Antiaircraft Warfare section).

Under the FY88 program, work continued on an ongoing program to develop 2.75-in rocket submunitions (M261/267). Under the Foreign Weapons Evaluation program, the navy tested a Canadian Bristol Aerospace high-impulse 2.75-in rocket motor (CRV 7), and it conducted a NATO Cooperative Test (NCT) of a Raufoss HEISAP (high explosive, incendiary semi-armor-piercing, analogous to the company's 0.50-caliber bullet) anti-ship warhead and a Thomson-Brandt antimateriel warhead. De-

velopment of a chaff warhead began in FY89, with smoke screening, smoke marking, multimode, and antiarmor flechette warheads and an Advanced Rocket System improved launcher following in FY90. Presumably, the latter warheads are the army types described below under Hydra 70.

◆ Advanced Rocket System

Early in 1989 the U.S. Navy announced a program to develop an Advanced Rocket System to replace the existing 2.75-in weapon, to enter service in FY95. The new rocket motor is to provide a velocity (with a 10-lb warhead) of at least 1000 m/sec [3280 ft/sec] at zero aircraft speed; it is to have a low smoke signature (for stealthy operation), and it is to be insensitive (i.e., relatively safe aboard a burning carrier). Minimum effective range is to be 10,000 m (15,000 m in loft mode). The new weapon will reportedly use multipurpose warheads. Initial work is funded under the 2.75-in-rocket account, but a new ARS project is to begin formally in FY92. An RFP was scheduled for FY90. Apparently the new rocket, like the current 2.75, would be carried in a 19-weapon pod.

Reported mission requirements are: dry marking (to use a family of different colored markers other than the current toxic white phosphorus); antipersonnel (1 pod to cover 15,000 m²); antimateriel (to penetrate a minimum of 1.5 in of armor); antiarmor (to penetrate a minimum of 3 in of armor); antihelicopter (4 rockets to cover an area of 2500 m²); anti-coastal shipping (to penetrate 1 in of steel at a range of 4 km, with a delayed-action fuze and incendiary effect); chaff (for self-protection and deception); flare (1 million candlepower for 1.5 min); night marking (2-min marker, observable by FLIR and other night-vision devices); smoke screening (pattern 50 × 400 m, duration 5 min in less than 5–10 kt wind, effective in visual, IR, and ER spectra); and training. The requirements stated above are for ranges of up to 10 km (up to 4 km for the antishipping mission) and are to be met from a hovering helicopter.

Some slippage in the advanced rocket schedule is likely to leave the marines short of the current Hydra rocket. In June 1990 it was reported that the marines were 200,000 rockets (24%) below their wartime inventory requirement and, hence, had to reduce the level of firings in training. At this time the advanced rocket was in preliminary full-scale development, to be completed in FY95. The rocket, which replaces both Hydra and Zuni, is to enter service in FY97. It will use either the current Mk 66 motor or a new high-performance motor now under development.

◆ Hydra 70

Hydra 70 is the current U.S. Army and Marine Corps 2.75-in rocket, superseding the earlier FFAR; it is manufactured by BEI, the only current U.S. 2.75-in-rocket maker. A variety of warheads can be combined with the standard Mk 66 motor: M151 HE (10 lb nominal, actually 8.7 lb, of which 2.3 lb is Composition B-4), M247 (shaped-charge antitank), M274 TP (10 lb [training]), WTU-1 inert, M261 (MPSM), M267 (MPSM, training), M255 (flechette), M262 (illumination flare), and M264 RP (smoke). Chaff, smoke marker, and shot rocket warheads have not yet been standardized.

BEI is currently developing 2 alternative navy smoke markers for this rocket: an orange smoke marker and a multimode smoke marker consisting of smoke, chaff, and a pulsating flare. The latter is intended as a target marker rather than as a countermeasure.

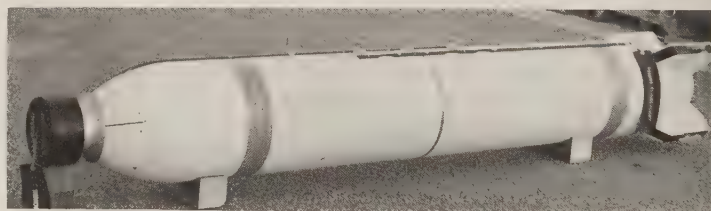
The Mk 66 motor supersedes the earlier Mk 4 and Mk 40; it has better performance and produces less smoke. Mod 1 is the standard army and air force version, Mod 2 the standard navy and marine version (it differs from Mod 1 in having a filter to protect the rocket from stray shipboard electromagnetic radiation). It achieves 1400 lb of thrust in 38 msec, providing a burn-out velocity of about 3300 ft/sec. The fluted nozzle spins the rocket to 600 rpm in the launcher and then to 2100 rpm in flight, for much better accuracy than previous U.S. 2.75-in weapons.

M261 is a multipurpose submunition warhead, carrying 9 M73 HE grenades and an expulsion charge that can be set by analog (to 6000 m) or digital (to 12,000 m) fuze. Each grenade has a shaped-charge to attack armor and is also scored internally for fragmentation. M267 is the corresponding training round. M264 ejects 72 red phosphorous wedges, to form a persistent smoke screen. The flechette warhead, M255, is currently being tested by the U.S. Army. It carries either 585 × 120-grain or 1200 × 60-grain flechettes, for air-to-air, air-to-surface, and surface-to-surface attack. The flechettes fly outward in a 6.5-deg cone when the rocket bursts, stabilizing about 150 yd from the point of burst to form a cylinder about 115 ft in diameter and 1 flechette deep, and moving at about Mach 2 (2400 ft/sec). The flechettes were originally developed to attack personnel; BEI proposes them as an antihelicopter weapon, effective out to 3500 m.

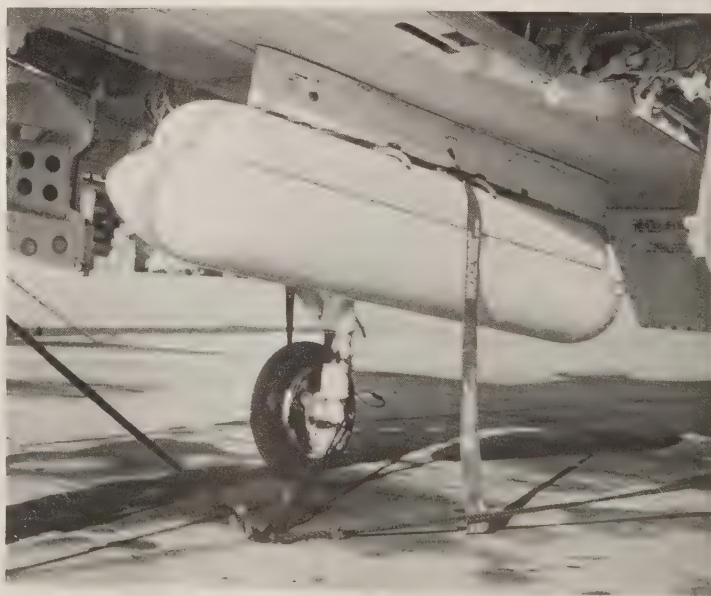
The shot rocket contains 2 clusters, each of seven 450-grain subrockets (kinetic penetrators), each with its own 21-mm rocket motor, to accelerate it by 1500 ft/sec, so that on impact each is traveling at about 4000 ft/sec. Applications include antiship attack, as well as attacks on armor and on aircraft such as helicopters.

◆ Rockeye/Sadeye/Gladeye/Gator

Rockeye is an unguided bomblet-dispenser. Unlike most such dispensers, Rockeye is dropped by the airplane carrying it, so the airplane need not fly directly over its target. This weapon was originally developed by China Lake and was widely used during and after Vietnam. The current Rockeye II carries 247 armor-piercing bomblets in a 13.2 × 92-in (94.5 in, including fuze cover) casing (490 lb total). Four fins pop out of the rear end of the casing (span 17.2 in closed, 34 in open). Minimum release altitude in level flight is 250 ft, or 100 ft in pitch-up (toss delivery). The typical bomblet pattern from 500 ft forms a 30,000-ft² oval. Each bomblet has a short standoff fuze and a shaped-charge warhead.



Rockeye (Cluster Bomb Mk 20 Mod 1). (U.S. Navy)



A Gladeye strongback with its submunitions containers. (U.S. Navy)

The basic Rockeye concept is well known, and many similar weapons are used by other forces. Chile produces its own version (Cardoen Industries).

The other major U.S. cluster bombs developed in parallel with Rockeye were Mk 15 (Sadeye) and Mk 17 (Gladeye); Rockeye is Mk 12, and Rockeye II is Mk 20. Sadeye is fin-retarded and carries 2100 bomblets. Gladeye uses 2 separate time-delay cartridges in a canister, which is itself carried on a standard strongback slung from a bomb rack. The strongback carries 7 Gladeyes, each filled with 330 M40 antipersonnel bombs.

The principal current naval cluster bombs are CBU-30, -52, -58, -59, and -71. The list below is more inclusive, as earlier weapons may still be available, and also as air force weapons may be available for naval use. It seems unlikely that the gas and BW bomblets listed below were ever deployed, and any examples produced have probably been destroyed.

Cluster bombs:

CBU-1 SUU-7 dispenser filled with 509 BLU-4 bomblets. SUU-7 was the first U.S. underwing (fixed) dispenser, launching bomblets to the rear by compressed air.

CBU-2 SUU-7 dispenser filled with 360 BLU-3 bomblets. *CBU-2B* is filled with 409 BLU-3 bomblets.

CBU-3 SUU-10 dispenser filled with 352 BLU-7 bomblets; total weight is 660 lb. *CBU-3B* is 371 BLU-7s in an SUU-10B dispenser.

CBU-7 SUU-31 dispenser filled with 1200 BLU-18s.

CBU-11 Smoke bomb: 261 BLU-16s in an SUU-7 dispenser.

CBU-12 Smoke bomb: 261 BLU-17s in an SUU-7 dispenser (640 lb).

CBU-13 Smoke bomb: mixture of 261 BLU-16s and -17s in an SUU-11 dispenser.

CBU-14 SUU-14 dispenser filled with BLU-3 bomblets.

CBU-15 Gas bomb: SUU-13 dispenser filled with BLU-19 bomblets.

CBU-16 Gas bomb: SUU-13 dispenser filled with CDU-9 clusters of gas bomblets.

CBU-17 SUU-13 dispenser filled with practice bomblets.

CBU-18 SUU-13 dispenser filled with BLU-25 bomblets.

CBU-19 Twin strongback for 16 modules, each carrying 33 BLU-39 gas bomblets.

CBU-22 Smoke bomb: 72 BLU-17s in an SUU-14 dispenser.

CBU-23 SUU-31 dispenser filled with BLU-26 bomblets.

CBU-24 SUU-30 dispenser filled with 665 BLU-26 or -36 bomblets. SUU-30 dimensions: 16.12 × 87.89 in (including nose cap).

CBU-25 SUU-14 dispenser filled with BLU-24 bomblets.

CBU-26 SUU-10 dispenser filled with dummy bomblets.

CBU-28 SUU-13 dispenser carrying 40 CDU-12 cluster units, each made of 120 BLU-43 bomblets.

CBU-29 SUU-30 dispenser filled with 670 BLU-36 bomblets (840 lb).

CBU-30 SUU-13 dispenser carrying 40 CDU-12 clusters, each made of 30 BLU-39 gas bomblets.

CBU-33 SUU-36 dispenser carrying 30 BLU-45 bomblets.

CBU-34 SUU-38 dispenser carrying 10 CDU-18 or -19 clusters, each of 54 BLU-42.

CBU-37 SUU-13 dispenser carrying 40 CDU-3 clusters, each of 120 BLU-44 bomblets.

CBU-38 SUU-13 dispenser carrying 40 BLU-49 bomblets.

CBU-41 SUU-51 dispenser carrying 18 BLU-53 bomblets (485 lb).

CBU-42 SUU-38 dispenser carrying 10 CDU-20 or -21 clusters, each containing 54 BLU-54 bomblets.

CBU-43 SUU-37 dispenser carrying BLU-48 bomblets (840 lb).

CBU-44 Antipersonnel fragmentation bomblets.

CBU-45 Cluster bomb carrying APAM bomblets (1000 lb).

CBU-46 SUU-7C dispenser carrying 640 BLU-24 or -66 bomblets (880 lb).

CBU-47 SUU-13 dispenser carrying BLU-55 bomblets.

CBU-49 SUU-30 dispenser carrying 670 BLU-59 bomblets (840 lb).

CBU-50 SUU-13 dispenser carrying 40 BLU-60 bomblets.

CBU-51 SUU-13 dispenser carrying 40 BLU-67 bomblets.

CBU-52 SUU-30 dispenser carrying 254 BLU-61 bomblets (770 lb).

CBU-53 SUU-30 carrying 670 BLU-70 bomblets (815 lb).

CBU-54 SUU-30B dispenser carrying 670 BLU-68 bomblets (815 lb).

CBU-55 FAE weapon: 3 BLU-73s, each 13.75 × 21 in (total bomb dimensions are 13.75 × 78.75 in). Each bomblet weighs 100 lb, including 72 lb of ethylene oxide; *CBU-55* weighs 460 lb (500 lb nominal) and has a retarding drogue chute.

CBU-57 SUU-14 dispenser carrying 132 BLU-69 bomblets.

CBU-58 SUU-30 dispenser carrying 650 BLU-63 bomblets.

CBU-59 Rockeye II, carrying 717 BLU-77 bomblets.

CBU-60 SUU-60 dispenser filled with 264 BLU-24 bomblets.

CBU-61 Gas bomb (using bomblets).

CBU-61 SUU-30 dispenser carrying M38 fragmentation grenades (840 lb).

CBU-63 SUU-30 dispenser carrying M40A1 fragmentation grenades (each 23 lb; total 840 lb).

CBU-66 SUU-51 dispenser carrying CDU-24 canisters carrying BLU-81 bomblets; canceled.

CBU-68 SUU-30 dispenser filled with BLU-48 bomblets.

CBU-70 SUU-30 dispenser bomb.

CBU-71 (*Gator*) SUU-30 dispenser carrying 670 BLU-86A/B fragmentation bomblets, or *Gator* antitank or antipersonnel mines.

CBU-72 FAE bomb, carrying 3 BLU-73s (see *CBU-55*, above). In this case the bomblets burst at an altitude of 30 ft, each creating a cloud 60 ft in diameter and 8 ft thick, producing 300 psi overpressure when it explodes.

CBU-75 SUU-54 dispenser carrying 1800 BLU-63 bomblets.

CBU-76 SUU-51B dispenser carrying 290 BLU-61 bomblets.

CBU-77 SUU-51B dispenser carrying 790 BLU-63 bomblets.

CBU-78 SUU-58 dispenser carrying 45 BLU-91 and 15 BLU-92 bomblets. Dimensions: 13 × 85 in (490 lb). This is the U.S. Navy version of the *Gator* air-delivered land mine system. The dispenser is a modified Rockeye.

CBU-83 SUU-58 dispenser carrying BLU-92 bomblets.

CBU-84 SUU-54 dispenser carrying BLU-91 or -92 bomblets.

CBU-86 SUU-4 dispenser carrying BLU-92 bomblets.

CBU-87 Combined Effects Munition using the SUU-65 dispenser and 202 BLU-97 bomblets. It is intended to replace the Rockeye series and *CBU-58* in air force use. Bomblets can be

delivered at any altitude over 200 ft and at any speed up to 700 kt, the dispenser spinning at a selectable rate of 0-2500 rpm.

CBU-89 Gator dispenser, consisting of SUU-65 carrying 72 BLU-91s and 22 BLU-92s (total 710 lb); it can be dropped from 200-40,000 ft. Dimensions: 16 × 92 in, including protruding nose fuze. This is the U.S. Air Force version of the Gator air-delivered land mine system.

CBU-92 Extended-range antiarmor munition, now under development by the air force for deployment in 1993; it is an SUU-65 dispenser carrying 9 antitank and 3 area-denial submunitions. The antitank submunitions carry Skeet submunitions of their own, plus fuzes capable of classifying objects within a range of 500 ft and then firing 2 Skeets at them. See BL-108, below. Total weight is 950 lb.

CBU-97 Sensor-fuzed weapon (SFW), the air force weapon now under development for direct attack against armored formations. Dimensions: 15.6 × 92 in, using an SUU-64 dispenser carrying 10 BLU-108 bomblets, each carrying 4 Skeets. In this application the Skeets are released in flight, and each uses its own IR sensor to decide when to burst.

Bomblets:

BLU-3 1.75 lb "Pineapple" bomblet for use against unarmored vehicles, carrying a 0.35-lb Cyclotrol filling and 250 steel pellets.

BLU-4 1.2-lb antimateriel bomblet, firing a spherical fragmentation device to explode 10 ft above ground. This is the filling of the CBU-1 bomb.

BLU-7 1.4-lb antitank (shaped-charge) bomblet using a stabilizing parachute.

BLU-16 1.6-lb cylindrical smoke bomblet.

BLU-17 1.1-lb cylindrical smoke bomblet (white phosphorus).

BLU-18 0.4-lb triangular antipersonnel fragmentation bomblet with delay fuze.

BLU-19 Gas bomblet.

BLU-20 Gas bomblet.

BLU-21 BW bomblet.

BLU-22 BW bomblet.

BLU-24 1.2-lb "Orange," a spherical antipersonnel fragmentation bomblet using plastic fins and a spin-delay fuze; its case contains 300 embedded steel fragments.

BLU-25 Cylindrical antipersonnel bomblet.

BLU-26 1.2-lb "Guava" spherical antipersonnel and antimateriel bomblet, 2.36 in in diameter, filled with 0.7 lb of Cyclotrol or TNT; forming 600 steel fragments (lethal to a 40-ft radius) on detonation. It has an air burst, impact, or delay fuze. The air burst is set at a height of 30 ft, and the delay can be 1 min or more.

BLU-36 0.95-lb antipersonnel and antimateriel (APAM) bomblet with a random-delay fuze.

BLU-39 0.18-lb gas bomblet.

BLU-40 1.7-lb fragmentation bomblet with random-delay fuze.

BLU-41 Spherical fragmentation bomblet with spin-arming and a spin-delay fuze.

BLU-42 Spherical antipersonnel minelet, 0.25 lb of Composition B explosive.

BLU-43 "Short Dragontooth," a triangular antipersonnel blast minelet.

BLU-44 "Long Dragontooth," a triangular antipersonnel blast minelet.

BLU-45 Shaped-charge antitank minelet.

BLU-46 Antipersonnel bomblet.

BLU-47 General-purpose bomblet.

BLU-48 Spherical fragmentation bomblet.

BLU-49 13.4-lb ring-tailed fragmentation bomblet.

BLU-53 Canister fire bomblet (Napalm-B).

BLU-54 Antipersonnel minelet (BLU-42 with long-life self-destruct).

BLU-55 Antipersonnel minelet.

BLU-59 0.95-lb fragmentation bomblet identical to BLU-26 but with shorter-life fuze.

BLU-60 13-lb fragmentation bomblet.

BLU-61 2.2-lb spherical antipersonnel/antimateriel, incendiary/fragmentation bomblet (filled with zirconium and Composition B).

BLU-62 0.95-lb antipersonnel and antimateriel fragmentation bomblet; bounces into the air upon impact.

BLU-63 0.95-lb spherical antipersonnel and antimateriel bomblet with spin and impact fuzes; prefragmented casing.

BLU-66 1.1-lb "Pineapple" spherical antipersonnel bomblet with plastic fins and 260 steel fragments embedded in its casing; impact fuzed.

BLU-67 11-lb cratering bomblet.

BLU-68 0.93-lb spherical incendiary antipersonnel and antimateriel bomblet (APAMB) with zirconium sponge filling.

BLU-69 1.6-lb spherical incendiary antipersonnel and antimateriel bomblet (APAMB).

BLU-70 0.88-lb spherical incendiary antipersonnel and antimateriel bomblet (APAMB).

BLU-73 100-lb FAE bomb, see CBU-55 above.

BLU-77 1.02-lb antitank fragmentation bomblet, intended to discriminate between hard and soft targets, and also with a secondary antipersonnel function (in which case the shaped-charge warhead bounces the bomblet up into the air to burst).

BLU-81 Antivehicle minelet, canceled.

BLU-86 1-lb fragmentation bomblet.

BLU-87 Dummy fragmentation bomblet.

BLU-91 "Gator" antitank minelet, 5.75 × 5.0 × 2.6 in (4.3 lb). Microelectronics in the minelet detect a vehicle and discriminate against unarmored vehicles. An upward-pointing shaped charge (Misznay-Schardin explosive) destroys the vehicle's belly armor.

BLU-92 "Gator" antipersonnel minelet. Dimensions match those of BLU-91, but weight is 3.7 lb. This minelet is intended to discourage attempts to clear BLU-91 mine fields.

BLU-97 3.4-lb submunition of the CBU-87 Combined Effects Munition; dimensions are 2.5 × 6.6 in (10.2-in length with tail extended). The bomblet contains a shaped charge at one end, a fragmenting shell (which disperses when the charge explodes), and an incendiary element.

BLU-106 43-lb (4 × 53.5 in) boosted kinetic-energy penetrator (BKEP) to be carried by Tomahawk cruise missiles (28 bomblets in 2 bays), by the SUU-54 dispenser (AGM-130 missile), and by the SUU-64 dispenser in the Direct Airfield Attack Combined Munition. The warhead is 6.5 lb of HE, and the rocket driving the bomblet into its target is fired when its nose dips below 65 deg below the horizon.

BLU-108 Skeet: each submunition carries 4 Skeet self-forging fragment antitank bomblets, each with its own IR sensor. The

explosive fuze inside the bomblet accelerates the fragment to 9000 ft/sec.

It was reported in 1988 that 40,000 of the 120,000 Rockeye II in U.S. service are to be modernized. Their filling will be replaced by insensitive explosives, and the bomblet casings will be prefragmented. This program is being conducted by the Tactical Systems Division of ISC Technologies (now Ferranti International Signal).

◆ Weteye

Weteye is the unitary chemical bomb analogous to the Mk 80 series. Weteye is currently considered unacceptable for ship-board use because of the danger of leakage; hence the need for Bigeye (see above). As of early 1985, 888 Weteyes were held in U.S. Navy inventory, for use from shore bases. The U.S. Navy also had Cluster Bomb Mk 23, Padeye, which carried 15 gas bomblets, but it is not certain whether this weapon was ever produced in numbers.

AIRCRAFT GUNS

FRANCE

◆ DEFA 552A

Caliber: 30-mm/47 **Muzzle Velocity:** 815 m/sec [2674 ft/sec]
Rate of Fire: 1250 rnds/min **Ammunition Supply:** 125 rnds/gun
Weight: 81 kg [179 lb]

This gun arms the Super Étendard strike fighter (2 carried). Rated barrel lifetime is 5000 rnds. DEFA 552A is a revolver cannon descended from the World War II Mauser MG213C (as is the British Aden). The ammunition is the same as that of the Aden 30-mm cannon.

The revolver has 5 cartridge chambers. Two positions are for loading, one is the firing position, one is for ejection, and one is empty for safety. The gun is gas operated.

DEFA 552 is the production version of DEFA 551, development of which was completed in 1954. Work on a successor, DEFA 553, began in 1968, with first deliveries following in 1971. The rate of fire is increased to 1300 rnds/min, and the new barrel has a 5000-rnd lifetime. The major change is that ammunition can be fed from either side without modification, for easier installation. DEFA 552A, the version in the Super Étendard, incorporates the longer-life barrel and cylinder introduced in DEFA 553.

GERMANY (WEST)

◆ Mauser BK 27

Caliber: 27-mm/62.96
Muzzle Velocity: 1025 m/sec [3363 ft/sec]
Rate of Fire: 1700 or 1000 rnds/sec (other rates selectable)
Ammunition Supply: 180 rnds/gun (Tornado)
Weight: 100 kg [202.5 lb]

This gun arms German Tornado strike fighters. The status of a project to develop a 4-barrel CIWS version is uncertain. BK (Bordkanone) 27 is a gas-operated revolver cannon. Projectile types are AP, APHE, APHE-SD, HE-SD, TP, and TP-FP. Ammunition can be fed from either side. The high rate of fire is intended for air-to-air use, the lower rate for air-to-ground firing. The weapon is unusual in that, although the Tornado program was multinational, it did not use an existing standardized NATO round. It seems likely that the caliber was chosen specifically to achieve a very high muzzle velocity within the weight available.

BK 27 is also carried by German Alpha Jet close-air-support aircraft, by the Swedish Gripen fighter, and by other Tornados.

BK 27 is the latest derivative of the German Mauser MK 213 of World War II, an attempt to achieve higher rates of fire than were previously possible. A conventional gun suffers in 2 ways. First, it must wait through a cycle of recoil, cartridge ejection, reloading, and chambering between firings. Second, that cycle is prolonged because it involves a considerable mass moving back and forth, accelerating and stopping. These problems

worsen if the gun has to fire at high velocity, since the moving breechblock has to be quite massive. Thus, conventional, World War II—aircraft machine guns divided into 2 types: weapons firing relatively light projectiles at high cyclic rates, and others firing much more energetic projectiles at lower cyclic rates. MK 213 tried to combine the virtues of both, which the Germans considered necessary when firing at fast airplanes. The revolver attacks both problems. Each time the gun fires, the chamber in which firing occurs moves away and a loaded and prepared chamber comes into line with the barrel. Second, the cylinder revolves, so there is no start-and-stop motion. Moreover, since the cylinder ejection position is not in line with the breech, cartridges can be punched directly out the back of the gun, making for a simpler design that can be fed from either side.

MK 213 was conceived in 1942, and a prototype was completed that year, but it did not enter service as scheduled in January 1944; at the end of the war there were only 5 firing prototypes and 10 assembled guns. France captured the Mauser factory and developed the MK 213 into its DEFA 552 series. The British equivalent was the Aden gun, and the U.S. version was the M39 (used only by the air force).

A Gatling gun might be considered an extension of the revolver cannon in which each chamber of the revolver is furnished with its own barrel. The advantage is simplicity. Since no gas seal need be made between chamber and barrel, more of the total gas energy can be used for firing. However, the greater inertia of the Gatling limits the rate at which it can be run up to full firing rate, and the motion of the barrels introduces some inaccuracy (the barrel moves sideways while the bullet travels down it).

USSR

◆ GSh-23L

Caliber: 23-mm (0.44-lb projectile)
Muzzle Velocity: 890 m/sec [2920 ft/sec]
Rate of Fire: up to 3000 rnds/min
Ammunition Supply: 200 rnds **Weight:** approx 72 kg [160 lb]

The podded cannon of the Forger VTOL carrier fighter is a twin-barrel gun based on the Gast principle (first tried by the Germans during World War I): the 2 barrels, which are connected by a rocker arm, fire alternately.

The carrier-based Su-27 and MiG-29 are armed with GSh-30-1, which is presumably a new single-barrel 30-mm gun. Because of the need to achieve a high rate of fire, it is presumably a revolver weapon.

◆ NR-23/AM-23

Caliber: 23 mm (0.44-lb projectile)
Muzzle Velocity: 690 m/sec [2260 ft/sec]
Rate of Fire: 850 rnds/min
Weight: 39 kg [86.0 lb]

The twin-turreted NR-23s and AM-23s arm Soviet land-based naval bombers. Some aircraft also carry fixed forward-firing weapons with longer barrels; the data above apply to the short-barreled version. This gun was introduced in 1949. Many bombers (such as later Badgers) are armed with the improved AM-23, which weighs 43 kg [94.8 lb] and is capable of firing 1300 rnds/min. The Badger is typically armed with 7 cannons: a long weapon in the nose (PU-88 mount, with 100 rnds), a twin remote-controlled dorsal turret (DT-V7, 500 rnds, elevation limits +90°–3 deg), a twin remote-controlled ventral turret (DT-N7S, 700 rnds, 95-deg traverse either way, elevation limits +2°–90 deg), and a twin tail turret (DK-7, 1000 rnds, 70-deg traverse either way, elevation limits +60°–40 deg). The overall FCS, which is based on the old U.S. system developed for the B-29, is designated PVB-53C. The tail turret employs a PRS-1 (Argon) radar.

UNITED KINGDOM

◆ Aden Mk 5 Cannon

Caliber: 30-mm/47.8 (projectile approx 1.1 lb)

Muzzle Velocity: 790 m/sec [2590 ft/sec]
Rate of Fire: 1200–1400 rnds/min
Ammunition Supply: 150 rnds/gun **Weight:** 87 kg [192 lb]



A Sea Harrier shows its 30-mm Aden gun pods, as well as 2 Sidewinder air-to-air missiles. (British Aerospace)

Carried by Sea Harrier and AV-8A/8C fighters in a detachable 2-gun pallet, the Aden (Armament Design Establishment, manufactured at Enfield) is a gas-operated revolver cannon based on the World War II German Mauser MK 213 and is broadly comparable to the French DEFA 552. MK 213 existed in both 20- and 30-mm calibers, the French choosing the former and the British the latter. Work on the Aden gun began in September 1945. A formal Air Staff requirement was issued in March 1947, based on the MK 213/30 and its low-velocity (530 m/sec [1740 ft/sec]) ammunition (the 20-mm version used a much higher velocity round, 1050 m/sec [about 3400 ft/sec]). The German barrel was 43.3 calibers long, and its rate of fire was 1150 rnds/min (the 20-mm version was 80 calibers long, and it fired at 1200 rnds/min). After initially adopting the 30-mm caliber, the British then derived a 20-mm version from it (ADEN 30/20), but by July 1950, 30/20 development had been suspended in favor of the original 30-mm version. The gun was first flight tested in a Beaufighter in August 1951, and the low-velocity (LV) ammunition was approved for service in 1953. By that time, however, work was already proceeding on a high-velocity (HV) alternative, which was approved for service use (superseding the LV) in 1955. The LV attained a muzzle velocity of 603 m/sec, compared to 713 m/sec for HV [respectively, 1980 and 2340 ft/sec], both of which could be compared to 1215 m/sec [3985 ft/sec] for the 30/20.

Mk 4 was the main production version. Mk 5, which arms the Sea Harrier, is a modernized Mk 4 with an increased rate of fire (1500–1700 rnds/sec). Mk 3 armed the English Electric Lightning. Earlier Mk 3 and 4 guns are being modified to Mk 5 standard.

RAF Harrier GR.5s are armed with a 25-mm version first tested in the air in October 1985; as of 1986, the Royal Navy reportedly favored Aden 25 for the rebuilt Sea Harrier FRS.2. The argument in favor of Aden 25 was that the existing Aden 30 had reached a limit in rate of fire and muzzle velocity; Aden 25 is credited with 1650–1850 rnds/min and with 1050 m/sec. The new cartridge is longer and has a greater diameter, imposing greater stresses on the breech cylinder, which is made of stronger material to keep down overall dimensions and weight (the increase is about 5 kg). Given its higher rate of fire, a twin Aden 25 matches the rate of fire of the U.S. GAU-12/A Gatling gun. Total weight, including 200 rnds, is 430 kg.

UNITED STATES

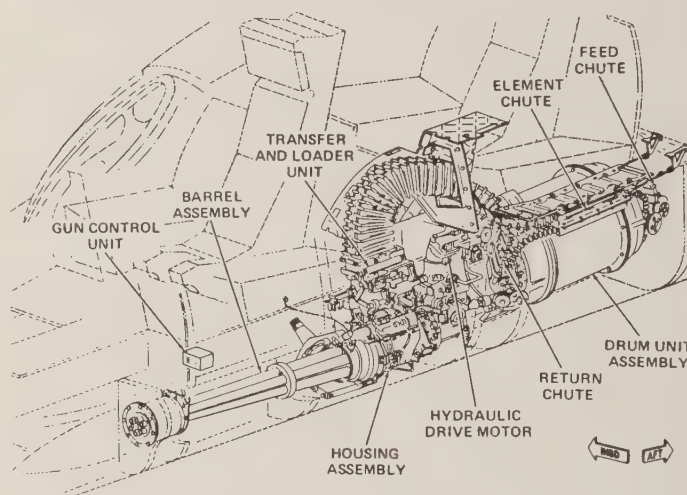
◆ Mk 12

Caliber: 20-mm **Muzzle Velocity:** 3320 ft/sec
Rate of Fire: 1000–1200 rnds/min
Ammunition Supply: 144 rnds/gun

This Hispano-type weapon arms the U.S.-built F-8E(FN) Crusader interceptor of the French Navy. Unlike more recent U.S. guns, Mk 12 is gas operated. Performance in combat, in Vietnam, was somewhat disappointing, the gun showing wider dispersion (12 vs. 3 mils) than its predecessors and sometimes jamming during dogfights. Some writers claim that the Pontiac M39, the U.S. version of the wartime German revolver gun (see DEFA 552A and the Aden), arms the F-8E(FN). However, M39 was limited to air force fighters, and it seems unlikely that the F-8E(FN) could have been modified so radically as to take it in place of the navy Mk 12.

◆ M61A1

Caliber: 20-mm/62 **Muzzle Velocity:** 3400 ft/sec
Rate of Fire: 4000 or 6000 rnds/min
Ammunition Supply: 570 rnds
Weight: total 841 lb (gun 252 lb, feed system 270 lb, ammunition 319 lb)



M61A Vulcan as installed in an F-14 fighter. (*Principles of Naval Weapons Systems*, vol. 3, Annapolis: Weapons Systems Engineering Dept., U.S. Naval Academy, 1979)

Data apply to the gun as mounted in the F/A-18.

General Electric's 20-mm Gatling gun is mounted in the A-7E bomber and the F-14 and F/A-18 fighters. This gun is also the basis of the Phalanx close-in defensive weapon (see the Anti-aircraft Warfare section). This gun was originally developed for the air force F-105 fighter, replacing a similar but much less reliable T-171 gun used in the B-58 and F-104. The key improvement was a powered linkless feed. The rounds are stored, nose inward, inside a cylinder on what amounts to a large worm gear. As the gear rotates, they are fed into the feed chute. Current rated barrel life is 20,000 rnds.

In 1986 General Electric announced an improved version of the basic gun, its barrels 48.3 cm (24 calibers) longer, firing improved ammunition with a more compact propellant and a better bullet shape. The muzzle velocity would increase from 1030 to 1200 m/sec. Ammunition would be wrapped in aluminum, and the barrels would be wrapped in composites to reduce total system weight from the current 360 kg to 275 kg.

In 1988 General Electric introduced a reduced-weight version of the M61. Gun weight is reduced from 252 to 205 lb. The company also showed an improved (higher velocity, for shorter time of flight) ammunition (PGU-28/B SAPHEI). Its aluminum cartridge case saves 87 lb per 500 rnds loaded, and the gun has a linear linkless feed that reduces overall system weight. Muz-

zle velocity is 3440–3600 ft/sec, and rate of fire is up to 7200 rnds/min. Dispersion is 8 mils (2.2 mils normal radial dispersion).

The 30-mm GAU-8/A, used in both the A-10 ground-attack airplane and the Goalkeeper (and related) close-in shipboard weapons, is an enlarged version.

With the demise of the F-4 Phantom in U.S. Navy service, all U.S. carrier fighters incorporate built-in cannon. The only major airplane lacking such a gun, the Grumman A-6 Intruder, is apparently not well suited to carrying an external gun pod and, therefore, does not carry it. These pods are, therefore, no longer in U.S. Navy service and are not described here.

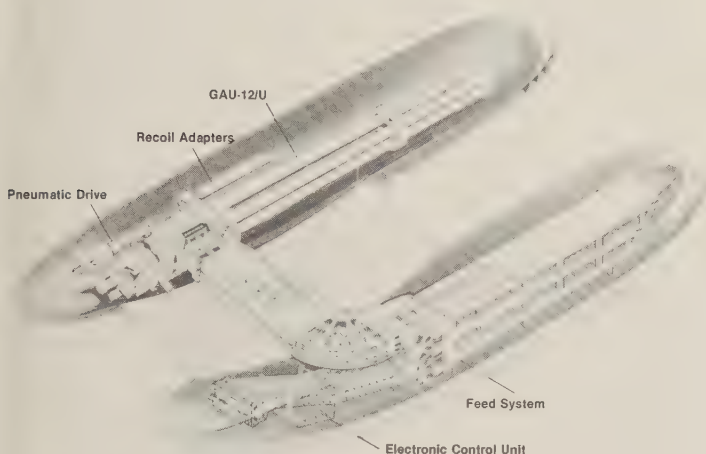
◆ GAU-12/U Equalizer

Caliber: 25-mm

Muzzle Velocity: 3500 ft/sec (HEI, TP; 3400 ft/sec AP)

Rate of Fire: 3600 rnds/min **Ammunition Supply:** 300 rnds

Weight: total 900 lb empty, 1230 lb loaded (280-lb gun)



The GAU-12 gun of an AV-8B Harrier II. (General Electric)

General Electric's 25-mm 5-barrel Gatling gun was developed specially for the AV-8B Harrier II attack fighter. This gun incorporates GAU-8/A (30-mm) technology. The gun is in the left-hand pod, and the ammunition on the right. The rounds are moved along a fixed track by a continuous-loop driving chain. The gun takes 0.4 sec to reach its firing rate. Rated barrel life is 15,000 rnds (20,000 rnds MTBF), and dispersion is 1.4 mil.

◆ M197

Caliber: 20-mm **Muzzle Velocity:** 3400 ft/sec

Rate of Fire: 750 or 1500 rnds/min (selectable)

Ammunition Supply: 750 rnds **Weight:** 145 lb

The armament of the Marine Corps AH-1T attack helicopter, M197 is a 3-barreled version of the M61. M197 is mounted in a turret, which has also been suggested as a patrol-boat weapon, and the Japanese Maritime Self-Defense Force uses this weapon as a pedestal-mounted gun.

◆ GECAL-50

Caliber: 0.50-caliber (12.7-mm) **Muzzle Velocity:** 2900 ft/sec

Rate of Fire: up to 4000 rnds/min (3 barrels); up to 8000 rnds/min (6 barrels). In the V-22, the gun is to fire at the rate of 2000 rnds/min. **Ammunition Supply:** 1200 rnds

Weight: 3 barrels 66 lb, 6 barrels 96 lb

GECAL-50 is General Electric's 0.50-caliber Gatling gun. Work began in 1982, and it was pushed harder after the loss of 9 helicopters in Grenada in 1983 showed that the existing 7.62-mm Minigun was not powerful enough. For a time this weapon was projected for the VS-22 tilt-rotor. Late in 1984 it was eliminated from the basic design, although it was later reinstated as an option. Special forces showed a limited interest in the project. GE has now found a partner, Astra Defence Systems of the United Kingdom. Astra is to pursue the naval market,

GE the helicopter market. A pedestal-mounted naval version was displayed at the RNEE show in the fall of 1989. It had a 750-rnd box magazine and was rated at 1000–2000 rnds/min continuous rate of fire for 3 barrels (4000 for 6).

COAST-DEFENSE GUNS

FRANCE

◆ GPFM-3 (155-mm)

Sixteen of these guns have constituted the Chilean coast defenses since well before World War II. GPF means *grande puissance Fillioux* (Fillioux high powered); the gun used a special wide-traverse carriage. Presumably, M-3 indicated a naval (*marine*) mount; this was not an official French army designation. The first GPFs were delivered in August 1917, and this weapon was adopted by the U.S. Army in 1918. In 1940 a derivative was the sole modern French heavy artillery piece. The U.S. "long Tom" 155-mm gun was developed from this weapon. The GPF gun was 38 calibers long and fired a 95-lb shell at 735 m/sec [2411 ft/sec] to a range of 18,600 m [20,300 yd].

FINLAND

◆ 130-mm

This weapon is a locally produced (Tampella) gun, in a turret emplacement, that replaces older 152-mm guns. Range is +25 km; it can fire 6 rnds/min and is remotely aimed (with manual backup). Training rate is 200 mrad/sec (approx. 0.11 deg/sec). Ammunition is of the separate type (12-kg shell, 33-kg cartridge, the latter power-loaded). The normal crew is 9, but the gun can be handled by 3 in an emergency. The standard light coastal weapon is a 100-mm gun derived from that of the Soviet T-55 tank, and there are also towed Soviet-supplied K54 130-mm guns. Finland also still uses some 152-mm guns in splinter shields, as well as 254-mm (presumably Bofors) weapons.

There are 6 readiness forts, 9 manned training forts, about 30 guarded forts, and 11 training units, all organized in 5 military districts. These numbers may be somewhat deceptive, in that many of the forts are probably quite small. The annual intake, in 1989, was 2300 conscripts, with about 3000 reservists being given refresher training that year. The organization consists of a mobile battalion in Vasa and 2 fixed battalions. Coastal artillery is administered by the army.

The fire-control system is RAVAL, a Finnish acronym meaning coastal-artillery automatic-surveillance fire-computing system; it is probably a BEAB system (see the entry for Sweden). Each computer serves up to 16 guns, taking into account local conditions as well as the position of that gun. The system can control fixed and mobile guns as well as missiles. There are 2 sets of software, 1 for surveillance and 1 for fire control. Each center contains 3 consoles and, thus, can engage 3 targets simultaneously. The system as a whole uses radar, laser range-finders, and optical range-finders.

GERMANY (WEST)

◆ 150-mm

Denmark, Norway, and Portugal use 150-mm guns, presumably of German manufacture. During World War II the Germans used a 150-mm/40 for coast defense, firing a 40-kg (88-lb) shell at 800 m/sec [2625 ft/sec] to a maximum range of 14,300 m [15,640 yd]. This weapon presumably survived postwar.

The Danish weapons are 15-cm SKC/28 guns from the battleship *Gneisenau*, in 2 twin turrets, plus 6 single SKL/45s manufactured specifically for coast defense. Both types fire 45.3-kg (99.8-lb) shells to a range of 23,500 m [25,700 yd]. Denmark also has a few ex-U.S. 3-in/50 naval guns in coastal mountings.

◆ 127-mm

Norway uses a 127-mm coast-defense gun, presumably an ex-German destroyer weapon. The German gun was a 127-mm/45,

firing a 28-kg [61.7-lb] shell at 830 m/sec [2723 ft/sec], to a maximum range of 17,400 m [19,030 yd].

◆ 105-mm

Now in Norwegian service, this gun is presumably the standard German 105-mm/65 antiaircraft gun, firing a 15-kg [33.3-lb] shell at 900 m/sec [2953 ft/sec] to a maximum range of 17,700 m [19,360 yd]. The Germans also used a variety of older lower-velocity 105-mm guns during World War II.

◆ 88-mm

Possibly Albania and Yugoslavia still use the old German 88-mm/56 gun in coast defenses, in fixed emplacements. It fires a 44-kg [97-lb] HE shell at a muzzle velocity of 820 m/sec [2690 ft/sec], to a maximum range of 14,860 m [16,250 yd].

SWEDEN

BEAB (formerly PEAB) supplies the electronic elements of Swedish coast defense, some of which have been supplied abroad:

Kondor (9KR 400) is the coastal-surveillance radar, based on the 9GR 600 X-band fast-tuned magnetron and the 9GA 205 antenna. It uses 2 of the same operator displays as STINA (see the Surveillance and Control section) and can be fixed or mobile. This is an ADT radar. This radar can be supplemented by a helicopter-borne 9HCI 200 standoff surveillance radar.

Kaskad is the local (battalion level) command center, using a 23-in color PPI and communicating with Kastell, Kardinal, or Karat battery-level control systems.

Kastell (9KA400)/Kardinal (9KA500) is the coastal TWS fire-control radar, capable of engaging 3 targets simultaneously. It operates in X- or in Ku-band. 9KA500 is the mobile version. See the 9GR series in the radar part of the Antiaircraft Warfare section for electronic details. Kastell/Kardinal can include optronic sensors.

Karat (9KM 400) is an integrated missile-launch and combat-control system, carried on a truck and including an X-band radar and optional optronic sensors. A typical battery might consist of 2 launch vehicles carrying Penguin Mk 2 missiles.

Kolibri (9KA 50)/Kobra (9KA 100) are optronic gun fire-control sensors using paired binoculars and a laser. An image intensifier (starlight scope) and a FLIR are optional. Azimuth and laser range are fed directly into a fire-control computer. Kolibri is a lightweight version for amphibious assault units. Kobra has a higher-powered laser range-finder and a computer-controlled azimuth servo for extra accuracy (presumably in rate-aided target tracking).

Klara (9KM 100) is a missile-firing analysis and launch-control system, displaying a tactical situation as seen at higher-echelon levels so that long-range missiles can be fired without relying on local sensors. It can also be used to integrate data from coastal-surveillance radars, naval vessels, and helicopters. In its brochure for these systems, PEAB mentions RBS 15 as a specific case of a long-range defensive missile that need not be based near the coast, i.e., near both its search sensors and enemy threats.

BEAB manufactures a combined automatic gun sight and ballistic computer, MARIA, for its mobile coastal guns (listed below). MARIA automatically compensates as the gun digs into the ground after each round.

◆ Bofors 254-mm Gun

This prewar weapon may survive in Finnish service; the gun was originally built for 2 Finnish coast-defense ships. This 10-in/45 fires a 225-kg [496-lb] shell at 850 m/sec [2790 ft/sec] to a maximum range of 30,300 m [33,140 yd].

◆ Bofors 155-mm L39 (CD77)

This mobile gun, developed specially for export, uses many

Karin (see below) components. Total weight is 12 tons, and elevation limits are $+70/-3$ deg. Rate of fire is 10 rnds/min. Muzzle velocity (range): 827 m/sec (HEER round: 41.65 kg, 30,000 m or HE round: 42.6 kg, 24,000 m) or 700 m/sec (HCER round: 53 kg, 30,000 m). The HCER is probably the gun bought by Finland.

Sweden still uses 152-mm and 210-mm coast-defense guns, presumably prewar Bofors naval weapons.

◆ Bofors ERSTA 120-mm/62

This fixed coast-defense gun, developed about 1970, had by 1987 replaced about half the Swedish heavy coast-defense weapons, the remainder dating from the 1950s. Maximum elevation is 50 deg (limits $+50/-3$ deg), to achieve maximum range. Rate of fire is 25 rnds/min (200 rnds in 20 min). The gun barrel is water-cooled. Total weight: 70.5 tons plus 103.5 tons of concrete. Muzzle velocity (projectile weight, range): 880 m/sec (HE: 24.6 kg, 24,000 m; HCER: 26 kg, 34,000 m). The shells are similar to those fired by the Karin gun (see below), but the cartridges are larger.

This weapon is used by the Swedish Navy and in 1980 was ordered by Norway (delivered 1987). Norway is installing these guns in 3 new fortifications, at Andfjord (in service 1989), Vestfjord (1990), and Trondheimfjord (1991).



A modern coast-defense weapon: The ERSTA 120-mm gun as emplaced in Norway. (*Ships of the World*)

◆ Bofors Karin 120-mm L55 (CD80)

This mobile gun was first delivered in 1978 and has many elements in common with ERSTA. Karin has the same carriage as the FH77 155-mm field gun.

Typically, there are 4 guns/battery, and they can be towed by road at 70 km/hr. When the guns are emplaced, their arc of fire is 60 deg. Each gun has its own computer. Elevation limits: $+50/-3$ deg. Rate of fire: 15 rnds/min. Muzzle velocity (range): 790 m/sec (HE: 24.6 kg, 21,000 m) or 830 m/sec (HCER: 26 kg, 30,000 m).

◆ Bofors 75-mm L60

This weapon is a turreted gun, actually a 76/62, developed about 1960 for the Swedish Navy and exported to Norway and, prob-

ably, other customers. Elevation has been limited to 20 deg (limits are +20/-5 deg) to minimize the opening in the turret (range is limited to 11,400-16,000 m). Rate of fire is 25 rnds/min. Muzzle velocity is 870 m/sec (range 12,000 m) for the 5.52-kg HE round, and 890 m/sec for the HCER round (6.4 kg, 16,000 m). Total weight is 17.5 tons.

Sweden also uses a mobile form of this gun, on a 4-wheel towed carriage. It has a total of 12 mobile and 53 fixed coast-defense batteries (including missile units).

USSR

◆ 305-mm

The Soviets used both their new 305-mm/56 and their old (dreadnought-type) 305-mm/52 for coast defenses during World War II and planned to emplace 12 batteries of the new guns and 8 batteries of the older ones (four 4-gun in the Baltic, two 4-gun in the Black Sea, and two 5-gun in the Far East). Many of these weapons must have been destroyed, but some reportedly survive in active service, perhaps in the Northern Fleet. The 305-mm/56, which was designed for the abortive battle cruisers, fired a 480-kg [1058-lb] shell to 43,900 m [48,000 yd], probably at about 850 m/sec [2789 ft/sec]. The older 305-mm/52 fired a 470.9-kg [1038-lb] AP shell at 762 m/sec [2500 ft/sec] to a maximum range of 24,620 m [26,925 yd]. In at least one case, the 305/52s were emplaced in a triple turret taken from a battleship.

◆ 152-mm

These guns are in Soviet, Bulgarian, East German, Romanian, and possibly Finnish service. These guns are mounted in the *Sverdlov* class, and some were mounted in Soviet coast-defense batteries during World War II. In coastal service the 152-mm fired a 55-kg [121-lb] AP shell to 29,000 m [31,700 yd], probably at a muzzle velocity of about 885 m/sec [2900 ft/sec].

◆ 130-mm SM-4-1

This gun has been very widely adopted; reported export users are Angola, Bulgaria, Egypt, North Korea, Poland, Romania, South Yemen, Syria, and Yugoslavia. The Israelis captured some when they took Sharm el Sheikh in 1967. In addition, Soviet-type 130-mm guns (presumably of earlier type) arm Chinese (PRC), Cuban, and Finnish coast defenses. Performance approximates that of the 130-mm/58 naval gun, probably with a maximum range of about 29,500 m. Maximum elevation is 45 deg. The APHE shell weighs 33.6 kg and is fired at a velocity of 1050 m/sec. Rate of fire is 5 rnds/min. The gun is mounted on a 4-wheel carriage (with removable axles) with a nearly vertical shield. This weapon does not fire the ammunition of the 130-mm M-46 field gun or the 130-mm KS-30 antiaircraft gun. The associated radar is ZALP-B (Long Bow).

Soviet client states first adopted 130-mm coastal guns in the early 1960s, at a time when the U.S. Navy was eliminating its heavy shipboard guns. The remaining 5-in guns were outranged by the new 130s, and the abortive lightweight 8-in gun program was begun as a counter to this new Soviet-bloc capability.

◆ Other Soviet Guns

122-mm guns are in Cuban, Finnish, North Korean, and possibly Yugoslav service. Finland uses T-55 (100-mm) turrets embedded in concrete and controlled from a blockhouse. Maximum range is about 15 km. Older 100-mm guns are in Bulgarian and Chinese (PRC) service. Finally, the 85-mm gun is in Yugoslav service, and also (presumably copied) in Chinese (PRC).

UNITED KINGDOM

◆ 15-in/45

Vickers Model 1926 is still in service in Spain. The AP shell weighs 859.65 kg [1895 lb], and the HE shell 801.84 kg [1767 lb]; muzzle velocity is 2500 ft/sec (AP shell), and range is 35,100 m [38,400 yd]. Guns are mounted singly, in armored gun houses. There are 12 or 16 mounts in Groupos of 4 (2 batteries

per Grupo). (Probably 7 are operational.) The associated fire-control system is the Swedish 9KA 410 built in Spain.

Spain will keep the 15-in gun in service until it is replaced by a coastal missile in the late 1990s.

◆ 12-in/50

Spain retains 14 Vickers 12-in/50 guns, some of them originally built for its dreadnoughts, some specially built. The gun fires an 850-lb AP shell at 3010 ft/sec.

◆ 9.2-in

This gun is in Portuguese and Turkish service. When Britain and Canada gave up their coast defenses in 1956, they transferred their weapons to the NATO Southern Tier nations, primarily Portugal and Turkey. The standard 9.2-in/47 fired a 380-lb HE shell at 2700 ft/sec, to a maximum range of 36,700 yd.

◆ 8-in

Spain retains 24 British-supplied 8-in coast-defense guns. It is alone in using this caliber. These weapons are probably Vickers 8-in/50 cruiser guns similar to those in the former Spanish heavy cruisers; the guns fire a 256-lb AP shell at 2725 ft/sec to a maximum range of 29,200 yd.

◆ 6-in/50

Vickers 6-in/50 guns, installed in 1915-25, remain in Spanish service, in both single and twin mounts; up to 113 may be operational. Maximum range is 21,600 m. There have been proposals to replace the gun tube with that of the Spanish 155-mm/39 howitzer, which fires standard NATO rounds. The 155-mm coast-defense gun would have a range of 22,500-24,000 m (30,000 m with enhanced-range ammunition) and fire 2 rnds/min (4 rnds/min in a burst).

Brazil and Paraguay use a 6-in Vickers Mk V. Portugal also uses 6-in guns, presumably also of Vickers type.

◆ 3.7-in AA

This gun, the British equivalent of the German World War II 88-mm, is used by Portugal in a coastal role. The original specification was drawn up in 1928, and the gun was placed in production in 1937 (first delivery was January 1938). A longer (65-caliber) 3.7-in gun in a 4.5-in jacket was introduced in 1943 as Mk 6, for use in static mountings; this may be the Portuguese weapon. The original 3.7-in/50 fired a 25-lb shell at 2600 ft/sec to a maximum range of 20,600 yd; maximum ceiling was 41,000 ft (effective ceiling, with contemporary fire control, was 32,000 ft). Mk 6 had a muzzle velocity of 3425 ft/sec, a maximum range of 25,600 yd, and a ceiling of 59,300 ft (effective ceiling, with contemporary fire control, was 45,000 ft).

◆ 6-Pounder

This World War II twin anti-motor-torpedo-boat weapon is used by Portugal in a coastal role. The original specification, for a twin automatic weapon (40 rnds/min/barrel), was drawn in 1925; the first 2 guns were tested in 1928, and the first mounting was delivered in 1934. The gun remained in British service until 1956. The guns were 57-mm/47s, firing 60 rnds/gun/min (6.25-lb HE shell, 2360 ft/sec). Maximum range was 5150 yd.

UNITED STATES

◆ 12-in/45

At least four 12-in Mk V Mod 9 guns were transferred to Brazil about 1945-46. These were originally U.S. Navy guns transferred to the army after the Washington Treaty scrapplings in 1923-24. Others were obtained in 1941-42. These were among the most modern army coastal guns at the time, and work on a new gun carriage began early in World War II, at Watertown Arsenal. The prototype (T 1) was completed only in 1945, and the pilot Brazilian gun shipped in 1945. This was the culmination of negotiations with Brazil begun about 1938. The gun was in an open mount, and elevation/depression limits were

+47/-8 deg. It fired an 870-lb shell with 310 lb of powder, and muzzle velocity was 2700 ft/sec, for a maximum range of 30,000 yd.

These guns may still be in service.

When the U.S. coast defenses were disbanded in 1948-49, some 6-in guns were retained for possible transfer to Norway, Portugal, and Turkey, but they were never shipped abroad. The only other heavy U.S. guns transferred abroad were about eight 10-in and eight 8-in to Canada in 1940-41, and 7-in guns to the Netherlands East Indies at about the same time. None of these weapons survive.

BOMBARDMENT ROCKETS

CHINA

◆ 122-mm Rocket Launcher

At the Paris Air Show in 1989 NORINCO announced a navalized 122-mm rocket launcher, designed for remote operation, and manually loaded with 40 rockets (10 × 4), each weighing 66.6 kg with an 18.4-kg warhead [146.8/40.6 lb], range 40 km [21.9 nm]. The launcher elevates to 60 deg and trains over a 240-deg arc. It can be fired in 17.5-21.5 sec. There was no indication of the state of its development.

ITALY

◆ Breda 81-mm Multiple Launcher

This multiple rocket system carries 36 rnds; elevation limits are +55/-2 deg, and training/elevating speeds are 60/30 deg/sec. Weights: empty, 1270 kg [2799 lb]; loaded, about 1980 kg [4364 lb], depending on rocket type. Trunnion height is 2.15 m, and working circle radius is 1.49 m [84.6 and 58.7 in].

The Oerlikon 81-mm SNORA folding-fin rocket fired by the Breda launcher weighs 19.7 kg and has a maximum range of

about 10 km; maximum speed is 520 m/sec [43.4 lb, 11,000 yd, 1706 ft/sec].

USSR

◆ BM 14/17 and BM 14/18

BM 14/17 is a 17-barrel 140-mm (5.5-in) army-type rocket that entered service in 1954. The 70-lb rocket has a maximum range of 4.8 nm. The designation has been applied by NATO.

BM 14/18 is a 140-mm rocket launcher specially designed for naval service, on board all *Polnocny*-class amphibious ships. This launcher fires the same rocket as BM 14/17.

Maximum elevation of the manually reloaded BM 14/18 is about 50 deg. Reloading takes about 4-5 min. Rockets are ripple fired at 1-sec intervals. Speed is about 400 m/sec [1310 ft/sec], and maximum range is about 10,000 yd.

The 17-rocket launcher is a lighter-weight version for river patrol boats such as the "Shmel" class; extra rockets are stowed in 2 crates abaft the launcher.

◆ BM 21

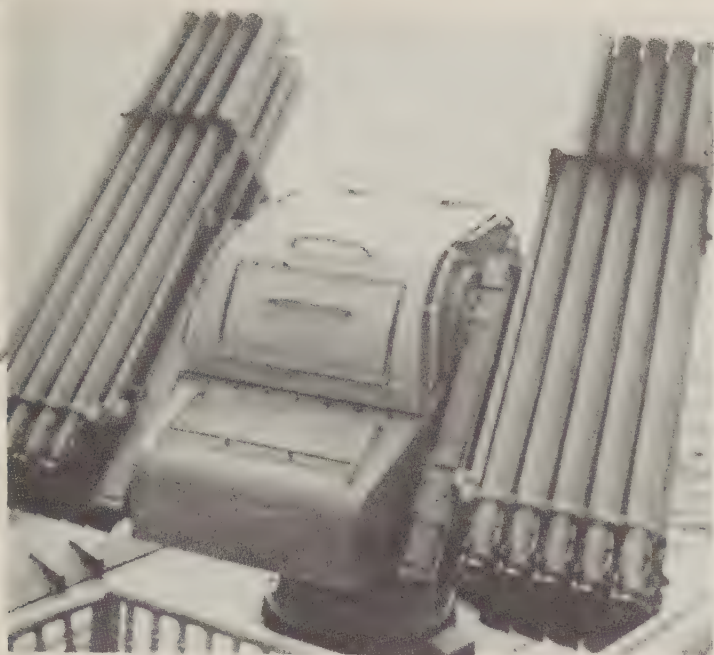
This 40-barrel 122-mm rocket launcher (101 lb, range 8 nm) is found on board some amphibious ships. It is automatically reloaded: the launcher carries 2 clusters of 20 tubes, empty sets being discarded and replaced from below. The rockets carry a 19.2-kg fragmentation warhead.

A 40-rocket BM 21 has been the standard Soviet army rocket launcher since the mid-1960s. The naval system is 2 half-launchers carried on a specially designed mounting. The rockets are 2.8 m long and weigh about 140 lb each; range is about 23,000 yd.

Shmel-class monitors can carry an 8-barreled 122-mm launcher. The *Pomornik* class LCAC carries 2 × 22-tube 122-mm rocket launchers. They retract into its side walls and reload below decks.



BM 14/18 rocket launchers forward on board a *Polnocny*-class landing ship. The radar is Drum Tilt, controlling a twin 30-mm gun at the after end of the superstructure. (U.S. Navy)



Soviet 122-mm barrage rocket launcher, showing its two 20-rocket clusters.

UNITED STATES

◆ ABRS/ATACMS

The army's bombardment systems were proposed to support the current Marine Corps OTH assault concept, which requires fire support from 50–60 nm. In October 1990 the Senate approved an amendment to the FY91 defense bill, calling for the navy to evaluate the LTV ABRS (assault ballistic rocket system), an unguided-rocket system already in NATO service. LTV has been trying to sell it to the navy for some years, and for several years there have been congressional calls for studies of dedicated landing fire-support ships or systems. These proposals generally die because the problem in really long range fire support is forward observation; finding and designating the targets cost far too much per target. Moreover, none of the proposed missile systems can provide the required volume of fire at a reasonable cost in terms of money or ship's volume and weight. The idea is not new: in the mid-1960s the navy considered a variety of landing fire-support weapons, including an adapted Lance missile, which could have been fired from the Terrier launchers of first-generation missile cruisers, then becoming obsolete.

In army service, ABRS weapons are fired from multiple launchers (MLRS). Each rocket carries 644 antipersonnel/anti-vehicle submunitions. ATACMS is a new longer-range (130-km) weapon (formerly Assault Breaker), offered as an alternative.

AIRBORNE ECM

Airborne EW systems divide into reconnaissance (ELINT and, to a lesser degree, ESM), targeting (ESM), standoff or escort jamming, and self-protection (also called defensive ECM, or DECM). Radar-warning receivers (RWR) are the major form of defensive ESM, the receivers being used to initiate chaff launching.

The distinction between RWRs and more elaborate forms of ESM is gradually fading; future systems are likely to provide a pilot (or, more importantly, an aircraft CDS) with detailed threat information. At present, the distinction is mainly in the degree of information provided. An RWR generally uses 4 antennas and does little in the way of comparison between their outputs. It provides little more than the quadrant in which the threat is detected. Similarly, it generally uses a crystal video receiver, so it obtains little threat-signal detail.

An early Vietnam-era RWR used 4 cavity-backed spirals; its output was distinguished by band. Video was passed to a processor measuring pulse train parameters and frequency ranges to determine the radar type. Directional signals, typically on a 3-in CRT, showed signal power vs. bearing. These RWRs could detect only the main lobe of a radar and, thus, could have no electronic intelligence capability. Wartime development effort was concentrated on the detection and identification of new types of radars (and new operating modes), and on improved displays. Digital RWRs developed (but not deployed) by 1975 had a single display showing both radar identification and relative location (using alphanumeric characters on a CRT). They could be reprogrammed for new threat types and could handle more signals simultaneously. However, location and frequency data were still crude.

The next step is better signal characterization, as in the U.S. ALR-67ASR. It is easier to achieve than better target location since it does not require installation of new (and, inevitably, larger) antennas. The new capability is bought by replacing older solid-state technology.

Beyond that is the integration of the RWR and targeting ESM. The A-12 may be the first such case, as stealthy operation makes fully passive target detection very attractive. In theory, because an airplane is a moving platform, a very accurate ESM device combined with very accurate inertial navigation should suffice for fully passive targeting of nonemitting weapons.

CHILE

◆ ITATA

This air electronic intelligence system is manufactured for the Chilean Air Force by ENAER (Empresa Nacional de Aeronautica) and is also probably used by the Chilean Navy. ITATA was first displayed at the FIDA show in 1984. Production began in 1986, and the system was installed in a Learjet 35-A in 1987. It has also been installed in Beech 99, Gardian Falcon 20, and EMB-111N aircraft; as of 1989 about 10 had been manufactured.

Frequency coverage is 3 MHz–18 GHz in 6 bands; it can scan either the entire range or any selected band or bands within it. Antennas cover 360 deg. ITATA is a microprocessor-controlled, superheterodyne system with a pulse analyzer, using a servoed dish antenna (under the fuselage) for accurate direction finding. Targets are located by triangulation as the airplane moves. Output: angle of arrival, bearing to emitter, threat type and classification. ITATA can measure PRFs of 0.092–12.83 kHz and pulse widths of 0.05–24 microsec (resolution 0.05 microsec). It analyzes PRF and pulse-width jitter. The dish beam is 8 deg wide in S-band, 1.8 deg wide in Ku-band (beamwidth resolution is within 0.2 deg). Signal amplitude is displayed in dB steps, and the system can blank out signals below a predetermined threshold. ITATA also examines the emitter antenna's rotation rate. Data are displayed on a CRT (selected signals can be strobed), and detailed parameters are shown on digital (LED) displays. Outputs can be recorded in digital form. There are 2 operators. Selected received signals can be heard as an audio tone by the DF operator. The DF module can use either crystal or superheterodyne demodulation for either broad sweep or high sensitivity, as required. Operation is manual or semiautomatic, the system locking onto a signal of interest and then analyzing it. Compared to contemporary U.S. and European ELINT equipment, ITATA is relatively bulky, but it is an indigenous development suggesting the sort of equipment that Third World manufacturers can currently produce.

FRANCE

◆ ARAR-10B/ARAX-10B

Thomson-CSF's ESM system for Atlantic 1 and Nimrod patrol aircraft covers 2.3–11.1 GHz. The antennas are on top of the tail fin. This system gives data on pulse width, PRF, beam width, and scan rate. ARAX-10B is the associated frequency-measurement device.

◆ ARAR-13A

This ESM system for the Atlantique Mk 2 maritime-patrol aircraft is similar to the Thomson-CSF Dalia 500 and to the shipboard ARBR 17. The antennas are in wingtip pods and in the tip of the vertical tail, for high DF accuracy and reduced interference with (and from) other aircraft systems. Bandwidth is greater than that of the Atlantic Mk 1 system.

ARAR 13 was designed specifically for antiship, as opposed to ASW, operation. Detection is automatic, and the system incorporates an IFM. Signals are analyzed, classified, and tracked; ARAR 13A incorporates a 2000-mode threat library. Radar signals are detected on 1 scan, and the system provides automatic threat warning. Signals are displayed on a panoramic 3-color screen (bearing vs. frequency) and on alfa display (analysis, ID data). Signal data are also automatically recorded for later analysis. Computer-integrated ECM is available as an option.

The first preproduction units were delivered in November 1986.

◆ BF

This Thomson-CSF RWR is for Super Étendard and other tactical aircraft, including helicopters. It employs 4 broad-band antennas (2 spirals flush with the aircraft sides, and 2 cones for fore and aft reception) and a video unit. It can detect and recognize pulse (600–12,000 pps), CW, and ICW signals and provides an audio and visual alarm. Signal direction is indicated by 4 lamps. Total weight is 9.2 kg.

◆ Caiman

This Thomson-CSF noise/deception support jammer is used on French Mirage F1 air force fighters and has been exported for users of French fighter-attack aircraft such as the Mirage 2000 and the Jaguar. Thus it may well be used in support of antiship attacks. The pod carries 2 jammers, each with its own receiver, and receiver antennas at each end. Each transmitter provides 250 W at 10 GHz and 1 kW at 1 GHz. The jamming bandwidth must be preprogrammed before flight. There are 3 operating modes: manual (the pilot selects 1 of 3 preset frequencies), semi-automatic (a signal indicates which transmission is being received), and automatic (the jammer is activated by a transmission). The jammer is driven by ram air.

Caiman was developed from the earlier Alligator.

◆ DR-2000/3000A/4000

These ESM systems are also used on board ships. Dalia (DR-2000) is a manual frequency-measuring system operating in the D- through J-bands. Applications include the Embraer EMB-111 (with 6 D/F and 1 omnidirectional frequency-measuring antenna) and German Navy Sea Kings.

The commercial designation for DR-2000 (when combined with an ARIAL 15 analyzer) is TMV 026. ARIAL is an acronym for *analyze radar pour identification et alerte*; the number indicates the size of its library, 15 emitters. Alternatively, it can be combined with Dalia 500 or 1000. A new DR-2000 Mk II is reported in production for EMB-III's and Sea Kings.

DR 3000 is a heavier (50 kg), fully automatic system for maritime-reconnaissance aircraft. It covers the D- through K-bands and has a direction-finding accuracy of about 6 deg.

DR 4000, which is also carried by frigates, is intended for large maritime-patrol aircraft. It uses 12 direction-finding antennas (DR 2000 uses 6). The commercial designation is TMV 202.

◆ Remora/Barem

Remora is a Thomson-CSF jammer pod, carried by Super Étendard and Mirage aircraft. There are 2 types, DB-3141 for low-band and DB-3163 for high-band threats. DB-3141 is 0.25 × 3.5 m (175 kg) and covers the H- through I-bands. Its pod carries a single receiver and fore and aft transmitters (TWTs). A look-through receiver cuts off jamming when the target radar ceases to transmit. The high-band pod (0.254 × 3.52 m, 175 kg) deals with both pulse and CW (illumination guidance) radars; it has



The Barem self-protection ECM pod. (Thomson-CSF)

a superheterodyne receiver with antennas at both ends. The pilot chooses among 6 preprogrammed frequencies, and the pod can jam 3 threats simultaneously by electronic switching (time-sharing). Threat data are stored digitally.

Barem (TMV 015) is a developed version, a reprogrammable pod with modular software and a superheterodyne receiver. It can be repackaged for internal installation. Threats are identified by comparison with a stored library and jammed using signals matched to the intercepted signals, all within 1 sec of reception. The pod can jam 2 threats at the same time (front or rear), and it records jammed parameters. Dimensions are 16 cm × 3.45 m (85 kg).

◆ Serval/Sherloc

These are Thomson-CSF RWRs for tactical aircraft, covering, respectively, the 2.5–11 and 2–18 GHz ranges. Sherloc can be extended to cover 1–40 GHz and can be integrated with a Thomson-CSF laser warner. Both systems employ sets of 4 antennas (wingtips and vertical fin). They display the direction of a received signal and estimate its threat level by identifying it in a look-up table. Sherloc employs crystal video receivers and a high-speed hybrid processor; its library contains 100 radar modes. It can display 8 threats simultaneously. Threats generate both an aural warning and (in Sherloc only) a synthetic voice message.

Thomson-CSF offers a combination system, MSDS (Barem and Sherloc), for combined crystal video and superheterodyne reception for more accurate signal identification. There is also a shipboard version of Sherloc, Shiploc.

◆ Spectra

The integrated EW suite for the new Rafale fighter is being developed by a consortium led by Thomson-CSF (with Dassault Electronique and Matra). Spectra's antennas are electronically steered, and it incorporates digital RF memories, VHSIC, and artificial intelligence for threat recognition and response. The device's technology is MMIC on GaAs substrate. The overall system's weight is less than 180 kg. Spectra is intended for direct integration with other combat-system elements, i.e., as part of the new generation in which RWR evolves toward ESM.

◆ SPIRALE

Matra's *Système de Protection Infrarouge et Radar avec Alerte et Leurage* is for the Mirage 2000 and other fighters. Presumably, it is also planned for the Super Étendard since Matra lists the associated Corail decoy dispenser as a Super Étendard system. SPIRALE detects both missile launches and missiles in flight using DDMs (*Detecteurs de Départ Missile*, i.e., launch detectors) and IR warning receivers in the backs of the Magic (AAM) launchers. The DDM, which is made by SAT, is an IR signal processor. The system is tied together by a pair of processors, 1 analog and 1 digital, and it includes 2 chaff-dispensing tubes in each wing root and 2 IR cartridge dispensers in the fuselage near the bottom of the tail pipe. Deliveries began in

1987 for several air forces (presumably including the only foreign operators of the Super Étendard, Argentina and Iraq).

◆ Syrel

Thomson-CSF's pod-mounted electronic reconnaissance pod is used on board French Air Force Mirage FIs and Mirage 2000s; it is presumably also applicable to French Navy Super Étendards. Dimensions are 0.42 × 3.57 m (265 kg). The pod carries antennas forward and aft.

◆ Expendables

The current standard Phimat chaff dispenser pod is 108 mm × 3.6 m (105 kg); it is also used by the French Air Force and by the RAF. Three expendable airborne jammers are under development, 2 by Thomson-CSF and 1 by ESD (CAMEL, *Cartridge Active Miniature Électromagnétique Expendable*). Of the 2 Thomson-CSF decoys, 1 is a self-protection device, fitting in a flare container, covering the C- through Ku-bands (ERP about 10 W); it has a delta wing and relatively long endurance to provide a realistic target for doppler radars. The other is an offensive (penetration) device, operating over the L- through S-bands, with about 20-min endurance.

Super Étendards carry Alkan Type 5020 chaff dispensers containing 7 modules, on a special hard point. There are 2 cartridge lengths, 150 mm (40-mm-diameter chaff cartridge, 60-mm-diameter IR cartridge, or 59 × 17-mm cartridge) and 8 in (1 × 1 in square or 1 × 2 in rectangular). The standard modular magazine carries eighteen 40-mm chaff cartridges or eight 60-mm IR cartridges or twenty-four 1-in²-section cartridges, or twelve 1 × 2-in rectangular-section cartridges. Each type of module carries an identifying chip that communicates with the decoy system. Firing sequences are chosen either automatically (by the threat-detection system) or manually (among 9 alternatives).



A Phimat chaff-dispenser pod carried by a French Navy Super Étendard. (Matra)

◆ Camel

Dassault Electronique's active expendable decoy works against pulse-doppler and monopulse radars as well as active/semi-active seekers. It is intended to fit current dispensers.

◆ CORAIL

CORAIL (*Contre-mesures Optronique et Radar Intégré par Leurage*) is a Matra pod or conformal gondola carrying 56 or 112 decoy cartridges (IR, radar, or electro-optical), for the Super Étendard and other fighters, complementing their internal SPIRALE systems. Matra also proposes it for heavy aircraft, such as the Atlantique 2. CORAIL operates in manual, automatic, semiautomatic, emergency, and navigation (presumably target marker) modes.

GERMANY

◆ Cerberus/TSPJ

The Telefunken Cerberus II (1980) and III (1985) are the standard countermeasures pods of German Tornado strike aircraft, carried on outer wing stations. Cerberus has reportedly encountered technical problems; Israeli RF subsystems are being fitted. Cerberus itself was derived from the Israeli EL/L-8202. In 1990 it was suggested that the latter had been derived from Loral's Rapport (ALQ-178) system, reportedly supplied to Israel on board F-16 fighters. Rapport is unusual because of its distributed architecture, which combines warning, jamming, and decoy launch in a single internal system. Signals are processed (and the system is controlled) by a central programmable computer; separate microprocessors are responsible for RWR, display, and jamming. Typically, separate fore and aft jammers are used.

TSPJ is the latest version of Cerberus for Tornados. It has a high output, with power management, and can operate in high pulse densities. Fully programmable, it works either autonomously or under ERWE control.

◆ ERWE II

This digital, hybrid, threat-warning system (C/D- and E-J-bands) was codeveloped by Litton and TST for the Tornado. ERWE II controls Cerberus/TSPJ.

◆ FL1800H

See FL1800S in the Antiaircraft Warfare section.

◆ ISRAEL

Apart from the recent Australian contract, known sales are limited to the Elta EL/L-8300 system. However, published information is too uncertain to determine that the other advertised maritime-patrol-aircraft systems have not been sold or used by Israel.

◆ CR-2800

This Elisra (Tadiran subsidiary) ESM/ELINT system is apparently a competitor to the Elta EL/L-8300. Maximum effective range is 330 km, and coverage is 0.5–18 GHz; the system can track up to 64 emitters simultaneously. Antennas: one omni (for IFM), four 10-in cavity-backed spirals, and eight 3-in cavity-backed spirals, for 2 frequency bands. All antennas are flush-mounted in pods or blisters. The directional antennas are grouped in 4 sets, each with adjacent amplifiers. For more precise signal data, for targeting, the system can be supplemented by a superheterodyne receiver and a rotating directional antenna. Total weight, in the basic version, is 300 kg. Reportedly, this system is operational with the Israeli Air Force, alongside the more elaborate EL/L-8300.

◆ EL/L-8300

Elta's electronic reconnaissance system is used for both ground and naval operations. Argentina bought 5 after the Falklands, 2 of them for installation in its Lockheed Electra maritime-reconnaissance aircraft. This system has probably also been installed on board 1 or more of the Indonesian Boeing 737 surveillance aircraft (which are also equipped with SLAMMR side-looking radars). It has been sold to South Africa and probably also to Thailand (for installation on board a converted DC-8F). The system first appeared on board a converted Israeli Boeing 707 in 1981. The Indonesian sale followed in 1983, and the Argentine sale in 1985. A total of at least 18 (plus 3 prototypes) had been manufactured by 1989.

The full system consists of:

EL/L-8312A, which monitors the C-J-bands (0.5–18 GHz). Key modules include EL/L-8312R, a superheterodyne microwave receiver; EL/L-8320, a pulse digitizer; the EL/L-8610 computer; and the EL/L-8570 display unit. The pulse digitizer operates on signals reduced to intermediate frequency, with 3 alternative bandwidths: 50–70 MHz, 140–180 MHz, and 300–500 MHz.

The system processes pulse descriptions in the form of four 16-bit words (giving pulse width, pulse amplitude, fine frequency, time of arrival, and status). Direction is measured by differences in time of arrival between nose, tail, and wingtip antennas. There is also an omnidirectional antenna in a radome beneath the forward fuselage. The manufacturer claims that an emitter can be triangulated within 20 sec of receipt of the first signal.

EL/K-7032, a narrow-band system with a frequency resolution of 1 kHz for the 20–500 MHz band, scanning over a 10-, 20-, 50-, or 100-kHz band around a preselected frequency. This section conducts signal analysis, monitoring, and intelligence gathering in the HF, VHF, and UHF bands. It uses microprocessor-controlled fast switching to cover a wide frequency range and can be entirely computer controlled. This system employs a series of blade antennas distributed over the belly of the airplane, some of them in pairs. The manufacturer claims that it can handle 300 signals simultaneously, 3 of them in the same frequency band. All are subject to automatic direction finding.

EL/L-8350, the Command and Analysis Station that controls the system.

The supervisor station contains an *EL/S-8570A* computer controller, 2 *EL/K-1150* VHF/UHF receivers, a display, and a tape recorder. In addition, there are up to 4 *EL/K-1150* or *-1250* receivers in a traffic-collection unit.

From nose to tail, an airplane equipped with *EL/L-8300* contains a 1- or 2-operator *ELINT* section (*EL/L-8312A*), a 2-operator supervisor/control section, a 4-operator *COMINT* unit (*EL/K-7032*), an operations section (*EL/L-8350*), and a command-and-analysis suite. This airplane carries a threat library for fast analysis of intercepted signals. Maximum detection range is 400–450 km from an airplane flying at 12,000 m.

An *EL/L-8300* is supported by an *EL/L-8352* postmission analysis station and an *EL/L-8353* ground station.

System capabilities are suggested by the range of signals that can be simulated by the associated *EL/L-8351* ground trainer: up to 270 distinct emitters, ranging over 100 MHz–40 GHz, 1 of 3 different antenna patterns, 1 of 4 scan patterns (circular, conical, bidirectional, or fixed), different scan rates (1–6 rpm circular, 20–50 Hz conical), variable effective power (over 2 orders of magnitude), and variable on-off time (20 sec up).

◆ Elta P-3C System

In the fall of 1989 Elta won a contract for new ESM systems for the 10 newest Australian P-3Cs, beating out Elisra. Best and final contract offers were submitted in March 1989. The 2 Israeli firms were the leading contenders, the other being BAe Australia/Thomson-CSF. As of late 1989, there was also an RAAF requirement for a new radar to replace the existing APS-115 of the P-3C.

Elbit had already won an Australian contract for a new omnidirectional ESM antenna; in the spring of 1989 it delivered the first of 4 under a November 1987 contract. The new antenna is a miniaturized version of the EA 2818 2–50-GHz antenna, a stack of 3 vertically polarized, biconical antennas covered by a slant 45-deg polarizer, sealed in a radome. Two short active stubs adjacent to the bicones extend the bandwidth to cover 100 kHz–2 GHz.

◆ Owl

Owl is a lightweight (136 kg total) Tadiran system for maritime-patrol aircraft and other surveillance. It employs 2 RF front ends (in pods, wingtips, or in the aircraft fuselage), to cover the 0.5–18 GHz band (extendable to 40 GHz). Signals are automatically detected and identified (using a library); the system uses a wide-band data bus to accommodate exotic signals. Direction of arrival accuracy is 0.5 deg, and instantaneous bandwidth is 5, 15, or 40 MHz in narrow-band mode, or 4 GHz in wide-band mode. Frequency accuracy is 1.25 MHz, and resolution is typically 0.2 MHz. Signals from up to 16 emitters can be deinterleaved. Response time is 0.5 sec.

A recent Tadiran pamphlet describes an Owl-MT version specifically for maritime reconnaissance using light aircraft (it shows a Dornier 228), with 5 antennas in each wingtip. Total weight is given as 90 lb, and direction-of-arrival accuracy as 2.5 deg.

Israel uses Arava light transports for communications and electronic intelligence, and this type of equipment would seem to be appropriately sized for such applications. Similar considerations probably apply to the naval Sea Scan (converted Westwind executive transport) aircraft.

◆ RAS-2A

Tadiran's wingtip-mounted interferometer ESM system covers 0.7–18 GHz (extendable to 0.5–40 GHz) and is described as intended for small- and medium-sized transports. The single operator console can show the detected enemy order of battle, and it can also be used to target antiradiation or antiship missiles. Direction-of-arrival accuracy is 0.8 deg (left/right; 5 deg fore and aft); elevation coverage is ± 10 deg. Frequency accuracy is 0.2 MHz; resolution is typically 0.4 MHz.

As of 1989, RAS-2A was described as in development. An earlier system, RAS-1A, was described as in service. It was designed to cope with 2 emitters/sec, and it requires 2 operators. Frequency coverage matches that of RAS-2A, but accuracy is not as good (1.3 deg over 0.7–2 GHz, 0.7 deg over 2–18 GHz); frequency accuracy (resolution) is 2.5 (1.25) MHz; and PRI accuracy (resolution) is 200 (100) nanosec.

ITALY

◆ Colibri (ELT/161)

Elettronica's ESM system is for naval helicopters such as the AB-212. The basic installation is ELT/161, consisting of a receiver, processor, and warning display. The typical antenna array consists of 2 conical omni antennas, 2 half-cylindrical half-omni antennas, and 8 hemispherical DF antennas. In a typical light helicopter (AB-212) installation, the 2 half-omnis are under the nose, facing port and starboard. One of the omni cones is mounted above the windshield, forward, and the other is in the extreme tail. The DF antennas are spread around the helicopter, 4 of them in the nose, 2 amidships (just below the engine exhaust), and 2 of them facing aft, on either side of the after cone. Two separate sets of omnidirectional antennas are needed to feed IFMs working at S- and X-bands; the IFMs in turn feed the warning processor. There is also a dual-band DF display.

Claimed performance (range at which an emitter can be detected):

<i>Flight Altitude</i>	<i>S-band</i>	<i>X-band</i>
300 ft	34 nm	26 nm
1000 ft	50 nm	41 nm
2000 ft	63 nm	47 nm

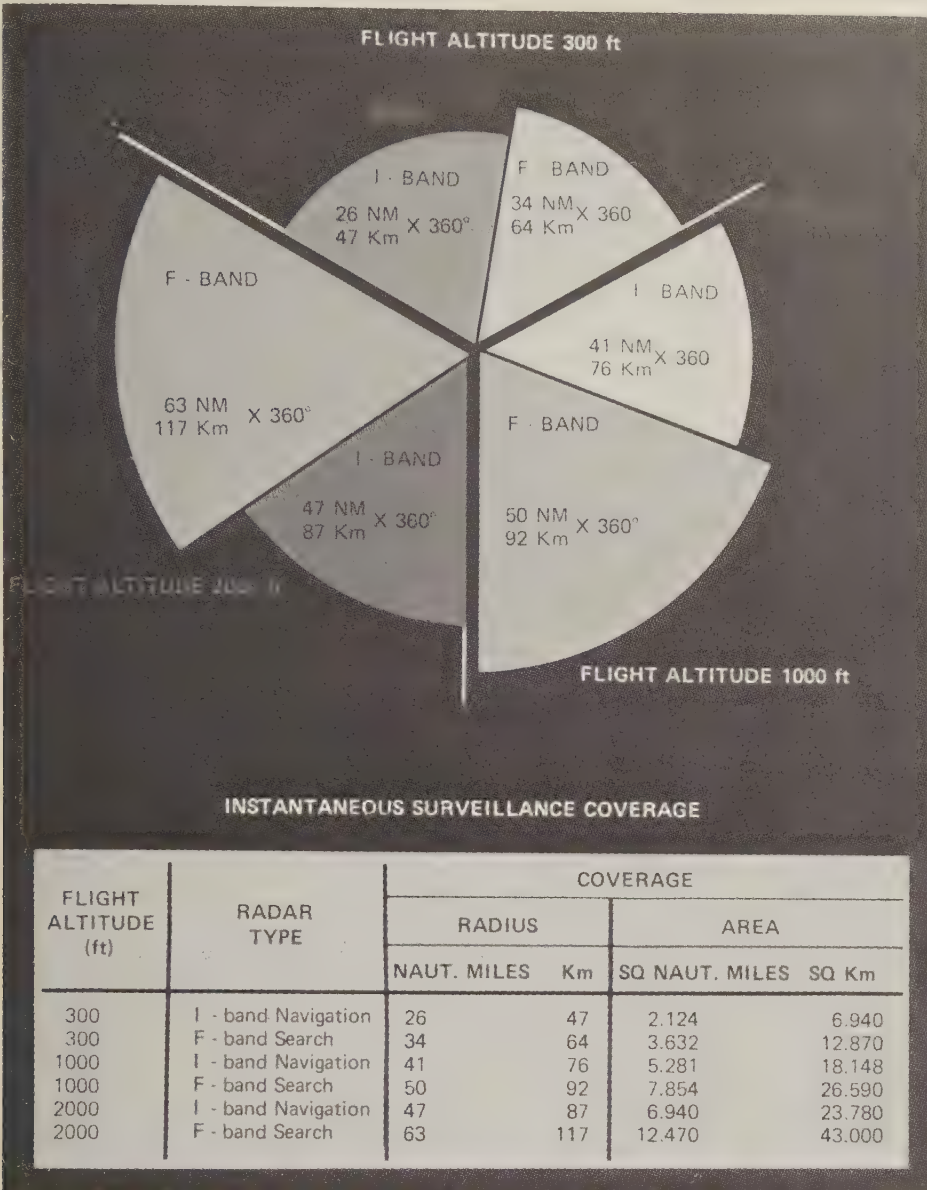
The basic warning device can be supplemented by an ELT/261 analysis module, for monopulse direction finding, automatic analysis, and library look-up of received signals. Selected emitters can be tracked. Other possible additions are the ELT/562 self-defense deception jammer (see below) and the ELT/361 noise jammer (used for standoff jamming of hostile search radars). ELT/361 requires its own directional antenna. The other 2 systems use Colibri antennas.

Colibri is in service with the Italian Navy and up to 10 export customers.

NICE (see below) is intended as a next-generation replacement for this system.

◆ ELT/156

Elettronica's tactical RWR uses 4 antennas and 2 radio-frequency heads. The display is the usual polar plot of bearing against frequency, and several threats can be displayed simultaneously. The device provides audio warning. Total weight is 10.3 kg.



Colibri DF antennas on an Italian AB-212 helicopter. The radome below the 2 forward antennas carries an omnidirectional (IFM) antenna, and the radome over the cockpit carries a directional antenna, typically a radar antenna that can be used for precision direction finding, in analogy to some versions of ALR-66. The tail carries a pair of DF antennas and another omni. (Elettronica)

◆ ELT/263

Elettronica's lightweight maritime-patrol-aircraft ESM system uses the same type of directional antenna as Colibri. ELT/263 is intended to detect and locate E- through J-band radars. ELT/263 employs 4-6 directional antennas plus an omnidirectional antenna for IFM. System memory is sufficient for the aircraft to locate an emitter by triangulation as it flies past, and the system can blank off reception of the airplane's own radar to avoid confusion. The system is arranged to transmit emitter location to a surface station.

Typical detection ranges, based on altitude, match those listed above for Colibri.

ELT/263 was originally designed for the Beech 200T light maritime-patrol aircraft but has been adapted for others, including the P68T, Casa C212, Bandeirante, F27, Gardian, GAI Searchmaster, Learjet 36A, Maritime Defender, and the Piaggio P-166. At least 60 are in service, in Algeria, Finland, Indonesia, Italy, South Africa, Spain, Thailand, and the United Arab Emirates.

◆ ELT/562 and ELT/566

These Elettronica jammers can function with an ESM system such as Colibri. They cover the 6-20-GHz band. ELT/562 counters pulse radars; /566 counters CW radars.

◆ IHS-6

This is Selenia's alternative to Colibri. It has less impact on the helicopter or airplane airframe but pays with some restriction on overall capability. Development began in 1975; IHS-6 is a combination of RQH-5 and TQN-2. The system can carry 50 target tracks, and it covers the 1-18-GHz frequency range. It was developed primarily for naval use, e.g., for task force EW and for standoff and stand-in jamming in support of strikes. Of several users, the only publicly announced one is Egypt (on board Westland Commando helicopters, delivered 1980). It has been selected for the Italian maritime-patrol-aircraft update (as SL/ALR-730) and for the Italian Navy version of the EH-101 helicopter (as SL/ALR-735). An RWR version for supersonic aircraft is SL/ALR-743.

Commercial variants: Series 730 for maritime-patrol aircraft; Series 740 for fighters; Series 780 for ESM/ELINT/EW aircraft.

◆ NICE

Elettronica's New Integrated Computerized ESM system is intended to replace the existing Colibri and ELT/263. It was displayed at the Paris Air Show in 1989. Compared to Colibri, NICE dispenses with the semicylindrical half-omni antennas

but retains the 2 conical omnis and the 8 DF antennas (which are air-backed spirals). NICE offers the full range of analysis, identification, and surveillance functions in a single set of lightweight boxes and with a single CRT display, this improvement over Colibri being possible thanks to adoption of surface-mounting semiconductor technology and a fast computer. The internal equipment consists of a processor, a correlation unit, a keyboard, and the single display. NICE uses both wide-open and superheterodyne receivers. It can detect coding within a pulse (i.e., pulse-compression coding), and should be capable of precise frequency measurement and accurate direction finding. As in Colibri, there is an emitter library.

◆ RQH-5(V)

Selenia's helicopter ESM set is a component of IHS-6. It can provide direction of arrival and target parameters to other systems. Frequency coverage: 0.65–18 GHz (optional extension to 40 GHz). Parameters: frequency, pulse width, intrapulse structure (e.g., to identify pulse-compression radars), fine structure (fingerprinting, for electronic intelligence, and fine frequency measurement), jitter, stagger, PRI agility, antenna pattern, amplitude changes (which can be displayed as a histogram). The system employs up to 2 omni antennas (for IFM) and 4 or (more usually) 8 directional antennas. It is designed for very dense environments, accepting up to 20 new emitters every 20 msec. The library normally contains 3000 radar modes but can be expanded to 20,000. Options include more accurate direction finding with a multibeam antenna (sectoral monopulse direction finding) and several alternative multibeam flat arrays for different instantaneous fields of view and increased accuracy. The system can also be fitted with a steerable K-band antenna and with a fine-analysis ELINT receiver.

SWEDEN

◆ BOH 300/BOL 300/BOP 300/BOZ 100

BEAB (formerly PEAB) chaff/flare dispensers. BOH is for helicopters; BOP is for combat airplanes. BOL is intended for installation inside a missile launcher rail. All are controlled from a dedicated data bus. There is also a BOZ series, for Swedish high-speed combat aircraft (BOZ 100 is a chaff pod). BOP 300 and BOH 300 fire standardized chaff cartridges.

BOH 300 is installed on board Swedish Navy Vertol 107 helicopters, the standard box carrying 2 triple rows of dispensers firing outboard, and 1 row of 4 dispensers firing aft.

The U.S. Navy is currently evaluating the BOL chaff dispenser, which can be controlled by an ALE-47 and which is being considered for installation on the F-14. BOL employs a unique chaff-dispensing approach: chaff is released like individually wrapped slices of bread. BOL has been tested on the F-14 and will be installed inside the LAU-7 missile rails, to take advantage of unused space there.

The British MoD has also ordered BOL for evaluation.

BOP 300 is the chaff dispenser planned for the Fokker Maritime Enforcer Mk 2 maritime-patrol aircraft. BOP 300 can include up to 8 units, each of them carrying 2 rows of 3 tubes each. The control system computer memory can hold 16 separate dispenser programs and is easily reprogrammable. In the automatic mode the associated RWR senses the threat, and the ECM system automatically selects program and ejects. There is also a semiautomatic mode, in which the computer selects the mode but the pilot initiates action, and a fully manual mode. Using the latter, in the event of malfunction, a pilot can still deliver decoys via a program permanently stored in the dispensers; all would launch simultaneously. To create the largest chaff cloud, within the threat radar range gate, solid-state squib drivers can generate firing pulses at intervals of less than 100 msec in 1 dispenser; they may generate firing pulses at shorter intervals using several dispensers. The system memory holds 16 separate dispensing programs, and it can be reprogrammed to deal with a specific threat.

The current versions, for fast combat aircraft, use 2 or 4 dis-

pensers, weighing, respectively, 17 and 31 kg empty (27–35 and 51–66 kg loaded, depending on ammunition type). Dispensers can be loaded with standard square-section ammunition (chaff and flares) and with BOP circular-section ammunition (which have greater chaff and flare capacity). A BOP magazine contains 6 rnds each loaded with IR flares (1, 2, or 3 bodies/cartridge) and chaff (broad-band or peaked dipole); chaff and flares can be ejected in subrounds.

BOZ 100 chaff/flare pods are carried by some Tornado aircraft, as well as by French Jaguars and by Swedish Viggens (designated BOX 9 in the latter case). It operates either manually or automatically and has a reprogrammable dispenser-program library. The pod is suspended from a 14- or 30-in bomb rack; dimensions are 380 × 4000 mm (maximum loaded weight is 325 kg).

USSR

◆ Naval Support ECM

Soviet naval air-strike tactics include the use of both jammers and chaff-corridor layers. Badger-H (Tu-16PP, for *postanev-schchik pomiekh*) carries up to 9000 kg [19,840 lb] of chaff, sufficient for a 60-nm-long corridor, in its bomb bay. As in U.S. bulk-chaff systems, the chaff is cut as it is dispensed; the bomber monitors the radars it is to jam to determine their wavelengths. Badger-H has a pair of radomes like those of Badger-E (see below), plus a smaller radome just forward of the bomb bay. This combination might equate to having a pair of high-gain antennas to determine an emitter's location and having an IFM in the small radome. The chaff itself is dispensed from a hatch abaft the former bomb bay. Badger-J (also Tu-16PP) is the complementary jammer (for A–I-bands), first identified publicly in 1987. The jamming antennas are carried in a canoe under the former bomb bay, and there are also flat-plate and podded antennas at the wingtips (presumably, to determine an emitter's location and to monitor the effects of jamming). There is a small blister immediately forward of the canoe. Reportedly, a typical antiship regiment of the early 1980s consisted of 2 strike squadrons (each consisting of 9–12 missile attack bombers), supported by a third squadron consisting of 2–4 Badger-Hs, 1 or 2 Badger-Js, and 3–6 Badger tankers.

No equipment code names have been released. As the Badgers are discarded, corresponding versions of the current Backfire will presumably appear.

Other Soviet naval electronic reconnaissance (signals intelligence) aircraft are:

An-12 Cub-B and -D Cub-D (first seen 1982) has very large teardrop fairings on the sides of its forward fuselage. Aircraft are, reportedly, assigned to the Baltic and Black Sea Fleets, although they have appeared over the Indian Ocean.

Il-20 Coot-A (Also surveillance) Radomes include a large canoe (10.3 × 1.2 m) under the forward fuselage, cheek radomes (about 4.4 × 0.9 m) on the forward fuselage, and a twin array atop the fuselage just abaft the cockpit. Reportedly, the canoe houses a



A Soviet IL-20 Coot-A ESM airplane, photographed from an F/A-18 of VFA-151 off the USS *Midway*, March 1988. (U.S. Navy)

J-band side-looking radar, the cheeks house optical or infrared sensors, and the dorsal array is for satellite communications. Aircraft are assigned to the Northern and Baltic Fleets.

Badger-D (Signals intelligence/maritime surveillance) Aircraft are, reportedly, assigned to the Northern and Pacific Fleets. The *Badger-D*, a converted *Badger-C* (missile bomber), was first observed in 1962. The missile pylons were deleted, but the big nose radome of the *Down Beat* radar was retained. The teardrop-shaped chin radome (for *Puff Ball*) under the nose was slightly enlarged. Three new radomes were added, 2 small ones (not quite identical) at either end of the former bomb bay, and a larger one (somewhat larger than the chin radome) just forward of the center of the former bomb bay.

Badger-E (*Tu-16R*) is a modified *Badger-A* (bomber, with glassed-in nose) with cameras in a bomb-bay pallet and a pair of radomes, fore and aft of the bomb bay. The radomes are about the same size; presumably, they are used to triangulate an intercepted signal. This and other later electronic-reconnaissance or jamming versions have the chin radome of the original *Badger* bomber, and the chin radome houses an RPB-4 (Rubin 1) ground-mapping radar. *Badger-E* entered service in the early 1960s.

Badger-F is another version of *Tu-16R*, first seen in January 1963. It has a pair of large under-wing radomes. Some *Badger-F*s also have the under-fuselage radomes of the *Badger-E*; others have 2 large blade antennas mounted on the lower fuselage just abaft the bomb bay, with a small radome forward of the bomb bay. The bomb bay itself may carry a camera pallet. Some *Badger-F*s have an internal noise jammer for strike support. At least one *Badger-F* had a large tail cone replacing its tail gun turret. Others have been observed with extra antennas over the cockpit or alongside the nose. *Badger-F* often operates with *Badger-D* and was probably a related program.

Badger-K is the most recent electronic-reconnaissance version (1981); it differs externally from *Badger-E* in that the -K's forward ESM radome is noticeably smaller than the after one. Some *Badger-K*s have enlarged chin radomes. A photograph of a modified naval *Badger-K* (unofficially designated *Badger-L*) appeared in August 1986. This aircraft has a thimble radome protruding from its glassed-in nose, and it carries a pair of under-wing pods, probably to dispense self-protection chaff or flares. There are also new blisters under the nose and around the air intakes (the latter have also been seen on *Badger-K*s). This aircraft has the new, larger, flatter nose radome, which presumably houses a new ground-mapping radar.

Tu-22 Blinder-C (Signals intelligence/photo-reconnaissance) This aircraft carries 6 cameras in its bomb bay, plus antennas under dielectric panels on its forward fuselage sides. Aircraft are assigned to the Baltic Fleet.

◆ Sirena

Sirena is a generic Soviet designation for RWRs, installed in aircraft ranging from fighters through large bombers. Soviet pilots claim that the *Sirena* 3 version in a *MiG-29* is accurate within 12 deg of bearing and that the system displays the type of threat and the direction of the most dangerous threat. A photograph of the *MiG-29*'s cockpit shows a small rectangular CRT or liquid-crystal display above a series of lamps around the outline of a generic airplane: 4 to either side of dead ahead, and 1 to either side of the tail; there are also 6 slits (probably lamps) below this display. Presumably, they give some indication of threat type. The lamp display recalls Western RWRs of the early-Vietnam period; one account suggests that *Sirena* 2/3 are equivalent to the old U.S. APR-25.

UNITED KINGDOM

◆ ARI 18228

Marconi's Sea Harrier FRS.1 RWR operates over 2–18 GHz and uses a CRT display to show the direction of the threat; several threats can be shown simultaneously. There is also an audio alarm. ARI 18228 was developed from the ARI 18223 carried by RAF Jaguars and Harriers; the earlier system used a lamp to

indicate threat quadrant. ARI 18228 was originally developed for 2-seat aircraft such as the *Buccaneer* and *Phantom*.

The antennas are on the vertical fin, in the squared-off protrusion.

◆ ARI 18240 (Yellow Gate)

Nimrod MR.2 ESM system. See Loral EW-1017 in the U.S. section below. This system is being installed on board British AWACS (E-3D).

◆ Hermes

Hermes is the Marconi Defense Systems's ESM system supplied for Indian Navy Sea King helicopters. It is derived from the ARI 18241/1 radar-homing-and-warning receiver fitted to RAF Tornado F.2 and F.3 fighters.

◆ Kestrel (Orange Reaper)

Racal's ESM system is made for the EH-101 helicopter and for small maritime-patrol aircraft. Orange Reaper uses the same 6-port antenna as Orange Crop (MIR-2) but is described as an airborne equivalent of Cutlass. The processor and display match those of Sabre (see under shipboard radars and fire-control systems in the Antiaircraft Warfare section). The design emphasizes accurate frequency data (for radar identification) over high bearing accuracy, and there is a 2000-emitter threat library. Total weight is 47 kg. Frequency coverage is 0.6–40 GHz, bearing accuracy is better than 3.5 deg, using pattern-correction techniques, and processing time is less than 1 sec.

Orange Reaper is the Royal Navy version for the EH-101 helicopter. In this application it shares the helicopter's main display. Kestrel has been ordered for Royal Danish Navy Lynx helicopters to replace MIR-2. In these helicopters the ESM display is a 20 × 7.5-cm color CRT.

◆ MIR-2 (Orange Crop)

Racal's ESM system for helicopters covers the C- through J-bands. Orange Crop was designed for the Lynx helicopter but was extended to Sea Kings during the Falklands War. The system uses 6 antennas, each covering a 60-deg arc. The display shows frequency band (the 0.6–18-GHz range is divided into 4), bearing (the scale is divided into 10-deg steps), and amplitude. Strobes are used to select signals by band and bearing for pulse analysis and accurate bearing measurement. For pulse analysis, the PRF is displayed digitally; bearing is displayed on a 30-deg display calibrated in 2-deg steps. Bearing accuracy is 4.5 deg. Signal limits: pulse width 0.1–10 microsec, PRF 50–10,000 pps. Total weight without antennas is 30.7 kg. This system was originally designed to intercept and locate submarine burst transmissions.



Two Orange Crop antennas (broadside and facing aft) on a Sea King helicopter, off HMS *Ark Royal*, 1990. There are 2 more such antennas on the nose of the helicopter, and each antenna consists of 2 cavity-backed spirals, to cover 2 frequency bands. (Author)

A current upgrade to Mk 3 configuration, involving 2 line-replaceable units (LRUs), provides a PRF library for pulse analysis and a capacity to recognize important CW (missile-guidance) radars. Mk 1 was the original system with an RWR and a search-radar receiver in the same modular unit. Mk 2 added an optional radar-altimeter input, as well as track-data input and output. It was installed on board all RN Lynx and Sea King helicopters, with some pods (Orange Blossom) for RAF C-130s, for radar surveillance and self-defense warning.

MIR-2 was first displayed in July 1978, and the first contract for installation in Lynx helicopters followed in October 1981. Unit cost is about \$350,000.

Although originally developed for helicopters, MIR-2 was later extended to surface craft. The ship-based version is described in the Antiaircraft Warfare section. Racal has discussed license production in France.

◆ Sky Guardian 200

Marconi's RWR for the Sea Harrier FRS.2 incorporates an EEPROM threat library (over 400 emitters, over 2500 emitter modes) and is capable of triggering defensive measures (presumably limited at present to chaff). It divides signals in the E-through J-bands into 3 bands; C-D-band and K-band coverage can be added as options. Four broad-band spiral antennas (52 mm in diameter) provide better than 10-deg DF accuracy. The basic system uses broad-band crystal video receivers and 3 computers: 1 for measuring signal parameters, 1 for sorting and initial analysis, and 1 for arranging signals into individual emitter tracks and comparing them with the threat library. Total multiprocessor memory is 336k (RAM, PROM, and EEPROM), with 100% growth capacity. It can be reprogrammed in about 60 sec on the flight line. The processor operates at 5 MOPS. Response time is less than 1 sec from detection to identified display.

The main display is a high-brightness 3-in CRT compatible with NVGs, showing up to 15 emitters with identity, status, and bearing (pseudo-PPI). There is also an alternative tabular format showing parameters such as frequency band and PRF. The CRT display is persistent, to show fleeting intercepts. The system's digital output can also be passed to a HUD, as in the Sea Harrier FRS.2. Aside from the CRT, the pilot is provided with continuous true audio (presumably at PRF frequency, giving an idea of the nature of the threat) and with synthetic alarm tones.

Antennas can be added for more precise direction finding; the basic system uses the amplitude comparison typical of RWRs. An IFM can also be added (normally Sky Guardian uses crystal video receivers). The threat library can be updated in flight, and emitter data can be recorded for later playback and analysis.

MTBF is over 700 hr.

Sky Guardian was developed from ARI 18223/18228 (see above). Series 100 is intended for helicopters and light aircraft, Series 200 for combat aircraft, and the projected Series 300 for large maritime-patrol and ASW aircraft. Series 300 adds an IFM and horn antennas for accurate DF. Series 200 is carried by RN and Indian Sea Harriers and Spanish EAV-8As. Sky Guardian is also on board Sea King and Puma helicopters.

The British MoD rejected a suggestion that the Sea Harrier be fitted with the Plessey Avionics Missile Approach Warner (MAW), a rearward-looking pulse-doppler radar analogous to the U.S. ALQ-156. MAW has been bought for RAF Harrier GR.5s.

◆ Yellow Veil

The Whittaker Electronics (U.S.) jammer for Lynx helicopters operating in the Persian Gulf is designed to protect British warships against Iranian antiship missiles. Based on the U.S. Navy ALQ-167(V), Yellow Veil can be carried either internally or as a pod, in the latter case replacing 2 Sea Skua missiles. Yellow Veil is also based in part on Falklands experience. The system protects a Lynx attacking with Sea Skua from hostile antiaircraft sensors; the helicopter is limited in maneuverability because it must keep the surface target illuminated. Yellow Veil is also carried by some Sea King HAS.5 helicopters.



The long pod of Yellow Veil is carried by this Royal Navy Lynx helicopter. (Whittaker Electronic Systems)

The U.S. Navy and NATO use the ALQ-167 dual-mode noise/deception pod (0.4–11 GHz) for training, to simulate enemy jammers. The pod in turn is a modified version of DLQ-3, a blip-enhancer that could be carried by a drone (operating as an antiaircraft target), to make it appear larger to an opposing radar.

◆ Prophet

Prophet is a Racal RWR designed for export, particularly on board Hawk trainer/attack aircraft. However, Royal Navy Sea King helicopters operating in the Persian Gulf have been fitted with this system, an installation completed in 2 weeks. Prophet reduces its false-alarm rate by measuring the frequency of an intercepted signal, an unusual feature in so simple a system (most measure only PRF within a broad band and may, therefore, easily confuse signals). Total weight, including a 4-port antenna and an LED display, is 9 kg. Coverage is either 2–18 GHz or 6–18 GHz, and the threat library can store signatures of more than 100 emitters. Designed response time is less than 1 sec.

EXPENDABLES

◆ ADS-10

The Widney-Aish helicopter missile decoy system was announced in 1989. Standard square-section (25 × 25 mm) chaff, IR, or smoke screen cartridges are loaded in four 4 × 4 magazines ("intelligent dispensers"), which swing out for reloading. Alternatively, the magazine can be loaded with 2 × 4 MJU-7/B type flares. The user can program the system to fire up to 64 rnds/salvo, at random or staggered intervals of 0.1–60 sec (the standard system fires up to 9 rnds/salvo, with intervals of 0.1–9 sec). Electrical contacts at the rear of the magazine detect the presence of ammunition and relay that information to the microcomputer that controls the system. Similarly, the contacts report back when cartridges are fired.

Total weight, loaded, is 24 kg.

UNITED STATES

◆ AAR-37

Hughes's IR warning system is made for P-3 aircraft.

◆ AAR-47

Honeywell's electro-optical warning sensor is designed to detect close-in incoming missiles that may not register on RWRs, e.g., IR- and laser-guided weapons. The system detects the IR signature of the missile plume and eliminates nonthreats by spectral analysis and also by temporal algorithms, i.e., by measuring



The ADS-10 helicopter-countermeasures dispenser, on display at the RNEE show in 1989. It is opened for loading, with a typical magazine at left. The contacts on the inner panel identify the magazine to the system and allow the system to launch cartridges. (Author)

the dynamics of the approaching object. The system automatically launches flares (e.g., from an ALE-39) and provides an audio and visual alarm for the pilot. Four sensors hard-mounted on the aircraft skin provide all-around coverage. AAR-47 was approved for production in 1987 after opeval and techeval, and in February 1988 the U.S. Naval Air Systems Command ordered 111 for the CH-53, CH-46, AH-1, UH-1, OV-10, SH-2 (LAMPS I), V-22, and MH-53J (air force special operations). Another 373 have been ordered, applications including army helicopters and air force reserve C-130s. Projected naval applications are the P-3C, the AV-8B, and the CH-46 helicopter.

AAR-47 was installed on board SH-60B LAMPS III helicopters of the Middle East Force during the Gulf War.

◆ AAS-43

This is GE's passive-IR detection system for the A-12.

◆ ALD-8

ALD-8 is the E-Systems direction finder for EP-3E aircraft.

◆ ALD-11

This is Litton's radar direction finder for the A-12.

◆ ALE-39

The Goodyear/Tracor chaff-cartridge dispenser is standard on U.S. Navy aircraft. It is a square container typically attached to the side of an underwing hard-point pylon. Normal capacity is

60 cartridges, but it can be expanded to 300. This pod can launch three types of decoy (flare, chaff, and expendable active) in multiples of 10; options include multiple flare ejection.

◆ ALE-40

Chaff pod, normally used by the U.S. Air Force; the (V)6 version is carried by British Nimrod maritime-patrol aircraft. In contrast to U.S. naval chaff launchers, air force launchers use square-cross section chaff cartridges. The (V)4, 5, and 6 versions are internal chaff dispensers intended originally for the F-16 fighter; each carries 30 RR-170 chaff cartridges or 15 MJU-7/B flares. (V)1, 2, and 3 are pylon-mounted for the F-4 series. (V)7, 8, and 9 are intended for semi-internal mounting on F-5s, (V)10 is for the A-10, and (V)11 is for the air force version of the A-7.

◆ ALE-41

This chaff pod, which can be carried underwing, is used to sow an 80-nm chaff corridor. It succeeds the earlier ALE-2 and ALE-32 and is based on the air force ALE-38. Bulk chaff is carried in the shell of the old ALE-2. Capacity: 280–360 lb of aluminum or metallized glass chaff. The chaff is carried in six 50-lb cartridges containing dipoles between Mylar films, spread by the wind as the tape unravels. Dimensions: 19 × 131 in (500 lb loaded). The pod is programmed on the ground, controlled either by a cockpit switch or by the aircraft's radar detector. It was approved for service use in 1977. ALE-41 is currently carried by EW training aircraft.

◆ ALE-43

The Lundy chaff dispenser cuts chaff from 8 spools of aluminumized glass fiber. The resulting chaff can counter radars from VHF up to millimeter-wave. In pod form (640 lb), ALE-43 carries 320 lb of chaff. This dispenser can also be housed internally, as in the EA-6B (total weight 420 lb). Chaff is carried in up to 9 packages, each feeding a roller and cutter.

This type of bulk pod is generally used to lay a chaff corridor.

◆ ALE-47

Tracor chaff dispenser, intended to replace both ALE-39 and the air force ALE-40; it is to be interchangeable with ALE-40. There will also be new programming formats, to take advantage of the range of new expendables now available. ALE-47 will be the second fully automatic dispenser system in U.S. service; the first was the ALE-45 on board the air force's F-15C/Ds. Tactics are programmable, and ALE-47 continuously receives data from both the aircraft platform's avionics (giving, for example, its air speed and altitude) and from the threat warner. ALE-47 can operate in fully automatic mode (the system selects its tactics), semiautomatic mode (the system selects tactics but the crew initiates), or fully manual mode. In each case, ALE-47 can program smart (active) expendables such as GEN-X. ALE-47's predecessors could operate in preprogrammed sequences but could not change from sequence to sequence, as ALE-47 can. Nor could they be triggered automatically by the aircraft's threat warner. Tracor received a 4-yr full-scale-development contract in August 1989; ALE-47 is to be integrated with the new ALQ-165 (ASPI) jammer. As of fall 1990, development was running about 12–18 months late because of the 1986 decision to make ALE-47 a biservice program (it began in 1983 as an air force program). The only difference between the 2 versions will be the magazines (cylindrical for the navy, square-section for the air force).

◆ ALE-50

Raytheon's advanced airborne expendable decoy (AAED, a towed decoy to confuse monopulse radars) is part of the IDAP program. ALE-50's 2.75-in-diameter shell contains a mini-TWT to generate a sufficiently large target to compete with the radar return of the airplane itself. Hughes is the follower producer. The current (1990) cost goal is \$10,000–\$15,000 per expendable decoy.

◆ ALQ-39

CHAFFBUOY is a delayed-deployment chaff cartridge intended to countersurveillance systems. Aircraft are used to deploy ALQ-39 so as to bring it far enough from the fleet. The distances involved permit delays of an hour or more in deployment, and the countersurveillance decoys need not be as large as those used to decoy missiles away from large ships. See also ALQ-190.

◆ ALQ-41

The Sanders track-breaker is part of the EA-6B suite. It is also carried by the EA-3.

◆ ALQ-76

Raytheon's jammer (2–8 GHz) for EP-3 aircraft.

◆ ALQ-78

Magnavox's ESM system for P-3 aircraft is to be replaced by ALR-66 in U.S. service. ALQ-78 uses a swept superheterodyne receiver fed by a high-speed rotating antenna in a pylon under 1 wing of the airplane. It intercepts and DFs submarine radar signals. Production began in the mid-1970s. A reprogrammable processor was added in the late 1970s to support Harpoon targeting. The U.S. FY82 program included modifications and upgrades to support operations in a multisignal environment, including modifications to system logic and the use of fine frequency information to improve sorting among pulses. A pulse-train separation circuit was added. ALQ-78 is manufactured under license by Mitsubishi, for Japanese P-3Cs. This device is also carried by the EP-3E signals-intelligence airplane. Foreign users are Australia, Canada, Japan, the Netherlands, and Norway. Estimated unit cost is \$160,000.



This Japanese P-3C shows an ALQ-78 radome under its port wing root (to the right in this picture). (W. Donko, 1989)

◆ ALQ-81

Sanders's jamming pod for A-7B and -7E light bombers was produced 1971–74.

◆ ALQ-86

The Bunker-Ramo ESM system was used originally in EA-6A (with the Loral ALQ-53 electronic reconnaissance system) and then in EA-6B ADVCAP.

◆ ALQ-91

Magnavox's communications jammer (to defeat the command links of surface-to-air missiles) for A-4Ms and F-14s was first ordered 1971.

◆ ALQ-99

ALQ-99 is the tactical support jamming system of the EA-6B Prowler, the standard U.S. Navy ECM airplane. The EA-6B de-

rives its flexibility from the use of pod-mounted jammers, analogous to the underwing stores of the A-6 attack bomber, that are controlled by an inboard computer and sensors (just as the A-6's attack is controlled by a computer and the APQ-148/156 radar). The pods were conceived in connection with a 1960 Grumman proposal for an EA-6 to be built around the new ALQ-53 (Giraffe) and to carry noise jammers (ALT-13, -15, and -16), track-breakers (ALQ-41 and -51), and a VHF jammer (QRC-1022 AL). The standard A-6 APQ-92 radar was simplified (as APQ-103) and moved slightly forward to create a bay for the ALQ-53. A radome was built on the vertical fin aft to accommodate most of the sensor antennas. The advantage of the radome's position was its 360-deg field of view. Other antennas were located in the canopy.

The logic of the podded jammer was a combination of flexibility (pods could be changed to match the threat) and the need for sheer jammer power: an internal jammer probably could not match what could be carried underwing, powered by a ram-air turbine. The proposed pod, designated ALQ-31, had a trainable, elevatable antenna so that the jamming airplane could track an enemy radar while maneuvering in an almost unrestricted manner. Moreover, because the jamming airplane probably would not face the full spectrum of enemy radars during any one mission, the aircraft could carry only the jammers it needed, using the remaining hard points for additional fuel or (now) for anti-radar weapons. ALQ-31 carried 2 complete jamming systems (noise, communications/navigation, or multitarget repeaters). The first pod to become operational, ALQ-76, carried 4, so that an airplane with 5 hard points could, at least in theory, jam up to 20 individual radars. The airplane itself was designed with the potential to add 4 more hard points, for a total of 9. Alternatively, each hard point could carry a 300- or 450-gal drop tank.

The first ECM version of the A-6, the EA-6A (which is still flown by reserve squadrons), carried an ALQ-86 receiver and display/control system instead of the ALQ-53 initially planned, and ALQ-76 pods. There was provision for the ALQ-54 noise-jammer pod and for chaff-dispenser pods (ALE-32, -41, and -42), so that the EA-6A could lay chaff corridors. EA-6As carried ALQ-55 communications jammers, to disrupt ground-controlled interception. The EA-6A also carried defensive systems to protect itself: an onboard chaff dispenser and a self-protection jammer (ALQ-100).

This system was limited because its different elements had been conceived and developed separately and could be integrated only through the skills of the single ECM operator. This operator in turn could easily be overcome by the sheer complexity of a dense electromagnetic environment. The operator had substantial electronic firepower but lacked the means to acquire and identify targets rapidly, particularly because the computer intended for ALQ-53 was not available in time. The operator, therefore, had to watch the system scan mechanically



An EA-6B of VAQ-140, 1988, displays the leading features of the ALQ-99 system: the tail radome (for all-around view) and the underwing pods. The 2 strakes on the vertical tail are ALQ-99 receivers for Bands 1 and 2. The short stub protruding aft from the tail radome (the "beer can") is for ALQ-126, added during the ICAP-1 program. (U.S. Navy)

through its frequency range every 2 sec, listening for the tone of an enemy radar. Worse, at this time the Soviets were introducing tunable radars, to overcome spot jamming. To be effective against such radars, a jammer must periodically shut down ("look through") to check whether its target is still emitting on the same frequency: the target has to be tracked both in position and in frequency (and, for that matter, in operating pattern).

Navy work on an integrated ECM airplane began in 1963, and Grumman conducted its own in-house study of an EA-6A at about the same time. The EA-6B, which is almost synonymous with the ALQ-99 system, was the result. The new idea was to develop the ECM system as an integrated whole instead of as a federated set of separate systems. The development contract was awarded in August 1966.

The key requirement was automatic radar identification and tracking in a very dense environment. Without accurate identification, jamming power could be wasted on low-priority radars such as IFF systems and airport landing systems. Very quick reaction was essential in the face of modern missile-control systems. Moreover, an operator would be presented with radars in very fast succession. Grumman estimated that in one case an airplane flying at 20,000 ft at 400 kt would encounter about 10 distinct emitters/sec, a rate that would double at 40,000 ft (because of the longer lines of sight). The solution was a combination of computer identification and of correlation of target bearing with emitter characteristics (radar function on land is generally associated with particular geographic positions). That solution, in turn, would require a computer memory.

The new system, ALQ-99, consisted of a series of antennas and signal processors feeding a central computer and integrated displays and jammer controls, which in turn fed self-contained pods with their own automatic frequency-and-direction tracking. The airplane itself had a doppler radar feeding a dead-reckoning navigator, which assisted in signal processing and jammer pointing, and defensive ECM for protection against counterattack. Even though ALQ-99 was much more automated than earlier ECM systems, it required 3 operators (ECM officers, or ECMOs). The standard A-6, then, had to be stretched to accommodate 2 more side-by-side seats.

Pods were designed for specific frequency bands, and aircraft were launched with a prebriefed set. Each consisted of an exciter flanked by 2 transmitters, with trainable antennas underneath. The typical load was 3 pods (centerline and outer store stations) and 2 drop tanks.

Thus the EA-6B began as a strike-support weapon, to jam acquisition and targeting radars. In the face of SAMs, for example, neutralizing the acquisition radar prevents hand-off to the missile-control system. Neutralizing the tracking radar of the missile system in turn prevents successful missile firing. Both tactics were often used in Vietnam. Early Prowler tactics called for the airplane to fly near a strike target, but outside the strike pattern proper. For example, an EA-6B on the strike axis could jam the radar net toward which the strike aircraft were flying. The next step was to jam defensive communications. The Soviets tend to rely very heavily on ground-controlled interceptors, and even if the directing radars work, the airplanes are helpless without their communications. It was natural, then, for the Prowler to be upgraded to deal with voice communications. The next step for the Soviets is to use a digital data link, which is more difficult to jam; and the next step for the Prowler is to neutralize that link as well.

A second mission, fleet defense, was added during the late 1960s. Prowlers could jam airborne targeting radars (which, in many cases, were needed to fire the surface-launched as well as the air-launched weapons) and, to a lesser extent, the missiles themselves. The EA-6Bs could also use their receivers for surface surveillance, providing passive early warning of the approach of enemy forces without disclosing the presence of the carrier group.

About 1985 the requirement to be able to physically destroy enemy radars, by firing HARM missiles, was added. By this time

HARM was valued not only as a means of neutralizing ground defenses but also as a means of rendering enemy warships vulnerable to salvos of antiship weapons. The rationales are quite different. A HARM may put a land-based radar out of action for a few hours or for a few days, when a particular target (among many) is hit. At sea, even temporary dislocation due to a HARM should open a ship to fatal damage.

These upgrades have been applied to virtually all EA-6Bs, which are periodically returned to Grumman for remanufacture (as of 1987, some had been rebuilt as many as 3 times). The major series are XCAP, ICAP-1, ICAP-2, "Block '86," and, in the near future, ADVCAP (Block '91). The flexibility inherent in the podded concept is very important here.

ALQ-99 coverage is defined in terms of bands, which are distinct from the usual ECM series. Bands are: 1, VHF; 2, A-band; 3, B-band; 4, C-band; 5/6, 1–2.5 GHz; 7, 2.5–4 GHz; 8, 4–7.8 GHz (most of G- and H-bands); 9, 7.8–11 GHz (upper H-, I-, and lower J-bands); and 10, 11–20 GHz. In traditional radar terms, Bands 6 and 7 are S-band, Band 8 is most of C-band, Band 9 straddles X-band, and Band 10 (for which there is as yet no ALQ-99 jammer) is Ku-band. Of current Soviet shipboard radars, only Top Dome (approximately 10.5–13 GHz) is outside ALQ-99 coverage.

The original EA-6B, which entered service in 1972, was limited to 4 countermeasures bands, together accounting for 96–98% of the electronic threat in Vietnam: Band 1, 64–150 MHz (VHF communications); Band 2, 150–270 MHz (some P-band radars); Band 4, 0.5–1 GHz; and Band 7, 2.5–3.5 GHz. XCAP (expanded capability) added Bands 5, 6, 8, and 9 to deal with newer high-frequency fire-control radars that were important outside Vietnam. XCAP, entering service in 1973, also incorporated a digital recorder (for electronics intelligence). Computer memory was doubled, and new computer-operated modes allowed simultaneous automatic coverage of several enemy radars. Jamming was driven by a new exciter.

XCAP and earlier aircraft can be distinguished by a pair of spear antennas protruding from the outboard pylons. The right-hand antenna transmits, the left-hand receives. The antennas initially served the ALQ-41 and ALQ-100 self-defensive (track-breaking) systems.

In the XCAP version, ECMO 1 (in the front seat) and ECMO 2 operated the main jammer, with ECMO 3 (who was not always needed) assigned to the ALQ-92 communications jammer. ECMO 1 also served as navigator and, therefore, had a disproportionate work load.

ICAP-1 (1977) added digital receivers, which fed a computer display system, and an automatic carrier landing system (ACLS). Major changes in displays and cockpit layout considerably reduced the work load of the crew members. The entire track/jam function was moved to the after pair of seats. ECMO 1 became communications jammer (ALQ-92), navigator, and radar operator. ICAP Prowlers can be distinguished externally by the 2 antennas of their ALQ-126 defensive (and deceptive) ECM system, which replace the 2 spears of the earlier aircraft: a receiving antenna on the refueling probe at the nose, and the "tin can" receiving antenna on the after edge of the fin radome.

ICAP-2 introduced the AIL-developed universal exciter, and it could jam communications on a limited basis. ICAP-2 has an automatic signal processor and a mission planner, as well as the current CAINS. The Band 7 search-receiver coverage was extended to the lower edge of Band 8, at 4 GHz (rather than 3.5 GHz as before).

The universal exciter substitutes a computer-generated signal for the previous analog-processed threat signal. The antennas are electronically steered, and output is about 1 kW/MHz, with a 30-deg beamwidth. Frequencies can be mixed within any pod, weight varying according to the 2 transmitters carried (the older pods could jam only 1 band each).

As the threat becomes denser, the operator cannot initiate action quickly enough, and the computer becomes the initiator, the human operator the monitor. The original ALQ-99 was semiautomatic, partly because it appeared before computers had

become particularly reliable. Problems with operator speed were first noticed in ICAP-1 aircraft, and ICAP-2 introduces full automation, with a faster (AYK-14) computer.

The next version (Block '86, 1988) adds encrypted HF communications, enhanced signal processing and recording, and VHF/UHF communications. Like ICAP-2, Block '86 can fire HARM missiles.

Block '86 will be the last version to incorporate the ALQ-99 that marked the entire series. In 1991 advanced capacity (ADVCAP) Prowlers will begin to appear, built around an entirely new system, currently described only as the RPG (receiver-processor group). The RPG system will respond to considerable improvements in threat radars, such as more complex (coded) pulses, to overcome spot jamming, and pulse-to-pulse frequency agility. Successful jamming now requires an ability to analyze pulse and pulse-train patterns so that they can be mimicked. Moreover, radars can now tune over wider bands, so that jammers limited to specific narrow frequency ranges may no longer be effective. Hence the vital interest in a "universal exciter" and in faster scanning of the spectrum. Increasing civilian use of the electromagnetic spectrum increases signal density and also makes it easier for a jammer to be seduced into action against a nontarget signal.

The RPG has been in full-scale development since 1983 and will be combined with the ALQ-149 system for command-control-communications countermeasures, which replaces the earlier ALQ-92. The RPG will substitute a disk recorder in place of the current digital tape, for greater information density and higher speed. ADVCAP aircraft will probably also have a new radar, which cannot be the multifunction type now specified for the A-6F. A third display (for the front cockpit) will be added to the 2 displays currently in the 2 rear seats. The forward operator currently is underutilized, and as the electronics environment becomes more complex, this operator will become vital to the 2 NFOs in the rear.

Versions are distinguished as

ALQ-99(V) Original EA-6B version, covering Bands 1/2, 4, and 7. The pods have the following dimensions:

Band	Weight	Length	Height	Width
1/2	959 lb	185 in	26 in	24 in
4	929 lb	185 in	28 in	18 in
7	962 lb	185 in	28 in	18 in

ALQ-99A EXCAP version, covering 8 bands (1/2, 4, 5/6, 7, 8/9). A single TWT covered bands 5/6; and a single new tube, a major development, sufficed to cover all of Band 9. New pods were introduced:

Band	Weight	Length	Height	Width
1/2	959 lb	185 in	28 in	24 in
4	929 lb	185 in	28 in	18 in
5/6	969 lb	185 in	28 in	18 in
7	962 lb	185 in	28 in	18 in
8	953 lb	185 in	28 in	18 in
9	983 lb	185 in	28 in	18 in

These pods were used in all naval versions through -99E.

ALQ-99B Minor improvements for reliability and maintainability.

ALQ-99C Additional reliability and maintainability improvements, modifications to frequency-sector mode of operation.

ALQ-99D ICAP-1 system with digitally tuned receivers and fully integrated computer-controlled jamming.

ALQ-99E RF-111A system for the air force.

ALQ-99F ICAP-2 version with universal exciter. Each generic pod (185 × 28 × 18 in) carries any 2 transmitters; they vary only in weight (1014 lb, for 2 Band 4, up to 1089 lb, for 2 Band 9).

◆ ALQ-108

Magnavox's IFF deception set, for E-2C, EP-3E, and S-3A aircraft, originated in the early 1970s. Over 300 were manufactured; reportedly some are carried by West German F-4 fighters.

◆ ALQ-110

United Technology's radar signal-collection system (Big Look improvement program) is for EP-3 aircraft. Big Look was originally used to monitor North Vietnamese SAM activity. See ASQ-171.

◆ ALQ-123

The Loral pod-mounted IR jammer produces a modulated IR signal. IR guided missiles use a technique equivalent to conical scanning, i.e., the missile associates directional information with the timing of the IR signal it sees. A suitably modulated jamming signal thus provides false directional information and causes the missile to pitch up. The choice of modulation frequency (see the Sidewinder description for some typical figures) depends on the design of the target missile; in 1986 ALQ-123 was reportedly being modified to provide additional pulse rates to defeat newer Soviet missiles.

Dimensions are 10 in (diameter) × 102 in (378 lb). In 1982 ALQ-123 was upgraded and modified to meet additional threats. MTBF is 280 hr. This assumes that the lamp is not continuously lit, as lamp life is 150 hr. MTTR is 30 min. Power is provided by a ram air turbine.

ALQ-123 was one of the first IR jammers. It was developed on a crash (QRC) basis in 1972, as part of the CAIR program begun in 1971, winning over a Sanders prototype. It was approved for service use in FY73, and 60 were bought under the FY73 QRC program. Estimated unit cost was \$20,000. ALQ-123 was originally designed to defeat the Soviet AA-2 IR air-to-air missile. An improved IR lamp was tested under the FY80 program, and about 170 were manufactured. Users included the Israeli airline, El Al. Loral received an upgrade contract in August 1984. British Aerospace was licensed to produce this pod.

◆ ALQ-126/164

The defensive ECM (DECM) system of the F/A-18 Hornet is manufactured by Sanders Federal Systems Group. ALQ-126B, the current version, is the first U.S. Navy/Marine Corps reprogrammable DECM system. This system is also used on foreign-sales F/A-18s. It operates either autonomously or in concert with the ALR-45F/APR-43 or ALR-67 RWR, the ALQ-162 CW jammer, and the HARM missile.

In an F/A-18, the system incorporates forward high-band antennas just aft of the radome (above and below the fuselage), an aft high-band antenna atop the port fin, forward mid-band antennas above and below the fuselage just forward of the air intakes (starboard above, port below), aft mid-band antennas just forward of the vertical fins (above and below), and low-band antennas (positioned with the mid-band antennas, but on the other side of the airplane).

Total weight is 190 lb (2 units, upper and lower deck, connected by blind-mate connectors), and the maximum power requirement is 3 kVA.

ALQ-164 is the podded version of ALQ-126B, for the Marine Corps AV-8B Harrier. ALQ-126 replaced the Sanders ALQ-100, which had been the standard navy self-defense jammer from the early 1960s on. ALQ-126 was initially referred to as ALQ-100X. The pod weighs 350 lb (16 in × 85 in).

The original ALQ-100 contract was awarded in February 1963, and production ended in February 1967, 2500 having been made. It was an E- through H-band track breaker, providing 1 kW of peak power at a 4% duty cycle, pulsed with 50 W of CW. Techniques were range-gate pull-off (RGPO), inverse conical scan (ISC), main-lobe blanking (MLB), swept square wave (SSW), and velocity-gate pull-off (VGPO). Response time varied between 0.120 and 4 microsec. ALQ-100 was designed to fit an A-4 Sky-

hawk; volume was 2.44 ft³, and weight was 180 lb. Presumably, these considerations also shaped its successor, ALQ-126. Compared to ALQ-100, -126 emits over 1 kW/band, and coverage expands to the I/J bands. Available tactics match those of the earlier jammer, but one variant uses a transponder jammer technique. Typical response time is 0.1 microsec, with 4-microsec memory duration. Coverage is typically 60 deg beamwidth, pointed down at about 15 deg.

◆ ALQ-129

ITT Avionics' mini-track breaker (in X-band) for the F-14 fighter. Technology from this pocket was offered for the Belgian Mirage 5 ECM package, a contest won by Loral's Rapport.

◆ ALQ-130

The AIL communications jammer on EA-6Bs is an updated ALQ-92. ALQ-130 attacks missile-command links, using broadband noise. This jammer is internally mounted on board EA-6Bs.

◆ ALQ-142

Raytheon's ESM system for LAMPS Mk III helicopters is a repackaged version of SLQ-32(V)1/2 (ESM without jamming). The antennas are 4 Rotman-lens array units, and target bearing is measured on each pulse. The system's threat library is carried in the helicopter's AYK-14 computer. There is a patrol-airplane variant with extended frequency coverage. See the Antiaircraft Warfare section for SLQ-32 details.

◆ ALQ-144

Sanders's infrared countermeasure for helicopters consists of a cylindrical heat source surrounded by a modulator, mounted either on top of or under the helicopter. It is used on board army AH-1S and UH-60 helicopters and on board marine AH-1J, -1T, and UH-1N helicopters. ALQ-144 was mounted on board LAMPS I helicopters deployed to the Persian Gulf as a countermeasure against hand-held IR missiles. Versions are -144(V)1, (V)3, and (VE), the last for export. Together with ALQ-147, ALQ-144 comprises the "Hot Brick" IR countermeasure of the army OV/RV-1D reconnaissance and observation aircraft. ALQ-147 is a fuel-fired IR countermeasure originally intended to fit the after end of the OV-1 drop tank; later a stand-alone version was developed. Presumably, the combination of 3 separate (and separately modulated) IR sources was intended to counter the IR equivalent of monopulse missiles (the combination would be equivalent to the "cross-eye" technique used to counter monopulse radar).

Deliveries of ALQ-144 began in March 1981; by 1988 over 1200 had been produced.

ALQ-144A is an upgraded version covering the long- as well as short-wave IR bands. The heat source is a piece of electrically heated graphite in a glass tube. The beam is concentrated by a lens, and a rotating reflector projects a beam. Total weight is 28 lb, and ALQ-144A operates at 1200 W.

◆ ALQ-146

The Sanders IR countermeasure to protect CH-46D helicopters was tested in 1976 and first ordered in 1977. Each CH-46D carries 2 ALQ-146s, 1 above the cockpit and 1 above the tail doors. The crew selects the modulating frequency.

◆ ALQ-149

The new EA-6B tactical communications jammer, by Sanders Associates, is compatible with the existing ALQ-99 and uses cooperative jam/look-through cycles to allow simultaneous operation of both systems. ALQ-149 is also intended to detect, identify, evaluate, and jam enemy long-range early-warning radars. Presumably, those abilities mean that it operates at somewhat lower frequencies than ALQ-99, e.g., against shipboard P-band radars.

In 1988 it was reported that this program had been delayed

because of a combination of severe technical problems and legal disputes between the original joint venture partners, Sanders and ITT. The current partners are Sanders and Lockheed Electronics. Reportedly, part of the problem was overambitious specification in frequency range; that problem has now been remedied. As of the fall of 1988, Sanders had delivered 6 of the 7 engineering-development models on order. Because the Vietnam-era ALQ-92 was removed some years ago, EA-6Bs are limited in their capabilities. ALQ-149 was planned as part of the ICAP-2 EA-6B upgrade, but delays have made it part of ADVCAP instead (FY91 and beyond). ASQ-191 was purchased as an interim solution (see entry).

◆ ALQ-156(V)

In October 1988 Sanders Associates received an FSED contract for the ALQ-156 Missile Detector, Integrated Defense Avionics Program (IDAP), for use on various navy tactical aircraft. ALQ-156 is a short-range pulse-doppler radar, intended to detect incoming missiles (such as IR types) that do not radiate and that, therefore, cannot be detected by RWRs. The radar creates a warning zone around an aircraft, and it is triggered by the closing rate and radar cross section of a detected object. It in turn fires IR decoys. It uses 2 blade antennas. The system was originally developed in 1976 to protect helicopters and slow aircraft; now it is being adapted to fast attack jets. Adaptation is relatively easy because the system is built around a programmable signal processor. A new buffer box connects it to other aircraft avionics. A new planar antenna has been developed for attack aircraft such as the A-6E (helicopters typically use a blade antenna, and slow aircraft, such as a C-130, use a horn antenna). The FSED contract calls for the design and production of 12 sets of equipment; the contract is to be completed by September 1990.

In IDAP (for modernized A-6E aircraft), the ALQ-156's spare processor capacity is used to integrate the system's ALQ-126B jammer, ALQ-156 MAWS, ALE-39 chaff dispenser, and ALE-50 towed decoy.

ALQ-156 (in helicopter form, with 2 blade antennas) weighs 50 lb and has an MTBF of 300 hr (MTTR is 15 min); power requirement is 425 W.

◆ ALQ-157

ALQ-157 is the Loral IR jammer for large helicopters. Two emitters are mounted, 1 on either side of the vertical tail of the helicopter, and the pilot can choose 1 of 5 jamming modes. Production began in 1983, for CH-53 and CH-46E helicopters. The system weighs 220 lb, and MTBF is 215 hr (lamp MTBF is 330 hr). Loral has proposed installation on heavy-lift aircraft (P-3, E-2C, C-130) as well as helicopters. In such aircraft, the optics would be shaped to correspond to the aircraft signature. At present ALQ-157 is carried by at least some Lynx helicopters (users unspecified), as well as by SH-3 and H-53 helicopters and P-3C and C-130 aircraft.

◆ ALQ-162 (Shadowbox)

Northrop's CW DECM system is a receiver-jammer and, thus, does not require any separate RWR. However, Shadowbox is compatible with any RWR, pulse jammer, or expendable countermeasure. Total weight is 40 lb plus two 0.5-lb antennas and a 1-lb remote control unit; demonstrated MTBF is 335 hr (260 specified). ALQ-162 uses 2 vertically polarized antennas, covering 60 deg to either side in azimuth and 30 deg up or down in elevation; the system can also interface with other ECM antennas as required. In 2 NATO air forces, the system is actually installed in the underwing pylons of F/A-18s.

ALQ-162 has been under test since 1981 and is planned for (or installed on board) A-7E, F-4S, AV-8C, and NATO F/A-18 aircraft.

ALQ-162 was the Compass Sail Clockwise jammer, intended to complement the non-CW ALQ-126; Northrop beat ITT for this contract.

◆ ALQ-165

ITT/Westinghouse joint-services Airborne Self-Protection Jammer (ASPJ) is made for upgraded F-14s, F/A-18s, and A-6s. Work on this system began in the early 1970s, a specification being issued in 1976. The ITT/Westinghouse team was chosen in 1981, but work was delayed because of the severe weight constraints imposed by the F/A-18. The final (12th) prototype was delivered, 2 years late, early in 1986. At that time the navy was comparing ASPJ to a combination of 2 existing jammers: the Sanders ALQ-126B and the new Northrop ALQ-162, which are less expensive and simpler. ASPJ survived this comparison, and initial production contracts, for 96 systems from each consortium partner, were let in September 1987 (for delivery in 1989). The total requirement is about 2500 systems for both navy and air force.

ASPJ is to be carried internally, and the original navy requirement called for very dense packaging. As of 1984, the required frequency coverage was 0.7–18 GHz, with a system response time of 0.1–0.25 sec; these capabilities were to fit within less than 2.4 ft³. Required resolution was 5 MHz, with an instantaneous bandwidth of 1.44 GHz and a minimum receivable pulse width of 0.1 microsec (false alarm rate 5/hr or less). The associated jammer was to be capable of dealing with 16–32 emitters (noise and deception jamming), with an accuracy of ± 0.5 –20 MHz. Frequency coverage is to be extended to 35 GHz in the 1990s. Required MTBF is 140–190 hr.

The ALQ-165 version for the AV-8B Harrier is podded; it weighs 380 lb, compared to 225 lb for the basic version and 306 lb for the internal common version.

ALQ-165 is connected to the aircraft RWR (e.g., ALR-67). The basic unit consists of 5 elements (WRAs): 1 high- and 1 low-band receiver, 1 high- and 1 low-band transmitter, and a processor. The F-14 version adds a high-band transmitter and receiver for aft coverage. Each TWT transmitter can operate in either pulsed or noise mode. An enhanced ("common") version has an additional high-band transmitter and an additional (simplified) receiver, for better aft-facing coverage. The original design was criticized because it could not simultaneously jam enough radars, and the number of range-gate deception jammers (effective against "older pulse radars") has been doubled in the production version.

ALQ-165 was also criticized for its volume and for the difficulty of producing it. The original design used multichip (hybrid) microcircuits, with reliability and quality problems. Now about half the original hybrids have been replaced with monolithic gate arrays, for a considerable savings in volume.

The current preproduction version is also easier to manufacture. For example, a hand-soldered wire harness was replaced by a multilayer mother-board (this reduced assembly time from 6 weeks to 4 hr). Plug-in modules for microwave signals now use plug-in RF connectors.

ASPJ passed a critical design review in June 1989, following successful completion of operational flight tests in the spring of 1989. Initial production (100 in FY89) was divided between ITT and Westinghouse; the partners compete for shares of the 150 ordered in FY90. Full-scale production is to begin in FY92, and ALQ-165 is to enter operational service in 1992. As of 1989, the system had undergone about 8000 hr of tests, including 500 of flight tests. Delivery of 20 preproduction (production verification, or PV) units began in the fall of 1989.

The U.S. Air Force withdrew from the program in 1990, but that is not expected to increase unit cost by very much.

The ASPJ is a navy-led program, derived from the ALQ-129 of 1972–77 and from the ALQ-136 (for helicopters) of 1977–80. The latter actually entered production.

◆ ALQ-190

AIRBOC (Air-Launched Rapid-Blooming Chaff) is a fleet countersurveillance decoy deployed from aircraft. Unlike CHAFFBUOY (ALQ-39), AIRBOC deploys immediately upon being launched.

◆ ALQ-192

This passive MAWS was developed by Cartwright Electronics for the navy; ALQ-192 is being considered for adoption by the air force.

◆ ALR-42

General Instruments's self-protection receiver is the primary threat allocator for the ALQ-99 system of the EA-6B Prowler. ALR-42 concentrates jamming power against the most hostile threat to the airplane itself, in order of lethality. It monitors both the threat and the output of ALQ-99 transmitters, ensuring that the system reacts to the threat, rather than to some side-lobe or harmonic of its own transmissions. It can also activate the chaff system automatically and display threats to the air crew. ALR-42 receivers are located in the pod atop the tail fin. ALR-42 is an analog system and was produced only in very limited numbers; ultimately all will be replaced by ALR-67s.

◆ ALR-45/ALR-68

The standard navy threat-warning receiver by Litton supersedes the earlier APR-25, from which ALR-45 was developed. It operates over a wider frequency range (2–14 GHz) and incorporates a fast digital threat processor. The antennas are 4 planar cavity-backed spirals, covering 360 deg around the airplane; and the display is a strobe on the aircraft's PPI. This system has been in production since the mid-1970s, and it has been adopted by several NATO countries. The current version is ALR-56F.

The original APR-25 was conceived in the early 1960s and purchased on a crash basis beginning in November 1965 after the first 2 U.S. aircraft, an F-4 and an RA-5C, were shot down by North Vietnamese SA-2s. APR-25 employed 4 antennas, and crystal video detectors concentrated in the threat bands. The direction of the threat signal was obtained by vector resolution of the 4 signals from the antennas, and the device was, therefore, initially called Vector IV. The related APR-26 was a launch-warning receiver, first employed in 1966. Both devices were developed by Applied Technology, Inc., a firm that had previously specialized in strategic reconnaissance and intelligence.

ALR-45 was a navy development based in part on the newly perceived Soviet naval surface threat in the Mediterranean. Introduced to the fleet in 1970, ALR-45 was a digital system employing early hybrid microcircuits. By this time it was essential that even an RWR sort and prioritize hostile signals on a semiautomatic basis, in view of the sheer number of hostile or potentially hostile radars both in Vietnam and in the Mediterranean.

In mid-1972 Applied Technologies decided to modify ALR-45 by substituting a digital computer for a projected circuit board change; the result was Vector V. Given the programmable computer (called a variable programmer-alarmer), the device could analyze the received probability distributions of frequency, pulse repetition interval, PRF, pulse width, pulse coding, and other radar parameters. All of these data were probabilistic because the receiver could never be sure whether it was sorting out signals entirely correctly. Even so, it could guess radar identifications based on pairs of frequency and pulse repetition interval (the inverse of PRF). The next step was for Applied Technologies to develop its own computer, the first intended specifically for EW. The desired characteristics were a volume of 100 in³, a power consumption of 80 W, and a throughput of 250 kwords/sec. The machine, the Applied Technology Advanced Computer (ATAC), appeared in July 1973, with a volume of 96 in³, a power requirement of 45 W, and a throughput of 1.25 Mwords/sec. The computer was made part of Vector V, and this system in turn became the ALR-68 of the West German F-4 force and also the basis for the Enhanced Radar Warning Equipment of German Tornados.

In U.S. service, ALR-45 is being superseded by ALR-67. During ALR-67 development, it was decided to retrofit the programmable processor being developed for the newer system into ALR-45. An engineering-development model (EDM) was com-

pleted in May 1978 and delivered the following July. Systems changes were required to support HARM, ASPJ, APR-43 (Compass Sail/Compass Clockwise), and the updated ALQ-126.

The current navy version is ALR-45D. The improved ALR-45F is to be installed on A-7E and AV-8C aircraft. It includes a software reprogrammable analyzer and an alphanumeric display of threat bearing, weapons, craft, etc., as well as identification and interface with ALQ-126B, ALE-39, and ALQ-162. The processor is designated CP-1293. Total production: 1015 ALR-45D, 341 ALR-45F.

◆ ALR-47/76/502

IBM manufactures these systems, which combine the ESM, ELINT, and RWR functions. The design is optimized to detect short radar transmissions, such as the single-pulse mode a submarine might use. RWR features are an audio alert and outputs to control a countermeasures dispenser. For the other 2 roles, ALR-47/76 provides emitter identification, location, and parameters in a digital interface to other aircraft systems. The system uses an array of 4 cavity-backed broad-band spiral antennas in each wing tip. The aeriels are directed to achieve monopulse direction finding. Signals are fed into 2 narrow-band superheterodyne (tuning) receivers, for automatic signal processing under programmed control.

ALR-47 is on the S-3A; ALR-76 is an improved version for the S-3B, the ES-3, and the EP-3E. The entire system weighs about 88 lb, and ALR-47 costs about \$150,000. The improved ALR-76 costs about \$250,000. Compared to ALR-47, ALR-76 has an extended frequency range, and other improvements include automatic emitter classification and modular design for future growth. It continuously tracks an emitter to obtain better location data.

ALR-47 development began in 1969, and it was first delivered in 1971 for S-3As. It entered full-scale production in 1972. ALR-76 was developed under an S-3A Weapons System Improvement Program (WSIP); the contract was let in July 1983. It has been adopted for the S-3B program (a contract for 40 was let in December 1987). ALR-66 beat out ALR-76 and ALR-77 in the competition for the P-3 Update IV program (July 1987).

ALR-502 is a version of ALR-47 for the Canadian CP-140 maritime-patrol aircraft.

A target-acquisition console Mk 105, developed from ALR-47, was built for the *Asheville*-class gunboats, and an upgraded Mod 1 version was installed on board the *Pegasus*-class hydrofoils and on board some frigates and missile destroyers. These Mk 105s are programmable passive fire-control systems.

◆ ALR-50

Magnavox's SAM threat-warning receiver, developed from APR-27, is being replaced (in U.S. service) by APR-43 and ALR-67. It detects target-tracking and missile-guidance signals. Production began in the early 1970s, and very large numbers were ordered (e.g., 800 sets, for \$22 million, in 1972). Platforms included the EA-6A and EA-6B, the A-7, and the F-14. Estimated cost is \$15,000. It is being replaced by the APR-43 in A-7E and AV-8B aircraft, and by the ALR-67 in F/A-18s, A-6Es, and F-14s.

◆ ALR-52

The airborne version of WLR-11 (see the Antiaircraft Warfare section), by ARGOSystems, covers 0.5–18 GHz and uses separate octave modules. ALR-52 is carried by P-3s.

◆ ALR-58

Sanders's ECM receiver for the P-3B Orion is a precursor of ALR-66(V)2. It uses the APS-88 radar antenna to generate bearing strobes of threat radars on the radar's PPI. ALR-58 uses both a crystal video and an IFM receiver and display; it can display 8.5–9.6-GHz signals, or it can be limited to 9.2–9.6-GHz signals. Signals received by the radar antenna are passed through the crystal video receiver and PRF sorter to the radar PPI; a blanker protects the crystal video from the normal radar transmissions.

◆ ALR-59/73

The passive detection system (PDS) for the E-2C Hawkeye uses 4 antennas: 1 at the nose, 1 at the tail, and 1 at the tip of each horizontal tailplane. PDS can process signals from any 2 of its 4 bands simultaneously, and it increases its dwell time on any part of the spectrum that shows increased activity. The system measures direction of arrival, frequency (by superheterodyne rather than IFM), pulse width, amplitude, and scan rate. Emitter data are presented at the edges of the PPI displaying the main radar picture and also on a separate tabular display. Emitter position can be obtained either by correlation between 2 E-2Cs or by triangulation as the E-2C moves.

ALR-59 was offered as a major enhancement to NATO AWACS (E-3A) aircraft.

ALR-73 is an improved version of ALR-59. ALR-73 employs 4 groups of antennas, 52 in all, to cover 4 bands (500 MHz–18 GHz). Each antenna has its own IFM, and pulse trains are separated and analyzed by a central computer. Direction finding is by phase interferometry. Frequency-scanning is automatic, and each band is separately and simultaneously processed. Signal data (pulse width, PRI, frequency, pulse amplitude, special tags) are sent to the central processor of the airplane for identification. The system cuts its overall data load by eliminating redundant emitters for a programmable period. The large phase tolerance inherent in its binary beam allows for considerable radome distortion and aircraft reflection. Direction-finding accuracy is about 2 deg. ALR-73 was developed by Litton about 1980. The associated computer is AYK-14. Unit cost is about \$2 million. This system will also be installed (in modified form) in the EA-6B ADVCAP.

ALR-59 development began in 1970, and the first example was delivered in 1973. In 1974 Litton proposed a modified version for *Spruance*-class destroyers, but less than a year later it was canceled in favor of SLQ-32.

◆ ALR-60 (Deepwell)

GTE's computer-controlled multi-operator communications intercept and analysis system is for EP-3E Orions. Seven have been manufactured.

◆ ALR-66/79/80/606

General Instruments manufactures these threat-warning and ESM systems. They are particularly interesting because the same series includes both relatively inexpensive RWRs and quite elaborate ESM devices to support long-range missile attack by detecting targets well beyond the visual horizon, the latter in the form of ALR-66(V)3.

The original ALR-66 replaced ALD-2D and ALR-52 on P-3C and other maritime-patrol aircraft. It had a fully programmable crystal video receiver (covering the E–J-bands, extendable down to the C–D-bands) for radar warning, and digital output for library comparison. A typical version, the export ALR-66(VE), achieves a direction-finding accuracy of better than 15 deg and has an associated threat library of 1000 radar modes. Other versions have over 1800 radar modes in their libraries. The -66(VE) library can be reprogrammed on the flight line in 90 sec or in the air using a computer memory reloader.

Emitters are represented by 3 alphanumeric symbols: 1 for pulse width (N for narrow, W for wide), a number (1–9) for PRF, and frequency band (E, G, I, J). Thus N5J would be a narrow-pulse medium-PRF signal in J-band. The usual polar display is used, and the code flashes to indicate a tracking radar (i.e., an immediate threat); symbols for search radars are illuminated steadily. The system can detect and identify pulse doppler, CW, interrupted CW, LPI, 3D (short dwell time), frequency-agile, jittered/staggered PRF, and pulse compression radars. Total weight in the (V)1 version is 59.4 lb.

Versions:

ALR-66(V)1 SH-2 (Sea Sprite), SH-3 (Sea King) helicopters. In LAMPS helicopters, this set was replaced in the early 1980s by the (VE) version. ALR-66A(V)1 is the newest configuration of

the (V)1 RWR for the SH-2F (see below). DF accuracy was better than 10 deg (resolution 1.4 deg). The library contained 100 emitters, and 15 could be displayed simultaneously on a 3-in CRT. The processor contained 8 kwords of RAM/ROM and operated at 1.2 MOPS. Emitters were described by 24-bit words, which could be compared in 1.1 microsec, for quick library search. This set replaced the earlier ALR-54. The contract was awarded late in 1974.

ALR-66(V)2 Development of this version was occasioned by the decision, in the early 1980s, to provide P-3Bs with Harpoon missiles. Thus (V)2 was designed for OTH-T rather than pure radar warning. Therefore, it had unusually high sensitivity (to detect weak signals) and an expanded signal memory (since it had to accommodate characteristic warship signals as well as threat radars). It also had much finer directional accuracy. It was integrated with other aircraft sensors and had had an interactive display and control panel. (V)2 combined the existing (V)1 RWR with the P-3B wide-band high-gain APS-80 radar antenna (Little Look Program) and some new hardware and software. This combination in turn inspired the development of the ALR-66(V)3 described next. (V)2 was carried by P-3Bs and was bought as an interim installation on P-3Cs.

This and similar versions of ALR-66 seem to be unique among airborne radar detectors in sharing the main radar antenna with the on-board radar. They do not, however, appear to use this antenna for BRIGAND.

ALR-66(V)3 This set was bought in 1984 specifically to provide P-3Cs with an OTH surveillance and targeting capability; it replaced the ALQ-78. It is similar in concept to (V)2, using the main radar antenna (in this case APS-115 rather than APS-80) for high-gain direction finding. (V)3 uses 4 C/D-band and 4 E/J-band spiral antennas, all mounted at the wing tips, mounted in groups of 4 to give 360-deg coverage in azimuth and ± 45 -deg coverage in elevation. These antennas are used to achieve nearly wide-open coverage. Once a target has been detected, its direction can be measured more accurately (and tracked) by using a subreflector in the main nose APS-115 radar dish, which provides high-gain directional cover of the C- through J-bands.

For high sensitivity, the E-J-band crystal video amplifier-receivers are mounted in the wingtips, close to the spiral antennas there. These receivers are computer controlled to receive signals in 1 of 4 bands (E/F, G/H, I, J). There are also dual-band C/D-band receivers. The frequency measuring unit (FMU) mounted in the fuselage has dual channels, corresponding to the 2 sets of receivers (wing tip and nose). The 2 channels (and the RF bands within them) are sampled in sequence, cyclically. The order in which they are scanned, and the time allowed per band, are chosen for optimum probability of intercept, depending on the expected emitter environment and the characteristics of the modified APS-115 radar. The FMU in turn feeds video signals to the computer-converter, where they are digitized for analysis and identification (either automatically or by the operator). In the targeting mode, the system measures emitter frequency, angle of arrival, PRF, scan width, scan illumination, and beamwidth. Emitters are identified by a 2- or 3-letter alphanumeric code and displayed on a polar screen. Those that the system decides represent lethal threats trigger aural alarms. The system also tags the highest-priority emitter with its ELINT catalog number and displays PRF, pulse width, angle of arrival, and frequency. The operator can call up similar data on any other emitter displayed.

The high-gain channel (using the nose antenna) operates independently of the low-gain wing-tip antenna channel. ALR-66 adds an ellipsoidal subreflector to the main APS-115 antenna. One focus of this secondary antenna is at the focal point of the main reflector, the other at the phase center of the radar. This arrangement allows for simultaneous operation of the radar and the high-gain ESM. This is the same arrangement as in the (V)2 version, and it has also been applied to the LN-66 radar in the LAMPS I helicopter. General Instruments offers a similar modification in the ALR-606 export versions.

B-52 bombers equipped with Harpoon missiles have had this system installed, using their search radars as the high-definition DF receivers.

ALR-66(V)4 High-sensitivity version of (V)1 with upgraded software and improved direction finding, for the E-6A TACAMO airplane, covering the C- through J-bands. Total planned production is 16 systems.

ALR-66(V)5 P-3C Update IV. Dual-channel version with parallel processing (one for ESM, one for targeting). The reference to targeting suggests that this is an outgrowth of (V)3. Unlike (V)3, (V)5 uses separate modules for the 2 roles. (V)5 uses a multilevel pulse-separation scheme to operate in very dense pulse environments. Signals are channelized (within frequency bands) at the detection stage to limit the spectrum being processed at any time. High-speed pulse encoders convert video signals to digital form, even during pulse overlap, to reduce shadow time. The preprocessor uses frequency and angle of arrival to limit data density at the signal processor. The manufacturer claims that this system uses a unique parallel pipelined architecture, with multiple processors. General Instruments emphasizes the use of generic threat processing, which permits the system to identify types of emitters even though those emitters are not in the threat library. Generic processing is important because many Third World threat emitters (manufactured in the West or in the Third World itself) may not be carried in libraries filled with the characteristics of Soviet-made equipment.

Lancer, an export version with passive targeting capability, has been developed from (V)5.

General Instruments also offers LESM, a lightweight version of (V)5 designed specifically for shipboard helicopters such as the SH-60 series. Apart from the associated radar antenna, LESM weighs 38 lb. It can track 1000+ threats simultaneously. LESM can use the main radar antenna for precise tracking, and it can also use ESM data to cue that radar onto a target before turning it on, for a lower probability of counterdetection. It uses 3 different RF-detection technologies: IFM, superheterodyne, and amplified crystal video, and multiple 32-bit processors. Presumably these features also apply to (V)5. LESM can use a separate dedicated directional antenna in place of the helicopter radar antenna. LESM was to fly night trials late in 1990.

ALR-66(V)6 Shipboard ESM, for self-protection and targeting, derived from the ALR-66 airborne series, for patrol boats up through destroyers. It employs a spinning/scanning antenna in a radome plus 2 sets of fixed antennas, each consisting of 4 spirals in a radome. It can operate automatically, or it can display signals to a dedicated EW operator; and it can feed digital data into an ECM, chaff/flare, or fire-control system. (V)6 is installed on board U.S. PHMs.

ALR-66(VE) Export version, used by Venezuela and New Zealand (in A-4s) and also in LAMPS I helicopters. This version is related to (V)3. It uses 4 spiral antennas, with 4 receivers, a digital signal processor, and a digital display, to cover the E-J-bands (some versions extend to the C/D-bands). Receivers are crystal videos (with superheterodynes added in some versions), and directional accuracy is better than 15 deg. The associated processor carries out 1.2 million operations/sec, a figure dictated by the density of the modern pulse environment. It has a 72×3 -kbyte memory, and the associated library can hold 100+ radar types and 1000+ modes; it displays 15. MTBF is 725+ hr.

ALR-66(VC) Transport aircraft version.

ALR-66(V)A1 System for LAMPS I helicopters and foreign Sea Kings. It operates in 4 frequency bands (E-J-bands) against all pulse types, including CW, ICW, pulse doppler, LPI (pulse-compression), 3D (pencil beam), jitter/stagger agile, and frequency agile. Up to 15 emitters can be displayed, each being assigned up to 3 alphanumeric symbols. Symbol positions on the 3-in CRT indicate approximate range (based on radar identification and thus on a comparison between received signal

strength and known emitter power) and bearing (based on comparison between strength as received by the 4 spiral antennas). Direction-finding accuracy is described as significantly better than 15 deg. Antenna coverage is 360 deg in bearing, and ± 45 deg in elevation. Shadow time is less than 2 microsec. The associated digital processor has a total capacity of 68 kwords, of which 28k are EEPROM/ROM; it operates at 1.2 MOPS. The processor accepts up to 500,000 pps. The full library (1800+ modes) can be reprogrammed in 90 sec. It has an MTBF of 700+ hr. Total weight is 60 lb. The antennas are 2.41 in in diameter and 1.53 in deep. Optional improvements are high-sensitivity detection, in-flight data recording, dual displays, extended frequency coverage, IFM, frequency set-on receiver, and a customized I/O bus.

ALR-79 This is a version of the basic ALR-66 for some SH-2F (LAMPS) helicopters. This is an upgraded version, more sensitive than its predecessor, with an IFM, a frequency set unit, and an interface for jammer control. It operates in the E-J-bands. The antennas are in the nose and tail of the helicopter; total weight is 102.75 lb. ALR-79 is described as a classified (special capability) system. The jammer connection suggests that it is used to supplement shipboard jammers, perhaps for operational deception. It may use the helicopter's LN-66 radar antenna for high-definition direction finding.

ALR-80 For A-4, F-4, F-5, F-16, Mirage, and Jaguar. It was announced late in 1985, based on ALR-66(VE)1. It carries 1800 radar modes in its memory. This system covers the C-J-bands. ALR-80 is intended as a direct substitute for APR-36, -37, -39, ALR-45, -67, and -69.

ALR-85 This is an outgrowth of ALR-66, for transport aircraft. New features include an IFM/superheterodyne receiver (IFM/SHR) and a C/D-band direction finder. With the IFM/SHR it can combine wide and narrow instantaneous bandwidths, for high sensitivity and high-density operations. The IFM provides a frequency measurement of each pulse using a wide-bandwidth receiver in a high-density environment; the superheterodyne gives more sensitive performance over a narrower band for earlier detection, providing a range advantage against weaker emitters (such as pulse doppler and CW radars) operating on narrow frequency bands. Coverage is C-J-bands; the library contains 1800+ emitters, and MTBF is 750 hr.

ALR-606(V)1 Export version for helicopters and fighters. It has the same hardware as ALR-66(V)1 and is typically installed on Sea Kings, Super Pumas, and Gazelles. There are some software improvements.

ALR-606(V)2 Export version for maritime-patrol aircraft. In March 1989 Pakistan bought this receiver for its P-3Cs. This system can track 35 radars simultaneously, and it can display 15 at any one time. Direction-finding accuracy is better than 15 deg, and shadow time is 2 microsec. The associated memory is 68 kbytes. This version is described as a cross between ALR-66(V)2 and (V)3, presumably also using the airplane's nose radar antenna for high-definition direction finding.

ALR-606(VE) Export version of -66(VE) for fighters including F-4, F-5, F-104, A-7. It differs from -66(VE) mainly in data presentation and threat library.

SLR-600 Shipboard version; see the Anti-aircraft Warfare section for details.

Approximate unit cost: \$75,000 for the pure RWR, \$250,000 for the ESM version.

◆ ALR-67

Itek's RWR is made for A-6E, AV-8B, F-14D, and F/A-18 aircraft. It covers 1-16 GHz, using 4 spiral antennas. The receiver is a hybrid (superheterodyne and TRF), and the system uses a digital computer (Vector V threat processor) developed from ATAC, the first computer developed exclusively for EW. The system is programmable in the field. Applied Technology, by that time a

division of Itek, won the ALR-67 competition in 1975. The company became a division of Litton in 1983. ALR-67 is form-fit-function compatible with the older ALR-45. The ALR-67(V)2 version is used on board the AV-8C (modernized AV-8A), F-14A, F-14D, and F/A-18, a total of 616 aircraft.

A similar system, ALR-68, was developed as the West German Advanced Radar-Warning Receiver. It uses a special version of the Vector V processor, but the RF and microwave sections are similar to those of the U.S. ALR-67.

In September 1988 the navy issued an RFP for an advanced special processor (ASR) to upgrade ALR-67; this new device was also expected to be the basis for a common navy-wide RWR. Hughes/AEL won the competition. ALR-67ASR is intended to enter service in 1995.

The ASR is so significant an improvement over ALR-67 that OSD opposed ASR on the grounds that it was in effect an entirely new program. OSD suggested that the navy buy an existing recent air force receiver, the Litton ALR-74. The navy successfully argued that its 1983-84-era technology would be obsolete by the time ALR-67ASR became operational in 1995. The ALR-74 components in question were its EPROM memory, its power supply, its superheterodyne receiver, its computer processor, its special receiver, and its quad receiver. Moreover, the navy argued that to adopt ALR-74 would be a maintenance disaster, as the carriers would have to support both ALR-67 and -74, rather than just ALR-67 and some additional components.

The ASR modification replaces the signal processor and some antennas but retains other elements and fits the form, power, and cooling of the original ALR-67. The new receiver provides increased frequency coverage, sensitivity, DF accuracy, and signal-processing throughput. Even so, the result is still an RWR rather than an ESM set.

In 1990 Litton was proposing ECP-510, which would be half-way between ALR-67 and -67ASR. ECP-510 has an interface with the host aircraft's INS and increases detection range by a factor of 10. If successful, it will enter service in 1992.

◆ ALR-75(V)

Scientific Communications's surveillance receiver system (0.1-40 GHz) is in service with FEWSG's EC-24A, ERA-3B, and NKC-135A aircraft. The digitally controlled system can use any combination of 8 independent tuners, covering either several bands (each tuner can handle 1 octave) or several portions of a single band, or a combination. The output of each tuner is analyzed separately, and signals are identified by comparison with the system's memory. Displays are digitally refreshed. Outputs include PRI, PRF, pulse width, frequency, antenna beamwidth, scan type, and scan interval. This system also exists in a ground version.

◆ ALR-87

General Instruments's RWR, a form-fit-function replacement for the air force ALR-46, uses the same azimuth indicator. It is carried by some F/A-18s. It operates over the C-J-bands, using 4 quadrant antennas and channelized crystal video receivers with a combination of IFM and distributed narrow-band superheterodynes. Memory is 128k EEPROM and 162 kwords of RAM (16-bit words), and the mission data recorder has a memory capacity of 1 Mword. There are 3 MIL-STD-1750A microprocessors, programmed in JOVIAL. The manufacturer claims up to 4 times the pulse processing capability of other systems. Preprocessing (deinterleaving) is based on frequency and angle of arrival. Total weight is 74 lb, and power input is 580 W. ALR-87 has 50% memory and processing capability reserve.

This device was announced in 1990.

◆ APR-39

This simple RWR, originally for light aircraft and helicopters, is also used in fast patrol boats and gunboats. The original (V)1 version was developed by E-Systems, (V)2 by Loral, and A(V)1 by General Instruments. As of January 1988, 6000 had been delivered, and the system has been exported to West Germany

(for PAH-1 antitank helicopters). Although the contracting agencies are the U.S. Army and the U.S. Air Force, APR-39 has important naval applications (e.g., to helicopters and to fast patrol boats).

Versions:

APR-39(V)1 Covers the F-I-bands, plus most of J- and parts of C- and D-bands. It has 4 cavity-backed spiral antennas in hemispherical radomes, plus 1 omni antenna (a blade) and 2 dual video receivers. The usual visual display (bearing, identity, radar mode) is supplemented by an audio tone whose frequency is proportional to the PRF of the intercepted signal. The entire system weighs about 3.63 kg and can be installed either internally or in a pod.

APR-39(V)2 This version has a new processor (Loral CP-480/APR-39(V)) that sorts and identifies intercepted signals, presenting them on the cockpit display. Memory is 19k (EPROM), and the system can filter signals by angle-gating or by PRI. Total weight is 6.5 kg.

APR-39A(V)1 New version with synthetic voice alert. The digital display indicates whether a threat radar is searching or has locked on, and when radar lock is broken. Threats are prioritized for display. The digital display automatically separates threat symbols when they become too dense for the pilot to read. APR-39(XE-2) is a special version for the Marine Corps and army special mission V-22s. The antennas are C/D-band blades and H/M-band spirals.

APR-39A(V)2 Shipboard Integrated Electronic Warfare System (SIEWS). SIEWS may also designate a larger system that uses APR-39A(V)2 as its warning receiver. The system operates in E-K- and C-D-bands (E-M optional), and provides synthetic speech warnings and alphanumeric symbology (for a ship combat system). It can be connected to other elements of a ship combat system via a 1553B bus and is compatible with NVGs. General Instruments envisages a system in which a laser warning receiver feeds into the APR-39, and the latter feeds missile warning systems and countermeasures launchers. This is apparently the ESM system on board U.S. Patrol Boats Mk III and IV.

◆ APR-43

Loral's radar-warning detector is installed in aircraft such as the A-7E. It was developed under the Compass Sail Clockwise program to provide tactical aircraft with threat warning and direction finding against C- and D-band pulse and CW missile-guidance systems; it provides C/D-band CW warning for other RWRs lacking such capability. APR-43 employs a single multielement blade antenna, a crystal video receiver (against pulse radars), and a superheterodyne receiver (against CW radars). It has a direct interface with ALR-45/45F (ALR-67 processor) and with ALQ-126/162 jammers. It contains those ALQ-162 antenna output elements required for CW jamming.

Compass Sail was a program to detect and analyze SAM guidance beams to warn pilots that a missile was en route. APR-43 replaced the earlier ALR-50.

◆ APR-44

AEL's CW RWR is used by both the army and navy and is adapted from the earlier APR-42. The antenna, mounted on a horizontal surface, provides coverage of a 50-deg arc to the rear of the aircraft. The receiver triggers an audio signal, a lamp, and a flashing light. Bandwidth is selectable.

◆ ARS-5

Cubic's ARS-5 is a sonobuoy reference system, an interferometer normally used to locate the buoys of a field by measuring phase differences between signals received by antennas spread over an airplane. See the description of the S-3A tactical system in the Surveillance and Control section; ARS-5 is the version in the P-3C Update III. Unlike earlier versions, ARS-5 contains its own embedded signal processor. Therefore, it functions as

an interferometric VHF direction finder. Cubic claims that it is designed for expansion into the ELINT DF role. The company also offers a stand-alone sonobuoy reference system (SRS) with similar potential.

◆ ASQ-171

This electronic intelligence system for EP-3E Orions is described as covering the A-J/K-bands and is capable of detecting back-scattered transmissions at long ranges. It is probably a direct descendant of the BRIGAND program of the early 1960s, and it may be a replacement for an earlier ALQ-110 (Big Look) carried by EC-121Ms and then by early EP-3s. This is probably the device that occupies the belly radome of the EP-3E.

BRIGAND is a technique for detecting the signals reflected by objects near a target radar; in effect it picks up a distorted version of the target's own radar picture. The technique was originally developed by VQ-1 technicians in 1960. They used the highly directional antenna of an APS-20 (the belly radar in the EC-121) to feed a very sensitive radar receiver (an APR-9). The resulting device was code-named GRAY SHOE and was used operationally in September 1960. It was soon discovered that, when receiver gain was turned up, the receiver showed not only the pulses of the target radar but also the ground clutter around it, i.e., the reflections of the target radar's own pulses. In theory, a really sensitive receiver could see not only the ground clutter around the radar but also some of the targets the radar was detecting beyond the clutter. Initially the clutter itself was well worth detecting because it could be used to map the terrain immediately around the target radar, and thus to locate the target radar very precisely. However, other applications were soon found. For example, even if only 1 ship in a group was radiating, back-scatter revealed the others.

In 1963 the VQ-1 technicians built a special receiver to exploit this phenomenon, using the EC-121's APS-20 antenna. The acronym BRIGAND (Bistatic Radar Intelligence Generation and Analysis, New Development) was coined at this time. The early EC-121 installation covered the 50-4000-MHz band. It comprised modifications to the APS-20, plus omnidirectional stub antennas for VHF and UHF band antennas, and 2 horn antennas in the dorsal radome. Presumably ASQ-171 employs similar antennas. BRIGAND first flew in June 1963 and was first operationally tested in August 1963. Tests early in 1964 showed that BRIGAND could be effective against both airborne radars and IFF transponders.

The first EP-3Bs were modified from P-3A airframes in 1969; they were flown by VQ-1. They were followed by conversions to EP-3E (and the 2 original EP-3Bs were modernized to -3E standard), beginning in 1971-72. Lockheed received a contract



An EP-3E, showing its large belly radome. Japan is reportedly converting 4 P-3Cs to a similar configuration, for naval surveillance. (Lockheed Aeronautical Systems Co.)

in 1986 for 10 further P-3C conversions. The major EP-3E signals-intelligence programs are Aries, Big Look, and Deepwell.

The JMSDF is the only other operator of a P-3 SIGINT version; it is not clear to what extent its aircraft correspond to the EP-3E. The JMSDF's first EP-3, converted by Kawasaki, was rolled out in July 1990. It carries NEC's LF and Mitsubishi's HF systems. The EP-3 replaces the current EP-2J, covering a wider frequency range and, because it flies higher, a larger area. The JMSDF expects to buy a total of 6 to replace the 2 current EP-2Js (2 have been ordered so far, the second for delivery in mid-1992).

◆ ASQ-191

Rockwell/Collins's communications jammer was developed originally by Collins to test its own communications system. The jammer was first purchased by the Fleet Electronic Warfare Support Group (FEWSG) to equip aggressor aircraft for fleet training. ASQ-191 was adopted for operational use on the recommendation of CDR James Powell, Readiness Officer for Medium Attack Tactical Electronics Warfare Wing, Pacific Fleet; he had encountered this jammer when he was a student at the Naval Postgraduate School. FEWSG lent 3 ASQ-191s to the Pacific Fleet VAQ organization, and VAQ-135 was the first squadron to deploy with the jammer. They used it during the Persian Gulf battle of 18 April 1988, helping to neutralize the Iranian Silkworm threat to U.S. warships in the Gulf. When VAQ-135 rotated home from the carrier *Enterprise*, the squadron left its ASQ-191s on board for the next EA-6B squadron to use. Ultimately the navy hopes to buy 40 ASQ-191s for use until the more sophisticated ALQ-149 is ready.

ASQ-191 is small enough to fit easily into the EA-6B equipment bay, betraying its nonstandard origins in its requirement for a special control console (in front of the right front seat of the airplane). The jammer's reported unit cost is about \$200,000.

◆ AVR-2

Perkin-Elmer's laser-warning receiver, usually for helicopters, is integrated with the APR-39 RWR. AVR-2 employs 2 warning heads and a comparator, to estimate threat direction. Work is currently underway on a version for fast aircraft.

◆ DLQ-3C(V)

The Pacific Missile Test Center developed this jammer for training (i.e., threat simulation) purposes, but DLQ-3C(V) is available as a "tactical contingency asset." SH-2 or SH-3 helicopters typically carry this jammer. The designation suggests a missile or drone application.

◆ ULQ-16

Electronic Support Systems Inc.'s (ESSI) pulse analyzer for ESM in ASW aircraft accepts signals at 160 MHz (intermediate frequency, reduced from the actual signal frequency by mixing upon reception). There are 1 automatic and 5 manual modes (time base, delayed time base, single sweep, self-test, and falling raster). ULQ-16 measures PRF/PRI, pulse width, pulse amplitude, scan time/rate, illumination time, and bandwidth. As of 1989, over 600 had been procured, and over 400 were in service.

◆ BGPHERS

The E-Systems Battle Group Passive Horizon Extension System is a passive detection system (ESM) to be carried by ES-3 aircraft. BGPHERS supplements land-based EP-3s. The surface-ship terminal for this system is SLQ-50.

BGPHERS was conceived as a replacement for the carrier-based EA-3, which was aging badly by the early 1980s. Lockheed had proposed an ES-3 during the 1970s, and under the EX program such an aircraft competed successfully with an EW version of the Grumman C-2. Plans called for the navy to buy 8 EXs initially, and ultimately a total of 24. EX in turn was canceled in 1987 in favor of BGPHERS, which was originally a palletized EW system that could be installed in the bomb bay of an S-3 and



The ES-3A (BGPHERS) prototype. (Lockheed)

controlled entirely from the carrier. Its virtue was that the carrier would not have to support additional special-purpose aircraft and so draw down either its strike or its ASW force.

As BGPHERS developed, however, the remote-control concept became less and less workable. Ultimately the navy chose to modify existing S-3As as special-purpose platforms.

◆ ES-3A

The ES-3A is the airborne element of BGPHERS, the Battle Group Passive Horizon Extension System. Much of the equipment matches that on board an EP-3, but the concept is very different. The ES-3A is an extension of carrier ESM, transmitting its data down to the carrier via a special wide-band data link (Link 11 is also installed). In this the ES-3A is broadly analogous to a LAMPS helicopter. Operator interaction with the sensors is minimized since the system is controlled primarily from the carrier. The predecessor aircraft, the EA-3B, was largely self-contained and had a crew of 7, compared to the 4 on board the ES-3A (the EA-3B also lacked the degree of automation in the ES-3A).

Most of the new electronic equipment is installed in the former weapons bay, with other equipment in the rear fuselage. It is served by 3 AYK-14 computers, which replace the single AYK-10 of the S-3A. All of the original ASW equipment is removed. The copilot's station is replaced by tactical displays for the NFO acting as EW combat coordinator. There are 2 EW operators, replacing the 2 acoustic-sensor operators of the S-3.

The S-3B imaging radar (APS-137) and FLIR (OR-263) are retained, as is its ALR-76. A fully passive navigational system, GPS, is installed for this passive sensor platform; this installation is part of a wider program to eliminate TACAN by 1997. Mission equipment includes signal analyzers and direction finders (covering all bands). A canoe radome is added along the spine of the airplane, and 2 circular radomes probably house very precise direction-finding antennas. It seems likely that the APS-137 radar is modified for BRIGAND operation. EP-3 digital processing and display systems are added (computers, mass memory, digital tape, color displays, and keyboards with trackballs). The net effect of conversion is to exchange nearly 6000 lb of new electronics for 3000 lb of ASW equipment. The new electronics spaces are air conditioned, which adds more weight.

Sixteen conversions are planned, under a 4-year contract. The first S-3A was delivered to Lockheed in 1988 and flew in 1989. Mission software was to be delivered at the end of February 1990, and the test program is to be completed in May 1991. Two squadrons will be formed, VQ-5 and -6, based at Rota and Guam, with 8 aircraft each. They will supply 2-aircraft detachments for carriers.

◆ FAEWS

These training EW systems are used to simulate enemy jammers. They are significant here for 2 reasons. First, the array of systems gives some idea of what Soviet-bloc jammers can be expected to do. Second, some of the training devices, such as

ASQ-191, have been used operationally. FAEWS is the FEWSG Airborne Electronic Warfare System; FEWSG is the Fleet Electronic Warfare Support Group. FEWSG flies ERA-3B Skywarriors and EA-7L Corsair IIs; it consists of 2 squadrons, VAQ-33 for the Atlantic Fleet and VAQ-34 for the Pacific Fleet.

The ERA-3B carries FAEWS, consisting of the ALT-40 noise jammer (0.1–17 GHz), the ALR-75 superheterodyne pulse-analysis receiver (100 MHz–18 GHz), the OE-320 direction finder (0.3–18 GHz), the DLQ-3 noise/deception jammer (0.4–11 GHz), and the ALE-39 chaff dispenser. The ALR-75 and OE-320 feed an HP-9826A computer, which in turn controls the ALT-40 jammer. The ERA-3B can also carry the ALQ-167 pod and the ALE-43 bulk chaff dispenser. The latter can lay a corridor 92 miles long. VAQ-34 was formed in March 1983, and the FAEWS system became operational in 1984. It replaced combinations of jammers carried aboard a variety of aircraft, including the last operational example of the B-47 Stratojet.

The EA-7Ls carry ALQ-167 pods and ALQ-170 pods that simulate the homing heads of antiship missiles. They also carry ALE-41 bulk chaff dispensers.

Other aircraft used for fleet training include A-4s used to simulate antiship missiles.

◆ Fly's Eye

This IR missile launch-warning system has been under development by the Naval Research Laboratory since 1983. It uses a set of wide-field of view indium antimonide focal-plane arrays (4–5-micron staring sensors) to achieve hemispheric coverage. Fly's Eye uses 2-color spectral/spatial/temporal processing to reject clutter and, thus, to detect the thermal plume of a missile being boosted into flight. Although the processing load is quite heavy (a 128×128 array typically produces more than 16 Mbits/sec of data), the program has been able to find a suitable processor developed for another program. NRL rejected a scanning approach because dwell times were short and because the associated software had to reconstruct the associated background seen by a staring sensor. As of 1990, Fly's Eye was still some years from the prototype stage.

The parallel air force program is SAWS (silent attack-warning system), using a scanning IR array. Its software uses multicolor spectral and track processing to reject clutter. Tests against a ground-based SAWS were scheduled for the spring of 1990, and an airborne version should begin flight tests in April 1991.

Both systems would replace the current electro-optical (uncooled sensor) AAR-47, which uses photomultiplier tubes to detect the radiation from a booster rocket.

◆ IDAP

The Integrated Defensive Avionics Program is built out of off-the-shelf items. An advanced development model has been mocked up and flight tested aboard an A-3 at China Lake. IDAP includes a missile detector and towed decoys. As of late 1989, tests against live missiles were expected in January and February 1990. IDAP is proposed for the Block-III A-6E upgrade, planned for FY91. The IDAP missile attack-warning system is the Sanders ALQ-156(V)N (see above).

◆ INEWS

Integrated Electronic Warfare System is the planned next-generation joint-service defensive ECM suite. The joint-venture team is Sanders/GE, augmented by Motorola and HRB-Singer. INEWS incorporates VHSIC technology. This program is led by the air force, and the planned applications are the next-generation tactical aircraft (ATF, ATA, and possibly ATB).

INEWS will differ from existing systems in that it will be an extension of the planned ICNIA (Integrated Communications/Navigation/Identification) suite that is to replace separate dedicated systems in future U.S. tactical aircraft, and that will be the most radical systems integration to date. Twenty separate systems, which together occupy about 8 ft^3 (600 lb), will be repackaged into a single box (4 ft^3 , 230 lb). Promised improvements in reliability will stem partly from a drastic reduction in

connectors and plugs between boxes. ICNIA was scheduled for flight testing in 1988. Integration of INEWS with ICNIA suggests that both systems will share common antennas and, indeed, that the total number of antennas on board the aircraft will be drastically reduced. That reduction should be possible partly through the increased use of electronically scanned arrays, e.g., in the aircraft skin ("smart skin").

Because INEWS will share antennas with ICNIA, the former will be able to detect and jam communications links, e.g., between fighters and airborne control aircraft. In theory, INEWS will cover the entire frequency range from HF up through infrared and laser.

◆ New Radar Warning System

For FY90 the Marine Corps plans to begin development of a new radar-warning system for its AV-8B Harriers. Unlike the current ALR-67, the new system would automatically begin defensive reaction. In addition, the new system is to be able to detect incoming infrared missiles as well as active and semi-active radar-guided weapons. No designation has been assigned. The initial requirement is for 160 such devices, with 70 more required later. Reportedly, the British are already installing such a system on their own Harriers.

◆ Boeing VJS/G-String

Boeing's Ventriloquial Jammer System was the unsuccessful alternative to the U.S. Navy (Raytheon/Hughes) AAED; G-String was the navy developmental name. VJS may be test-flown on a Canadian F/A-18. A jammer in the towing airplane feeds a simple conical reflector and polarizer towed on the end of a 90–150-m line. The result is a power centroid representing a virtual target; the line is (in effect) a high-grade video cable with the outer layer stripped off. The line and reflector cost \$500 and are jettisoned after a mission (the airplane cannot land with it). Boeing claims that 600 AAEDs, for A-6s, will cost \$255M, compared to \$30M for its VJS. The Boeing estimate does not include the cost of aircraft modification.

◆ Challenger

Loral's helicopter IR countermeasure is in service on board at least 1 country's Lynx helicopters. It has Matador and ALQ-157 features. Each system uses 1 or 2 transmitters, with multithreat jamming codes. Loral is marketing it for installation on Atlantic and Super King Air 300 maritime-patrol aircraft.

◆ EW-1017/ARI 18240/1

Loral's ESM system for maritime-patrol aircraft was adopted for the British Nimrod MR.2 under the designation ARI 18240/1. EW-1017 is on board German Atlantic maritime-patrol aircraft and also the British version of the U.S. AWACS (E-3). This system uses 16 cavity-backed spiral antennas in wing-tip pods, with front-end receivers also in the pods. The antennas form 2 sets (8 each) for high- and low-frequency bands; system coverage is probably 2–18 GHz. The associated receiver is a hybrid superheterodyne, operating broad-band for acquisition and then narrow-band for identification and direction finding. The system uses several parallel processors to deal with large numbers of pulses.

◆ Loral Advanced IR Countermeasures

In 1989 Loral announced that it was working on 3 categories of advanced IR countermeasures, all of them potentially applicable to naval aircraft.

Laser Jammers Loral is working on an air force program, Have Glance, for a laser-based IR countermeasure. It seems likely that Have Glance would use a laser to find a hostile IR sensor (by reflection in the appropriate frequency band), and then increase power to blind the sensor. Such operation would be analogous to several current or proposed laser anti-optics weapons. The company may also be working on direct counters to laser-guided missiles such as the Swedish RBS 70.

Pointable IRCM This is a counter to all-aspect IR missiles, such as the later versions of Sidewinder. Pointability is required because existing sources are not sufficiently intense when operated to cover all directions.

Advanced Expendables Loralei is a family of forward-fired expendables with multispectral emulators and aerodynamic maneuverability, i.e., a counter to future more intelligent IR seekers that can measure target motion and target spectrum.

Although these are largely proprietary Loral programs, they are interesting as indications of current trends.

◆ Matador

Loral's modular IR countermeasure is for large aircraft, such as Boeing 747s. Installations include dual sources aft (shown on a BAe 146), a single source forward, and sources underwing, in the slipper pylons carrying jet engines. A single control can handle 1–5 transmitters, each emitting 4–12 kW of IR energy. A standard transmitter can emit sufficient energy to overcome the emissions of a TF-33, JT3D, or CFM-56 jet engine. Current installations include the Lockheed L-1011, the VC-10, the Boeing 707, and the Boeing 747; this is probably one of the countermeasures protecting U.S. presidential and national-command-authority aircraft, and it is the sort of countermeasure likely to be applied to the E-6A.

◆ Peace Peek

E-Systems's SIGINT system was supplied for 5 German navy Atlantic aircraft.

◆ Varo LWS

The U.S. Navy is now testing this Laser-Warning System (reportedly for the 0.1–0.4-micron band).

EXPENDABLES

In 1986 the U.S. Navy was experimenting with semiexpendables, small radar repeaters towed on cables. Compared to full expendables, these repeaters could provide long-term coverage (whereas the launch of an expendable must be accurately timed).

◆ AAED

The next-generation active expendable is under development by Naval Research Laboratory. There are 2 versions. One is a forward-fired version, based on the 2.75-in rocket, that is intended to use an autopilot to fly relatively slowly ahead of the airplane. The other version is towed on a cable, probably powered by the airplane. Naval Air Systems Command is developing a 600-lb pod (based on the current 2.75-in pod) to carry both AAED (forward-fired) and chaff/flare decoys.

In 1989 a Raytheon-Hughes team was selected for 2-year full-scale development of the towed decoy. NRL remains the prime contractor for the forward-firing decoy, with a Teledyne CME payload, Garret guidance, and Atlantic Research propulsion.

◆ GEN-X

Texas Instruments's generic expendable jammer is to be carried in existing chaff/flare dispensers. In 1986 the design objective was a unit price of \$3000. The standard expendable size is 1.63-in diameter $\times$ 5.8 in (the air force cannot use navy expendables because the air force's chaff chutes are rectangular in section). Compared to POET, GEN-X can operate over several frequency bands. Thus an airplane need not carry many different types of active expendables and can devote valuable chute space to chaff and flares.

In September 1987 the Naval Air Development Center awarded Texas Instruments a contract for 288 of these decoys, to be delivered by September 1989 (\$19 million). The navy has an option for up to 30,000 such jammers. As of September 1987, Texas Instruments had already delivered 25 test decoys, as part of the competition leading up to the 288-decoy award.

Raytheon was selected as second-source in May 1988. Production is expected to begin in 1991.



GEN-X expendable jammer in combat. (Texas Instruments)

◆ POET

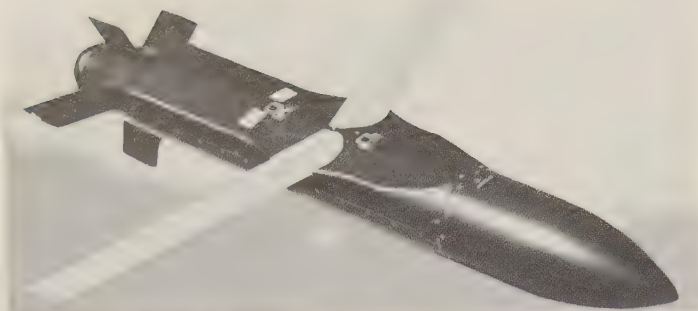
Sanders's Primed Oscillator Expendable Transponder (AN/AM-6988/A) is a small active system. POET was developed in the late 1970s in response to a suggestion by the Defense Science Review Board that the navy take the lead in developing expendable microwave decoys; POET was one of the first active expendables. It is launched via the standard chaff/flare dispenser. POET has a single antenna and is limited in frequency coverage. As of 1986, POET was the only expendable jammer in the U.S. inventory and was being manufactured at the rate of 2300 per month. POET fits within standard expendable dimensions, 1.4 in (diameter) $\times$ 5.8 in.

POET is to be replaced by GEN-X.

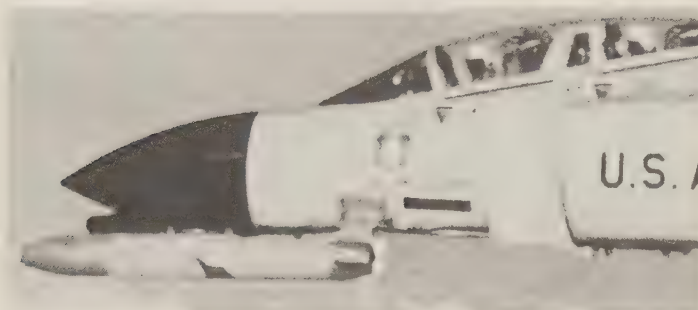
POET is the culmination of several earlier programs. In the mid-1970s Tasker Industries developed a low-frequency (A-band) expendable noise jammer, T-1219 (output 10 W, endurance 5 min), which could be ejected from standard chaff dispensers (and which was suspended from a parachute), and an adaptive expendable jammer to be carried by a Zuni or 2.75-in folding-fin rocket (in I-band). Bowmar/TIC developed a high-powered E/F-band expendable jammer, and Raytheon conducted a design study of a high-powered expendable TWT for I- and J-bands. Of these projects, the E/F-band jammer had been delivered by early 1975, and 250 T-1219s were scheduled for delivery by mid-1976. The Bowmar/TIC jammer was a fixed-tuned 55-lb device developed under a program called Tree Moth; output was 1 kW and endurance was 10 min (parachute descent). By early 1975 Tree Moth had been used in exercises, against ground-based S-band radars. At this time there was considerable interest in small jammers that could be carried on board RPVs, a theme that was revived in the 1980s. In the mid-1970s the primary sponsor was DARPA. For example, the navy tested the Tacit Rainbow (loitering ARM vehicle) concept in the form of PARM (persistent ARM), a Motorola radar seeker on board an MQM-74 Chukar drone, which could loiter over a presumed radar. DARPA and the air force were working on a complementary very low cost harassment vehicle.

◆ Samson

Samson is the expendable decoy developed by Brunswick and produced by Israel Military Industries (IMI). Samson's success in the Bekaa Valley in 1982 prompted the U.S. Navy to buy 100



The SAMSON decoy, predecessor of TALD. (Brunswick)



SAMSON being launched. (Brunswick)

for operational evaluation. The decoy is a glider, carried on a standard aircraft hardpoint, that dispenses chaff or generates false targets as the plane flies toward the target. This decoy was the outcome of a series of studies and prototypes for the U.S. Air Force; when U.S. support ended, the Israeli Defense Ministry took over.

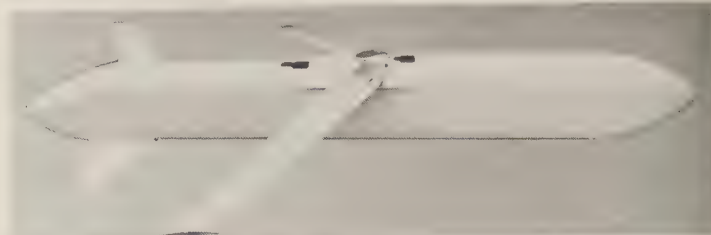
Brunswick developed the Model 150 Maxi Decoy (tested 1973) for carriage, with folded wings, in the external-stores rack of a strike aircraft. Three Maxis could be carried in each of a Phantom's Sparrow-missile positions, and 2 could be carried on a 750-lb hard point. Maxi was a high-subsonic glider, but Model 290P (1974) was self-propelled, with a circular rather than square-section fuselage. That model in turn led to the design of the cylindrical-fuselage unpowered Samson 1, manufactured under license by IAI. The U.S. Navy bought 100 Samsons in 1985, for further operational evaluation, and in 1987 bought another 1000, plus 1500 of the improved TALD.

◆ TALD

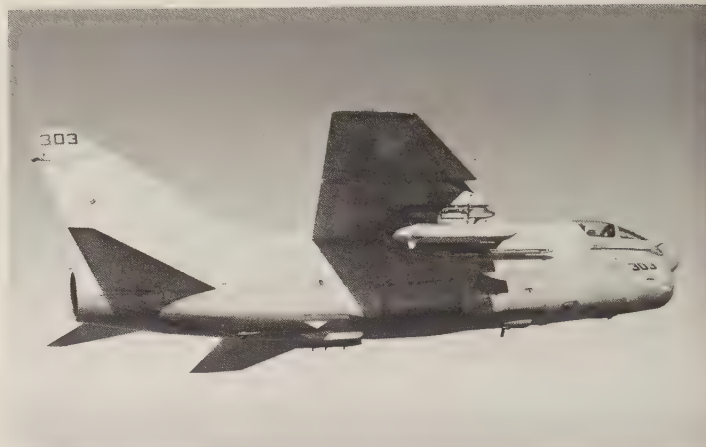
The Tactical Air-Launched Decoy was developed from Samson and shown for the first time in 1986. TALD carries emitters, mimicking fighter radars and ECM systems, in its nose and dispenses chaff from its belly. The navy ordered its first batch of 500 TALDs from Brunswick in December 1985. In November 1987 the navy ordered another 600, with an option for 1000 more, production to be split between IMI and Brunswick. TALD reflects Brunswick experience in decoy design under the air force Maxi program (1973). Brunswick was also involved in an air force powered-decoy program in the late 1970s. The TALD development contract was let in December 1985.

The decoy can dispense chaff, either continuously or in packages, from its tail. It weighs 450 lb and achieves a 10:1 glide ratio, so when it is launched from 40,000 ft at 250 kt it flies for 68 nm. Launched from 2000 ft, at the same speed, it flies 14 nm. The manufacturer claims that 1 TALD costs about one-thousandth as much as a combat airplane, which probably means much less than \$50,000 each.

Both TALD and Samson are carried like 500-lb Mk-82 bombs, their swept wings folded back; over 20 can be carried in the multiple ejectors of a typical attack bomber or fighter. The decoy carries an autopilot, which can be programmed with launch altitude and flight profile (and, presumably, deception program)



The Brunswick TALD decoy. (Brunswick)



TALD under the wing of an A-7E of VA-76. (U.S. Navy)

before takeoff; no special on-board control equipment is required.

Compared to Samson, TALD has a square (rather than round) cross section for greater chaff capacity, a better active emitter, a better chaff dispenser, and a wider carriage-and-release envelope. There are several different versions. RF TALD has active radar amplifiers and a "reflective lens" system. Chaff TALD is for force masking, ejecting chaff from its rear in 40 increments. IR TALD is for IR-missile training. TALD has been in service since 1986, and 2900 are scheduled for delivery by the end of 1991. Brunswick has proposed (and displayed at Farnborough in 1990) an Improved TALD with turbojet power (with an improved IR signature and a more realistic flight profile); range would be about 125 km [68 nm] at M 0.8 at 20,000 ft. This ITALD is now in development.

The FY91 defense-appropriations conference's report calls for development of a TALD variant for defense suppression, with a seeker and a warhead. Feasibility studies are currently underway. There is some question as to whether any version of TALD could duplicate Tacit Rainbow's capabilities, and as of late 1990, it seemed likely that the navy would rejoin the Tacit Rainbow program in FY92. The FY91 report called upon the navy to accelerate work on the powered ITALD by using unspent FY90 money as well as FY91 R&D money.

◆ Tracor's Smart Expendables

In the fall of 1990 Tracor was reportedly working on 3 new expendable decoys. They are probably typical of next-generation concepts. Two are free-flying IR decoys: one is a free flier that uses its own heat (pyrotechnic) source both to generate a signature and to propel itself, and the other is a towed decoy that carries a burner heating a bulb tuned to the airplane's IR signature. The fuel and bulb coating can be varied to suit the towing airplane. Both concepts are intended to defeat IR missiles that can measure the spectrum of the emitter (mainly using 2-color seekers) and missiles that measure an emitter's dynamics to reject unpowered decoys (mainly using gyros for proportional navigation). Tracor is also developing an expendable RF emitter, the Straight Through Repeater Antenna Performance (STRAP) decoy. The company is developing a short-life TWT amplifier for future active RF decoys.

ANTIAIRCRAFT WARFARE

Naval air defense is directed both against missiles fired at warships and against enemy aircraft. The same systems that can deny an enemy access to a fleet can also help cordon off an area some distance away in which friendly aircraft may be operating, e.g., while they attack shore or surface targets or pursue submarines. In peacetime or cold war, naval air-defense systems may be naval air-control systems, supporting surveillance or examining potentially unfriendly aircraft. Thus U.S. naval air defense, in the form of F-14s controlled by airborne radars (on board E-2C Hawkeyes), was able to identify and then to force down the Egyptian airliner carrying the hijackers of the *Achille Lauro* in 1985. The same air defense was able to isolate strike zones in Libya in 1986 so that A-6 Intruders could attack without fear of Libyan air attack. In Vietnam, naval surface-to-air missiles offshore actually shot down enemy fighters attempting to engage U.S. strike aircraft.

Because modern aircraft are so expensive, they cannot be produced in vast numbers, and naval air-defense systems can help to achieve air superiority by the destruction of enemy aircraft. Such air superiority would result, for example, if the air defenses of American carrier battle groups destroyed a significant fraction of attacking Soviet bombers. In this case, defense would be transformed into an offensive means of gaining sea control (maritime air superiority). On the other hand, shorter-range missile systems almost certainly would not be positioned well enough to engage the bombers but would find themselves defending the carrier and her consorts from whatever missiles the Soviet bombers managed to fire.

Modern naval air-defense systems divide naturally into long (area), short (point), and very short (close-in) ranges, with systems straddling each of these divides. Really long ranges become more difficult to achieve as incoming targets approach at higher speeds, since the fundamental limits of all air-defense systems include reaction and, therefore, detection times. At very long range, moreover, air defense can turn into an attack on the platforms from which the original attack is launched, be they aircraft (missile-carrying bombers), ships, or shore launchers. Only in the case of the bombers is this end of the air-defense spectrum included in classical anti-air warfare measures.

Thus, the longest-range anti-aircraft weapons are the long-range missiles carried by naval-defense fighters. For the purposes of this book, these defenders are carrier-based fighters, which are operated by only a very few navies. Land-based fighters, generally not under naval control, can, of course, contest the passage of antiship bombers. However, the historical record strongly suggests that such fighters often cannot appear in time to engage passing bombers, especially if the bombers can evade over enormous sea areas. The advantage of the carrier-based fighters is that their bases are in the bombers' target areas, so the bombers must necessarily fly toward them.

All long- and medium-range weapons are necessarily terminally guided. At shorter ranges, however, unguided gunfire can be effective, particularly if produced in sufficient volume. Missiles are generally limited not only in maximum but also in minimum range, as they require time to accelerate to a speed at which sufficient air is flowing over their fins for effective guidance. In contrast, guns can be aimed down to zero range.

Maximum effective gun range is largely determined by how well the target's future position can be predicted, since the shell travels to an aim point computed slightly before the gun is fired. Any error in aim point against an air target will cause a shell to miss. Proximity fuzes make up for such errors by exploding a shell near a target, and in such cases maximum effective range is determined by the maximum miss range within which the proximity-fuzed shell is still lethal. That range depends on the speed of the target and on the average speed of the shell, since the miss distance will increase over time. Effective range also depends on how quickly the associated fire-control system computes a solution; the faster the computation, the less outdated the data on which firing must be based. The faster the shell, the less a target can move while the shell is en route, and thus the lower the chance that the fire-control solution will be wrong

by the time the shell arrives near its target. Hence the current U.S. interest in exotic high-velocity weapons such as rail guns. For a gun firing against a surface target, maximum range is determined by the steepness of the trajectory. A flat-trajectory shell will pass through a target even if the aim point is slightly in error. A steeply falling shell, however, will pass in front of or beyond a target. The tolerable miss distance corresponding to a given range is the danger space associated with the gun.

For all air-defense systems, there is a minimum acceptable kill range, since even a badly damaged missile may well follow a ballistic trajectory into a targeted ship, and since the fragments of a severely damaged missile will continue along its original path. Weapon lethality is, therefore, a very important issue. Proponents of very small caliber weapons, such as Phalanx, rely heavily for the physical destruction of an incoming missile on the fuzing of its warhead as a result of penetration by 1 or more projectiles. If the warhead is not fuzed, the missile may well continue into the ship. For example, in a 1986 U.S. Navy incident, a self-propelled Chukar target was hit by USS *Antrim* and scored as killed. It flew into the water but glanced off and continued into the ship, killing a man and severely damaging the ship's unarmored combat information center. Proponents of larger-caliber weapons (such as the Bofors 40- and 57-mm guns) claim that, although shots are much fewer, each is far more lethal, as its fragments can fatally damage a missile.

Thus, even if an air-defense system defeats all the missiles attacking it, those missiles may still do some damage. The lesson would seem to be, not that active defense is pointless, but rather that it must generally be combined with some form of passive defense: ships will be damaged, but they must remain afloat and at least partly effective. Most passive-defense issues are outside the scope of this book, but one is very important: the rise of distributed rather than centralized combat systems. To the extent that a combat system (and its power supply) can be spread over the length of a ship, the system cannot be eliminated by a single concentrated hit. Here the key technologies are probably data busing (so that several widely distributed computers can maintain the same current combat data base) and relatively inexpensive high-density electronics (so that there is no need to concentrate the combat system in a single central computer, either to provide enough computing power or to provide that power at a reasonable price). If a ship and her combat system can survive several hits, an increased burden will fall on the attacker, who must launch more weapons (of individually greater power) and who, thus, may find it difficult to deal with as many separate ships. Survivability may make decoying more effective or may force the attacker to concentrate an attack (e.g., to fly several aircraft together) in a manner increasing vulnerability and reducing saturation.

Lethality issues also apply to missiles. Very few missiles can be expected to actually hit small incoming targets. Rather, most will employ proximity fuzes to convert a near miss into a hit. The proximity fuze is triggered by the nose of the missile, and defending and attacking missiles may well be passing each other at or above Mach 4. There is a finite time lag while the proximity impulse activates the missile's fuze. Then there is also a finite interval while the explosive effect of the defending missile propagates to its target. Mach 4 is approximately 4000 ft/sec, and this speed leaves very little time to destroy a missile less than 10 ft (i.e., less than 1/400 of a second) long.

This problem explains the decision to abandon continuous-rod warheads in the U.S. and British navies. Continuous rods were adopted after World War II as a means of cutting through the airframes of large bombers and thus inflicting fatal damage; these warheads consist of rods joined together at alternating ends, wrapped around explosives. When the warhead detonates, the rods are forced apart into an expanding ring, which eventually breaks apart. The rods have considerable inertia and cannot move very fast. An alternative is pure blast-fragmentation, which may not chop up a bomber as effectively as a continuous rod but which propagates much faster. Presumably, the ultimate

warhead would employ a shaped charge focused in one direction; the missile would roll toward its target before bursting.

The air-defense missiles described here vary considerably in guidance, ranging from self-guided (by infrared or active radar) to semiactive (homing on a signature imposed on the target) to command-guided (following decisions made externally). Each type of guidance has its own advantages. Self-guidance minimizes the load on the launch platform. In an airplane, self-guidance means fire-and-forget operation, allowing a fighter to engage multiple targets in quick succession. Similarly, in a ship, self-guidance helps counter saturation. However, because the intelligence that can be packed into a small missile is necessarily limited, the missile may be unable to overcome target countermeasures. In theory, the greater the intelligence that can be incorporated in a fighter or a ship, the greater that platform's abilities. However, pure command guidance necessarily becomes less accurate as range increases, since any particular angular error equates to a greater and greater miss distance (and ultimately to a miss distance beyond the lethal radius of the missile). Semiactive guidance is a compromise: the ship or airplane imposes a signature on the real target (and so limits the efficacy of countermeasures); but, homing on reflected energy, the missile, in theory, gains accuracy as it approaches the target. Semiactive guidance, however, requires that the weapons system dedicate a guidance illuminator to one target throughout the flight of the missile or missiles. For a ship, the number of such illuminators is limited by topside configuration. No airplane can afford more than a single illuminator. Thus, systems designed to defeat saturation are driven toward some mixture of command and self-homing. Command guidance has the additional advantage of extending a missile's range by flying the missile along an energy-efficient path. In contrast, semiactive guidance requires some type of pursuit path, which is inherently inefficient.

For the present, perhaps the single most important question is the extent to which shipboard systems can continue to provide area defense against faster and faster incoming attackers, i.e., in the face of shorter and shorter warning times. Without some form of area defense, each ship (and, ultimately, each merchant ship) needs its own point defense. On the other hand, if even modest area defense becomes sufficiently expensive, navies will be unable to field sufficient numbers of effective warships. One possibility is that missiles as they are currently understood will be superseded by lasers or other exotic directed-energy weapons, for which time of flight will no longer be a meaningful limitation.

This section includes a wide variety of shipboard missile countermeasures, both active (jammers) and passive (decoys). Often they are associated, the jammers pulling an incoming missile off into the cloud of chaff. One problem with such systems is that the missile is unlikely to detonate in the chaff cloud. The missile may emerge from the cloud only to begin a target-reacquisition routine; and the missile, if it still has sufficient fuel or energy on board, may then find the original target. That scenario would be most probable for missiles that hit their targets at very shallow angles, such as most sea-skimmers; missiles designed to make terminal dives may well dive through a chaff cloud into the sea. Thus, the best defense against a sea-skimmer may include some means of triggering the missile after it has been decoyed. One possibility would be to fire shells into the sea under the chaff cloud, to create a wall of splashes into which the missile would fly (or that would, at the least, trigger its fuze). No system integrating chaff and jammers and medium-caliber guns currently exists; but as combat systems become more fully integrated, such tactics would seem to be very easy to implement.

This section also includes submarine periscopes, with an emphasis on optronic devices. Because sonar may be limited in its ability to detect and track surface craft, periscopes are often the submarine's primary surface-search sensors and, thus, are in the same category as the submarine radars listed and described here.

Moreover, the newer optronic (or photonic) periscopes share the technology of the optronic sensors and fire-control devices described in this section.

Periscopes are changing radically. Until the last decade, they were all optical, and most submarines had 2 types, a wide-angle search periscope and a narrow-angle attack scope, the latter intended to leave the narrowest possible wake so as not to reveal too easily the position of the submarine. A submarine commander would obtain a surface picture by making a quick sweep with the search periscope, the duration of the sweep determining both the quality of that picture and the extent to which there has been exposure to detection. Much of the submarine officer's training (for example, in the British "perishers' " course) was devoted to forming a coherent surface picture after the briefest sweep.

As for the technology, very compact optics was developed to provide such facilities as alternative air and surface search in the same narrow tube, as well as stadimetric range finding. A stadimeter measures the angle between the horizontal and the observed height of an object; if the height (usually the masthead height) is known, the range can be calculated. From a submarine's point of view, the advantage of stadimetry is that the baseline is the object being measured, rather than the range-finder (which must be quite small, so as to be unobtrusive). The horizontal equivalent of stadimetry, using the observed length of the target, is impractical because most targets will not be at right angles to the line of sight of the periscope.

There are also special night periscopes with greater light-gathering power. Some search periscopes are binocular, with duplicated windows at the top. At one time many search periscopes provided for air search, but now air warning is more usually the function of a radar-warning receiver found atop the search periscope.

Two major developments are associated with the post-1945 revolution in submarine design and performance, the combination of high underwater speed and indefinite submerged periods (snorkeling when required). The first development required search and radar periscopes that could be extended at relatively high speeds (the U.S. Navy called for periscopes that were extendable at 14 kt). High speed in turn induced severe vibration, and images had to be specially stabilized. The second development required sextants for taking navigational fixes to be incorporated in search periscopes. Conceivably, this requirement will lose its urgency with the rise of very accurate and universally available satellite navigational systems such as GPS, but surely the sextant will always be desirable as a backup against the destruction of the satellites.

Optronics is an outgrowth of television and thermal (IR) imaging technology. Periscopes were initially provided with these sensors, such as image intensifiers (low-light-level television, in effect), to extend the periscopes' usefulness to lower light levels. However, as with surface-ship and aircraft applications, the potential of converting the image into an electromagnetic signal is much greater since the image itself can be processed. In surface or air applications, the emphasis is usually on processing for tracking. In a periscope, the emphasis is more on processing the image to extract all of its information content and even to merge it with other relevant data.

The 2 applications of such cameras are quite different. A conventional or LLLTV camera can be inserted in the bottom of the periscope, taking the same image as the periscope's eyepiece, on much the same principle as a single-lens reflex camera. However, an infrared sensor is best placed at the top of the periscope since thermal photons traveling all the way down the tube (e.g., to a camera at the base of the periscope) would suffer from added noise. Moreover, the optical components of the periscope will not focus or reflect infrared radiation as they do light itself. Thus, a conventional periscope cannot be converted to infrared operation by simply installing a new crosshead, whereas that periscope can relatively easily be provided with an image intensifier.

Infrared operation requires installation of a thermal camera at the head of the periscope. The IR sensor must be cooled, and the coolant led up a very narrow periscope tube (or else a very compact refrigerator must be incorporated in the small periscope head).

Existing optronic periscopes employ a camera analogous to the window of a periscope, fixed rigidly to a tube that the observer rotates. However, there is no reason for the observer to memorize the scene as quickly as the periscope is turned. In principle, the sensor can make a very quick scan (or even look simultaneously in several directions), and the image can be stored either digitally or in a video recorder, for display as desired on a CRT. The newer sensors can provide images of optical-periscope quality. That capability, in turn, opens up some very interesting possibilities.

The exposure associated with a periscope depends on 2 factors: the sheer size of the head and the time during which the head projects above water. Optonics probably always requires more space than simple optics, but optonics can also greatly reduce exposure time, since observation need not coincide with exposure. The submarine commander can view the resulting images for a protracted time, well after they have been created. Modern digital CRTs can display these images alongside other sensor data, such as ESM data collected at the same time by the same mast. The officer viewing such a windowed CRT can fuse the data from these various sources to form a much better tactical picture. In theory, the same CRT could also display relevant sound data, again adding to the overall tactical picture in a way impossible for a conventional optical system.

Perhaps at least as importantly, the commander of the submarine would no longer have to be the operator of the periscope sensor, just as the commander is not the operator, but rather the supervising user, of the various other acoustic and non-acoustic sensors on board a submarine. The skipper could obtain the full tactical picture without having to concentrate on the necessarily fleeting periscope image. Those manufacturers offering digital optronic or photonic periscopes, such as Dowty and Plessey, tend to suggest radically revised arrangements for submarine control rooms or operations rooms, in one case with the periscope image on a large screen on one bulkhead, surrounded by relevant data-base readouts (e.g., the characteristics of the ship shown on the screen, to the extent that the expert computer system connected to the data can identify the contact).

An optronic sensor unit might also be far lighter than conventional periscope-head optics and, thus, might be much easier to stabilize and even to control in an autotrack mode.

Moreover, there is no reason why an optronic or photonic sensor must be mounted on a mast penetrating into the control room of the submarine. In some submarines, such as the German IKL designs, all masts other than the periscope are already nonpenetrating; they telescope out of the sail of the submarine. Nonpenetration reduces structural stress in the submarine's hull and can simplify mast design, since the body of the mast no longer needs to be pressure tight. Instead, most of the mast can be free flooding. That design would allow the use of non-metallic (i.e., non-radar-reflecting) materials. Moreover, there are considerable advantages (both in drag and in radar cross section) to be gained by using a noncylindrical mast (which is acceptable if the head, rather than the entire mast, rotates).

A control room or CIC served by an optical periscope must be directly under the sail, and that requirement complicates the arrangement of the submarine. For that matter, the central position of the optical periscope greatly complicates the internal arrangement of the control room or CIC; in theory, a much more efficient arrangement is possible. Presumably, the ultimate simplification would be to eliminate the mast altogether, placing the optronics and other sensors in a towed body that the submarine could launch and recover and that would use some inertial device (such as a ring-laser gyro) to locate itself relative to the hull of the submarine. In theory, such a devel-

opment would greatly reduce the drag and noise of the submarine's hull, and the submarine could remain much farther below the surface at what would amount to periscope depth.

In practice, submariners have resisted total dependence on any form of electronics; an optical periscope will still work even if electrical problems have put computers and displays out of action. Attempts to eliminate the submarine's sail altogether have been quite frequent, at least in the U.S. Navy, but have generally failed because the sail is needed for some other quite essential purposes: for good depth keeping near the surface in relatively shallow water (but this requirement does not apply to a submarine with her foreplanes on her hull); for navigating on the surface, e.g., when entering port; and for supporting the snorkel.

It would be impractical to convert an existing optical periscope to optronic or photonic operation because considerable information is lost between the lens at the top and any sensor inserted at the bottom, particularly with infrared images. On the other hand, periscope photography, which is a sort of predecessor to optronics, has been common for many years.

SHIPBOARD RADARS AND FIRE-CONTROL SYSTEMS

CANADA

RADARS

◆ SPG-515

Band: X (8.5–9.6 GHz) **Beam:** 2.6 deg **Peak Power:** 250 kW
Gain: 39 dB **Pulse Width:** 0.25 microsec **PRF:** 1000 ($\pm 10\%$)
Scan Rate: 29.2 Hz in conscan or spiral scan
Scan Angle: 4.1 deg conscan, 12.6 deg spiral scan; beam shift 0.5 deg in conscan, 0.5–5 deg in spiral scan
Antenna Dimensions: 40 in diameter



SPG-515 fire-control radar (MK 60 director) on board the Canadian destroyer *Annapolis*, 1989. (G. Till)

This new solid-state Norden radar replaces the U.S. SPG-48 on board Canadian destroyers (frigates); the modified FCS is designated Mk 69 Mod NC6 (not Mk 60, as sometimes reported). The new FCS is said to show a 40% improvement in accuracy against moving, incoming targets. Mod NC6 is a digital version of the old U.S.-supplied Mk 69 analog system. Additions include an angle-error indicator and a digital range computer.

The original SPG-48 was a repackaged Mk 35, using the 250-kW transmitter and reflector of Mk 25. Maximum target range was 40,000 yd, and acquisition range was 25,000 yd.

◆ SPS-501

This radar is essentially a Dutch LW-03 antenna combined with a U.S.-type SPS-12 transmitter. In 1984 a Canadian company, SPAR, marketed a new solid-state receiver for SPS-12 radars,

presumably intended largely for the modernization of existing Canadian SPS-501 radars. The company also improved range resolution (to 200 m in wide-band/short-pulse mode, and to 800 m in narrow-band/long-pulse mode). Specified MTBF was over 10,000 hr. The modification kit was also much smaller than the original SPS-12 receiver.

◆ SPS-502

Cardion Electronics's solid-state surface-search radar, although using the SPS-10 antenna, has more than 95% of its parts compatible with the company's SPS-55.

◆ SPS-503

Band: S (2.7–3.2 GHz, i.e., frequency-agile over 500 MHz)
Beam: $1.5 \times \csc^2$ to 40 deg
Peak Power: 20 kW (average 800 W) **Gain:** 30.75 dB
Pulse Width: 54 microsec (0.6 microsec subsidiary pulse)
PRF: 739 pps (stagger, plus or minus 12.5%)
Scan Rate: 10 or 20 rpm **Antenna Dimensions:** 4.7-m width
Antenna Weight: total system weight 1300 kg [2865 lb]; antenna 490 kg [1080 lb]



SPS-503 and (above it) SPS-10D radars on board the Canadian destroyer *Annapolis*, 1989. The director atop the bridge carries an SPG-515 radar. (G. Till)

This air/surface-search radar, by Canadian Marconi Radar (CMR), is made for the modernized frigates (DELEX program) and replaces the older U.S. SPS-12. An adapted Marconi S1821, SPS-503 is a pulse-compression radar using a coherent transmitter (providing digital MTI); it has both MTI and non-MTI channels. The SPS-503's antenna is that of the Plessey AWS-4. This radar can employ either linearly or circularly polarized radiation, the latter being useful in severe weather. There is an



SPS-503 radar antenna at the Canadian Marconi plant, Kanata, Ontario. (Canadian Marconi)

alternative 2.44-m stabilized antenna in a radome, providing a beam of $2.8 \times \text{csc}^2$ to 30 deg, with a total weight of 500 kg and a scan rate of 12 and 24 rpm. Gain is 28.5 dB. Signals are horizontally polarized. The basic radar using the alternative antenna is designated CMR-1 (a Canadian Marconi designation).

Canadian Marconi also offers a version using an unstabilized planar-array antenna (3.5-m aperture, $2.1 \text{ deg} \times \text{csc}^2$ to 40 deg beam, 29.8-dB gain, 10/20 or 15/30 rpm scan). Signals are vertically polarized.

SPS-503 uses 2 TWTs driven in parallel (with output phase matching) by a solid-state frequency synthesizer. Transmission modes: pulse-to-pulse frequency agility among 16 frequencies (non-MTI), block-to-block (3-pulse) frequency agility (MTI), and fixed-frequency (MTI). PRF can be staggered to protect against lock-on jamming, and a jamming-strobe indicator alerts the operator to the presence and azimuth of noise jammers. The transmitted pulse consists of a 54-microsec chirp (which is pulse-compressed) and a short (0.6-microsec) unmodulated pulse, the latter for short ranges, to reduce energy on target (and thus the reflected energy from nearby clutter). The receiver compression ratio is 207.7:1, and the range cell is 39 m (minimum range is 200 m). The first blind speed is 1700 m/sec (3300 kt). Rated ranges against 4-, 1-, and 0.1-m² targets: 152, 108, 61 km (126, 90, and 51 km, respectively, with the 2.4-m antenna). Instrumented range is 160 km. Accuracy: 2.5 m in range, 0.29 deg in azimuth. Resolution: 39 m, 1.5 deg. Rated reliability: 305 hr MTBF, 1.0 hr MTTR.

A related radar, CMR-4, uses the 2.4-m antenna also, but at C-band (5.4–5.9 GHz), with a single TWT, the same transmission modes as CMR-1, and peak power 14 kW (mean power 330 W, PRF 1600 pps). Rated ranges against 4-, 1-, and 0.1-m² targets are 74, 52, and 30 km, respectively.

◆ LN-66 (CMR-85, SPS-59)

Band: X (9375 MHz) **Beam:** $2.5 \times 22 \text{ deg}$ **Peak Power:** 75 kW
Gain: 30 dB **Pulse Width:** 1.0 or 0.1 microsec
PRF: 500 or 2000 pps **Scan Rate:** 22 rpm
Antenna Dimensions: 36 in
Antenna Weight: total weight 22.9 kg

Data in this table refer to LN-66 HP, the search radar of the U.S. LAMPS I helicopter.

This surface-search radar, built by Canadian Marconi, has been very widely exported, both in its shipboard version and in a related helicopter version (on board U.S. LAMPS I helicopters). A related radar is used for submarine navigation (U.S. *Ohio*-class submarines), on board U.S. LCAC landing craft, and also on board U.S. small combatants such as the SEALs' Seafox. In the 75-kW version described above, range discrimination is 18.3 m. Range scales are 1, 2, 3, 12, 24, 48, and 72 nm.



LN-66 occupies the small radome halfway up the mast of the USS *Barnstable County*, 1986. The masthead antenna is SPS-10, and the "washtub" in the foreground is the OE-82 satellite-communications dish. (S. Terzibaschitsch)



The 75-kW version of the LN-66 radar. A modified form is installed on board U.S. Navy LAMPS helicopters. (Canadian Marconi)

The basic 10-kW version is designated SPS-59(V)1 in U.S. Army service. 59(V)1 uses a 5-ft slotted-waveguide antenna (AS-3146). A current solid-state version of the basic radar increases power to 12 kW. These radars can also be used with a 3-ft (radome-enclosed) or 8-ft slotted waveguide. This 3-ft antenna, not described above, produces a $2.7 \times 26 \text{ deg}$ beam (gain 26.5 dB). Pulse widths are 0.5 and 0.09 microsec (PRFs 800/1250 and 2500 pps, respectively). Minimum range is 20 yd, and range

scales are 0.25–48 nm. There are also 5-ft (60-in) and 8-ft (96-in) slotted-array antennas used with the 75-kW transmitter described in the table. The 60-in version has a 1.6×19 -deg beam (gain 29 dB) and scans at 24 rpm. The 96-in version has a 0.88×19 -deg beam (gain 31 dB). A version with a dual-display is used as TPS-66 in the U.S. Navy AN/TSQ-108 Radar/Sonar Surveillance Center.

As of 1988, Canadian Marconi was offering a 90-kW version of the basic radar to replace the 75-kW version. The former has the same pulse widths and PRFs as the 75-kW version.

In addition, there is LN-66 SP, a 6-kW version for submarines and small craft, that uses either a 3-ft radome antenna or a 4-ft detachable slotted waveguide (1.9×26 -deg beam, gain 28 dB). Pulse widths are 0.5 and 0.12 microsec (PRFs 1200 and 3000 pps). Minimum detection range is 25 yd, and range scales are 0.5–32 nm. About 1988 the LN-66 SP was redesignated CMR-85. Despite the official AN/SPS-59 designation, LN-66s in U.S. naval service are almost invariably called LN-66.

◆ Sperry Mk 127E

Band: X **Beam:** 1 deg **Peak Power:** 25 kW
Pulse Width: (i) 0.05 (ii) 0.025 (iii) 1.2 microsec
PRF: (i) 4000 (ii) 2000 (iii) 500 pps

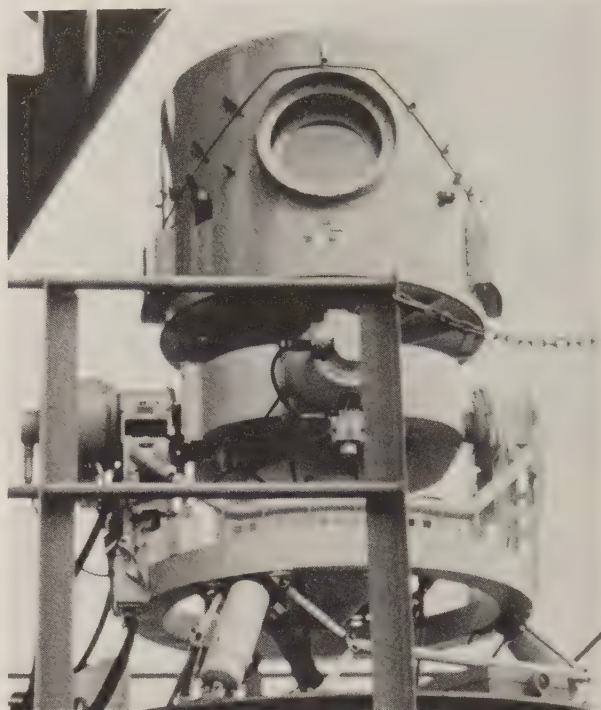


A Canadian *Annapolis*-class destroyer shows, top to bottom, SPS-10D (turned toward the mast), SPS-503, and Mk 127E (the slotted waveguide at bottom), with SPG-515 below atop the director. (G. Till)

Mk 127E is now the standard Canadian naval navigational radar, superseding Sperry Mk 2. It was introduced about 1983. Range accuracy is about 1%. Range scales: $\frac{1}{4}$, $\frac{3}{4}$, 1.5, 3, 6, 12, 24, 60, 120 nm. This radar supplements SPS-502/SPS-10.

OPTRONICS

◆ SAR-8



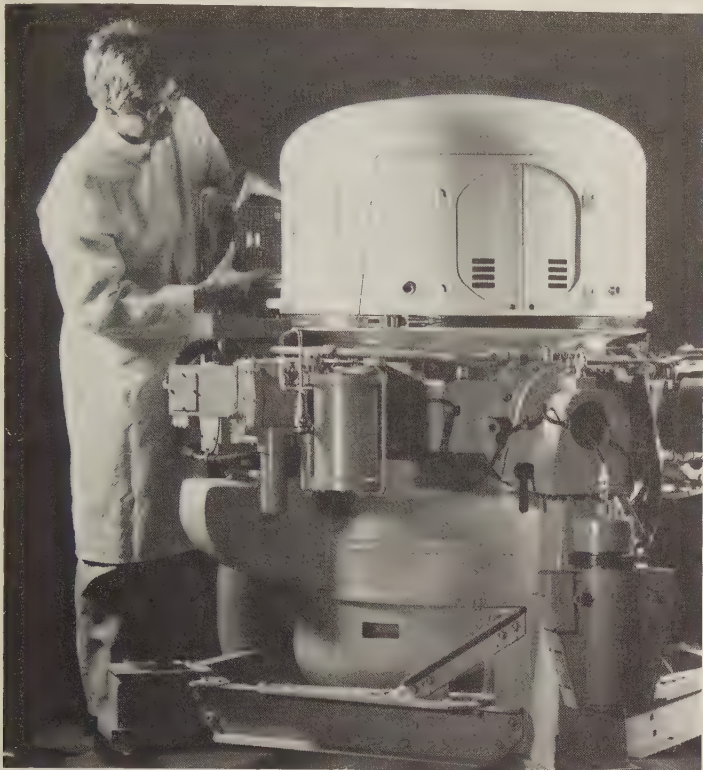
The Advanced Development Model of the SAR-8 IR search-and-tracking sensor. (SPAR Aerospace)

The General Electric/SPAR infrared-search and target-designation (IRST) system was a joint U.S.-Canadian project. SAR-8 was tested at sea in 1978 on board HMCS *Algonquin* and in 1979 on board USS *Kincaid*. Full-scale engineering development began in FY84.

SAR-8 is a cylindrical mechanism gimbal-mounted for stability, continuously scanning for a 2-sec data rate (track-while-scan). This system can passively detect both air and surface targets, using a signal processor to detect small targets in heavy clutter. The surface display provides both a 360-deg panoramic view and an expanded display of any selected sector, for target identification. The published description suggests that SAR-8 is able to detect incoming air targets by the glint on their forward surfaces or by the aerodynamic heat generated on the targets' bodies. This type of system can also detect incoming missiles beyond the horizon by sensing their exhaust plumes. Although generally not precise enough for missile counterbattery fire, such detection can be used to trigger countermeasures under EMCON conditions.

Total weight is about 6500 lb, of which 1350 lb is above decks. The ship provides heading, speed, and altitude data, and SAR-8 scans at 0.5 revolutions/sec. Power requirement is 25 kVA, and above-deck volume is about 150 ft³. The associated computer is the new standard UYK-44. A combination of filters (spatial and temporal) and tuned algorithms is applied to the scene as observed; each source is analyzed to determine whether it is either (i) an airplane or missile or (ii) clutter. Any source classified as (i) has its bearing, elevation angle, and track data transmitted directly and automatically to the combat system. This point-source processing is supplemented by a panoramic image of the surrounding ships and other surface features, which is provided to the operator.

SPAR Aerospace developed its first infrared search-and-track system in the early 1960s, and between 1962 and 1967 developed an infrared acquisition system for the abortive U.S. Mauler point-defense missile. In 1968–70 the company developed and tested an Infrared Electronic Warfare System (IREWS) for the U.S. Navy, and this system was further modified in 1971–73.



The prototype SAR-8. (SPAR)

In 1974-77 the Canadian Navy sponsored the development and test of a Shipboard Passive Surveillance-and-Detection System (SPSDS). That project in turn led in July 1976 to a U.S.-Canadian MoU and Joint Project Agreement to develop an advanced development model of the IR Search-and-Track System (IRST), which became SAR-8. The Joint Agreement for Engineering Development of SAR-8 was signed in January 1983, and SPAR was selected as prime contractor in August 1984.

Full-scale development should have begun under the FY81 program, but Congress decided that the more sophisticated U.S.-built Seafire was superior. Work on SAR-8 was, therefore, suspended, while Seafire died of gross cost overruns. SAR-8 was then revived, and the prototype was scheduled for land tests at Port Hueneme through mid-1990, followed by shipboard tests in 1990-91, followed by production in 1991 and installation on board *Spruance*-class destroyers beginning in 1993. SAR-8 will probably be installed on board later *Wasp*-class (LHD 5-7) and *Arleigh Burke*-class ships. The U.S. Navy also evaluated the French VAMPIR but decided that its signal-processing capability was less than that of SAR-8. Meanwhile, work is proceeding on integration with other systems. The 1990 tests included operation with the Mk 23 Target Acquisition System, to support Sea Sparrow missile operation, and there were also efforts to integrate SAR-8 with the Aegis combat system and with the evolving NAAWS system. Follow-on work is scheduled for integration with ACDS and with SLQ-32.

CHILE

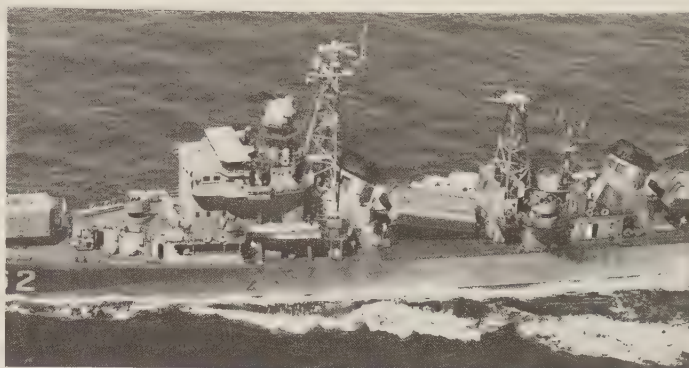
The ASMAR national shipyard exhibited several radars at the 1984 Feria Internacional del Aire (FIDA) at Santiago. Foremost among them were a dual-band (S and X) shipboard fire-control radar (6 of which had been produced) and a containerized S-band air-search radar.

The radar development group dissolved soon after, and it was being revived, on a more modest scale, in 1989.

CHINA (PRC)

SEARCH

◆ Bean Sticks/Pea Sticks



This *Luda*-class destroyer carries a Bean Sticks long-range air-search radar (4 × 4 array of yagis) just forward of her after funnel. The foremast radar is an Eye Shield (MX-902) short-range (target-indication) air-search set. The forward end of the platform carries a surface-search radar. The secondary battery consists of twin 37-mm and 25-mm machine cannon, and she carries 2 triple missile launchers. (U.S. Naval Institute)



This *Luda*-class destroyer carries a Pea Sticks long-range air-search radar. (U.S. Naval Institute)

The 2 names indicate alternative antennas for the same P-band early-warning radar, in *Luda*-class destroyers. Bean Sticks consists of 4 bays, each with 8 yagis.

◆ Eye Shield (MX-902)



An Egyptian *Jianghu*-class frigate shows, on her mast, an Eye Shield air-search radar at top and a Square Tie missile target-designator 2 levels down. One of the slotted waveguides is a Decca radar; the other is a Chinese Type 756. The director carries what appears to be a yagi array (like that of the old British Type 285) on its roof. The twin 37-mm guns are locally controlled. (U.S. Naval Institute)



A Chinese *Jianghu*-class frigate shows an Eye Shield radar at her mast-head, with a Type-756 navigational radar (the slotted waveguide) and Square Tie (missile fire control) below it. (U.S. Naval Institute)

Eye Shield is the air-search radar in *Jianghu*-class frigates. The antenna is a long, slim paraboloid, similar in overall shape to such Soviet radars as Slim Net and Head Net A, except that the Chinese antenna is of solid rather than lattice construction. (Slim Net is still in Chinese service on board 4 Riga-class frigates built in Chinese yards [with Soviet parts] in the late 1950s.)

The Chinese designation for Eye Shield is MX-902.

This radar is also in service on board the Chinese frigates transferred to Egypt.

◆ ESR-1

Band: S **Beam:** 2×10 deg (dual-beam pattern) **Gain:** 33.5 dB
Scan Rate: 30 rpm **Antenna Weight:** 350 kg [770 lb]

This low-altitude air-search radar was displayed at the ASIANDIX exhibition in Beijing in the fall of 1988. The antenna is roll-stabilized, and the 31-cm [12-in] PPI is arranged for plot extraction by roller-ball. The scope can also display synthetic video, and the radar can extract moving targets. The MTI improvement factor is 22 dB. The manufacturer, the China Shipbuilding Trading Co., claims that ESR-1 can detect a 0.1-m^2 sea-skimming missile (flying at a height of 8 m) at a range greater than 12 km [about 13,000 yd].

The data above are taken from the manufacturer's brochure. No power or pulse data were given.

◆ Rice Screen (Sea Eagle)

Band: C (described as upper end of G-band)
Beam: 2.7×1.4 deg **Peak Power:** 150 kW
Pulse Width: (i) 40 (ii) 20 microsec (compressed to 1 microsec)
PRF: (i) 370 (ii) 730 (average power 2.2 kW) pps
Scan Rate: 5 rpm

This planar-array 3D pulse-compression radar entered service in the mid-1980s and was publicly displayed (with the data given above and below) at the ASIANDIX 1988 exhibition in Beijing. Rice Screen is marketed for export by the Nanjing Marine Institute.

There are 2 types, with larger and smaller antennas. The data above refer to a large antenna, much taller than it is wide. A smaller type is reportedly 2.3×3.0 m, which would not quite correspond to the beam figures above. However, the beam figures come from the claimed resolution performance, and the resolution in azimuth may be degraded somewhat as the beam sweeps up while the radar turns. The radar antenna shows a prominent fin on one side, presumably carrying a serpentine (frequency-scanning) waveguide. Phase shifters are presumably used to allow the radar to sweep in frequency (both for pulse compression and for frequency agility) without sweeping its beam up and down.

This radar can semiautomatically track 10 targets simultaneously, using what the manufacturer calls an extraction PPI operating semiautomatically. Probably the operator designates the targets to the associated computer. Two or more entries of the same target (on subsequent scans) provide the computer



Rice Screen (top), Type 756, and Fog Lamp (bottom) on a *Jiangdong*-class frigate. (U.S. Naval Institute)

with a track. The operator then monitors later detections of the same target to see whether it remains on a constant course and speed. The target's altitude may be as high as 25,000 m [82,000 ft]. There are 2 operating modes: low angle (up to 7.2 deg in elevation) to a maximum tracking range of 180 km [197,000 yd], and high angle (to 28.8 deg) out to a maximum range of 120 km [131,000 yd].

The transmitter is a TWT CFA chain, and reception is coherent, with an MTI improvement factor of 30 dB. Accuracy is 100 m in range and 0.8 deg in azimuth and elevation. Resolution is 200 m in range. Operation is over a wide band (10% of frequency), with adaptive frequency selection on a pulse-to-pulse basis.

◆ Type 354

Band: C **Beam:** 1.2×5 deg **Peak Power:** 500 kW
Pulse Width: 2 microsec **PRF:** 400 or 800 pps
Scan Rate: 4–10 rpm

This low-altitude air-search radar is used for target acquisition on board missile frigates. The antenna is roll- and pitch-stabilized. Claimed range on a 10-m^2 target is over 50 nm, accuracy is 5 m in range and 5 mrad in bearing, and resolution is 300 m in range and 1.3 deg in bearing.

◆ Type 756

Band: (a and b) X (c) S
Beam: (a) 1.3×20 deg (b) 0.8×18 deg (c) 2×22 deg
Peak Power: 50 kW **Gain:** (a) 30 dB (b) 32 dB (c) 27 dB
Pulse Width: (i) 0.08 microsec (ii) 0.5 microsec (iii) 1 microsec
PRF: (i) 2000 (ii) 1000 (iii) 500 pps **Scan Rate:** 18–22 rpm
Antenna Dimensions: (a) 2 m (b) 3 m (c) 3.8 m

This navigational radar uses a slotted-waveguide antenna. Range scales are 0.5, 1.5, and 3 nm with short pulse; 6, 12, and 24 nm with 0.5-microsec pulse; and 48 and 96 nm with long pulse. The complete system uses both X- and S-band antennas for all-weather performance. Minimum range is about 30 m (mast height 15 m), and range discrimination is 25 m. Accuracy is 1% of range or 0.02 nm (whichever is greater) and 1 deg.

FIRE CONTROL

◆ EFR-1

The China Shipbuilding Trading Co. displayed this new naval radar fire-control system at the ASIINDEX exhibition at Beijing in November 1988. EFR-1 is a radar fire-control system externally similar to the French Castor series (i.e., with a Cassegrain antenna), with a television camera and a laser alongside the radar. EFR-1 was described as operating in X-band, with MTI processing, and was credited with the ability to acquire targets with cross sections of less than 2 m^2 at ranges beyond 30 km (and small sea-skimming missiles at 13 km).

EFR-1 is being offered as a feature of several new warship designs being offered for export; presumably this system is planned for a new generation of Chinese warships.

◆ Fog Lamp

This radar is the H/I-band SAM fire control for the HY-61 missile.



Top to bottom: Rice Lamp, Fog Lamp, and a twin HQ 61 missile launcher on a Zhongdong-class frigate. (U.S. Naval Institute)

◆ Rice Lamp

This radar is an X-band gunfire-control radar.

◆ Coastal Radars

Details of 4 types of coastal radars have been published. Type 404A is an X-band set with a solid elliptical antenna similar in shape to that of Eye Shield. Claimed accuracy (resolution): 100 (200) m, 0.35 (0.8) deg. The second type is an otherwise undesignated X-band coastal tracking radar, using a 200-kW transmitter (pulse width 0.2 microsec), and a 1×2 -deg beam antenna. Claimed range on a 7500-ton target is 60 nm; accuracy (resolution) is 30 (60) m and 1.5 (20) mils. The third type is the Eagle coastal radar, a mobile (truck-mounted) X-band radar. A published photograph suggests that the radar proper is radome-

mounted, with a large colocated IFF antenna (which itself resembles a radar antenna but has far too thin a mesh to work at X-band). Claimed range is 50 km on a 1000–2000-ton ship, and accuracy is 15 m in range and 0.09 deg in bearing.

In addition, at the Paris Air Show in 1989, CEIEC (China National Electronics Import & Export Corp.) announced a new JY-9 low-altitude search radar, which could also be used for coastal defense. It operates in S-band, using a dual-beam low-sidelobe antenna ($4.2 \times 7.5 \text{ m}$, for a 1.3×40 -deg beam; the upper and lower beams cross at 4 deg of elevation). The transmitter is pulse-to-pulse frequency agile and coherent, for doppler MTI, and the radar automatically detects and tracks targets. The antenna can be erected on a lattice mast for better low-altitude coverage. The radar can be set up or dismantled by 4 operators in 20 min.

DENMARK

The Royal Danish Navy uses a variety of British radars under its own designations. CWS-1, -2, and -3 are Plessey AWS-1 with different antennas (CWS-2 and -3 use Selenia reflector antennas; CWS-1 uses a slotted waveguide similar to one of the AWS-6 antennas). NWS-3 is Terma 20T48, a Decca 1629 built under license. NWS-1 is presumably an earlier Decca slotted-waveguide radar.

◆ Terma GCA Radar

Band: X (9.0–9.2 GHz)

Peak Power: 80 kW

Pulse Width: 0.18 microsec (± 0.02 microsec)

PRF: 3500 pps

This radar has been adopted (in navalized form) for the Brazilian carrier *Minas Gerais*. The data above refer to the land-based version. The radar uses 2 separate antennas for elevation and azimuth, as in the U.S. SPN-35 and the Italian SPN-720. Both outputs are displayed together on a 16-in CRT (elevation above, azimuth below, both in expanded form: $8 \times$ elevation, $3 \times$ azimuth). The range scales are 10 and 15 nm (range markers at 1-nm intervals). Electronic cursors on the elevation display show glide path and maximum permissible downward deviation (safety cursor). Typically, the elevation display shows alignment lines at 6, 3, and 1 deg, and the azimuth display shows similar lines at 15, 5, 0, and -5 deg. These data apply to a GCA-radar modernization program offered by Terma for any of a range of standard GCA radars. The beam characteristics are probably similar to those of the U.S. SPN-35.

◆ Terma Skanter Mil Radars

Band: X (9 GHz) or S (3 GHz)

Beam: 1 deg (horizontal beamwidth) at X-band (2 deg for S-band version)

Peak Power: 20 kW **Pulse Width:** (i) 0.06 (ii) 0.6 microsec

PRF: (i) 4400 (ii) 2200 pps

Gain: greater than 30 dB (X) or 28.5 dB (S-band)

Scan Rate: 24 or 48 rpm (60-Hz power; 20 or 40 rpm using 50-Hz power supply)

Antenna Dimensions: 2.1 m (X-band), 4 m (S-band)

Terma Elektronik AS, a Danish company, has developed several slotted-waveguide surface-search and navigational radars for the Danish and Swedish Navies. The Danish designations are NWS-1, -2, and -3; the standard Swedish unit is Skanter 009. The published data above refer to a radar whose development was completed in 1972. The transmitter is a magnetron, and the system as a whole can accommodate either S- or X-band operation, or a combination of the 2 (using different transmitters and antennas, feeding a common display). All displays are raster rather than rotating scan and are usable in daylight; they are adapted to show tactical system symbology and to operate with automatic tracking.

FRANCE

All French shipboard naval radars are products of Thomson-CSF. TRS numbers in parentheses are the commercial designations.

nations, where they apply. Many directors are produced by CSEE.

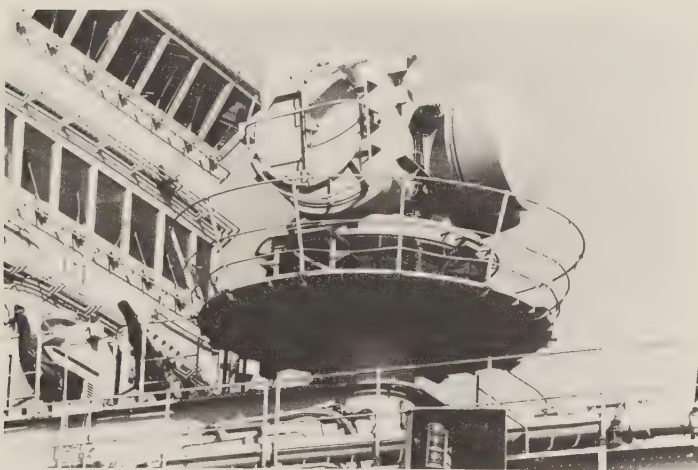
RADARS

◆ DRBC 32

DRBC 32 is an X-band monopulse pulse-compression radar designed specifically to control the 100-mm automatic gun. Its beam is 1.5 deg wide. Targets are automatically acquired, and all processing is digital.

This series was begun in 1961. DRBC 32A is on the *Suffren* class, some frigates, the *Jeanne d'Arc*, the *Clemenceau* (replaced by 32C in the *Foch*), and the *La Galissoniere*, and the T-47 ASW destroyers. DRBC 32B is on the *Aconit*. DRBC 32C is on the cruiser *Colbert*, the *Foch*, on *Commandant Rivière*-class frigates, and on some A69-class corvettes. DRBC 32D is on the *Tourville* and *Georges Leygues* classes (the 3 last ships of the latter class have DRBC 33 instead). DRBC 32E is on the *d'Estienne d'Orves*-class corvettes. DRBC 33 is replacing the DRBC 32 on the *Suffren* class.

The DRBC 32A and 32B versions both employ Cassegrain antennas; the others are all lightweight dishes with offset feeds. Originally DRBC 32 was always mounted on a quadraxially stabilized director carrying a stereo range-finder, designated TT type A (as installed on board the frigate *Aconit*); approximate weight is 11 tons. The director (*télépointeur*) was initially to have had a crew of 3, but that was reduced to 2 (pointer and observer/range-finder), at least in the case of the *Aconit*. Presumably, earlier versions had pointer, trainer, and range-finder operator. In this type of director, 2 of the axes are used to stabilize the platform of the director, and the other 2 point it at



DRBC 32C radar/optical director on board the carrier *Clemenceau*. (L. van Ginderen)



DRBC 32E fire-control radar on board the corvette *d'Estienne d'Orves*. (U.S. Naval Institute)

the target. Elevation limits: +80/-2 deg. A new lightweight unmanned biaxially stabilized radar-only director was developed for the *Tourville* class, based on the Masurca director. It is used with DRBC 32D and 32E, and with some 32Cs (the *Commandant Rivière* class retains the earlier manned director).

In the A69-class corvettes, the associated fire-control system employs a hybrid (analog-digital) computer.

Of the earlier fire-control sets, DRBC 31 survives to control 57-mm guns in the *Colbert* and the *Tartar* destroyers.

The first postwar French fire-control radar was ACAE (*Artillerie Contre Avions Éloignés*), which appeared about 1950. It employed 2 dishes side by side. ACAE was apparently a CW radar, since a recent French account notes that it could automatically generate height and bearing information, but not range. ACAE was installed on board the battleship *Jean Bart*, on the antiaircraft cruisers, and on the *Surcouf*-class destroyers. It was later replaced by the more conventional single-antenna DRBC 11. This radar was roughly contemporary with DRBC 10A (first tested 1955), the main-battery fire-control radar of the *Jean Bart*, which had an effective range of 25,000 m against surface targets. It used a "double cheese" antenna. The other fire-control radar of this generation was DRBC 30, a stabilized blind-fire radar director similar in concept to the U.S. Mk 63, used to control the standard twin 57-mm gun mount. It was succeeded by DRBC 31.

◆ DRBC 33 (Castor II: TRS 3203)

Band: X Beam: 2.45 × 2.3 deg

Peak Power: 30 kW, 120 W average **Gain:** 36 dB

Pulse Width: 0.5 microsec

PRF: computer controlled between 4000 and 8000 pps

Antenna Dimensions: working circle 1.6 m; dish diameter 1.053 m

Antenna Weight: total director weight 620 kg

Data are for the Castor IIC version. The original Castor II may have used 4-microsec, 80-kW pulses.

Reportedly capable of acquiring and tracking a 0.1-m² target at 8 nm, this radar is built both for the French navy and for export.

Castor II is a monopulse tracker using a Cassegrain antenna. Tracking includes multigate doppler filtering (900 m) using an 8-point FFT; the fully coherent transmitter is a TWT that can produce numerous computer-chosen frequencies over a 700-MHz bandwidth, somewhat less than 10% of base frequency. Tracking range is 500-30,000 m, and the first blind speed is at or beyond Mach 2. Elevation limits are -25 and +85 deg.

Acquisition is automatic, for very quick reaction, at ranges up to 25 km on a fighter and 15 km on an antiship missile. To ensure accurate tracking, the radar operates in short bursts (1.5 msec) at constant frequency, associating frequency agility and doppler processing; the radar can also jump from frequency to frequency on a pulse-to-pulse basis. Castor II can also passively track a jammer using range information from a tracker linked to a search radar. When directing shellfire, this system can display the angular error between shell and target. The radar can also be used for autonomous surveillance, scanning at a fixed elevation.

Castor IIB (TRS 3200) is a somewhat less sophisticated radar using the same antenna as II, but with single-knob tuning within the 700-MHz band. Pulse width is set at 0.4 microsec and PRF at 3600 or 7200 pps (with staggering). MTI processing uses a 3-memory filter. Compared to Castor IIC, IIB's sea clutter rejection ratio is 30 rather than 40 dB, and the transmitter weighs 80 kg rather than 200 kg.

Castor IIC limits: tracking range 0.5-27 km, radial speed 1000 m/sec, maximum train (elevation) speeds 1 (1.5) rad/sec. The probability of automatic acquisition in free space, for a 2-m² target, is 80% at 25 km. Clutter cancellation ratio is 40 dB for ground clutter, 35 dB for sea clutter. The associated TV/IR camera (TRAKIR) can place extraction gates (2.2 × 1.7 or 4.4 × 3.4 mrad) around a target, for tracking. The camera has a 35 × 27 mrad field of view.



Castor IIC. (Thomson-CSF)



Castor III. (Thomson-CSF)

Castor III is a J(Ku)-band radar/TV/IR director, designed as the basis of an all-weather antimissile system. This radar is specially designed to track in a cluttered and jammed environment, even at low altitude. Castor III uses a Cassegrain antenna (gain 43 dB, beam 1.5×0.67 deg) and a TWT transmitter (pulses 7.5 microsec). As in Castor IIC, there is an associated TRAKIR TV/IR tracker. Total height above deck is 2.422 m. The associated software uses a special low-altitude tracking algorithm that compensates for the image (multipath) effect of the sea's surface. In tests at Gavres in 1987 (see also the entry for the SATAN close-in weapon) the target, flying at an altitude of 7 m at 300 kt, was tracked with a standard deviation of 0.3 mrad (about 35 cm) at 1000 m range. Operational limits: tracking range 0.35–30 km, elevation $+85/-25$ deg, maximum speed 1000 m/sec. Acquisition time on an air target, with 90-deg bearing-slewing angle and 5-deg elevation search, is 2.8 sec; if identified as a sea-skimmer, 1.75 sec. The probability of automatic acquisition in free space (1 false alarm/min) is 90% at 18 km for 0.1 m^2 and 90% at 30 km for 2 m^2 : both figures are calculated for Swerling class 3.

Castor II is used with Vega fire-control systems in fast minor craft, including West German fast attack craft.

◆ DRBI 10

Band: S **Beam:** 2×2 deg **Peak Power:** 1000–2000 kW
Gain: 37 dB **Pulse Width:** 4 microsec **PRF:** 500 pps
Scan Rate: 4 rpm (vertically: 800 scans/min)
Antenna Dimensions: 3.4×3.4 m



The French carrier *Clemenceau*, 1972, shows typical radars: from top to bottom, they are: TACAN, IFF Mk 10, DRBV 22, DRBV 20 (large-ship version), DRBI 10 (both fore and aft of the funnel). (Giorgio Arra)

DRBI 10 is the height-finder on board the *Clemenceau*-class carriers. Like the extinct U.S. SPS-8 and -30, DRBI 10 uses a high-speed (Robinson) scanner to move its beam vertically. Work on this radar began in 1958, and each carrier was fitted with 2 sets; DRBI 10 was also installed on board 5 radar-picket destroyers, the missile cruiser *Colbert*, the training cruiser/helicopter carrier *Jeanne d'Arc*, and the missile trials ship *Ile d'Oleron*. A mobile land-based radar, Picador (TRS 2200), was developed from it (the prototype appeared in 1968). Data above are taken from the published details of Picador. Range on a fighter is said to be 100–140 nm.

◆ DRBI 23

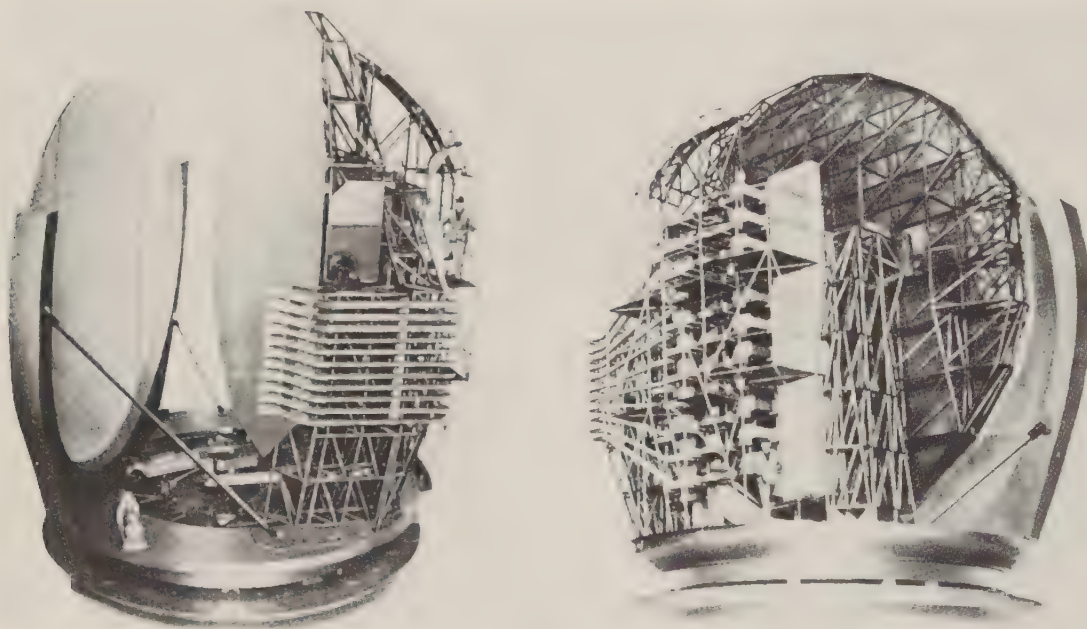
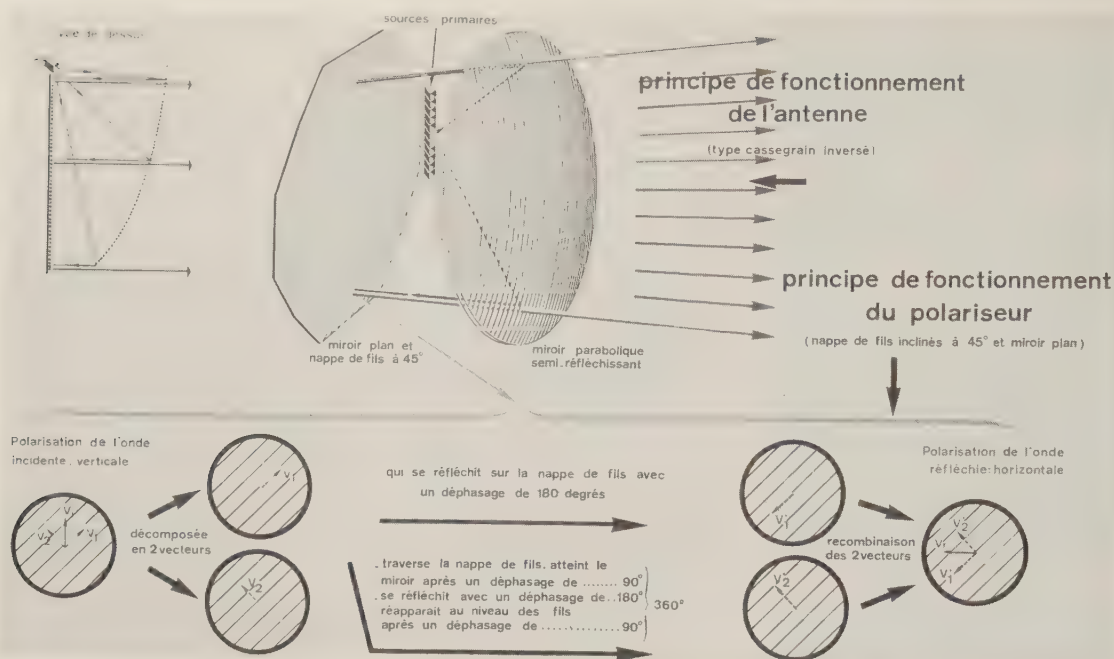
DRBI 23 is the large L-band radome-enclosed pulse-doppler antenna on board the missile frigates *Suffren* and *Duquesne*. The antenna is a big inverse Cassegrain reflector using stacked beams (monopulse height finding). The peak power of several megawatts is generated by a carcinotron fed through 6 amplifier stages. Plots are automatically extracted. A smaller version, DRBV 13, was formerly carried on board the destroyer *Aconit*.

◆ DRBJ 11

Band: S **Scan Rate:** 15 rpm
Antenna Dimensions: diameter 3 m (dish)

The Thomson-CSF electronically scanned radar uses a circular planar antenna covered by 1000–1500 phase shifters, which steer the beam in elevation (over a 60-deg angle) and in bearing. The antenna itself is inclined at a 15-deg angle and rotates inside a radome. Surveillance range is about 100 nm.

Development began in 1982. DRBJ 11 was not delivered because of ECCM problems. *Cassard*, therefore, had to be completed without the radar. The improved version, DRBJ 11B, is now in service on board the second C70AA ship, *Jean Bart*.



The antenna of the DRBI 23 radar, shown (bottom) without its radome. The array of stacked microwave horns produces the stacked beam used for monopulse height finding. (top) shows the principle of the antenna. The horns ("sources primaires") illuminate a semireflecting parabolic mirror. The mirror reflects onto a secondary reflector that twists the polarization of the beam so that it can pass through the first reflector. This type of folded optics makes it possible to achieve considerable focusing of the radar beam in limited dimensions, i.e., within a radome. Moreover, the elaborate feed does not block the main beam of the radar, an important consideration in any stacked-beam or monopulse system. This type of operation is typical of inverse-Cassegrain antennas, although most of them are not nearly as elaborate. (Thomson-CSF)

DRBI 23 occupies the big radome of the French frigate *Suffren*. The two 100-mm guns are controlled by the DRBC 32A forward of the bridge, and the navigational radar is DRBN 32. The small radar on the foremast just above the big radome is DRBV 50. (Dr. Robert Scheina)



◆ DRBN 32

Decca RM 1226 navigational radar (see the British section, below) is being superseded by Decca 1229.

◆ DRBR 51

DRBR 51 is the Masurca missile's C-band monopulse guidance-radar, roughly equivalent to the U.S. SPG-55. The missile is built in both beam-riding and semiactive versions; each radar group consists of a pair of antennas, a large-diameter tracker (which can also measure the deviation of the missile from the line of sight) and a small-diameter command transmitter. A third antenna generates the initial gathering beam. CW power is injected into the main dish for semiactive operation. Missiles are tracked at a wavelength of 5 cm and command signals transmitted at a wavelength of 7 cm; the tracking channels are designated "blue" and "yellow."

◆ DRBV 15 (Sea Tiger: TRS 3001)

Band: S **Beam:** $1.65 \times 8 \text{ deg cos}^2$ (to 45 deg)

Peak Power: 60 kW (1 kW average) **Gain:** 29.5 dB

Pulse Width: (i) 5.5 (ii) 12 microsec (compressed to 0.5) [In a later version, this radar produces 2 types of burst, each consisting of a 0.5-microsec pulse and then a chirp, either 7.5 or 15.5 microsec long, compressed to 0.5 microsec in either case.]

PRF: (i) 2200 (ii) 1100 pps

Scan Rate: 12 or 24 rpm (also given as 15 or 30 rpm)

Antenna Dimensions: 4.54 m **Antenna Weight:** 675 kg

Sea Tiger is a combined surveillance radar for medium and larger ships, its design emphasizing a low false-alarm rate to permit automatic tracking. The radar can carry out full air surveillance out to 170 km (55-deg elevation), surface surveillance to the horizon, and surveillance against sea-skimming missiles.

The chief antijam and anticlutter measures are coherent transmission/reception (which allows doppler filtering of clutter), true frequency agility (either pulse-to-pulse on the nondoppler channel, or randomly in short bursts of 10 pulses on the doppler channel), and use of 2 pulses at 2 different frequencies. The radar uses pulse compression and detects automatically using CFAR; and DRBV 15 can provide digital data to a weapons system. Doppler processing is by 4- or 8-point FFT.

There are 2 operating modes, each using 2 pulses: 1 long pulse with compression followed by 1 short pulse for short-range sur-



DRBV 15C. (Thomson-CSF)

veillance, at a different frequency. PRF can be jittered ("wobulated").

Free-space range on a 2-m² target (Swerling 3 case) is 110 km, on a 0.1-m² nonfluctuating target (probability of detection 0.9), 40 km. Actual performance depends upon the degree of surface clutter. Clutter-rejection ratios: 45 dB vs. ground clutter, 40 dB vs. rain and sea clutter.

Sea Tiger can be used as the search radar for a Vega fire-control system. Derived from the French Army Tiger air-search radar, Sea Tiger displaced the Saturne 2 naval air-search radar.

In November 1989 DRBV 15C (Sea Tiger Mk 2) was ordered for the new nuclear carrier *Charles de Gaulle*; this was the first order for the new version, which will also equip the new *La Fayette*-class frigates and will be tested on board the experimental ship *Monge*.

DRBV 15C (Sea Tiger Mk 2) has a roll-stabilized planar-array antenna (30 dB, 1.65-deg beam) with reduced sidelobes and better gain at high elevation (to detect steep divers). Free-space range is 100 km on a fighter and 50 km on a missile. The antenna is based on earlier work on planar arrays, for such radars as Arabel, DRBJ 11, and land-based types. The short-range 2D battlefield radar, TRS 2630, uses a very similar antenna technology. The new antenna is designed so that it can be coupled to an existing Sea Tiger transmitter/receiver assembly. However, Sea Tiger Mk 2 also employs a new 2-stage (TWT and CFA) coherent transmitter/receiver. The 2 stages allow it to operate at 2 power levels, depending on whether a voltage is applied to the CFA. There are 2 channels: air (long pulse and pulse compression) and surface (short noncompressed pulse). The transmitter is frequency-agile (pulse to pulse or burst to burst). There are 4 receiving modes: normal surveillance (60 nm instrumented range, 15 rpm, FFT4), long-range surveillance (90 nm, 15 rpm, MTI sine²), antimissile surveillance (30 nm, 30 rpm, FFT4), and antimissile surveillance in bad weather (30 nm, 15 rpm, FFT8). Here FFT4 and 8 refer to the use of 4 or 8 FFT doppler filters. By rejecting signals in 5 out of 8 doppler filters, the radar can filter out moving clutter (sea returns). The receiver improvement factor is 40 dB against sea and rain clutter. Air tracks are automatically initiated (ADT); they are also automatically associated with IFF returns. The system can carry up to 128 tracks.



DRBV 15 (Sea Tiger). (Thomson-CSF)

◆ DRBV 20

This large, high-powered (1-MW) P-band radar, with a flat mattress antenna (carrying 3 rows of dipoles), is found on board the cruiser *Colbert* and, formerly, on board the 2 French carriers. Pulse widths: 8 and 4 microsec (PRF 100 and 200 pps).

DRBV 20 was the first French air-search radar. One was installed on board the battleship *Jean Bart* in June 1949. This series also included the DRBV 10 surface-search set (installed November 1948) and the DRBV 30 navigational set (installed November 1948). The slightly later DRBV 11 was conceived as a dual-purpose (air/surface) search set but proved inadequate against jet aircraft, hence the development of DRBV 22. The other radars of this generation were DRBC 10 (surface fire control for 15-in guns), DRBC 11, DRBC 30, and DRBC 31 fire-control sets.



DRBV 20C on board the cruiser *Colbert*. (Sea Power)

◆ DRBV 22/23 (Jupiter: THD 1077)

Band: L **Beam:** 2.5×50 deg (3.5×16 deg csc²)
Peak Power: 2000 kW (600 kW) **Gain:** (26 dB)
Pulse Width: 2.5 microsec (1.3 or 4 microsec)
PRF: 450 pps (600 or 200 pps)
Scan Rate: 7.5 and 15 rpm (6 or 12 rpm)
Antenna Dimensions: 24.6 × 9.9 ft (DRBV 22: 5.18 × 2.13 m)

Jupiter is the export version of DRBV 23, and its characteristics are listed above (DRBV 22 data in parentheses). DRBV 22 resembled the U.S. SPS-6B externally; DRBV 22C introduced a new elliptical stabilized antenna, which in turn was combined with a new and much more powerful transmitter in DRBV 23. Development of this set began in 1961; its maximum range is about 160 nm. DRBV 22's range is about 70 nm.

Installations: DRBV 22A—*Aconit*, *La Galissonnière*, *Duperré*, *Du Chayla*, *Cdt. Rivière* class (in French, Portuguese, and Uruguayan service); 22C—trials ship *Ile D'Oléron*; 22D—*Jeanne d'Arc*; 22E—experimental ship *Rance*; 23B—*Clemenceau* class carriers.

◆ MARS (DRBV 24)

This 2D L-band radar, for the new *Floreal*-class patrol frigates, is related to the solid-state DRBV 26C and to Astral. MARS

uses a solid-state transmitter and employs digital pulse compression. It employs a 2-module transmitter (DRBV 26C has 16 modules), with a total of 32 (rather than 256) power elements. Instrumented ranges are 110 km for the air channel and 80 km for the optional surface channel. The MTI improvement factor is 45 dB for fixed echoes. The radar cabinet is fitted for (but not necessarily with) an extraction/tracking (ADT) unit to automate its operation. The 600-kg antenna (a modified version of that of DRBV 22) has a gain of 26 dB and scans at 12 rpm. The receiver is that of DRBV 15C.

This radar was announced in the fall of 1990. Its commercial designation is TRS 3015.

◆ DRBV 26 (Jupiter II: TRS 3010)/DRBV 26C (Jupiter IIS)

Band: L (23 cm) **Beam:** 2.5×8.3 csc² (to 50 deg)
Peak Power: 2 MW (average 2 kW) **Gain:** 29 dB
Pulse Width: 2.5 microsec **PRF:** 450 pps (fixed or staggered)
Scan Rate: 7.5 or 15 rpm **Antenna Dimensions:** 7.535 × 3.05 m
Antenna Weight: 1000 kg approx (total 1450 kg)

Work on an improved Jupiter, DRBV 26, began in 1972, for the new generation of missile ships. Range is said to be 150+ nm (on a 10-m² target). Protection against false alarms and clutter includes a low-sidelobe antenna, filters for protection against signals from nearby ships (high-frequency bands as well as the same band), multiple reception channels with wide dynamic-range receivers and anticlutter circuits, MTI for air surveillance, and a CFAR antijam receiver. The main improvement over Jupiter I may have been in reliability. Resolution is 400 m and 2 deg.

Jupiter IIS (TRS 3011) has a pulse-compression transmitter (130 microsec, compressed to 0.8) and is frequency agile on a burst-to-burst or pulse-to-pulse basis. The tube transmitter of Jupiter II is replaced by a solid-state transmitter consisting of 16 modules in parallel. Claimed reliability: MTBF for each module is 6060 hr, and for the entire transmitter, excluding the modules, 2180 hr. MTTR is 15 min for the transmitter (excluding modules) and 4.5 min/module; modules can be replaced while transmitting. Thomson-CSF claims that the new transmitter makes for a service life 6 times that of any earlier radar, and better than 99% availability. Operating voltages in the transmitter are only 50 volts since no single transmitter need be particularly powerful. Transmission frequency is very stable



DRBV 26C (Jupiter IIS). (Thomson-CSF)

because of the use of a frequency synthesizer, making it possible to use more sophisticated types of signal processing, such as doppler filtering (using FFTs). Air tracks are automatically initiated and followed; surface targets are automatically tracked after manual acquisition. The radar can track up to 64 targets automatically, handing over their coordinates to the associated CDS. A 2-m² fighter can be detected at 215 km (which can be increased to 250 km by adding an additional transmitter module to the 16). Instrumented ranges: 350 km at normal power, 200 km at reduced power (backup mode, 1/10th power, at which level no cooling is required), 60 km in optional surface-channel mode. The MTI improvement factor is 45 dB for fixed echoes. In this version the antenna weighs 1630 kg.

The first DRBV 26C was installed on board the frigate *Jean Bart*.

Growth possibilities for DRBV 26 include provision of a 3-beam antenna (for "2.5D" search capability) and an increase in transmitter power by a factor of 2 or 4. As of October 1990, it was not altogether certain whether the carrier *Charles de Gaulle* would be fitted with a developed version of this radar (DRBV 26D) or with a new radar (DRBV 27, presumably the Astral radar chosen as the long-range search element of the French version of the FAMS missile system). The RFP for the ship's L-band long-range radar is to be issued in 1991.

DRBV 26 is virtually the standard French large-ship air-search radar. The commercial Jupiter, which was carried on board South African frigates, had the same antenna as DRBV 26 but a different receiver.

◆ DRBV 31

This license-built Decca X-band navigational radar survives on board the destroyer *Du Chayla*.

◆ DRBV 50

The development of this low-flier/surface-search radar began in 1961. It equipped the *Jeanne d'Arc* and *Maille Breze* classes and was planned for the *Commandant Rivière* class (which is equipped with the DRBN 32 instead). This radar survives on board Portuguese *Cdt. Rivière*-class frigates, the *Jeanne d'Arc*, the cruiser *Colbert*, the old destroyer *La Galissonnière*, the *Suffren*, and the missile-test ship *Ile D'Oléron*.

◆ DRBV 51A

Band: C (5.5–5.8 GHz) **Peak Power:** 200 kW

Pulse Width: (i) 0.6 (ii) 1.7 microsec (DRBV 51A and 51B) (iii) 0.6 microsec (DRBV 51C)

PRF: (i) 1045–1090, 1165–1190, 1215–1245, 1280–1305, 1383–1393, 1500–1600, 1808–1830, 1960–2020, 2085–2145 pps (ii) 349–360, 420–440, 500–510, 540–580, 590–615, 675–715 pps (iii) 1013 pps staggered

Scan Rate: 24 rpm (DRBV 51A and 51B); 30 rpm (DRBV 51C)



DRBV 51 (top) and DRBV 26 (below) search radars on board the destroyer *Duguay-Trouin*. (L. Van Ginderen)

DRBV 51A is a low-altitude air-search and Exocet target-designation radar, a Triton with a higher-gain slotted-waveguide antenna (for longer range). DRBV 51A, most closely comparable to Triton II (see below), is the main radar of the *d'Estienne d'Orves*-class (A69 type) aviso. DRBV 51 and DRBV 51C are secondary air-search versions with conventional antennas.

◆ DRUA-33 (Calypso)

Band: X **Beam:** 3 × 8.5 deg **Peak Power:** 70 kW

Gain: less than 29 dB **Pulse Width:** (i) 0.15 (ii) 0.5 microsec

PRF: (i) 1500–3000 (ii) 500–1000 pps

Scan Rate: 12 or 24 rpm **Antenna Dimensions:** 1 m × 48 cm

Antenna Weight: 60 kg (total weight 450 kg)

Data are for Calypso III. Calypso II had a slightly greater gain and somewhat lower power. Calypso III has anticlutter processing for better range.

The DRUA-33 submarine surface-search radar of 1964 led to the Calypso export radar. Calypso III was developed in conjunction with the German IKL design organization, for Type 209 submarines. As such, it uses a nonpenetrating mast, with the scanning mechanism at the masthead.

Operating modes are continuous transmission, sector surveillance, short-time transmission (0.1 or 1 sec only), and silent operation with a dummy load. Scan modes are full 360 deg, sector (adjustable between 10 and 180 deg), short-time scan over 10 deg, or manual scan. In 1 version of Calypso, a separate range-only antenna is mounted on the attack periscope. Calypso II could detect a 10-m² airplane at 16 nm. The improved Calypso III can detect an ASW airplane flying at 8000 ft at 18 nm.

This radar is in service in 3 navies.

Calypso IV is built around a navigational radar and is intended to simulate merchant ships' radar signals. It has the same antenna as earlier radars of the series, but a new klystron (25 kW peak power) using 1 microsec and 50 nanosec pulses for long



The corvette *d'Estienne d'Orves* shows a DRBV 51A main search radar and a DRBC 32E fire-control radar atop her superstructure. The 2 light-colored circles in the after superstructure cover 2 torpedo-firing catapults. The small slotted waveguide immediately above the bridge is DRBN 32. (U.S. Naval Institute)

and short (high-resolution) ranges. Operating options are continuous scan, sector scan, burst, and receive-only. Range on a low-flying 10-m² target (i.e., a maritime-patrol aircraft) is 20 km (10.9 nm).

Calypso II is THD 1030, Calypso III is THD 3100, and Calypso IV is THD 3110.

Danish submarines use the standard Calypso antenna with Terma-supplied electronics, and for export Terma supplies its transmitters and receivers to HDW via Thomson-CSF, which combines them with the standard Calypso antenna.

The Calypso radars are descended from a series of specialized submarine radars begun in 1956 with DRUA-30.

◆ Arabel



Arabel radar. (Direction de Constructions Navales)

Arabel is the multifunction X-band radar for ASTER missile control. The planar antenna is inclined at 30 deg inside a radome, rotating at 60 rpm. The beam is 2 deg wide and can scan up to 70 deg in elevation. The transmitter can hop frequencies over 10% of its frequency range. Thus, the radar is a much shorter-range, higher data-rate expression of much the same technology as is used in DRBJ 11. Production antennas will use a lens antenna (Radant) to steer the beam, reducing the overall number of phase shifters from several thousand to about 100, and drastically reducing both cost and energy consumption.

The first development contract was announced in April 1988, with completion of a naval prototype scheduled for the early 1990s, to meet the SAAM schedule (service entry 1999). SAAM is a short-range system, and Arabel is designed to match, with a stated range of about 50 km against 0.5-m² missiles and 100 km against larger targets. The associated computer is to be able to conduct simultaneous monopulse tracking of 50 targets, and to direct 10 simultaneous engagements. Trials were scheduled for 1988–89.

Arabel stands for *Antenne Radar à Balayage Electronique*.

◆ Astral (DRBV 27)

This new 3D radar has been chosen as the long-range acquisition radar of the French version of FAMS. Astral is derived from DRBV 26C but uses a new planar-array antenna (weight 3500 kg) and scans 1 beam electronically in elevation from 0 to 45 deg (as compared to 2 beams in DRBJ 11). Mean power will be twice that of the earlier radar (5 kW compared to 2.5 kW), and maximum range on an airplane will be about 275 km [150 nm];



Astral. (Thomson-CSF)

missiles will be detected at 50 nm. Instrumental range is 400 km [219 nm]. The ADT has a capacity of 300 tracks. Astral is a digital pulse-compression radar using doppler speed filtering (i.e., pulse compression is by phase coding rather than by frequency, and the beam is elevated by phase shifters rather than by frequency scanning). Like DRBV 26C, Astral uses a solid-state transmitter for high reliability and availability. Its software, including that used for energy management, is written in ADA.

Coverage and other characteristics are compatible with those of Arabel, so that the 2 radars can work in tandem.

The commercial designation is TRS 3505.

◆ Calypso

See DRUA-33, above.

◆ Canopus

The radar version of this director was never used. For details, see the last edition.

◆ Castor I (TRS 3200)

Band: X **Beam:** 2.3 deg **Peak Power:** 175 kW
Gain: 37 dB **Pulse Width:** 0.4 microsec
PRF: 4000–8000 pps (stepped variation) **Antenna Weight:** 80 kg

Used with Vega fire-control systems in medium-sized ships, Castor I is a stabilized monopulse-MTI tracker. Maximum acquisition and tracking range is about 30 km. A 2-m² air target can be detected (PD 0.9) at 20 km; a 0.1-m² missile can be detected (PD 0.9) at 15 km. Range accuracy is 15 m between 200 m and 15 km, and angular accuracy is 0.5 mrad. Tracking accuracy (18 km, 2-m² fluctuating target) is 15 m and 0.3 mrad.

Castor was conceived as a replacement for Pollux, to track fluctuating targets more accurately. Castor II, which entered French naval service, has a Cassegrain antenna with a multi-mode feed behind the reflector.

There is a colocated television camera.

This director replaced Pollux within the Vega II weapons system. Development began in 1969.

For later versions of Castor, see DRBC 33 above.

◆ Jupiter

See DRBV 26 above.

◆ Neptune (THD-1040)

This C-band set was the original search radar of the Israeli missile boats, and it probably survives, at least on board some of the units exported to Chile and South Africa. Israeli boats have all probably been refitted with EL/M-2207 or -2208. Neptune seems to have been an alternate name assigned to a slightly modified Triton (it shares the same THD number, and Triton and Neptune were alternate names for the same sea god); no details specific to Neptune were ever published.

◆ Pollux (THD 1280, TRS 3220)

Band: X **Beam:** 2 deg **Peak Power:** 200 kW (90 W average)
Gain: 30 dB **Pulse Width:** 0.3 microsec **PRF:** 1500 pps
Antenna Dimensions: diameter 1.1 m **Antenna Weight:** 450 kg



The Ecuadorian missile boat *Quito* has a Triton air/surface-search radar on her mast (with an ESM array above it), and a Pollux fire-control radar. The mast platform just aft of the Pollux dish carries a Decca 1229, barely visible because its antenna is end-on to the camera. (U.S. Naval Institute)

A Thomson-CSF export conical-scan fire-control radar, Pollux was capable of acquiring and tracking a small aircraft at 16 nm. Accuracy was 1 mrad in bearing and 20 m in range. Tracking accuracy was 0.5 mrad and 20 m in range at 18 km (2-m² air target). Acquisition range on a 2-m² air target was 30 km. Conscan requires several pulses to define a target's angular error, and conscan can, therefore, introduce errors if the target fluctuates. Hence the development of Castor.

Pollux was the tracker of the original Thomson-CSF Vega weapons-control system. Pollux was not accurate enough to control heavy (100-mm) guns, had limited ECCM capability, and was, therefore, replaced by Castor II (0.3-mrad tracking accuracy).

Pollux users: Ecuador (*Manta* class) and Qatar (Combattante-III class).

◆ RODEO Naval

Band: S **Beam:** 6.5 deg csc² **Peak Power:** 0.1 kW
Scan Rate: 40 rpm **Antenna:** 105 × 80 cm

This ESD lightweight pulse-doppler radar is derived from the land-mobile Rodeo 2. It tracks 6–10 targets simultaneously (TWS mode) and can distinguish fixed- from rotary-wing aircraft. It is radome-enclosed and can be stabilized. RODEO is an acronym for *Radar d'Observation et de Designation d'Objectifs*; it is designed to detect and target low fliers. A moving

target can be acquired at 12 km, and a hovering helicopter beyond 8 km (with rotor motion detected beyond 6 km). The beam can be elevated or depressed within the range +45/–5 deg. Rodeo 2 is the army's mobile version; Rodeo 2S is an extended-range fixed version.

The original land-based version appeared in 1978.

RODEO is to be used on board the carriers as a target-acquisition radar for Mistral missiles.

◆ Sea Tiger

See DRBV 15, above.

◆ Triton (TRS 3030, THD 1040)

Band: C (5.3 cm) **Beam:** 2 × 22 deg
Peak Power: 250 kW (200 kW in early units)
Gain: 38 dB **Pulse Width:** 0.2, 0.5, or 0.7 microsec
PRF: variable over a wide range **Scan Rate:** 12 or 24 rpm
Antenna Dimensions: 2.5 × 0.4 m
Antenna Weight: 170 kg (350 kg if stabilized)



A Nigerian Combattante-IIIIB-class fast attack boat shows a Triton radar at her masthead, with a Castor II director; at the right, at the foot of the mast, is a Panda optical director. (U.S. Naval Institute)

This combined air/surface-surveillance and target-indication radar, for small- and medium-sized ships, was developed as part of the Vega system. Triton can shift both frequency and PRF as a counter-countermeasure. The antenna is not stabilized. Triton can detect a 2-m² air target at 30–45 km. Accuracy in range is 30 m. Work began in 1967, and the prototype appeared in 1968.

Triton users: Ecuador (*Quito* class), Greece (Combattante-IIIIN class and Combattante-II class), Libya (Combattante-II class), Malaysia (Combattante-II 4AL class), and Peru ("Daring" class and PR-72-560 class). See also Neptune, above.

◆ Triton II MTI (TRS 3035)

Band: C (5.3) **Beam:** 2 × 22 deg
Peak Power: 250 kW (average 200 W) **Gain:** 28 dB
Pulse Width: (i) 0.5 (ii) 1.0 microsec
PRF: Non-MTI mode: adjustable PRF: (i) 1000–2000 pps (ii) 333–666 pps
MTI: 3 staggered PRFs around 1820 pps
Scan Rate: 12 or 24 rpm
Antenna Dimensions: 2.3 × 1.4 m (includes pedestal)
Antenna Weight: 180 kg

Triton II MTI is a combination air- and surface-search radar intended as the primary search and target indicator for small ships, and as the target indicator for ships equipped with a long-range air-search radar such as Jupiter (DRBV 26). Detection range on a 2-m² air target is over 30 km.

The main features are a lightweight low-sidelobe antenna; a tunable-frequency (and adjustable-PRF) transmitter; an antijam (STC, CFAR) receiver; and a linear digital MTI, useful at ranges of up to 56 km, for clutter rejection. The MTI uses a 3-memory filter with a minimum blind speed of 340 m/sec (0.5-microsec pulses). The CFAR channel uses 1.5-microsec pulses. Clutter-rejection ratio: ground, 30 dB; sea (3 m/sec), 25 dB.

DRBV 51 is the French navy's version of this radar. It was also tested on board a German fast attack boat (1980).

◆ Triton G (TRS 3050)

Band: C **Beam:** 2.1 × 22 deg **Peak Power:** 8 kW **Gain:** 27 dB
Pulse Width: 6.5/12 microsec (compressed to 0.5 microsec) (A 0.5-microsec uncompressed pulse can be included in the burst for close-range surveillance.) **Scan Rate:** 40 rpm
Antenna Dimensions: 2.3 m wide **Antenna Weight:** 180 kg total



Triton G. (Thomson-CSF)

This C- (now redesignated G-) band medium-range air- and surface-search radar has a lightweight antenna so that it can be mounted at a masthead. Triton G uses pulse compression and a frequency-agile coherent TWT transmitter (for MTI, for clutter rejection). Clutter improvement factor is 40 dB. Detection range on a 2-m² target is over 19 km. The lowest blind speed is 800 m/sec. Up to 32 air and/or surface targets can be tracked automatically. Air target tracks are automatically initiated (ATD).

The signal-processing hardware of this radar duplicates that of Sea Tiger (DRBV 15).

The prototype Triton G was installed on board a German S148-class fast attack boat in 1986, and West Germany ordered 23 of these radars in 1987 (for the S148 class) to replace their existing Tritons. One ship of the class, *Storch*, had already been fitted with Triton II and Castor II for trials (1980). The other German fast attack boats all have Dutch WM27 radars.

◆ Triton S (TRS 3033)

Band: S **Beam:** 3 × 22 deg
Peak Power: 10 kW (average 250 W) **Gain:** 25 dB
Pulse Width: 2.7 microsec (doppler channel); 0.17 microsec as pulse-compressed; compression ratio of 10
PRF: 5380 pps (doppler channel); pulse compression: fractions of 5380 pps **Scan Rate:** 24 rpm
Antenna Dimensions: 3 m wide **Antenna Weight:** 215 kg

Triton S is a pulse-doppler development of the basic Triton. Triton S uses a crystal-controlled TWT and produces 3 frequencies for air search and 6 frequencies for surface search. Air-



Triton S (above Castor, on board a fast attack boat). (Thomson-CSF)

search frequency can be shifted on a scan-to-scan basis. Surface-search frequency can be shifted on a pulse-to-pulse basis.

Triton S is a combined air/surface-search radar, effective against sea-skimmers by virtue of its very high clutter-cancellation ratio (50 dB) and its high data rate (2.5 sec). Like several other recent Thomson-CSF radars, Triton S uses a coherent transmitter for doppler processing (16-point FFT), both to get target speed and to reject clutter. Using pulse compression on the nondoppler channel, the radar is also frequency agile on a scan-to-scan basis. The lowest blind speed is Mach 1.

Performance of the pulse-doppler channel: 1-m² (Swerling III case) at 26 km; 10-m² target (Swerling III) at 44 km.

Triton S users: Nigeria (Combattante-III class) and Tunisia (Combattante-III class).

◆ MRR

Band: C
Beam: 1.75 deg (azimuth). See below.
Scan Rate: 10 or 30 rpm

The Thomson-CSF Multi-Role Radar is intended as a Triton/DRBV-51 replacement; it is the radar element of the Vega-successor small-ship combat system now under development. It can also serve as the target-designation radar (self-defense radar) of a larger ship. There are 2 operating modes, surveillance (mainly to detect medium- and low-altitude targets, primarily for peacetime) and self-defense (all elevations fully covered with a high data rate, primarily for missile defense). Each mode is further divided into fine- and bad-weather modes. In the normal surveillance mode, the instrumented range is 70 km. The maximum altitude is about 25 km [about 80,000 ft]. The vertical beamwidth, then, is probably about 20 deg. In the self-defense mode (presumably using the higher of the 2 scan rates given above), the main low beam (instrumented out to 60 km) is supplemented by 2 higher-elevation beams, instrumented out to 40 km (high) and 50 km (medium); the maximum elevation is 70 deg. The intermediate beam probably extends from about 20 deg to about 30 deg. The brochure describes the radar as monolobe, so presumably the 3 self-defense beams are generated in sequence as the main beam scans up in elevation. However, the brochure can be read to imply that at least in normal surveillance operation the radar generates a single 2D fan beam and then switches to a pencil beam once a target has been detected (like Astral and the U.S. ITAS, for example). The surface-channel instrumented range is 40 km. The air channel uses long compressed pulses, the surface channel short pulses. Pulses can be transmitted in bursts. The coherent transmitter uses a TWT. In some modes the air-channel signals are Doppler processed (on a burst-to-burst basis) for better low-altitude performance

in clutter. MRR is an ADT radar programmed in ADA. It has a capacity of 64 tracks. Signals are horizontally polarized, and the antenna is roll- and pitch-stabilized.

The RAC alert and coordination radar is a ground-based equivalent.

◆ TRS 3405/3410

Band: X **Beam:** 0.24×25 deg (inverted csc² to -25 deg)
Peak Power: 200 kW **Pulse Width:** 0.05 microsec
PRF: 1300–3000 pps

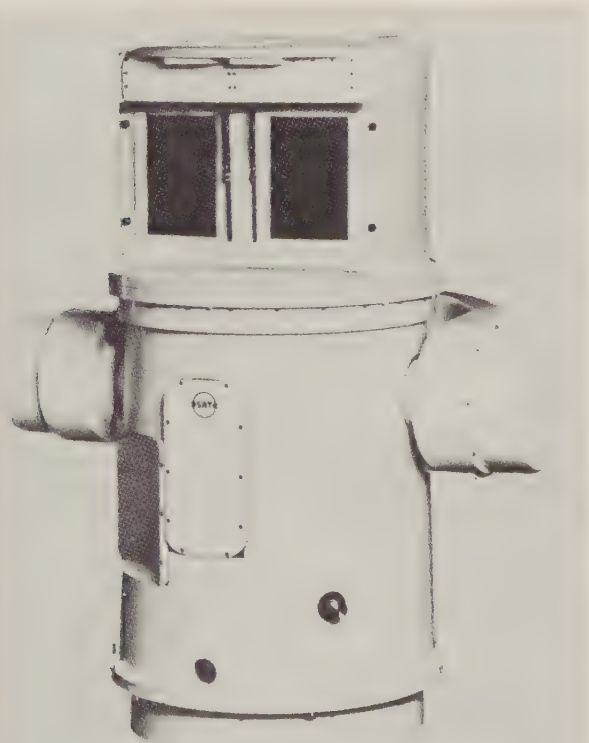
These coastal-surveillance radars are intended to sit atop cliff tops. TRS 3405 is fixed; TRS 3410, mobile. Sea clutter is reduced by frequency diversity, an adaptive detection-threshold, short pulses, and a very narrow beam. These radars can detect a wooden fishing boat (cross section 5 m^2) at 25 km.

TRS 3410 has a 5-m antenna producing a 0.5-deg beam.

OPTRONIC SYSTEMS

◆ DIBV 10 (VAMPIR)

VAMPIR was announced in 1980. It was developed by SAT to meet a NATO requirement for an IR surveillance sensor, analogous to the Canadian SAR-8. Providing all-around low- and medium-altitude surveillance, VAMPIR can provide threat warning and target acquisition to a CIC. For example, this system can be used as acquisition sensor for both chaff launchers and point-defense weapons such as Mistral. VAMPIR can also designate targets to an optronic fire-control system such as Totem, or to a radar fire-control system such as DRBC 32. The sensor head weighs 450 kg and scans at 60 rpm. VAMPIR covers both IR windows (3–5 and 8–14 micrometers) with 25-deg fields of view. An approaching missile would probably be detected at a range of about 10 km, and target designation could be accurate to within 1 mrad (bearing and elevation). The display is divided into 3 horizontal strips, 2 for the 2 IR windows and 1 for processed video. Both windows are shown because the differences between the pictures seen through them can provide valuable information. In films shown at Bourget Navale in 1980, the processed-video strip displayed a missile marker before it was apparent in either window, suggesting the degree to which



VAMPIR optronic sensor. In trials, VAMPIR reportedly detected sea-skimming missiles beyond the horizon by sensing the IR plumes rising out of the missiles' exhausts. (Société Anonyme de Télécommunications)

signal processing could enhance a target above the surrounding IR noise.

In 1980 it was reported that this sensor had detected a small helicopter at a range of 8 nm. In 1988 it was reported that VAMPIR had detected the heat plume of an Exocet before the missile came over the horizon.

VAMPIR (DIBV 10) equips the *Cassard*-class missile destroyers (C70AA type) and will equip the new nuclear carrier. DIBV 10 equips the 3 *Tourville*-class destroyers and will be installed on board other ships. VAMPIR means *Veille Air-Mer Panoramique Infra-rouge*.

In 1988 VAMPIR ML 11 was announced as a lighter and less expensive ($\frac{1}{3}$ – $\frac{1}{2}$ the price) of the existing VAMPIR. Operating in only 1 of the 2 IR windows used by VAMPIR, VAMPIR ML 11 is designed so that the operating wavelength can be changed relatively easily from range to range. The sensor is provided by SAT, the processor and turret by CSEE. Total weight is 80 kg, compared to 450 for VAMPIR, and scan rate is doubled to 120 rpm for better detection of sea-skimming antiship missiles. Elevation limits are $+60/-10$ deg, compared to a maximum elevation of 25 deg for the original VAMPIR. Target designation accuracy is 3 mrad, compared to 1 mrad for the earlier system. FoV is 6 deg. ML 11 is stabilized to within 0.4 mrad (limits: ± 30 deg roll, ± 10 deg pitch). Range in good weather should be about 15 km. The operator presets ML 11 in elevation (e.g., at 15 deg). Once it detects a target, it autotracks on each scan (TWS operation), changing elevation angle to match. As of October 1990, the prototype was in the factory, with trials expected in 1991.

In the fall of 1989 ITT Avionics agreed with SAT to apply new "multi-discriminant" algorithms developed by ITT to a new IR search-and-track device. The algorithms were tested at the U.S. Naval Surface Weapons Center, using a VAMPIR-like device.

◆ COTOL/COTROL/Totem/TRS 906

It appears that these competing lightweight optronic directors were never sold. For details, see the last edition.

◆ Lynx/PAON

CSEE's pedestal-mounted target designator is used in the Radop FCS, described below. The binocular sight (FoVs 19 or 5 deg at magnifications of 2.5 or 8) views the target via a gyro-stabilized mirror, which scans in elevation to acquire a target (limits $+65/-25$ deg). The maximum elevating speed is 1 rad/sec. Target coordinates are transmitted to the sight via the mirror gyro, and from the sight via synchros. The total weight is 120 kg.

When fitted with an image intensifier for night operations, Lynx is called PAON.

Aside from Radop applications, Lynx is installed on board the Kuwaiti TNC 45-class fast attack boats, the Omani *Nasr Al Bahr*, and the Moroccan frigate *LCol. Errhamani*.

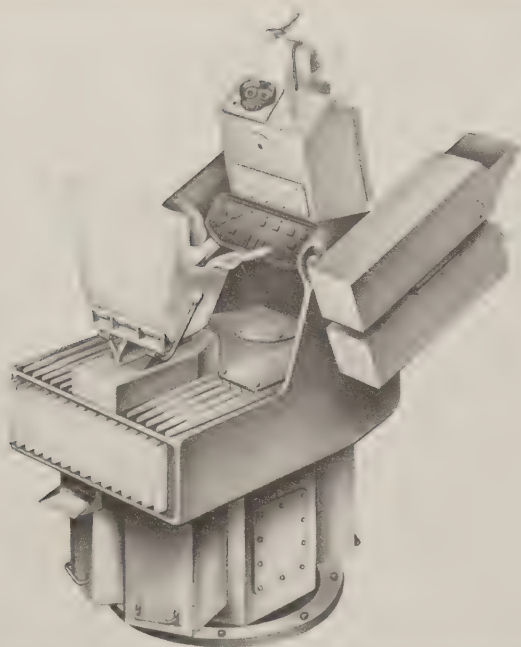
◆ NAJA/NAJIR

The manned optronic sight is used either as a primary director for a small ship or as a backup to a radar director. NAJA can accept designations from other sensors (e.g., radar, ESM, or IR). It carries a pair of $2\times$ binoculars and a standard or low-light television. The line of sight is biaxially stabilized.

Weight is about 500 kg (260 kg for the remote-control console), and elevation limits are -25 to $+70$ deg.

In 1982 CSEE announced a private-venture version, NAJIR, which adds an IR camera to the existing optical, television, and laser channels. The IR image can be observed either through the binoculars above deck, or on a below-decks monitor. Targets can be tracked automatically, by either television or IR, and the modernized system uses a digital computer in place of the analog unit of NAJA, for easy integration with any weapons system. The improvement was too substantial to be back-fitted to existing NAJAS. NAJIR was first shown publicly in 1986.

NAJA was developed from the earlier Panda power-driven



NAJIR director, with IR camera and laser range-finder alongside. (Compagnie de Signaux et d'Entreprises Électriques)

optical director and by 1987 had replaced the latter in many Third World navies. NAJA is used in the Radop FCS and on board the Malaysian landing ship *Jerong* and the Saudi *Al Madinah*-class frigates. NAJIR is used by the French navy (*Cassard* and *Floreal* classes), by the Royal Navy (as DMAC), and by 1 other foreign navy.

◆ Panda

CSEE's optical director was the basis for the later NAJA/NAJIR. It is used in 1 version of the Radop FCS. Panda consists of a power-driven platform carrying a stabilized LOS binocular sight and an operator's seat. It can be remotely controlled to bring it into line with a target designated by some other system, such as a search radar. The platform and the sight can search in elevation (limits $+65/-25$ deg, rate 0.5 rad/sec) and in bearing (1 rad/sec). Once the target has been acquired, the operator tracks it visually, and Panda transmits target angular velocities. It incorporates an on-board ballistic/parallax computer. Presumably, Panda is basically an elaborated Lynx power-driven in bearing. Its binocular sight has 2 alternative FoVs (3 and 9 deg, corresponding to magnifications of 8 and 2.66). Total weight is less than 330 kg.

Panda is the CSEE Model 71 director; NAJA (essentially Panda plus a television camera) is Model 74. Users include Bahrain, Belgium, France, Germany, Greece, Libya, Morocco, Nigeria, Peru, Portugal, and Spain. By 1976 more than 150 sets had been ordered.

◆ Pirana

This passive 2-color tracker is typically added to a radar or director. FoV is about 17 mrad for acquisition (optical aperture 170 mm), and Pirana can detect sea-skimming missiles at about 10 km. It is used as part of optronic directors such as Totem (see below). The detector is a nitrogen-cooled focal-plane array. Total weight is 50 kg. The current version, Pirana III, is carried on board the frigates *Cassard*, *Duquesne*, *Jean Bart*, and *Suffren*.

◆ SAS 90

SAGEM's low-cost, lightweight, optronic, antiaircraft FCS and sighting system for fast attack craft was shown at Bourget Naval 1990 (October 1990). It is intended for both ground (fixed and mobile) and naval applications. The gyro it incorporates (to measure target motion) can also be used to stabilize a naval gun mount. The target range is measured passively, apparently by

comparing the target motion with the assumed target speed. SAS 90 consists of a sight-display assembly (color LCD matrix projecting a generated image overlaid on the optical image and the measuring/stabilizing gyro); an automatic tracking and range-finding CCD camera (the picture is directly digitized for easier image processing); an electronics unit (which tracks and ranges based on the CCD camera image, which generates the LCD images and conducts lead-angle computations and firing calculations; it also transmits sight data outside the system); a monocular optical sight for ground firing ($5\times$ magnification and etched reticle); and an optional FLIR. The direct-view sight has a 30×30 -deg FoV. The target direction is measured by gyro or potentiometer. The telescopic sight has a 150-mrad FoV. The CCD camera has 2 FoVs (50×40 mrad or 80×100 mrad) with a resolution of 500 pts/line. The overall fire-control accuracy is 2 mrad. An optional IR camera operates at 8–12 microns, with 2 FoVs; it has an effective detection range, in average weather, of 5000 m [5500 yds].

◆ TRS 906 (Canopus Director)

Thomson-CSF's remotely controlled optronic director was announced in 1978 as part of the Canopus system. TRS 906 can carry an LLLTV and a laser range-finder. The maximum load is 40 kg on each side. TRS 906 is controlled in azimuth by a joystick. The angular tracking accuracy of the television is 2 mrad, and the director can continue to track by memory if the target is lost briefly. Elevation range is $+85/-30$ deg, and maximum speeds in bearing and elevation are 3 and 1 rad/sec, respectively (the director can slew through 180 deg in 1.8 sec).

When carrying only a television camera, the director weighs 120 kg (0.77 m high, 0.80 m in diameter), the associated servo box weighs 80 kg, and the control console weighs 300 kg.

The projected version with an MMW radar was never sold.

◆ VISION

This CSEE periscope is currently under development. When fitted with a fire-control computer, it can function as an optical fire-control device. The head is stabilized, with a 30- or 7.5-deg field of view and with a television camera (for auto-tracking) in the optical path. Magnification is $2\times$ or $8\times$, and elevation limits are $+70/-25$ deg. The head and periscope weigh about 125 kg, and total system weight is about 300 kg.

◆ VOLCAN/Narval/VIGY 50

SAGEM's electro-optical tracker is a lighter alternative to VAMPIR. It is the sighting element of the company's SAMOS close-in weapon (as first tested in 1984) and is also offered on a stand-alone basis. VOLCAN stands for *Viseur Optronique Leger pour Conduite d'Arme Navale*. It will probably replace the relatively bulky optronic elements of directors such as NAJIR. VOLCAN is compact because its optical elements are fixed, pointing up, and because its large stabilized mirror makes for a very narrow optical path. A single 200-mm, 2-axis, gyro-stabilized mirror (stabilized to within 10–20 microrads) in the rotating head reflects the optical path onto 2 aspheric mirrors fixed in the rotating head, which in turn reflect that path down into the combination of TV and IR cameras and a laser. The rotating turret weighs 80 kg [176 lbs]; total weight is 200 kg [441 lbs]. Dimensions are 1045 mm height $\times$ 950 mm width $\times$ 660 mm depth. VOLCAN was being offered in 1990 with a 200-mm [8-in] aperture. The elevation limits are $+80/-40$ deg; the rates of train and elevation are 180 deg/sec. The line-of-sight accuracy is 0.2 mrad (stabilization is better than 20 microrad). The angular-tracking rate is 1 rad/sec (2 rad/sec for fire control). The CCD TV camera operates at 0.4–1.1 micron (FoVs 2.5–10 deg using a zoom lens); the output is 525 lines at 60 Hz (625 lines at 50 Hz is available as an option). Resolution is 0.1 mrad. The SAT CT 11 IR camera uses a SPRITE detector (Stirling cooled) operating at 8–12 microns (FoVs 2.5–10 deg using a zoom lens); output is 525 lines at 60 Hz (625 lines at 50 Hz is available as an option). The laser operates at 1.06 microns (1.54 as an option), producing a 0.3-mrad beam with a peak power of 5 MW.



The Volcan optronic director. (SAGEM)

(pulse rate 2–20 Hz); maximum range is 20 km, and range resolution is 5 m.

Narval is a CSEE/SAGEM optronic FCS using the VOLCAN tracker. The below-decks control console carries the TV and IR monitors (one above the other), the joystick for target designation, and the associated FCS computers. TV/IR FoVs are 1.5×2 to 6×8 deg. SAGEM claims that aircraft will typically be detected at 12 km and will be identifiable at 7 km. Surface ships can typically be identified at 15 km. Narval is conceived as a replacement for the much heavier (600 rather than 200 kg) CSEE NAJIR, described above.

VIGY 50 is a smaller version of VOLCAN, announced at Bourget Naval in October 1990. SAGEM's modular, stabilized, panoramic sight (optronic director) is intended for small patrol craft. It incorporates an electronic calculator (to compute lead angles for transmission to a weapons-drive system). The turret carries a CCD camera for day operation, a thermal imager, and, optionally, a laser range-finder. Elevation limits are $+60/-20$ deg. The line of sight is stabilized within 100 microrad, and line-of-sight pick-up accuracy is better than 0.3 mrad. The day camera operates at 0.5–0.9 microns, with 2 FoVs (1.7×1.25 and 6.7×5 deg). The IR camera operates at 8–12 microns (2.7×2 and 5.5×4 deg FoVs). The laser operates at 1.06 or 1.54 microns. Overall dimensions: diameter, 350 mm; height, 450 mm (sight, 50 kg; electronics, 15 kg).

FIRE-CONTROL SYSTEMS

◆ Radop

CSEE's small-ship FCSs combined an S- or X-band surface-search radar (initially Racal-Decca Series 12), a CSEE optical/optronic director, an artillery-supervision unit, and a radar display. Any version could be extended by integration with a plotting table, radio-electronic navigation system, and/or an air-

search radar. The first 2 extensions were in line with Racal's CANE series of command/control systems. Different versions of Radop were distinguished mainly by the type of CSEE optical or optronic device they incorporated:

- Radop 10, for craft under 100 tons, controlling up to 2 guns, used Lynx and, typically, an X-band radar. This was the version in the Bahreini FPB 38 boats.
- Radop 20, controlling up to 2 guns, used Panda Mk 2 and a CTC vertical console with, typically, an S-band radar. Installations: the Argentine corvette (A 69 type) *Granville*, the Congolese *Pirana*, the Libyan PS700, and the Moroccan PR72.
- Radop 30, for craft over 100 tons, used a NAJA director and a dual-frequency radar, a CTC console, a remote-control console, and a ballistics calculator. The remote control was an integral tracker and processor. Installations: Algerian Brooke-Marine-type landing ships, Argentine A69-class corvettes (other than the *Granville*), the Malaysian *Sri Indera Sakti* class, the Saudi *Durance*-class replenishment ships, the Senegalese PR72M class, the Turkish *Girne*, and the Uruguayan *Vigilance* class.
- Radop 40, for craft over 200 tons, was intended to use the Totem fully automatic director (see the last edition for details) or at least NAJIR, but the only example installed (on board the Cameroon P48S-class patrol boat) used NAJA. This version used a CANE console and could control several guns.

The Radop series was first announced at Asian Defense Expo 80, although the first example appeared on board the Turkish *Girne* in 1976. Twenty-five systems were delivered to 11 navies before production ended in 1984.

GERMANY (WEST)

◆ KAE 7600/8600

Band:	X	S
Beam:	0.9×21	1.7×20 deg
Peak Power:	25	30 kW
PRF: (both)	2000 (to 1.5 nm)/1000 (to 12 nm)/500 (above 12 nm) pps	
Scan Rate:		23 rpm
Antenna:	8 ft	14 ft

Atlas 8600 radar was selected in 1989 for the Australian/New Zealand ANZAC (MEKO 200 variant) frigate. It is the most sophisticated of a series of KAE navigational radars and uses a 61-cm (24-in) raster-scan memory-backed screen. The minimum range setting is 0.3 nm, the next is 0.75 nm, and 7 further settings double that figure, to a maximum instrumented range of 72 nm (note the variation in PRF associated with the various range scales [listed above]). This radar can manually acquire up to 20 targets, automatically tracking them with data readout including CPA and TCPA (theoretical closest point of approach). The operator can set guard zones and limitation lines for automatic acquisition and tracking of up to 40 targets. Up to 40 navigation lines can be selected, and there is storage of up to 180 video maps of 40 elements each.

Atlas 7600 AC/TM is a simpler radar, capable of plotting 10 manually acquired targets semiautomatically.

◆ TRS Series

AEG's family of C-band surveillance radars is derived from the land-based TRM series. Although a major radar supplier to the German Army, AEG is only now (1988) producing naval radars, and only the simplest of its radars has been purchased by the West German navy. Presumably, the navy considers TRS-C a test case for AEG's digital radar technology, and orders for the more elaborate 3D radars (for example, for the new Type 123 interim frigate) may well follow. It was announced in the fall of 1990 that later units of the Danish Stanflex 300 series would be fitted with a C-band Telefunken TRS-3D/16 radar in place of the AWS-6 of the initial units. The German *Thetis*-class corvettes; Type 351 minesweeping drone-control ships; and Type 331, 340, 341, and 394 mine-countermeasures craft all have

TRS-N surface-search radars, which are presumably related to other types within the TRS series.

The other major German manufacturer of land-based radars, Siemens, has not produced any naval sets, although its pulse-doppler missile-warning radar reportedly inspired the U.S. development of SPS-58/65 (see below).

The basic land-based model is TRM-S, a mobile planar-array 3D radar employing phase-coded pulse compression; this model is capable of varying its PRF. The beam is steered in elevation by phase shifting, the large version of the antenna containing 4000 elements. Phase coding can be altered on a pulse-to-pulse basis, as can transmitting frequency. The receiver has 2 identical channels, 1 for sidelobe suppression. Signal processing includes MTI and CFAR. Targets are automatically detected and correlated with targets detected by IFF, and the output is a combination of raw and processed video. AEG claims that TRM-S can detect a 1-m² target at 100 km (probability of detection is 90%). Scan rate varies from 4 to 20 rpm, and up to 4000 targets can be displayed simultaneously.

TRM-S is unusual in employing polarization agility (horizontal, vertical, and circular), and the radar can vary its vertical beamwidth by a factor of up to 8. Polarization agility is useful because circular polarization limits the effect of rain but imposes a sacrifice in target cross section. Each row of the array is fed by 2 sets of feeds, each set having its own ferrite phase shifters. Each shifter feeds a series of polarized elements, and adjustment of the phase between each pair of structures produces the desired polarization.

TRM-S was first installed in 1979.

TRM-L is a 2D version using many TRM-S components but having a much less powerful transmitter (a 1-m² target can be detected at 46 km with 80% probability). TRM-L is the standard search radar for German Roland short-range air-defense missiles. TRM-L can change its PRF and frequency on a burst-to-burst basis, using doppler filtering to reject clutter, and using separate adaptive detection thresholds for each doppler channel (to defeat ground clutter, rain clutter, chaff, and noise jammers). As in the larger TRM-S, TRM-L automatically extracts radar targets (ATD). In addition, it uses doppler velocity data to calculate target velocity, thus improving overall tracking. Again, like the larger radar, TRM-L employs pulse compression to reduce the size of its resolution cell, uses sidelobe blanking, and has a jam detector. For TRM-L, the data rate is 2 or 4 sec (15 or 30 rpm), and the maximum elevation coverage is 60 deg (csc² beam).

The naval versions are:

TRS-S, a navalized TRM-S, intended for larger vessels. The size, capability, and weight can be gauged from TRS-S's replace-



TRS-S as it would appear on board a *Bremen*-class frigate. (AEG)



TRS-3D as it would appear on board a fast attack boat. (AEG)

ment of the current DA-08 2D radar on the German *Bremen*-class frigate.

TRS-MFR is a multifunction frigate or destroyer radar, currently under development, presumably for a future German air-defense frigate (Type 124).

TRS-3D is a smaller 3D radar adapted to fast patrol boats. It is presumably comparable in size to the Raytheon MBAR and to the Hughes TAS Mk 23, both of which have been considered for installation on board German attack boats. This is the version bought by the Royal Danish Navy. At Defendory in October 1990 it was described as an agile pencil-beam radar, which may mean that it can maintain 2 simultaneous scan patterns, like EMPAR. Presumably, it competes with the new French MRR. Like the French radar, it offers MTI Doppler processing, ADT, and clutter suppression; it is intended to detect both high divers and surface-skimmers.

TRS-C is a 2D C-band radar for medium vessels, using either the S-band TWT of the others or a magnetron. TRS-C has recently (early 1989) been ordered by the German government for auxiliaries ("fleet service boats").

◆ KR-75

This AEG-Telefunken X-band coastal radar was first installed in 1977, and by mid-1982 at least 9 had been sold. Peak power is 60 kW (average power is 0.07 kW, and PRF is 4800 pps), and the beam is 0.35 deg wide, scanning at 18 rpm. A typical aircraft is detected at 13.5 nm.

◆ OFLA-M

This optronic fire-control system is optimized to detect low fliers. A television tracker and laser range-finder are mounted on a pedestal above decks, the below-decks console showing range, elevation, and azimuth data. The television tracks automatically to provide a bearing rate for the ballistic computer. OFLA-M was designed specially for simplicity, and as a result the system initially lacked an IR sensor for night or bad-weather operation. However, when the contract was amended, an IR tracker and a laser range-finder were added, with a millimeter-wave radar available as an option.

The manufacturer was AEG-Telefunken, and the name means *Optronische Feuerleitanlage-Marine*. The German navy awarded the first development contract in 1975, for delivery in 1978 for the hydrofoils then planned. The hydrofoil was canceled, and the contract amended to allow for all-weather operation.

OFLA-M was one of several optronic fire-control systems competing for the German 1985 minehunter contract, and later for the S143A fast patrol boat and the Type 122A frigate. The others included Canopus (Thomson-CSF), Totem (CSEE), LIOD (Signaal), and the Swedish 9LV100.

INDIA

Bharat Electronics manufactures several radars, details of which are not available. RAWS is a version of the Signaal DA-05. RAWL is probably a version of LW-04, but with different parameters (pulse widths 2 and 4 microsec, PRFs 500 and 250 pps, respectively, range 180 km on a 1-m² air target). Each uses a magnetron with 6 spot frequencies. RAWS has digital MTI.

According to the Indian annual Defence Ministry report for 1988/89, an indigenously developed naval surveillance radar has been installed at INS *Dronacharya*, Cochin, to detect very fast sea-skimmers. Presumably, it is the prototype for a shipboard radar, and almost certainly it is a Bharat Electronics product.

Bharat also manufactures a navigational radar, Type 1245, which is fitted to the new corvette *Khukri*.

ISRAEL

RADARS

◆ AMDR

The Automatic Missile Detection Radar by Elta is associated with the Barak defensive system. The transmitter is a TWT, and the masthead antenna produces a csc² beam. Velocity coverage is Mach 0.3–3, and maximum instrumented range is 30+ km. Elta claims 90% probability of detection of a 0.1-m² target at 15 km; estimated range against a sea-skimming missile is 16 nm.

Operating in S-band, AMDR is a coherent doppler radar using DFT (discrete Fourier transform) and doppler filtering to reject slow-moving (less than Mach 0.2) targets and to measure a target's radial velocity from a single burst of pulses (i.e., during a single antenna scan). This mode of operation makes for TWS capability. Threats are automatically evaluated and ranked, and threat data passed to the Barak weapons system, target azimuth and speed being extracted by a microprocessor. The display may be a 16-in PPI, a digital scan converter (colored TV), or an alphanumeric display (CRT). The 64-kword data processor used for correlation and tracking is programmable.

The masthead weight is 220 kg.

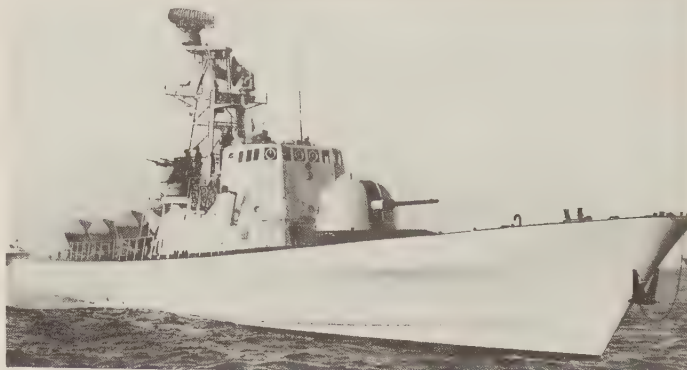
AMDR is presumably the successor to the earlier EL/M-2207. The first installation was probably on board the Singaporean missile boat *Victory*; this radar will also be mounted on board the experimental missile boat *Nirit* (Sa'ar 4.5) and almost certainly the new *Lahav* (Sa'ar 5). It is the target-designation radar for the Barak missile system, designating missile targets (including sea-skimmers) to the tracking and guidance radar. Besides its antimissile role, AMDR also has a role as a conventional air-search radar.

◆ Barak FCS Radar

The Elta X/Ka-band, pulse-Doppler, target-tracking and missile-guidance radar of the Barak point-defense missile system is coherent in both bands. At least as illustrated thus far, the typical ship installation employs 2 such radars for 360-deg coverage. The topside antenna weight is 700 kg, with 3 m² of deck space required internally for the radar and FCS. Missile elevation limits are +85/–25 deg. Published references to 1 radar handling 2 targets simultaneously suggest that this system time-shares its receiver/transmitter between 2 topside dishes.

◆ EL/M-2207

Band: S (3.1–3.3 GHz tunable)
Beam: 3.3 × 10 deg (csc² to 30 deg)
Peak Power: 425 kW (average 425 W)
Gain: 28 dB **Pulse Width:** (i) 1.4 (ii) 0.4 microsec
PRF: (i) 500–700 (ii) 1000–1500 pps **Scan Rate:** 12 or 24 rpm
Antenna Dimensions: 2.4 × 1 m **Antenna Weight:** 245 kg



An Israeli missile boat of the *Reshef* class, equipped with an ELTA air-search radar (either EL/M-2207 or -2208; both use the same antenna) and probably with an EL/M-2221 gunfire-control radar. The gun is an OTO-Melara 76 mm. Two single-barrel long-range chaff launchers are visible alongside the superstructure, under the bridge windows. Two box launchers (24 barrels each) for short-range chaff are visible, canted outboard, abaft and below the bridge. (U.S. Naval Institute)

Elta's air- and surface-search radar is part of the EL/M-2200 series of shore and naval radars, all of which use the same basic transceiver unit. The AT-101 antenna is stabilized, and the manufacturer, Elta Electronics, Ltd. (an IAI subsidiary), claims that its design is such as to require only 66% of the reflector area of a more conventional radar. Range is 30 nm against a 2-m² target. Resolution is better than 75 m for the short pulse, better than 230 m for the long pulse.

The AT-101 antenna is also used in the EL/M-2208 dual-band radar, and the antenna can be used in the L-band (7 × 20-deg beam) for IFF.

◆ EL/M-2208

Band:	S	X
	3.1–3.3 GHz tunable	9.345–9.405 GHz fixed
Beam:	3 × 10 deg	1 × 5 deg
Peak Power:	425 kW	25 kW
Gain:	28 dB	34 dB
Pulse Width:	(i) 1.4 microsec (ii) 0.4 microsec	0.25 microsec
PRF:	(i) 500–750 pps (ii) 1000–1500 pps	1000–1500 pps
Antenna Dimensions:	2.4 × 1 m	
Antenna Weight:	245 kg	

EL/M-2208 is Elta's air- and surface-search radar. S- and X-band transmitters (and the L-band IFF) share the same fully stabilized masthead antenna, for reduced total weight. The long pulse and digital MTI give long range and air surveillance; the short-pulse feature is useful for navigation. Estimated detection range of a jet fighter is 30+ nm, and surface targets can be detected out to the horizon. The PRF can be staggered for MTI without blind speeds.

Data above refer to the AT-101A antenna. In L-band, for IFF, this antenna produces a 7 × 20-deg beam (gain 17 dB). Scan rate is 12 or 24 rpm, and the antenna is stabilized. Antenna elevation angle can be remotely controlled. The antenna weight listed is that of the basic unit; as fitted for X-band operation it weighs 200 kg, and as fitted for S-band, 270 kg. Resolution is 1 deg in azimuth and 50 m in range.

The EL/M-2200 radar series was introduced about 1980, to replace the French Neptunes that had previously equipped Israeli warships. These radars are described as suitable for ships of over 250 tons, i.e., the *Sa'ars*. Radar volume and weight were reduced by exploiting IAI's experience with airborne radars.

This radar was conceived as a dual-purpose unit for small warships, which could not accommodate separate air- and surface-search radars. Air search requires relatively long wavelengths to achieve long range (reduced transmission loss); hence the S-band feature. On the other hand, surface search requires

a short wavelength (to reduce multipath effects), a narrow beam, and very short pulses (the last 2 to reduce clutter). IAI concluded further that the signal-to-clutter ratio is not a function of transmitted power, so the surface-search portion of the radar can operate at moderate power. The company argues that moderate power is an advantage to a ship operating in narrow waters such as estuaries (or just offshore), since under such conditions the radar may send and receive strong signals through its sidelobes, introducing ghosts and false targets. The choice, then, was S-band for air search (air alert), X-band for surface search, and L-band for the usual IFF. The same antenna is connected to 3 separate transceivers, and all data are collected in a single signal processor and then a single unified display.

The S-band beam is vertically polarized to reduce the effects of lobing, which creates holes in air coverage. On the other hand, the X-band beam is horizontally polarized to reduce the effects of sea clutter. In addition, the S-band beam can be circularly polarized to reduce weather clutter (circular polarization improves the signal-to-clutter ratio by 10 to 20 dB but reduces the target's radar cross section). The operator changes S-band polarization from vertical to circular by inserting a mechanical polarizer in front of the feeder connecting the radar transmitter to the mast waveguide.

To achieve high gain (to detect small surface targets), the designers selected a narrow pencil-beam shape. That choice in turn required stabilization, which was difficult to achieve within the 200-kg total antenna weight. The solution was to stabilize only the reflector rather than the complete antenna pedestal.

For air search, the choice was between a csc² beam-form and helical scanning. The latter was rejected because the radar would require several scans to complete an air search up to a given elevation angle and, thus, would lose data rate (a key consideration for a radar designed to detect fast attackers). The radar has 2 alternative scan rates, fast (for high data rate) and slow (for longer range).

The X-band transmitter is a frequency-agile (for ECCM as well as to reduce STA problems, to eliminate target fading, and to decorrelate sea and rain clutter) TWT, for pulse compression. For short-range detection, short noncompressed pulses are interlaced between the compressed pulses. The operator can vary both pulse width and PRF, and can synchronize PRF with the S-band transmitter (not necessarily in a 1:1 ratio). The system incorporates an adaptive (rather than manual) STC (sensitivity time control) to keep the threshold for displayed signals just above the sea clutter, taking into account the clutter's range and bearing. In at least some versions, the radar is not automatically frequency agile but instead can be tuned rapidly by hand knob, to use frequency-band diversity.

The S-band portion of the radar avoids clutter (such as chaff) by digital MTI, using a tunable magnetron capable of operating at multiple pulse widths and PRFs.

There is also a sidelobe blanker that uses a separate omnidirectional antenna and receiver.

Processing is by a combination of plot extraction and operator viewing of raw video. For example, in the surface picture a nearby land mass may appear to an automatic extractor (ATD) to be a mass of real targets (which will saturate the system's track memory), whereas the operator can ignore the land as irrelevant. Surface tracks are, therefore, manually initiated, although once they have been tagged, the system automatically tracks them (in TWS mode). On the other hand, air and sea-skimmer targets must be rapidly (hence automatically) detected and dealt with. The associated combat system, therefore, automatically detects and tracks air targets, conducts threat evaluation, and assigns weapons.

This radar equips Taiwanese Wu-Jinn II destroyers, which are armed with Hsiung Feng I missiles, similar to Gabriel.

As of 1980, well over 50 EL/M-2200 series radars were delivered or on order, many of them for export to unspecified customers.

◆ EL/M-2221

Elta's X-band fire-control radar is associated with guns and Gabriel missiles. The monopulse antenna is sometimes housed in a trainable, elevating barrel-shaped radome. There is an autonomous search mode, although targets can be designated from other sensors. Diameter is 1 m, and overall weight is 150 kg.

This radar probably originated as a reverse-engineered version of the Italian RTN-10X.

◆ EL/M-2216

Band: S (3.1–3.3 GHz, with 2.7–2.9 GHz optional)

Beam: 1.4 × 5 deg **Peak Power:** 425 kW

Pulse Width: 0.95 or 0.4 microsec (latter only in 2216)

PRF: fixed 1 of 4 or 4 staggered (900–1050 pps) plus short-pulse mode (1360 pps) in 2216 only

Scan Rate: 12.5/6 rpm

This coastal-surveillance radar is the EL/M-2215 ATC radar with a different (AT-102) antenna; data above (including antenna data) are for EL/M-2215 (AT-103 single-beam antenna). EL/M-2216 is a high-resolution dual-band (X- and S-band) system with a fast-scanning X-band component, for surface search (including small-target detection) and optional low-flier search. The 2215 radar has dual MTI, and the first blind speed is Mach 3. In addition to the single-beam antenna, -2216 has an optional dual-beam (high-low) type, AT-104. The same radar is also sold in a mobile version, EL/M-2220. It was developed from the earlier EL/M-2205.

EL/M-2216 is capable of detecting ships at a range of 20 nm.

OPTRONICS

◆ GSSS-1A1

The Gabriel Stabilized Sight System (GSSS) by Tamam (which produces the pedestals of the Elta radars) entered Israeli navy service in the early 1980s. The upper mirror of the periscope is gyro-stabilized, and the system has dual magnification (10×, 2.5×, corresponding to 5- or 20-deg field of view). A laser or IR detector can be mounted in parallel, and the system is designed for integration with an LLLTV. Tracking rate is 30 deg/sec in azimuth or elevation, and elevation limits are +60/–30 deg. Total weight is 65 kg.

◆ MKD 600

Tadiran's gyro-stabilized daylight television camera is suitable for use on board ships and helicopters. It uses a 40/400-mm focal length zoom lens (field of view 15.7 down to 1.57 deg), and can use a 60/600-mm lens. Acquisition range on a tank is 29 km, and the vehicle can be identified at 3 km. As of mid-1989, MKD 600 had been exported to 2 countries, and a publicity photograph showed it on board the hydrofoil *Shimrit*.

The earlier MKD 400 is used on board the Pioneer UAV.

◆ MSIS

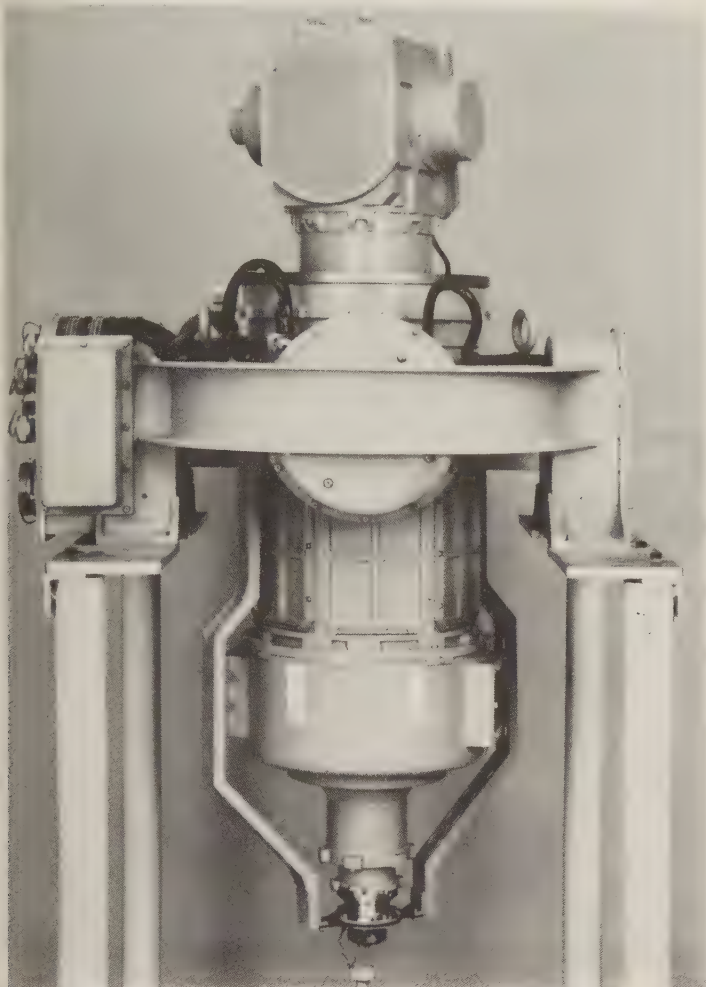
El-Op's Multisensor Stabilized Integrated System carries 3 sensors (FLIR, television, and laser) in a 4-axis stabilized spherical turret. The associated command/display unit incorporates a video tracker and can control guns of up to 76-mm caliber. The laser ranger has a minimum range of 300 m. Angular coverage is +85/–15 deg, and maximum slew rate is 60 deg/sec. Line-of-sight stabilization is within 20 microrad. Fields of view are 25.7 × 9.2, 7.4 × 5.5, and 2.1 × 1.57 deg.

El-Op claims that the FLIR can detect a missile boat (4 × 6-m target, presumably head on) at 17,000 m and recognize it at 8200 m; the FLIR detects an aircraft (2.5 × 4-m target) at 16,000 m and recognizes it at 5900; and it detects a dinghy (1.5 × 1 m) at 6500 m and recognizes it at 2100 m. Corresponding figures for the daylight television camera are: missile boat, 12,000/6500 m; aircraft, 9000/5000 m; and dinghy, 6500/3500 m.

Turret diameter is 550 mm; turret height, including pedestal, is 650 mm. The turret weighs 60 kg, and total system weight is 100 kg (220 lb).

MSIS was ordered by the Israeli navy in 1988.

◆ SPIRTAS (DS-35)



DS-35 SPIRTAS (Shipboard Passive IR Target Acquisition System) sensor head. (E1-Op)



DS-35 console. (E1-Op)



MSIS turret on board a patrol boat. (E1-Op)



MSIS command and display unit. (E1-Op)

The details for this IR target-acquisition system by El-Op were first published in 1982. SPIRTAS is primarily a sea-skimmer detector, operating in the 3–5 micron band. The 120-kg mast-head sensor unit is 120 cm tall and 80 cm wide and houses a stabilized scanning head. The CRT in the CIC console can show 3 alternative displays: a low-resolution picture of the overall scene, an enlarged thermal display, and a special auxiliary display showing the intensity (i.e., heat) behavior of selected targets as well as the target data transmitted to other shipboard systems. Scanner elevation limits are $+20/-2$ deg, and a full 360-deg scan takes 8 sec (1.25 sec in the antimissile mode). The accuracy of target data is within 7 mrad. The detector is an InSb multi-element array, cooled to 77 deg Kelvin.

ITALY

RADARS

Selenia uses the prefixes RAN (*Radar Avvistamento Navale*, or naval research radar), RAT (*Radar Avvistamento Terrestre*), and RTN (*Radar Tiro Navale*, or naval fire-control radar) for its radars. The letter in the suffix generally indicates the frequency range, at least for recent radars (e.g., RAN-10S operates in S-band).

RAN-2C, -7S, -13X, and -14X, which are all listed in many reference books, were experimental sets that did not enter production.

◆ BPS-704

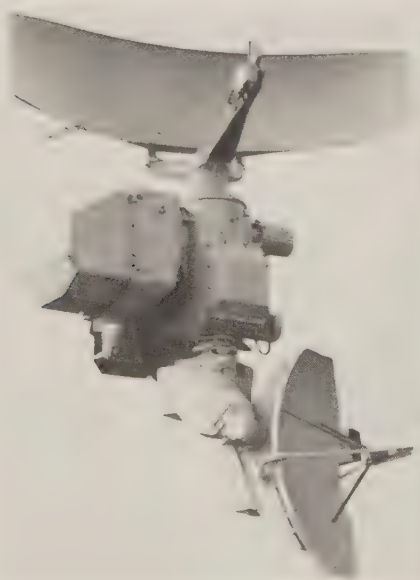
See 3RM Series below.

◆ SPN-703

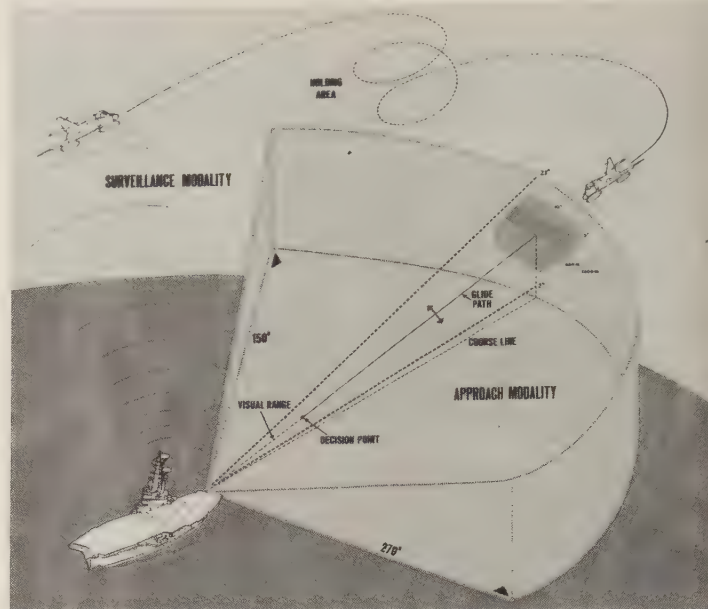
See 3RM Series below.

◆ SPN-720

This combined carrier-landing radar was initially supplied to Argentina for the carrier *25 de Mayo*, and then to the Italian navy for the carrier *Giuseppe Garibaldi*. SPN-720 was developed by linking the SPS-702 search radar with a new tracker. This radar, developed by SMA, was announced in 1984. The radar covers the 150–270-deg sector abaft the ship, and the glide path is adjustable between 2 and 21 deg. Search range is about 15 nm; approach-control range is about 8 nm. Aircraft can be detected at altitudes up to 2000 m [about 6600 ft]. This radar is the only current Western alternative to the U.S. SPN-35, and it is shown as installed on board the Argentine carrier *25 de Mayo*.



SPN-720 carrier-controlled-approach radar. Search range is about 15 nm; approach-control range is about 8 nm. Aircraft can be detected at altitudes up to 2000 m (about 6600 ft). (SMA)



Coverage of the SPN-720 carrier-controlled-approach radar. The only current Western alternative to the U.S. SPN-35, SPN-720 is shown as installed on board the Argentine carrier *25 de Mayo*. (SMA)

◆ SPN-728

SMA's X-band surface-search radar uses a high-gain double-curvature antenna with csc² vertical cover; SPN-728 can be used for helicopter control. This medium-power X-band radar is supplied with several alternative roll- and pitch-stabilized antennas. There are 4 alternative pulse widths, and the display is raster- rather than rotating-scanned, partly so that the radar can use low-cost television-type monitors as repeaters. Targets are automatically detected.



SPN-728 antenna, for navigation and surface search. This medium-power X-band radar is supplied with several alternative roll- and pitch-stabilized antennas. There are four alternative pulse widths, and the display is a raster rather than a rotating scan, partly so that the radar can use low-cost television-type monitors as repeaters. Targets are automatically detected. (SMA)

◆ SPN-748

Gem Elettronica's X-band navigational radar for large ships uses a 10-in CRT. This radar is used on board the training ship *Amerigo Vespucci*, in 2-antenna form.

◆ SPN-749

Gem Elettronica's navigation radar for the carrier *Giuseppe Garibaldi* consists of a master antenna at the bow and a slave antenna at the stern, for 360-deg coverage that does not interfere with the flight deck. Both antennas operate in X-band (9345–9405 MHz with peak power of 20 kW), and both antennas feed a single PPI.

◆ SPN-753(V)

Gem Elettronica's raster-display ARPA navigation radar was announced in 1989. Up to 50 targets, including fast (600-kt) aircraft, are auto-tracked. They can be auto-acquired, or up to 20 can be manually acquired. Each tracked target is assigned a 2-digit tag, and data for each target can be read out: bearing and range, course and speed, CPA, theoretical CPA, latitude, and longitude. The display also shows alert and failure signals. The display can be either a ship-centered or off-centered PPI. The color display (1280 × 1024 pixels, 4 bits per pixel) can show video maps (including those drawn by the operator) and alpha-numerics as well as raw video. There is a data window (alpha-numerics) to the right of the radar image. The system can carry up to 200 target-identification symbols, as well as a selectable alert zone. The radar image can be zoomed, and it can also be frozen. Because SPN-753 interfaces with navigational systems such as GPS and Loran, own and target positions can be associated with their latitude and longitude. Both 19- and 26-in displays are available.

The commercial equivalent appears to be GEMANT 2(V)1, which uses 6-, 7.5-, and 9-ft antennas and has alternative 10-, 25-, and 50-kW transmitters.

SPN-753 can feed Gem's SSN-752 automatic tactical table.

Gem also manufactures an SPN-751 navigational radar, apparently the last of its line not to incorporate a digital scan converter (the company makes a scan converter for SPN-748 and -751).

◆ SPQ-2 (and MM/SPQ-701 and SPS-702)

Band: X **Beam:** approx 0.6 deg wide **Peak Power:** 180 kW
Pulse Width: (i) 0.15 (ii) 1.5 microsec
PRF: (i) 2500–3000 (ii) 450–550 pps
Scan Rate: fast rotation (40 rpm) available as option
Antenna Dimensions: approx 3 m wide

Data listed are for SPQ-2.

SPQ-2D operates with alternating 1.0- and 15.0-microsec pulses at a peak power of 60 kW, scanning at 15–20 rpm. This is the version on board Canadian *Iroquois*-class destroyers.

SPQ/SPS-701/702 operates in 2 modes, tactical (180 kW, 8450–9220 MHz, frequency-agile, with 0.3-, 1.0-, and 1.6-microsec pulses) and navigational (50 kW, fixed frequency between 9440 and 9500 MHz, 1.1-microsec pulses). PRFs: navigational, 1000 or 1028 pps; tactical, 593–594, 622–623, 837–839, 934–936, 1000–1004, 1036–1038, 1968–1984, 2034–2032. These radars scan at about 15 rpm.

This radar, produced by SMA, time-shares long and short pulses for both medium-range air and surface search and precise short-range navigational coverage. SPQ-2 is sometimes used for target designation. Users: Italian, Canadian (SPQ-2D in the *Iroquois*-class frigates), and Venezuelan (SPQ-2D in *Constitution* class) navies. Options include fast antenna rotation (up to 40 rpm), MTI with an L-band system using the same antenna to detect low fliers, and a transponder. Both stabilized and non-stabilized versions exist. The current variant is SPQ-2F. This radar should not be confused with the U.S. SPQ-2, an obsolete (and extinct) missile-control set for the Regulus surface-attack missile.

SPQ-701 and SPS-702 are developments of the SPQ-2. SPQ-701 is the radar of the *Sparviero*-class hydrofoil; SPS-702 is for *Maestrale*-class frigates. The SPQ-701 antenna is a parabolic reflector with a narrow vertical dimension, for surface- and air-target detection. SPS-702 uses a broader antenna with a high-elevation component above the main reflector.

SPQ-3 is an S/X-band coastal-surveillance radar, the 2 units being mounted back to back; either can vary its angle of elevation from –5 to +15 deg. Presumably, SPQ-3 uses the same transmitter as SPQ-2.

◆ SPS-768

See RAN-3L below.

◆ SPS-774

See RAN-10S below.

◆ MM/SPY-790 (EMPAR)

Band: C (5.6 cm) (frequency agile over 10% of frequency)
Beam: 2.5 deg (scan angles ±45 deg in azimuth, +95/–25 deg in elevation)
Peak Power: 120 kW (10–12% duty cycle)
Scan Rate: 7.5 rpm (data rate 8 sec)
Antenna Dimensions: 1.5 m square
Weight: 2500 kg above decks, 5000 kg below



Mock-up of the Marconi-Selenia EMPAR antenna, RNEE, 1989. (Author)

EMPAR (the European Multi-Purpose Array Radar) is to be used in the Italian variant of the Franco-Italian FAMS missile system, for target search, acquisition, and tracking. The French equivalent is Arabel. Under development by Selenia and Marconi, EMPAR employs a square array of 2200 pin diode 4-bit phase shifters, tilted back at an angle of 30 deg. The beam is steered by phase scanning in both elevation and azimuth, while the antenna itself turns; it is also electronically stabilized. The designers chose a rotating rather than a fixed array for its simplicity and relatively low cost. They rejected elevation-only scanning (as in, say, SPS-48) because that would have made for too low a data rate. By scanning in both directions, the radar can vary its effective data rate on a mode-by-mode basis, with slow scanning for longer range and faster scanning for higher data rates closer in. Scanning in 2 directions also makes it possible for the radar to track targets by monopulse techniques, since adjacent beams can rapidly be formed.

The entire array is liquid-cooled, through a water rotating joint. The transmitter is a driven TWT, for frequency agility; the radar can automatically choose optimum frequency. The radar can operate at low or medium PRF, and its signals are digitally pulse compressed. Processing includes doppler filtering (using FFT and DFT), and targets can be tracked by monopulse, using adjacent beams. Higher frequency was attractive for good target discrimination and angular accuracy, for good low-level

coverage (multipath effects can be minimized at higher frequencies), and for good ECCM (required jammer power is proportional to the square of the frequency). However, a lower frequency was attractive to avoid interference with existing X-band radars, for better weather penetration, and for better clutter rejection. Selenia considered the choice to be limited to S- or C-band and chose S. The radar was originally designed to produce a 2.5-deg beam using a 2×2 -m antenna, and the reduction in antenna size reflected in the data given above presumably means that the beam is somewhat wider.

Selenia considered both active and passive arrays. An active array, with the transmitters in the array proper, was attractive because it made for greater efficiency (no losses between antenna and transmitter), hence for reduced overall IR emissions, reduced system weight (but with more of it concentrated in the antenna), better system reliability, and lower costs (thanks to the use of standardized components). However, it would be difficult to match phases between the different modules, the modules would produce heat that would have to be carried away, and the antenna itself would weigh more. Moreover, the promised industrial production of C-band active modules, which seemed imminent in the 1970s, failed to occur.

The design emphasizes high effective data rate, to track small fast targets that suddenly pop up at short range, and also nearly simultaneous tracking of numerous widely separated targets. The phased array forms one pencil beam at a time, but it can be shifted very rapidly from position to position, on a pulse-to-pulse basis. A 1987 account of the design (which described EMPAR as a 4D radar) listed requirements as medium-altitude detection at 50–100 km, and low-altitude detection at 20 km; the radar had to scan over a 120-deg angle in elevation (and over 360 deg in azimuth).

The radar management computer is a Selenia MARA series machine, programmed in ADA. Among its functions are translation of signal data from coordinates fixed in the rotating antenna to coordinates fixed in the ship. Actual signal processing is done by a separate processor based on the Marconi transputer array processor.

Operating modes: (i) volumetric search (VOS), which can be at short or medium ranges (SRS or MRS), in each case in elevation as well as azimuth; (ii) long-range search (LRS); (iii) high-priority tracking (HPT); and (iv) low-priority tracking (LPT). VOS is conducted at a data rate of 8 sec and consists of a horizontal search (HOS) and a vertical medium- and short-range search. The horizontal search is conducted over 144 directions, the vertical over 3191 directions (spread over elevation and bearing). HPT operates at a 1-sec data rate and can maintain 36

tracks. LPT operates at a 4- or 8-sec data rate, tracking up to 264 targets, but with lower-quality information. In main (VOS) mode, on every antenna rotation (i.e., every 8 sec), the radar scans once in each MRS and SRS direction; conducts 4 scans in every horizontal direction (HOS); updates each HPT target 8 times (effective tracking data rate 1 sec), then updates each LPT target once or twice (effective data rate 8 or 4 sec); and conducts 8 up-link transmissions to the missiles it controls. Maximum operating load is 300 aircraft tracks and 24 missiles under control. Estimated tracking accuracy is 3–5 mrad. Fully loaded, the radar spends 75% of its time searching for new targets, 20% tracking ones already detected, and 5% up-linking. The 3191 beam positions cover the entire hemisphere around the radar, over a 120-deg elevation sector passing through the zenith.

The original design was a back-to-back version (for twice the data rate) but also with about half as many phase shifters (in a 2-m square face).

EMPAR is designed to detect a 0.1-m^2 target at 50 km, a 2-m^2 target at 100 km, and a large aircraft (10-m^2) at 180 km. EMPAR is to be able to handle about 300 long-range targets and to track 50 of them well enough for missile engagement.

Selenia began studies of multifunction radars as early as 1965 and conducted a feasibility study in the 1970s. The company was awarded the development contract in 1986, for prototype completion in 1990, with sea trials in 1992 aboard a *Carabinieri*-class frigate. Marconi and Thomson-CSF joined the program. The Royal Navy is reportedly interested in a shorter-range (30 km) version for its Support Defence Missile System (see entry under Surface-to-Air Missiles). EMPAR was originally the Italian radar offered for the NATO frigate and for the associated NAAWS program, and its characteristics reportedly reflect NAAWS requirements.

In FAMS, EMPAR is associated with a longer-range surveillance radar, the French Astral. This radar was chosen in 1989 instead of the Selenia RA30 (presumably an S-band equivalent to EMPAR) and SLORA (a radar using existing Ceselsa modules plus Marconi Radar components).

◆ MLA-1B

Band: L **Beam:** 3.7×45 csc² deg **Peak Power:** 600 kW
Pulse Width: (i) 1.0 (ii) 4.0 microsec **PRF:** (i) 800 (ii) 200 pps
Scan Rate: 5 or 15 rpm

Data apply to MLA-1, the original version. Resolution in this version was 170 yd.

This L-band air-search radar was the first major Italian domestic set. It appeared in 1957 and was manufactured only for export; it survives only on board Portuguese *Joao Coutinho*- and *Dealey*-class frigates. It was also widely used in the Spanish navy, and on board Italian *Almirante Clemente*-class frigates

MLA-1B air-search radar antenna on board the Portuguese frigate *Joao Coutinho*. (Embassy of Portugal)



exported to Indonesia, Portugal, and Venezuela. Peak power is 250 kW, and maximum instrumented range is about 150 nm. The antenna is about the size of that of SPS-6, but its shape is quite different.

The manufacturer, Microlambda, merged with SINDEL in 1959/60 to become Selenia. The company produced 2 other radar series, navigational sets (MLN) and fire-control sets (MLT), the latter based on U.S. Mk 26 and Mk 39 radars. The MLTs were distant forerunners of the current Orion series.

◆ RAN-3L (MM/SPS-768)

Band: L **Beam:** 2.15×9 deg plus csc² **Peak Power:** 135 kW
Gain: 30 dB **Pulse Width:** 78.4 (compressed to 1.6) microsec
Scan Rate: 6 rpm
Antenna Dimensions: 7.56 × 3.65 m [24.9 × 11.8 ft]



RAN-3L (SPS-768). (Selenia)

The Selenia large-ship search radar was developed for the Italian Defense Science Technical Committee and the Italian navy. RAN-3L is one of a range of such radars, the suffix indicating the frequency band. Rated maximum range is 150 nm (100+ nm on a fighter). Range accuracy is 70 m, and angular accuracy is 0.4 deg. The transmitter is frequency agile, and the receiver uses doppler processing for MTI. The waveform is multipulse coded, as in RAN-10S (see below). Maximum range can be increased to 160 nm by using dual-frequency diversity (to overcome the problem of STAs); range is slightly shorter with only 1 channel. The antenna is designated G12.

RAN-3L began in May 1966, following a navy proposal, as an Italian government research and development project (CTSD MM-9) for an early-warning radar with stringent anticlutter and

ECCM requirements. Selenia was chosen on the basis of its work in ground radar. A contract was signed in 1968; the defense ministry R&D organization (CTSD) paid for the breadboard version and the first prototype, and the Italian navy for 4 production prototypes, 2 of the bichannel and 2 of the mono-channel versions. The project included Selenia's development of its own pulse-coding technique and also BITE. The breadboard model was completed in 1972, and 3 years later the prototype was tested on board the test ship *Quarto*. Operational tests were completed in November 1975, in the Gulf of Gaetta, against F-104S and T-33 aircraft.

This radar in its 2 versions replaces earlier U.S. types (SPS-12 and SPS-40) on board Italian cruisers and the *Audace*-class destroyers, and RAN-3L is the 2D air-search set of the carrier *Giuseppe Garibaldi*. However, this radar was considered too heavy for small and medium ships. A new lighter radar, RAN-10S (MM/SPS-774), was, therefore, designed for the *Lupo*-class frigates, using substantially the same technology. RAN-10S is described below. Selenia also used some of the same technology in RAN-11L, which was intended for small warships and patrol craft.

◆ RAN-10S (MM/SPS-774)

Band: S **Beam:** 1.5×17 deg (coverage to 60-deg elevation)
Peak Power: 140 kW **Gain:** 28 dB
Pulse Width: 20.8 (compressed to 0.4) microsec
PRF: about 900 pps **Scan Rate:** 15 or 30 rpm
Antenna Dimensions: 4.3 × 0.7 m [14.1 × 2.3 ft]

This radar, derived from RAN-7S, was introduced in 1980 and is intended for frigates and corvettes. RAN-10S is installed on board *Lupo*-class frigates of the Italian, Peruvian, and Venezuelan navies. Maximum unambiguous range is 90 nm; effective range, about 40 nm on a fighter. Range accuracy is 20 m, and angular accuracy is 0.35 deg. The transmitter is frequency agile (sweep to sweep), and the receiver uses doppler processing for MTI. The processor includes CFAR.

RAN-10S was an early application of pulse coding, an operation in which bursts of related pulses are transmitted in place of the usual single pulses. Pulse coding was adopted to achieve a combination of sweep-to-sweep frequency agility (for antijam performance) and doppler filtering (for MTI and clutter rejection). The idea was to filter on a single-sweep basis, then shift the filter criteria for the different frequencies used on the next sweep. Matched filters tuned to different doppler frequencies can directly reject clutter on each sweep. The interval between bursts determines the maximum unambiguous range, just as the interval between pulses determines that range in a conventional pulsed radar. As with pulse compression, the use of a burst of pulses reduces peak power but maintains sufficient average power for the radar to achieve a reasonable chance of detecting a target at long range. Each pulse within the burst requires its own doppler filter, and it is, therefore, impractical to use too many pulses. However, the use of only a few pulses per burst also limits the effective pulse-compression ratio, and a high pulse-compression ratio (since it provides, in effect, shorter pulses) makes for better range accuracy and also for better clutter rejection. The solution in this case is to code each pulse within the burst, so that it is (in effect) a pulse-compression pulse.

The returning pulses are subject to Fourier analysis, to extract doppler shifts. The measured shifts cannot exceed the spacing between the different frequencies making up the pulses. For the RAN-10S, 4 filters are provided, each with the maximum bandwidth (as determined by the pulse coding), and each shifted by that bandwidth so that they cover the whole bandwidth defined by the pulse spacing within the burst; this spacing (frequency) determines the range of frequencies within the pulses.

Scan-to-scan frequency agility is accompanied by scan-to-scan shifts in coding within the bursts, and that shifting in turn reduces clutter and makes deception jamming more difficult.

Each burst cannot be more than about 10% of the interval between bursts, to avoid excessive minimum range (dead time).



RAN-10S. (Selenia)



RAN-10S. (Selenia)

RAN-10S uses 4 pulses, and the ambiguity speed is set at Mach 3 (1000 m/sec), corresponding to a pulse spacing of about 50 microsec within the burst. Since that spacing implies a burst length of about 150 microsec, the burst repetition interval is probably about 1.5 msec, corresponding to a burst repetition rate of about 670.

RAN-10S shares some of the design concepts (and parts) of RAN-3L. The roll-stabilized antenna is designated G10.

A new stabilized SMA-7104 antenna was exhibited at Genoa in June 1986 (beam 1.5×15 deg, gain 28 dB, scan rate 15/30 rpm, and weight 960 kg).

◆ RAN-11 L/X and -12 L/X

Band: L and X (combined antenna)

Beam: (L) 6.6×16 deg, (X) 1.1×6 plus csc² deg

Peak Power: (L) 0.3 kW, (X) 135 and 180 kW

Gain: (L) 22 dB, (X) 35 dB

Pulse Width: (L) 20 microsec (compressed to 2.9), (X) 1.5 and 0.15 microsec

PRF: (X) 450–550 pps **Scan Rate:** 15 or 30 rpm

Antenna Dimensions: 8 ft wide



RAN-11 L/X. (Selenia)

Selenia/SMA's small-ship (hydrofoil) search radar operates simultaneously in L- and X-bands, using the X-band transmitter of the SPQ-2 and a new pulse-doppler L-band transmitter. The latter uses pulse compression. The antenna is cut horizontally, the upper portion reflecting in L- but not in X-band. Range accuracy is 160 m in L-band and 45 m in X-band; angular accuracy is 1.5 deg in L-band and 0.2 deg in X-band.

RAN-12 L/X is the same radar as the -11 modified with a higher-power (1.1 kW) L-band transmitter. Effective X-band range against a low flier is 20+ nm. At medium altitude, range (L-band) is 12+ nm for RAN-11, and 14+ nm for RAN-12. These figures are shorter than X-band ranges because the pulse-doppler L-band transmitter necessarily operates at a higher PRF.

Development of this system began in 1969.

◆ RAN-30S

Selenia's 3D S-band radar was under development as of 1989. It has 2 operating modes: long-range, with a low data rate; and short/medium-range, with high elevation cover and a high data rate. The radar employs a planar-array antenna, roll- and pitch-stabilized, and a frequency-agile transmitter (with staggered PRF) for pulse-compressed signals (uncompressed in a supplementary short-range mode). Targets are automatically detected and tracked, and processing includes MTI. There is a single transmitting beam, with multiple receiving beams (as in SMART, or the British Type 996). Accuracy: 50 m, 0.1 deg. Range on a fighter aircraft: 50 nm in short/medium-range mode, 100 nm in long-range mode.

◆ RAN-30X

The new (ca. 1987) Selenia shipboard air/surface-search radar for small- and medium-sized ships was derived from RTN-30X. RAN-30X can use a single- or multibeam antenna. The multibeam antenna has 3 feeds that time-share power, to provide 3 stacked beams. The horn for the uppermost beam can be tilted, to vary its angle, by remote control. The transceiver is fully coherent, for MTI, and can also hop frequencies between pulses. Pulse compression is used to increase range. Range accuracy is

25 m, and angular accuracy is 0.4 deg. The planar antenna is roll- and pitch-stabilized; it has a 3-m swing circle and scans at 15 and 30 rpm. There are 2 operating modes: long-range with low scan rate and coverage of medium elevation angles, and medium/short-range with fast scan and coverage of high elevations. The manufacturer claims that a fighter can be detected beyond 20 nm.

It is possible to arrange RAN-30X and RTN-10X so that both operate from the same transmitter and receiver, with separate displays.

◆ **RTN-10X/RTN-12X/RTN-16X/RTN-20X/RTN-25X (Orion)**

Band: X **Peak Power:** 200 kW **Pulse Width:** 1.5 microsec
PRF: 450–550 pps **Antenna Dimensions:** 1.4-m diameter



RTN-10X trackers of an NA-21 fire-control system. (Selenia)

The first of the Selenia Orion fire-control radars (RTN-10X, -20X, -30X), the RTN-10X conical-scan set employs the same X-band transmitter as RAN-11 L/X. Orion was designed for one-person operation and particularly for integration into the Albatros fire-control system. Orion can scan in 3 modes: automatic blind-fire, operator-assisted blind-fire, and area. In the first mode the radar searches around a designated point, then locks on and tracks without further assistance. In the second, less accurate data are available, and the tracker searches a larger area. If the radar fails to lock onto a target, the operator can steer the radar to the target position shown on the display. Area search is a horizon or sector search at low elevation, or near a passive ESM bearing. A television camera is bore-sighted to the radar for use under heavy jamming. Targets can be acquired out to 35 km.

The Orion series was developed beginning in 1958 by SINDEL, 1 of the 2 companies that formed Selenia in 1959–60. Series production of Orion RTN-10X began in 1972. It was almost certainly derived from the 200-kW Orion 250 of the original NA-9 FCS. Versions of Orion: Orion 3A/3C for the Argentine cruiser *Belgrano* (sunk in the Falklands), 7/A for the Italian *Doria*-class cruisers and *Pietro de Cristofaro*- and *Bergamini*-class corvettes, and 10/A for the Israeli Gabriel missile boats. Orion was redesigned from 1974 on for coherent operation using TWTs and then with digital technology. Versions: 10/XF (license production in Britain from 1975 on as Type 912), 10/X7 (Italian *Audace* class and hydrofoil *Sparviero* and Peruvian ships), 10/XP (with frequency agility, for the *Lupo* class), 20/X (first monopulse version, optimized for low-altitude tracking, initially for the *Maestrale* class), and 30/X (1980, with twice the power of earlier versions). Falco (H) is a version of Orion 30/X for land-based Aspide air-defense systems.

RTN-10X is the fire-control tracker of the British Type 21 frigate (the Royal Navy designates it Type 912), and it is the tracker of the Ferranti WSA 400-series export weapons-control systems.

RTN-12X is a monopulse version using a 1.2-m-diameter inverse-Cassegrain antenna (presumably the antenna of the RTN-20X and -25X). Beamwidth is 2.2 deg (gain 37 dB), and peak power is 200 kW (0.5 microsec pulses, PRF 2000 pps) at X-Band (8850–9350 MHz). Operating modes include pulse-to-pulse frequency-agile and random-PRF. Typical tracking accuracy on a frigate is 2 min of arc and 3 m; on an airplane (2 m²), 1.5 min of arc and 3 m. In frequency-agile mode the predicted maximum acquisition range against a 1-m² target (95% probability of detection) in free space is 40 km (21.6 nm).

RTN-16X, begun in 1969, is a private-venture development of RTN-10X.

RTN-20X/25X are further derivatives of RTN-10X. Development began in 1973, and they were intended particularly for the Dardo close-in weapons system (for automatic target acquisition and for spotting rounds). RTN-20X is a digital coherent monopulse radar (TWT transmitter tube) with special ECCM features (antinodding and anticlutter). Image effects (because of reflections off the water) are reduced by comparing received signals in sequence, to select the direct-path signal. RTN-20X acquires its targets at 2–6 nm. This radar can acquire and track a target (e.g., an antiship missile) fired by the target being tracked. The antenna is a Cassegrain with twist polarization. There are 2 different (selectable) pulse widths, and the radar hops frequencies on a pulse-to-pulse or burst-to-burst basis; special signal processing is employed to avoid multipath effects when tracking low fliers.

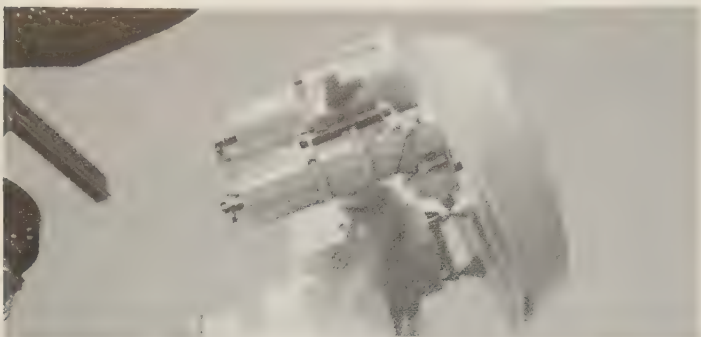
RTN-25X is a higher-powered version of the same radar. The 2 operating modes are long pulse (coded waveform) and short pulse (single pulse). This radar is part of the NA-25 fire-control system.



RTN-25X. (Selenia)

◆ **RTN-30X**

This automatic-target-acquisition and monopulse tracker was designed as part of the Albatros Mk 2 system. Range on low-level targets (such as sea-skimming missiles) in clutter is up to 8 nm. Features include MTI, frequency agility, a coded waveform (i.e., pulse compression), and jam alarm. As in the earlier Orions, there is special antinodding (i.e., antimultipath) signal processing. RTN-30X is the most powerful tracker of the RTN series and alone incorporates CW injection for missile guidance.



RTN-30X tracking radar of the NA-30 system. (Selenia)

This radar is part of the NA-30 fire-control system (*Garibaldi*, *Maestrale* class, *Minerva*-class corvettes, etc.).

◆ 3RM Series (BPS-704, SPN-703, etc.)

Band: X

Beam: 0.8–2.0 deg × 26 deg (shaped to 40 deg) (SPN-703: 1.2 × 25 deg, BPS-704: 2.2 × 11 deg)

Peak Power: (a) 7 (b) 20 kW **Gain:** BPS-704: at least 27 dB

Pulse Width: (i) 0.05 (ii) 0.15 (iii) 0.5 (iv) 1.5 microsec

PRF: (i) 6000 (ii) 3000 (iii) 1500 (iv) 750 pps (SPN-703: 5200, 2600, 1300, 650, respectively) **Scan Rate:** 25 rpm

SMA's surface-search radars have limited air-search capability. All use slotted-waveguide antennas, beamwidths depending upon dimensions. Two transmitters are available, as noted above.

The 3RM20-H version is the U.S. SPS-63 (see below) for the *Pegasus*-class hydrofoils; the Italian navy uses the 3RM7-250 (with a second 250-kW transmitter, for air search) for its experimental hydrofoil *Sparviero*. 3RM20 is MM/BPS-704, in the *Sauro* class; her sisters all have SPQ-701. 3RM28-B is MM/SPN-703. Components of this radar are also used in the



MM/SPS-702 antenna. (Segnalamento Marittimo ed Aereo)

MM/APS-705 and -707 and in the MM/APQ-706 (see airborne radars).

In 1984 SMA announced a new radar, SPS-702, with a smaller antenna mounted back-to-back with the first and tilted at an angle of 45 deg to the vertical. This antenna would provide something like the limited 3D cover of the Soviet Head Net C.

◆ HSS-1

SMA's X-band harbor-surveillance radar employs a single narrow-beam reflector. HSS-1 employs frequency and polarization decorrelation to distinguish targets in high-density shipping lanes within highly reflective land areas, such as estuaries. The radar is semimobile.

◆ PLUTO

Selenia's coast-defense radar detects low fliers and surface craft. Its mast is self-erecting. Characteristics: S-band (TWT transmitter), peak power 135 kW (phase-coded pulses, fixed or randomly staggered PRF), beam 1.5 × 4 deg (super csc² vertical coverage), tilt between +5/–2 deg, scan rate 12 or 15 rpm. The receiver includes an adaptive clutter attenuator. Signal processing techniques include an azimuth correlator (using a moving window and pattern recognition) and a jam strobe (to provide an unambiguous bearing on a jammer; but it is not clear how or whether signals entering through a sidelobe are eliminated). MTI is digital (first blind speed is faster than Mach 3). Plots can be extracted automatically in a form suited to narrow-band data-link transmission, using a programmable message format.

IFF is integrated into the antenna (using a secondary feed in the main horn).



Pluto coastal-surveillance radar. (Selenia)

◆ RAT-10S

This is a Selenia S-band coastal radar, operating at a peak power of 450 kW (500 pps); the 0.8-deg beam scans at 6 rpm. The magnetron transmitter is tunable, and the radar incorporates an MTI canceler. A mobile version, using a smaller antenna (which made for solid coverage up to 3000 m altitude), was designated RAT-8S. Its development began in 1965.

Selenia also produced several other coastal radars, including RAT-5C and Argos 800; the RAT series is also prefixed with the name Argos.

RAT-5C was a C-band radar with a lens antenna producing stacked beams; it had 2 transmitters, to provide frequency diversity. Development began in 1965, but it seems unlikely that it entered service.

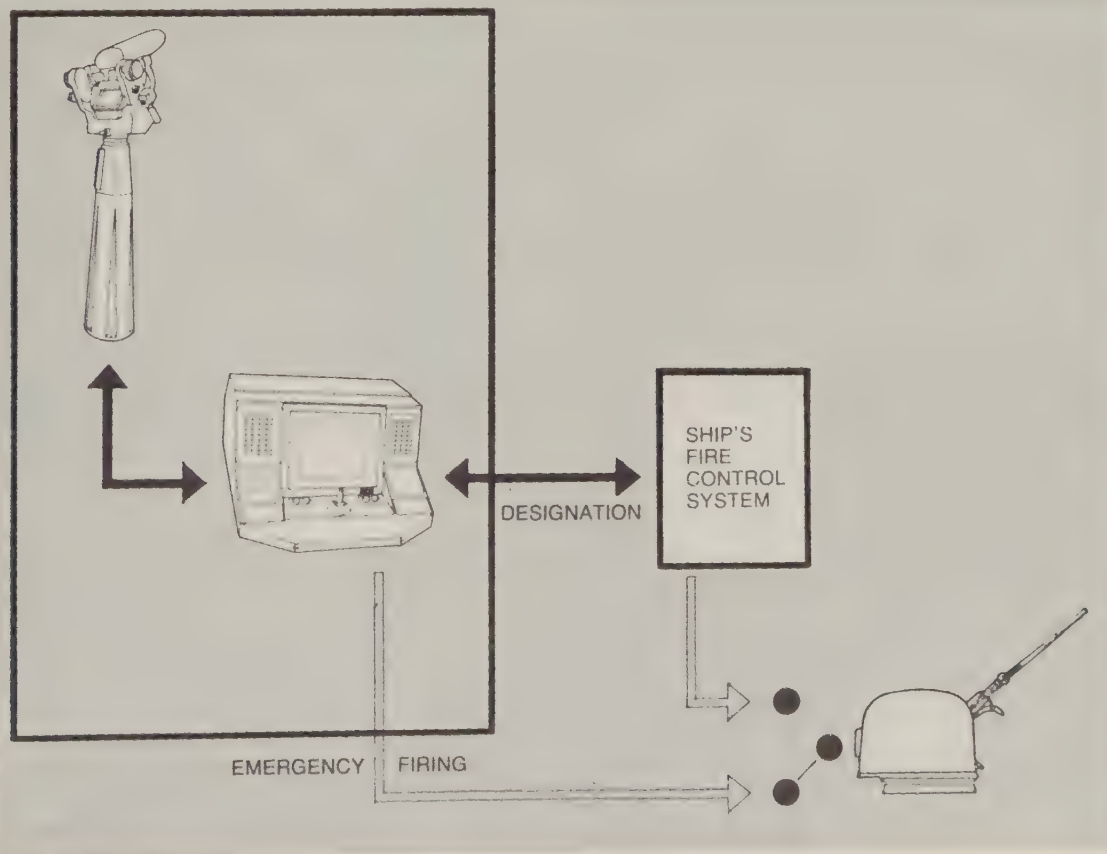


RAT-33 S/M coastal-surveillance radar. (Selenia)

◆ RAT-33S/M

RAT-33S/M is Selenia's medium-range coastal-surveillance (combined air and surface) radar. The radar operates in the S-band and has a dual-beam antenna (swing circle 5.5 m) and a scan rate of 15 rpm. Peak power is 450 kW, PRF is 1000 pps, and the 1.5-deg beam scans at 15 rpm. Accuracy is 50 m in range and 0.35 deg in angle. Polarization can be linear, circular, or elliptical. The radar samples its clutter environment in the absence of targets and automatically adapts its operation accordingly, distinguishing, for example, between clear areas and

The Medusa lightweight optronic director. (Selenia)



ground (or sea) clutter. RAT-33S/M appears to employ ATD techniques (with CFAR), and signal processing includes doppler filters and an azimuth correlator (to reject false targets behaving nonphysically). PRF is staggered to avoid STAEs. RAT-33S/M is designed for remote operation via a narrow-band data link.

◆ SPQ-3

SMA's S- and X-band transportable coastal-surveillance (air and surface) radar is related to its SPQ-2 naval radar (see above). The SPQ-3B version has a special mine-watching feature to detect the splashes of mines dropped by air into coastal waters or harbors. This radar employs 2 separate antennas: back-to-back reflectors fed by slotted waveguides in X-band for spotting and tracking, and a more conventional horn-fed parabolic reflector in S-band. Typically the 2 antennas are mounted on a single pedestal, the X-band units below the S-band. Both elements are frequency agile, and PRF is variable. Data can be transmitted in either analog or digital (ATD) form.

OPTRONIC SYSTEMS

◆ MEDUSA

This nonstabilized target-designation sight by Selenia/Elsag is used for remote control of light-caliber guns or as a building block for a more sophisticated system. MEDUSA carries either a twilight television camera or a low-light television camera, either feeding a 7-in monitor. The pedestal carries a target-designation button and an open-fire switch, and the console with the monitor carries a keyboard and a joystick, primarily to monitor the situation as viewed through the director.

◆ NA-12

The optronic backup director in the private-venture fast patrol boat *Saettia* was built by Fincantieri as a technology demonstrator.

◆ NA-16

This optronic director for the *Minerva*-class frigates, for the 76-mm gun, is used in conjunction with the Dardo E fire-control system.

◆ NA-18

NA-18 is Selenia-Elsag's optronic director. See fire-control systems, below.



NA-18 optronic fire-control console, showing a combination of synthetic video on the upper screen and a television image below. (Selenia)

◆ Galiflir

This lightweight (8 kg) FLIR is being developed by Officine Galileo. It uses an 8-element CMT Sprite detector, with serial-parallel scanning to produce a 512-line IR image, with a 4×26.7 — or 16×10.8 —deg field of view. Resolution in the narrow field is 0.15 mrad.

◆ OG 30

The Officine Galileo optronic director, for *Maestrale*-class frigates, was introduced in 1980. The current version, OG 30A, is the electro-optical component of the NA-30 fire-control system but can also be combined with other systems or used alone. OG 30A carries a laser range-finder, an IR imaging camera, and a television camera on a stabilized pedestal. The system includes a video converter, TV tracker (i.e., signal processor: it is designated P4700), and displays. With the tracker, the daylight and IR cameras can operate in either a surveillance or a tracking mode. The standard devices are: P4651 daylight television camera (1.8×2.4 —deg field of view, 700 lines to CCIR standard), a Galileo IR television camera (8–14-micron wavelength, 3×6 —deg field of view, 200 lines per frame, at a frame rate of 25 per sec), and a P0700 laser range-finder (1.06-micron wavelength, peak power 20–25 MW, 15 bursts/sec, range 400 m to 15 km). The entire system can elevate at 2.2 rad/sec (about 126 deg/sec) within limits of $-25/+85$ deg, and it slews at up to

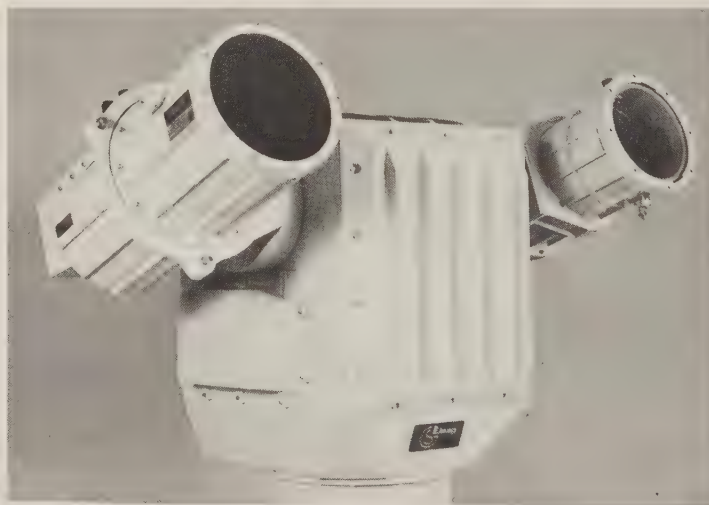
1.5 rad/sec (about 86 deg/sec). It can turn continuously for surveillance or automatically track an air or surface target. Typically, the range on an air target is 16 km, and on a sea-skimmer, 6 km. OG 30B is a simpler (thermal imager only) version, feeding directly into an NA-30 director.

◆ OG.R7

The Officine Galileo manned optical director is essentially a telescope and is open sight linked to a computer. Targets are tracked and guns (e.g., 76-mm) controlled by means of a joystick. About 250 had been manufactured as of late 1988, buyers including Greece, Peru, and West Germany (the last for secondary control in Type 143 fast attack craft). OG.R7/2 is a tracking system using a binocular telescope and an open sight, coupled to a fire-control computer, with joystick control and a stabilized line of sight. Magnifications are $2.3 \times$ and $7 \times$ (corresponding to 30- and 10-deg fields of view). Maximum rates of train (elevation) are 100 (60) deg/sec; maximum lead angle (in train) is 25 deg; maximum lead angle (in elevation) is 20 deg. Crossing range limits are 100–2000 m, and target speed limits are 60–350 m/sec. OG.R7/2A is a more elaborate pedestal sight with an optical head, external image intensifier, 2-axis stabilization, and a digital computer for lead-angle computation. The sight is moved electro-hydraulically in azimuth, and in elevation by a servo. OG 20 (OG.R7 Sea Cat) was a special version for Sea Cat missile control, employing additional telescopes for missile guidance and gun direction. A typical total weight (for OG.R7/2A) is 550 kg, and the current version is OG.R7/3.

◆ PEGASO

This optronic director by Selenia/Elsag, similar to NA-18, carries several sensors (e.g., IR camera, TV camera, laser range-finder), with a single-operator below-decks console and a digital computer. Pegaso is used in the NA-16 system (*Minerva*-class corvettes).



PEGASO optronic fire-control system director, showing television and infrared cameras. (Selenia)

◆ SIR-3

The Selenia thermal imaging surveillance system was announced in 1984. Unlike most IR sensors, SIR-3 consists of a pair of boxed sensors carried on the 2 sides of a central pedestal. The 2 detectors elevate to track air targets, and the pedestal scans in azimuth. Each box contains a linear-array detector (presumably, each side detects in a different IR band), cooled to 77°K. Selenia claims that SIR-3 provides particularly accurate elevation data. The output is compatible with a television monitor, the usual display being a 60-deg-wide strip.



The SIR-3 IR surveillance system. (Selenia)

◆ VTG 120/N

Officine Galileo announced this new naval thermal imager, based on the army's VTG 120, at Mostra Navale 1989. VTG 120/N is a pedestal-mounted lookout and target-designation sight, which can transmit target elevation and bearing in digital form. The detector is a 60-element, parallel-scanning, linear-array detector using cooled cadmium-mercury-telluride (CMT) elements (8–14-micron band); the detector is cooled by air bottles (for 2 or 4 hr) or by a Stirling closed-cycle refrigerator. The operator views the scene through a miniature CRT in the eyepiece, and the same original can also be passed to a remote monitor. There are 2 alternative magnifications, 4× and 12× (corresponding fields of view are 60 × 120 and 20 × 40 mrad).

◆ VTG 240/N

This thermal imager was announced at Mostra Navale 1989. It is intended as part of an optronic or radar/optronic fire-control system. Like the smaller VTG 120/N, it uses a 60-element parallel-scanned CMT array detector; the output is a 240-line IR image that can be fed into a tracker or converted to 625-line television format for display. Resolution is 0.16 mrad; the IR telescope has a 2-position lens (fields of view 2.3 × 1.15 or 6.9 × 3.45 deg). Total weight, including control console, is 28 kg.

FIRE-CONTROL SYSTEMS

◆ Albatros

Selenia-Elsag's medium-range surface-to-air missile system uses the semiactive Aspide missile. Albatros is designed to be added to an existing gunfire-control system so that no additional tracker/illuminators are required. Instead, Albatros uses 1 or 2 slaved illuminators (presumably CW injection in existing tracking radars).

The original Albatros Mk 1 fired the Sea Sparrow (RIM-7H) missile. Tested in 1973, Mk 1 never entered production. Mk 2 fires the Aspide. Mod 2 and Mod 5 employ Elsag (Elettronica San Giorgio) fire controls. Mod 8 uses the Ferranti WSA 400; Mod 9 uses a Signaal radar. Both the Elsag and the Ferranti versions use the Selenia Orion RTN-10X radar for fire control. Illumination is provided by a Selenia RTN-12X Sirio radar that uses the same antenna as the Orion. Total reaction time, from target designation to missile launch, is 8 sec.

In some installations 2 radar channels are provided. The tracking radar can receive CW illumination reflected from the target and track that radiation, or the tracking radar can track conventionally. Both channels share the same antenna.

The system exists with both 4- and 8-cell launchers, the latter duplicating the existing NATO Sea Sparrow launcher; however, in Albatros the 8-cell launcher can be combined with an automatic reload magazine carrying up to 16 missiles; the missiles are carried in 4-round trays, each of which duplicates 1 layer of the missile launcher. The magazine pivots up to mate with the rear of the launcher for reloading, and each missile is rammed into its launcher cell by a loading arm.

◆ Dardo

Selenia-Elsag's close-in weapons-control system was designed to deal with sea-skimming missiles. Dardo uses an Orion RTN-20X and a television camera to control a twin 40-mm/70 gun mount. The radar was developed specifically for the CIWS role, the television being used to monitor the engagement and also to control the gun in a jamming environment. Targets are detected by a separate search radar, and any target within a preset range can be engaged automatically. The system will shift automatically to deal with a sequence of targets.

Dardo is designed to engage targets between 900 and 3000 m. Its effectiveness derives from its very low dispersion, 2.5 mrad for the system as a whole (based on about 1 mrad for the 40-mm gun).

This system was first used on board *Lupo*-class frigates (the first of which was delivered in 1976). In July 1980 the frigate *Sagittario* used Dardo and the associated twin 40-mm to engage a series of 6 Rushton aerial targets (19-cm diameter, 2.8 m long) towed at high speed to simulate sea-skimmers. Four were shot down by the initial bursts, and 2 more were considered sufficiently damaged to count as kills at a range greater than 1000 m.

An extended Dardo E system was announced in 1984. It consists of the 2 separate systems of the carrier *Garibaldi*, a Dardo for close-in defense, and the line-of-sight NA-30 Mod B. The weapons might be a twin 40-mm gun, a 5-in/54, and an Aspide launcher, controlled by a search radar and a tracker.

◆ NA-9

This fire-control system by Nuova San Giorgio is based on the Orion 250 X-band radar and is derived from the earlier Italian navy Argo system. The first of 23 ordered by the Italian and other navies entered service in 1964. Claimed performance: for a target approaching at up to 600 m/sec (angular velocity 6 deg/sec), average miss distance at 1000–4500 m is 8 m.

NA-9C simultaneously controls 40-mm and 5-in guns.

NA-9D simultaneously controls guns and short-range anti-aircraft missiles (two 5-in and 2 launchers against 1 or 2 targets).

The system occupies a fixed cabin, with the radar dish on top and 2 periscopes flanking a cab in front. Each periscope operator has a director control panel.

Current applications: *Vittorio Veneto*- and *Andrea Doria*-class cruisers and *Audace*- and *Impavido*-class destroyers.

◆ NA-10

These fire-control systems use the Orion 10X and 20X con-scan radars. Mod 2 is intended for frigates and larger ships, Mod 3 for fast attack craft. Orion 10X was designed specifically for the Albatros system, so that NA-10 may be equated with the fire-control part of Albatros (see above). NA-10 is similar to NA-9 but incorporates further miniaturization and a closed-circuit television.

Users: Iraq (*Lupo* class), Italy (*Lupo*, *Alpino*, *Cassiopea*, *Sparviero* classes), Libya (Mod 2 in *Dat Assawari*, Mod 3 in *Assad al Bihar* class), Peru (*Lupo* class), Venezuela (*Lupo*, *Alm. Clemente*, and *Constitucion* classes).

◆ NA-18

Selenia-Elsag's optronic fire-control system is used to control guns up to 3-in caliber. The system consists of an optronic director (twilight TV camera, laser range-finder, IR camera) and an operating console (raster displays for the images; a joystick for target acquisition and manual tracking; and processing, interface, and television automatic-tracker units). The console carries a 15-in high-resolution monitor for synthetic video and a 9.5-in monitor for television and IR images. As an option, the 15-in monitor can carry the ship's search radar video. The system can then be used for navigation and command/control, becoming the SEN-100 small ships' combat system.

If the radar option is adopted, the 15-in monitor can be arranged in either PPI (rastered) or B-scan (range × bearing rec-



NA-18 optronic director. (Selenia)



NA-18's display-and-control console, for one-person operation. (Selenia)

tangular format: $7.2 \text{ km} \times 60 \text{ deg}$) form. The B-scan is particularly useful for splash spotting in a surface engagement. Radar targets are manually initialized, the system then performing rate-aided tracking on up to 9 of them. They can be designated for fire control either with the trackball or by track number.

Targets can also be designated to the system from CIC or from shipboard ESM. To overcome difficulties in tracking fast targets by TV or IR, the 15-in monitor uses a special display of 4 con-

tiguous images corresponding to 4 adjacent director positions (either in elevation or in azimuth), all frozen, corresponding to a vertical or horizontal swath. This frame freezing eliminates blurring due to director motion and makes for easier acquisition by the operator. Laser echoes are presented as bars with range-gate limits superimposed.

The 9.5-in monitor shows the cross hairs and the tracking window, the system status and warning messages, target data (coordinates, radial speed, angle of attack), main weapons status, and alarm messages. The 9.5-in monitor is located under the large monitor, flanked by 2 keypads for quick inputs, with a trackball and joystick in front.

The NA-18 computer incorporates several alternative tracking models (algorithms), automatically selecting the 1 it supposes is appropriate to the target at hand. Targets are tracked in 3 dimensions (in range by the laser), and the computer filters these tracking data in all 3 dimensions. In the event the laser fails, the system can track in angle at a prefixed firing range (corresponding to a barrage-firing mode). The operator can always shift from automatic to manual (joystick) tracking and can aim using the cross hairs of the TV monitor.

The system can digitally control up to 2 guns of different caliber, and it can carry 2 independent sets of ballistics (for different ammunition) for each gun in the computer's memory. Control takes account of parallax and ship's motion, and guns are automatically triggered when the target comes within their precomputed effective range. In surface firing, spotting corrections are manually entered through quick-input devices at the console. In the antiaircraft mode, observed spotting errors are compensated for by joystick.

The standard TV camera uses a zoom lens (focal length 30–360 mm), with a $2.54\text{--}30.5\text{-deg}$ field of view; the camera operates at CCIR 625/50 scan standard. The IR camera operates in the 8–12-micron band, using a closed-cycle cooling system, with a $4 \times 2.6\text{-deg}$ field of view. An alternative IR camera has 2 fields of view (6.9×3.45 and $2.3 \times 1.15 \text{ deg}$). The laser range-finder operates at 1.06 microns (neodymium YAG3), with a 15-Hz PRF and a peak power of 18 MW; the range-finder can provide ranges between 400 m and 15 km. The associated computer is a 24-bit machine with a 250-nanosec memory-access time (clock rate 4 MHz) with a combination of ROM, semiconductor memory, and tape memory.

The tracking platform servo's operating limits are as follows: elevation limits $+84/-22 \text{ deg}$, training speed 126 deg/sec, elevating speed 86 deg/sec.

Elsag described NA-18 as the simplest of a series of modular weapons-control systems using common consoles and a data bus. NA-18 uses the simplest computer (which is also used by the SCLAR rocket launcher) and very nearly the simplest console. The more elaborate versions of the same system are NA-21 and NA-30.

User: Thailand (PSMM Mk 5 class).

◆ NA-21

Selenia-Elsag's radar gunfire-control system was announced in 1980. A digital version of the earlier NA-10, NA-21 is designed to control 3 guns of 2 different calibers plus a surface-to-air missile (typically Albatros), and can also designate targets to a surface-to-surface missile. The associated fire-control radar is the Orion RTN-10X, with a television camera for visual control.

Like NA-18, NA-21 is a modular combat system using standard consoles, computers, and data busing. Users: Ecuador (*Esmeralda* class) and probably Iraq (modified *Wadi M'ragh* class).

◆ NA-25

This modular Selenia-Elsag radar and optronic fire-control system controls 2 guns of different calibers, using an Orion RTN-25X. An IR sensor and a neodymium YAG laser can be mounted on the radar director to provide an alternative range sensor, and a television camera is an alternative tracker. NA-25 can perform command/control as well as fire-control functions, using a

multiprocessor (MARA 286) and a special console (MAGICS) incorporating 2 high-resolution color monitors. The system can be set for programmed autonomous search (360 deg or by sectors) or can be fed by video from the ship's search radar. NA-25 automatically evaluates the threat presented by various targets and engages them.

◆ NA-30

Selenia-Elsag's radar/optronic weapons-control system controls up to 3 guns of 2 different calibers, as well as anti-aircraft missiles. The associated tracking radar is the Orion RTN-30X, combined with an electro-optical ranger (IR/laser) and a television tracker (as in NA-25). NA-30 is a modular combat system using a data bus and 1 or 2 control consoles.

NA-30 is designed to operate automatically (with operator veto) against a target designated by a search radar, by the system's own fire-control radar (in search mode), or by some other sensor, such as ESM. NA-30 is designed to control several weapons against a single target in coordinated firing mode: typically, an Aspide missile and up to 3 guns (with parallax corrections and 2 independent sets of ballistics with 1 fuze-setting computation). Automatic operation is intended to counter fast targets such as antiship missiles; there is also a manual mode for use against surface ships or slow air targets.

The main (supervising) console carries 2 monitors: a 19-in raster-scan CRT to show radar PPI (search radar or fire-control radar, the operator choosing between them) or a B-scan (azimuth/range) track presentation with track labels and other graphics; and a 15-in raster-scan CRT for TV or IR images with superimposed alphanumeric (e.g., CIC orders, FCS and weapons status, and alarm messages). The operator interacts with the system mainly by means of a variable-function keyboard, a numeric keypad, a trackball, a joystick, and a range handwheel. There are also pedals for gunfire control and for "voluntary" tracking initialization.

The radar/optronic director has elevation limits of $+84/-22$ deg; and the maximum training speed is 2.7 rad/sec (elevating 1.5 rad/sec), corresponding to 155 deg/sec (86 deg/sec). Like NA-18, NA-30 employs a 24-bit computer.

NA-30 was announced in 1982 and entered service in 1985. It is installed on board Italian *Maestrale*-class frigates and the carrier *Giuseppe Garibaldi*. When combined with the RAN-30X search radar, ESM, and CIC equipment, NA-30 forms the SEN 300 combat system for low- and medium-tonnage ships. In Italian naval service this system is called Dardo-E.

NA-30 was carried by 2 Italian ships operating in the Persian Gulf for 18 months; it reportedly experienced only 1 significant fault, which was corrected on board. In a test, controlling a 76-mm gun, this system hit 8 out of 8 Rushton targets, flying at less than 24 ft altitude, and at 2-3 km range.

◆ OG 3

This Officine Galileo GFCs for small ships, broadly comparable to the U.S. Mk 56, survives on board the *Pietro De Cristofaro*-class corvettes. It was formerly also on board the *Bergamini*-class frigates. The associated radar is RTN-7A. OG 2 (now extinct) was a simpler FCS, comparable to the U.S. Mk 57.

JAPAN

RADARS

◆ OPS-1

Designed about 1955, OPS-1 was a Japanese-produced version of the U.S. SPS-12. The structure of the antenna is more like that of SPS-6B/C (which was electronically much like SPS-12). Physically, the OPS-1 antenna showed features of both SPS-6B/C and SPS-12.

◆ OPS-2

Reportedly OPS-2 was a Japanese-produced version of the U.S. SPS-6C. Peak power was given as 400 kW.

◆ OPS-4

This surface-search radar, with a solid antenna, still equips the former submarine-rescue ship *Chihaya* and once was common on board both combatants and auxiliaries. OPS-4 may be a Raytheon 1404 commercial set.

◆ OPS-9

This surface-search radar, with a very long slotted-waveguide antenna, operates in X- (I/J) band. OPS-9 equips the mine-countermeasures craft and some of the miscellaneous auxiliaries.

◆ OPS-10/13/19/22/29

These surface-search radars for small ships have slotted-waveguide antennas. OPS-13 is the search radar of the PT 11 class. OPS-29 equips the small patrol boats (PB type).



The Japanese torpedo boat PT 13 is equipped with an OPS-13 surface-search radar. (*Ships of the World*)

◆ OPS-11

OPS-11 is the first Japanese-designed air-search radar. The antenna is an 8×4 array of yagi antennas. Previous Japanese



OPS-11 air-search radars at the mastheads of 3 *Iakatsuki*-class destroyers. (Jake Yamada)



OPS-11 on board a *Takatsuki*-class destroyer, with OPS-17 surface-search radar above, and GFCS-1 atop the bridge. The big radomes are part of a jamming system called OLT-3; the small ones are probably DF radomes (NOLR-6). (Author)

dependence on U.S. radar technology suggests that OPS-11 may be related to SPS-40, with a radically different antenna. Reports that OPS-11 is a UHF long-range pulse-compression radar would corroborate that relationship.

OPS-11B reportedly operates at about 300 MHz, its low frequency having been chosen for long range and for fewer fades. The antenna is an array of 24 yagis.

◆ OPS-12

This planar-array air-search radar is probably similar in operation to SPS-52. Unlike SPS-52, OPS-12 lacks a serpentine feed running up 1 edge. However, an extension visible on the right side of the main antenna may contain the feed. This arrangement might make for a more symmetric array, easier to stabi-



OPS-12 3D air-search radar on board the destroyer *Shirane*, with OPS-28 above it. The 2 gun directors above the bridge are GFCS-1A. (Japanese Maritime Self-Defense Force)

lize. OPS-12 equips only the *Kurama*-class helicopter-carrying destroyers.

NEC produces a land-based air-search radar, NPG-880, whose antenna is similar in appearance to that of OPS-12. NPG-880 is a frequency-scanning (serpentine feed) radar employing ferrite phase shifters between the serpentine feed and the radiating elements themselves. That arrangement makes it possible to use chirped (pulse-compressed) pulses at fixed elevation angles, the ferrites canceling out the effect of frequency change within each chirp. The U.S. SPS-48E employs similar techniques. NPG-880 employs a TWT/CFA transmitter.

◆ OPS-14

OPS-14 is an L-band radar with a somewhat larger (higher gain) antenna than that of OPS-1/2. This radar is manufactured by Mitsubishi Electric. The first was fitted to the destroyers *Akizuki* and *Teruzuki*, and the radar is on board all destroyers and frigates after the *Murasame* and *Yudachi*. FY67 ships and later have OPS-14. FY73 and later have OPS-14B, with MTI. However, large warships are also being fitted with OPS-11. The peak power of OPS-14B is 400 kW (500 kW in OPS-14), and the beam dimensions are $5 \text{ deg} \times 30 \text{ deg csc}^2$. The improved OPS-14C version will be on board Improved *Hayatsuki*-class destroyers.

◆ OPS-15/16/17/18/35/36/37

Band: C (5450–5825 MHz) **Beam:** $2 \times 20 \text{ deg}$
Peak Power: 150–200 kW **Pulse Width:** 0.3 or 1.4 microsec
PRF: 604–667 pps **Scan Rate:** 15 rpm

Data apply to OPS-18, built by Nihon Musen.

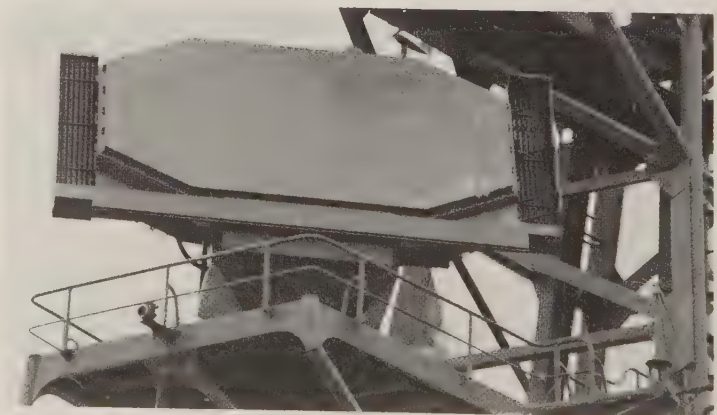
These surface-search radars superficially resemble the U.S. SPS-5/10, with their openwork antennas. OPS-37, a Japanese version of the U.S. SPS-5B, has an antenna that is noticeably smaller than those of the others. OPS-16, -17, -35, and -36 operate at somewhat higher frequency, closer to X-band. OPS-15 equips the training ship *Katori* and some of the ex-destroyers (now serving as auxiliaries). OPS-16 is the surface-search radar on board some older frigates. OPS-17 was the standard destroyer surface-search radar; it is now being replaced by OPS-28. OPS-18 equips the new *Towada*-class underway-replenishment ships.

◆ OPS-19

A slotted-waveguide navigational radar, OPS-19 is sometimes used in combination with the much larger OPS-28 (e.g., in the destroyer *Kurama*, on the foremast, and in the *Yubari*-class frigates).

◆ OPS-24

This new planar-array (probably phase-phase) radar replaces OPS-14 on board the *Hamagiri* and later *Asagiri*-class destroyers.



OPS-24 air-search radar on board the new Japanese destroyer *Hamagiri*, 1990. The flat-plate antenna is tilted back, so this photograph, taken from below, somewhat reduces its apparent height. (Sea Power)

◆ OPS-28

OPS-28 is a large slotted-waveguide surface-search and short-range air-search radar. The current version, OPS-28C, is the functional successor to OPS-17, replacing it in the *Tachikaze*-class destroyer *Sawakaze*. OPS-28 is also replacing OPS-18.

OPS-28 is a specialized sea-skimmer detector, broadly comparable to the U.S. TAS Mk 23.

◆ ZPS-4

This search radar, installed in the *Uzushio*-class submarines, uses a fully enclosed antenna in a cylindrical radome.



The Japanese submarine *Makishio* shows a ZPS-4 radar. (*Ships of the World*)

◆ ZPS-6

ZPS-6 is a submarine search radar in the current *Yushio* class.

◆ Furuno Radars

These commercial navigational radars are used primarily by the U.S. Navy; they do not appear to be used by the Japanese Maritime Self-Defense Force. For details, see the U.S. entries below.

FIRE-CONTROL SYSTEMS

◆ GFCS Model 1 (GFCS-1)

Model 1A controls 5-in guns; Model 1B controls 3-in guns. This system is mounted from the *Natsugumo* and *Nagatsuki* on. Made by Mitsubishi Electric, GFCS-1 is also designated Type 72. An earlier Type 68 system is on board the *Harusame*. This

The new Japanese destroyer *Asagiri* shows both the OPS-14C air-search radar (forward) and the new FCS-2-12E missile (Sea Sparrow) fire-control radar (aft, under the big radome). The small surface-search radar on the platform atop the foremast is OPS-28, and the radomes on the main mast are part of an EW suite consisting of an OLR-9C passive system, an OLR-6C, and an OLT-3 jammer, plus SRBOC launchers. The gun director atop the bridge is FCS-2-21A. (*Sea Power*)

radar-equipped director, similar to the U.S. Mk 56, is for 5-in guns. In some ships it replaced a U.S. Mk 63.

◆ GFCS Model 2 (GFCS-2)

This Type 79 fire-control system exists in 2 versions. Model 2-12, enclosed in a radome, controls guns and Sea Sparrow missiles from the *Ishikara* on. Model 2-21, on an open pedestal, controls guns only. Both are manufactured by Mitsubishi Electric.

Type 79 is a digital system replacing the earlier analog Type 72. Type 79 employs an unmanned director whose Cassegrain monopulse tracking antenna can be seen mounted on a pedestal. This arrangement is an improvement over the conscan tracker of Type 72, in which the on-mount operator is exposed to the elements. Reportedly, the search antenna in the 2-12 system shares the same transmitter as the tracker, as in the Signaal "eggs."

◆ FCS 3

The current research-and-development plan includes a phased-array fire-control system, FCS 3.



FCS-2-21A. (*Sea Power*)



NETHERLANDS

RADARS

◆ DA-01/02/04

Band: S (2.9–3.1 GHz) Beam: $1.5 \times \text{csc}^2$ (DA-02 1.7 deg)
 Peak Power: 400 kW Gain: 32 dB
 Pulse Width: (i) 1.3 (ii) 0.5 microsec
 PRF: (i) 500 (ii) 1000 pps Scan Rate: 6–60 rpm
 Antenna Dimensions: 15.3 ft wide Antenna Weight: 4400 lb

DA-01 was the first postwar Dutch target-designation (DA) radar, introduced in 1954 on board Dutch destroyers. The commercial (Signaal) designation was SGR-105. Claimed performance included detection of a 2-m² target at 50 nm and at 35,000 ft. DA-02 used a broader-beam (1.7-deg) antenna but greater power (500 kW, 40 nm at 30,000 ft) and was first exported to Argentina for the former U.S. light cruiser *Nueve de Julio*. There was no DA-03. DA-04 was the last of the series, a simplified version of DA-01 using an unstabilized antenna (1200 lb).



DA-01. (Signaal)

◆ DA-05



DA-series antenna on board a Dutch frigate, 1978. The British UA-8/9 ESM antenna is on the pole mast above. For DA-05, see the photograph of the Indonesian *Malahayati* under the entry for the Bofors 4.7-in/46 gun. (U.S. Naval Institute)

Band: S (6 preset frequencies between 2900 and 3100 MHz)
 Beam: 1.5×8 deg (csc^2 cover up to 40 deg)
 Peak Power: 1200 kW Gain: 32.2 dB
 Pulse Width: (i) 1.3 (ii) 2.6 microsec
 PRF: (i) 1000 (ii) 500 pps Scan Rate: 10 or 20 rpm
 Antenna Dimensions: 4.87 × 2.75 m [about 16 × 9 ft]
 Antenna Weight: 725 kg

DA-05 was the first of a new series of DA radars, analogous to LW-04, using elliptical antennas and more powerful magnetrons. Like LW-04, DA-05 has digital MTI. Claimed performance includes detection of a 2-m² target at 72–84 nm and about 60,000 ft; minimum range is 1000 m. This radar can discriminate targets 1.5 deg apart in azimuth and 200–400 m apart in range. DA-05 is the primary air-search radar of the Belgian *Wielingen* class and is also used by the Dutch and Spanish navies. DA-05/M is a land-based mobile version, and both DA-06 and -07 are land-based.

DA-05/4 on board the Irish *Eithne*, 1986, with IFF interrogator above. (Author)

DA-05. (Signaal)

◆ DA-08

Band: S Beam: $1.5 \times \text{csc}^2$ to 40 deg
 Peak Power: 145 kW (5.1 kW average) Gain: 33 dB
 Pulse Width: (i) 35 (ii) 69 microsec PRF: (i) 1000 (ii) 500 pps
 Scan Rate: 10 or 20 rpm (selectable)
 Antenna Dimensions: 4.4 × 3.9 m; depth 6.5 m
 Antenna Weight: 2500 kg



DA-08 on board a Turkish frigate. (Stefan Terzibaschitsch)

This coherent pulse-compression radar is derived from, and is analogous with, the larger LW-08. Claimed range on a 2-m^2 target is 78–92 nm. Minimum range is 0.8 nm. The antenna is stabilized. Each pulse consists of a 1-microsec non-modulated pulse and a 34- or 68-microsec frequency-swept (pulse-compression) pulse. Compressed pulse length is 0.6 microsec. There are 6 fixed crystal-set frequencies plus a jumping frequency. Resolution: 1.5 deg in azimuth, 120 m in range. A modified version of this radar scans at 15 rpm and has a PRF of 2400 pps; instead of the digital MTI of the basic radar, it uses an FFT for MTI.

DA-08 is the primary air-search radar of German *Bremen*-class frigates and *Hamburg*-class destroyers.



DA-08. (Signaal)

◆ LW-02/03

Band: L (1220–1350 MHz) **Beam:** $2.2 \times \text{csc}^2$ (ratio 1:10) deg
Peak Power: 500 kW **Gain:** 31 dB
Pulse Width: (i) 2 (ii) 5 microsec **PRF:** (i) 500 (ii) 250 pps
Scan Rate: 1–10 rpm (in some, 3/6 rpm)
Antenna Dimensions: 7.8×4.25 m [25.6×13.9 ft]
Antenna Weight: 2100 lb

LW-02 was the first postwar Dutch destroyer radar, and it was exported to Australia, Colombia, Sweden, and West Germany under the commercial designation SGR-114/12. Claimed performance included detection of aircraft at 100 nm and 59,000 ft.

LW-03 was a similar radar with a scan rate of 5 or 10 rpm.

There is also LW-01, a much larger radar (antenna 11×4.88 m [36.1×16 ft], 3200 lb, with a beam $1.8 \text{ deg} \times \text{csc}^2$ [ratio 1:12], gain 33 dB, scan rate 3 or 6 rpm or 1–6 rpm) using the same transmitter, for cruisers and aircraft carriers. The commercial designation was SGR-114/06, and the sole survivor is on board the Argentine aircraft carrier *25 de Mayo*.

◆ LW-04

Band: L (6 preset frequencies between 1250 and 1350 MHz)
Beam: $2.2 \times 10 \text{ deg}$ **Peak Power:** 1100 kW (LW-04/2 version)
Gain: 30 dB **Pulse Width:** (i) 1.3 (ii) 2.6 microsec
PRF: (i) 1000 (ii) 500 pps (staggered) **Scan Rate:** 7.5 or 15 rpm
Antenna Dimensions: 7.35×4.8 m **Antenna Weight:** 1400 kg

LW-04 introduced the elliptical antenna characteristic of current Dutch air-search radars. No commercial (SGR) designation has been announced, but LW-04 first appeared on board the German destroyer *Hessen*. These radars have digital MTI and can operate on any 1 of 6 preset frequencies. Claimed range on a 2-m^2 target is 120 nm at 55,000 ft. Resolution is 2.2 deg in azimuth, 200 or 400 m in range.

No LW-05 has been announced; LW-06 and -07 are land systems.



LW-04. (Signaal)

◆ LW-08

Band: L (6 preset frequencies between 1250 and 1350 MHz)
Beam: $2.2 \times \text{csc}^2$ to 40 deg
Peak Power: 150 kW pulse compressed; average power 5.2 kW
Gain: 30 dB **Pulse Width:** (i) 35 (ii) 69 microsec
PRF: (i) 1000 (ii) 500 pps **Scan Rate:** 7.5 or 15 rpm
Antenna Dimensions: 8.8×7.525 m
Antenna Weight: total 5000 kg (antenna 1500 kg)

The pulse-compression waveform includes a 1-microsec pulse for short-range resolution, and then a long "chirp" for long-range performance. The high average power (5.2 kW) corresponds to 5100 kW applied to 1-microsec pulses; that power gives some idea of range performance (a range of 145 nm at 85,000 ft is claimed for a 2-m^2 target). The short initial pulse is



LW-08 on board a *van Heemskerck*-class missile frigate. This version has a double feed; there is also a single-feed version. (Signaal)

used for surface warning. Any of 6 preselected frequencies can be used, and there is provision for pulse-to-pulse frequency jumping through the entire band. Resolution is 2.2 deg in azimuth, 300 ft in range. Pulse-compressed pulses are equivalent to 0.6-microsec pulses. LW-08 can handle target speeds up to Mach 5 (which must be the first blind speed), and up to 64 tracks. The MTI improvement factor is 35 dB. Minimum range is 2 km. The antenna is stabilized.

The British Type 1022 marries an LW-08 transmitter to a Marconi narrow-beam (squintless) antenna.

LW-08 was first used on board the Dutch "standard" frigate *Kortenaer*.

◆ SPS-01

Band: S

Beam: [search] 1.5×2 to 30 deg; [track] 1.5×1.5 deg (approx, depends on elevation)

Peak Power: 750 kW **Gain:** about 39 dB

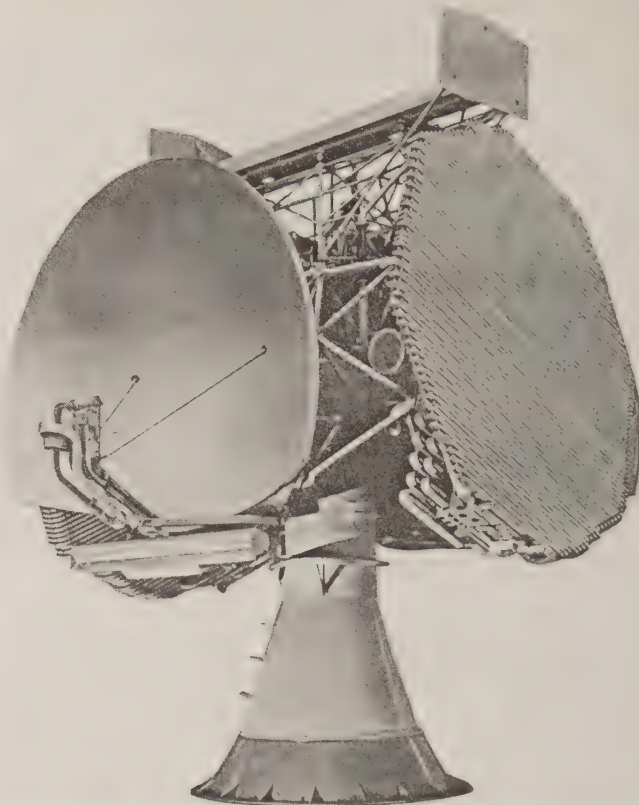
Pulse Width: 40 microsec **PRF:** 460 and 540 pps, staggered

Scan Rate: 20 rpm

SPS-01 is the big multifunction radar of the Dutch missile-destroyers *Tromp* and *de Ruyter*. It combines a broad-beam search radar with a high-data-rate radar for tracking multiple targets. Five antennas are mounted to rotate together: 2 back-to-back paraboloids (with feed horns moving to generate any of 5 alternative beams, plus a sixth, fixed, low-angle beam); 2 back-to-back frequency-scanned arrays at right angles to the paraboloids; and an IFF mounted below 1 of the 2 paraboloids. The low-angle search beam operates continuously to provide short-range warning (40 scans/minute using the back-to-back anten-



SPS-01 occupies the large radome of the Dutch destroyer *Tromp*. The small radome forward of the bridge is for a Signaal WM-25, and 2 SPG-51s aft control the Standard Missile. The 2 slotted-waveguide surface-search radars are Decca 1226s. (U.S. Naval Institute)



SPS-01 array. The serpentine waveguide feeding the diagonal slotted waveguides is visible between the 2 arrays. (Signaal)

nas). The other 5 search beams are used in sequence (1 by 1 during subsequent rotations), so that for each the effective data rate is 8 scans/min. This scheme is used, not for height finding, but rather to give solid vertical coverage. The search beam's dimensions vary with elevation, the vertical beamwidth being 2 deg at an elevation of 2.5 deg, but 30 deg at an elevation of 21 deg. Targets are automatically detected, and their 2D (range and bearing) positions fed into the central computer, which instructs the 2 frequency-scanned radars to find the contacts in 3 dimensions for tracking. Each of the 2 frequency-scanned arrays is slanted to the vertical, the combination of the 2 oppositely slanted arrays making for full 3D operation. The net data rate is 40 scans/min, because of the back-to-back operation.

The entire radar is fed by a single time-shared power source.

Discussions with the Royal Netherlands Navy began in 1958, and a first working model was completed in February 1964. The 2 operational radars were completed in 1969. SPS-01 was originally known as MTTR, the Multi-Target Tracking Radar, and for a time was a joint project with the Royal Navy.

◆ VI-01 (SGR-109)

Band: S **Beam:** 3.5×1.2 deg **Peak Power:** 500 kW

Gain: 39 dB **Pulse Width:** (i) 1.5 (ii) 0.5 microsec

PRF: (i) 500 (ii) 1000 pps

Scan Rate: (elevation) 50 scans/min (+8/-2 deg) or 20 scans/min (+50/-2 deg); the sector scanned varies automatically with range. Scan in terms of bearing: 51 deg/sec

VI-01 is the nodding height-finder on board the Argentine carrier *25 de Mayo*. The transmitter is the same as that of the contemporary DA-01 series. Claimed performance for the very similar land-based radar is a range of 150 nm, coverage to 120,000 ft. Up to 6 randomly spread targets (over 360 deg) can be handled per minute.

◆ ZW Series

ZW-04 no longer survives; no sales of ZW-08 or -09 have been reported. See the last edition for details.

◆ ZW-01/3 (SGR-103)

Band: X (8.5–9.6 GHz) **Beam:** 1.0×3.5 deg
Peak Power: 180 kW
Gain: 39 dB **Pulse Width:** (i) 0.1 (ii) 0.3 microsec
PRF: (i) 2000 (ii) 1000 pps **Scan Rate:** 7.5 or 15 rpm
Antenna Dimensions: width 2.56 m **Antenna Weight:** 300 kg

ZW-01 appeared in 1954 and was widely used in the Dutch and German navies. ZW-03 is an improved version, also widely used. These radars are described as surface and low-altitude air-search sets. The search antenna is stabilized on the horizon.

Typical performance: a jet fighter ($1\text{--}3\text{ m}^2$) can be detected at up to 30 nm, and a bomber ($10\text{--}40\text{ m}^2$) at up to 48 nm. Small vessels can be detected at about 18 nm, and periscopes at 4.5 nm. Minimum range is 50 m.

◆ ZW-06/07

Band: X (9.325–9.475 GHz) **Beam:** 0.9×19 deg
Peak Power: 60 kW **Gain:** 32 dB
Pulse Width: (i) 0.06 (ii) 0.6 microsec
PRF: (i) 4000 (ii) 2000 pps **Scan Rate:** 24 rpm
Antenna Dimensions: 2.9×1.2 m [about 9.5×3.9 ft]
Antenna Weight: 130 kg [287 lb]

For ZW-06, range on a 10 m^2 target is about 14 nm, and an airplane at 20,000 ft can be detected at that range. The very short pulse was adopted for high resolution. The air coverage is necessary for helicopter control in ASW. The transmitter is coherent, for clutter and jamming rejection.

Applications include the Dutch *Kortenaar* class, the Brazilian *Niteroi*, the Spanish *Descubierta*, and the Indian *Leanders*.

ZW-07 is a submarine version of ZW-06, with a peak power of 50 or 60 kW (pulse width 1 microsec, PRF 1200 pps). There are also a short-pulse mode (0.1 microsec, 35 kW, 2400 pps) and a single-pulse mode (0.22 microsec, 100 kW, can be 2500 pps). Gain is 28 dB; dimensions of the half-cheese antenna are 1.0×0.250 m. The beam is 2.4×16 deg. Resolution is 2.4 deg in azimuth. Performance: range on a 10 m^2 target is about 16 nm (at 25,000 ft). In the single-pulse mode a ship (50 m^2) can be detected at 13.5 km, and a 10 m^2 target at 9 km.



ZW-06 surface-search radar. (Signaal)



ZW-07 surface-search radar for submarines. (Signaal)

◆ ZW-12

Band: X **Beam:** (i) 0.9×19 deg (ii) 1.5×10 deg
Peak Power: 50 kW (100 W average)
Gain: (i) 31.2 dB (ii) 32.2 dB **Pulse Width:** 0.55 microsec
PRF: 4000 pps **Scan Rate:** (i) 24 rpm (ii) 60 rpm
Antenna Dimensions: (i) $2.65 \times 1.2 \times 1.78$ m (ii) $1.5 \times 1.2 \times 0.85$ m **Antenna Weight:** (i) 130 kg (ii) 175 kg

In the data above, (i) is the conventional parabolic antenna and (ii) the stabilized slotted waveguide (version 12S).

Despite the radar's surface-search designation, Signaal describes ZW-12 as a helicopter-control (using a special VESTA transponder) and limited air-warning radar. There are 2 antennas, a conventional mesh reflector and a stabilized cylindrical (slotted-waveguide) antenna (ZW-12S). There is provision for an optional TWS unit, capable of tracking 2 surface targets simultaneously. ZW-12/1 has an unstabilized antenna, and ZW-12/2 is stabilized.

The control console has a 12-in PPI and a 15-in television for light-pen control.

◆ LIROD-8 GFCS4

See LIOD under optronic systems below.

◆ MR-05

Band: L (1200–1400 MHz) **Beam:** 3.5×18 deg
Peak Power: 5 kW **Gain:** 26.5 dB
Pulse Width: 50 (compressed to 0.6) and 1 microsec
PRF: 700/1400 pps **Scan Rate:** 15 rpm
Antenna Dimensions: $4.8 \times 2.54 \times 3.34$ m
Antenna Weight: 600 kg

Signaal announced this new air-search radar, to replace DA-05, in 1990. It combines solid-state transmitter technology (4 solid-state amplifier modules, each providing part of the RF power) with a stealthy, i.e., low-peak-power (pulse compression) waveform. The alternative short-pulse mode is used to achieve a short minimum range. The antenna is a double-pillbox (an enclosed radome) with very low sidelobes (45 dB down from main lobe). Operating modes: normal surveillance (360 deg), sector scan, and silent operation. The radar operates in PRF stagger, fixed frequency, and in frequency-agile (FA) mode, hopping pseudorandomly among 8 frequencies. FA modes are either MTI (frequency maintained over several sweeps) or jumping (frequency jumps from sweep to sweep). The video processor supplies air video as MTI and LIN video; the MTI channel uses a 3-point moving-target indicator. All targets are displayed in the LIN (linear) mode. The video processor supplies surface video in linear or log form. In both channels, interference from other radars and multiple-trace (STA) echoes are suppressed by an interference-suppression unit (ISU) and a correlator. Maximum range is $100 + \text{km}$ [55 + nm].

MR-05 is fitted for, but not with, IFF. The number of alternative frequencies can be increased from 8 to 56. Other options are a stabilized antenna and a tracking processor (for ADT operation).

Signaal describes MR-05 as suitable for vessels displacing 1000 tons and up. The antenna outwardly resembles that of MW-08, albeit without the latter's striplines.

◆ SMART/MW 08

Band: S
Beam: 2 deg horizontal; each beam is about 9 deg wide
Peak Power: 150 kW **Gain:** 23-dB transmitter; 31.5-dB receiver
Pulse Width: 0.6 microsec compressed **PRF:** 3800 pps
Scan Rate: 27 rpm **Antenna Dimensions:** $4.8 \text{ m} \times 2.05 \text{ m}$
Antenna Weight: 1200 kg (plus 385-kg drive)

SMART is the Signaal 3D radar designed particularly to deal with antiship missiles, with radar cross sections as small as 0.1 m^2 , and with speeds as high as Mach 3. SMART covers all threats from sea-skimmers up to divers approaching at a 60-deg angle. SMART can automatically detect and track (ADT) up to 160 air and 40 surface targets at medium and long range. Signaal chose S-band as the best balance between range, clutter rejection,



SMART. (Signaal)

tion, and overall dimensions (for frigate installation). An X-band version was also designed.

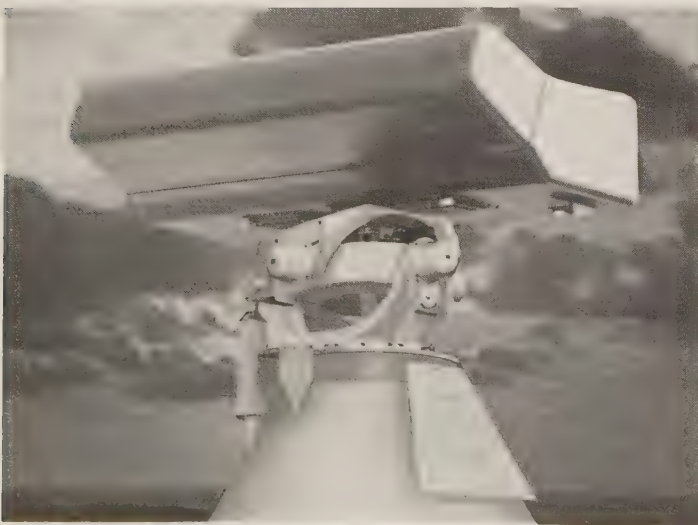
Inside the antenna are a single horn transmitting antenna and a linear array of 16 strip-line receiving antennas. Received signals are preprocessed within the antenna itself: the output of the 16 receivers is fed into a digital beam-former producing 12 independent elevation beams. The antenna rotates in bearing. In effect this operation is monopulse height finding by a novel form of stacked beams. The 12 beams cover the entire hemisphere (from 0 to 90 deg of elevation). The combination of narrow beams (in bearing and elevation) and a high data rate makes it possible to designate targets directly to directors. Sidelobes are very small.

The transmitter is a TWT for pulse-to-pulse coherence and, therefore, MTI. MTI analysis (by FFT) is applied only to areas affected by weather or sea clutter, to reduce the overall processing load. PRF is optimized to avoid second-time-around problems. The radar is arranged to react automatically to jamming by changing PRF, and the radar can vary PRF or frequency by burst. Target range and speed are compared on a burst-to-burst and scan-to-scan basis to avoid false targets (which can be discerned by their unnatural behavior).

Transmission modes are fixed frequency, frequency agility over scan, and burst-to-burst frequency jump.

The antenna is stabilized against roll and pitch.

SMART is to replace DA-08 in both *van Heemskerck*-class missile frigates and in all 8 *Karel Doorman*-class frigates



MW 08. (Signaal)

(formerly the M class); the order was placed on 24 December 1986. SMART was an unsuccessful contender for the British Type-996 requirement.

SMART has been adopted for the German Type 123 frigate (in preference to the French Arabel, the British Type 996, and the U.S. Target Acquisition System). As a result, the German frigate will have much the same air-defense-radar system as the new Dutch M class; SMART will also equip the 2 Dutch L-class area-defense missile ships. This radar is being adapted for land-based use under the designation Vanguard.

MW 08 is a SMART development in G- (formerly C-) band for short- and medium-range cover, up to 70 deg elevation. MW 08 can automatically detect and track up to 20 air and 10 surface targets, and it can control gunfire against 2 surface targets. The array is reduced to 8 strip-lines (hence the reduced elevation coverage). Each of 6 pencil beams is 2×12 deg, and peak power is 50 kW (pulses are compressed to 0.6 microsec). The antenna is 2.488×1.160 m (weight 430 kg plus 90-kg drive). Maximum free-space range (single scan, 80% probability of detection) on a 0.1-m^2 target is 17 km (45 km for SMART); on a 1-m^2 target, 27 km (65 km). The radar can handle target speeds of up to Mach 4 (Mach 5 for SMART).

MW 08 has been ordered for the 3 Portuguese MEKO frigates.

◆ SCOUT

SCOUT is the Signaal equivalent of the Swedish BEAB PILOT; Signaal and BEAB are no longer associated companies, so each must have its own version. SCOUT was first shown at Bourget Naval in October 1990 (Signaal is now associated with Thomson-CSF). The X-band SCOUT has an output (equivalent to the average power of a conventional radar) of 1 W. It scans at 24 rpm, and its antenna is 1.84 m wide and weighs 75 kg (the associated processor weighs 21 kg). It is expected to detect a corvette at the horizon and a 15-ft wooden or GRP boat at 8 nm. The ESM counterdetection range (free-space, using a -60-dBm receiver) is estimated as 1.5 km, i.e., well within its own detection range. Range scales are 0.75, 1.5, 3, 6, 12, and 24 nm. Signaal claims that SCOUT is equivalent to a conventional 20-kW radar.

◆ STIR

Band: X and K **Beam:** 1.4 deg (0.3 deg K-band)

Peak Power: 220 kW (20 kW K-band)

Pulse Width: 0.29 (0.14) microsec **PRF:** 1800 or 3600 (7200) pps

Antenna Dimensions: diameter 1.8 m

Antenna Weight: total weight 1700 kg

This Signaal Tracking-and-Illuminating Radar is the lineal successor of the postwar M 40 series dishes. Essentially the tracking radar of the WM 20 series, STIR is removed from the egg and weather-proofed. The original version used a magnetron transmitter. Then the TWT transmitter developed for Goal-keeper was combined with a larger antenna, primarily for missile fire control in the Dutch *van Heemskerck*-class frigates. The Canadian TRUMPs will use the TWT transmitter with the earlier 1.8-m antenna, as the larger antenna would add too much top weight.

STIR uses a Cassegrain monopulse antenna. There are 2 basic versions, STIR 180 (1.8-m antenna and magnetron transmitter) and STIR 240 (2.4-m antenna and TWT transmitter). STIR 180 can also be supplied with the TWT transmitter. The data above are for the STIR 180 magnetron. Instrumented range is 60 km, and total weight is 1800 kg. The TWT version uses pulse compression (0.3-microsec pulses, PRF 3200 to 6400 pps). Average power is 5 kW (peak power 100 kW), compared to 230 W (40 W in K-band) in the magnetron-driven version. Instrumented range is 180 km. STIR 240 (TWT) provides a 1-deg beam and a target-acquisition range (not instrumented range) of $140+$ km for a 1-m^2 target.

A version with a 1.2-m antenna is under development.

By the end of 1986, over 50 STIRs were operational, with over 30 more on order. The 100th STIR was ordered in 1988.



STIR (1.8-m version). (Signaal)



Both versions of STIR with ZW-06 (below) and DA-08 (above) on board the missile frigate *Jacob van Heemskerck*. (Signaal)

A version of STIR, VM40, was proposed (but rejected) as the British lightweight Sea Wolf director.

In 1987 Signaal announced STING, a modified STIR intended to control vertically launched Sea Wolf. The result is small enough (710 kg) to fit on board a fast patrol boat. A single unit time-shares the processing of all 3 signals produced by the radar: X- and Ka-band tracking, and a missile gathering beam (receiving a signal from the missile itself). Signaal credits the combination of X- and Ka-bands with image-free tracking virtually

down to the sea surface. MTI (achieved through the use of an FFT) is used for clutter rejection.

◆ Signaal Coastal Radar

This slotted-waveguide radar is in service in the Netherlands, Belgium, France, West Germany, and Saudi Arabia. Characteristics: X-band (8850–9150 MHz); beam 0.25, 0.4, or 0.5 deg $\times$ inverted csc²; pulse width 0.050 or 0.200 microsec; PRF, respectively, maximum of 4000 and 2000 pps; peak power 40 kW.

◆ Reporter

Signaal's TWS coast-defense radar was announced in 1980. It can track up to 8 targets automatically or 4 manually. The prototype was completed in 1979, using parts from the existing Flycatcher (Goalkeeper) radar.

OPTRONIC SYSTEMS

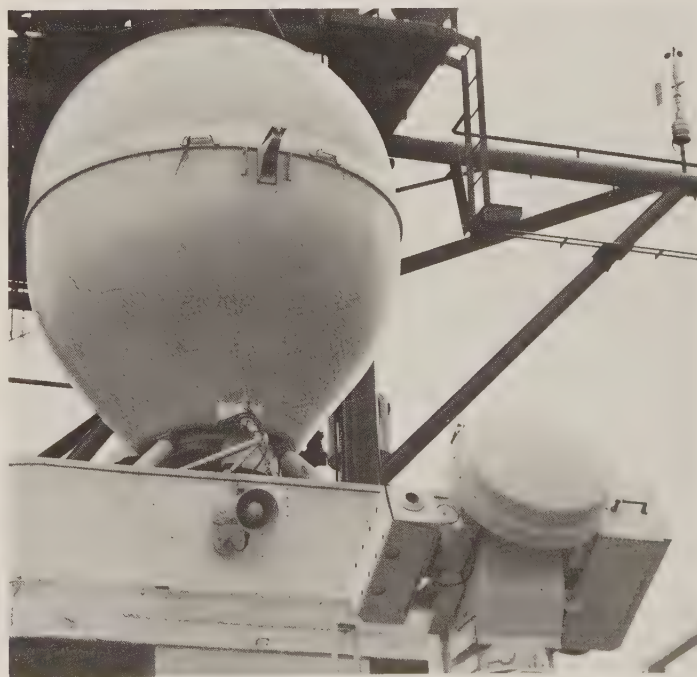
◆ LIOD/LIROD-8

LIOD is an unmanned optronic director carrying a television camera or IR sensor and a laser range-finder. LIOD can operate either autonomously or in conjunction with a larger fire-control system. Range on fast aerial targets is about 11,000 yd in good weather. By 1980 LIOD had already been sold to Indonesia, Morocco, Nigeria, and South Korea. LIOD is designed for simultaneous control of 2 dual-purpose guns (with identical ballistics).

LIROD is a smaller version in which a Ka-band or X-band tracking radar replaces the IR sensor. In LIROD-8, the radar is the Ka-band (35 GHz, beam 1 deg) set used in Goalkeeper. Peak power is 20 kW (pulse width 0.14 microsec, PRF 14,400 pps); the antenna is 0.6 m in diameter. The director does carry a television camera, and LIROD-8 can be used as a tracking channel for a WM20-series fire-control system.

Estimated reaction time from target designation to open-fire was 5.5 sec. The director could slew at 120 deg/sec and could elevate at 80 deg/sec (limits -25 to $+85$ deg). The director proper weighed 300 kg and had a width of 1.5 m.

LIOD is the basis of the Signaal/Bofors RBS 70-based small-ship defense systems; see the Swedish RBS 70 missile and the Signaal OPTICAT below. Users: LIOD—Indonesia (PB 57-class ASW version), Ireland (*Eithne*), Korea (HDC 1150-class frigates), Malaysia (FS 1500-class frigates), and Turkey (FPB 57 class). LIROD—Argentina (MEKO 360 and 140 frigates), Australia (River-class frigates), Greece (Osprey 55 type), Korea (*Ulsan* and



LIROD (foreground) and a WM20-series "egg." (Signaal)

Donghae classes), Indonesia (*Fatahillah* and former Dutch *van Speijk* classes), Kenya ("Province"-class missile boats), and Mexico (*Cormoran* class). LIROD-8—Thailand (*Ratanakosin*-class and *Chonburi*-class fast attack craft).

◆ IRSCAN

Signaal's infrared scanner, usable both as a stand-alone system and as part of Goalkeeper, is to be evaluated with the latter in mid-1991. It employs a rotating stabilized turret, scanning in 3 alternative elevation patterns (low, medium, and high [to 40 deg]) and carrying 3 sensors (3–5-, 8–12-micron bands). Output is displayed on a 15-in television monitor, and processing is TWS.

FIRE-CONTROL SYSTEMS

Signaal does not distinguish between fire-control radars and the associated fire-control systems.

The Dutch M1 and M2 FCSs are now extinct, having been superseded in surviving ex-Dutch cruisers and destroyers (in Peruvian service) by WM25 and M45. For details, see the last edition.

◆ M4

Band: X Pulse Width: 0.5 microsec PRF: 1600 pps

M4 (SGR-108) can be distinguished from earlier Dutch fire-control radars by its cut-parabola antenna with a central feed supported by heavy pylons. Versions of the M4 fire-control system include M4/1 for 40-mm guns (1957), M4/2 for 40-mm guns (1961), and M4/3 for 40-mm guns and Sea Cat missiles (West Germany, 1961). M4 users: Germany (*Rhein*-class tenders) and Turkey (former *Koln*-class frigates and former *Rhein*-class tenders). Formerly on board Colombian modified *Holland*-class destroyers (no longer in service).

◆ M40 Series

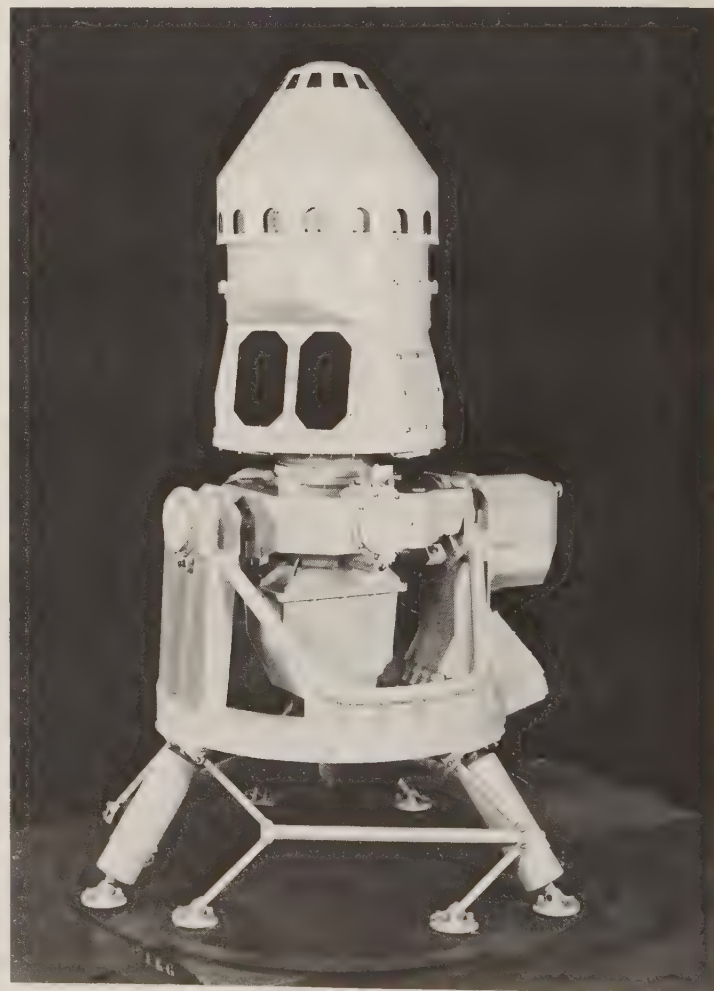
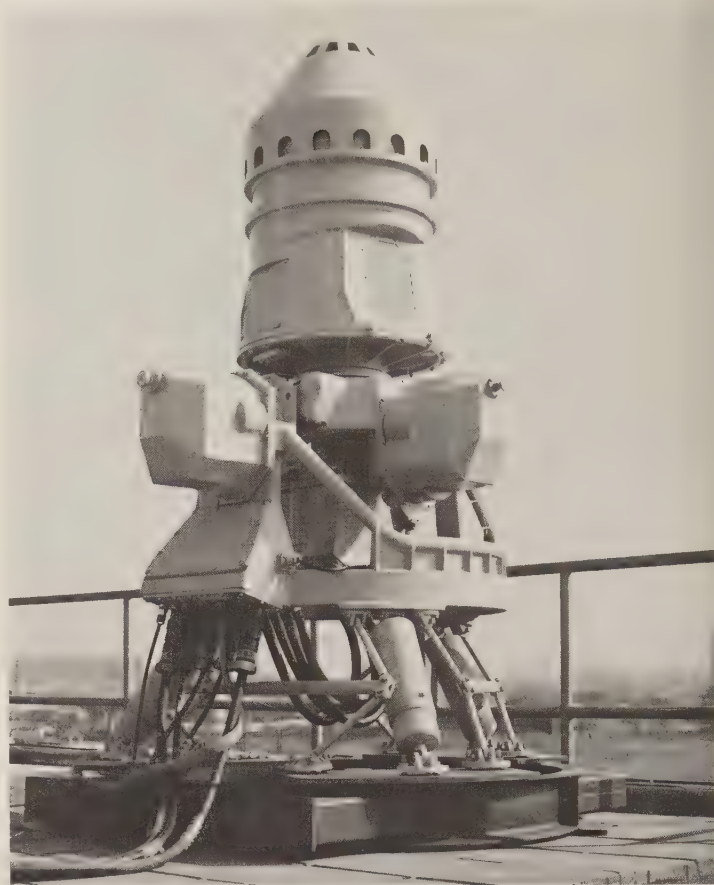
Band: X Peak Power: 180 kW

These radar directors succeeded the M1 through M4; they use roll- and pitch-stabilized enclosed-dish antennas with conical scan for air-target tracking and elliptical scan for surface targets. Because the stabilizer is in the director, no axis conversion is needed (as it would be from a below-decks stable element), and overall weight is reduced. These directors can be fed by a target-indicating radar, which provides an initial bearing and range. The radar then automatically locks on and tracks. There is no optical range-finder, the director operator acquiring and following the target using a pair of binoculars on an aiming bar. Total director weight is 1250 kg; working circle diameter is 2.8 m.

The radar transmitter is almost certainly the same one originally used in the M20/WM20 series described below, and computing limits match those of the other system (maximum target air speed 900 yd/sec, maximum surface target speed 34 yd/sec, maximum target range 32,000 yd). The 2 main versions are M44 (Sea Cat missile control) and M45 (medium- and light-caliber guns). Each has an associated optical sight, but fields of view differ depending on application: 12 deg (magnification 4×) for M44, 8 deg (magnification 6×) for M45. Displays are A- and B-scopes. The associated solid-state digital computer of M45 is hard-wired for particular ballistics (for 2 or 3 different weapons, depending on how extensive the range tables are, i.e., on how much memory they consume). Computer functions: tracking of an air target, tracking of a surface target, antiaircraft fire, surface fire, and shore bombardment, in the last 2 cases with starshell fire. In the case of M44, the gunfire functions are replaced by firing bracket computation and launcher control.

M44 gathers the Sea Cat missile by means of a flight controller on the aiming bar. Guidance is generally visual, but the director can guide the missile by radar, using a second range gate and an F-scope.

Users: M44—India (*Leander*-class frigates), Indonesia (former *van Speijk*-class frigates), and Turkey (former German *Koln*-class frigates). Formerly on board Swedish destroyers. M45—



The Signaal IRSCANIRST turret. (Signaal)



An M45 director on board the German training ship *Deutschland*, now discarded. A similar radar, without a manned cab, was mounted above the ship's bridge. (R. Cheung)

Australia (River-class frigates), Germany (*Hamburg*-class destroyers and *Rhein*-class tenders), India (*Leander*-class frigates), Indonesia (former *van Speijk*-class frigates), Peru (former Dutch *Friesland*-class destroyers), and Turkey (former *Koln*-class frigates and former *Rhein*-class tenders). Formerly on board Swedish destroyers.

◆ WM20/M20 Series

Band: X

Beam: 1.5 × 7.0 deg (search antenna)
1.5 × 4.7 deg (later search antenna)
2.4 deg (track antenna)

Peak Power: 180–200 kW **Gain:** 33.5 dB (small search antenna)

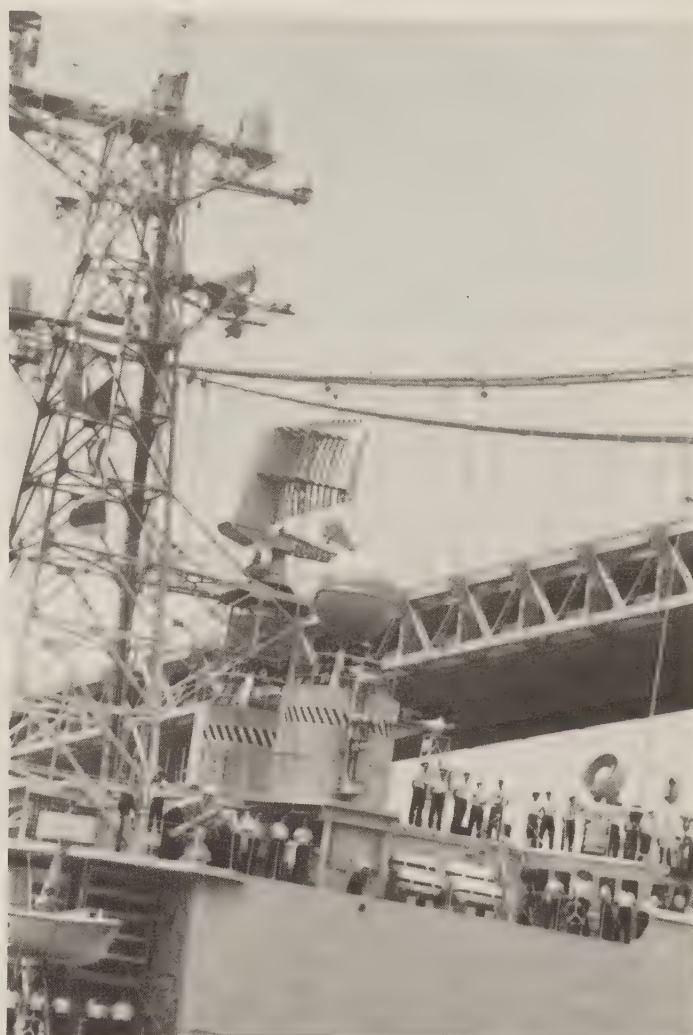
Pulse Width: (i) 0.22 (ii) 0.45 microsec

PRF: (i) 3600 (ii) 1800 pps **Scan Rate:** 60 rpm

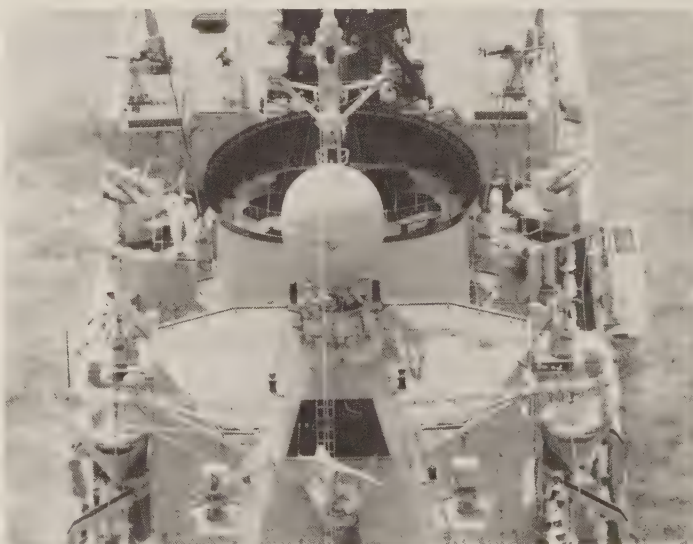
Radar data are for the system as originally developed. The early "eggs" were nearly spherical and had small search antennas (e.g., for Norway and Australia). The U.S. Mk 87 was derived from 1 such version (M22). About 1970 Signaal developed a larger search antenna (for greater gain, to achieve about 20 km greater range) with a larger vertical dimension (hence a narrower beam in the vertical). To accommodate it, the standard egg-shaped radome was enlarged, the portion below the joint being given a short straight section so that the entire egg seemed elliptical rather than spherical. The new search antenna entered service in 1973 and is exemplified by the U.S. Mk 92 system. In each case, the search antenna can scan either horizontally or helically, rising by 1 vertical beamwidth every second (i.e., every 360-deg scan) to reach its maximum height in 4.5 sec. That maximum is 25.5 deg in the case of the 7-deg antenna, and 21.1 deg for the 4.7-deg antenna. During the early 1970s a new 1-MW crossed-field amplifier was introduced. The transmitter was presumably that used in the earlier M44/45, with an added short-pulse mode intended primarily for navigation.

These multichannel WCs can generally be recognized by their egg-shaped radomes. The weatherproof egg saves weight by eliminating the requirement to weatherproof antennas separately; dry air is pumped directly inside. Colocation of the search and track antennas eliminates parallax corrections. Because both antennas use the same transmitter, there is no need to shift range scales between them. The result is very rapid reaction. Similar colocation is used in Goalkeeper (though without a common radome), in the U.S. Phalanx, and in the Soviet Pop Group and Cross Sword fire-control systems. The chief disadvantages of colocation are a relatively low location for the search antenna and possible blind spots in a ship with several fire-control radars. The air tracker is monopulse; surface targets are tracked by TWS operation of the search antenna (scan rate 60 rpm).

The WM-series replaces an earlier M-series (M20, M24, M26, M27, M29) that used the same radars but had much more prim-



The original version of the Signaal "egg," in this case for WM22 on board the Canadian destroyer *Iroquois*, 1986. (Author)



The later, more elongated, version of the Signaal "egg," in this case for WM25, is shown on board the Dutch frigate *Abraham Crijnssen*, 1986. The hemispherical top, housing the tracking antenna, matches that of the earlier version. (U.S. Navy)

itive computers. The latter were digital, but their programs were hard-wired into them, so that they could carry only a very limited set of ballistics. The first Signaal "eggs" appeared on board Norwegian *Storm*-class gunboats (M26), Swedish *Visby*-class frigates (probably M24) and *Spica*-class missile boats (M22), and German *Zobel*-class torpedo boats (M20) in the mid-1960s. The

U.S. Navy tested M22 (as Mk 87) on fast gunboats, and later adopted the WM system as Mk 92.

All examples of the WM-series share a standard weapons-control console and a standard radar (tracker) cabinet; target-designation sights and a lightweight optronic director (LIOD) can be added as required. The weapons-control console contains an SMR-S1 computer, and it in turn can be connected to a horizontal tactical display console. In that case the system becomes a "Mini Combat System," a miniature version of SEWACO. Signaal designated its mini-combat-system versions of the WM20-series by the fire-control number, as in WM25/41. WM26/41 was unique in lacking any separate tactical display console, the command function being exerted from the weapons-control console. Signaal defined a "Compact Combat System" as a WM-series weapons-control system and 2 or 3 tactical data consoles.

Type numbers indicate system capability:

- WM20 is designed to control torpedo and gunfire on board small attack boats. WM20 has 1 air and 1 (with an option for another) surface gun-control channel and 2 torpedo fire-control channels. The system can control 2 light or medium guns against 1 air and 1 surface target, or 2 torpedoes against 2 surface targets. WM20 can track 1 air and 3 surface targets simultaneously.
- WM22 is a simpler system for larger surface ships (such as frigates), tracking 1 air target. This system is intended for use with a long-range air-search radar and can control 2 guns against 1 air and 1 surface target simultaneously. A third gun channel can be added as an option. As an application, the WM22/41 mini combat system controls 2 gun channels. Performance, as of about 1980: air-search radar detection of a 1-m² target at up to 30.5 kyd (height, by helical scan, of up to 25,000 ft); surface surveillance up to the radar horizon; tracking of a 1-m² target at up to 29,000 yd, accommodating a target speed of up to 720 yd/sec. Maximum surface tracking speed was 100 kt in horizontal scan, or 60 kt in helical scan. System reaction time, from detection to firing, was about 6 sec. These performance figures are typical of all dual-antenna (egg radome) systems as they were delivered about 1975.
- WM24 has 1 air and 1 surface gun-control channel (with an option for a third) plus an ASW-control channel; it is the only system in the series with an ASW capability.
- WM25 can control a semiactive surface-to-air missile (providing CWI for target illumination); this system also has 2 gun channels. It can simultaneously track 1 air, 1 surface, and 1 shore target; or 1 air and 2 surface targets. Air targets are tracked by the pulse doppler dish and surface targets by the search antenna in TWS mode.
- WM26 is a simplified system for fire control and navigation, limited to 2 single-purpose guns. WM26 is the only version of the basic system that does not employ the double-antenna radome.
- WM27 has 1 antiaircraft gun channel, 1 surface gun channel, 1 surface-to-surface missile-control channel, and 2 torpedo-control channels. Besides WM20, WM27 is the only system in the series with torpedo-control capability.
- WM28 can track 1 air and 1 surface target simultaneously, plus 1 surface-to-air missile and 2 light or medium guns. This system is license-built (in modified form) in the United States as Mark 92. In its original form, WM28 has 2 gun channels and 1 surface-to-air channel.
- WM29 controls 1 command-guided surface-to-air missile (such as Sea Cat) and 2 gun channels (1 surface only). WM29 is designed to include a Signaal lightweight optronic director (LIOD), which can be used as a secondary tracking channel.

In each case, 1 of the surface gunfire-control channels can be used for shore bombardment.

The series is modular; Signaal, the manufacturer, integrates it into a full combat information system, using a combination of vertical and horizontal displays, weapons-control consoles,

target-designation sights, and optronic directors, plus the characteristic egg-shaped radome.

The egg-shaped radome (diameter 2.39 m, height 3.26 m, weight 780 kg) encloses a pair of antennas fed by a common radar transmitter and stabilized on a common platform. Generally there is a tracking dish above and a cut paraboloid search antenna below. In one case, M26, only the search antenna is used, and it is mounted above the platform. During search, all power is fed to the lower antenna, but once a target has been detected, some power is fed into the tracker. Signaal points out that mounting both antennas on a single platform eliminates errors in transferring a target from search to track. A small ship may, moreover, have only a single position suitable for antenna mounting. The search antenna can also be used to designate to a separate tracking antenna (STIR).

Radar features include digital MTI, circular polarization (CP) for search, and pulse doppler tracking (PDT) for tracking air targets in clutter. The main search radar scans either in fixed elevation or helically. The associated optical sight can be used to track surface targets, or air targets up to an elevation of 5 deg. The optical sight has an 8-deg FOV, and a magnification of 8×. Some versions also had a television tracker.

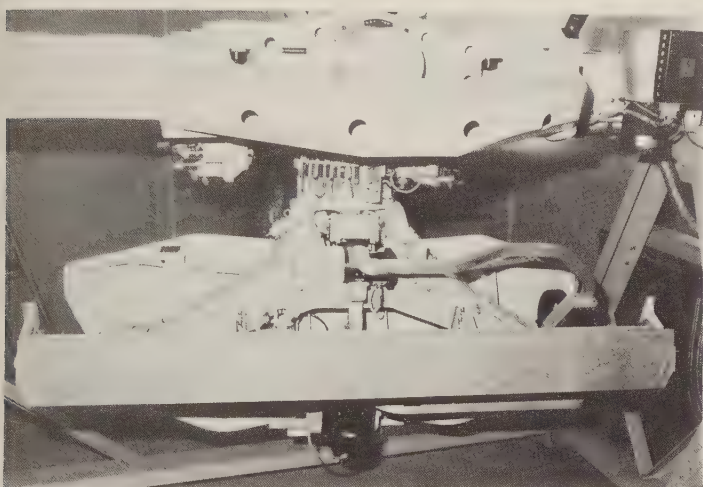
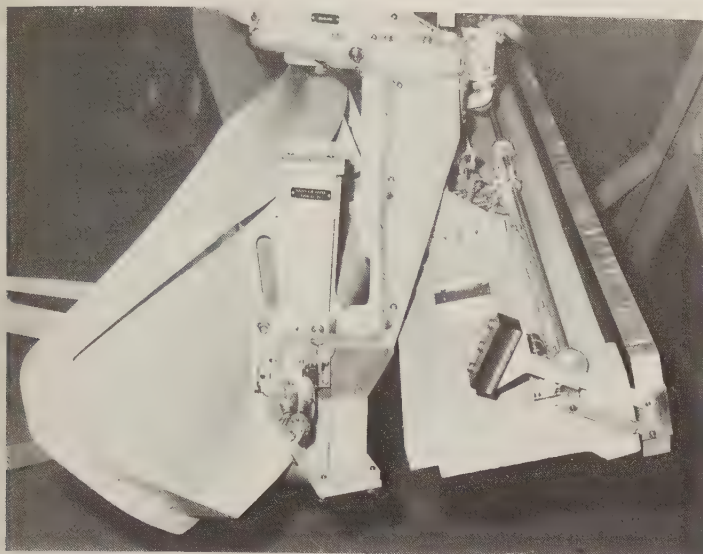
In its original form the system could detect a 2-m² air target at up to 30.5 kyd and at an altitude of up to 24,000 ft (in helical-scan mode). A similar target could be tracked at 29 kyd. Maximum tracking speed for an air target was originally 900 yd/sec (later reduced to 720 yd/sec, probably reflecting the somewhat slower speed of programmable digital computers compared to their hard-wired cousins), and surface targets can be tracked at up to 100 kt (horizontal scan; 60 kt during helical scan). Maximum allowable projectile time of flight was 64 sec (depending on ballistic tables), a figure that was probably determined by the cycle of ballistic calculation and correction. Signaal claimed that system reaction time was 6 sec from moment of detection to opening of fire.

The weapons-control console carries a 16-in PPI, as well as A- and B-scopes and an alphanumeric display. The PPI is an analog type, showing raw radar video plus synthetic data. The associated alphanumeric display shows 16 lines of data (32 characters each).

In 1973 it was claimed that the effect of cumulative improvements, including an enlarged search antenna, had been to double the effective range: 20% from the enlarged antenna, 20% from the use of a tunnel diode amplifier, and 50% from the power increase to 1000 kW by using a cross-field amplifier. At that time the claimed search range was about 25 nm on a 1-m² target.

As of 1979, Signaal was offering a fully coherent traveling-wave transmitter as an option in WM20-series radars, for clutter rejection and ECM resistance. Signaal also offered alternative frequencies for search and tracking, and doppler MTI for clutter rejection (FFT analysis of returning signals to extract their frequency shifts). Fitted with this transmitter, the radar was expected to detect a 1-m² target at 60 km (search mode) or to track it at 50 km. Pulse compression was used for search, so the peak power may seem low. Transmitter characteristics were: peak power 150 kW; search pulse width 12.4 microsec (compressed to 0.2) with PRF of 2000 pps, or 6.2 microsec (compressed to 0.2) with PRF 4000 pps, or 0.2 microsec with PRF 2000/4000 pps; tracking pulse width 0.6 microsec with PRF 12,000 pps for pulse-doppler performance.

Signaal is currently (1989–90) offering an upgrade to existing WM20-series radars, based on 1 applied to German WM27s on board Type 143 fast attack craft. The original Philips spin-tuned magnetron transmitter, which was replaced by a Varian coaxial magnetron in later WM20-series radars, is replaced by a solid-state coaxial magnetron. The original spin-tuned unit had the virtue of providing great frequency diversity, but it was not very stable at any 1 frequency, and its lifetime was relatively short. Moreover, as it degraded, it did so gracefully, and operators could not always be sure that their radars were losing performance. The new magnetron is very stable (for good MTI) and



The back-to-back squintless search antenna added to a West German WM27. (Signaal)

very reliable, and when it does fail, it does so catastrophically so that the operator knows when it has to be replaced. It is tuned by a piston, among 6 crystal-controlled frequencies, for limited frequency diversity.

At the same time, a slotted-waveguide (squintless array) antenna, with a vertical beamwidth of 30 deg that is tilted up at 15 deg, is being added back to the existing 4.7-deg antenna. The existing antenna scans up to 21 deg in 4.5 sec. The new antenna provides much greater instantaneous elevation coverage, and the operator can feed radiation either to it or to the existing antenna. This antenna can be fed either by the 230-kW driver or by the 1-MW cross-field amplifier. The 4.7-deg antenna retains its helical-scan mode. The new antenna has a low gain, and the modification was practical only because the ships were equipped with cross-field amplifiers, which produced sufficient radar power. New software greatly reduces the multipath problem at low angles of elevation. The new software also improves ballistics and prediction calculations.

Signaal offers sidelobe suppression: the combined antenna mounting ring is replaced by 1 carrying a pair of horns (facing outward) as well as a sidelobe-suppressing switching box. The preamplifiers, MTI plus linear amplifiers, cross correlator, test generator, and filter are all replaced. The horns are used for an auxiliary receiving channel.

Signaal also offers multipath/STAE clutter suppression by optimized PRFs and also by installing adaptive threshold circuitry in the MTI canceler. The existing pseudorandom PRF-stagger program is replaced by a PRF-step-stagger program, which divides the PRF range (3200–4000 pps) into 10/11 steps, causing

the STAE pulses to appear in different range bins and so to be rejected by the video correlator (ATD program).

For future upgrades, Signaal is offering to replace the existing magnetron transmitter with a 1-kW TWT (for pulse compression and coherent operation). The resulting digital radar employs FFTs (in place of the earlier analog MTI) to detect moving targets by their doppler shifts. Up to 20 targets can be automatically detected and tracked. Presumably, the TWT involved is the same as that now being introduced in production versions of the STIR fire-control radar for the new Dutch and West German frigates (the Canadian TRUMP project employs the earlier magnetron version).

Signal M20 and WM20 Series Applications:

- M20: Germany (*Zobel*-class torpedo boats, then transferred to Type 343 mine-countermeasures ships)
- M22: Finland (*Turunmaa* class), Indonesia (PB 57-class patrol boats), Malaysia (FS 1500 frigates and the frigate *Rahmat*), Nigeria (formerly on board Vosper Mk 3 frigates), Norway (*Oslo*-class frigates, now removed), Spain (*Lazaga*-class fast attack boats), and Sweden (*Halland*-class destroyers and *Spica*-class fast attack boats, now discarded; survives on board *Alvsborg*-class minelayers)
- WM22: Argentina (Lurssen TNC 45-class FACs), Australia (River-class frigates), Canada (Tribal-class frigates), and Thailand (frigate *Makut Rajakumarn*; WM22/61 in *Chonburi*-class patrol boats)
- WM24: Nigeria (*Erin'mi*-class frigates)
- WM25: Argentina (MEKO 360H2-class frigates), Belgium (*Wielingen*-class frigates), Germany (*Bremen*-class frigates), Greece (ex-Dutch *Kortenaer*-class and Osprey 55-class missile corvettes), South Korea (*Ulsan*-class frigates), Morocco (41 version in frigate *LCol. Errhamani*, FCS version in *Lazaga*-class attack boats), Netherlands (*Tromp*-class destroyers and *Kortenaer*-class frigates), Nigeria (MEKO 360H frigate), Peru (cruisers), Spain (*Descubierta*-class frigates; some may have WM22/41), Thailand (PFMM Mk 16 corvettes, *Ratcharit*-class missile boats), and Turkey (MEKO 200-class frigates)
- WM26: Norway (*Storm*-class fast attack boats), Singapore (110-ft Type B fast attack boats)
- WM27: Germany (S143/143A/143B-class fast attack boats)
- WM28: Argentina (MEKO 140 A16-class corvettes), Bangladesh (*Megna*-class fishery-protection patrol boats), Indonesia (*Hajar Dewantara* training frigate, *Fatahilah*-class frigates, and PSK Mk 5-class patrol boats), Iran (Combattante II-class attack boats), South Korea (*Donghae*-, HDC 800-, and HDC 1150-class frigates), Nigeria (WM28/41 in FPB 57-class fast attack boats), Singapore (FPB 45-class fast attack boats), Thailand (*Prabrarapak*-class patrol boats), and Turkey (WM28/41 in *Dogan*-class fast attack boats).

◆ Sea Sparrow Radar Upgrades

There are 2 new Signaal radar concepts to increase the capability of existing Sea Sparrow missile systems. SIR, a Slaved Illumination Radar, would be controlled by a 3D radar such as SMART; it is similar in concept to the SPG-62 slave illuminator used in the U.S. Aegis system. SIR would be a STIR without its radar components, retaining only its CW illuminator. No prototype has been made.

The alternative is MEMPHIS (Multiple-Engagement Phased-Array Illumination System). A single director can track 4 targets within a 90-deg sector, and the director can rotate to cover the full 360 deg. MEMPHIS uses an X-band reflector composed of numerous small pistons, tightly packed, each driven by what amounts to a loudspeaker motor. Each has 8 alternative positions. The reflector as a whole, then, shows a series of alternative stepped surfaces. It might be termed a Fresnel reflector, in analogy to a Fresnel lens consisting of a series of alternating steps. The direction in which the reflector stares is changed by moving the pistons, and they can move continuously in a ripple.

This motion can also be used to distort the beam produced by the reflector. Although the resulting motion is not as fast as that of an electronically driven phased array, MEMPHIS is much simpler and much less expensive. A proof-of-concept reflector has been built, but as yet there is no full prototype. An operational MEMPHIS would be radome-enclosed.

SPAIN

◆ Dorna

This is a new secondary fire-control system proposed by Inisel, combining a TV and IR tracker with a laser rangefinder/designator and with a tracking radar. Work has been proceeding since 1986, but the Spanish navy has yet to choose a radar type, which may be single- or dual-band (Ka/X). The TV/IR tracker will be based on a TV/IR tracker Inisel uses for a land-based system, Felis. Inisel hopes that Dorna will be adopted for the modernization of Spanish frigates and corvettes.

SWEDEN

The primary electronics manufacturers are Ericsson and Bofors (BEAB). BEAB was formerly PEAB (Philips), formed in 1975 by combining 3 companies of the large Philips industrial electronics group. Philips also owned Signaal and MEL, and Signaal and PEAB had a noncompetition agreement. However, in 1989 Philips decided to sell off its defense arms. It sold PEAB to Bofors (hence the renaming, to BEAB), and it sold majority control of Signaal to Thomson-CSF, ending the noncompetition agreement. MEL was sold to Thorn-EMI.

Most of the Philips (now BEAB) radars are based on a tunable (i.e., frequency-agile) magnetron developed in 1955. This device was intended primarily to solve the problem of echo fluctuation (due to small phase differences from different parts of the target, so that reflections from different parts of the target interfere with each other) and glint (apparent movement of the target echo center, even beyond the physical area of the target). Both phenomena vary with signal frequency and, thus, can be avoided if the radar rapidly changes frequency. The PEAB (BEAB) magnetrons change resonant frequency by spinning a tuner coupled magnetically to an external motor. These magnetrons entered production in the mid-1960s; Ferranti uses a license-built version in the Seaspray helicopter radar.

RADARS

◆ BEAB C/X-Band Radar

Band: C and X

Beam: csc^2 in C-band, linear in X-band

Scan Rate: 30/60 rpm

Antenna Dimensions: 2.4×1.0 m

Antenna Weight: 100 kg [220 lb] (plus 350-kg platform)

This is the primary radar of the 9LV Mk 3 systems. The BEAB X-band radar and the Ericsson C-band Giraffe share a single new antenna to solve the masthead space problem. Both use BEAB displays. The BEAB element is probably the standard 9LV magnetron search set. Signals from both radars are vertically polarized. Because the radar is not sold separately from the 9LV Mk 3 system, it has no separate designation. This is the main radar of the Swedish *Göteborg* class, and it is the target-indication radar of the Australian-New Zealand ANZAC frigate (these ships have SPS-49 for long-range air search). In the Finnish *Hel-sinki-II* class, this antenna (stabilized) serves the Sea Giraffe C-band radar and an X-band navigational radar.

◆ Eagle

PEAB's K-band (35 GHz) narrow-beam (0.8 deg wide) coherent pulse-doppler tracker, intended to work with the Trinity 40-mm gun, was announced in 1988. This radar employs pulse compression to reduce counterdetectability, and there is a special operating MTI mode allowing pulse-to-pulse frequency agility. Two nearby targets can be tracked simultaneously, and

PEAB claims that the inherent multipath error at 10 km is less than 0.4 mrad. PEAB claims that antenna gain is so great (and sidelobes so small) as virtually to preclude any attempt at escort jamming. Peak power is 75 W, and PRF is 30–40 kHz. The radar head weighs 80 kg, and PEAB claims that a sea-skimming missile at an altitude of 5 m can be tracked at 5 km.

◆ Sea Giraffe 50/50HC/100/150/150HC (PS-75)

Band: C (5.4–5.9 GHz)

Beam: 2.1 deg (50), 1.8 deg in larger versions

Peak Power: 15 kW (50, 50HC, and 100); 60 kW (150, 150HC)

Gain: 29 dB (50); 30 dB (50HC and 150HC); 36 dB (100 and 150)

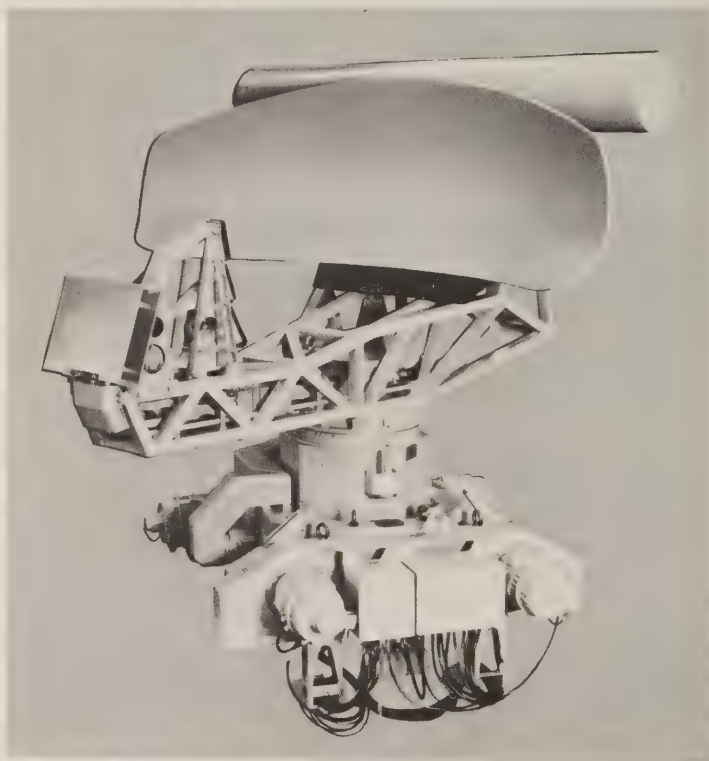
Pulse Width: 3.2 and 6.4 microsec, compressed to 0.3 microsec in surface-search mode. There is also a short pulse (0.2 microsec) for fire control.

PRF: 1000–7000 (depends on mode) **Scan Rate:** 30 or 60 rpm

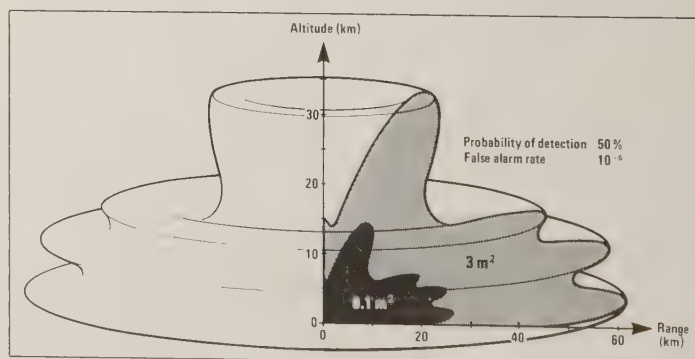
Antenna Dimensions: 2.3×0.7 m (50); 2.4×0.8 m (50HC and 150HC); 2.4×1.8 m (100, 150HC)

Antenna Weight: 250 kg (50); 700 kg (100, 150HC)

Sea Giraffe, announced by Ericsson in 1982, is a family of 5 multipurpose (air- and surface-search, fire-control) naval radars, using 3 different fully stabilized antennas (1 for Sea Giraffe 50, 1 for 50HC and 150HC, and 1 for 100 and 150) and 2 transmitters (1 for Sea Giraffe 50, 50HC, and 100, and 1 for Sea Giraffe 150 and 150HC). Both transmitters operate in C-band and are fully coherent so that MTI can be used for clutter rejection



The Sea Giraffe 150HC 4-beam antenna chosen for the Canadian "City"-class frigates. (Ericsson)



Sea Giraffe 150HC coverage. (Ericsson)

(50–55 dB ratio). In the designations, HC denotes an optional high-elevation antenna to detect missiles diving at angles of 60–80 deg.

Sea Giraffe 50 and 50LW (lightweight) use antennas with single beams; 50LW uses a slotted waveguide. Sea Giraffe 150HC has 4 beams to provide high cover against steep divers. Sea Giraffe 50 and 150HC are stabilized. Sea Giraffe 150HC covers 0–70 deg in elevation. Instrumented ranges are 25, 50, and 100 km.

At least in the case of the Canadian-frigate 150HC, air targets are automatically detected and tracked; surface targets are manually detected and then auto-tracked. Presumably, the surface targets of interest are mixed with large numbers that are irrelevant (e.g., fixed points ashore), and a radar attempting to track all of the targets it can see would be overloaded.

These radars are all derived from the Ericsson Giraffe (PS-70R) land air-defense radar, so named because it is carried at the upper end of a tall tower. The main difference from Giraffe is the greatly improved range resolution (through pulse compression), so that the radar can distinguish small targets close together.

Waveform, PRF, and pulse width can all be varied to combine short- and long-range performance, e.g., for search out to 100 km or for high-accuracy search at 20–25 km. All versions are frequency agile both in MTI and in non-MTI modes, the frequency changing about 4–10 times while the beam is on a target. Antennas have very low sidelobes to reject standoff jamming; all are of csc^2 form, and all have integrated IFF via their antenna feeds. There are separate air- and surface-search modes. For air search, pulses are transmitted and received uncompressed, their nearly pure frequencies making for effective digital MTI performance. For surface search, the signal is modulated at the TWT by a linear FM signal (a chirp) produced in a surface acoustic wave (SAW) delay line.

Radar frequency was chosen partly on the basis of the requirement for clutter rejection through MTI. MTI performance varies with both the radar frequency and the character of clutter. Sea clutter has a typical velocity of 10 m/sec; and rain and chaff speeds depend on wind velocity: 25–30 m/sec are not unusual. The longer the wavelength (the lower the frequency), the higher the clutter velocity at which MTI begins to lose its efficacy. For X-band that velocity is about 10 m/sec, for C-band about 20 m/sec, for S-band about 35–40 m/sec, and for L-band about 70 m/sec. This characteristic limits selection to C-band and lower frequencies, Ericsson preferring the highest possible frequency to limit antenna dimensions and weight. On the other hand, the higher the frequency, the better the radar's resistance to jamming, and higher frequency produces less lobing loss against low-flying targets.

Ericsson chose a TWT rather than the more usual magnetron transmitter for its better MTI improvement factor (typically

50–55 dB rather than 25–30 dB in an incoherent magnetron, i.e., successful detection in clutter 100 times as strong); for its ability to suppress STA echoes (which become a serious problem for a radar operating at short instrumented range; the coherent radar remembers the phase of the transmitted pulse and so can reject any returning STA pulse because it will have the wrong phase); for its ability to combine MTI with frequency agility (the radar sends a burst of pulses with 1 frequency, then shifts to another); and for its flexibility in waveform (the TWT merely amplifies the incoming signal, whereas the magnetron both creates the signal and amplifies it). Sea Giraffe exploits this last quality of the magnetron by using both long uncompressed pulses (for air search) and compressed pulses of the same length (for surface search).

For air search, the signal processor uses MTI to eliminate clutter. The operator can avoid blind speeds by shifting or staggering PRF. MTI reduces sea clutter by 40 dB by using shifted PRF, or by 50 dB by using staggered PRF. The MTI can compensate for own-ship speeds of up to 45 kt. For surface search, the radar moves among 4 frequencies to avoid spot jamming. This mode employs pulse compression and instantaneous gain control (IAGC). The operator can select a combined mode, in which every 2 air-search scans are followed by a surface-search scan, and would choose to watch either air- or surface-search video. Finally, there is a fire-control mode employing a narrow pulse, in which the radar scans a narrow area around the target. The operator designates targets, and shell splashes can be spotted with an accuracy of 0.1 deg and 20 m.

Sea Giraffe 50 and 50HC were indeed for fast attack craft. Maximum range against a 0.1-m² target (single scan, 50% probability of detection) is about 18–19 km; a 4-m² target at low altitude can be detected at about 40 km by version 50 (45 km by 50HC). Accuracy is 0.3 deg in azimuth and 25 m in range; resolution is 1.7 deg in azimuth and 45 m in range.

Sea Giraffe 100 and 150 were intended for offshore-patrol vessels and fishery-patrol vessels. Sea Giraffe 150HC was intended for larger attack craft, corvettes, and frigates. Maximum range against a 0.1-m² sea-skimmer is about 27 km; against a 4-m² airplane, about 63 km. The HC suffix means high (angle) coverage.

Sea Giraffe 50, 50HC, and 100 are designed for minimum equipment below decks, all the radar units being mounted in a single cabinet.

The Swedish Navy ordered Sea Giraffe for its modernization of the Spica-II-class fast patrol boats, and the first boat completed her trials in September 1982. Sea Giraffe 150HC was ordered for the Canadian "City"-class frigates.

A modified system, embodying a new openwork antenna and a second (3-cm) transmitter, is to equip the new Swedish Göteborg-class corvettes. Philips supplies the 3-cm transmitter and the antenna; the rest of the system is the existing Sea Giraffe 5.5-cm transmitter. No designation has been released.

Coastal Giraffe 75F is a new version, with an instrumented range of 75 km. The radar should be able to detect a 3-m² target, flying at about 2000 m, at a range of about 100 km; a 0.1-m² target flying at about 1000 m should be detectable at about 43 km.

◆ 9GR600

Band: X (8700–9500 MHz, with 400–450 MHz bandwidth)
Beam: 1.1×7 (1×3) deg **Peak Power:** 200 kW
Gain: 35.5 (38) dB **Pulse Width:** (i) 1 microsec (ii) 0.25 microsec
PRF: (i) 1000 (ii) 3000 pps **Scan Rate:** up to 60 rpm
Antenna Dimensions: 2.1×0.3 m (2.7×0.7 m)
Antenna Weight: 260 kg including turntable

Data refer to the radar with the 9GA209 antenna used in the 9LV200 fire-control system. This antenna is stabilized, and it can scan helically, elevating its beam to cover up to 40 deg vertically (20 deg vertically as used in the 9LV200 Mk 2 system). Elevation and scan are independent, so the operator can trade off coverage against data rate. Data in parentheses refer to the 9GA218 antenna. This latter can also be used at L-band



Sea Giraffe on board a Spica-II-class attack boat, at the masthead. The gun is a Bofors 57-mm/70 Mk 2. The box launchers aft carry RBS 15 missiles. (Ericsson)

(1010–1110 MHz and 1250–1350 MHz), with a 6×20 - or 8×25 -deg beam (gain 20 or 17 dB, respectively).

The transmitter is a tunable magnetron, with a tuning rate of 1000 cycles/sec.

The same radar is used with a stabilized 9GA202 antenna in the TORCI torpedo fire-control system, with the 9GA205 in the Mareld coastal radar, and with the 9GA300 antenna in the Subfar submarine set. Characteristics of these antennas are:

	9GA202	9GA205	9GA300
Dimensions	2100 × 560 mm	4500 × 625 mm	1000 × 140 mm
Weight	135 kg	225 kg	85 kg
Beam	1.1×4 deg	0.6×4.5 deg	2.4×16 deg
Gain	37 dB	40 dB	26 dB
Scan	to 60 rpm	to 40 rpm	to 24 rpm

9GA202 can spiral-scan, up to 20 deg elevation (this optional feature adds 25 kg to the antenna's weight).

◆ 9LV200 Tracker

Band: Ku (bandwidth 670 MHz) **Beam:** 1.3 deg

Peak Power: 65 kW **Gain:** 40 dB

Pulse Width: 0.2 microsec **PRF:** about 2000 pps

Antenna Dimensions: diameter 1 m

The antenna is a stabilized monopulse Cassegrain, and television or IR trackers (including a laser range-finder) can be mounted alongside. Processing is MTI, and frequency can be shifted randomly on a pulse-to-pulse basis. The hydraulic drive can slew at 85 deg/sec.



9LV200 search (top) and tracking (bottom) radars. (PEAB)

The transmitter is a tunable magnetron, with a tuning rate of 1000 cycles/sec.

9LV200 Mk3 employs a new coherent Ku-band (15.9–17.1 GHz) tracker, using a new TWT transmitter. This tracker operates over a bandwidth of more than 10% of its base frequency, among more than 100 frequencies. It uses multiple PRFs and pulse widths, but in all cases pulses are compressed in its receiver to 0.2 microsec. The new Cassegrain antenna has a multi-mode feed to achieve low sidelobes in both its sum and difference channels. Operating modes are pulse doppler, MTI, frequency agile, and fixed frequency.

With the radar are mounted a television (FOV 42×31 mrad), an IR camera (8–12-micron band, FOV 52×35 or 157×105 mrad, with closed-cycle Stirling cooling), and a laser range-finder (Nd-Yag, 1.06-micron wavelength, peak power 4 MW, PRF 10 Hz). The associated TV/IR tracker can follow either a centroid or an edge, with an accuracy of better than 0.15 mrad. The radar of the 9LV200 Mk 3 system is designated 9GR400.

◆ ELSA

ELSA is a lightweight 3D radar, under development by Ericsson and Marconi, for fast attack craft and frigates. This radar scans only in elevation (it rotates to scan in bearing), by phase shifting (by about 30 ferrites) rather than by the frequency scanning of current U.S. radars. Like Sea Giraffe, ELSA will operate at a wavelength of 5.5 cm and presumably will use a Sea Giraffe transmitter. Marconi is responsible for the antenna and beam-steering computer. The carbon-fiber antenna is electronically stabilized so that it weighs about one-third as much as a conventional 2D stabilized antenna.

This approach is interesting because it suggests that the addition of a special antenna and a small beam-steering computer can convert an existing 2D radar to 3D operation.

A sketch released by Marconi in 1989 shows 10 beams, providing solid coverage out to 60-km range and up to a height of 20 km, the lower beams reaching greater ranges (i.e., provided



ELSA, the new Ericsson-Marconi 3D radar, as sketched by Marconi, 1989.

with more energetic pulses). The drawing suggested a maximum elevation angle of about 85 deg, each beam being about 6 deg wide. Marconi suggested that the new radar could replace current search radars in small warships, and that it could support longer-range search radars in larger ones, functioning as a target-indication radar to cue a fire-control tracker onto a target. For example, it could replace Sea Giraffe in the Canadian "City" class. This radar will scan at 30 rpm, and it will operate in C-band (5 cm). Approximate antenna dimensions are 2×1 m.

◆ PILOT

Band: X (9345–9405 MHz) **Beam:** 1.2×20 deg
Average Power: 1 W **Gain:** 30 dB
Frequency Sweep: 50, 25, 12.5, 6.25, 3.125, 1.5625 MHz
PRF: 1000 pps **Scan Rate:** 24/48 or 20/40 rpm
Antenna: single or dual 5-ft slotted-waveguide
Antenna Weight: 55 kg single antenna; 90 kg for dual antenna [121/198 lb]

PILOT is a naval low-probability-of-intercept ("quiet") radar that uses frequency-modulated continuous-wave (FMCW) technology. Radar range is a function of average radar power, not of peak power. However, radar intercept receivers are triggered by the presence of a powerful peak signal; they do not sense the build-up of radar energy over time. The greater the pulse repetition rate, the closer the average power comes to peak power; conversely, the lower the peak power must be to provide useful amounts of average power. Ultimately, then, the least detectable way of providing sufficient average power would be a continuous radar transmission (CW). If continuous transmission occurred at a pure frequency, no information would be gained. In PILOT, the transmission frequency varies so that information can be recovered. This scheme seems analogous to the operation of an FM radio (as contrasted with normal radar, which is like an AM radio). It seems possible that FM transmissions are also easier to receive than standard AM transmissions (as most radio listeners have discovered), so that the average power level can be reduced, compared to that required by a conventional radar. PILOT uses 512 range-resolution cells; and at short range, resolution is typically about 3 m.

CW radars typically require separate transmitting and receiving antennas. However, a reflected-power canceler (RPC) makes it possible to use a single antenna. The RPC subtracts a sample of the transmitted signal from the received signal. In the data above, both antennas transmit and receive; the dual antenna adds about 25% more range.



PILOT. (Signaal)

PILOT is a joint venture of Signaal, Philips Electronics of Sweden, and the Philips Research Laboratories in the United Kingdom. PILOT was announced (in April 1988) at the British laboratory. The name means Philips Indetectable Low-Output Transceiver, and the radar is to be marketed jointly by Signaal and Philips of Sweden. It was announced in the fall of 1988 that PILOT would equip the new Swedish Göteborg-class corvettes, presumably as a stealthy navigational radar.

It was announced in December 1989 that PILOT had been tested as the navigational radar of the Dutch frigate *Jacob van Heemskerck* and also on board the German trials ship *Walther von Ledebur*. In one case a PILOT-equipped ship was able to turn on her radar during a radar-silence exercise without being detected by ships operating in company with her. PILOT also ran trials in the Baltic on board a Swedish *Spica*-class gunboat.

As of mid-1989, Philips and Signaal were considering several new versions for airborne and submarine installation. Signaal was in contact with submarine radar mast manufacturers in Germany (IKL), Italy (Riva Calzoni), and Britain (Barr & Stroud). PILOT can also use an existing navigational radar antenna, the operator switching between it and the conventional set.

COAST DEFENSE

◆ 9KA100

PEAB's electro-optical coastal-artillery fire-control system consists of a sighting unit (Kobra) and a ballistic computer. Kobra incorporates a laser range-finder, and the pedestal can carry an LLLTV or an infrared imager. This device is used to supplement the heavier 9KA400 and 9KA500 and also, as a stand-alone unit, to modernize older fixed or mobile coastal-defense batteries. At least 20 have been ordered, for use in Sweden and abroad.

◆ 9KA400 (Mareld/Kastell)

9KA400 are the current Swedish fixed coastal fire-control systems. The original Mareld entered service in 1965, and a digital version became operational in late 1976. A Mk 2 version is now in production. Sweden and at least 4 other countries, including Norway and Spain, ordered at least 70 Kastells, and Inisel produces the 9KA410 version under license. See 9KR400 for details of the radar. The digital computer is the same type as used in the 9LV200 Mk 2 naval fire-control system. 9KA400 is made by PEAB.

◆ 9KA500 (Kardinal)

PEAB's mobile coastal-artillery fire-control system is derived from the fixed 9KA400. There are 2 alternative versions, using 2 antennas: GA250/K (K-band, 15.9–17.1 GHz) and GA250/X (X-band, 8.5–9.6 GHz). Each is 2.3×0.55 m, the different frequencies making for different beams (respectively, 0.7×2.2 and 1.2×4 deg, gains 42 and 36 dB). Both are horn-fed reflectors, scanning in 2 alternative speeds (ratio 1:2, in the 6–60 rpm range). The K-band version gives the same precision as 9KR400 in a lightweight mobile form but has lower peak power (65 kW rather than the 200 kW of the X-band version). On the other hand, the K-band version suffers less from multipath.

In fixed form, 9KA500 is designated 9KA400 Mk 3 Kastell; it has been sold to Norway. 9KA500 is designated ARTE 727 in Swedish service. Each m/80 coastal battery has 2.

◆ 9KR400

Band: X (8700–9500 MHz) **Beam:** 0.6×4 deg
Peak Power: 200 kW **Gain:** 40 dB
Pulse Width: 1 or 0.25 microsec
PRF: 1000 or 3000 pps, respectively **Scan Rate:** up to 40 rpm
Antenna Dimensions: 4.5×0.625 m
Antenna Weight: 260 kg (including turntable)

The standard Swedish coastal-artillery radar, 9KR400 employs a 9GR600 X-band frequency-agile transmitter and a 9GA205 antenna. 9KR400 is the main sensor of the 9KA400 Mareld coastal-artillery fire-control system, which is also used by Spain, and of the 9CSI600 STINA naval command system. This radar is used by Spain and Yugoslavia, in the latter case

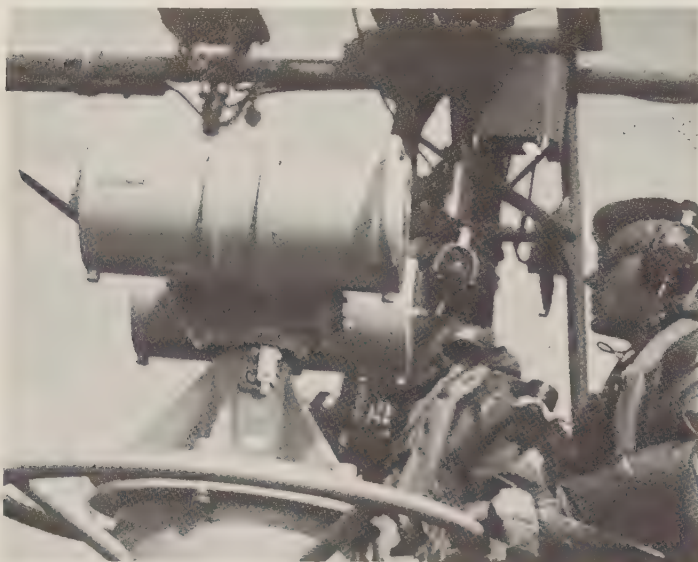
integrated with 9LV200 fire-control systems on board fast attack craft.

OPTRONIC SYSTEMS

♦ TVT-300

The simple SAAB optronic director consists of a television camera on a gyro-stabilized platform, tracking electronics, and a display console. Targets are acquired either manually or from a search radar. The operator moves an electronic gate over the displayed target to initiate autotracking. The camera tracks the contrast between the target and its background (i.e., presumably the edge of the contrast rather than the centroid of the target).

Users: Norway (*Sleipner*, *Hauk*, and *Storm* classes) and possibly Singapore (110-foot Type B class).



TVT-300, a television sight. (Saab)

♦ EOS-400

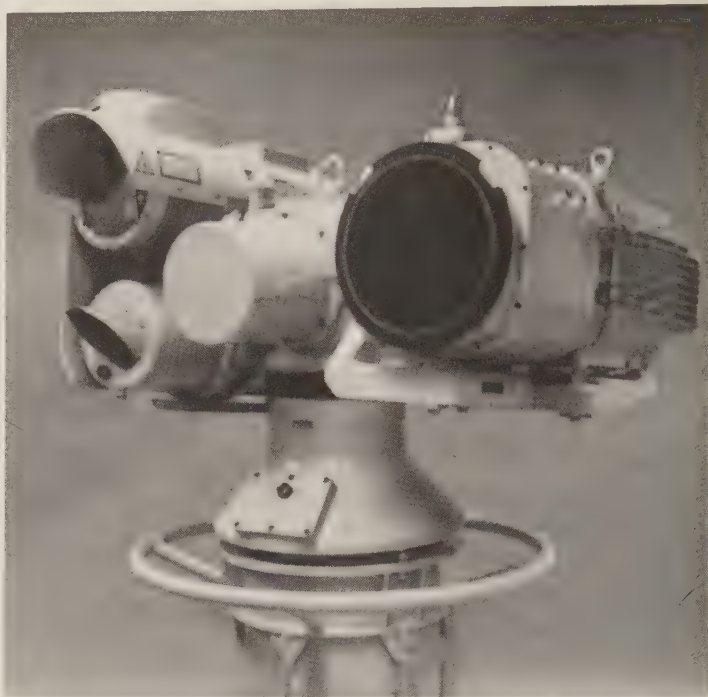
SAAB's optronic director, announced in 1979, incorporates an automatic television tracker and a laser range-finder. The target is designated using coarse data from an associated radar, and a below-decks operator locks on the television tracker for auto-tracking. The operator can also manually track by joystick. The system can continue to project the position of a target by memory when visibility is poor or when the target is temporarily obscured, e.g., behind trees. The tracker locks onto the target again when it reappears. The tracker also has an optional surface-target search mode.

One or two weapons can be slaved to the director, ballistics being computed by an associated microcomputer. Elevation limits are $+85/-30$ deg. Reaction time: operator time to lock on is 1–2 sec, and gun data calculation time for a target approaching at low altitude is 3 sec; maximum platform transient time (180-deg slew) is 3 sec. Slewing speed is 150 deg/sec in both train and elevation.

The television camera is a 40×30 -mrad FOV, and a 300-mm focal length; the laser range-finder is an Nd-YAG type pulsing at 10 Hz, with a maximum effective range of about 20 km. Range accuracy is 4 m for ranges less than 5 km, and 5 m for greater ranges. An optional thermal imager has a 52×35 -mrad FOV. The television tracker is digital and uses correlation tracking; it can deal with contrasts as poor as 5%. Calculated maximum tracking range, for a target occupying 1% of the full picture frame, and with a contrast of 60%, in a situation where visibility is 23 km, is 14 km. Angular tracking accuracy is 0.4 mrad. The entire platform is roll- and pitch-stabilized.

The director proper weighs 220 kg, and its swing circle is 1.006 m in diameter. Below-decks equipment adds another 405 kg.

EOS-400 was conceived as intermediate between TVT-300 and EOS-500. It is on board the Finnish *Turunmaa* class.



EOS-400. (Saab)

♦ EOS-500

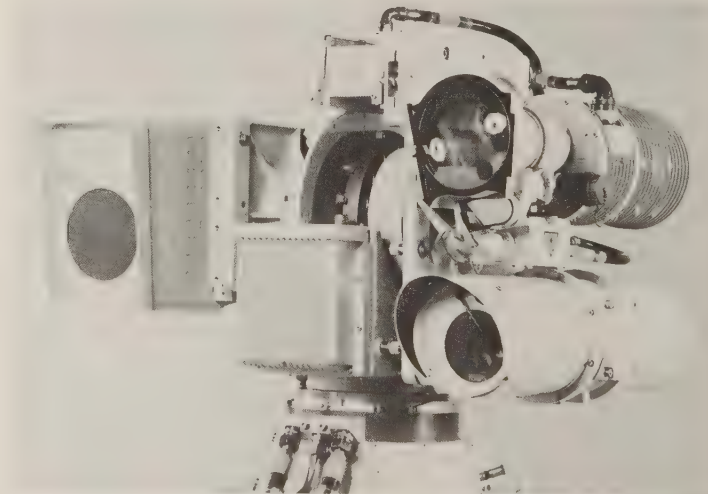
EOS-500 is a more sophisticated equivalent of EOS-400, usable either autonomously or as part of a larger fire-control system. On designation of a target the system is automatically turned onto the appropriate bearing, the operator scanning the sensor head vertically by joystick. The operator then manually tracks until the target is within a gate, when the switch to autotrack can be made. Like EOS-400, EOS-500 can memory-track in bad or obscured visibility.

The first example was built for the Swedish coast-defense artillery.

FIRE-CONTROL SYSTEMS

♦ 9LV100 Series

This lightweight optronic fire-control system for small patrol boats (75–100 tons) is manufactured by PEAB. The director car-



The 9LV100 optronic director, carrying an IR camera and gyro on the left, a laser range-finder on the upper right, and a television camera on the lower right. The most basic version of the director lacks the infrared camera. (PEAB)

ries a SAAB television camera and an LM Ericsson laser ranger (wavelength 1.06 microns, PRF 10 kHz) and is comparable to the Signaal LIOD. A Philips USFA thermal camera (8–13-micron range) is available as an optional extra. The optronic director is based on KALLE, a ground antiaircraft system (using the 40-mm/70 Bofors gun) in service with the Swedish Army. The associated surface-search radar is an unstabilized standard navigational type, operating in S-band for maximum aircraft detection range (15–20 km). The radar has both long and short pulses, for, respectively, search and navigation. In KALLE land tests, which should approximate the 9LV100's performance, a 40-mm/70 was able to place 80% of 300 rnds within lethal radius (5.5 m) of a target at 2000–3000 m, and average reaction time was about 5 sec.

This system was announced in 1977 and thus was developed after 9LV200. The first was for the Finnish minelayer *Pohjanmaa*, and others were sold to Bahrain and to Malaysia.

LV indicates antiair warfare (luftvarn).

◆ 9LV200 Series

The 9LV200 is a fast-patrol-boat fire-control system, designed initially for the Swedish *Spica* class, to replace the Dutch Signaal M22 of the *Spica-I* class. The requirement, issued in 1968, emphasized defense against antiship missiles, using a new Bofors 57-mm/70 gun with special ammunition. The system also had to be very compact, given the small platform for which it was intended. PEAB (now BEAB) won the competition in 1969, using its own broad-band pulse-to-pulse frequency-agile radar transmitter (a spin-tuned magnetron) as well as a new type of motor and bearing promising very high tracking accuracy. Both were needed to detect, track, and engage small targets at relatively low altitude in a very cluttered environment. The pulse-to-pulse agility (frequency diversity) would seem to eliminate the STA problem for longer-range targets.

This system is normally integrated with Ericsson EPLO command/control consoles, so that a typical missile boat will have an EPLO horizontal 3-operator console, plus 1-operator 9LV200

consoles (with 12-in CRTs) for gunfire control (separate units for AAW and antisurface) and, if required, also for torpedo control. The associated mainframe computer, which conducts the actual fire-control calculations, is a Philips P800. The Mk 1 version of 9LV200 employs a hard-wired version of the computer; Mk 2 introduced the programmable digital version. Mk 2.5 introduced a new high-level RTL 2 software language. In Mk 3 distributed computers located in the consoles, and connected by a data bus (LAN), replace the single mainframe. Some versions of Mk 3 also include the command/control element formerly supplied by the separate (albeit integrated) EPLO consoles and their associated computers. In other cases, such as the Danish Standard Flex 300, the command/control consoles are still separately supplied.

The Royal Swedish Navy designates the Mk 1 computer as ARTE (*Artillerieldledning*) 722 (*Norrkopping* class). The equivalent Royal Danish Navy designation, applied to the *Willemoes* class, is Rakel 203 Mk 1 (Rakel means *Radar Kanoneldledning*). The Royal Swedish Navy designates Mk 2 as ARTE 726 (*Hugin* class; 726E in the *Stockholm* class). The PEAB designation for the *Stockholm*-class system is 9LV300 (see below). The associated torpedo fire-control system is TORCI, which is described separately in the ASW section.

Mk 1 is fitted to the Swedish *Spica-II*-class missile boats, to the experimental *Jaegaran* (prototype of the *Hugin* class), to the Danish *Willemoes* class, and to the Yugoslav *Rade Koncar* (as 9LV202). The Malaysian *Handalan* class (*Spica-M*) is equipped with a 9LV212 system.

Mk 2 was introduced in 1977 for the Swedish *Hugin* class. Export versions include 9LV223 (Bahreini *Ahmad al Fateh* class), 9LV225 (Finnish *Helsinki* class), and 9LV228 (Kuwaiti *Istiqlal* and *Al Boom* classes). Other export versions equip the Iraqi training frigate *Ibn Khaldun* and the UAE *Baniyas* class, and later units of the Yugoslav *Rade Koncar* class have Mk 2 systems, but precise designations are unknown.

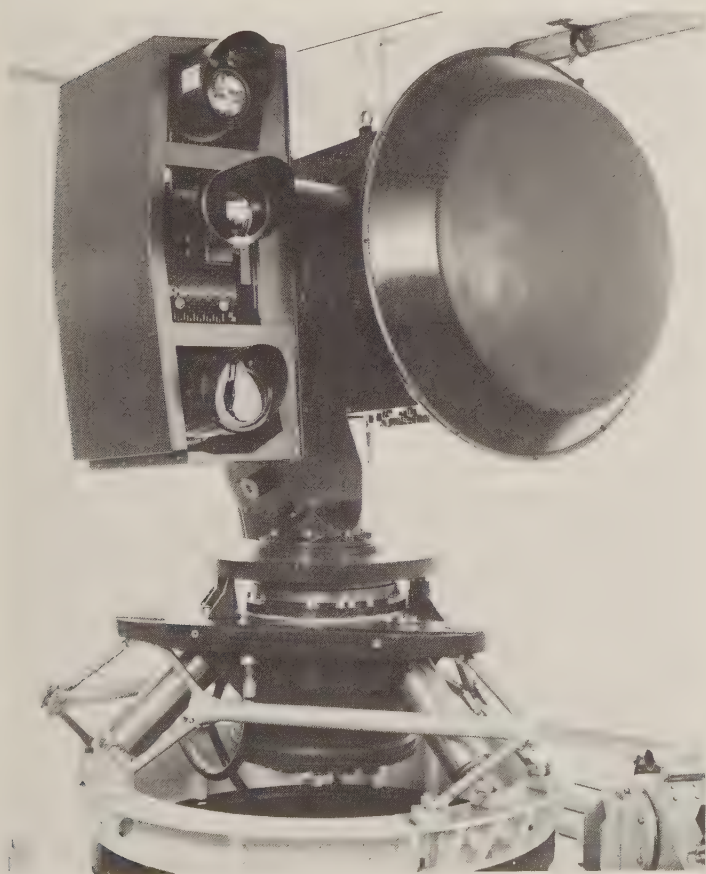
Mk 2.5 versions include 9LV230 (Malaysian *Musytari*).

Mk 3 has been adopted for the Swedish *Göteborg*, for the Danish Standard Flex 300, and for the later units of the Finnish *Helsinki-II* class. Development began late in 1980 and was completed in 1985, the first production contract (for the *Göteborg* class) following in December 1985.

Mk 1 was conceived as a family of systems to control 1 or more dual-purpose guns (40–120-mm) simultaneously against 1 or more targets, for 80 tons and up. Its main sensors were a stabilized 200-kW X-band target-indication radar (which would also be the main search radar for systems installed on board small warships) and a 65-kW Ku-band monopulse target tracker (with Cassegrain antenna) mounted coaxially with a television tracker (such as the TVT-300 optronic director, described above). The search radar also functions as the surface-target tracker (TWS operation at 60-rpm scan rate, as in the *Seafire* system described below). It scans helically, its feed rising as it rotates to tilt its beam upward.

For a larger ship, 9LV200 was designed to work with a longer-range L-band pulse-doppler air-search set, an Ericsson Sea Giraffe that replaced the 9LV200 search set (e.g., in the Swedish corvettes and on board the training ship *Carlskrona*). The design also allowed for pulse-doppler operation of the tracker, to improve its performance against low fliers.

The main displays are a 16-in true-motion (TM) PPI for surface targets, plus a 12-in PPI in the main control space and a display unit with a north-stabilized relative motion display. There is also an operator television display, taking the output from the camera mounted with the tracking radar. The system operator designates air targets from the 12-in PPI, and the separate tracker automatically tracks them. Surface targets are designated from the PPI to a B-scope (for rate-aided manual tracking) or to the main search radar's TWS memory, as in *Seafire*. The system can, therefore, track and engage 2 targets (1 surface and 1 air) simultaneously. As in *Seafire*, the fall of shot can be observed on the B-scope; in this case it can also be observed by television using the tracker A-scope to detect misses in range.



The 9LV200 Mk 3 director, with television, laser, and infrared camera on the left. (PEAB)

Thus, although the system was designed for very quick reaction, it appears to have been conceived too early to benefit from the automatic radar detection and tracking techniques embodied in, say, Phalanx or Goalkeeper.

Mk 1 uses a hard-wired computer with limited memory for either ballistics or targets. Mk 2 can maintain up to 16 tracks in TWS mode. The manufacturer estimates that a target can be detected at 9 km (with some margin), designated at about 7.5 km (5 sec after initial detection), with loss of tracking quality because of multipath occurring at about 6 km (9 sec). At that point the system shifts to IR tracking, the target symbol being positioned on the IR display at about 4.8 km (12 sec) with IR lock-on achieved at about 4.3 km (14 sec). Fire begins at a range of about 3.7 km (15–16 sec) and becomes effective at about 2.8 km (i.e., after about 19 sec). These figures are for a 0.1-m² sea-skimmer (altitude 2–3 m, speed 333 m/sec, or about 650 kt).

The current Mk 3 uses different radars and also emphasizes standardization of consoles, computers, programming language (ADA), data bus (Ethernet), and interfaces. The basic system consists of a C-band TWT (pulse compression) search radar, a fire-control channel (including a new pulse-compression monopulse tracker), a gun-control (surface-fire) channel, an interface unit, a video distribution unit, a C3 processor (with data base), and control consoles. ECM and an X-band radar can be added. The system has sufficient capacity to add more tracker channels, a CIWS-control channel, SAM and SSM control, ASW functions, helicopter control, and additional EW capacities. Several of these options have been realized in the Australian frigate system described below under the 9LV400 series.

In the *Göteborg* class, the search radar is a dual-band (C/X) unit, with a separate high-beam C-band antenna, made of "air porous" material to reduce wind loading. The X-band channel may be used with a stealthy PILOT radar (see above) or with a conventional slotted-waveguide set.

The standard console is a 3-CRT (one 20-in for color or random scan, two 12-in to display video or tables) work station. There are 2 touch-input boards on which variable menus can be displayed (equivalent to variable action buttons), a standard keyboard, and 1 or 2 "joy-balls" (a mix between joysticks and trackballs). The associated single-board CPU is based on a Motorola 68020 processor; it carries 4 Mbytes of RAM (random access, i.e., working, memory) and 256 kbytes of EPROM holding permanent programs. There are 3 serial channel interfaces. Typically a ship will have a tactical console, a weapons console, and (optionally) an EW console. The consoles are tied together by a dual Ethernet bus, each of whose elements has a capacity of 10 Mbits/sec. The bus can accommodate up to 100 nodes per segment, far beyond the requirements of 9LV200.

The 9LV systems are descended from a series of Philips torpedo fire-control systems of the 1950s (see the Antisubmarine Warfare section). A late 1950s system, RATSI, was the first in the series to use radar to track and localize the target. Evaluated in a destroyer, RATSI showed that it could display the fall of

shot. In the mid-1950s a gunfire control system, PROSIT, displayed target and hit data, but had no ballistic computer. The next system, SLAC, introduced a ballistic computer. Philips introduced a corresponding ASW FCS for Swedish destroyers in 1958. All of these systems became extinct when the Swedish destroyers were stricken (the only foreign application was a pair of Colombian destroyers, now also stricken).

◆ 9LV300 Series

This WCS for 250–400 ton vessels is manufactured by PEAB. 9LV300 consists of 9LV200 plus 9LV100. This system is on board Swedish *Spica*-III (*Stockholm*)-class fast attack boats. This system can handle 2 air targets simultaneously; its search radar operates in TWS mode to control antiship missiles. The Royal Swedish Navy designation for the system, as installed on board the *Stockholm* class, is ARTE 726E. The Omani *Dhofar* class is equipped with 9LV307 (but *Dhofar* herself is equipped with a Plessey AWS-4 radar in place of the usual 9LV-series search set). There is also a 9LV331 (Bahreini 62-m Lurssen boats) version.

◆ 9LV400 Series

This WCS for frigates and corvettes up to 1450 tons, by PEAB, was announced in 1978. 9LV450 incorporates ASW as well as antiaircraft and antiship fire controls and is suited to a flotilla leader carrying an ASW helicopter. The 450 designation indicates a system with ASW capability added (" + 50"); similarly, 9LV250 would be 9LV200 plus ASW.

9LV400 is installed on board the Swedish training ship *Carlskrona*. Its EPOs (see the Surveillance and Control section) employ 23-in PPIs, and it has a high-capacity TDMA data link. The Royal Swedish Navy designation is *Stridssock Eldlednings System for Marinen* (SESYM). As a training ship, *Carlskrona* has 2 CICs, 1 duplicating that of a *Hugin* and the other that of a *Stockholm*.

9LV450 will equip the new Swedish corvettes of the *Göteborg* class. It will incorporate ARTE-726E (i.e., 9LV300) for gun fire control, as well as RCI-400 (missile fire control), TORPE (torpedo fire control), 9AU300 (ASW fire control), and 9CM300 (ECM control).

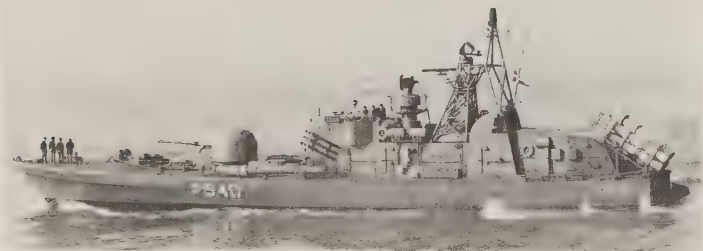
9LV453 has been selected as the combat system of the Australian-New Zealand version of the MEKO 200 frigate. It is described (in the Surveillance and Control section) under tactical data systems.

◆ Seafire

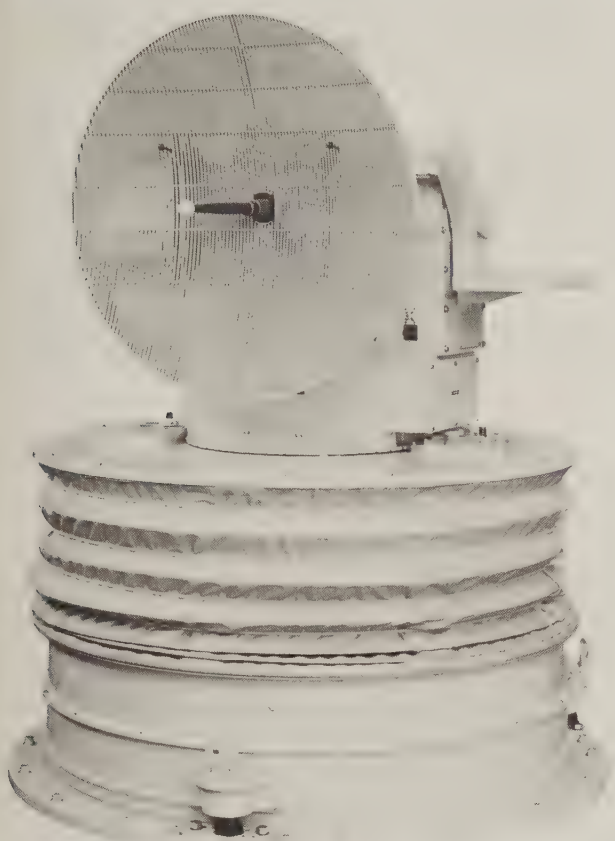
Seafire was an integrated PEAB WCS for fast attack boats, developed from the TORCI torpedo fire-control system of the Norwegian *Snogg* class. It competed with the Signaal WM-26 system of the Norwegian *Storm* class (armed with one 75-mm and one 40-mm gun, 4–6 Penguin missiles, and a 57-mm flare launcher) and was presumably a forerunner of the 9LV200-series system in the Swedish *Hugin* class. Seafire retained the special-purpose analog computer of the earlier TORCI, which used electromagnetic components. It incorporated 3 separate sets of 75-mm ballistics, among which it could switch rapidly. No 40-mm ballistics were incorporated, on the theory that the gun's range hardly merited such sophistication.

The search radar was the standard PEAB stabilized X-band 9LV spiral-scan search set described above, for continuous surface and limited air search. It could be provided with 2 magnetrons for improved ECM resistance. There were 2 displays, a PPI and a B-scope for target tracking and spotting. The system could also maintain indirect fire against a short target. Seafire included a 3-axis stabilized periscope as a backup for target indication and optical tracking of surface targets. Alternatively, the system could incorporate a television sight.

The radar scanned at 60 rpm and tracked surface targets by TWS. Targets were designated to the tracking memory by trackball on the radar console. One such target could be displayed on the B-scope, which also showed the fall of shot. The radar generally used regenerative rate-aided tracking, monitored by



The Danish missile boat *Bille* is equipped with a 9LV200 fire-control system, including the 9GA208 search antenna (on the masthead platform). The slotted-waveguide is designated NWS-2 in the Danish Navy. (L. Van Ginderen)



The Denezy tracker radar, tilted for stabilization. (Contraves)

the operator, and corrected by trackball. An electronic symbol on the main display showed the area covered by the B-scope. The system could engage the target shown on the B-scope, then quickly shift to a second target stored in its memory (and rate-aided tracked). Targets could also be acquired manually.

SWITZERLAND

◆ Denezy/M-46/CGS-1

The 4 Danish *Falster*-class minelayers and the 2 *Peder Skram*-class frigates, all completed in the 1960s, use this Contraves FCS to control their guns (3-in/50 for the minelayers, 5-in/38 and 40-mm for the frigates). A seventh system was installed at the Danish naval training base. This project, the first full Contraves naval system, was code-named Denezy within Contraves, and the designations M-46 and CGS-1 have been published; they are presumably Royal Danish Navy designations. The system consists of X-band conscan trackers, with unique 6-axis stabilization, and a below-decks analog predictor, using the Contraves computing capacitor. The trackers are probably those used later in Sea Hunter. This system competed with the contemporary Signaal M40 series. Previous Contraves naval work, from the early 1950s on, had been at the subsystem level for the French, German, Japanese, and U.S. navies.

◆ Sea Hunter 4

This system was developed by Contraves and Contraves Italiana; it entered service in 1967 on board the modernized Iranian destroyer *Damavand* and was later installed on board 4 Iranian frigates (delivered 1961–72; 3 survive) and on board the Libyan frigate *Dat Assawari* (1973). The Libyan system was replaced by a Selenia FCS when the ship was modernized in Italy in 1979–83. It employed only a single tracker; the surviving systems each have dual trackers and are sometimes described (incorrectly) as double systems.

Sea Hunter was designed to control guns, surface-to-surface missiles (Standard SSM in the destroyer, Sea Killer in the Iranian frigates), and the Sea Cat anti-aircraft missile (only in the Libyan case did the system not control an antiship missile). The X-band tracker is probably that originally developed for the Denezy system, described above, but has a simpler 4-axis (roll, pitch, bearing, and elevation—hence the suffix “4”) mounting. The same mounting can also carry a search-radar antenna, which rotates about the base of the tracker and shares the same radar transmitter, as well as an LLLTV and (in the case of Sea Killer) a small dish transmitting the beam-riding guidance signal. In the Iranian ships, only the upper of the 2 trackers carries the search antenna.



Sea Hunter 4: the upper forward stabilized mount shows the search antenna, track antenna, and Sea Killer Ku-band command antenna below the television camera. The search antenna could also be mounted separately. (Contraves)



Sea Hunter 4 on board an Iranian Vosper-Thornycroft frigate, with a separate search antenna. Both tracker mounts carry Sea Killer command antennas. (Contraves)



Operations room (CIC) of an Iranian Vosper-Thornycroft frigate, showing the target-designation console, with its pantograph, in the foreground. (Contraves)

The radars use an X-band magnetron (peak power 180 kW, randomly variable PRF of about 2000, adjustable frequency). The search radar operates at a pulse width of 0.27 or 0.5 microsec, the tracker only at 0.27 microsec. The tracker is a 100-cm paraboloid generating a 2.2-deg beam (4.4-deg when off-axis dur-

ing conical scanning), using linear or circular polarization. The search antenna is a 2-m slotted waveguide feeding a cylindrical hog-trough reflector to form a 1×30 -deg csc² beam. It scans at 20–50 rpm (continuously variable). Detection range on a 3-m² target (Swering Case I) is 45 km [49,000 yd]; the same target can be tracked at about 40 km [44,000 yd]. Reports that the tracker is the Selenia RTN-10X are incorrect; the tracker is a Contraves design.

The combination of search and tracking radars on the same stabilized base (and connected by a large U-shaped waveguide, hence presumably sharing the same radar transmitter) recalls the slightly earlier Signaal "egg." The system can accept external target designation, or it can acquire targets using its own fan-beam radar or the tracker (scanning in a helical pattern). The fan-beam search radar operates against surface targets in TWS mode.

Sea Hunter 4 was probably the first application of television guidance to a missile (in this case, Sea Cat); it used a Marconi Aerospace television.

Below decks are two 1-operator consoles (surface engagement and system control). The radars and the external target designation sight feed into the system-control console, whose PPI carries a pantagraph for target designation (the position of the pantagraph, positioned over raw radar video, reads target coordinates into the system). A small TV monitor is located above the main console, which carries the weapons-assignment panel and a B-scope (for splash spotting). Typically, the main console is used to engage the primary target, using the main tracker; the surface console can engage a separate surface target, using the search radar in TWS mode. Both consoles connect to the single system fire-control computer, which automatically computes a solution for the assigned target. The analog computer uses the Contraves computing capacitor, as in the land-based Super Fledermaus.

The basic system can control self-guiding surface-to-surface missiles (Standard), but it requires an additional tracker and an additional console to control the command-guided Sea Killer. This console selects missiles for launch, selects guidance mode, and monitors the system and the missiles. The console contains a television monitor and a joystick for optical command guidance. This version also includes a Sea Cat blind-fire control console (note, however, that the Sea Cat missile launcher was replaced by a twin 23-mm gun during the Iran-Iraq war; it is unlikely that the gun is controlled by the Sea Hunter system).

The Iranian ships also have a stabilized optical sight (the operator sits on a stabilized platform) as an emergency alternative channel for 35-mm-gun control.

Sea Hunter was originally the FCS of the Sea Indigo beam-riding surface-to-air missile, an abortive adapted land weapon. Sea Indigo in turn was adapted to the antiship role as Sea Killer Mk 1, controlled by Sea Hunter 2 on board the defunct Italian fast attack boat *Saetta*. Sea Hunter 4 was carried only on board the 4 Iranian Mk 5 frigates (1 of which was sunk during the Iran-Iraq war, and 1 of which was severely damaged). The Sea Killer Mk 2 missile carried by these ships is also used by the Italian navy as an air-to-surface weapon (Marte), and a version using the helicopter radar was proposed as Mariner.

Sea Hunter competed with the Signaal M20 and WM20 series; it appeared just as digital FCSs were replacing analog types. After losing the competition for a large contract, Contraves dropped Sea Hunter and began to rethink naval gunfire-control requirements, a process that ultimately led to the design of Sea-guard.

◆ Seaguard

Contraves's modular combat system is usually associated with a standard quadruple 25-mm gun (Sea Zenith 25). Seaguard includes a dedicated high-data-rate dual-beam C-band radar (the Plessey Dolphin/AWS-6) to detect both sea-skimmers and high divers (70-deg coverage, to 14 km altitude, and to 35 km range), and a 3-axis tracker (Ku-band radar, FLIR, and laser). The Siemens-Albis Ku-band radar (0.9-deg beam) incorporates a pat-

ented means of suppressing mirror (multipath) effects, encountered in tracking very low flying targets, that result from reflections off the sea surface. Missiles flying at up to Mach 3 can be engaged.

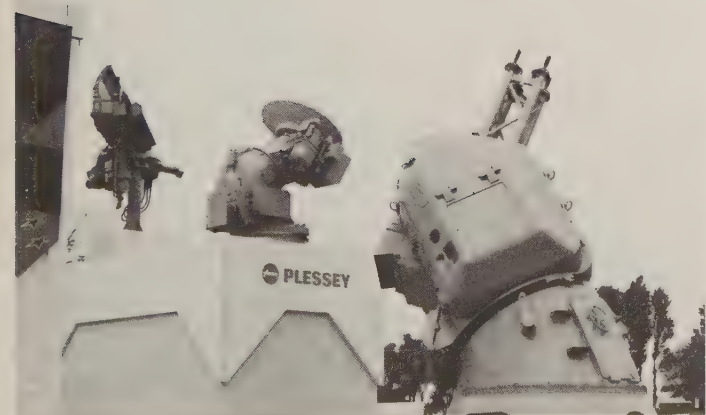
The Ku-band tracking radar operates at 15.7–17.5 GHz, with a peak power of 85 kW, and 80 nanosec (0.08 microsec) pulses; beam width is 19 mrad. This radar acquires missiles at 0.25–10 km and aircraft at 0.25–16 km. Weights: above-decks 1350 kg, below-decks 1350 kg. The radar antenna's diameter is 1.23 m. The alternative X-band tracker (for SAM control, if desired) operates at 8.6–9.5 GHz (peak power 2 or 4 kW, with 0.4–4 microsec pulses and a 31-mrad beam). Tracking range is 0.3–45/70 km. Weights: above-decks 1200 kg, below-decks 1300 kg. CW illumination can be provided through this tracker. This radar's antenna diameter is 1.315 m.

The associated FLIR has an FOV of 3×2 deg (operating at 8–11.5-micron wavelength). It incorporates a centroid tracker. The laser operates at a wavelength of 1.06 microns, with a 25-Hz data rate, and a 13-nanosec pulse length. The television sensor has an 11×8 -deg FOV.

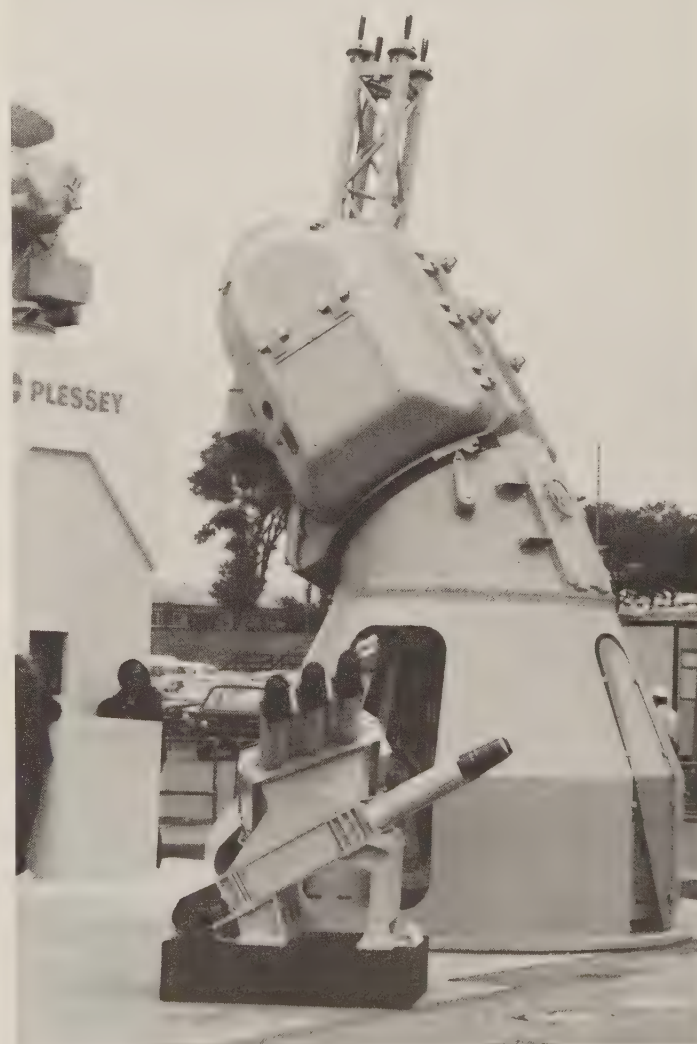
The Ku-band module is designated TMK. It tracks with an angular speed of 3 rad/sec (172 deg/sec) in all 3 axes and weighs 1350 kg [2975 lb]. The 3 axes are alpha (train), beta (the offset radar turns around an axis at an angle to the horizon), and lambda (the radar antenna elevates through $+120/-30$ deg relative to the canted beta axis). The alternative separate X-band module is designated TMX-CW.

An alternative X/Ka-band tracking and illumination module (TMX/Ka-CW) employs a TWT transmitter and pulse compression; the module carries optional electro-optical sensors (TV or FLIR). The Ka-band radar operates at 34–34.45 GHz with a peak power of 75 W (pulse length 0.13/3.7 microsec: compressed/uncompressed lengths). Beamwidth is 8 mrad (0.5 deg), and tracking range is 0.3–20 km. The associated X-band radar, which shares the same antenna, has a peak power of 25 kW (pulse width 0.3/1.65 microsec) and a beamwidth of 30 mrad (1.7 deg). Tracking range is 0.3–70 km. Total above-decks weight is 1440 kg [3174 lb]; below-decks weight is 1390 kg [3064 lb]. Angular speed in all 3 axes is 3 rad/sec (172 deg/sec), and the radar dish's diameter is 1.4 m [55 in].

X-band is used to achieve long enough range (70 km) for the system to engage air targets with a surface-to-air missile. The tracker can avoid multipath problems by using all of its sensors, and it can track targets all the way to the zenith, elevating up to 120 deg. CWI can be injected into the X-band tracker waveguide. Contraves offers configurations controlling both conventionally mounted surface-to-air missiles and vertically launched missiles.



The main external elements of the Seaguard system, on display at RNEE 1989: the Dolphin acquisition radar, the radar director, and the 4-barrel 25-mm gun, capable of pointing up to the zenith and very agile. (Author)



The Seaguard gun mount demonstrates the agility it gains from its canted roller path. The device in the foreground is the Plessey Shield chaff-rockets launcher. (Author)

There is also an alternative electro-optical tracking module, TMEO, a pedestal carrying a FLIR or television on 1 side and a laser on the other; alternatively the pedestal can carry a light-weight W-band radar. The module is biaxially stabilized; the above-decks equipment weighs 230 kg, and the below-decks equipment weighs 490 kg. Elevation limits are $+80/-20$ deg, and train and elevation rates are both 1.3 rad/sec (74.5 deg/sec). The FLIR operates in the 7.5–11-micron band, with 2 alternative FOVs, 20×15 and 2.7×2.0 deg; resolution is 0.11 mrad. The alternative television camera has 31×23 - and 3.1×2.3 -deg FOVs. The laser range-finder, which is eye safe, operates at 1.57 microns and emits 1–3 pps.

For data concerning the associated Dolphin C-band search radar, see the description of the British AWS-6 radar.

The gun consists of 4 independent Oerlikon KBB 25-mm cannon, with a combined rate of fire of 3400 rnds/min. The axis of the mount is canted to allow for very high angle engagement of diving targets even from a heavily rolling or pitching ship. Ammunition capacity in the standard system is 1600 rnds, sufficient for about 18 engagements without reloading (one 80-rnd burst per target), and the manufacturer claims that tests of the high energy AMDS (Antimissile Discarding Sabot) ammunition show that it can kill with a single hit. Contraves claims that the special 25-mm AMDS round is equivalent to a standard 30-mm round.

The original deck-penetrating module was designated GM25. Elevation limits are $+127/-14$ deg, and angular speed (both for elevation and for train) is 2.5 rad/sec (143 deg/sec). Ammunition is carried in four 300-rnd drums, the hoists making up the rest of the total of 1660 rnds. The ammunition itself incorporates a 156-gram penetrator (total weight is 288 grams), and time of flight to 1000 m is 0.78 sec (muzzle velocity is 1355 m/sec, or 4444 ft/sec). Total weight above decks is 4400 kg (2690 kg below decks), and swept radius is 2.591 m.

In 1989 Contraves announced a second gun module, Sea Shield (GM25-SS), to supplement the earlier Sea Zenith (GM25-SZ). Sea Shield is mounted entirely above decks (without any magazine below decks), and omits the very high elevation firing feature of the heavier Sea Zenith. Ammunition supply is limited to 1000 rnds in four 250-rnd magazines (11 engagements), and elevation limits are $+80/-20$ deg. Train rate is 2.0 rad/sec; elevation is at 2.5 rad/sec. Total weight above decks rises to 5450 kg, but below-decks weight is only 1590 kg. Swept radius is 2.6 m. Sea Shield cannot be reloaded while it fires; however, Contraves argues that there is enough ammunition on the mount to deal with a concentrated multiple missile and aircraft attack.

In both modules, burst length (and the number of cannons fired) can be controlled, e.g., when the gun is used in limited surface actions (e.g., in the naval policing role).

The manufacturer claims a reaction time from acquisition to open fire of 4 sec, compared to a reported 6 sec for Phalanx. The manufacturer also estimates that 2–4 scans by the search radar (i.e., 2–4 sec) are required before the tracker can begin its own target search in azimuth. Seaguard is designed to shift targets every 5 sec or so, depending on the change of angle involved. Contraves claims that the last round will generally reach the target at about 300 m, where it must burst the target to avoid damage to the firing ship; the company claims a 95% net probability of hitting by that time.

The system is designed to permit expansion to control all ship's weapons, using additional trackers and a NAUTIS multiconsole combat system. All versions are linked together by data bus, the individual modules (tracker and gun) having their own microprocessors. The manufacturer claims that this architecture (as opposed to 1 incorporating a single central computer) makes for quicker reactions. Modules are: gun (CIWS-GM), tracker (CIWS-TM), general-purpose tracker (GPTM), electro-optical tracker (EOTM), electronic warfare (EWM), and command/control (CCM). GPTM can be used to control medium-caliber guns and surface-to-air missiles, using a Contraves

X-band pulse-doppler radar. The CCM is a horizontal 2-operator console that can be used both for command/control and for threat evaluation/weapons assignment, incorporating a 24-in PPI screen.

Seaguard was adopted by the Turkish Navy for its *Yavuz*-class MEKO frigates. In these ships the system consists of 1 search module (SRM), 2 trackers (TMK), and 3 guns (GM25), each of the last provided with sufficient ammunition for 15 engagements. A land-based version has been purchased for the Chinese Army (PLA).

Seaguard is a private-venture system; development began late in 1977. Contraves-Oerlikon collaborated with Plessey, with Siemens (both the German firm and its Swiss subsidiary), and with Elettronica of Italy. The project was announced at the beginning of 1980. By mid-1982 prototypes of all the modules had been tested, and the Italian Navy had priority for deliveries for trials. However, Italy did not adopt Seaguard.

A variant of the Seaguard FCS is being used to control an Emerlec twin 30-mm gun on board the Saudi minehunters being built in Britain. This is a combination of Contraves Pittsburgh and Contraves Zurich equipment (presumably, the EO element is from Pittsburgh). In addition, Contraves is supplying the tracker for a customer (unnamed) with its own SAM under development.

◆ Sea Hawk Mk II

Sea Hawk is a Contraves electro-optical fire-control system for small warships and auxiliaries; it can also work within a large-ship command/control system. Announced in the United States early in 1990, it was an unsuccessful competitor for the *Arleigh Burke* (DDG 51)-class electro-optical system, as a replacement for the abortive Seafire (Mk 121). A 2-axis gyro-stabilized platform carries a laser range-finder, a FLIR, and a television camera. Contraves claims that superior stabilization is achieved by placing the rate gyro module directly on the elevation axis of the pedestal, rather than using a takeoff and a servo. The pedestal is designed to operate in sea-state 3 and to survive in sea-state 5.

The below-decks elements are a pedestal electronics cabinet (PEC) containing the central system controller (a 16- or 32-bit microcomputer), the read-out unit for pedestal pointing angles, the servo unit, and the sensor power unit; the operator control console, with two 9-in monochrome monitors (FLIR and TV, simultaneously), a keyboard, and a joystick; and a weapons-control module (WCM) containing its own 32-bit processor. The WCM processes target and gun stabilization data and calculates gun ballistics; it can accommodate several different sets of ballistics simultaneously. Motion analysis techniques are chosen based on the type of target (fast, slow, or shore). For air targets, the system can do intermittent tracking (e.g., when a target is obscured), projecting ahead target motion. For surface targets, it can fire either to hit or to make a near miss (for policing). The shore-target mode includes offsets from beacons or other prominent points. The WCM also holds fire when a gun is pointing into the ship.

The television has a zoom lens (32–320-mm focal length) and uses CCIR format. The FLIR operates at 8–12 microns and has 2 FOVs (12×8 and 3.16×2.1 deg); its output is in CCIR format. The Nd-YAG laser has a 1-mrad beam (PRF 10/pps); range limits are 280–20,500 m [300–22,400 yd].

Targets can be designated by the host command/control system, from bridge target indicators, or by the FLIR or television. When targets are designated by radar, the director acquired them by scanning in elevation. Targets designated from the bridge are brought directly into the camera's FOV, and they are acquired by joystick and tracking window. If 2 targets are visible, then the system can change from 1 to the other by joystick; targets can also be designated via the keyboard, or by automatic horizon or sector scans. Once a target is acquired, it can be automatically tracked in 2 or 3 dimensions (in the latter case, using the laser).

The pedestal weighs 310 kg and requires 1.5 m of swing clearance; the PEC weighs another 320 kg, the OCC another 230, and the WCM another 130 kg [for a total of 2182 lb].

TAIWAN (GOC)

Taiwan currently manufactures a fire-control radar, designated SPG-24, which is used on board fast patrol boats armed with Hsiung Feng I missiles. Reportedly, the U.S. contractor for the SPG-24 program was ABA. The main developmental problem was conversion of the radar from analog to digital processing.

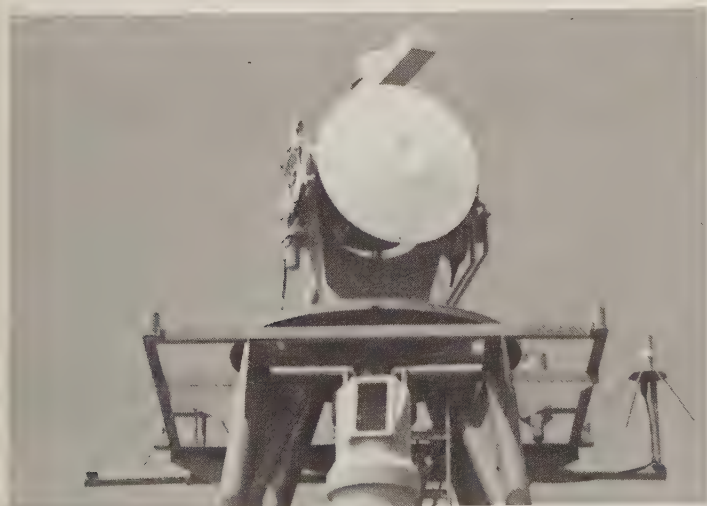
Taiwan also manufactures a navigational radar using a small X-band slotted-waveguide antenna, designated UPS-60. The initial batch, to equip missile-firing boats, was 57 radars, and more have been ordered. UPS-600 is a larger (and presumably lower-frequency) surface-search set, possibly derived from the U.S. SPS-64. At least 15 SPS-64s have been bought for coastal surveillance.

UPS-60(X)C is employed with mobile coastal-defense units. CS/SPG-24 has replaced HR-76 in some coastal-defense units.

In July 1988 a model of a phased-array radar, externally similar to the U.S. SPY-1D of the *Arleigh Burke* class, was exhibited in Taiwan. This is 1 of 2 alternative radars for the second series of *Perry*-class frigates; it is a modified version of the FARS radar that RCA (now the RCA Division of GE) proposed for the German navy and then for NAAWS. It is now designated ADAR-2N. The alternative, which was proposed in competition with FARS for the German contract, is the Raytheon CMAR, a fixed-array radar operating in C- rather than X-band, and employing some SPG-51 technology. Compared to ADAR-2N, CMAR should be larger and heavier, but it should have superior anti-clutter performance. As of early 1990, Taiwan was expected to choose the second-series combat system, including both the radar and the tactical data system, about mid-1990.

The RCA radar also exists in a larger land-based version, designated Chang Bai (Long White). It is a joint development project with the Taiwanese CSIST (Chang Shun Institute of Technology), which is responsible for advanced Taiwanese systems. A land-mobile version, controlling Sky Bow 1 missiles (similar in outline to the U.S. Patriot), is now operational. Each land-based system consists of a main radar with 4 illuminators, linked to 3 or 4 launchers each. Each launcher contains 4 missiles. The expected range of the phased array is 500 km.

At least initially, the frigates will be armed with SM-1 missiles, fired from vertical launchers. However, it seems likely that ultimately a navalized version of Sky Bow, controlled by the chosen phased-array radar, will appear.



The SPG-24 radar on board a Taiwanese (GRC) *Hai Ou*-class missile boat. The slotted waveguide above is UPS-60. There is a periscope in the foreground. (Fu S. Mei)

USSR

The *Sverdlov*-class cruisers and "Kotlin"- and *Skory*-class destroyers are now being discarded. As a result, the following radars have been omitted from this edition (details can be found in the previous edition of this book): Cross Bird, Egg Cup, Half Bow, Knife Rest, Long Bow, Post Lamp, Top Bow, and Top Trough. The following fire-control systems have been deleted: Fire Iron, Four Eyes, and Round Top.

SEARCH RADARS

Of all these radars, High Sieve survives on board the patrol icebreaker *Purga*. Ball End survives on board T-43-class fleet minesweepers.

◆ Band Stand

This radome is associated with the SS-N-9 missile on board *Nanuchka*-class missile corvettes and also with the SS-N-22 missile on board *Sovremennyy*-class destroyers and some *Tarantul*-class missile corvettes. Because these missiles have OTH range, Band Stand probably accommodates a targeting data link. However, *Tarantuls* also have a masthead antenna, Light Bulb, described as a probable missile data link. The combination of Band Stand and Light Bulb might be comparable to the combination used to target SS-N-3/12 missiles, the missile sending back its own radar picture for comparison with that provided by a targeting aircraft. Alternatively, Light Bulb may be the shipboard antenna for a Soviet equivalent of Link 11, as in the German AGIS system (in which missile boats are tied directly into a shore-based command/control system). *Tarantul-II* (the first production version) has Band Stand even though the ships are armed with SS-N-2C; in this case whatever is inside the radome replaces Square Tie/Plank Shave (as in *Nanuchkas* built for export: see Square Tie below). These ships have Light Bulb, which thus far has not appeared on board any other Soviet warships.

In export *Nanuchkas*, Band Stand covers a Square Tie antenna, apparently for cosmetic reasons.

◆ Big Net

Band: L (about 850 MHz) **Beam:** 5 deg
Pulse Width: 3.5 or 2.0 microsec **PRF:** 250 or 550 pps
Scan Rate: 6.7–8.6 rpm **Antenna Dimensions:** 25 ft wide

The large air-search radar, on *Kresta-I*- and some *Sverdlov*-class cruisers, and on some *Kashins*, Big Net can probably detect a large airplane at altitude at ranges of 100+ nm. Big Net is probably the cruiser/destroyer air-search radar developed in 1948–55 under the designation Fut-N, tested in the Baltic in 1955. The radar detected aircraft at a range of up to 150 km.



A Big Net air-search radar on board the *Kashin*-class destroyer *Strogii* at Massawa, 1972. (Royal Navy)

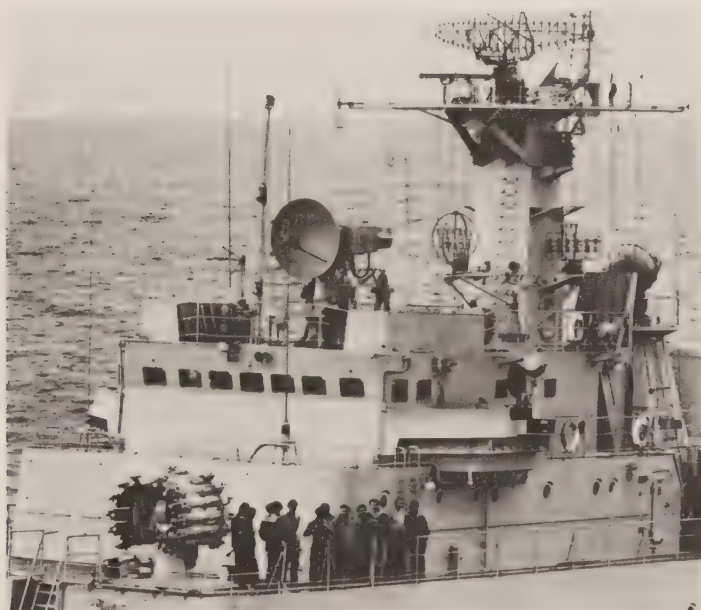
This radar entered service about 1957 and is contemporary with Top Trough.

Big Net was the last major Soviet 2D long-range air-search radar. Its Soviet name is Echo. About a decade after its introduction it was succeeded, in effect, by Top Sail.

◆ Don Series

Band: X (9375 MHz) **Beam:** 1.1×20 deg
Peak Power: 80 kW **Pulse Width:** (i) 1 (ii) 0.5 microsec
PRF: (i) 800 (ii) 1600 pps **Scan Rate:** 12 or 15 rpm

This series includes Don-2 and Don Kay. There was also a Donets-2, with a slotted waveguide (68.7×4.8 in, 1.4×20 -deg beam, seen in 1960 on board a trawler). The data here are for Don itself.



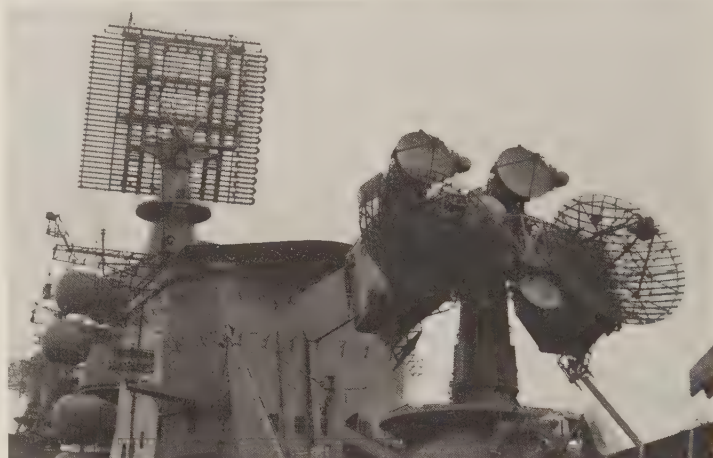
A Koni-class corvette shows a Don-2 radar just above her yardarm. The air-search radar above is Strut Curve; the fire-control radar forward of the mast is Hawk Screech, and Drum Tilt is partly obscured aft. (U.S. Naval Institute)



Don Kay surface-search radar is visible below and forward of the Head Lights C missile-guidance director on board the "Kresta II"-class cruiser Vasily Chapaev. The small radomes visible just abaft the missile director (1 pointed up, 1 down) are the Bell Slam and Bell Tap associated with the Side Globes ECM system. The larger radome on the centerline is Bell Clout. (Sea Power)

◆ Flat Screen

This previously unknown planar-array UHF air-search radar replaced Top Sail on board the Kara-class missile cruiser *Kerch*. This radar seems to have been fitted during a refit begun in April 1988 and completed about February 1989. The antenna consists of a series of slotted waveguides, the gaps between the arrays being quite visible. The serpentine feed characteristic of frequency scanning is quite visible on the right-hand side of the array, and the antenna is crowned by an IFF interrogator. This new long-range 3D air-search radar probably operates at a much higher frequency than Top Sail, most likely S-band. The antenna is about 6 m wide and 7 m high; it is tilted back at a 5-deg angle.



Flat Screen on board the Soviet cruiser *Kerch*, early 1989. The radar in the foreground is the Head Lights set used to control the ship's SA-N-3 missiles. The small flat array projected out from the uptakes is an IFF interrogator (Square Head). Although the ship retains her original series of ESM/ECM radomes, Rum Tub has been added (array visible just behind Square Head). (Eric Grove)

◆ Half Plate

The modified Top Plate, as its name implies, operates in S-band. Half Plate A is on board the missile transport *Aleksandr Brykin*. Half Plate B is on recent Grisha-Vs, superseding Strut Pair.

◆ Head Net A/B/C

This S-band small-ship radar is roughly contemporary with Slim Net. Range on a large high-altitude airplane is about 60–70 nm. Head Net A is a single antenna, about 22.5×5 ft. That size implies a fan beam somewhat less than 1 deg wide.

Head Net B had 2 antennas arranged back to back, providing a higher data rate. B is now extinct, having been installed only in *Desna*-class missile range ships (removed 1980, replaced by Head Net C). The back-to-back arrangement is widely used in Soviet naval radars (see Strut Curve, Strut Pair, Top Pair, Top Steer); presumably, both antennas typically share a common waveguide feed running up the mast between them. This arrangement reduces structural interference with radar emissions and increases the net data rate of the radar. In the case of a 2D/3D combination, the back-to-back arrangement probably greatly simplifies designation of a target from radar to radar, since there is no parallax error, and also economizes on the mechanical stabilizers the Soviets seem to favor.

Head Net C, which is the height-finder used with the SA-N-1 missile (and is the secondary 3D radar in *Kresta II*- and *Kara*-class cruisers), has 1 of its 2 back-to-back antennas canted at 30 deg to the horizontal. The 2 fan beams are, therefore, canted, and the relative apparent positions of the same target in the 2 beams measure its height (vee-beam height-finding). The operator finds the target with the conventional antenna, marks it, and sets range gates on the second beam to measure altitude. This vee-beam system was invented during World War



Head Net C air-search radar on board the Kashin-class destroyer *Strogii* at Massawa, 1972. The object at the base of the radar pedestal is a Watch Dog ESM antenna. (Royal Navy)

II, and a U.S. vee-beam set, CPS-6, provided to the Soviets under Lend-Lease, was copied postwar. The system is simple, but it is not as satisfactory as a true 3D radar. Head Net C entered service in 1963.

The Soviet designation for Head Net C is MR 310 (at least in the export version used by the Indian Navy). The Soviet name is Angora.

It now appears that Head Net C has been superseded by Top Plate.

◆ Kivach 3

Kivach 3 is a current small-combatant (e.g., mincraft) navigational radar.

◆ Mius

X-band surface-search radar.

◆ Mad Hack

This is the large flat object, which some have described as a phased-array radar, on board the intelligence-collection ships SSV-33 and SSV-501. Each flat plane has 12 sides. Although these objects are generally described as radar arrays, 1 of the flat planes on SSV-33 faces aft directly into extensive superstructure, which seems odd for a radar. One of the planes on board SSV-33 faces directly up. Close-ups of the amidships structure of the ship suggest that each plane may be a cover for some other sensor, hinged on 1 side.

◆ Neptune

Band: X (9430 MHz) **Beam:** 1.6×20 deg
Peak Power: 42 kW **Pulse Width:** (i) 0.25 (ii) 1.0 microsec
PRF: (i) 2700 (ii) 675 pps **Scan Rate:** 14 rpm

Neptune is a navigational radar of the 1950s. Production ended in 1960, but this radar remains in service.

◆ Nyada

X-band surface-search radar.

◆ Palm Frond

This surface-search radar is the current standard, replacing Don 2 and Don Kay from the Krivak class on. In accord with previous Soviet policy on surface-search radars, the usual complement is 3 sets (Krivaks have only 1, plus a Don Kay in Krivak-II; all Krivaks have 2 navigational radars).



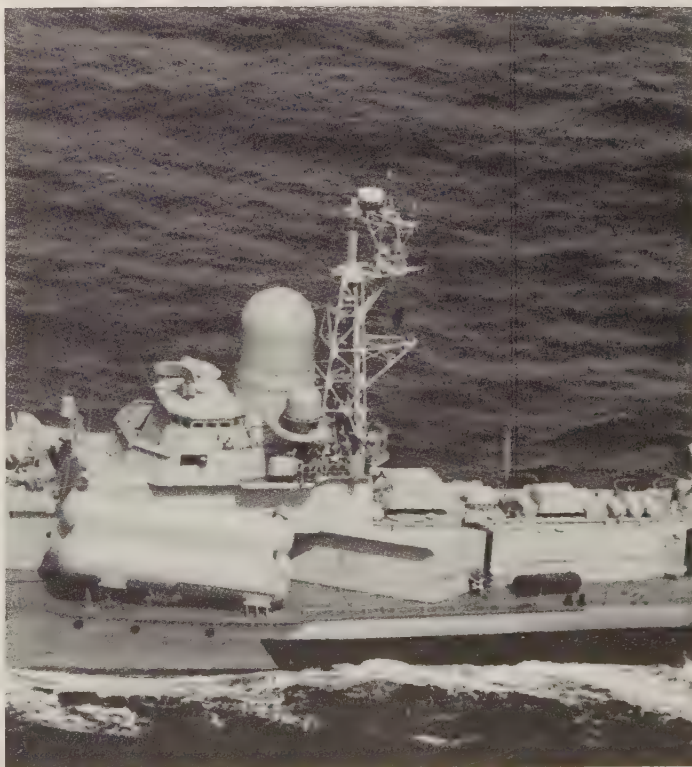
A Palm Frond antenna is visible in front of the Strut Pair air-search radar on board the *Udaloy*-class destroyer *Admiral Vinogradov*. The back side of another Palm Frond is visible at left, and Kite Screech is in the foreground, right. (S. Zaloga)

◆ Peel Cone

This air/surface-search radar on Pauk and Stenka classes supersedes Pot Drum.

◆ Peel Pair

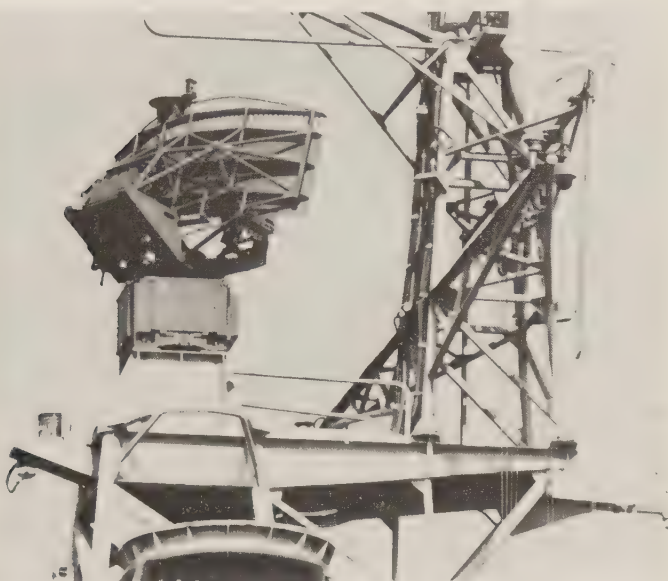
X-band surface-search radar of the late 1960s. It looks like a pair of Don-2 antennas mounted back to back.



Peel Pair (forward of the Band Stand missile-control antenna) on board a Nanuchka-class missile corvette. The smaller radomes are Fish Bowls (data links). (Ships of the World)

◆ Plank Shave

This search/missile-targeting antenna on Tarantul-class missile corvettes is the successor to Square Tie. The Indian navy calls this radar Harpoon; the name may be a translation of the Soviet name. This antenna is about the size of that of Don-2 and is marked by its large stabilizing vane and its overhead feed.



Plank Shave radar on board a Pauk-class corvette. (U.S. Naval Institute)



A Matka-class hydrofoil shows her Plank Shave targeting radar at her masthead, with a Bass Tilt fire-control radar below, atop her bridge. (German Ministry of Defense)

◆ Plate Steer

The modified Top Steer/Top Plate combination operates in S-band in *Sovremennyy* units 4–5 and *Kiev* and *Baku*. It consists of 1 flat (canted) antenna and the 2D antenna of Top Steer.

◆ Pot Head/Pot Drum

Band: X (9275–9460 MHz) **Beam:** approx 3 deg
Peak Power: 100 kW **Pulse Width:** 0.25–1.0 microsec
PRF: 1600–1650, 3200–3300 pps
Scan Rate: circular at 2.5–4 or 5–6 rpm; sector at 7–8

Standard radar in SO.1-class submarine chasers and on many other patrol craft, Pot Head superseded Skin Head from about 1960 on. Pot Drum, which is externally very similar, entered service in 1958 and was carried by patrol craft such as the *Turya*,



A Soviet *Turya*-class hydrofoil torpedo boat shows a Pot Drum radar forward (with Square Tie IFF interrogator below it) and Drum Tilt aft. Some units have a new Peel Cone radar with a large reflector instead. The guns are twin 30-mm (AK 230). (U.S. Navy)

Stenka, *Shersten*, and *Pchela*. It appears that Pot Drum had a peak power of 150 kW and a pulse width of 0.5–1.0 microsec, whereas Pot Head, which would have needed more resolution (e.g., for periscope detection), had a shorter pulse width (1 source gives 0.3–0.5 microsec). These radars were succeeded by Square Tie (which has a somewhat different role) in missile boats and by Peel Cone in recent patrol craft; Square Tie in turn gave way to the current Plank Shave. However, Square Tie is still in production for export craft.

◆ Ship Bowl/Ship Globe/Ship Shell/Quad Series

These are probably space tracking or communications antennas on board some Soviet space-events instrumentation ships and also on board a few of the larger intelligence-gathering ships. Ship Bowl is a 12.5-m-diameter radome; Ship Globe is 30 m in diameter; Ship Shell is a 27-m-diameter dish. Ship Globe's dishes may be enclosed in radomes or they may be uncovered. Ship Shell is a large uncovered dish incorporating what appears to be a monopulse feed. Both the uncovered antennas (and presumably Ship Bowl as well) are stabilized. In some cases Ship Globe is described as a satellite-communications antenna, but in others it presumably receives missile telemetry (either friendly or in an intelligence role).

Quad Spring is a large stabilized dish with a double (side by side) feed, the Quad referring to the four (2 × 2) supports for the feeds. Other space-support ships have Quad Leaf, in effect 4 merged dishes each with its own large feed (presumably for super-monopulse tracking), Quad Rods, and Quad Wedge.

◆ Skin Head

Band: S (3000 MHz) **Beam:** 17 deg
Peak Power: 80 kW **Pulse Width:** 1 microsec
PRF: 400 pps **Antenna Dimensions:** radome: 0.8 × 1 m

This patrol craft surface-search radar is reportedly derived from the U.S. SO series, now in PRC service. Skin Head was developed in 1946–48 and tested in the Black Sea in April–June



Skin Head radar on a Soviet torpedo boat preserved as a memorial. Although the memorial is for World War II, the P-4 class boat and its equipment (including the twin 14.5-mm machine gun aft) are postwar. (U.S. Navy)

1948. Test results: destroyer detected at 7.5 nm; torpedo boat at 3.4 nm; aircraft at 100–300 m altitude detected at 9–17 nm. The Soviet name is Zarnitsa. This radar was manufactured in China during the 1960s.

◆ Sky Watch

The carrier *Baku*, the fourth of the *Kiev* class, emerged in mid-1988 with a new flat-sided 4-faced array radar on her superstructure; the same radar has also appeared on the newer carrier *Tblisi*. It replaces the Top Pair of earlier ships of the *Kiev* class and presumably operates at a similar frequency to achieve a similar range performance. Top Steer is retained as a backup. It is possible that the internal space required for the radar (and, presumably, for those maintaining it) precluded the installation of any long-range surface-to-air missile system; the other ships of the *Kiev* class all have SA-N-3. *Baku* is limited to the SA-N-9 point-defense system.

◆ "Pomornik" Search Radar (Positive E)

A new air- and surface-search radar, radome-enclosed, and as yet without any published NATO reporting name, appeared on board the large air-cushion vehicles of the "Pomornik" class, as well as on board East German-built "Parchim II" corvettes built for the Soviet Navy, and on the new Indian corvette *Khukri*. In the case of the Parchims, the East German version of the class has Strut Curve radar in the position occupied by the new radome. The new radar may have a secondary fire-control role, as the "Pomorniks" lack any specialized fire-control radar for their 30-mm guns (although 1 was photographed with Drum Tilt in place of its big radome).

Sky Watch electronically scanned arrays on the island of the Soviet carrier *Tblisi*. Above the arrays are Big Ball satellite-communications antennas and the big cylindrical Cake Stand, a Soviet equivalent of TACAN. The back-to-back antenna above Cake Stand is Top Plate. (SOVFOTO)



Sky Watch on board the Soviet carrier *Baku*. (U.S. Navy)



An account of the new Indian corvette *Khukri* calls this radar Positive E and credits it with a range of 70–75 nm; it is said to be effective against low fliers. The E may refer to the radar band in ECM notation (i.e., low S-band). Positive is presumably a translation of the Soviet name. Radome diameter is about 3 m.

◆ Slim Net

Band: S (2840 MHz) **Beam:** (est) 1×3 deg
Pulse Width: 1–1.5 microsec **PRF:** 420–425 pps
Antenna Dimensions: 5.5×1.8 m

This early (ca. 1957) S-band radar on some cruisers, destroyers, and frigates can be used for both air and surface search, varying rotation rate (data rate) for the 2 functions (slow rotation for surface targets, fast for air targets). This radar appeared on board all Kotlins as built and was eventually mounted on all but 1 Riga. Slim Net was a slightly modified Hair Net (1950, now obsolete).



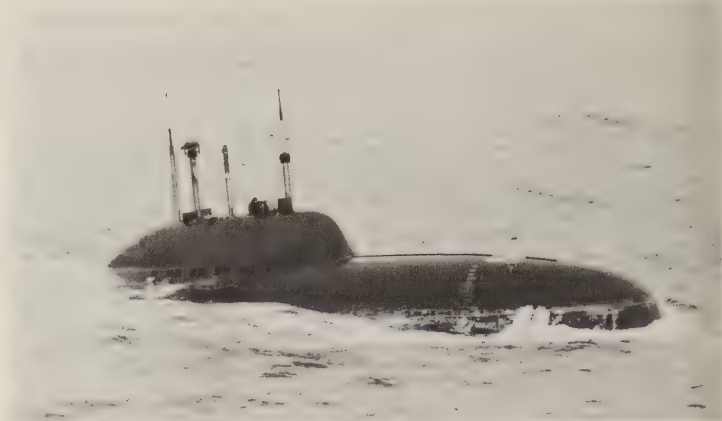
Slim Net on board a Mirka-II-class corvette. (MoD Bonn)

◆ Snoop Head

This X-band submarine search radar has an ESM radome (Bald Head) on the same mast, above it. The reflector is slotted. This radar appeared in the late 1970s, on board Alfa- and Oscar-I-class submarines.

◆ Snoop Pair

This X-band submarine surface-search radar has back-to-back antennas for increased data rate. The 2 feeds appear to be somewhat different, so it may be a dual-beam (dual elevation, not vee-beam) set. The radar reflector is solid and resembles that of Snoop Slab (albeit with feed from above rather than from below,



A surfacing Alfa-class submarine shows its Snoop Head radar (with Bald Head ESM radome above it). It also shows 2 periscopes and a VHF whip, abaft the radar.



Snoop Pair (with its associated Rim Hat ESM antenna) is the second antenna from aft on this Sierra-class submarine; the cone abaft it is Pert Spring (satellite navigation). (Royal Norwegian Air Force, 1984)

as in other Soviet radars; this type of feed is probably necessary since the waveguide runs up the mast between the reflectors). This is the current standard nuclear-submarine radar, appearing in the early 1980s on board Typhoon-, Sierra-, Akula-, and Oscar-II-class submarines. The associated ESM antenna is Rim Hat, which includes a ring of intercept antennas (presumably for monopulse DF) around the base of the radar.

◆ Snoop Plate

Band: X (around 9370 MHz) **Peak Power:** 80 kW
Pulse Width: 1–2 microsec **PRF:** 1618 pps
Scan Rate: 10 or 20 rpm (but rotation can be manual or sector scan, and minimum rate is 4 rpm)

The first Soviet postwar submarine search radar was seen in 1953; Snoop Plate was standard through early Foxtrot-class boats. Many components duplicate those of Neptune, Don, and Post Lamp. Range scales are 2, 5, 10, and 40 nm, but maximum range is about 10 nm in practice. Snoop Plate was replaced by Snoop Slab in Foxtrot-class and later submarines. Snoop Slab was later retrofitted to many earlier submarines, although Snoop Plate remains in service.

◆ Snoop Slab

This X-band submarine surface-search radar replaced Snoop Plate from about 1957 on. Snoop Slab has a massive parabolic reflector and very noticeable motor housing. It is carried by Echo-II- and by some Juliett-class submarines.



Snoop Slab search radar on board an Echo-II-class submarine. Aft it is a Stop Light C ESM antenna, a hemispherical antenna atop a series of monopulse DF antennas operating in 4 bands. The Front Door/Front Piece missile-guidance antennas are forward of the windshield, submerged, and the after end of the sail carries a standard HF whip.

◆ Snoop Tray

This X-band submarine surface-search radar was introduced in 1962. It has a nearly flat and almost rectangular reflector, tipped over at an angle of about 25 deg. This radar succeeded Snoop Slab in production (initially on board Tango, Golf, November, Hotel, Echo classes). Snoop Tray 1 appeared in the early 1960s; it is carried by Charlie-, Echo-, some Tango-, Foxtrot-, Yankee-, Golf-, some Golf-II/III-, Juliett-, November-, Victor-I-, Yankee-I/II-, Lima-, Hotel-, Bravo-, and some Romeo-class submarines.



Snoop Tray search radar on board a Foxtrot-class submarine, 1982.

Snoop Tray 2 appeared in the mid 1970s and is carried by Delta-I/II/III/IV-, some Echo-II-, Charlie-II-, Victor-II/III-, some Tango-, Kilo-, India-, and Yankee-Notch-class submarines.

◆ Spin Trough

The X-band surface-search radar in Krivaks and in auxiliaries, small craft, etc., is an alternative to Don 2.



A Soviet ocean minesweeper (T-58 class) shows typical slotted-wave-guide surface-search radars (Spin Trough and Don-2) and a Muff Cob fire-control radar for her twin 57-mm guns. The long cylindrical object on deck under the after gun mount is presumably an acoustic sweep. This Soviet ship is missing the clutter that is typical of Western mine-countermeasures craft. [U.S. Navy]

◆ Square Tie/Type 331

This X-band surface-search/targeting radar for SS-N-2 missiles is now being superseded by Plank Shave. Square Tie is enclosed in the Band Stand radomes of export Nanuchka-class missile corvettes, which are equipped with SS-N-2C rather than SS-N-9 missiles.

The PRC designation for this radar is Type 331.



Square Tie search and missile-targeting radars at the mastheads of Chinese Osa-type missile boats, center and left. [U.S. Naval Institute]

◆ Strut Curve/Strut Pair

This S-band small-ship air-search radar, contemporary with the Head Net series, is installed on Petya and Mirka frigates and Poti and Grisha corvettes. Strut Curve reportedly operates at the high end of the S-band and is unusual in lacking a balancing vane behind its reflector. That lack might indicate that the antenna was not stabilized, the vanes on other Soviet antennas being used to reduce the load on the stabilizer.

Strut Pair is 2 Strut Curve antennas arranged back to back (for high data rate), using pulse compression. There are 2 versions. Strut Pair I appeared in the mid-1970s and is carried on board Mod Kildin- (*Bedovyy*), Udalo- (first 2 units), and some Grisha-V-class ships and on board the space-events ship *Marshal Nedelin*. Strut Pair II, with improved air-search capability, appeared in the early 1980s and is carried on board the carriers *Novorossiysk* and *Baku*, on board some Grisha-V-class ships, on board the *Marshal Nedelin*, and on some *Udaloy*s.



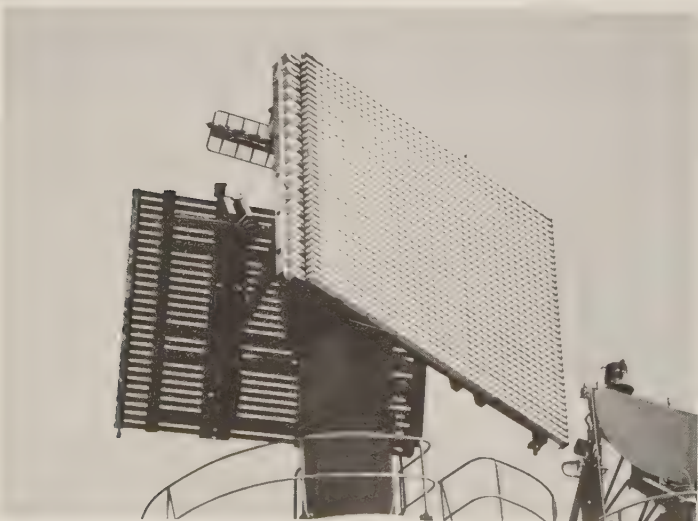
Strut Curve air-search radar on board an East German Koni-class frigate, 1978. (U.S. Naval Institute)



Strut Pair radar on board the *Udaloy*-class destroyer *Admiral Vinogradov* at Norfolk, July 1990. (S. Zaloga)

◆ Top Plate

Top Plate has back-to-back S-band planar-array antennas (1 shorter but apparently wider than the other) and is installed on the *Tbilisi*, *Kirov*, *Slava*, on 8 *Udaloy*-class and 5 *Sovremennyy*-class destroyers, as well as 2 *Krivak*-IIIs, and on the



Top Plate antenna on board the *Udaloy*-class missile destroyer *Admiral Vinogradov*, July 1990. The near plate shows the characteristic sinuous waveguide of a frequency-scanning radar on its left side, and the separate slotted waveguides of the other plate are clearly visible. (S. Zaloga)

new Bal-Aux 2 nuclear auxiliary. Top Plate seems to be the successor to Head Net C. Both arrays are canted to the horizontal, at opposite (i.e., analogous) angles. The conclusion that the arrays are in fact frequency-scanned would seem to flow from the replacement of Top Steer by Top Steer/Top Plate; that replacement also suggests the likely frequency.

The effect of canting would be to run the beam diagonally across the sky as the radar elevated. If the beam is relatively narrow, and the time between pulse trains of different frequencies relatively long, it might be argued that such operation would compensate for the rotation of the antenna. The advantage of such a design would be that the radar could dwell longer at each elevation angle, achieving a better probability of detection. Back-to-back construction might make for a better net data rate, the shorter antenna producing a somewhat broader beam (in elevation) intermediate between the fan beam of a 2D radar and the pencil beam of a true 3D radar.

◆ Top Sail/Top Pair

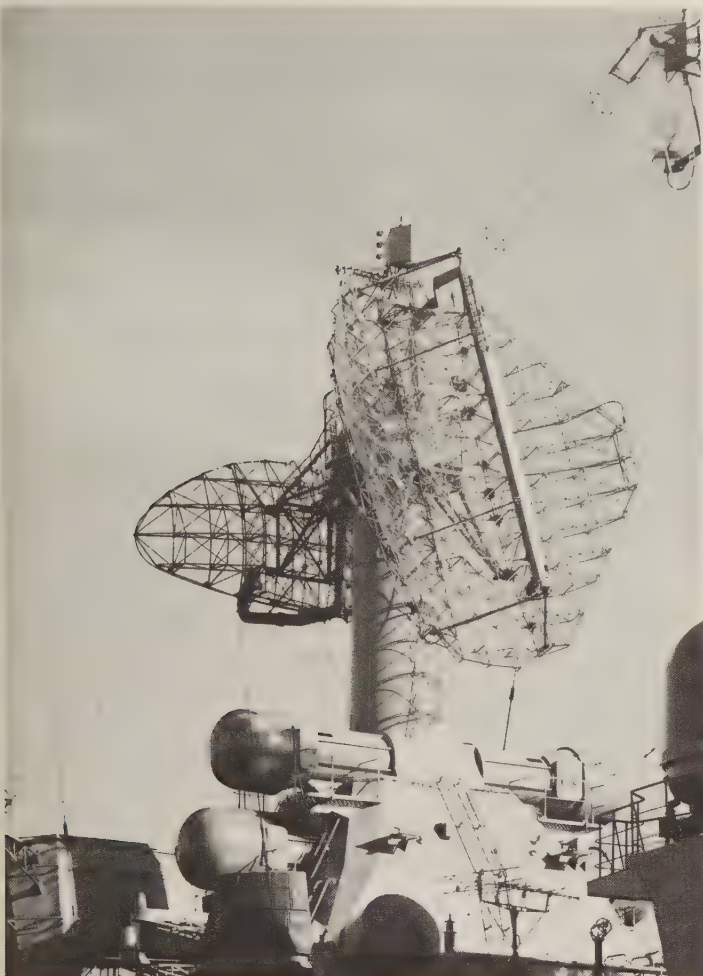
The large frequency-scanning 3D radar introduced in 1967 in the *Moskva* is the main search radar in all ships armed with SA-N-3 missiles. Top Sail probably operates at about the same frequency as Big Net, i.e., about 850 MHz, which is well below that used by the roughly analogous U.S. systems of a decade earlier (SPS-39/52 series). The typical U.S. flat serpentine waveguide is replaced by a waveguide twisted around a vertical pole in front of the reflector; very clear photographs show the twists, which are required to provide the greater length needed to operate at a longer waveguide. Presumably there are radiating slots on the pole where it faces the reflector. Antenna dimensions are about 6.1×7.5 m.

The Soviet name for Top Sail is Voskhod (Dawn), which would be particularly appropriate to a radar whose beam rises (like the sun).

Top Sail is invariably combined with a Head Net C secondary or backup 3D radar.



Top Sail on board a *Kresta-II*-class cruiser. The long straight element in front of the reflector is the twisted feed, which performs the same function as the sinuous feed in a U.S. frequency-scanning radar. The extra feed at the top is presumably for IFF. (U.S. Navy)



Top Pair radar on board the missile cruiser *Marshal Ustinov*, Norfolk, 1989. Note the interrogator (IFF) atop the array. (S. Zaloga)

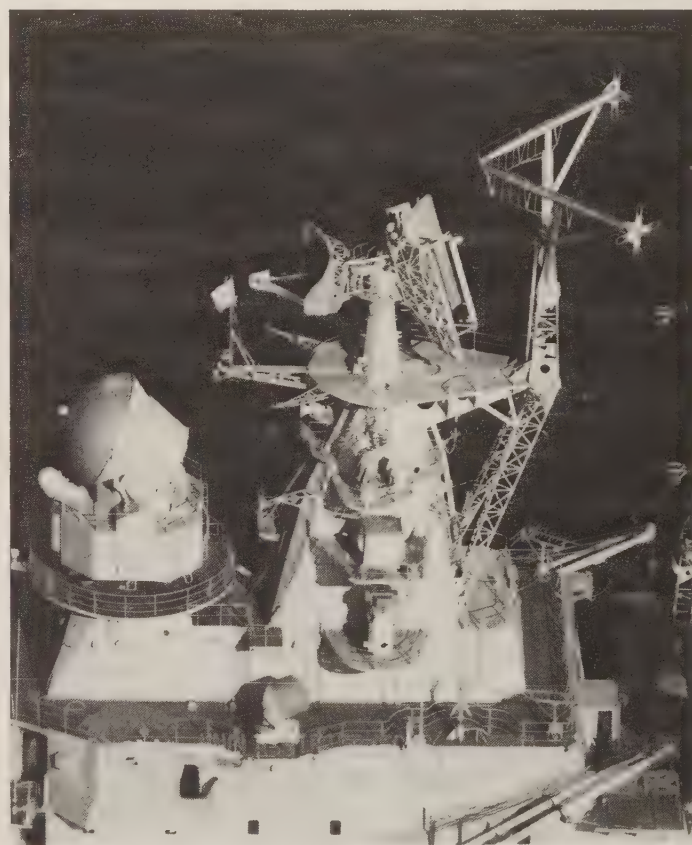
Top Pair consists of Top Sail and Big Net antennas arranged back to back. Presumably that arrangement makes for better long-range coverage; the U.S. Navy has found that frequency-scanning radars do not dwell on any particular part of the sky long enough to provide the sort of detection probability achievable with a fan-beam (2D) radar. Top Pair first appeared in the *Kirov* and *Slava*. The usual backup radar is Top Steer.

◆ Top Steer

This 3D S-band radar consists of a frequency-scanned antenna arranged back to back with 1 Strut Pair antenna. There is no known example of the S-band frequency scanner alone (analo-



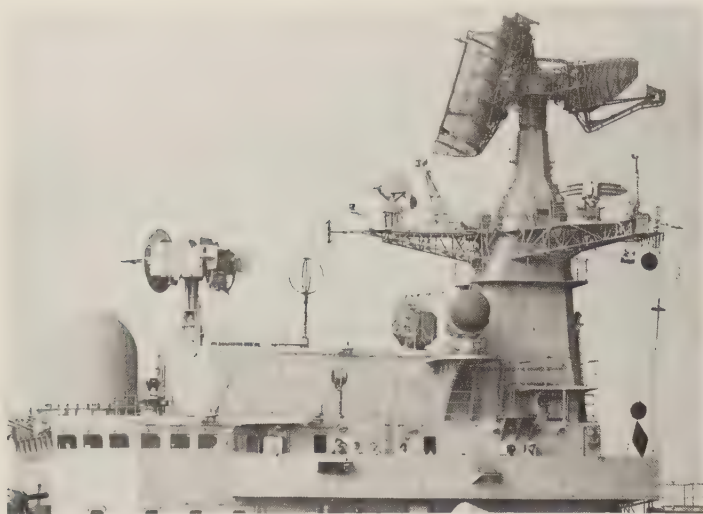
Top Steer radar on the missile destroyer *Otlichnyy* visiting Norfolk, 1989. The tube running up in front of the radar reflector carries the serpentine feed for frequency scanning. The array above the antenna is the Long Head IFF interrogator. (S. Zaloga)



Top Steer radar on the cruiser *Kirov*, 1981, with a Top Dome missile director on the left and Vee Tube HF radio antennas on the right. Below the radar are the box for a Fly Screen landing-control device and a Tin Man television camera. The small fire-control radar is Bass Tilt. (U.S. Naval Institute)

gous to Top Sail). The 2 antennas share a common feed. Since Strut Pair is known to have been the first Soviet pulse-compression radar, it is difficult to avoid concluding that the Soviets use a single frequency-scanned pulse in the height-finder, rather than changing frequency pulse by pulse as in most Western frequency-scanned radars.

This radar actually preceded Top Pair into service, the *Kiev* carrying Top Sail (not Top Pair) and Top Steer. It appeared as the secondary 3D radar of the *Kirov* and is the primary 3D radar on the first 3 *Sovremennyy*-class destroyers; it is also on board 2 *Kievs*, 2 *Kirovs*, 2 *Slavas*, and the experimental destroyer *Provornyy*.



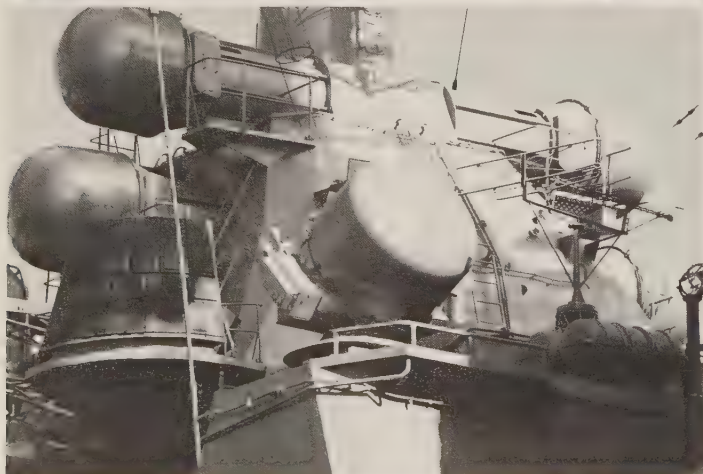
Top Steer on the destroyer *Sovremennyy*, with Palm Frond surface-search radars. (U.S. Naval Institute)

Plate Steer is an analogous antenna, in which the 3D element of Top Steer is replaced by the planar array of Top Plate, canted to the vertical (as in other Top Plate installations), on the *Sovremennyy*-class destroyers *Osmotritel'nyy* and *Bezuprechnyy*.

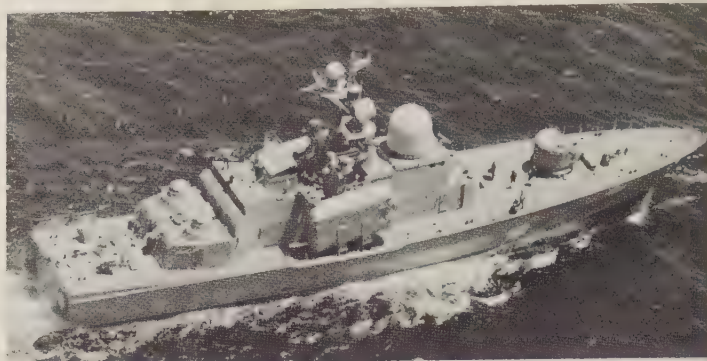
FIRE-CONTROL RADARS

◆ Bass Tilt

This radar operates in C-band and is used with the Soviet AK 630 Gatling gun. In *Grisha*-III, Bass Tilt also controls the twin



A Bass Tilt radar director on board the missile cruiser *Marshal Ustinov* at Norfolk, 1989. The object tilted back alongside carries a microwave horn and may be used to cancel sidelobes. (S. Zaloga)



A Tarantul-II-class missile corvette shows her Light Bulb data link antenna at the top of her mast, with a Bass Tilt gunfire-control antenna below. The small slotted waveguide atop the bridge serves a Kivach-3 navigational radar. The 2 objects right aft are standard chaff launchers. (*Ships of the World*)

57-mm gun; and in *Nanuchka*-III, *Matka*, *Grisha*-III, *Tarantul*, and *Pauk*, Bass Tilt controls the 76.2-mm gun. As its name implies, this radar operates at a somewhat lower frequency than Drum Tilt, which it superficially resembles. Bass Tilt entered service about 1972. This radar is called *Vympal* in Indian service; that may be its Soviet name. It controls 2 separate guns, the single 76-mm and the AK-630, in the new Indian corvette *Khukri*.

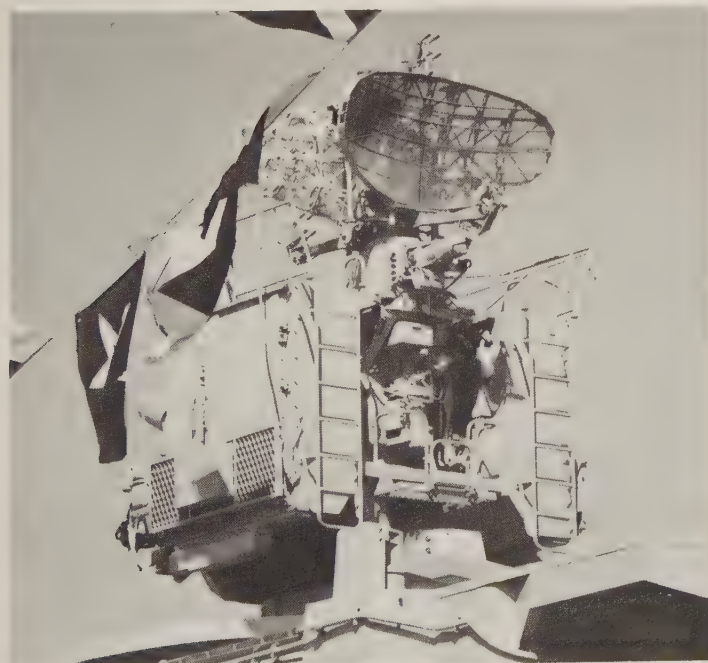
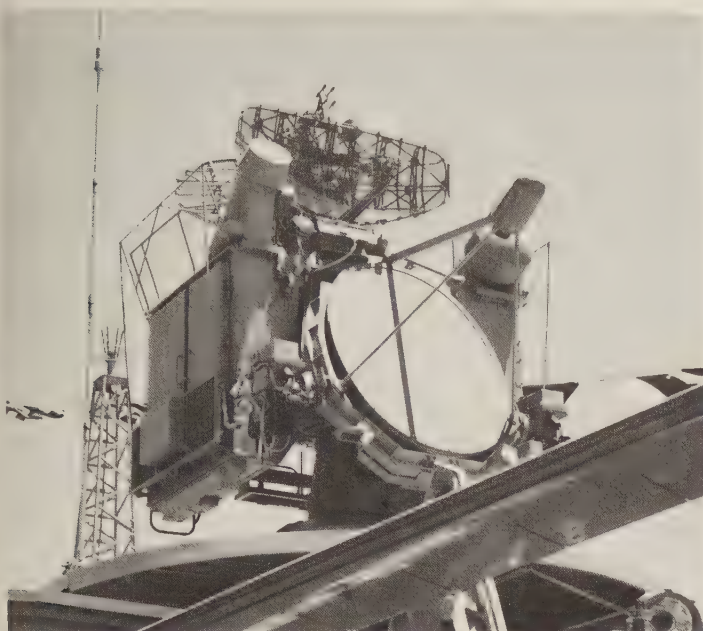
◆ Cross Sword

Serving as the missile guidance for SA-N-9, which is the successor to SA-N-4, the Ku/X-band Cross Sword, like the Ku/C-band Pop Group, incorporates its own search antenna. In this case, however, there are no separate target and missile-tracking antennas, only a single flat face with a prominent illuminator. The antenna is not dished in any way and, therefore, cannot be a passive reflector for the feed. Nor is there sufficient depth for the flat plate to be merely a weather cover. Most probably the flat plate is an active reflector, in the sense that different elements change the phase of the incoming signal (from the feed) in different ways, so as to form 1 or more beams. Such a solution would square with the fact that Cross Sword is roughly contemporary with the phased-array Top Dome, and also that Cross Sword has apparently encountered serious manufacturing problems (a simple monopulse would not present any great difficulty). Presumably, the prominent pimple centered on the Top Dome radome is an analogous feed.

Such radars are quite different from Western phased arrays, in which the phase shifter is interposed directly between transmitter/receiver and antenna element. Presumably, they are simpler to wire and need not pass quite the same amount of power as in such Western radars as SPY-1.

The surveillance system consists of 2 paraboloids arranged back to back for a high data rate. They differ in configuration (particularly at their edges), and each appears to be made in 2 layers. In other cases, this type of construction is used with 2 beams of different polarization, 1 layer reflecting only in 1 polarization. Such an arrangement might provide 2 beams at slightly different angles, so the radar could not only acquire a target but also determine its position more precisely (similarly, the 2-beam radar might provide initial altitude information). The high data rate (compared to the 1-antenna Pop Group) may have been chosen in response to a new requirement to protect ships against very small antiship missiles appearing suddenly at the horizon at a relatively short range. The double surveillance radar incorporates its own IFF interrogators, carried above the search antennas.

Cross Sword has 2 smaller antennas above its main antenna, aligned with its main axis. One is probably a missile-command



Cross Sword missile director (for SA-N-9 missiles) on board the *Udaloy*-class destroyer *Admiral Vinogradov*, July 1990. Note the IFF interrogators mounted on the search radar, and what appears to be a fixed telescope on the left-hand side of the director. (S. Zaloga)

transmitter. The other might well be a phased-array missile-beacon tracker. There are also electro-optical devices at the lower corners of the main antenna.

In the case of Cross Sword/SA-N-9, the initial installation was on board *Udaloy*-class destroyers, which have 8 vertical launchers but 1 or 2 directors. Since the missiles are all vertically launched, either director should be able to control all of them. An analogy can be made with the design of the *Kirov*, in which all the missiles are forward but there is a second director aft. Past Soviet practice has been to associate 2 launchers or launcher arms with each target channel, so one would assume that Cross Sword can handle 4 targets with a total of 8 missiles. The presence of 2 directors on the same ship would not be too significant since each has only a limited effective arc (whereas each missile, like a Western vertically launched weapon, can presumably cover all 360 deg).

◆ Drum Tilt

This radar operates in C- and X-bands; on Osa missile boats and others Drum Tilt controls twin 30-mm guns. Drum Tilt was the first of a new generation of drum-shaped fire-control antennas (1961). The housing is tipped up permanently at an angle of about 25 deg, and approximate dimensions are 1.5 m in diameter and 1.7 m in length. This radar is fully stabilized. Like the earlier Hawk Screech, it is almost certainly designed for TWS operation, the feed rather than the antenna as a whole scanning a limited volume of space. The fixed radome elevation would seem to imply that the antenna itself is fixed in elevation. TWS operation presumably suits Drum Tilt to more conventional search operation (it is the primary search radar in *Natya*- and *Yurka*-class minesweepers). Reported acquisition range on an aerial target is 41,000 m [about 45,000 yd], and maximum tracking range is 22,800 m [about 25,000 yd]. Reportedly, at least the early radars of this type required skilled operators because the radar tended to lose targets even if locked on. The initial version could track only a single target. The Soviet designation is Rys.



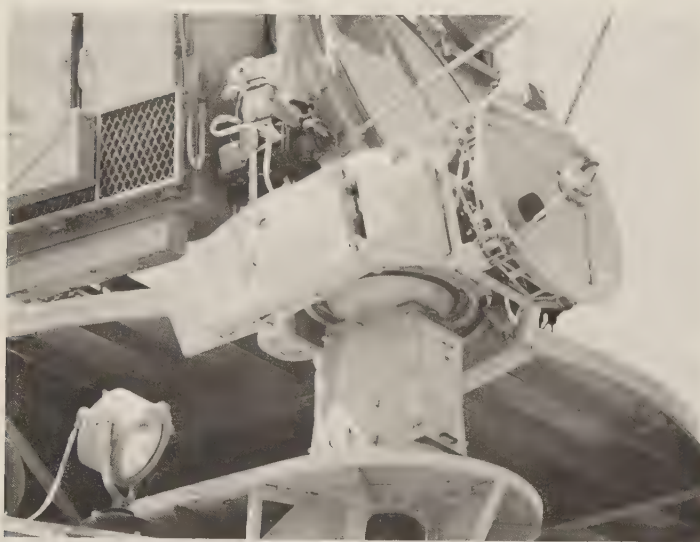
Drum Tilt radar on board an East German *Koni*-class frigate. (U.S. Naval Institute)

◆ Eye Bowl

S-band tracker for the SS-N-14 ASW missile, which is command-guided. Ships with Head Lights SAM guidance radars use those sets to track and guide their SS-N-14s. Eye Bowl (2 antennas) is on board *Kirov*-class cruisers, *Udaloy*-class destroyers, and *Krivak*-class frigates.

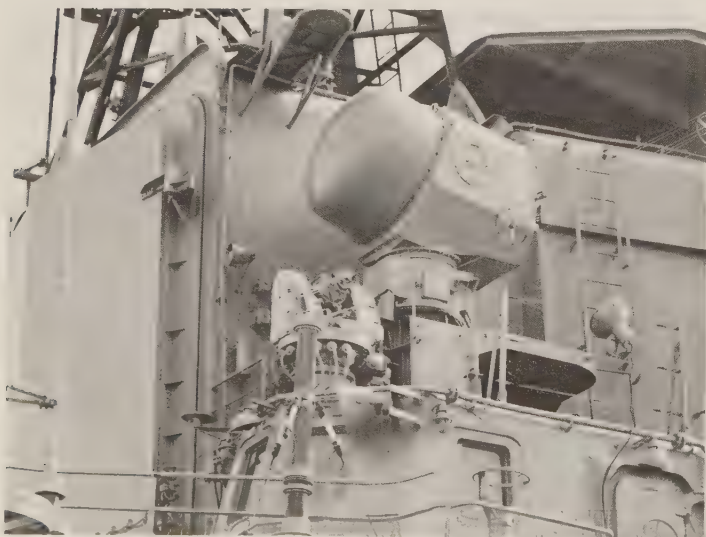


Eye Bowl (SS-N-14) control antennas are shown above the bridge of the Krivak-class frigate *Komsomolets Litvii* at Kiel, June 1990. Below them is a Pop Group director (with a Don Kay antenna below it); above them are Palm Frond and Head Net C, with a Salt Pot IFF interrogator above the Head Net radar. (L. van Ginderen)



Eye Bowl on board the *Udaloy*-class missile destroyer *Admiral Vinogradov*, 1990. (S. Zaloga)

◆ Front Dome



A Front Dome missile-guidance radar, on board the destroyer *Otlichnyy*, at Norfolk, 1989. The optronic device next to the guidance radar is unique to the *Sovremennyy* class and is paired near the SA-N-7 launchers; presumably, it is an electro-optical part of the SA-N-7 system. (S. Zaloga)

The missile guidance for SA-N-7 is a C-band tracker-illuminator. It resembles the Bass Tilt gunfire-control radar but is larger. In the *Sovremennyy* class, 3 such radars are associated with each SA-N-7 launcher.

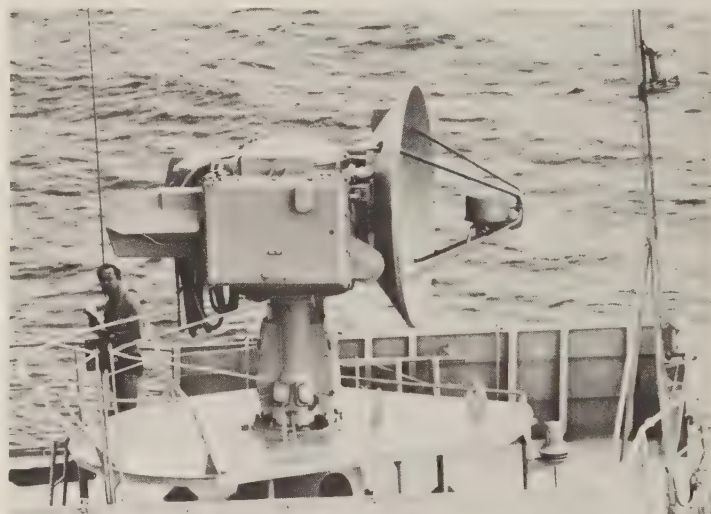
◆ Front Door

Tracker/command antenna for SS-N-3 and -12 antiship missiles. It is a slightly cylindrical antenna, taller than it is wide, which can scan in bearing. Echo- and Juliett-class submarines have a second antenna, Front Piece, which probably tracked the missile in altitude. It folds up atop the main antenna. The submarine version of the antenna folds down about its horizontal centerline. Its housing turns 180 deg to expose the antennas, and it can train to follow the outgoing missile. Surface-ship versions were initially designated Trap Door; they do not fold (but the version in the *Kiev* class folds down at one end, hence the name). The submarine antenna is now designated Front Door A, and Trap Door is now designated Front Door C. As an indication of size, the antenna in the *Kiev* is covered by a 3 × 5-m door.

Scoop Pair is the corresponding antenna on Kynda- and Kresta-I-class cruisers.

◆ Hawk Screech

Band: X (9.2–9.5 GHz) **Beam:** 0.6 deg
Peak Power: 150 kW **Pulse Width:** 0.6 microsec
PRF: approx 1250 pps
Scan Rate: 30–31 cycles/sec linear scan (narrow sector)
Antenna Dimensions: diameter approx 1.7 m



Hawk Screech radar on board an East German Koni-class frigate. (U.S. Naval Institute)

Hawk Screech is the X-band fire control for 45-mm, 57-mm, and 76.2-mm dual-purpose guns (1954); it always has an optical backup. Probably the radar conceived in 1949 and designated *Yakor'* by the Soviets, Hawk Screech introduced a new auto-track technique (lobing) that was used in several other radars. This radar was fully stabilized, for blind-fire and autotracking. Maximum range is probably about 6500 yd and 18,000 ft (altitude). The new tracking technique was almost certainly TWS, the technique used in several contemporary or somewhat later missile-control systems. The scanning beam is generated by a rotating feed (evidenced by its circular housing) in an "organ-pipe." The radar presumably nods in elevation to acquire its target. Although all Western TWS FCSs have been limited to relatively slow-moving surface targets, in the early 1950s the Soviets seem to have become interested in TWS approaches to dealing with very fast targets. Presumably, the radar operator tracks a target and then uses a succession of plots to insert data that the radar can project ahead, for rate-aided tracking. If that is indeed the case, then these systems are unlikely to be very

effective against maneuvering targets. That in turn would explain the rise of a new generation of systems, such as Kite Screech and Muff Cob.

◆ Head Lights

The X-, C-, and S-band missile-control radar for SA-N-3 consists of 2 large (4-m) and 2 small (1.8-m) tracking dishes and a small dish for the command uplink. The large dishes track the target, the small dishes the missile. Soviet doctrine appears to be to fire 2 missiles (from 1 launcher) at the target, and in this system each missile apparently needs its own target tracker, the command signals presumably being generated by measurement of the expected miss distance between missile and target. There are several versions. Head Lights B added SS-N-14 control. All *Kievs* have Head Lights C, which presumably has additional power to control a longer-range version of SA-N-3. Head Lights C appeared in the Kara class. The early *Kresta-II*s had Head Lights B forward and Head Lights A aft, but later ones had Head Lights B fore and aft.

Head Lights was probably 1 of the earliest Soviet applications of monopulse radar technology.

The Soviet name is Grom (Thunder).



Head Lights on board the cruiser *Kerch*, 1989. (Eric Grove)

◆ Kite Screech



Kite Screech B radar director for 130-mm guns, on board the destroyer *Otlichnyy* at Norfolk, 1989. The hole is for a television camera. The radar abaft the director is Palm Frond. (S. Zaloga)

The fire control for 100-mm and new 130-mm dual-purpose guns is similar in appearance to Hawk Screech but larger.

The fire-control radar for 100-mm guns and for the new 130-mm dual-purpose guns is externally similar to Hawk Screech but has a larger dish and almost certainly a very different principle of operation. These radars have a characteristic V-shaped strut supporting a feed, most likely monopulse. Kite Screech appeared about 1975. Kite Screech A (mid-1970s) operates at C- and Ka-bands. Kite Screech B (early 1980s) operates at X- and Ka-bands.

◆ Kolonka

Kolonka is a simple optical director, used to control light automatic guns, such as AK 230s, which lack any on-board controls. Kolonka carries a very simple sight with speed rings, so it is almost certainly not a lead-computing sight like the old U.S. Mk 14 used in the Mk 63 fire-control system.



A Kolonka visual sight on board a Soviet torpedo boat. This is not a lead-computing sight; the operator uses simple speed rings to estimate the required lead. The radar in the background is Drum Tilt. (TASS from SOVFOTO)

◆ Muff Cob

For 57-mm twin automatic guns, Muff Cob operates in C-band and has an attached TV camera. This system first appeared about 1962. Although Muff Cob has a barrel-shaped radome similar to that of Drum Tilt, it elevates; therefore, the entire antenna presumably tracks its target in both elevation and azimuth. Muff Cob might, therefore, be seen as marking the transition to monopulse tracking radars, even though the TWS radars have survived.

The Soviet name is Bars (Wildcat).



Muff Cob 57-mm gunfire-control radar director, on board the Indian frigate *Ganga*. In Indian service this director is designated MR-103. (Ships of the World)

◆ Owl Screech

This C- and X-band fire control for 76.2-mm DP guns (about 1961) is an improved Hawk Screech. The cylindrical (rotating) feed is tilted at 45 deg to the horizontal so that its beam scans in both elevation and azimuth. The reflector's diameter is about 2.3 m. Peak power is reportedly 250 kW. There is no associated backup director/target designator.



The Mod Kildin-class missile destroyer *Ozorlivyy* shows Owl Screech (above) and Hawk Screech (below). Owl Screech is the larger and has its feed at 45 deg to the horizontal. (Markku J. Paananen, 1979)

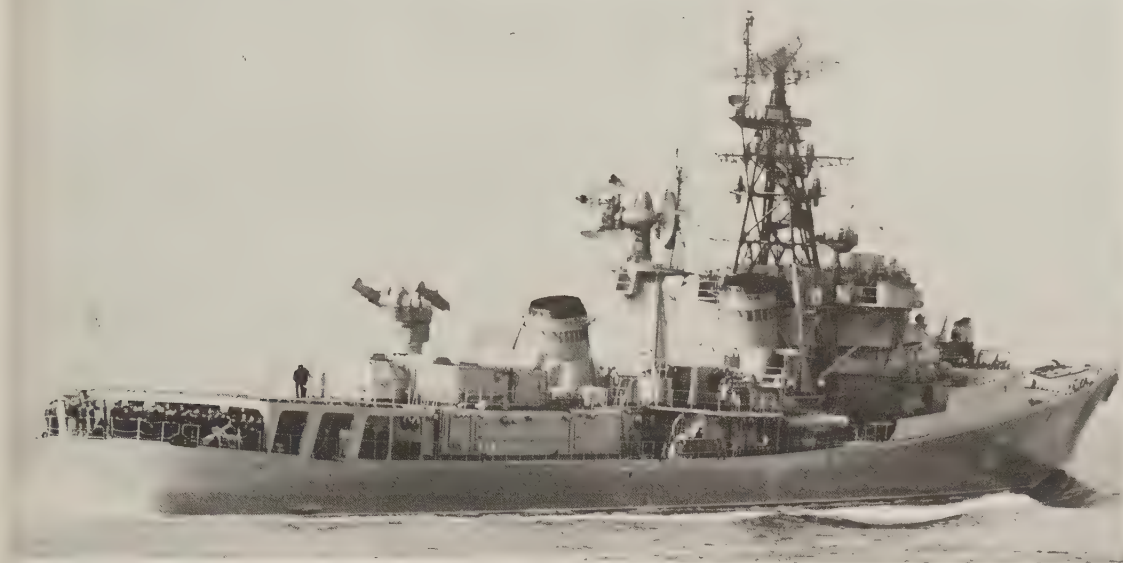
◆ Peel Group

This missile-control radar for SA-N-1 consists of a command dish plus 2 groups of antennas: 1 to track the target, the other to track the 2 missiles normally fired in a salvo. Each group consists of 2 parabolic reflectors, 1 vertical and 1 horizontal; hence the name (they resemble pieces of orange peel). The feeds are almost certainly organ-pipe scanners, rotating rapidly to form beams scanning in height and elevation, like the beams of the old U.S. SPS-8 and SPS-30 series. Presumably, the command dish sends the missiles signals for vertical and horizontal course correction. The target is tracked in S-band, the missile in X-band. The director also carries a TV camera for use under heavy jamming. Maximum range is about 30–40 nm.

Although unknown in contemporary Western missile-control systems, Peel Group's TWS operation was typical of contemporary Soviet missile-guidance radars. Compared to a single conscan tracker, a TWS tracker requires much less in the way of accurate radar-antenna movement, as the antenna need not track the target (except when the target reaches the edge of the available beam motion). TWS tracking is, however, relatively difficult to automate. In the Soviet case there are probably separate elevation and azimuth operators who match the observed target motion with rate-aided tracking, applying corrections as required. Such operation would seem to imply poor performance against a radically maneuvering target and explains the shift to



Peel Group missile (SA-N-1) fire-control radar directors on board the Kashin-class destroyer *Strogii* at Massawa, 1972, showing the characteristic pairs of large and small horizontal and vertical antennas, for target and missile tracking. (Royal Navy)



Peel Group on board a Kanin-class missile destroyer. (U.S. Navy)

monopulse operation (i.e., to fully automatic tracking) in the next-generation Head Lights (SA-N-3) and Pop Group (SA-N-4). TWS fire control also carries the disadvantage that the radar spreads most of its energy outside the target and, thus, should be easier to jam (and should enjoy shorter effective range) than a radar continuously pointed at a target.

The major contemporary Western naval example of TWS operation was the World War II Mk 8/Mk 13 main-battery fire-control radar. In its case, TWS permitted the same radar to observe both the target and the nearby splashes. The alternative lobing radar could track a target more precisely, but it could not observe splashes to either side. In theory, a single pair of TWS antennas could track both target and missiles (as in the land-based equivalent to Peel Group, Low Blow), but Soviet naval practice has been to provide separate missile and target trackers. In theory, at least in this case, that should permit the use of more energy-efficient missile trajectories (the missiles need not fly near the targets), as well as up-and-over surface-attack trajectories.

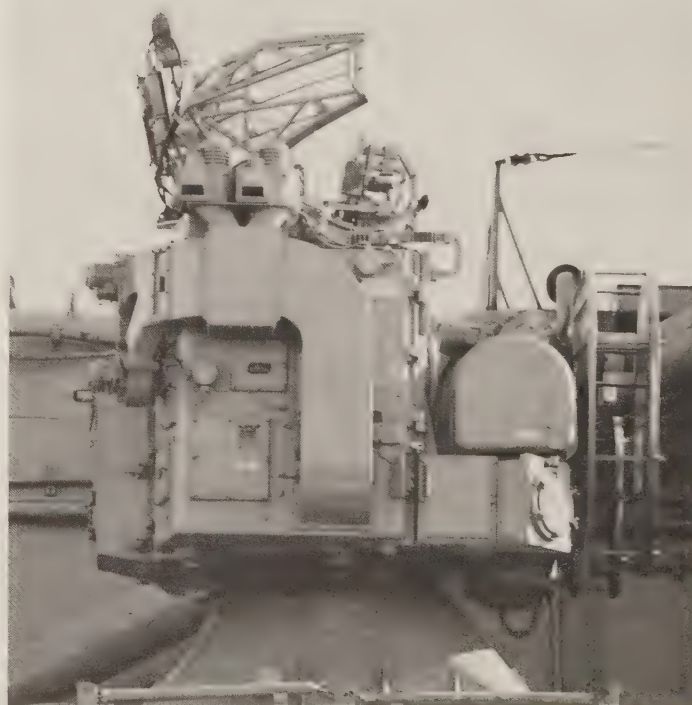
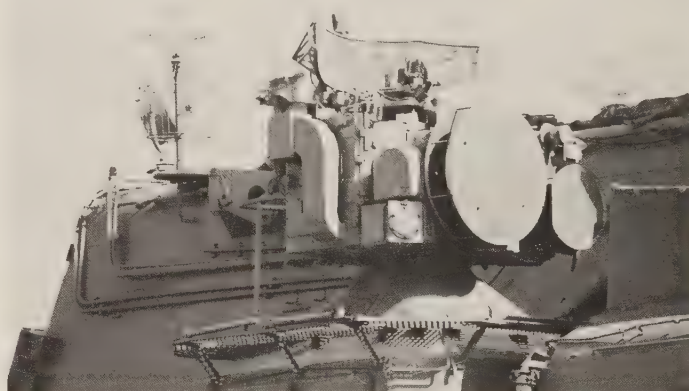
The Soviet name for this system is Yatagan.

◆ Pop Group

Pop Group is the missile-guidance radar for SA-N-4, incorporating its own acquisition radar, atop the cab, with target and missile trackers in front (flat plate antennas). Presumably the acquisition radar is colocated with the trackers to reduce hand-over delays; in this sense Pop Group is analogous to the Signaal M20 series and to the U.S. Mk 92.

Although the missile launcher has 2 arms, there are only a single missile-tracker antenna and a single target-tracker antenna. Dual operation would still be possible using polarization diversity, 2 signals sharing a common antenna. That sharing might be the reason for the flat plate some distance ahead of the antenna proper.

The analogous land system (Land Roll) has 1 large and 2 small antennas plus a surveillance/acquisition antenna similar in appearance to that of Pop Group. In the land system, the search antenna operates at 6–8 GHz (slightly below Western C-band wavelength), with stacked feeds (probably for frequency diversity, possibly for integral IFF). Reportedly, the big target tracker is a frequency-hopping monopulse antenna operating at 14.2–14.8 GHz (slightly above X-band as used in the West); re-



A Pop Group missile director on board the cruiser *Marshal Ustinov* at Norfolk, 1989. (S. Zaloga)

ported maximum range is 25 km (effective range 20 km). The target tracker is almost certainly an inverse Cassegrain. The smaller antenna is a higher-frequency replica of the larger.

In the case of the land-based system, the 2 missile trackers can operate at different frequencies, to track 2 separate missiles engaging the same target.

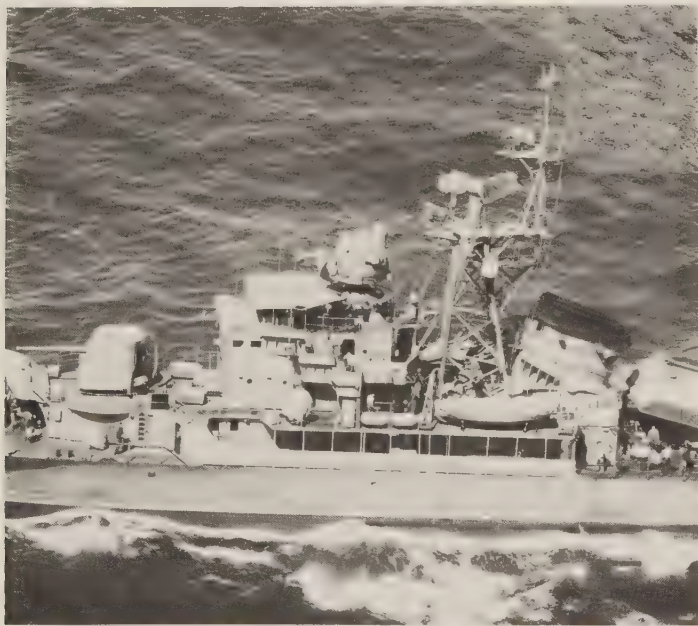
◆ Scoop Pair

This is the SS-N-3 guidance antenna on Kresta-I- and Kynda-class cruisers. One antenna group is used for each quartet of missiles; it consists of 2 separate stabilized antennas (top and bottom), each provided with a pair of horns and what appear to be 2 superimposed reflectors, about 4.2 m wide. With dual polarization, each antenna set could handle 2 sets of signals, to control 2 missiles. The system dates from the early 1960s, when the Soviets were using TWS systems to control surface-to-air missiles. Presumably, Scoop Pair is an application of much the same technology.

◆ Sun Visor

Band: X (9.3–9.44 GHz) **Beam:** 0.8 deg
Pulse Width: 0.2 microsec **PRF:** 2500, 3500 pps
Scan Rate: 40 scans/sec

This X-band fire control for 100-mm and 130-mm dual-purpose guns is mounted on a Round Top or Wasp Head director. Sun Visor appeared in 1953. The antenna feed is a dipole, and elevation limits are +90/–5 deg. Variations in the feed differentiate between Sun Visor A and B.

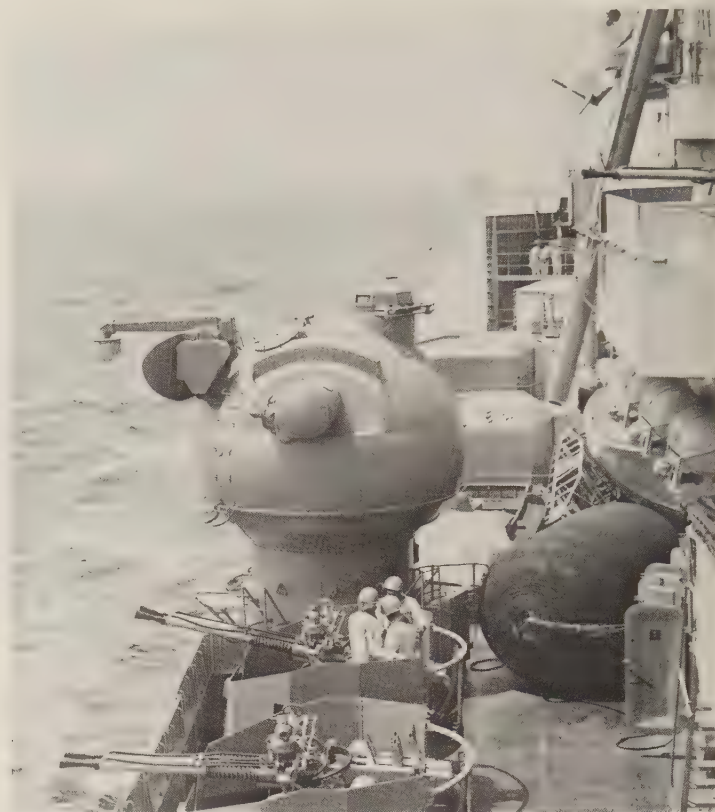


Sun Visor radar is visible on the front of the Wasp Head director of this Chinese Riga-class frigate. The main air-search radar above is Slim Net. The dome alongside the mast is presumably 1 of the 2 elements of Jug Pair, which is probably a Chinese version of Watch Dog (ESM). (U.S. Naval Institute)

◆ Top Dome

The X-band missile-guidance radar for SA-N-6 uses a 4-m-diameter radome fixed in elevation but trainable. Three smaller radomes are mounted on the face of the mounting pedestal, and there is also a much smaller hemispheric radome below. The smaller radome may be the link transceiver for the track-via-missile system. The main tracking radar almost certainly operates in X-band, in analogy to the land-based Flap Lid engagement radar.

Each Top Dome is associated with 6 vertical launchers; on the basis of 2 missiles per target, presumably Top Dome can simultaneously control 3 intercepts against 3 targets. Since



The secondary battery director of the Sverdlov-class cruiser *Dzerzhinskiy*, now discarded, shows its Sun Visor radar and its range-finder. The aerials in the background were part of the Fan Song radar controlling the SA-N-2 missile carried by this ship. In the foreground are standard twin 37-mm guns. (TASS via SOVFOTO)

there is no separate target or missile tracker, the system must time-share between the target- and missile-tracking functions. Because Top Dome does not elevate, it must scan electronically (as, indeed, the land-based SA-10 fire-control radar does).

In the past, it has been Soviet practice to assign 1 launcher per director per target. However, it is possible that the Soviets consider the array of 6 SA-N-6 launchers as a single entity, and that doctrine now calls for more than 2 missiles per engagement.



Top Dome missile-guidance radar on board the Soviet *Slava*-class missile cruiser *Marshal Ustinov* at Norfolk, 1989. (D. Steigman and S. Zaloga)



Top Dome missile-guidance radar on board the Soviet *Slava*-class missile cruiser *Marshal Ustinov* at Norfolk, 1989. (D. Steigman and S. Zaloga)

◆ IFF

As in the Western navies, the Soviets have developed interrogator-transponder IFF systems. There is no evidence of any attempt to integrate IFF for a ship; each air-search radar has its own interrogator. Transponder feeds are integrated into the feeds of most of the standard microwave radars, but it appears that the big frequency-scanning types require separate interrogators. Sky Watch has small flat panels near its main panels; they are presumably interrogators. The other large-radar interrogators are Long Head (a long array of dipoles, e.g., atop Top Plate) and Tooth Brush (square enclosure atop Top Sail and Top Steer and their relatives). Small combatants generally have Square Head (a 2.0×1.5 -m reflector carrying an array of vertical dipoles). Square Head dipole dimensions correspond to a wavelength of 50 cm (600 MHz). In an Osa-class missile boat there are 2 Square Heads, 1 for the Square Tie surface-search radar and 1 for the Drum Tilt gunfire-control radar. It is not clear whether different interrogators correspond to different IFF systems. Square Head(s) and a High Pole A or B transponder are part of a Soviet system designated Nkhrom-2. The other current transponder is Salt Pot (there are A and B versions), generally in larger ships. A few older large ships (*Moskva*- and *Kynda*-class cruisers) have an earlier transponder, Hour Glass. Presumably, it is part of an older IFF system now being discontinued (some ships have both it and Salt Pot).

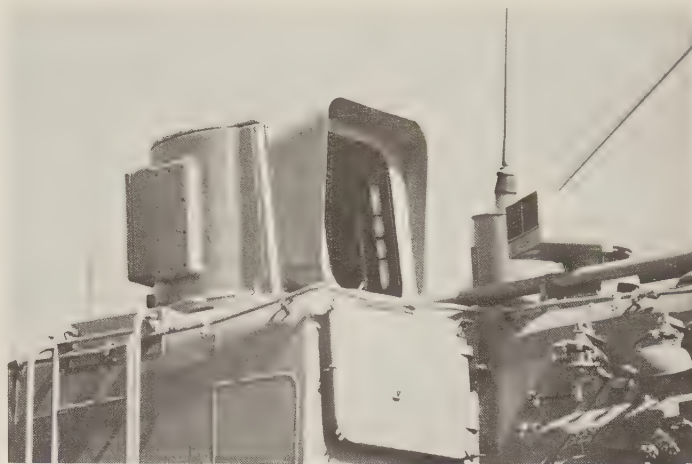
OPTRONICS

◆ Squeeze Box

In *Sovremennyy*-class destroyers and in amphibious ships with 140-mm bombardment rockets, Squeeze Box probably combines infrared television with a laser range-finder. An "uncovered" version is carried by Pomornik-class ACVs. Squeeze Box is a fire-control device, not a remote-vision device like Tee Plinth or Tin Man.

◆ Tee Plinth

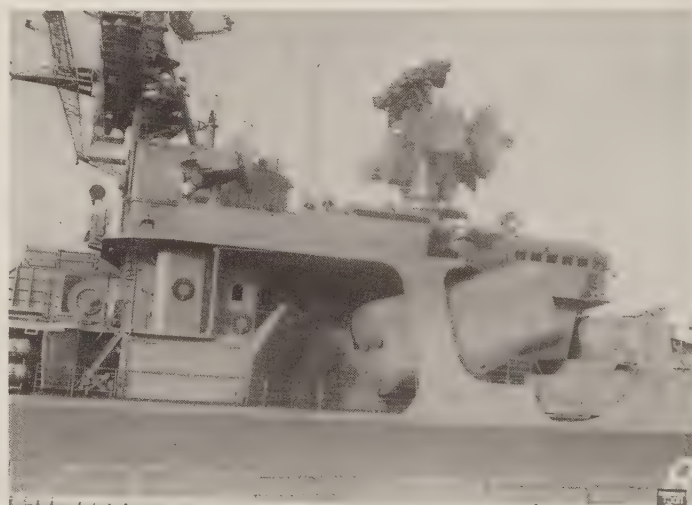
This television sensor was installed in the 1960s and 1970s and is now replaced in newer ships by Tin Man. Tee Plinth supplements the large optical periscopes that modern Soviet warships (from the *Kynda* class on) carry either atop or abeam their bridges. Both Tee Plinth and these periscopes presumably serve a below-decks command center. Such a center would be re-



Squeeze Box on board a *Sovremennyy*-class destroyer. This electro-optical device is associated with 130-mm-gun fire control; it contains a laser, presumably for range-finding. Reports that the same device was used to blind or dazzle pilots temporarily (like the British LDS) suggest that it can operate continuously, which in turn would be useful primarily to guide shells. (S. Zaloga)

quired if, as is said to be the case, the Soviets plan to fight their ships under fallout and chemical-attack conditions, using citadel protection (the center would be within the below-decks citadel). This type of arrangement would correspond to the much earlier and nearly universal practice, in the world's cruisers and battleships, of providing command facilities under armor, in a conning tower, served by periscopes projecting through the top of the tower. Presumably, Tee Plinth replaces human lookouts, who could not survive in a nuclear- or chemical-warfare environment.

The presumed existence of a below-decks command center is suggested by the very minimal dimensions of the bridges of ships of the *Kynda*, *Kashin*, *Kresta*, *Kara*, and *Moskva* classes. Most are just not large enough to include adjacent missile and radar control spaces. These spaces must, therefore, generally be below the bridge, and they are probably the same spaces served by the periscopes. One would suspect, then, that the Soviets tend to combine the functions of a Western CIC and a Western ship-control space, using television and periscopes to provide the commanding officer, who is below decks during combat, with a reasonably complete picture of the outside world. The U.S. Navy will probably adopt a somewhat similar arrangement



The bridge structure of the cruiser *Kerch*, 1989, showing the forward Head Lights director (which controls the SS-N-14 ASW missiles as well as the SA-N-3 battery) and an Owl Screech radar gun director further aft, above the enclosed bridge wing. The object visible above the Owl Screech is a periscope. The object just beneath the Head Lights radar is a Tee Plinth television camera. (Eric Grove)



The periscope in the enclosed combat command station of the cruiser *Kerch*, on the same level as, and abaft, her bridge. This station does not contain radar fire-control equipment but does include radar directors like the one visible in the background, as well as a steering console. (Eric Grove)

in its next-generation ships, to reduce the sheer size of its bridges and also to make collective protection (i.e., a citadel system) more practicable. For the U.S. Navy, a smaller bridge is attractive because it would reduce the ship's radar cross section. The Soviets presumably had to reduce bridge dimensions to provide more topside space for their large radars and weapons directors; the *Kynda* and later classes are very cluttered topside.

Ironically, it appears that the Soviets had to adopt larger topside bridges, presumably for better ship-handling, in later designs, such as the *Krivak*, *Kiev*, and *Kirov*. This development would seem to parallel U.S. experience with conning towers (i.e., protected command centers) in battleships before World War I. About 1910 the U.S. Navy sought to minimize open bridge space so that commanders would always operate from their protected conning towers. During World War I, when U.S. battleships operated with the British Grand Fleet, the American commanders found it difficult to conduct high-speed maneuvers from closed conning towers; substantial (unprotected) bridges were restored, though not on the same scale adopted by other navies. All major Soviet ships are still provided with the periscopes and electro-optical sensors (televisions) characteristic of their below-decks command spaces, i.e., of their citadel protection.

Tee Plinth and its successor (Tin Man) are trainable. The Soviets also use small fixed television cameras (Tilt Pot).

◆ Tin Man

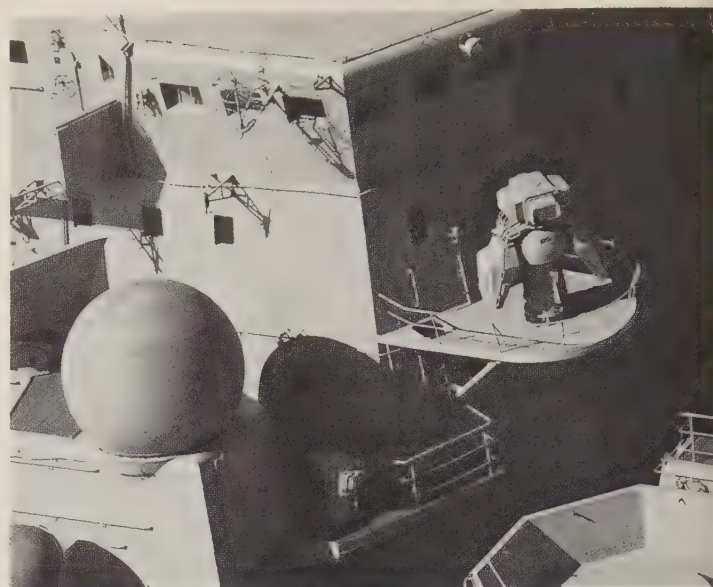
Successor to Tee Plinth, Tin Man probably incorporates a laser range-finder, in newer ships.

FIRE-CONTROL SYSTEMS

Later radar fire-control systems (e.g., Hawk Screech) are designated by the associated radar. The systems listed here are early postwar optical/radar directors.

◆ Wasp Head (Sphaera 50)

This dual-purpose director is installed in Riga-class frigates. The associated radar is Sun Visor. The director is stabilized and is suited to blind-fire. Maximum tracking range is 81,000 yd, and maximum antiaircraft speed is reportedly 950 kt (70 kt for surface targets). This system is not capable of autotracking.



A Tin Man optronic device on board the cruiser *Kirov*. The nearby radome is a Big Ball for satellite communications. (Sea Power)

UNITED KINGDOM

RADARS

◆ Type 262

Band: X Beam: 5 deg Peak Power: 30 kW
Pulse Width: (i) 20 (ii) 200 microsec PRF: 1500 pps

This close-range armament blind-fire (CRBF) radar survives in the GWS 21 Sea Cat missile system (Indonesian "Tribal" class). Type 262 oscillates in both planes while searching for a target and then tracks by conical scanning, the antenna spinning. The associated fire-control system tracks by measuring apparent target angular rate (using a gyro).

Type 262 could autotrack at 5000 yd, acquiring its target at 7000 yd. Targets were acquired by scanning 30 deg/sec in azimuth (elevating 3 deg at the end of each horizontal sweep), at the same time searching for 750 yd on either side of the indicated range at 30 cycles/sec.

◆ Type 275

Band: S Beam: 6 × 8.2 deg Peak Power: 400 kW
Pulse Width: 0.25, 0.5, 0.75 microsec PRF: 500 pps
Antenna Dimensions: diameter 4 ft (2 dishes)

This dual-purpose fire-control radar was introduced at the end of World War II and is still in service in India and in Bangladesh.

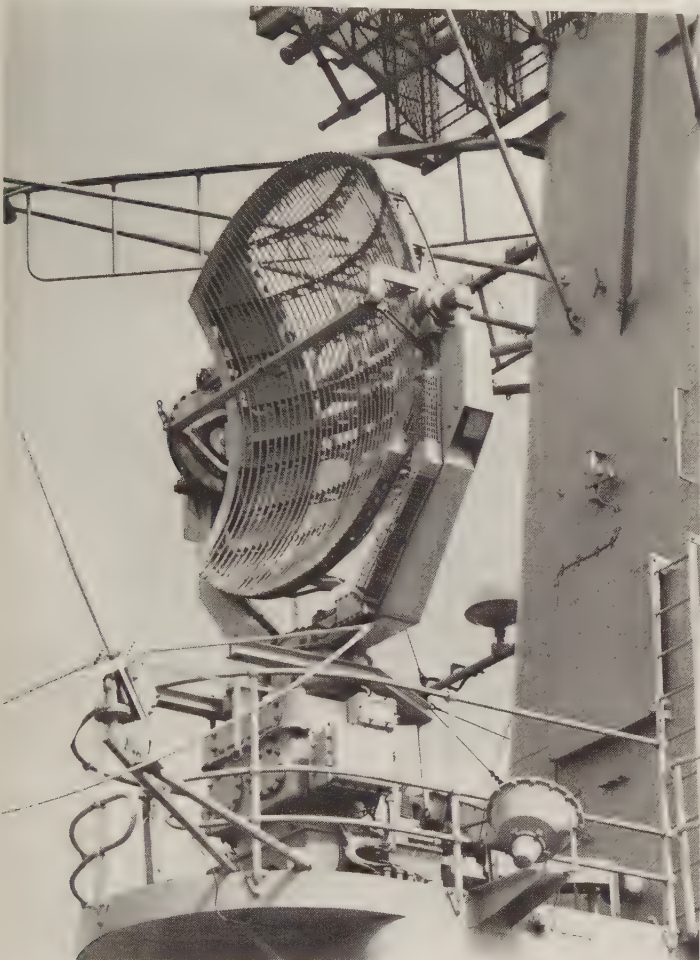


HMS *Puma*, a Type 41 anti-aircraft frigate, shows her Mk 6 director with its Type 275 fire-control radar (just abaft her bridge). The gun mount forward is a 4.5-in Mk 6. Two sisters survive in the Bangladesh Navy. (HMS *Excellent*)

Type 275 was intended for the postwar Mk 6 director, and some were also fitted to U.S.-supplied Mk 37s. The antennas are 4-ft dishes that can elevate and that scan conically. Detection range is 36,000 yd (tracking range 30,000 yd).

◆ Type 277/278

Band: S **Beam:** 4.5×2.2 deg **Peak Power:** 500 kW
Pulse Width: (i) 0.7 (ii) 1.5 or 1.9 microsec
PRF: (ii) 500 pps **Scan Rate:** 7.5 rpm
Antenna Dimensions: 8-ft spherical parabola with clipped sides



Type 278 radar, on board a "County"-class missile destroyer (second series). (R. Cheung)

Data are for the postwar 277Q, with antenna outfit ANU.

This nodding height-finder is still in service on board "County"-class missile destroyers and 1 Bangladeshi frigate. In modernized form (operating under weapons-system-computer control) this system was designated Type 278. Type 277Q performance: aircraft between 5000 and 20,000 ft could be detected at 55 nm, and height-finding range on an airplane at 20,000 ft was 60 nm.

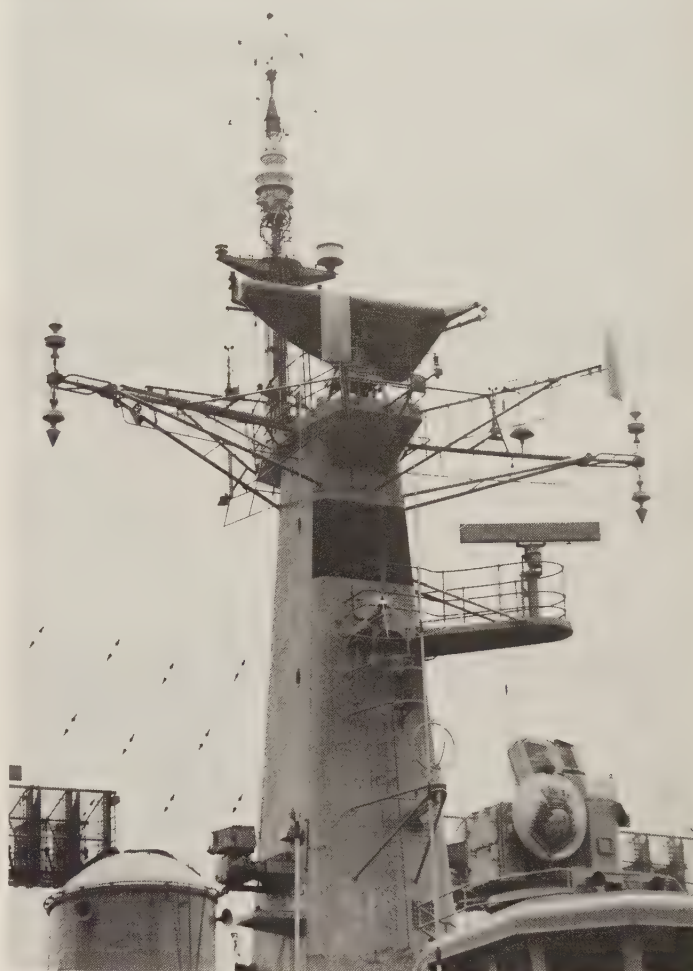
◆ Type 293/993/994

Band: S **Beam:** 2×35 deg **Peak Power:** 500 kW
Pulse Width: (i) 0.7 (ii) 1.5 or 1.9 microsec
PRF: (ii) 500 pps **Scan Rate:** 5, 10, or 15 rpm
Antenna Dimensions: 12 ft

Data are for the 293Q version (antenna outfit ANS).

This short-range air/surface-search radar (target indicator in large ships) was succeeded by Type 993. The remaining examples are on board the Indian *Leopard*-class frigates. Estimated range was 30–35 nm.

Type 993 is Type 293 with a new "quarter cheese" antenna, outfit AKD. In this antenna the feed horn does not obscure the main radar beam, so that the beam is better defined, even over a broad tuning band. This antenna scans at 24 rpm.



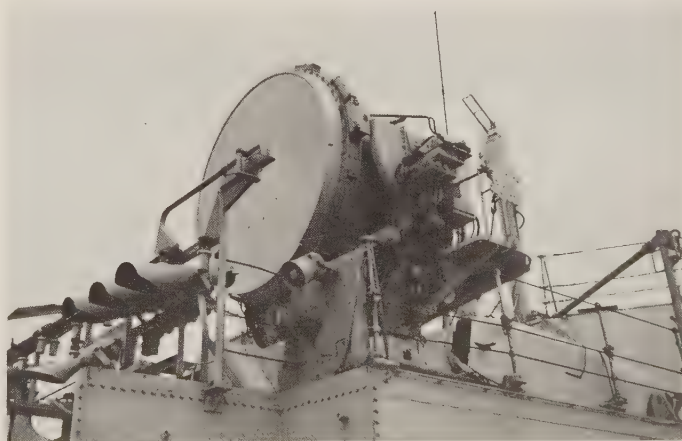
Type 994 radar on board the British frigate *Penelope*, 1988. The slotted waveguide is for Type 1006. (A. Raven)

Type 994 retains the same antenna but has a new transceiver based on that of the Plessey AWS-4 private-venture radar. Installation, e.g., on board frigates, began in 1978. As of 1990, the AKD antennas of Type 994 are being replaced by AWS-4 antennas.

◆ Type 901

Band: X (9–10 GHz) **Beam:** 0.9 deg **Peak Power:** 750 kW
Pulse Width: 0.2 or 0.3 microsec **PRF:** 1840 pps
Gain: 24 dB **Antenna Diameter:** 9 ft
Scan: Conical, 2 deg at 30 scans/sec

Data above are illustrative; they apply to the earliest version of Type 901. In this version maximum range was 60,000 yd.



Type 901 radar. The gathering horn is on the other side. (R. Cheung)

The associated gathering beam was 7.4 deg wide, scanning over a cone 18.8 deg wide, at a peak power of 250 kW (0.1-microsec pulses).

The missile-guidance radar for the Sea Slug system survives in the Chilean navy. It was conceived in 1944 as the basis of a new long-range anti-aircraft system, then adapted to missile guidance. The antenna is stabilized in roll and pitch. It scans conically or in a rosette pattern, and it also generates a secondary (transmitted only) missile-guidance beam. The associated computer coordinates the beams. A third (gathering) beam is generated by a small horn on the right-hand side of the nacelle (the gathering radar was originally designated Type 902).

The front of the nacelle is a dielectric lens. A pivoted reflector inside (the beam-deflector unit) is fed by an off-center horn that can itself rotate about an axis perpendicular to that of the radar. A second horn is used to generate the guidance beam. The combination of reflector and horn motion produces a conical or rosette scan (a petal scan in British parlance), depending on whether the reflector rotates about 1 or 2 axes. Pulse coding is used to guide 2 missiles along the same beam (the radar tracks the missiles by transponder). Given different ratios of horn and reflector motion, it can also scan vertically or horizontally to acquire a target.

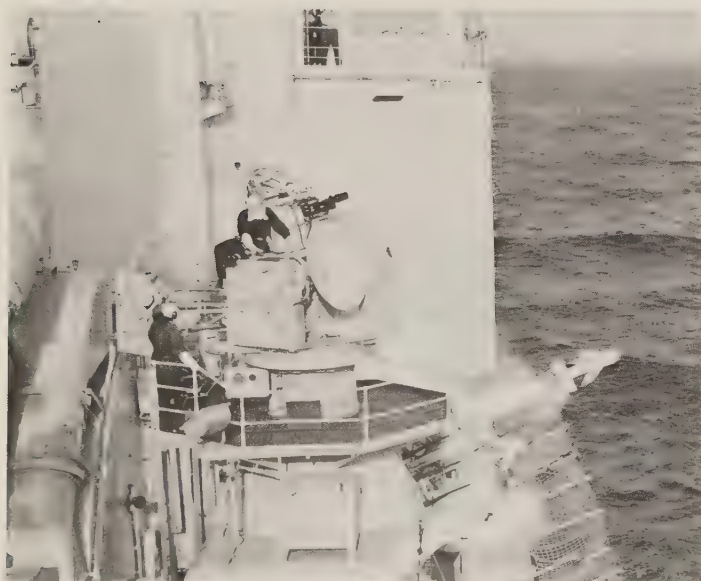
◆ Type 903/904

Band: X (8.5–9.05 or 9.05–9.6 GHz) **Beam:** 2 deg
PRF: 3000 pps **Pulse Width:** 0.1 microsec

This X-band conscan fire-control radar, used in the MRS 3 system, was based on the U.S. Mk 35 (which is described below). Data given here apply to the Mod 1 version, as used in MRS 3. Scanning was spiral (to acquire targets) or conical (for tracking). Minimum range was 32.8 yd, and maximum lock-on range was 29,500 yd. Range accuracy was 10 yd, and targets could be resolved within $1\frac{1}{2}$ deg or 25 yd. Typical preset range rates in the MRS 3 system were 180 yd/sec (closing) in anti-aircraft mode, or 22 yd/sec in the surface-fire mode. The director could turn 100 deg/sec when being run in to a designated target.

Type 903's development began about 1946, and the radar entered service in 1958. Type 904 is a modified version for Sea Cat missile control, as part of the GWS 22 system.

Users: Chile ("County" class and *Leander* class), India (*Leander* class), Indonesia ("Tribal" class), New Zealand (*Leander* class), Pakistan ("County" and *Leander* classes), and the United Kingdom (*Leander* class).

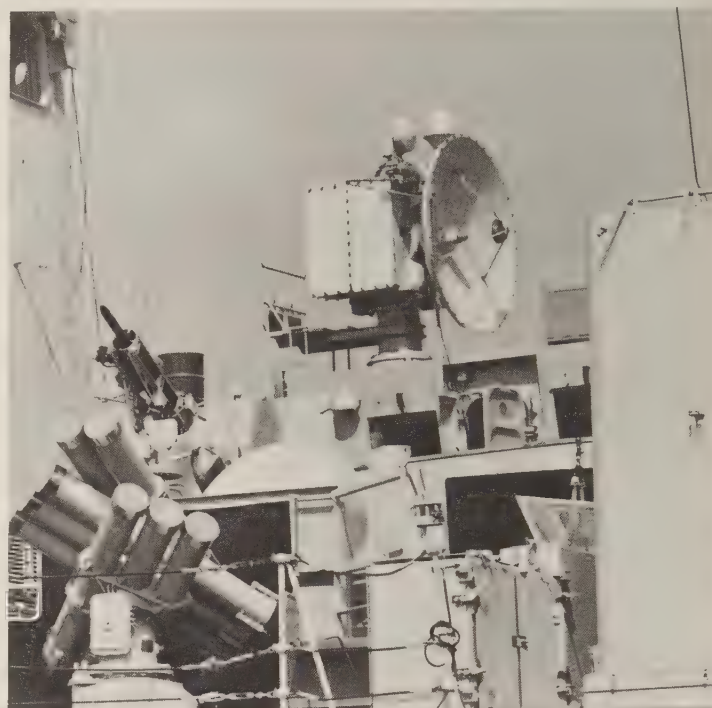


Type 904 radar-equipped GWS 22 Sea Cat missile director, with Sea Cat being fired. The open hood contrasts with the enclosed hood of the very similar MRS 3/903 combination. (U.S. Naval Institute)

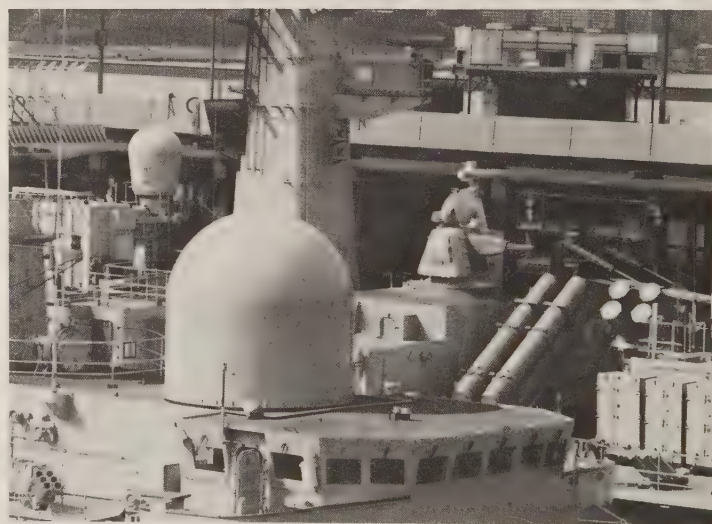
◆ Type 909

Type 909 is the tracking and illuminating radar for the Sea Dart missile system. The typical installation includes 2 radars. Type 909 is normally radome-enclosed but may be seen uncovered when ships are undergoing alignment trials. It is relatively heavy and, reportedly, unreliable, and it is being replaced by a lighter-weight radar, derived from the Marconi 805SD. Some existing Type 909 radars are being replaced by a more reliable derivative, Type 909I.

Type 909 dish diameter is 2.4 m.



Type 909 with the radome removed. (R. Cheung)



A Type 909 radome, HMS Glasgow. The ship in the background is HMS Cumberland. (Author)

◆ Type 910

Type 910 is the X-band pulse-doppler target-tracking radar for the Sea Wolf point-defense missile system. Electronic angle tracking is used to make small angular corrections to boresight without moving the radar itself.

Type 910 tracks a 0.2-m² target at a range of about 10 km, and smaller targets at 5–6 km. The main dish is about 1.6 m in diameter (beamwidth about 1.5 deg). This radar also tracks



Type 910 Sea Wolf control radar on board HMS *Brazen*, 1984. (R. Cheung)

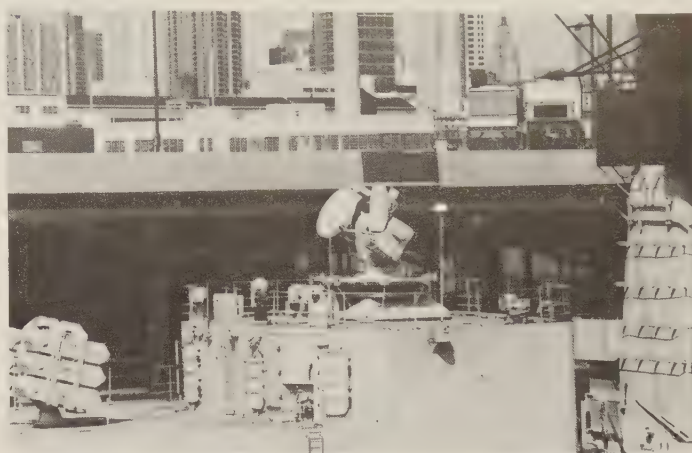
the Sea Wolf missile, using signals from transmitters in 2 of the missile's wings (the other 2 wings carry command-link receivers). Command signals are calculated on the basis of the difference between the missile's and the target's positions (differential tracking). Two 80-cm dishes alongside the main antenna carry the microwave command links for 2 missiles, which can, therefore, be fired in salvo against a single target. Multiplexing from a single dish was rejected as too complex. Command frequency is probably in the 10–15 GHz range. Between the main antenna and the 2 dishes is a gathering antenna consisting of a horn (for transmission) and 4 rectangular horns (for monopulse reception). The antenna also carries a television differential tracker, which uses a flare in the missile tail.

Marconi has developed a manually controlled infrared tracker that is being retrofitted into existing GWS 25 Mod 0 with the 910 tracker. The company is working on a fully automatic IR system for tracking and also for surveillance, to provide fully passive operation up to the point of launch, when the command link would have to be activated. Infrared alone is not sufficient, since it is not effective under some conditions, e.g., high humidity. Marconi therefore advocates a combination of 2 radar frequencies and infrared.

Type 910 is now being superseded by the lighter-weight Type 911. Two alternative replacements were considered. In Type 910M (about 1980), the television camera was replaced by a Blindfire Rapier DN181 mm-wave radar. There was also a Signaal VM40 radar director.

◆ Type 911 (805SW)

The lightweight Sea Wolf control radar, 1 of the Marconi 805 series, consists of 2 radars mounted side by side: A (left side of the array), a twist-Cassegrain narrow-beam reflector with a monopulse feed (and with an associated 4-horn monopulse cluster gathering antenna); and B (right side of the array), a tracker (offset folded Cassegrain reflector with a steerable sub-reflector). The receiver of Radar A is coherent-on-receive, measuring target velocity by FFT. The system measures the angle between the missile's and the target's paths. Both radars use filtered electronic angle tracking to overcome problems such as reflection from the sea surface.



Type 911 Sea Wolf control radar on board HMS *Cumberland*, 1990. (Author)

Radar A operates in X-band, radar B in Ku-band. Ku-band was chosen to overcome low-level multipath problems by frequency diversity. Both have magnetron transmitters. The director automatically selects the best of the 2 radars to track a given target. The drum-shaped command-link transmitter is located behind the Ku-band antenna, transmitting through it (commands are initially transmitted via the wide-angle beam cluster, then through antenna B after gathering). No electro-optical tracker (as in the original GWS 25) is fitted, as it would have required additional operators. Above-decks equipment weighs 1725 kg; between-decks equipment adds another 2155 kg. About 60 Type 911 radars had been sold as of late 1989.

Type 911 is a relatively elaborate device capable of controlling salvo-fired missiles. Marconi has developed a simpler, lighter XL version with a Javelin television on its right-hand side (to gather the missile), which is television or beam guided. The XL director has a large antenna that tracks the target, with 2 small (higher-frequency) dishes on its left-hand side (and a wide-beam horn between them, to gather the missile). The 2 dishes are the missile uplinks, operating in 2 frequencies to overcome multipath problems. The director weighs less than 700 kg and has a 1.2-m working circle (radius); the control console weighs 250 kg, and the transmitter/receiver cabinet another 700 kg. The tracker radar is the Marconi 1802SW.

The Marconi 805SW was adopted in preference to the Signaal VM40.

◆ Type 912

Type 912 is the British designation for the Italian Selenia Orion RTN-10X, used on board Type 21 (*Amazon*)-class frigates (with a Ferranti WSA-4 processor).



Type 912 radar director as installed on board a Type 21 frigate, with television camera visible at right. (GEC Sensors)

◆ Type 965/966

Band: P (about 1.4 m) **Beam:** 12×40 deg
Peak Power: 450 kW **Gain:** 20 dB
Pulse Width: (i) 3.8 (ii) 10 microsec **PRF:** (i) 400 (ii) 200 pps
Scan Rate: 8 or 10 rpm (depending on whether the power supply is 50 or 60 cycle)
Antenna Dimensions: 26 ft $\times$ 8 ft 11 in (or 16 ft 9 in) $\times$ 6 ft 1 in
Antenna Weight: 2425 or 5480 lb

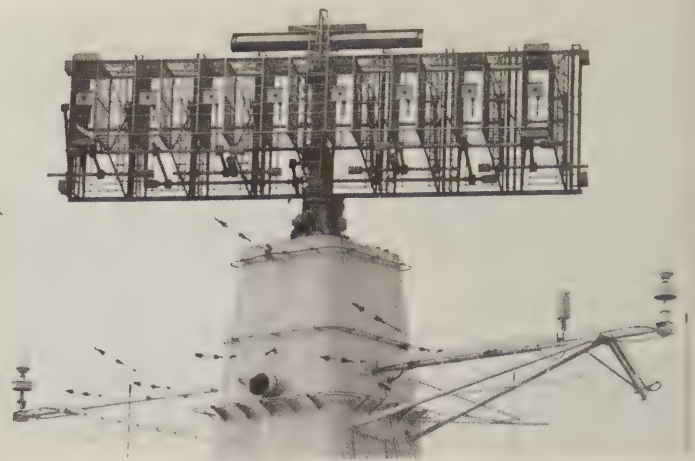
Type 965 is the standard British long-range air-search radar of the 1960s, adopted in place of the roughly contemporary U.S. SPS-6. There are 2 alternative "bedstead" antennas (in effect, squintless horn arrays), AKE(1) and AKE(2), the latter in effect 2 AKE(1)s superimposed. Each of the 8 or 16 array elements is shaped as a reflector horn surrounding a loop dipole.

Reportedly, this radar performed poorly in the Falklands because, without MTI, it was unable to detect Argentine aircraft approaching from overland. A modified version with crude MTI, 965M, has been reported. Type 966, which may be a private designation, is Type 965 with a modernized transmitter/receiver (but with the same antenna), which Marconi advertised in the mid-1980s.

Type 965 was first proposed in 1953 (and revived in 1955) to meet a staff requirement for a small-ship air-warning radar. Marconi proposed a modification of the existing Air Ministry Type 15 Mk 5, with a redesigned aerial (16 $\times$ 4 ft, 1500 lb including the antenna-rotation motor) and a reduced radar office. The radar would scan at 6–10 rpm, with a 17-deg beam (190–215 MHz, 3.8-microsec pulses, gapless vertical cover, range 100+ nm on a 20-m² target). U.S. trials of 200 vs. 400 MHz radars (resulting in the adoption of the SPS-17 and then -28/29) were cited in support of this frequency choice; and the Dutch LW-02 was rejected because it would not meet the range requirement and because its high frequency would prevent detection of streamlined aircraft. In 1955 the aerial was expected to be 24 $\times$ 7 ft (beam 17 $\times$ 45 deg); LW-02 used a 19.5 $\times$ 9.75 ft antenna (2300 vs. 1800 lb, the latter figure including IFF). LW-02 would require a separate IFF antenna, special venting arrangements, and adaptation to British requirements (Anglicization).



Type 965 (AKE-2) on board a "County"-class missile destroyer, with Type 904 in the foreground. (R. Cheung)



Type 965 radar (AKE-1 antenna, seen from behind). The "candlesticks" on the yardarms are UHF radio antennas, in this case either receiving or transmitting (the double candlestick carries both antennas). (Author)

A third alternative, the U.S. SPS-6C, was considered but rejected.

The 2-array version was developed to meet a 1957 Staff Requirement for a radar-picket/missile-destroyer set, using the Type 965 transmitter and a new antenna. This version was to have been capable of detecting a Canberra bomber flying at 70,000 ft at 200 nm (150 could be accepted), with a 10 rpm data rate. The proposed antenna was about 24 $\times$ 20 ft (weight no more than 2 tons, probably 1–1.5 tons). If the aerial were not ready in time, the existing 965 (small-ship air-warning) could be used temporarily. The Staff was not happy with the Type 965 beam (17-deg beamwidth), wanting 2 deg. DND wanted no more than 10 deg.

It appears that the choice was to feed each of the 2 superimposed arrays in AKE(2) to a separate receiver (channel) and, in effect, to compare the 2 so that the result lay somewhere between the broad beam of the original 965 and the narrower beam achievable by 2 antennas side by side.

Type 965 is being superseded in British service by Type 1022.

◆ Type 967/968

Type 967:

Band: L (1260–1360 MHz) **Beam:** 4.6×68.6 deg (est)
Peak Power: 50–60 kW **Pulse Width:** 6 microsec
PRF: 7320 staggered

Type 968:

Band: S (2950–3040 MHz) **Beam:** 2×30 deg
Peak Power: 3 MW **Gain:** 30 dB **Pulse Width:** 2 microsec
PRF: 750 pps **Scan Rate:** 30 rpm (max)
Antenna Dimensions: 4 $\times$ 1 m

The Sea Wolf search-and-acquisition radar consists of 2 units arranged back to back that designate to the Type 910 target tracker. Type 967 is an L-band pulse-doppler air-search radar; Type 968 is an S-band radar for low air cover and surface search. The Type 967 antenna contains the IFF interrogator. Signals from both radars are fed into a common Ferranti FM 1600B computer, which evaluates targets, decides to engage, and feeds target coordinates into the tracker.

The antenna mounting is fully stabilized, and detection and tracking are automatic.

In 1987 Type 967M was described as a special self-adaptive pulse-doppler radar for automatic detection of small targets.

These systems are manufactured by Marconi.

Type 968 is basically a repackaged 992 with a different antenna; Type 967 is a pulse-doppler radar comparable in principle to SPS-58. This system uses a Ferranti FM 1600 series computer for track formation, threat evaluation, and director assignment. It has an integral IFF. In the new "Duke"-class frigates (Type 23), the more compact 996 was selected over 967/968.



Back-to-back Type 967/968 radars at the masthead of the British Type 22 frigate HMS *Cumberland*, 1990. The antenna halfway down the mast is a Type 1007 surface-search set. The flat oblong visible near the base of the mast is used to calibrate the ship's forward Sea Wolf director. The array of directional antennas surrounding the mast beneath the 967/968 platform serves the UAA-1 ESM system; several small radomes on yards are omnidirectional antennas (for IFM) for the same system. Near the base of the mast is a DS-30B gun. (Author)

◆ Type 975

Band: X **Beam:** beamwidth 1 deg **Peak Power:** 50 kW
Antenna Dimensions: 6 or 10 ft

Kelvin-Hughes's surface-search and seaward-defense radar was replaced in British service by Type 1006. Minimum range is less than 35 yd. Type 975ZW is a minehunter radar with true motion display and with provision for marking sonar contacts on its PPI. The only surviving examples are on board the Bangladeshi frigate *Umar Farooq* and the Portuguese *Cacine*-class patrol boats.

◆ Type 978/979

Band: X **Beam:** beamwidth 1.2 deg **Peak Power:** 20 kW
Pulse Width: (i) 0.1 (ii) 1.0 microsec
PRF: (i) 1000 (ii) 500 pps **Scan Rate:** 24 rpm

Obsolescent and being replaced, Type 978 uses a double cheese antenna (outfit ATZ), whose upper half transmits and lower half receives. This radar is based on the Decca 45, details of which are given above.

Type 979, first installed on board the survey ships *Echo* and *Vidal* in 1969, consisted of 978 plus an additional B-scope display.

Surviving examples of 978/979: Australia (River class, *Stalwart*, and "Ton" class), Bangladesh (*Leopard*-class frigates), Chile ("County"-class and *Leander*-class frigates), India (*Leander*- and *Leopard*-class frigates and "Ham"-class minesweepers),

Indonesia (former "Tribal"-class frigates), Malaysia (*Hang Tuah*), New Zealand (frigate *Waikato*), Pakistan ("County"-class destroyer), South Africa ("Ton"-class minesweepers), and the United Kingdom (some *Leander*-class frigates, "Ton" class, *Fearless* class).

◆ Type 982

Band: S **Beam:** 1 deg **Scan Rate:** 0–7 rpm
Antenna Dimensions: 26.5 × 3 ft

The sole surviving example of this long-range air-control radar is on board the Bangladeshi frigate *Umar Farooq*. Even so, this set makes an interesting comparison with Type 1022, which was intended to combine 982's sort of directional accuracy with long range. In British service, 982 often operated with a height-finder, Type 983, to provide a composite 3D radar picture.

Altitude coverage is limited by the "squint" of the waveguide feed: the waveguide produces, not a narrow fan beam, but rather a cone, so that aircraft at different altitudes register at somewhat different bearings. Squint results from internal reflections within the waveguide.

Range scales are 40 nm and 80 nm (accuracies 250 and 500 yd).

◆ Type 992

Band: S **Beam:** 1.25 × 15 deg **Peak Power:** 2 MW
Gain: 30 dB **Pulse Width:** 2.0 microsec
PRF: 750 pps **Antenna Dimensions:** 6.4 m
Antenna Weight: 640 kg

Data are for 992Q. The improved Type 992R has a peak power of 3 MW.

This target-indicator radar is the last of a long series of high-precision short-range S-band air-search radars. All the earlier ones had cheese antennas; but the current version, 992Q, employs a slotted waveguide instead. 992 is the target designation radar in Type 42 destroyers (working with 965/1022) and is the principal air-search radar in Type 21 frigates. In larger ships, 992 can be synchronized with other radars in pulse and in rotation, for quick correlation with their targets. 992 is manufactured by Marconi. Effective range on an air target is about 80 or 90 nm; 992 is the primary source of radar data for the AIO, since the longer-range Type 965 has such poor definition.

Type 992 was originally designed as a very high data rate set (scanning at 90 rpm) to feed the GDS 3 WDS. In service, this high scan rate turned out not to be very useful, and sets operate



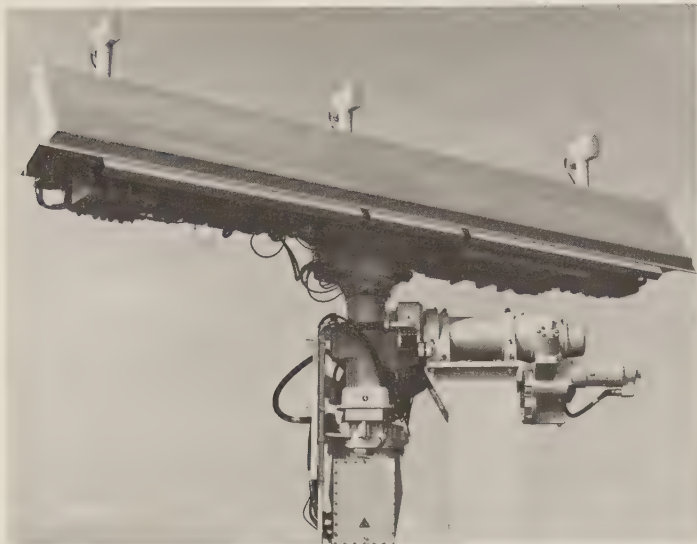
Type 992 on board HMS *Ark Royal*, 1990, with the UAA-1 DF array below it. The 4 small radomes at the ends of the short yards below the antenna platform are the omnidirectional antennas of UAA-1, for IFM. The "candlesticks" on the longer yards are UHF radio antennas. (Author)

at 15 or 30 rpm. The original high scan rate may have been used only on board the *Tiger*-class cruisers, now defunct.

Work on the original version began in 1948 and was completed in 1952. Type 992Q/R is now being replaced by Type 996.

◆ Type 996/AWS-9

Band: 2850–3100 MHz **Peak Power:** 60–80 kW
Pulse Width: 1.8–2.2, 20 microsec **PRF:** 700–800 pps
Scan Rate: 12.5–20 rpm



Type 996. (Plessey)

Data are unofficial estimates.

Type 996 is the 3D S-band radar of the new Type 23 ("Duke"-class) frigate. 996 is replacing Type 992Q (target-indication radar) in Type 42 Sea Dart destroyers and on board the *Invincible*-class carriers. The carriers will be fitted with 2 radars, 1 for Sea Dart and 1 for Sea Wolf. Type 42 destroyers are fitted with a single degraded version, shared between both functions. The staff requirement (Cardinal Points Specification) called for 2 versions, 996/1 and 996/2, the total likely order (as of 1982) being 19 Type 996/1 for retrofit and 24 Type 996/2 for new Type-23 frigates. Both were conceived as 3D radars. Technical proposals for Type 996 were submitted in January 1983. The other contenders were a Marconi 1800-series dual-beam radar (reportedly using Martello height-finding technology), the Thorn X-band *Stix* pencil-beam radar with back-to-back phased-array antennas (based on Searchwater), and a version of the Signal SMART.

Plessey won the design contest in 1983; 996 is based on the Plessey AWS-5, reportedly incorporating the 3D signal-processing technology developed for the Plessey AR-320 radar. The commercial version, announced in 1985, is designated AWS-9. AR-320 uses an S-band FM pulse that scans in elevation (over a 30-deg range) by frequency-scanning. The radar determines target elevation by measuring the frequency of the reflected signal. Phase shifting is also used, so that the radar can alternate between frequency bands (the phase shifters are interposed between the serpentine feed and the antenna proper). The AR-320 transmitter operates at 125-kW peak power (average power 5 kW), and its pulses are of 2 types: 65 microsec (5 subpulses at differing frequencies) for low angles, 31.5 microsec (5 subpulses) for high angles, in each case with pseudorandom phase coding (31-bit at low angles, 15-bit at high angles). Pulses are sent at intervals of 550–3000 microsec (i.e., 0.55–3.0 millisec), depending on the elevation angle. The AR-320 array itself is much larger than that of Type 996 (5.1×4.3 m, tilted back at 10 deg, consisting of 76 slotted-waveguide arrays, and with a gain of 41 dB; beam dimensions are 1.4×1.5 deg).

Phase coding within the long pulses provides pulse-compres-



Type 996 seen from behind and below. (A. Raven)

sion operation without interfering with frequency-scanning for height-finding. Multimode operation (in this case, controlled by software) was important because 996 had to replace both 992 and 967/968, radars operating in very different modes and over very different ranges.

The radar has 3 operating modes: normal, a combination of long-range surveillance for air-picture compilation and target indication for Sea Wolf missiles (a fighter can be tracked beyond 115 km); missile mode, optimized against sea-skimmers; and long-range mode, in which power is concentrated in long pulses in the bottom beam (a maritime-patrol aircraft can be tracked beyond 150 km). There are 2 alternative frequency-management modes, and MTI processing is used to reject rain and land clutter. IFF Type 1010(5) is mounted with the 996 antenna.

Type 996 is described as incorporating Falklands experience, particularly in the provision of a moving target indicator (MTI) to detect aircraft popping up from over nearby land.

AWS-9 is the commercial version. Scan rate is 30 rpm; mast-head weight is 1090 kg, and below-decks weight 2700 kg; the power requirement is 52 kW. In the long-range mode, a maritime-patrol aircraft can be detected beyond 150 km.

◆ Types 1002/1003

These types are the standard British submarine radars. Type 1002 is the X-band (9650 MHz) radar for *Porpoise*-class and later diesel-electric submarines. Type 1003 is the standard surface-search radar on board British nuclear submarines of the *Valiant*, *Swiftsure*, and *Resolution* classes. Compared to Type 1002, 1003 omits the periscope-attack (range only) and limited-air-search features. Recent British diesel-electric and nuclear submarines are equipped with the later Type 1006 (see below) or with the new Type 1007.

Type 1002 is descended from a series of experimental postwar British submarine radars, Types 973, 1000, and 1001. They were developed to replace the late wartime Type 267PW, which used 2 separate antennas, a P-band (214-MHz) air-search (airguard, in British parlance) antenna and a separate X-band (seaguard) unit. There was no periscope ranging radar. A postwar project for an X-band periscope radar, initially modeled on the U.S. ST, led to the design of Type 973, tested in October 1951. This radar was rejected because the transmitter/receiver at the base of the per-

iscope was unsatisfactory. The next stage was to integrate Type 973 with Type 267PW (using a common control panel, but different transmitters) as Type 1000, which was tested on board HMS *Thermopylae* in November 1952. The next step was to replace both the air- and sea-search antennas of 267PW with a new X-band antenna, so that the previous pair of radar masts could be replaced by a single mast. This new set, which was intended for the first postwar British diesel-electric submarines, was designated Type 1001. Type 1002 has better range accuracy and uses a new display and ranging system.

Operational requirements, as stated in 1952, were: detection of a 15-m² air target at a range of 8 nm at 5000 ft (the requirement had been 15 nm at 10,000 ft); bearing accuracy of 0.25 deg; range accuracy (for the periscope radar) of 25 yd at 6000 yd, with information transmitted directly to the torpedo's fire-control computer. The main antenna was not to exceed 4 ft in width, and it was to be stowable while the submarine proceeded at periscope depth at 12 kt. In 1952 it was expected that the 4 ft × 8 in cheese antenna, which would be tilted up at an angle of 3 deg, would have a gain of 33 dB.

◆ Type 1006

Band: X (9445 MHz) **Beam:** (a) 1 × 18 deg (b) 0.75 × 18 deg
Peak Power: 25 kW **Gain:** (a) 31 dB (b) 34 dB
Pulse Width: (i) 0.8 or 0.25 (ii) 0.75 microsec
PRF: (i) 1600 (ii) 800 pps **Scan Rate:** 24 rpm
Antenna Dimensions: (a) 2.4 m (b) 3.1 m

The navalized Kelvin-Hughes 19/9A replaces Type 975. Type 1006 was developed beginning in 1969, in response to an Ad-

miralty request for a solid-state successor to vacuum-tube systems, with sea trials in 1970 on board HMS *Grenville* and *Otus*. Production began in 1971. This radar is now being replaced by Type 1007.

Both antennas, Outfits AZJ and AZK, are slotted waveguides, and there is also a submarine version. The PPI can also display helicopter transponder data, for ASW. Range scales are 0.5, 0.75, 1.5, 3, 6, 12, 24, 48, and 64 nm.

◆ Type 1007

Band: X (9410 MHz) **Beam:** (i) 1.0 × 18 (ii) 0.75 × 18 deg
Peak Power: 25 kW **Pulse Width:** (a) 0.08 (b) 0.3 (c) 0.8 microsec
PRF: (a) 1600 (b) 800 (c) 800/400 pps **Scan Rate:** 26 rpm
Antenna Dimensions: (i) 2.4 m (ii) 3.1 m
Gain: (i) 31 dB (ii) 33 dB
Antenna Weight: (i) 58 kg (74 kg dual version) (ii) 64 kg

Replacement for Type 1006, Type 1007 is a Kelvin-Hughes Series 1600 + Red Pac, a navigational radar with a manual plot. Type 1007 was developed in 1971, adopted by the Royal Navy in 1984 (production began in 1986), and also bought for Norwegian *Ula*-class submarines. There are 9 range scales ($\frac{3}{8}$ –96 nm), and the radar can display target track history and guard zones; it can operate in sector-scan mode. Besides the 2 conventional slotted-waveguide antennas, there is a dual-array for use with a helicopter transponder and Outfit RBB.

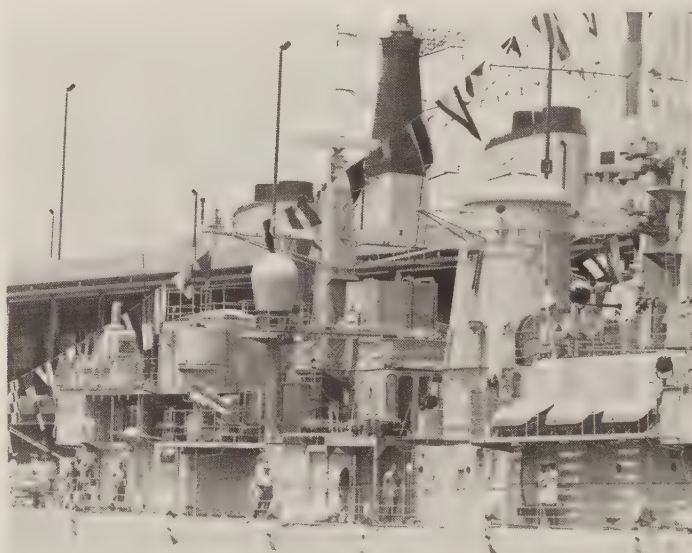
Kelvin-Hughes offers an alternative 25-kW S-band transmitter for use with this radar.

◆ Type 1010

Type 1010 is a Cossor IFF interrogator (Mk X system). It can be mounted either independently or on the antenna of a radar, such as Type 965. A typical Cossor interrogator antenna, CS.381, is 3.35 m long. The combination of Types 1010 and 1011 supersedes the earlier interrogator-transponder combination, Types 944 and 954.



A *Leander*-class frigate shows a Type 1006 surface-search radar (the slotted waveguide) below her Type 994 "quarter cheese" short-range air/surface-search antenna. The masthead array is UA-13, and below it are UA-8 and -9. The "sword" on the right just below Type 994 is a standard Anglo-American intercept antenna. This photograph was taken in 1986. [Author]



Some British warships carry an independent IFF interrogator, Type 1010. This slotted waveguide is visible atop the mainmast of a *Leander*-class frigate. The radome alongside contains a SCOT satellite antenna; below it is a Corvus chaff launcher. [Author]

◆ Type 1011

Type 1011 is an IFF transponder (Mk X system).

◆ Type 1013

Type 1013 is a lightweight, nonmagnetic IFF Mk X transponder, the Royal Navy version of the Cossor IFF 2720 airborne set. Type 1013 is carried by British minecraft.

◆ Type 1022

Type 1022 was described as a STIR, a combined Surveillance-and-Target-Indication Radar, to replace both 965 and 992Q.



Type 1022 on board HMS *Ark Royal*, 1986, seen from below and behind. The squintless feed array of horns is visible. [Author]



Type 1022 from the front. [A. Raven]

1022 combines a new Marconi antenna with a Dutch LW-08 L-band radar transceiver. Type 1022 was first installed on board the carrier *Invincible* in 1979. An all-British STIR, Type 1030, was scheduled for operation in 1985, using a very similar antenna, but that STIR was canceled, with the associated Sea Dart Mk 2 (GWS.31), in the summer of 1980.

The Marconi antenna is probably Outfit AZV, with a squintless feed (an array of 40 feed horns) and a single-curvature reflector. Beamwidth is 2.3 deg (the vertical beam is csc^2). The feed is derived from that of the land-based S625 radar, although the reflector is different. Reportedly, Type 1030 would have used 2 such antennas arranged back to back, and a single-sided Type 1031 was proposed. This antenna was first tested on board the frigate *Grenville* and was first installed on board the Type 42 destroyer *Exeter* (the first Batch-II ship) in 1978.

◆ MESAR

MESAR is an ARE/Plessey single-array electronically scanned S-band radar. The designation means Multifunction Electronically Scanned Adaptive Radar. MESAR is an octagonal array of 1060 radiating elements, 918 of which can be elementary radiators rather than the usual phase shifters. The array is inclined at an angle of 15 deg, and the beam (3.1 deg on transmit, and 3.4 deg on receive at broadside) scans through 45 deg to each side in bearing and between -35 and $+37.5$ deg in elevation; and the array can compensate for a 15-deg roll. Individual elements are $40 \times 95 \times 10$ mm (weight 135 g).



MESAR. (Plessey Siemens)

MESAR operates over 20% of S-band, using pulse compression with a duty ratio of up to 25%. Pulses are between 0.1 microsec and 1 millisecc long (i.e., over a range of 10,000), and the pulse compression ratio is 256:1 (with an extension to 500:1 planned). Range discrimination is 30 m. MESAR can handle target velocities of up to 1000 m/sec, and clutter is rejected using coherent and noncoherent MTI and pulse-doppler processing. Target position is determined by 2-channel monopulse measurement. Each module transmits at a minimum peak power of 2 W, for a total of about 2-kW peak power. Higher power is planned.

See also TRISAR, below.

MESAR is a technology demonstrator rather than a prototype for an operational radar. Development began in 1982, and trials were scheduled for 1989. The key future technology, as reflected in the MESAR design, seems to be the active array. In theory each element of the antenna should be provided with its own receiver, for the fullest sort of monopulse operation. That provision is impractical; in MESAR, low-power microwave networks combine groups of array elements into the 16 subantennas actually used for adaptive beam-forming. Each such subarray has its own receiver controllable in both amplitude and phase, and monopulse patterns can be formed by comparing the outputs of the subarrays.

Beams are formed digitally; Plessey claims that MESAR will be unique in its ability to null (shut out) jamming signals, even in the main beam, and that MESAR can reject up to 15 jammers per face.

◆ OTH Radar

ARE has tested a shipboard OTH radar system on board the Royal Fleet Auxiliary *Grey Rover*, achieving ranges as great as 100 km. Reportedly, that range was achieved by coupling special signal processors to the ship's high-frequency radio system. HF

signals commonly propagate well beyond the horizon, and there is always some back-scatter. Reportedly, the trick is to set up an interference pattern between the outgoing and back-scattered waves. That interference might indicate the presence of a target, but apparently no ship is large enough to provide sufficiently accurate beams for much more than sheer warning.

Existing HF OTH radar arrays are far too large for ship installation; typically, too, the receive and transmit arrays have to be widely separated because wavelengths are so long that otherwise they interfere. Reportedly, the British experiments are proceeding toward a bistatic mode in which reception and transmission would be on board separate ships.

Long-wavelength radar is now attractive because it is unlikely that any stealth technology can be effective at such wavelengths. It is not clear that OTH radar wavelengths are needed, although some years ago Australian scientists claimed that the Jindalee OTH radar could surely detect incoming stealthy aircraft. It is entirely possible that the longer (but still quite conventional) wavelengths from a system that can be practicably installed on the hull of an airship would suffice. That argument was made in 1988 in support of continuing the U.S. Navy's airship program.

The British program is not a ducting or surface-wave radar, which can detect targets at but not well above the sea surface. Stealthy aircraft and missiles might well approach at high, rather than low, altitude, to enjoy the aerodynamic fruits of their design. Many navies currently use ducting to target anti-ship missiles beyond the horizon, but that phenomenon is associated with short wavelengths such as X-band.

See also the discussion of the Marconi HF radar, below.

◆ AWS-1/AWS-2

Band: S (2880 and 3020 MHz) **Beam:** 1.5×40 deg
Peak Power: 750 kW **Gain:** 32 dB
Pulse Width: (i) 0.35 (ii) 1.5 microsec **PRF:** (i) 1000 (ii) 400 pps
Scan Rate: 10–12 or 20 rpm
Antenna Dimensions: 16 ft $\times$ 6 ft 6 in **Antenna Weight:** 576 lb

These private-venture Plessey air-search radars are based on the land-based AR-1 and AR-15. The first prototype AWS-1 appeared in 1960. The very similar AWS-2 was begun in 1965, the prototype appearing in 1970; it is described as the first radar to go to sea with a digital MTI processor. Claimed range on a "small aircraft" is 60 nm.

AWS-2 is a frequency-diversity radar with modular signal processing, so that more sophisticated versions could be built up for larger ships. In the simplest form, AWS-2 had 2 transceivers feeding a single display. A more sophisticated version used a stabilized antenna. Either version could be fitted with a digital MTI signal analyzer, to compensate for ship motion and to help reject low-altitude (or overland) clutter. Plessey described the antenna coverage as gapless, from low altitude (vs. sea-skimmers) to relatively high altitudes (because of the shape of the fan beam).

These radars sometimes appear with very different antennas. The Danish *Peder Skram*-class frigates combined AWS-1 transmitter-receivers with different Selenia antennas fore and aft; in their case, the antennas are cross-connected so that the ship can



The Ghanaian corvette *Kromantse* uses AWS-1 as her air-search radar. The small slotted waveguide serves a Type 978 navigational set. This ship and her sister are armed with single 4-in and 40-mm guns and with Squid. (U.S. Naval Institute)



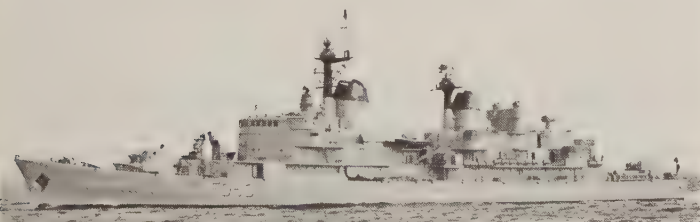
CWS-3 antenna. The minelayers have CWS-2, whose antenna resembles that of the Italian RAN-10S but is wider. (U.S. Naval Institute)

continue to use both in the event 1 transmitter breaks down. The Danish fishery protection frigates use a single AWS-1 with a Selenia antenna. The Chilean *Almirante Riveros* has AWS-2 feeding the old slotted waveguide antenna originally installed for her Marconi SNW-20 radar. These ships have AWS-1 (with the standard antenna) aft.

◆ AWS-4

Band: S **Beam:** 1.9×30 deg
Pulse Width: (i) 1 (ii) 0.3 microsec **PRF:** (i) 680 (ii) 1360 pps
Scan Rate: (i) 10 (ii) 20 rpm **Antenna Dimensions:** 3.8×0.8 m
Antenna Weight: 990 lb (unstabilized version) or 2640 lb (stabilized version)

AWS-4 is a further development of the AWS-1 series with a new antenna, a wide-band tunable magnetron transmitter, and pulse compression. There are 2 receivers, 1 matched to plot extractor requirements and 1 with various ECCM fixes. The radar can also be fitted with 2 parallel transmitters, for frequency diversity. AWS-4 was intended to provide AWS-2 performance at half the weight. Claimed detection range is 80–110 km on a 4-m² helicopter, using the long pulse (maximum range).



The Danish frigate *Herluf Trolle* shows 2 different air-search antennas, manufactured by Selenia for an abortive RAN-7S radar, but serving Plessey AWS-1 receiver-transmitters. In Danish service these radars are designated CWS-2 and -3. The fire-control radars are Signaal's M-46s. (U.S. Naval Institute)

Using the short pulse for best resolution, AWS-4 can detect the same target at 85 km (height 9000 rather than 12,000 m).

Combined with the Type 993 antenna, this radar forms Type 994; and combined with the World War II Type 293 antenna, AWS-4 forms the commercial Type 294. There is also a light-weight (450-kg) linear-array antenna for installation in fast patrol craft (as AWS-4B). Maximum range is 70 km (8200 m target altitude). AWS-4BH has a high data rate (1 sec, i.e., 60-rpm scan rate) to detect sea-skimmers; typical aircraft detection range is reduced from 54 to 24 nm. It has a noncoherent digital MTI processor.

As of 1990, the old quarter-cheese antennas of existing Type 994 radars are being replaced by AWS-4 antennas.

This radar is currently in service with the Royal Navy, the Royal New Zealand Navy, the Royal Norwegian Coast Guard, the Sultan of Oman's Navy, the Republic of Kenya Navy, and the Royal Canadian Navy. Britain and New Zealand use Type 994.

◆ AWS-5

Band: S

Beam: High beam is 1.5×30 deg, directed upward at 45 deg; low beam is 40 deg wide in elevation, directed upward at 5 deg. AWS-5B antenna: 1.5×32 deg (azimuth squint less than 1 deg over the operating range).

Peak Power: 58 kW (mean power 1.3 kW)

Pulse Width: (i) 0.4 (ii) 20 microsec (typically transmitted in sequence) **PRF:** 1100 pps

Scan Rate: 15 or 30 rpm **Antenna Weight:** 2640 lb



AWS-5 at the foremasthead of the Danish frigate *Peter Tordenskjold*, with a NATO Sea Sparrow fire-control radar (Mk 91) aft. The 2 slotted waveguides are probably Decca TM 1229s (Skanter 009). (L. Van Ginderen)

Transmitter data are estimated from those of the Watchman ground radar (see below).

AWS-5 incorporates a new dual-beam (high- and low-cover) stabilized antenna, essentially the AWS-4 double-curvature unit plus a squintless linear array canted back to provide cover above 60-deg elevation. With the low beam, a 4-m^2 target can be detected at about 85 nm and 50,000 ft; a 0.1-m^2 target (such as an antiship missile) at about 40 nm and 25,000 ft. Like AWS-4, AWS-5 is a pulse-compression radar (for good range resolution). Pulses are coded for clutter and jamming resistance. AWS-5 has programmable frequency agility, and the IFF is integrated with the main antenna (IFF signals are fed directly into the antenna). The transmitter is coherent, so the radar can extract digital MTI information from returning pulses.

There are 2 pulse lengths: 0.4 microsec for high resolution, and a longer 20-microsec pulse that is compressed to 0.4 microsec on reception. The 2 signals are separated by using a different frequency for each.

The TWT transmitter allows for considerable frequency diversity. One advantage of the dual-beam design is that the high beam is clutter-free: unlike a conventional fan beam, the

high beam does not touch the sea. Processing features include skew correction for fast targets (i.e., correction of the error in bearing because of the motion of the antenna while the echo is returning).

AWS-5 is available in 3 basic versions: medium-power, AWS-5(MP); high-power, AWS-5(HP); and long-range, AWS-5(LR). The MP version has an instrumented range of 240 km; the high-power version uses the more powerful AWS-9 transmitter; and the LR version uses a high-gain, linear-array antenna for target indication to 200 km and long-range surveillance to 400 km. The MP version uses the same transmitter as the Watchman coast-defense radar. It has 3 operational modes: target indication for a point-defense system, and medium- and long-range surveillance. All antennas are stabilized, and all of the radars have ADTs with a capacity of up to 250 tracks.

AWS-5A was sold to the Danish and Nigerian navies. A light-weight version, AWS-5B, employs a stabilized linear array antenna (1280 lb, 1.5×32 -deg beam). Claimed performance: detection of an aircraft at 40 nm at 100,000 ft. AWS-5C is a land-based version using a low-beam horn and reflector (range 60+ nm, because of the higher gain of the antenna, and elevation up to 40 deg). AWS-5D is a stabilized version of AWS-5C for ship installation, with 2-speed scanning.

Development began in 1972, and design work in 1975, when the radar was announced. These radars have been installed on board Danish *Nils Juel*-class corvettes and 1 Nigerian frigate. The new British Type 996 (AWS-9) is partly based on this radar.

◆ AWS-6 (Dolphin)

Band: C **Beam:** beamwidth 1.5 deg (See below.)

Peak Power: 49 kW **Gain:** 29/26 dB (low/high beams)

Pulse Width: 0.1 and 4.3 microsec **Scan Rate:** 30 or 60 rpm

Antenna Dimensions: 2.6 m wide [102 in]

Antenna Weight: 520 kg, including mounting [1150 lb]



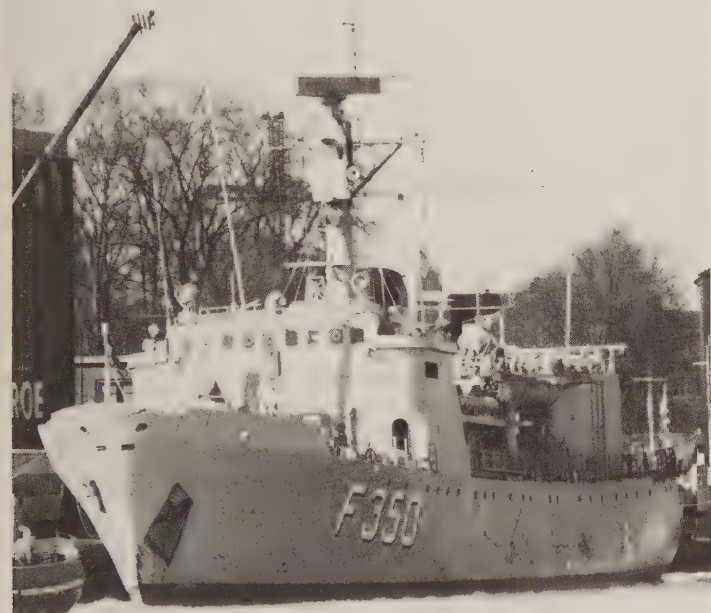
AWS-6 (Dolphin). (Plessey)

Like AWS-5, AWS-6 is a dual-beam frequency-agile radar that uses a coherent (TWT) transmitter. Its beam is narrow enough for target indication, and the radar can be used for that purpose in conjunction with a very long range air-search set. The transmitter has a very broad band frequency agility. Radar contacts are automatically extracted, using CFAR processing. The pulses are frequency-coded and pulse-compressed; a high pulse-compression ratio was chosen for better target detection in chaff. The long pulse width listed above (4.3 microsec) is a frequency-swept pulse for target indication; the short pulse is for navigation and splash spotting. There is also an optional long-

range mode using a 10-microsec pulse, in which the radar scans at 30 rpm. Pulse patterns include fixed frequency, scan-to-scan frequency agility, burst-to-burst agility, and pulse-to-pulse agility. There are 4 operating modes: 2 for antimissile defense, and 2 for extended-range surveillance using the optional 30/60 rpm dual-rotation-rate version of the basic radar.

The main reflector is center-fed by a squintless linear array, as in Type 1022; a second squintless array provides a high beam. This combination provides much smaller sidelobes than a conventional horn-fed reflector because radiation at the antenna edges is better controlled. The manufacturer claims further that the use of independent beams makes jamming difficult, and that random frequency agility forces the jammer to spread out its power. The main beam of the radar covers all angles between 0 and 20 deg, with csc² shaping up to 40 deg. The separate illuminator extends coverage to 70 deg of elevation. The antenna as a whole is stabilized against roll (within 25 deg) and pitch (within 10 deg). Total weight of antenna and mounting is 520 kg; below-decks weight is another 1340 kg [2953 lb]. Average power input is 21.9 kVA.

Under the designation Dolphin, AWS-6 is part of the Plessey-Contraves Seaguard anti-aircraft system (see the entry under Switzerland, above). A larger-antenna version (in a radome) was supplied for Danish fishery-protection vessels, and there is also a single-beam target-indication version.



AWS-6 at the masthead of the Danish frigate *Ingolf*. (Gilbert)

AWS-6 has developed into a family of 4 radars. The suffix A indicates 2 beams; B indicates a simpler radar with a single beam. A suffix number indicates relative range. All radars in the series are intended to detect low-flying missiles out to 35 km, and steep divers (at up to 70-deg angles) to 20 km; medium-range air surveillance out to 70 km; area air surveillance to instrumented ranges of 200 or 400 km (depending on model); splash spotting to 20 km; navigation to 20 km; and helicopter control. The main versions, as of 1989, are:

Dolphin scans at 60 rpm and has an instrumented range of 30 km; it has 2 beams. The tabulated data refer to this version.

AWS-6A/100 is for both Sea Guard and general search. It scans at 30 rpm for long- and medium-range search and for target indication. Once a missile has been detected, the radar scans at 60 rpm to provide an adequate data rate. Instrumented ranges are 30/70/200 km.

AWS-6A/200 is a pure search radar with a scan rate of 30 or 15 rpm and instrumented ranges of 35/70/200 km.

AWS-6B/200 has a scan rate of 30 or 15 rpm and instrumented ranges of 60/120/240 km.

AWS-6B/300 is the Danish fishery-protection radar (*Danfish*), scanning at 20 or 10 rpm, with instrumented ranges of 60/120/240 km.

As of 1989, over 30 AWS-6-series radars had been sold. Plessey attributes this success to their better-than-expected ability to track missiles.

AWS-6 introduced stripline feed into Plessey naval radar practice.

◆ AWS-7

This Plessey S-band radar was announced in 1985 as the first fully solid-state radar (i.e., using neither magnetron nor TWS) in its frequency range. AWS-7 can be supplied with either a single- or a dual-beam antenna.

The power-amplifier stage consists of 40–70 identical modules operating in parallel, each supplying 20 kW, for a total peak power of about 800 kW to 1.4 MW. The modules are mounted in a carousel, and they can be replaced even while the radar is operating. They need no special high-voltage power supply and no special liquid cooling (as is the case with a conventional single high-powered tube).

The AWS-7 designation was applied earlier to an AWS-2 with a higher-gain antenna. It attracted no sales.

◆ AWS-10

AWS-10 is TRISAR (see below).

◆ Decca TM 1226C/1229C/RM Series

Band: X (3 cm: 9410 MHz) **Beam:** 1.2 deg **Peak Power:** 25 kW

Gain: 30 dB **Pulse Width:** (i) 0.05 (ii) 0.25 (iii) 1.0 microsec

Scan Rate: 28 rpm

Antenna Dimensions: 72 in slotted waveguide (The same radar, with a 108-in antenna, is TM 1229C; beamwidth is then 0.8 deg.)

This Decca commercial pulse-compression radar is used as a small-ship search/target-indication set and as a secondary (surface-search) set on board larger ships. Decca's system is the basis of the Norwegian MSI-80S system. There is also an alternative S-band 30-kW version using a 12-ft antenna. In the designation, TM means true motion (display) and C means clearscan; 1226 means a 12-in PPI and a 6-ft antenna. Similarly, AC1629C would be an anticollision radar with a 16-in clearscan display and a 9-ft antenna. Clearscan itself is a form of clutter suppression. There are 9 range scales: 0.25–48 nm, with short pulse on 0.25 nm, short or medium on the next 3 scales, medium or long pulse on the next 3, and only long pulse on the last 2. Resolution is 10 yd on the 0.5-nm scale with a 10-m² target. Bearing accuracy is better than 1 deg.

Radars designated RM (e.g., RM1226C) show relative rather than true motion and are, therefore, somewhat simpler and less expensive. Many warships combine a TM and an RM radar.

Users (for main radars on patrol boats) include the navies of Abu Dhabi, Argentina, Belgium, Brunei, Ecuador, Egypt, France, Iran, Indonesia, Libya, Malaysia, the Netherlands, Nigeria, Norway, Oman, Peru, Thailand, and Turkey. This series is one of the world's most widely used radars.

◆ Marconi 400 Series (and Sea Cobra)

Band: X (8–16 GHz) **Beam:** 3.5 deg **Peak Power:** 2.5 kW

Scan Rate: 60 rpm in surveillance mode

Antenna Weight: 168 kg (350 kg overall)

This new series of gunfire-control radars was announced in 1983. The antenna is an offset front-fed parabola that uses vertical polarization. A frequency-agile TWT transmitter provides MTI, and tracking is by monopulse. Marconi has employed a patented method for reducing angular errors due to multipath reflection off the sea surface; that method may be similar to



Sea Cobra combines a Marconi 400-series radar with a Breda gun mount. (Marconi)

that described by Thomson-CSF in connection with Crotale Navale (see entry under SAMs below).

The transmitter is unusual in that it covers a full octave in frequency, pulse-to-pulse frequency agility over this range being used to reduce multipath effects.

In the surveillance mode, the radar scans at 60 rpm. It tracks with an accuracy better than 1 mrad in angle (RMS) and 5 m in range (RMS). Elevation is -30 to $+85$ deg.

Instrumented range: surveillance, 12 km; autotracking, 10 km. These ranges can be increased to 30 km if the radar is used to control medium-caliber guns.

The Breda-Marconi Sea Cobra integrates the Breda twin 30-mm gun with a Marconi 440 radar fire control.

◆ Marconi HF Radar

Since 1980 Marconi has been working on a long-range OTH radar that uses the ground (actually sea) wave instead of the sky (ionosphere-reflected) wave employed by more conventional OTH types. A vertically polarized HF signal will follow a conducting surface path, extending between the surface and the ionosphere. For example, it can detect icebergs as gaps in the conducting sea surface. This principle can be used both for very long range detection over the sea (from a large land site) and for shorter-range detection by a ship. Because the signal fills the space between the sea and the ionosphere, the radar can detect aircraft (such as airliners at 60,000 ft) and even low-flying missiles. Range depends on the frequency chosen, and the choice in turn depends in part on the available base length for reception. At 2 MHz, a typical range is 500 nm; at 10 MHz, this figure drops to about 200 nm. The lower the frequency, the more susceptible the radar to the movement of the ionosphere. The higher, the greater the attenuation of the signal. The appropriate balance will vary with the application.

The basic idea is not new: early World War II radars, which transmitted at relatively low frequencies, were credited with both ground- and sky-wave ranges. Similarly, wartime shipboard HF/DF sets generally detected the ground waves of U-boats transmitting beyond the horizon. The great barrier to using this physics for radar purposes was the long wavelength used by a system with a worthwhile range, hence the sheer size of the antenna required. That ceased to be a problem when electronic switching (for beam-forming) became cheap and reliable.

Some years ago Marconi, working with ARE, put receiving loops over the side of a frigate, using the usual vertical wire antennas to transmit signals. In effect, the entire length of the ship became the antenna aperture. This arrangement achieved better than 3 times the usual microwave range, albeit with less precision. As of 1989, Marconi estimates that a shipboard production version would have the following characteristics:

Transmitter Antenna:	single whip
Receiver Antennas:	8 port, 8 starboard
Mean Power:	500 W
Frequency:	3–12 MHz
Detection Ranges:	
Frigate in sea-state 4:	180 km
Fighter (low):	120 km
Small iceberg:	150 km
Accuracy:	2 km, 5 deg

A coastal site could be spread out over a larger area, and thus could operate at lower frequency. Typical parameters:

Antenna:	1000 m array
Mean Power:	40 kW
Frequency:	5–14 MHz
Detection Ranges:	
Large ship:	300 km
Frigate:	250 km
50-ft vessel:	70 km
Large aircraft (high):	350 km
Fighter (low):	150 km
Large iceberg:	350 km
Growler:	35 km
Accuracy:	2 km, 1 deg

Marconi has been operating a land site since 1980, its transmitter derived from the company's H1141 10-kW unit. As of 1989, the company regarded the ground-wave HF radar as about 2 years from development, should a customer appear; there were several possibilities, and Marconi expected that this system would be in service somewhere by about 1993. The prototype had already demonstrated an accuracy of 2 km and 3 deg, and it had detected aircraft flying at altitudes of 90–40,000 feet. On this basis Marconi saw the HF radar as a useful and much less expensive substitute for AEW radars.

Since the returning signals are necessarily weak, the bulk of the effort has gone into a combination of signal coding and signal processing. The associated computer is a DEC PDP-11 with an AP120B floating-point array processor (10 MFLOPS). Targets are detected via their doppler shifts; the processor carries out 4096-point FFTs to achieve a frequency resolution of $\frac{1}{16}$ Hz. That makes it possible to filter target velocities with a resolution of about 2 kt.

This system uses 4 transmitters to emit at a peak power of 40 kW, at 300 pps, each pulse being 200–300 sec long, to achieve sufficient average power. For aircraft signals, the radar uses an integration period of up to 16 sec (a longer period, which might make for better velocity discrimination, is impractical because the signals lose their phase coherence). A typical system would operate at 4–10 kHz, i.e., at wavelengths of about 30 m.

For a production radar, Marconi would use CW FM signals (without gaps between pulses) and a wide floodlight beam; the receiver would have 16 beams, processed in parallel (which would require a total computer power of 500–1000 MFLOPS). There would be 2 alternative displays: 1 showing the amplitude of all doppler components in a given range cell (a range cell corresponds to a set delay after transmission) or a synthetically generated equivalent to a PPI. This PPI would be refreshed every 4 sec, and it would show 3 previous positions for each target, for tracking.

A typical transmitting array would consist of 4 masts, each with a top-fed cone array. Four similar masts behind the transmitter provide a reflector; the result is a 30-deg beam, which can be slewed to cover a 90-deg sector. The corresponding receiver is 2 lines of 8 masts, for a 15-deg beam.

◆ Marconi SNW-10

Band: P (1.5 m) **Beam:** 19 deg
Peak Power: 450 kW **Pulse Width:** 3.8 microsec
PRF: 250/500 pps **Scan Rate:** 10 rpm
Antenna Dimensions: 14 × 7 ft **Antenna Weight:** 336 lb

The mattress antenna carries 12 dipoles (4 × 3) in front of a reflecting screen. SNW-10, developed in the 1950s, survives only on board the Egyptian destroyer *El Fateh*.

◆ Marconi SNG-20/21

Band: X (9200–9280 MHz) **Beam:** 2.3 deg
Peak Power: 160 kW **Pulse Width:** 0.35 microsec
PRF: 3000 pps **Antenna Dimensions:** diameter 45 in
Antenna Weight: 1400 lb

This fire-control radar is found only in the Chilean *Almirante Riveros* class. The original SNG-20 was a monopulse tracker used with a Vickers director. The Chileans replaced its original vacuum-tube electronics with solid-state units, redesignating it SNG-21; that was the naval fire-control radar displayed at ASMAR 1984. Ericsson components may have been installed in the front end of the radar about 1988–89.

The original SNG-20, details of which are given in the table above, was designed to detect targets at 35,000 yd and track them at 25,000. Minimum range was 300 yd. SNG-20 was a monopulse tracker that could search in elevation and bearing to acquire a target indicated by another radar (SNW-20). In the elevation-search mode, the radar nacelle could be scanned at 8 deg/sec. In bearing-search mode, it scanned over a 12-deg range, at 4 Hz. Range accuracy was 25 yd at 700+-yd range; range resolution was better than 100 yd. The radar could track targets moving at up to 600 kt, and range-rate accuracy was 2 yd/sec.

◆ Marconi ST802

Band: X **Beam:** 2.4 deg
Peak Power: 150 kW (100 kW at PRF 4400) **Gain:** 36.5 dB
Pulse Width: (i) 0.33 microsec (ii) 0.67 microsec
PRF: (i) 4400 (MTI) (ii) 3000 (non-MTI) pps
Antenna Dimensions: aperture 1 m (1.4 m in ST858)
Antenna Weight: director 550 kg; double-bay cabinet 690 kg; weapons-control console 450 kg



An Egyptian 6 *October*-class missile boat (with her Otomat racks empty) shows an S810 search radar (in the big radome) and an ST802 fire-control radar (atop the superstructure). (L. Van Ginderen)

ST802 is one of a series of Marconi radars (ST802, ST858 land mobile tracker, ST858 instrumentation radar, S810 and S820 shipboard surveillance radars). ST802 and S810 share a 200-kW X-band transmitter; S820 has a 400-kW S-band transmitter. All share a common digital MTI processor.

ST802 is the tracker associated with the S800-series surveillance radars (S810 and S820, below). ST802 is a fully automatic lightweight monopulse tracker; a television camera is mounted alongside. The antenna is a stabilized twist Cassegrain, and

there is a second radar channel for shell spotting. Frequency is variable over 900 MHz (i.e., about 10% of the base frequency). Peak power is increased to 200 kW in one version.

In the search mode, the radar rotates at 20 rpm, stepping upward by a full beamwidth (2.4 deg) under computer control to perform low, medium, and high scans. The radar can detect an aircraft at 10,000 ft at 20 km. If any target does appear on the target allocation panel, a button allows the radar to shift to tracking mode.

ST802 is the radar associated with the Sapphire FCS (see separate entry). There is also a land-based equivalent, ST850, and an ST858 range instrumentation radar. ST801 is an alternative version designed for direct interface with a ship's weapons-system computer. See also the Sapphire fire-control system.

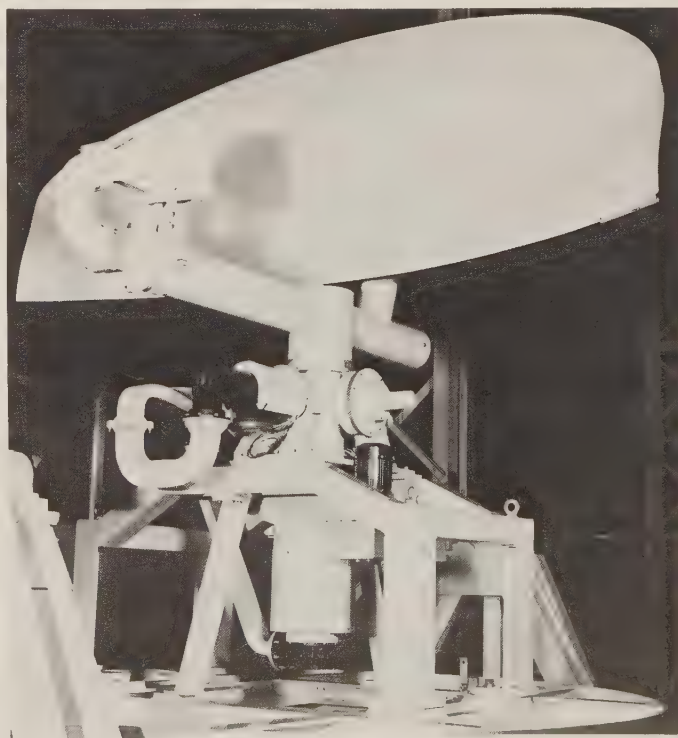
◆ Marconi 805 Series

This series of privately developed tracking radars is designed for a variety of weapons: 805SW, lightweight Sea Wolf (adopted by the Royal Navy as Type 911); 805SD, lightweight Sea Dart; 805AS, Aspid; and 805SS, Sea Sparrow. Each radar can also control medium- and small-caliber guns. 805SW is a dual-frequency tracker that includes a missile command link. 805SD is a tracker-illuminator incorporating Type 909 and S1800 series components. 805AS was developed in cooperation with Selenia and uses a Selenia illuminator; 805SS uses a Raytheon illuminating transmitter and can control either vertically or horizontally launched missiles.

◆ Marconi S810/S811

Band: X (8.6–9.5 GHz)
Beam: 2.2 × 25 deg (S810P: 2.2 × 4.7 deg; S810: 1.5 × 25 deg beam with alternative 1.8-m antenna)
Peak Power: 180 kW (MTI: 135 kW)
Gain: 29.5 dB (S810P: 33.5 dB)
Pulse Width: 0.67 or 0.33 microsec
PRF: 1500 (4400 for MTI) pps **Scan Rate:** 24 rpm (S810P 40 rpm)
Antenna Dimensions: 1.2 m wide (radome diameter 1.7 m; 2.3 m with 1.8-m antenna)
Antenna Weight: 250 kg at masthead (plus 695 kg transmit/receiver)

This lightweight surveillance radar is used on board the Egyptian *October* class (Egyptian-built Komars). The antenna is mounted inside a radome. There is an alternative 1.8-m radome



Marconi S810, without its radome. (Marconi)

[1.5-deg beam, masthead weight not including radome 300 kg rather than 180 kg).

MTI is by a double canceler using shift register storage, i.e., by pulse-to-pulse comparison. In this mode PRF is staggered around 4400 pps to eliminate blind speeds. Instrumented range is then either 10 or 20 km. The transmitter is a tunable magnetron, the operating frequency being motor controlled (i.e., the transmitter is not frequency agile but is adjustable).

S811 is a version without provision for MTI.

Estimated ranges against a 5-m² airplane: 28 m at 2000 m altitude (1.2-m antenna), 20+ km at 6000 m; with a 1.8-m antenna, 32 km at 3000 m and 25+ km at 8000 m. S810P (for better low-altitude coverage) will detect a 0.1-m² target at 15 km.

These radars were announced about 1974.

The companion large radar (S820) did not sell. See the last edition for details.

♦ Marconi ST1802

Band: X (8.9–9.5 GHz) **Beam:** 2.4 deg
Pulse Width: 0.67, 0.3, or 1.0 microsec
PRF: 3000 (non-MTI); 4400 (MTI) pps
Peak Power: 50 kW (average 150 W) **Gain:** 37 dB
Antenna Dimensions: aperture 1 m
Antenna Weight: 550 kg (director weight)

ST1802 is the weapons-control radar for the S1800 series of small-ship weapons systems. ST1802 employs a fully coherent (TWT) transmitter (for pulse-doppler MTI) and enjoys truly random frequency agility. MTI can be switched on and off; presumably that selectability means there are alternative high and low PRF modes, corresponding to the 2 rated tracking ranges given below.

Data above apply to the 1802AS radar, for Aspide missile control (part of the Albatros 10/0 system), which employs a twist-Cassegrain antenna and a side-mounted television tracker. The radar uses monopulse tracking, and the CW guidance beam is injected directly into its antenna. Maximum tracking range is 40 km (24 km if MTI is used), and maximum slewing rates are 120 deg/sec in train and 50 deg/sec in elevation. Continuous elevation rate (for target acquisition from a 2D search radar) is 20 deg/sec. Elevation limits are –30 and +85 deg. Above-decks weight is 550 kg, plus a total of 1200 kg below decks (including a 650-kg transceiver and processor). These data were released in 1985.

ST1802SW is a Marconi commercial Sea Wolf director radar; at 1900 kg, it is about half the weight of the 805SW that became the Royal Navy's Type 911. Even so, ST1802SW's characteristics are a measure of the requirements imposed by the Sea Wolf system. The tracker uses a gregorian offset feed and is mechanically counterbalanced (for quick tracking) by an optronics head.



ST1802 fire-control radar, with optronic backup. (Marconi)



ST1802SW. (Marconi)

The separate missile-command transmitter, in a drum-shaped radome, is on the antenna's left side. Antenna and transmitter characteristics match the figures above. Acquisition range is 32 km against a 3-m² target, and 13 km on a 0.1-m² target.

The associated thermal imager has a 3 × 2-deg FOV.

A Samsung-built version of ST1802 equips some Korean frigates (*Ulsan* and *Donghae* classes).

♦ Marconi ST1805SW Multifire

This advanced Sea Wolf tracker, conceived as a phased-array version of Type 911, was originally developed as part of the British GWS 27 program, now canceled. Multifire is now (1988) a Marconi private venture. ST1805SW operates at X-band (3 cm), using 5000 phase shifters to form an agile 1.5-deg beam scanning through 45 deg. The stabilized antenna itself can elevate to scan from the zenith down to the horizon. This radar might be used either for low-altitude surveillance or as a multiple target illuminator for semiactive missiles. Total weight is 4500 kg (1500 kg above decks).

♦ Marconi S1810

Band: 3 cm (X-band: 8.6–9.5 GHz) **Beam:** 1.1 × cos² 5–30 deg
Peak Power: 50 kW **Gain:** 36 dB (midband)
Pulse Width: (i) 2 microsec compressed to 0.1 microsec (chirp);
 (ii) 1 microsec for air search; (iii) 0.2 microsec for surface search
PRF: (i) 2000 (ii and iii) 4000 pps
Scan Rate: 24 (standard, with radome) or 20/60 (lightweight, no radome) rpm
Antenna Dimensions: 2.44 × 0.84 or 1.2 × 0.42 m
Antenna Weight: 640 or 250 kg

S1810 is a small-ship frequency-agile surveillance radar intended for use as part of an S1800 series integrated weapons system. This radar can also be used for coastal surveillance. Typical detection ranges are: aircraft at 45 km (limited by the horizon) and small surface craft at 30 km; free space detection range is 60 km. Marconi claims that the radar can easily detect low-fliers and surface-skimming missiles well beyond engagement range. The lightweight (GRP sprayed with a metallic coating) antenna is fully stabilized.

Beamwidth data refer to the larger antenna. The smaller antenna, referred to as a compact system, scans at 24 rpm. Both the standard and the compact radars are housed in spherical



The Egyptian patrol boat *El Yarmouk* shows a Marconi S1810 radar in a radome on her foremast and a Cygnus jammer in the smaller radome on her mainmast. At her fore masthead she carries Cutlass and Matilda ESM, and she also carries 2 Protean chaff mortars. (L. Van Ginderen)



Racal-Decca 2459 F/I radar on board the Dutch replenishment ship *Poolster*. (Racal)

radomes. The TWT transmitter is capable of both pulse-burst agility and pulse-to-pulse agility; the transmitter can also be turned on and off easily, to permit radar silence without losing the ability to switch back on. Signal processing includes digital MTI, and the ship's motion (including velocity) is automatically compensated for.

ECCM features include low sidelobes, frequency agility, the ability to discriminate between signals of different PRF (as well as variable pulse length and PRF, and PRF stagger and jitter), sector transmission, a wide-dynamic-range receiver (with image rejection mixer), instantaneous automatic gain control, Dicke fix, and forward or reverse swept gain.

S1810 is the primary radar of the Egyptian *Ramadan* class. It also equips 2 Korean *Ulsan*-class frigates and some of the *Donghae* class. The S1800 radar series was first publicly discussed in 1978.

◆ Marconi S1820/1821

This S-band search radar uses a TWT transmitter for coherence (digital MTI) and frequency agility; pulses are compressed, so that peak power is only 20 kW (average power is 800 W). S1820 is the minimum configuration, with a 2.4-m stabilized antenna, and dual rotation rates. S1820 is the minimum configuration in the series. S1821 has a larger (4.7-m) but unstabilized antenna; S1822 has a stabilized antenna. The Canadian SPS-503 is derived from S1821. All 3 antennas have csc² coverage to 30 deg and scan at 24 rpm. Approximate ranges: 105 km for S1820, 145 km for S1822. These radars incorporate below-decks equipment originally developed for the abortive Type 1030 STIR radar, which Marconi had hoped to market as S1800. Type 1030 would have had a back-to-back antenna, to achieve a high data rate without sacrificing range.

S1826 was a derivative offered for the British Type 996 requirement. It used a Cassegrain main antenna (feed pointing forward and up into a secondary reflector) with a secondary squintless feed (slotted waveguide) antenna pointed up to achieve 70-deg coverage against high divers.

◆ Racal-Decca 2459 F/I

Band:	S (3.2 cm)	X (10 cm)
Beam:	2 × 30 deg	0.8 × 20 deg
Peak Power:	30 kW	25/75 kW
Gain:	26 dB	32 dB
Pulse Width:	(i) 1 microsec (ii) 0.25 microsec (iii) 0.05 microsec	(i) 1 microsec (ii) 0.25 microsec (iii) 0.05 microsec
PRF:	(i) 825 pps (ii) 1650 pps (iii) 3300 pps	(i) 825 pps (ii) 1650 pps (iii) 3300 pps
Antenna Dimensions:	12 ft	9-ft aperture

2459 F/I is a dual-band air/surface-search and navigational radar; the designation derives from the ECM band names (F and I). Returns on both bands appear together on the single display, and a master controller feeds the most appropriate combination of processed video to the weapons-control stations, which may include both surface and antiaircraft (and helicopter control). The use of a single rotating unit (X-band antenna atop S-band antenna) saves weight on top and makes for a clear arc for both frequencies. Timing and pulse length (and gain, swept gain/sea clutter, and rain differentiation) are provided by a frequency-independent unit, both antennas feeding into a single signal processor.

The S-band beam is centered on an elevation angle of 15 deg, the X-band beam pointed horizontally (for surface search). An alternative horizontal scanning S-band antenna can be provided.

Estimated range: 25 nm on a large airplane, 15 nm on a medium airplane.

This radar, and the associated Racal-Decca Command Tactical Console and 2690 Brightrack color ARPA, were selected in 1989 (announced in January 1990) for the 4 new Spanish coastal-patrol cutters.

◆ Racal-Decca 2490/2690 Series

Band:	X	S
Beam:	(i) 1.3 × 23 deg (ii) 0.8 × 23 deg	— —
Peak Power:	25 kW	30 kW
Pulse Width:	(a) 0.05 microsec (b) 0.25 microsec (c) 1.0 microsec	(a) 0.05 microsec (b) 0.25 microsec (c) 1.0 microsec
PRF:	(a) 1300 pps (b) 1300 pps (c) 650 pps	(a) 1300 pps (b) 1300 pps (c) 650 pps
Gain:	(i) 30 dB (ii) 32 dB (iii) 26 dB	(i) 30 dB (ii) 32 dB (iii) 26 dB
Scan Rate:	25 rpm	22–26 rpm
Antenna Width:	(i) 6 ft (ii) 9 ft (iii) 12 ft	(i) 6 ft (ii) 9 ft (iii) 12 ft
Antenna Weight:	(i) 34.3 kg (ii) 44 kg (iii) 219 kg	(i) 34.3 kg (ii) 44 kg (iii) 219 kg

These radars are the natural successors to the 1629 and similar Decca radars, which are so often used on board both fast patrol boats and larger vessels. These radars can be switched with the Master Series radars (see below). Alternative forms of signal processing include ARPA (automatic radar plotting aid) and AC (true motion, i.e., anticollision). The ARPA versions can carry up to 20 tracks, acquiring targets at ranges of 0.5–20 nm and tracking between 0.25 and 20 nm. Targets are continuously tracked after they are acquired and are retained on the display for 5 out of 10 consecutive scans. Plots are extracted by

a limited-area analysis system (a preset window), the gain within the window being set according to expected target size (i.e., target strength) and the local measured noise level. The track table is assembled in true motion format.

The first 2 digits in the designation refer to the size (diagonally measured) of the rectangular raster-scan display. Like the Japanese Furuno radars described with the U.S. entries, this Racal-Decca series employs a multilevel display, providing synthetic graphics in combination with the rastered PPI. The 24-in display is monochrome; the 26-in display is in color. In both cases, the display is a standard high-resolution television type (819 lines, 64-Hz raster). The image is refreshed often enough to eliminate all apparent flicker. In place of the afterglow of conventional PPI tubes, these radars generate trails of specific duration to assist in picture interpretation. The operator selects true or relative motion, and this type of display does not "smear" when the operator changes mode, e.g., from "north up" to "ship's course up." Tracks are displayed as vectors.

Eight video maps are stored in the system's memory.

Minimum range is 30 m on a 10-m² target using the short pulse, with the antenna at a height of 4.5 m (14.75 ft). Range discrimination is 30 m on the 0.75-nm scale. Scales are 0.25, 0.5, 0.75, 1.5, 3.0, 6.0, 12.0, 24.0, 48.0, 96.0, and 192.0 (optional) nm.

◆ Racal-Decca Master Series (1290 and 1690 Series)

These X- and S-band radars preceded the 2490/2690 series. The first 2 digits indicate the diameter of the circular PPI. As in the 2490/2690, the X-band radar operates at a peak power of 25 kW and uses either a 6- or a 9-ft antenna. The S-band radar operates at 30 kW, with a 12-ft antenna. Prefixes indicate the display chosen: AC for anticollision (true motion), RM for relative motion, and ARPA for automatic plot extraction (surface ATD). The system can carry up to 20 target tracks, and up to 9 markers can be positioned to monitor the bearing of a potential threat vessel. The markers are all short constant-bearing lines pointing back to own-ship: an echo that remains on the marker is closing at constant bearing and is on a collision course. The system also easily measures CPA.

There are 10 range scales, from 0.25 to 96 nm.

Racal-Decca offers a bright color PPI, the color being used to denote echo characteristics, e.g., orange for targets, black for tracks, white for ancillary data, and red for a guard zone. This display is raster scanned using digital scan conversion (DSC) and refreshing the picture 30 times a second, so fast that the eye detects no flicker. The color PPI is bright enough to be used in daylight.

Racal 1690/9 radar equips the Dutch *Karel Doorman* (M-class) frigates.

◆ Trisar

Trisar is a Plessey development of MESAR, a rotating active phased-array radar with 3 independent active-array faces. Their pictures are integrated by software. Each face is to contain 2560 independent transmitter/receivers. No prototype has been built, but Plessey expects Trisar to be ready for production by 1994, in time to succeed Type 996. Current efforts are concentrated on reducing the size and cost of the active elements, including reducing their cooling requirements. The current (late 1989) arrangement is the quadpack, in which 1 controller runs 4 GaAs modules. Ship installation is simplified, in that the system requires neither chilled water nor a below-decks transmitter. There are no rotating high-power RF joints, and since each transmitter operates at relatively low power, the radar uses no high voltages. System reliability is increased further in that the radar can continue to function with only 1 or 2 faces.

Trisar is expected to operate over a wide range in S-band, rotating at 10 rpm. Because there are 3 faces, this slow rate (making for a good probability of target detection) is equivalent, in data-rate terms, to the 30 rpm of 996. A diagram displayed at RNEE 1989 showed a fourth (zenith) face atop the rotating array, for full hemispheric coverage. Missile uplinks (for com-

mand guidance) can be accommodated in the narrow areas between the main faces. A 3-face X-band active-array multichannel illuminator can be mounted above the main faces, a system Plessey calls TRIXAR.

Plessey argues that pointing errors in a single phased-array face (such as that in EMPAR) increase sharply as the target moves away from broadside. Providing 3 faces limits this error, because a target is never very far from the broadside position. Multiple faces also make for a high data rate at a low scanning rate. The latter increases the number of pulses hitting the target and so can reduce the effects of clutter and ECM. Plessey also claims that the very wide bandwidth and special monopulse algorithm of Trisar will improve angular accuracy. Frequency agility should also help eliminate multipath effects.

Like EMPAR, Trisar promises a combination of long-range (low-PRF) and horizon search (high-PRF) operation, in each case with the variable dwell time permitted by electronic beam steering (in a conventional radar, dwell time is determined by the rate of rotation). To indicate performance against stealthy targets, Plessey estimated radar range against a pigeon (0.008 m²: 105 km, or 57.4 nm), a sparrow (0.0016 m²: 70 km), and against a worker bee (0.0002 m²: 42 km), all in clear conditions.

Like MESAR, Trisar would overcome jamming by steering its nulls into the jamming beam.

◆ Sentinel

Marconi coast-surveillance radar is for surface and low air cover out to 30 km against a 5-m² target. It uses an S1810 antenna and a standard marine radar transceiver, probably that of the Type 1007 radar. Peak power is 25 kW (90 kW optional), and the antenna scans at 20 rpm. Pulse widths: 0.08, 0.3, 0.8 microsec (PRFs 1600, 800, 400 pps, respectively). The 2.44 × 0.84-m antenna produces a csc² beam over 5–30 deg in elevation.

◆ Watchman/Guardsman

Watchman and Guardsman are Plessey's coast-defense radars. Watchman has been selected by the British Ministry of Defence, and Guardsman has been exported. The S-band Watchman can detect a 1-m² target at 148 km (30 km at low altitude), and it can track over 100 targets simultaneously. The Watchman's transmitter is a high-powered TWT using pulse compression. Characteristics of the air-search version: peak power 58 kW; pulse pattern 0.4 microsec short pulse followed by 20 microsec long pulse (compressed to 0.4 microsec); average power 1.3 kW (implying a PRF of about 1100 pps; there is also an 840-pps mode); scan rate 12 or 15 rpm. Range on a 1-m² target is 100 or 110 nm. The air-search version uses a dual-beam antenna similar in form to early AWS-series naval radars. There are also a transportable air-search version and a coastal version with special signal processing for surface and low-flying targets.

Watchman was first ordered, for the RAF, in June 1983 (33 fixed and 6 transportable units); the first was handed over in September 1986. Current users include the Finnish air force, Bahrain, Dubai, China (PRC), Ghana, Oman, Portugal, and Spain; it is not clear whether any of these radars is being used for coastal surveillance.

The C-band Guardsman is based on the Plessey AWS-6, and in at least 1 form Guardsman uses much the same antenna as that in the Contraves Skyguard system. Scan rate, however, is 15, 30, or 60 rpm. Maximum range on a 3-m² target is 55 nm, and the beam is 1.5 deg wide.

There is also a Guardsman S, in which the Watchman radar electronics are combined with the Guardsman transportable cabin and mast. In this case the mast is 10 m high (15 m optional), compared to 9.5 m in the standard Guardsman.

RADAR INTEGRATION

◆ British Radar Plot Extractors

Radar plot extractors are, in U.S. parlance, radar-video converters. Those in current service are the Ferranti LFX and LAX intro-

duced in the early 1970s, associated with radars of Types 965, 992, and 1006. These systems are all semiautomatic: as in the U.S. NTDS, the associated combat system performs rate-aided tracking based on a series of initial plots, which the operator confirms. Further details of LAX can be found in the discussion of the British ADAWS combat system in the Surveillance and Control section of this book.

The great drawback of the British systems is that the operator must still process large numbers of individual radar contacts, deciding which subsequent ones are properly associated with earlier ones to form tracks. That association can be difficult in a very cluttered environment: hence the need for automatic correlation of individual contacts to form tracks. The Royal Navy calls such systems radar automatic track extractors (RATES), which are equivalent to the U.S. ADT.

The first experimental British RATE system was developed by Thorn-EMI and ARE Portsmouth in the late 1970s; that experiment led, in turn, to 3 production systems: LFA (for Type 996), LFB (for Type 1022, for which a contract has not yet been awarded), and LFC (for Types 1006/1007). These RATES will appear on board ships now under construction and will also be retrofitted to ships already in service. At least in the case of LFC, the system combines radar plots with information from the radar transponder (Outfit RRB) used to track the ship's ASW helicopter.

ADIMP, the ADAWS improvement program, includes a Thorn-EMI track combination system comparable in theory to the U.S. SYS series. Previously, ADAWS had selected the radar providing the best track information, rejecting all the rest.

OPTRONIC SYSTEMS

◆ DAS

Defence Equipment and Systems (Laurence Scott) director aiming sight is a line-of-sight-stabilized unit carrying a pair of binoculars, with provision for 2 other sensors (e.g., FLIR and laser range-finder) alongside the seated operator. The operator can control the training and elevating servos by joystick, or they can be slaved to the associated fire-control system. The director can also be remotely controlled. Outputs are target bearing, elevation, and range (if a range-finder is fitted), sent either directly to a gun or missile launcher, or via an associated fire-control system.

Maximum balanced sensor load is 150 kg, and total weight is 650 kg. Elevation limits are $+70/-20$ deg, and train (elevation) rates are 90 (100) deg/sec; corresponding acceleration rates are 245 (400) deg/sec². Training slew time over 180 deg (rest to rest) is less than 3.5 sec; over 60 deg elevation (rest to rest) is less than 1.5 sec. Overall height is 1.82 m, the binocular axis is 1.735 m above deck, and the swept radius is 0.64 m. Below-decks weight is 182 kg.

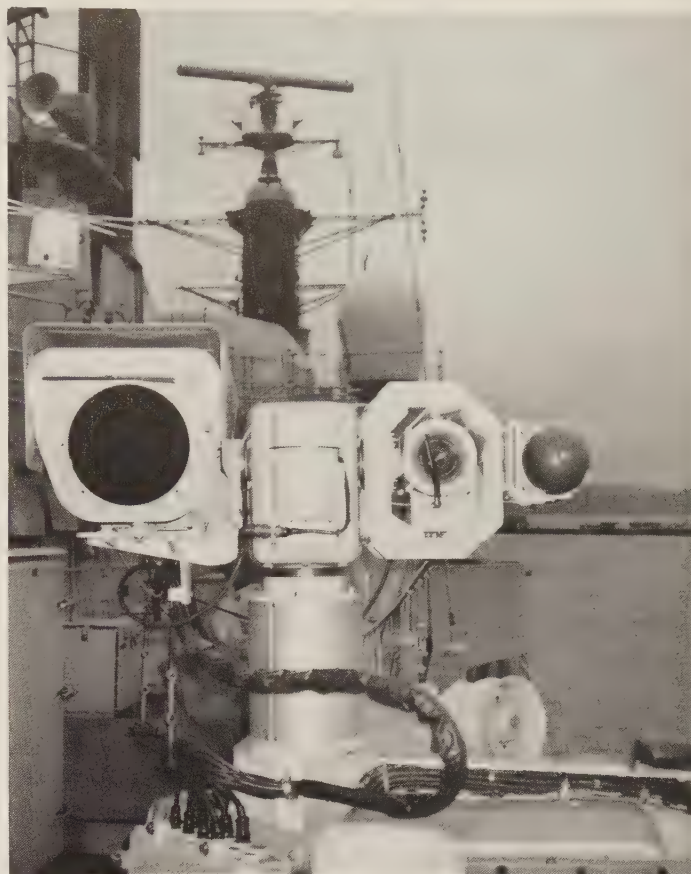
◆ DIMITIS

Barr & Stroud's Director-Mounted Thermal Imaging System is being developed for use on a RADAMEC Type 409 director. The imager is an IR26, a development of the earlier Barr & Stroud IR18 family. It uses a cryogenically cooled SPRITE detector (8–13 micron band). FOV is 13.6×9.1 or 4.75×3.18 deg. The sensor head weighs 19.9 kg.

◆ EOSS/Series 1000/HK 409-010/EPO 409-010

Radamec Electro-Optical Sighting System was bought by the Royal Navy for Type 22 frigates and Type 42 destroyers operating in the Persian Gulf. There is no other designation. It was first installed in 1988, the first batch of 2 being delivered in 5 months. As of the fall of 1989, 5 ships had been fitted (2 EOSS each), and 1 was still to be fitted. EOSS was initially bought to detect floating sea mines and was then used to identify ships and aircraft. It is, then, broadly comparable in role to the U.S. mast-mounted sensors installed on board *Perry*-class frigates. EOSS proved successful in Sixth Fleet exercises.

Series 1000 is the current Radamec designation for the sta-



Radamec Series 1000 electro-optical director. (Radamec)

bilized electro-optical surveillance system, which is mounted on an HK 409 dual-axis stabilized director (the HK 409 designation was used in the past). In this case the director carries a Radamec daylight television camera and a GEC thermal imager. As of late 1989, over one hundred 409 directors were in service in various navies, including over 60 in the Royal Navy. Apart from the current EOSS, Royal Navy 409s carry Series 2000 sensors (see separate entry below).

Series 1000 is itself a recent designation, but this equipment is used (under other nomenclature) by the Royal Danish Navy, by the Finnish Coast Guard, by the Hong Kong police, by the Spanish Navy, and by a Middle Eastern customer. Series 1000 is designed for surveillance and for limited fire control (it can incorporate a lead computer for 30-mm and 40-mm guns). Series 2000 (see below) is a larger equivalent, enjoying substantial commonality with Series 1000.

A typical Series 1000 director weighs 150 kg, including typical sensors; it is 0.5 m high, and swept radius is 1.2 m.

Some of the applications described as Series 1000 surveillance may be more recent versions of the EPO 429 or HK 429 first displayed at RNEE 1983, carrying a Marconi day or low-light-level camera and a FLIR. The Series 1000 fire-control device was also described as the Optical Fire Director (OFD).

The Radamec surveillance/tracking television camera is designated HK 202-002. It has a 16–160-mm zoom lens (FOVs range from 21×16 to 2.1×1.6 deg). The sensor is a CCD (6×4.5 mm) with 604×576 active elements, to produce an image with a resolution of 450 lines horizontally and 420 lines vertically (scan rate 625 lines at 25 frames/sec or 525 lines at 30 frames/sec). The boresight remains stable within 1 mrad at full zoom (10 mrad nominal) as the lens zooms. Total maximum camera weight is 8 kg. Dimensions: 178×450 mm.

Radamec also produces a low-light-level camera (HK 203-001). It, too, has a 16–160-mm zoom lens (FOVs 48×36 to 4.8×3.6 deg). It can tolerate levels of illumination from starlight to full sunlight, a dynamic range of 80 dB. The sensor is a CCD

carrying 604×576 elements; resolution and frame rate match those of the daylight camera. Maximum weight is 12 kg.

These cameras can feed an IDT 2000 video tracker (described under Radamec Series 2000, below).

Series 1000 is derived from manned fire-control directors and surveillance systems; it is a low-cost system for small vessels. Several related manned systems have recently been installed on 30-m patrol craft carrying twin 30-mm guns.

See also Radamec Series 2000, below.

Radamec was formerly Evershed Power Optics (EPO), and HK 409-010 was formerly EPO 409-010.

◆ Ferranti Electro-Optic Multi-Sensor

This is a spherical turret with 2 windows, carrying a Ferranti Type 118 laser (NdYAG, 0.4-mrad beam, 100-mJ power). It can be joystick or auto-track controlled and can be linked with a Ferranti helmet acquisition and tracking indication system (HATIS), so that targets can be designated by someone on a ship's bridge. Targets are passively tracked by infrared (8–14-micron band) and a television with a zoom lens. Typical FOVs for the latter are 8 and 30 deg. The turret is stabilized in 4 axes and can turn through 220 deg. Elevation limits are $+90/-60$ deg. The accuracy of angular (track) outputs is within 3 mrad. Laser range accuracy is 5 m. The turret slews at 1 rad/sec. Auto-tracking circuits keep the target within a 2-pixel area (150 mrad in narrow FOV). Turret diameter is 425 mm (height 520 mm); weight is 32 kg.

◆ GP250

Ferranti's new (1990) gunfire predictor is based on its Series 500 command/control system; it is the element recently sold to Denmark for coastal defense. The most basic form of the system is the predictor proper (GP250P), consisting of software resident (as EPROM) on a series of extended double Eurocards that can fit a customer's computer. The associated microprocessor in the existing GP250P is the Motorola 68020; the Eurocards fit a standard VME bus. The system is programmed in ADA, and the algorithms used are based on those developed for Ferranti large-ship systems, the 400- and 500-series.

GP250P initializes the gun system, predicts ship and target motion, filters/smooths the data it receives both from own-ship sensors (wind and log, gyro and vertical reference) and from the target tracker (e.g., a radar), and calculates aim points. The system can accommodate ballistics for guns from 25-mm up to 5-in or 155-mm. Target-track prediction is based on Kalman-filtered data, and the method of prediction can be either a straight line (SLP), goal-oriented prediction (GOP, for initial engagement of long-range air targets), or SLP with maneuver detection. The system is sensitive to pop-up targets, and it takes into account such corrections as deck movement (roll and pitch), the curvature and movement of the earth, and sensor and gun offsets (parallax). Ship velocity, wind, air temperature, humidity, and air pressure are all taken into account automatically. Splash spotting is inserted via a manual data entry, and fixed gun aim-offs can be provided for warning shots. One or more guns can be controlled.

GP250M is GP250 with full color-graphic MMI (man-machine interface).

GP250T is the total predictor, with its own operator workstation, capable of controlling the principal tracking source. This is the prediction General Processing Unit of the Ferranti WS500 (Series 500) command/control system. GP250T is GP250P plus a control/display unit, a gun synchro drive, and gun tellbacks (feedback to indicate gun status to the system).

GP250L is the land-based version for coastal defense.

◆ GSA 200/300 Series

Ferranti gyro-stabilized lead-computing sights for medium-caliber guns. In Series 200, the gunner selects 2 gyro sensitivity ranges, e.g., 1 to accommodate distances around the maximum gun range and 1 to accommodate the minimum range at which a target can be manually tracked; or 1 for computed tracking

mode and 1 for preliminary slew mode (the gyro is caged for quick slew toward the target). There are 2 displays, a fixed reticle (left-hand side) for slower targets, and as a standby, and a gyro reticle (right-hand side) for lead prediction, showing 40 and 10 mrad circles. Approximate weight is 17 lb.

Series 300 has 3 factory-preset gyro sensitivities, to suit the type of gun and ammunition (for long/medium/short ranges), plus a slew position. Ranges are selected in the sequence slew/long/medium/short, by means of a hand- or foot-push button. The displays match those in Series 200, and weight is about 17 lb.

◆ Laser Dazzle System (LDS)

ARE's laser gun is intended to dazzle, and thus to drive off, approaching pilots. Typically, 2 are mounted on tripods abaft the bridge of a frigate. They are portable and may be cross-decked. LDS was first tested on board HMS *Euryalus* in the Irish Sea in 1981, and several ships (reportedly including the 2 carriers and the frigates *Brilliant*, *Broadsword*, and *Argonaut*) carried it during the Falklands War. It may have caused the loss of several Argentine aircraft, including 1 whose pilot reported that intense glare had driven him away from an attack on HMS *Argonaut*. LDS has also been fitted to (and reportedly used by) British frigates on the Armilla Patrol in the Persian Gulf. The existence of LDS was not reported until January 1990 because of British security restrictions.

Current units may be a second-generation version directed by the Sea Wolf director; LDS seems to be associated with Sea Wolf. The advent of LDS may be associated with the shift, in the Sea Wolf system, from a combined radar/electro-optical to a fully radar-controlled director.

LDS is manufactured by Irwin Desman Ltd.

Possibly because of the existence of LDS, the official British Institute of Aviation Medicine developed antilaser goggles for pilots, using reflecting filters.

◆ NTIS/TIGS

Thorn-EMI's Naval Thermal Imaging System/Thermal Imaging Gun Sight is an application of their Thermal Imaging Common Module Class 1, which was originally developed as a direct-view night-observation device. It in turn evolved into a Multi-Role Thermal Imager (MRTI). The detector is a cadmium-mercury-telluride array (8–13-micron band) scanned across a scene in series-parallel mode; outputs are displayed by means of a scanned red LED array. The same electronic output can be fed into a television. The detector array is cooled to 80°K. There are 2 FOVs (NTIS 1: 4.3×2.8 and 11.1×7.4 deg; NTIS 2: 3.3×2.2 and 8.1×5.4 deg).

NTIS may be integrated with a director, such as Sea Archer. Weights: director and imager 100 kg, compressor (for cooling) 115 kg, console 130 kg. Total travel in azimuth is 190 deg; elevation limits are $+65/-35$ deg. Maximum slewing speed (bearing) is 120 deg/sec.

The much smaller TIGS weighs only 5 kg. TIGS FOV: 20×6.6 deg with $2 \times$ magnification, 8×3.4 deg with $5 \times$ magnification. There is also a hand-held version (HHTI) of TIGS, using hybridized modules to reduce weight.

Both NTIS and TIGS are, reportedly, in current British naval service.

Thorn-EMI is currently under contract to produce an IR naval threat warner to complement ESM systems. The naval requirement was formulated about 1987, and the device will use a dual-band detector. The near band (3–5 microns) is considered preferable in very humid weather and is used to detect missile and aircraft exhaust plumes. The far band (8–13 microns) is used to detect aircraft and helicopters by their skin friction. The threat warner includes a processor that classifies targets, prioritizes them, and indicates their azimuth to operators, automatically pointing the sight and auto-tracking in azimuth and elevation. Thorn-EMI is already developing an analogous single-band (8–13-micron) system, ADAD (air-defense alerting device), for

the British army. It is used to alert and to point hand-held anti-aircraft missiles such as Javelin. ADAD consists of a tripod-mounted scanner, a separate signal processor, and up to 4 remote terminals, typically lying on the ground near the missile operators. As of late 1989, ADAD was scheduled to enter British service in 1991.

◆ OFD

Defence Equipment and Systems (Laurence Scott) Optical Fire Director is the director chosen for the Royal Navy GSA 7 (Sea Archer) system. The operator stands on a ring around the base of the director, observing the target through a pair of binoculars, and controlling the director using a 2-axis joystick. In the alternative remote-training mode, the OFD is manually controlled in elevation only. There is also a full remote-control mode, the operator presumably acting to check the tracking of the remote sensor. Like the same manufacturer's DAS (described above), OFD can carry 150 kg of electro-optical sensors (the Royal Navy leaves the sensors on the separate Sea Archer pedestal).

Total weight is 485 kg, and overall height is 1.95 m (binoculars are 1.858 m above deck); swept radius is 0.795 m. Elevation limits are $+70/-20$ deg, and train (elevation) rate is 96 (67) deg/sec; corresponding elevations are 120 deg/sec² for both train and elevation. Tracking accuracy is better than 1.5 mrad, and MTBF is greater than 1100 hr.

Users include the Royal Navy (in OPVs), Brunei, Egypt, Hong Kong, Kenya, Nigeria, and Oman.

◆ Radamec Series 2000/HK 409-029

Series 2000 includes both fire-control and surveillance systems. Current applications include the Korean KCX/KFX corvettes and frigates and British warships. The stabilized director can carry a variety of electro-optic sensors, normally a daylight or low-light-level television (see the descriptions under EOSS/Series 1000), a FLIR, and a laser range-finder (Series 1000 lacks the laser range-finder). The video tracker is the IDT 2000, below.

Series 2000 includes an integral gun predictor, carrying ballistics in its ROM (and thus requiring no program loading prior to battle), and it can include a special Radamec lead-angle processor. Targets can be designated optically. The display console includes the tracker electronics and also the fire-control (predictor) electronics and, thus, can serve as the basis for a small-ship WCS. This system can include an optional Ka-band tracking radar. Radamec also offers a manned version, in which the pedestal carries an optical sight and, for example, a laser range-finder. The optical line of sight is motion-stabilized; a FLIR can be added (with a small monitor on top of the director).

The intelligent digital tracker (HK 250-001) or IDT 2000 is carried on a VME bus-compatible extended double Euro-card (and expected to be available shortly on an IBM PC/AT-compatible circuit board). The video signal is digitized at 10 MHz, giving 512×512 -pixel resolution. The board carries dual $128 \times 128 \times 8$ -bit (the latter for shades of gray) high-speed image memories, which can be reconfigured as $512 \times 512 \times 1$ -bit memories to cover the full FOV. Alternatively, the image may be digitized at 5 or 2.5 MHz, so that a larger (but less distinct) image may be stored. The board also carries a $256 \times 256 \times 4$ -bit overlay memory to store graphics and text. Six "areas of interest" in the image can be captured and/or processed independently. Some frequently used image-processing functions are realized directly in hardware, and the board is provided with a 20-MHz 32-bit processor and 64 kbytes of program and data memory. Outputs are Video 1 (raw video with superimposed graphics) and Video 2 (digitally enhanced video without graphics); target position and size output; servo tracking outputs; and target and scene data output to a master control processor in a multisensor application.

Besides the basic Type 409, Radamec offers 4 other stabilized director mountings: 429, 449, 459, and 469 (mirror mount; direct drive). Slewing rates are up to 360 deg/sec.

◆ ROD

Laurence Scott's Remote Optronicon Director is a remote-controlled device stabilized in line of sight. Control is by joystick, or ROD can be slaved to another director for target acquisition. ROD incorporates memory tracking for use in bad or interrupted visibility. The stabilized platform can carry 150 kg (75 kg on either side of the training head) of sensors, typically an Ericsson laser range-finder, Ericsson IR camera, and Marconi TV tracker. Total weight exclusive of sensors is 155 kg, and elevation limits are -30 and $+85$ deg.

ROD was first displayed in 1980.

A very lightweight development of the Laurence Scott ROD was announced in 1981. The director weighs 45 kg and carries a 45-kg optronic payload, typically an Ericsson laser range-finder and a Marconi LLLTV. Height is 620 mm, and typical train and elevation rates are 45 deg/sec. Elevation limits are -30 and $+85$ deg.

Like ROD, this director is joystick-controlled and can auto-track.

◆ SLC-001

This new twin-axis, stabilized, optical, lead-computing sight was announced by Astra Holdings (Laurence Scott) at the 1989 RNEE show. It is intended for 12.7-mm (0.50-caliber) to 40-mm guns. SLC-001 automatically computes the lead in both azimuth and elevation and projects them electronically in the form of a cross wire in the gunner's FOV. The gunner can select a fixed display for a stationary target. Because SLC-001 operates electronically, Astra claims that it shows significantly less recovery and prediction time than electro-mechanical sights. It also requires fewer precision parts, and Astra estimates that it should cost only a quarter to a third as much as a conventional sight (which costs £ 15,000–20,000).

The sight can be powered either externally or by its own 4-hr battery. The battery cuts in automatically when external power is lost, and in this case the usual electronically generated display is replaced by a fixed-graticule display. The sight is aligned to the gun boresight by a dovetail fitting, which slides into a universal alignment bracket, and is clamped by 2 thumb-screws. The FOV is 50×17 deg, and the aperture is 100×35 mm. Focal length is 75–100 mm. SLC-001 incorporates Reactolite Rapide optics, as are used in commercial sunglasses that react to changes in light level. In the sight, the effect is to darken a very bright sky so that the bright graticule generated within the sight remains clearly visible. Other sights use pop-up filters.

Total weight is 3 kg.



The SLC-001 lead computing sight on a 20-mm gun. (Astra Holdings)

As of September 1989, development was almost complete, and Astra hoped that its sight would be tested for application to the new British twin 30-mm gun. Chile and Ireland had also shown interest. SLC-001 began Royal Navy tests in May 1990. The Royal Navy has asked that the sight be arranged so that its ballistics can easily be changed (the sight might be shifted from weapon to weapon). That is done by changing the gain of the internal amplifier (which is used to compute the lead angle); the production sight will presumably incorporate a switch controlling the amplifier. SLC-001 may also be coupled with a thermal imager and with a laser range-finder in future.

♦ TDS

Target Designation Sight, manufactured by Defence Equipment and Systems, Ltd. (formerly Laurence Scott). TDS is the standard Royal Navy target designator, comparable in function to the U.S. Mk 24. It is also in service with 9 other navies. The head, to which a standard pair of binoculars is fitted, is counterbalanced for easy tracking in elevation, and height can be adjusted to suit the operator; an illuminated bearing scale atop the pedestal allows the operator to align the sight with a given target bearing. The target-designation switch is in the right hand grip. The pedestal (less binocular) can be extended from 1.52 to 2.03 m in height, and swept radius is 0.3 m; total weight is 77 kg. Training limits are ± 170 deg, and elevation limits are $+85/-15$ deg. Transmission accuracy is ± 30 minutes of arc.

The Laurence Scott LASS (Look-Out Aimer Stabilized Sight) has been made for the Royal Navy since about 1964.

♦ V3800

GEC Sensors thermal imager is part of the Ferranti fire-control system for 4 new Brazilian corvettes, and also for Seaguard, for Thai naval systems, and for Hong Kong patrol craft. It is based on the UK Thermal Imaging Common Module Class II (TICM II), and has a zoom lens (2×3 –to 8×12 -deg FOV). TICM II uses a SPRITE detector and operates in the 8–13-micron band, with alternative FOVs (60×40 deg, for 625 lines at 50 Hz, or 48.4×32.5 deg, for 525 lines at 50 Hz). Resolution is 2.27 mrad (60-deg FOV), and pupil diameter is 10 mm. The detector uses 8 parallel CMTs. The scanner head weighs 9.5 kg.

FIRE-CONTROL SYSTEMS

♦ FPS 5

This Flyplane Predictor System, developed as an interim alternative to MRS 3, survives on a few ex-British frigates. It can be recognized by the presence of a large Mk 6M director carrying the twin nacelles of the Type 275 radar. The original Mk 6 was considered inadequate, and Mk 6M was entirely different in configuration. Unlike previous British directors, which measured the direction to the target (goniometry), Mk 6M followed U.S. practice in measuring target rates of motion (tachymetry). Also unlike Mk 6, Mk 6M had no optical range-finder, although it did have a dome for the Director Officer. All-up weight was 3 tons less than that of Mk 6 (total 8 tons, 5 of it revolving weight). Targets could be indicated either blind or visually.

Elevation limits are $+75/-15$ deg. The anti-aircraft predictor (computer) can handle range limits of 500–15,000 yd, and shell time of flight of up to 30 sec. Target speeds can be up to 700 kt (70 kt for surface targets). The tracker can handle rates of train and elevation up to 10 deg/sec; the predictor (GRU) can generate 45 deg/sec in bearing and 25 deg/sec in elevation. Maximum effective range of the associated 275 radar is 36,000 yd.

There was also an FPS 3, now extinct, with very similar components.

♦ GDS Series

These Gun Direction System designations were applied at the end of World War II. GDS 2 was the standard destroyer system. Particular GDSs were associated with Target Indication Units (TIUs) and with particular radars. In theory, a GDS was the basis

of an integrated gun-control system, with a target designation display on the bridge or in the operations room. These concepts carry over directly to the later GSAs and WSAs. Similarly, a GDS would correspond to the somewhat later U.S. WDS, each having a limited number of analog target-tracking channels. GDS 2* survives on board old ex-British frigates equipped with FPS 5 fire-control systems. The few even older ex-British destroyers equipped with Mk 6 directors are probably fitted with GDS 2.

In each case, the TIU provided a form of TWS performance to the basic target indication (i.e., short-range air-search) radar, and insufficient data rate (to handle fast aircraft) was a major problem.

In this series, GDS 1 was the old visual-only system.

GDS 2 used Radar Type 293. It was associated with TIU 2, which could handle 3 or 5 targets simultaneously.

GDS 2* used Radar Type 293Q; it was also associated with TIU 2. GDS 2* was conceived as an interim system pending the development of the ultimate GDS 3, to be available in time for installation on board the new postwar frigates. GDS 2* was ultimately limited because Radar 293 could not rotate at any rate higher than 30 rpm (and more commonly at 15 rpm). For 400–600-kt targets the preferred data rate was 1 sec (60 rpm) or less. GDS 2* could detect a medium bomber at 55,000 yd and a fighter at 35,000 yd; net accuracy was 2 deg in bearing and 150–400 yd in range. It used 2 operators, 1 for range and 1 for bearing. The blind indication channels fed directly to the weapons systems.

GDS 3 used Radar Type 992; it was associated with TIU 3 (4 or 6 channels). GDS 3 was chosen as the ultimate GDS in 1948. Unlike 293Q, 992 could scan at 90 rpm. A medium bomber could be detected at 70,000 yd and a fighter at 45,000 yd; accuracy was $\frac{3}{4}$ deg and 200 yd, irrespective of range. The system incorporated auto-following circuits (which could not function in heavy clutter; operators used joysticks under such circumstances to track targets). Target channels could be flexibly assigned to various weapons. GDS 3 was massive (it weighed 19 tons, compared to $4\frac{1}{2}$ tons for GDS 2*, and cost £ 148,000 in the early 1950s, compared to £ 25,000 for the simpler system). It was a prerequisite for successful Sea Slug missile operation. A 6-channel version was tested in 1956, and GDS 3 was the British equivalent of the early U.S. WDS, for the first series of County-class destroyers. In effect, it was replaced by ADAWS. GDS 3 was used largely for missile control, although it was installed on board the 3 *Tiger*-class cruisers.

Type 992's effective range was 25–30 nm, but the original Sea Slug required radar data out to 100 nm, despite its much shorter range. The existing small-ship air-search radar, 965, had too broad a beam to provide sufficient long-range detection. Two Signaal radars, LW 02 and VI-01, could have provided sufficient performance, but they were rejected because of the expected cost of Anglicizing them. In theory, given a target approaching at 600 kt, the missile system required 15–40 nm for evaluation and 10–30 nm for target indication to the Type 901 fire-control radar, for a total of up to 70 nm before the Sea Slug missile could be fired.

When the County class were designed, there was little hope of providing them with better radar coverage, and the proposed solution was DPT, the digital plot transmitter. Destroyers would operate in company with a ship carrying a high-capacity 3D radar (Type 984), which would transmit its plot data to consoles in their operations rooms. The carrier would have a computer track-keeping system, CDS (the comprehensive display system), but the destroyers lacked any corresponding computer; they acted as out-stations of the carrier's CDS. At best, CDS could carry 48 tracks, to an accuracy of 1:1000. Each track was specified by a number (1–48), a category (1–9), a raid-size indicator (1–9), and an altitude (2 digits, for height in thousands of feet), plus X and Y coordinates. Each missile destroyer had 2 intercept positions, which could use CDS data to cue the Type 901 missile-engagement radar and increase the available engagement time by 15%. The CDS track repetition rate, equiv-

alent to a data rate, was 20 targets/sec, i.e., a data rate of 2.5 sec on each target.

This solution was adopted partly because the DPT reception consoles and other equipment were much the devices that would later be needed for the successor system, then (1955) called DTE, or digital translation equipment. DTE was, presumably, the terminal associated with the digital ADA system, which replaced CDS. It required a digital computer on board the destroyer. The DPT solution was adopted for the first series of County-class missile destroyers, which never were fitted with tactical-data-system computers. The great limitation of the system was that it used a line-of-sight (UHF) data link, so destroyers had to remain within 12 nm of the parent carrier. There was also some question about the timeliness of CDS data; processing was slow because there were (in the 1955 version of the system) 4 operators who could process 2 targets per minute. Thus, individual plots could be as much as 6 minutes late, far too stale to be accurate as a target came within 992's range.

In 1955 the British also considered an alternative plot-transmission system, the Dutch Teleplot. It automatically displayed raw radar video to plotters over a VHF analog link. Teleplot was probably fitted to contemporary Dutch warships.

GDS 4 was an abortive system, intended to meet a 1949 Staff Target for a system capable of providing a 3D solution to fire-control problems, with complete sky cover up to 50,000 ft. The associated radar was an unspecified TWS type, and GDS 4 was considered superseded by the 2D GDS 3. It was canceled in 1955.

GDS 5 was the intended successor to GDS 2*, using a 293Q or 992 radar, and TIU 5 (3 or 4 channels). Originally, 2 other radars, the U.S. SPS-6C and a new Type 976 (a composite air/surface/gunnery set), were alternatives. GDS 5 was planned for installation from 1958 on, using a new universal PPI scope, and 3 operators with electronic markers who could designate targets to specific weapons. Thus it was similar to the simpler U.S. TDS systems. This is the GDS employed in British frigates and missile destroyers prior to the adoption of automated digital systems such as ADAWS and CAAIS. For example, GDS 5 survives on board the Pakistani County-class destroyer and Indonesian Tribal-class frigates. The radar in the Indonesian ships is 293Q; in the Pakistani ships, 992.

◆ GWS 20/21/22

These are Sea Cat directors of increasing sophistication. GWS 20 carries only a pair of binoculars. The aimer elevates and trains the binoculars, and 1 of the pistol grips carries a joystick



Sea Cat and 2 of its guidance systems: the launcher, with missiles, is at left; the GWS 22 director (Type 904 radar) is at the center of the photograph; and a Dutch M40-series director is at the right. This equipment was on board British and Dutch *Leander*-class frigates lying alongside at Portsmouth, 1979. The big radar at the left is Type 965, and that at right is the Dutch LW-02, which the Royal Navy considered buying instead of 965. (Author)

controlling the missile. GWS 21 uses the Type 262 close-range radar; it is equivalent to MRS 8. The director is an open-topped cylinder carrying an aimer and a director officer, and there is a secondary optical sight. GWS 21 was an interim development pending availability of GWS 22, the full blind-fire director.

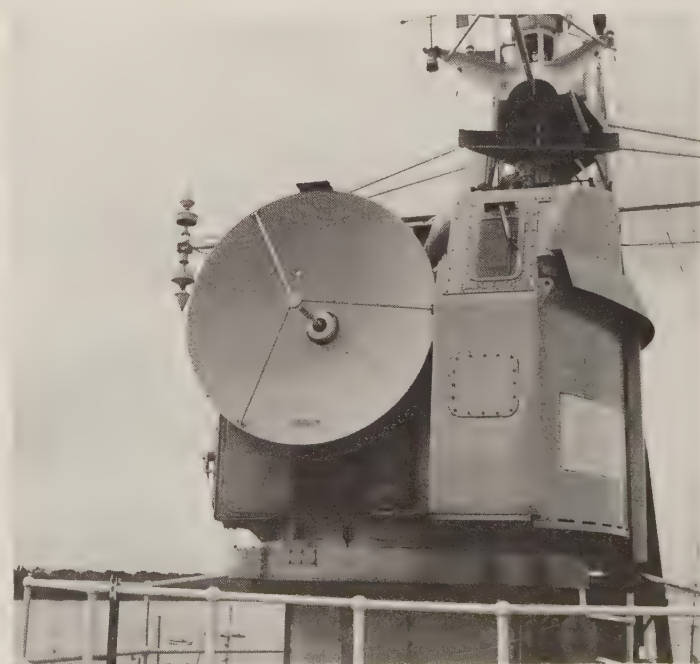
GWS 22 is an adapted MRS 3, with a Type 904 radar. The enclosed director-officer's blast hood of MRS 3 is replaced by an open platform carrying binoculars, and there is no director-aimer's position; the sole occupant of the director slews it into tracking position. GWS 22 entered service in 1962.

◆ MRS 3

This medium-caliber fire-control system was adapted from the U.S. Mk 56. The standard postwar British medium-gun control system, MRS 3 is distinguishable by the projection rising from its roof, the director-officer's blast hood. The window on the front of the director indicates the director-aimer's position, with the Type 903 antenna alongside.

MRS 3 was conceived as a version of the U.S. Mk 61 director, but when that was canceled the project was recast as a British version of the larger and more complex Mk 56. It was Anglicized, using standard British components, and thus was not a direct copy. When the full range of British fire-control systems was reviewed in 1949, the long-range type (LRS 1) was canceled; and it was decided that, since MRS 3 was the only surviving type with a useful blind-fire capability, it would be expanded at the expense of other prospective long- and medium-range systems. The development effort was cut by substituting an electro-mechanical predictor (like the one developed for Flyplane) for the U.S. mechanical linkage. This choice carried a space and weight penalty, but it also made for easier changes in ballistics. This predictor still used the same basic formulae as Mk 56, and its empirical solution was most effective between 3000 and 5000 yd. The result was a 2-operator director with a 903 radar, an electro-mechanical predictor and plane converter, and a gun data unit for separation corrections (corrections due to the difference in location between gun and director) and outgoing transmissions. Maximum range error was 500 yd, and maximum angular error 6 deg in spiral-search mode.

There were several modifications. The addition of Fire Control Box Mk 10, for better surface fire, resulted in the AA/SU 1 system. For blind-fire, GRU Stabilizer Mk 3 was added (AA/SU 2). A splash-spotting radar, Type 932, could be added for



MRS 3 director, HMS *Diamond*, resembles the U.S. Mk 56. The radar is Type 903. (A. Raven)

improved spotting in surface fire (this was AA/SU 3, in the *Tiger*-class cruisers, now extinct).

The first contract was awarded to Sperry in 1947, and work on MRS 3 (as a Mk 56 derivative) began in 1948. The director entered service in 1958, and work on the related GWS 22 began in 1959. In all, over 120 MRS 3/GWS 22 were manufactured, for 8 navies. An MRS 3 update program (Mod 3) began in 1962. Finally, 60 MRS 3 were updated with solid-state electronics in 1974–78.

Of other systems in the MRS series, MRS 6 was a cruiser secondary battery control system using the Mk 6 director, with radar Type 275; it is now extinct. MRS 7 was another system using the Mk 6 director, but to control 4.5-in rather than 4-in guns, i.e., for destroyers (modernized *Battle* class). It, too, is now extinct. Both systems used electric computers (SEDC, the Simple Electric Deflection Calculator). MRS 7 also incorporated a range-control fuze unit and firing-control unit, an electric cross-level calculator and cross-level-angle calculator, and a tangent elevation unit. The main weaknesses of the original Mk 6 had been poor deflection computing by the old fuze-keeping clock, the absence of an automatic fuze predictor and transmitter (which made for excessive dead time), limitations of the cross-level stabilizer, and the excessive number of hand follow-ups (which were slow and could be inaccurate).

The SEDC used a simple solution, which was not always accurate because some constants were used to replace variables. Two sets of constants were provided, for target speeds of 110–150 kt ("practice values") and 250–450 kt ("operational values").

The automatic fuze transmitter replaced a hand follow-up used in earlier directors to transmit future ranges (i.e., fuze time delays) calculated by the fuze-keeping clock. In the earlier system the fuze number still had to be called out to the fuze transmitter, who transmitted manually to the gun. The result was excessive time lag and error. The replacement was a Range Control Fuze Unit (RFCU). Typical RFCU parameters would be target speed 450 kt, future range 3500 yd, and dead time 4 sec.

◆ MRS 8

This short-range anti-aircraft fire-control system uses the Type 262 radar and evolved from the earlier CRBFD (close-range blind-fire director). MRS 8 could control 40-mm, 4-in, or 4.5-in guns. MRS 8 was essentially a CRBFD with its predictor replaced by a below-decks computer (single or dual ballistic unit, depending on which guns were being controlled). The dual ballistic unit also automatically opened fire when a target came within effective range.

As these directors became obsolete, they were converted into GWS 21s for Sea Cat control.

◆ Sea Archer 1 (GSA 7)

Sea Archer is the Sperry (UK) manned optronic weapons-control system. Sea Archer 1A adds below-decks controls. Sea Archer uses a modified Laurence Scott optical fire director (OFD). Applications include the Omani landing ship *Al Munassir*. As GSA 7, Sea Archer 1 controls the 76-mm gun of the British *Peacock*-class patrol vessels. A GEC V3800 thermal imager was added to their GSA 7s in 1986.

As supplied to the Royal Thai Navy in 1986, Sea Archer 1A had an LLLTV (dual 12/3 deg FOV), a GEC V3807 thermal imager (LST version only), and a laser range-finder.

A Sea Archer 1B version, announced in 1983, has an unmanned director and autotrack.

The director is line-of-sight stabilized. The associated predictor turns the director into the direction of the target; the operator searches only in elevation to acquire the target. The operator tracks it by using a joystick with a pistol grip that contains controls for slew, for doubling the director rate. There is also a rate memory. Once the target has been acquired, the operator releases the director from predictor control and triggers

the range-finder. The latter may be either a range-only radar or a laser. Because the laser has so narrow a beam, the operator needs an indication that the beam has in fact pointed at the target; when the laser finds the target, the operator is given an audible click in the earphone. The operator's binoculars can be replaced by a trillite image intensifier or by an LLLTV. It is also possible to replace the binoculars with a day/night scope, which allows the operator to view a scene either in natural light or in IR.

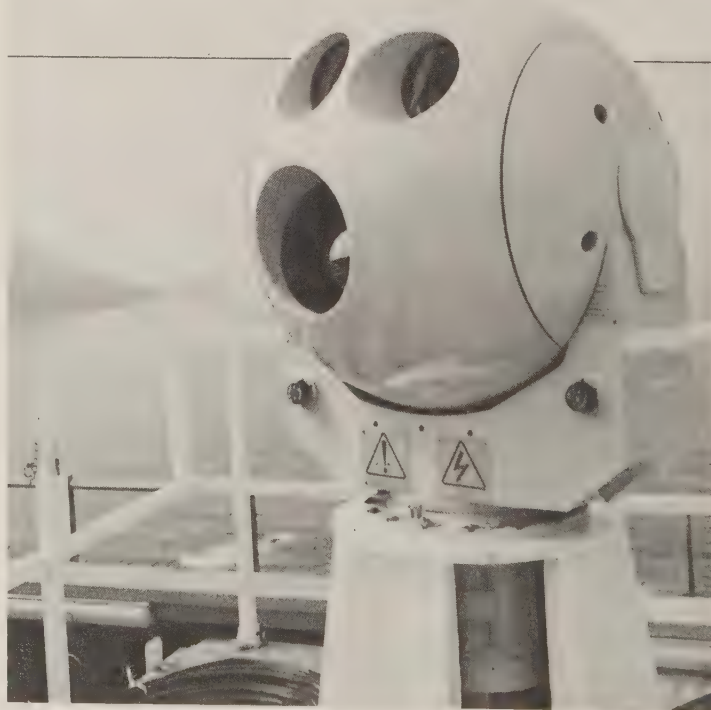
Sea Archer development began in 1974; Sea Archer 1 was ordered by the Royal Brunei and Omani navies in 1976. Sea Archer 1A Mod 0 was ordered for Oman and for the Royal Navy (as GSA 7) in 1980. Mods 1 and 2 were ordered for the Royal Thai Navy in 1985–89.

◆ Sea Archer 30

This optronic gunfire-control system was developed by Sperry (UK) and then taken over by British Aerospace. First displayed at RNEE 83, Sea Archer 30 was adopted in 1985 by the Royal Navy to control 4.5-in guns on board Type 22 and 23 frigates, under the designation GSA 8/GPEOD (Gun System Automation 8/General Purpose Electro-Optical Director). It is the first entirely autonomous digital Royal Navy gunfire-control system.

Sea Archer 30 was conceived as a follow-on to the original Sea Archer 1 and the abortive Sea Archer 2; it was initially to have been marketed as Sea Archer 3. The development of an autotracker and a remote optical director (1980) led to work on an entirely new system. In 1982 BAe developed a General-Purpose Electro-Optic Director (GPEOD), and Sea Archer (GSA 8) followed in 1985. An entirely new unit was needed because Sea Archer 1A was clearly at the end of its development potential; Sea Archer 30 uses a new single-board computer and a data bus. It can accept inputs from a tracking radar, tactical data system, or 1 or 2 bridge pedestal sights. The fire-control system can be directed onto an urgent target by a special externally generated ALARM AA signal; the system can also be used for passive surveillance.

The above-decks director is spherical, both to reduce wind loading and to reduce radar cross section. It has a swept radius



Sea Archer 30. (British Aerospace)



Sea Archer 30s atop the bridge of the British frigate HMS *Cumberland*, with a Sea Wolf director between them. (G. Arra, 1989)

of 448 mm and weighs about 200 kg. The internal power unit weighs another 45 kg, the gun-control console 230 kg, and the predictor unit 110 kg. Elevation limits are $+75/-35$ deg; training and elevation rates are both 90 deg/sec. Designed MTBF is 175 hr.

The spherical director carries an IR camera, a laser range-finder, and a daylight television. The IR camera operates in the 8–12-micron band and has a zoom lens giving magnifications of 3.6–20 (corresponding FOVs are 16.7×11.1 deg and 3×2 deg). Resolution is 512 lines. The detector is a Stirling-cooled Mullard SPRITE. The Ne-YAG laser operates at a wavelength of 1.06 microns, with maximum peak power of 10 MW and maximum PRF of 12.5 Hz. Range accuracy is less than 4 m for ranges of less than 5000 m, and less than 5 m for longer ranges. The daylight television uses charge-coupled devices (CCDs) and has a zoom lens with resolution and FOV similar to those of the IR camera; horizontal FOV is continuously variable between 17 and 3 deg, with a 4×3 aspect ratio. It has a remotely operated focus control.

The 2 below-decks units are a predictor (ballistic computer) and a console with a joystick and firing switch. Data buses connect the electro-optic director to the console (desk unit), and the console and predictor are connected by data bus. The predictor is itself connected to the guns and to the target-designation sight. The predictor has 2 filtering and prediction channels so that it can control guns of up to 2 calibers. The

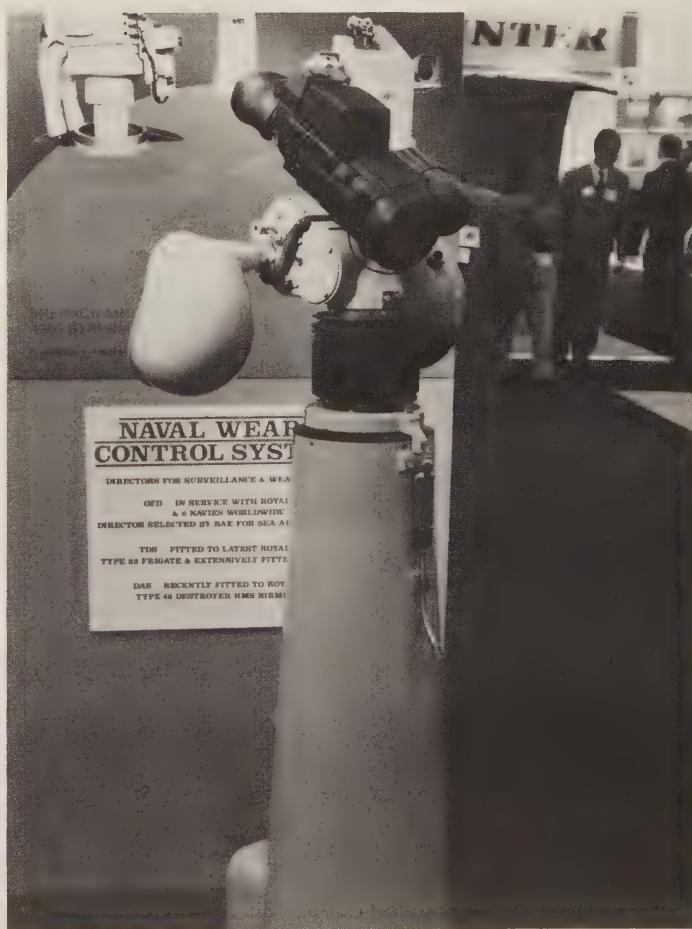
prediction programs are held in read-only nonvolatile memory and, thus, can survive power failure.

There are 3 automatic tracking modes: edge, centroid, and correlation. Centroid is automatically selected for air targets and correlation for surface (i.e., for targets in strong clutter), but the operator can override these choices. The tracking gate around the target automatically adapts to target size and shape, to avoid confusion with decoys such as flares. The point of aim can be moved manually while the system is autotracking, e.g., while tracking a crossing air target. In the correlation tracking mode, the system automatically coasts at the last known target angular rate if track is lost, e.g., if the target disappears behind clutter. The optional auto-acquisition feature marks and tracks detected targetlike objects within the sensor's FOV.

The Royal Navy initially expected to order 2 separate systems, 1 for gunfire control (GSA 8) and the other for electro-optic surveillance. The GSA 8 specification demanded 4 director functions: naval gunfire support, antiship engagement, anti-aircraft engagement, and chaff shell firing for both distraction and wind-finding. The BAe system competed against 1 based on the Ferranti WSA 500 Modular Combat System.

BAe proposed that the 2 requirements be merged, using common modules from the UK Common Module Thermal Imager program. The resulting system has a very large (240-mm) object lens (with a 3-deg FOV at maximum zoom) and a 20-power telescope, and the manufacturer claims that it can detect targets beyond 20-km range. At 10 km, IR resolution is less than 1 m.

In the British competition, BAe won primarily because of the quality of the EO director, and particularly its stability and resilience to vibration. The Royal Navy also imposed very stiff



The DES Target Designation Sight, on display at RNEE 1989. The bulbous object is a handhold (the target side of the designator is visible). (DES)

weight, size, and power constraints. The Royal Navy ordered Sea Archer 30 in 1985. It is fitted to Type 22 Block III frigates (1 on each side) and to Type 23 frigates (1 per ship); as of October 1989, 20 were on order for the Royal Navy. BAe has developed the necessary software for 76-mm, 57-mm, 40-mm, and 30-mm gunfire control, in addition to the basic Royal Navy 4.5-in requirement.

The Royal Navy did not want automatic target acquisition, but the Sea Archer system can accommodate such a system, and it was tested in the U.S. trials mentioned below. Further planned improvements include an anamorphic lens for greater range.

BAe offers Sea Archer both as a full-up EO/GFCS system and also as a pure IRST, the latter in competition with equipment such as the Canadian SAR-8.

With the failure of the U.S. Seafire program, BAe proposed Sea Archer as an interim substitute. It does lack some of the features of the U.S. system, particularly the long-range laser-designation capability (stability and beamwidth) required to control laser-guided 5-in shells at maximum range; but Sea Archer is much lighter, and it does provide a valuable IR surveillance capability.

Sea Archer 30 was tested at NSWC Dahlgren between mid-September and mid-December 1988, under the Foreign Weapons Evaluation program. The targets were A-4, A-7, and F/A-18 airplanes, helicopters, surface craft, and moving shore targets. In a typical run, an A-7 flying at 1000 ft was first seen at 32,300 yd and acquired at 23,000 yd. Image processing was very important for such performance. For example, images could be edge-enhanced to make them stand out at long range.

Late in 1990 McDonnell Douglas Helicopters and GEC Sensors proposed an alternative optronic system based on the U.S. mast-mounted sight (see the U.S. section) and the GEC search/track system. Reportedly, the proposal was made after production problems were encountered with Sea Archer 30s for new Type 23 ("Duke"-class) frigates.

◆ Sapphire

The Marconi/Sperry (U.K.) Sapphire radar fire-control system employs a Marconi ST802 or ST1802 radar, the predictor (the Sperry Digital Weapon Controller [DWC 100], consisting of a Sperry 1412 Computer and its interface and power supply) developed for the Sea Archer system, and a 1-operator control console. The system can function against air targets (in direct or coasting mode), against surface targets at relative speeds of up to 60 kt, and for naval gunfire support (including fuze computation for starshell and chaff). The AA coasting mode is extrapolation of target motion in the event that a target fades, e.g., passes behind terrain or chaff. Normally engaging targets designated from a search radar, Sapphire can also search autonomously, particularly against low-flying targets. In the horizon-search mode, a 0.1 m² sea-skimming missile can be detected at 12–15 km.

Typical system reaction time, including slewing to a designated target, is 7 sec. The ST802 radar director accommodates a television camera, which automatically becomes the main tracker if the target drops below an elevation angle of 1.5 deg, to eliminate multipath effects. Full radar tracking resumes automatically when the target passes above this angle. In a mass stream attack, the television can be used to acquire a second target while the first is being engaged, the radar being used to track the target being engaged.

The associated Sperry 1412A computer has a capacity of 16 kwords. It recalculates gun orders 64 times per second and provides new output 512 times per second.

Sapphire was evaluated for the Royal Navy in 1975 and announced in 1976 (and first sold that year); and an improved version was announced in 1985 (using the ST1802). The first Sapphire entered service about 1979. As of 1989, sales were: single systems in each of 6 Egyptian 6 *October*-class fast attack boats and 6 *Ramadan* class and 2 Kenyan *Nyayo* class.

UNITED STATES

RADARS

◆ BPS-5/12/14

Band: X **Beam:** 2.6 × 16 deg **Peak Power:** 75–110 kW
Gain: 29 dB **Pulse Width:** 0.5 microsec
PRF: 600 pps **Scan Rate:** 0–8 rpm
Antenna Dimensions: 3 × 0.75 ft
Antenna Weight: 300 lb (total weight 2050 lb)

Data apply to BPS-5.

Lockheed Electronics's submarine surface-search radar was originally designed for special target submarines (SSTs) but later installed on board *Permit*-class attack submarines. Reliable range on a destroyer was 12 nm, and accuracy up to 60,000 yd was 25 yd ± 0.1% (to 120,000 yd, accuracy was 2% of range). Bearing accuracy was 0.25 deg. Range limits: 200 and 160,000 yd.

BPS-12 is a redesigned version, by Fairchild Camera and Instrument, using both a periscope antenna and a conventional one. Peak power is 75 kW and range limits are 400 and 80,000 yd. BPS-14 is very similar, except that its antenna drive is designed for use from within the submarine.

◆ BPS-9

Band: X **Beam:** 2.6 × 16 deg **Peak Power:** 75–110 kW
Gain: 36 dB **Pulse Width:** 0.5 microsec **PRF:** 600 pps
Scan Rate: 0–8 rpm **Antenna Dimensions:** aperture 16 ft
Antenna Weight: total installation weight 4000 lb

This submarine surface-search radar is a modernized equivalent of the early postwar SS-2. BPS-9 was developed by Western Electric and first delivered in December 1958 (for SSBNs).

BPS-9A has a retractable antenna.

◆ BPS-11

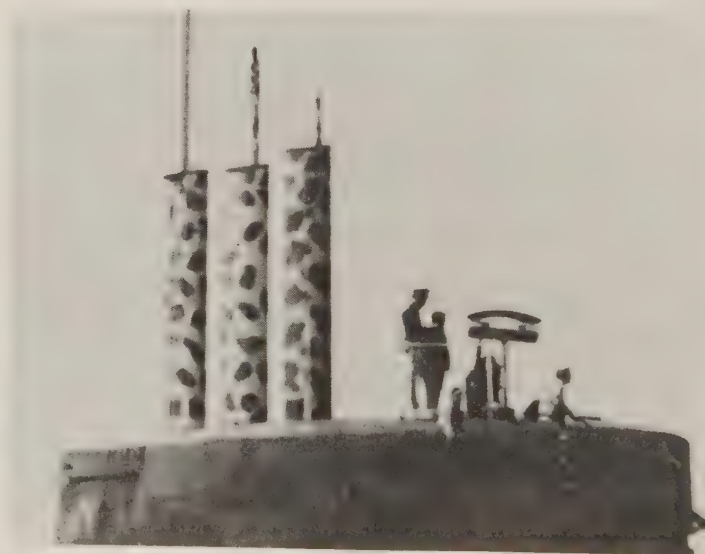
Band: X **Beam:** (i) 2.6 × 16 deg (ii) 30 × 10 deg
Peak Power: 75–100 kW **Gain:** (i) 29 dB
Pulse Width: 0.5 microsec **PRF:** 600 pps
Antenna Dimensions: (i) parabolic (ii) periscope antenna

BPS-11 is a redesigned BPS-1/4 for the SSBN 616 class, similar to BPS-5 except for the antenna. BPS-11 uses a horn (parabolic in BPS-11A). Range limits are 200 and 160,000 yd.

◆ BPS-15/16

Band: X **Beam:** 3 × 13 deg **Peak Power:** 35 kW **Gain:** 29 dB
Pulse Width: (i) 0.1 (ii) 0.5 microsec **PRF:** (i) 1500 (ii) 750 pps
Scan Rate: up to 9.5 rpm **Antenna Dimensions:** aperture 40 in
Antenna Weight: 168 lb

Sperry's surface-search/navigational radar uses a horn-array antenna. Minimum range is 25 yd, and range resolution is 30 yd in the short-pulse and 100 yd in the long-pulse modes.



BPS-15 radar, USS *Hawkbill*. (Ships of the World)

BPS-16 is the successor to BPS-15. Radar performance will be very similar, the main improvement being in the mechanical reliability of the mast. The 2 bidders were Norden and Sperry Marine, Norden being awarded the contract for what was then called BPS-() on 29 April 1987. The contract called for the development and production of 36 modular submarine radars. Sperry protested, and the contract was recompeted. Sperry ultimately received the contract, the radar now being designated BPS-16. First deliveries were due in 1990.

◆ SPS-5

Band: Xb (6400 MHz); C (5450–5825 MHz) in SPS-5C and -5D
Beam: 1.75×15 deg (csc² to 22 deg) **Peak Power:** 350 kW
Gain: 29 dB **Pulse Width:** 0.5 microsec
PRF: 680 pps **Scan Rate:** 17 rpm
Antenna Dimensions: 101×52.5 (including pedestal) $\times 101$ (depth) in
Antenna Weight: 205 lb including pedestal

Raytheon's small-ship surface-search radar was first delivered in 1952. Data above are for SPS-5C, introduced about 1960, which shifted from Xb- to C-band and used the AS-1002 antenna. Earlier versions used the AS-511 and -651 antennas.



USS *Bronstein* shows an SPS-5C surface-search radar, above her SPS-40 air-search set. Comparison with ships carrying SPS-10 will show how much smaller the -5C's antenna is. (U.S. Navy)

◆ SPS-6

Band: L (1250–1350 MHz) **Beam:** 3.5×30 deg
Peak Power: 500 kW **Gain:** 27 dB
Pulse Width: (i) 4 microsec (ii) 1 microsec
PRF: (i) 150 (ii) 600 pps **Scan Rate:** 2.5–15 rpm
Antenna Dimensions: $204 \times 95 \frac{7}{8}$ in
Antenna Weight: 924 lb (including pedestal)

SPS-6 was the first of the postwar generation of L-band air-search radars. These data apply to the SPS-6C version commonly installed on board destroyers and frigates. This radar could detect large high-altitude aircraft at 70–140 nm and fighters at 60–80 nm. SPS-6D omitted the integral IFF of SPS-6C, and -6E had a better receiver. Some sets may have had a peak power of 750 kW. The antenna was deliberately designed with a beam broad in its vertical dimension so that the radar could reliably detect high-altitude jets.

In U.S. service, SPS-6 remains on board only the *Thomaston*-class amphibious ships, but it is also in service on board destroyers, frigates, and similar vessels in foreign navies.



Although SPS-6 is virtually extinct in the U.S. Navy, many survive abroad. This photograph was taken in 1950, but current installations use the same antenna, typically at the masthead. (U.S. Navy)

◆ SPS-10

Band: C (5450–5825 MHz) **Beam:** 1.5×16 deg
Peak Power: 500 kW **Gain:** 30 dB
Pulse Width: (i) 0.25 (ii) 1.3 microsec
PRF: 625–650 pps **Scan Rate:** 15 rpm
Antenna Dimensions: $126 \text{ in} \times 76 \text{ in}$ (with pedestal)
Antenna Weight: 442 lb including pedestal

Data are for SPS-10B (AS-936 antenna).

SPS-10 was the standard U.S. surface-search radar; it has been superseded, to a limited extent, by SPS-55 and is being replaced



USS *Whipple* has an SPS-10 surface-search radar and an SPS-40. The tall antenna above the SPS-10 is her LAMPS data link. (U.S. Navy)

by SPS-67. In 1976 SPS-10 was considered the most reliable U.S. surface-search radar, with an MTBF of 150 hr (but with 5–6 hr MTTR because of the absence of automatic fault-finding equipment). The latest version is SPS-10G.

SPS-10 had a 285-kW transmitter; -10B introduced the current 500-kW type. SPS-10E introduced a new antenna (1.9 × 16-deg beam, 17 rpm), and -10F a new PRF (625–660 pps). The 2 pulse widths make for resolutions of, respectively, 41 and 213 yd. During trials in 1956 SPS-10 showed that it could detect a continuously exposed snorkel in sea-state 2 at an average of 9630 yd (maximum reliable range 12,100 yd) and could track a periscope (with 6 ft exposed) in sea-state 1 at 16,000 yd. Maximum reliable tracking range on a 3-ft attack periscope in sea-state 1 was 10,100 yd. These trials showed that the radar could reliably detect a submarine attack periscope intermittently exposed during an attack in sea-state 2 and below.

The associated IFF is integrated with the basic radar, and the IFF beam is 6 × 22 deg.

Some versions of this radar used the AS-1161 lightweight antenna, identical with the AS-1002 of SPS-5C. SPS-10 and -10A used AS-615; later versions use AS-936, which is essentially the same antenna with a 440-volt 3-phase drive instead of the earlier 110-volt single-phase drive. AS-936B adds an extension to the bottom of the antenna and "blinders" on the sides of the feed horn, to reduce sidelobes and minor interference with other ship antennas.

Deliveries began in October 1953. See also SPS-58, which sometimes uses the same antenna, and SPS-67.

◆ SPS-12

Band: L (1250–1350 MHz) **Beam:** 30 × 3 deg
Peak Power: 500 kW **Gain:** 25 dB



SPS-12 and SPS-10 radars on the foremast of the Canadian destroyer *Fraser*, 1989. (G. Till)

Pulse Width: (i) 4 microsec (ii) 1 microsec
PRF: (i) 300 (ii) 600 pps **Scan Rate:** 2.5–15 rpm
Antenna Dimensions: 205 × 92 in
Antenna Weight: 990 lb (with pedestal)

SPS-12 was, in effect, an improved SPS-6. Total weight was about 4600 lb compared to 2550 lb for SPS-6B. Although peak power did not increase, long pulses could be emitted at a higher rate, for twice the average power of the earlier radar.

SPS-12 was first delivered in September 1953. This radar was also manufactured under license in Italy. The Canadian SPS-501 consists of a Dutch LW-03 antenna combined with an SPS-12 transmitter. The last U.S. set was removed from the training carrier *Lexington* in 1984.

◆ SPS-29/37

Band: P (215–225 MHz) **Beam:** 19 × 25.5 deg
Peak Power: 750 kW **Gain:** 18 dB **Pulse Width:** 10 microsec
PRF: 300 pps **Scan Rate:** 7.5 or 15 rpm
Antenna Dimensions: 210 × 102 in (140 with pedestal)
Antenna Weight: 1275 lb including pedestal (below-decks weight is 8700 lb)

Although extinct in the U.S. Navy, this P-band radar survives in some foreign ships. The mattress antenna, AS-943, consists of 28 folded dipoles spaced a half wavelength apart vertically and horizontally, and about a quarter wavelength in front of a flat reflector.

This radar was first delivered in 1958; in all, 89 were made.

A few ships had SPS-28, whose antenna was virtually indistinguishable from that of SPS-29. SPS-28 operated in the same frequency band, but peak power was only 300 kW, pulse length 4 microsec, and PRF 120 pps; gross weight was 4440 lb, compared to 7510 for the much more powerful SPS-29. The antenna was AS-839.

A few U.S. destroyers had SPS-37, externally indistinguishable from SPS-29; some of these sets may also be in foreign service. SPS-37 is a pulse-compression radar with a peak power of 180 kW; pulse width is 200 microsec (compressed to 6), and PRF is 230–250 pps. The improved version, SPS-43, is now extinct. See the previous edition of this book for details.



SPS-29 antenna, USS *Intrepid*. (A. Raven)

◆ SPS-39/42/52

Band: S (2910–3100.5 MHz)
Beam: 1.1×2.25 deg. (1.9×2.25 deg in SPA-64)
Peak Power: 1000 kW **Gain:** 39.5 dB (37 dB in SPA-64)
Pulse Width: (i) 2.5 (ii) 4.6 (iii) 10 microsec
PRF: (i) 1850 (ii) 925 (iii) (see notes below) pps
Scan Rate: (i) 15 (ii) 6 (iii) 6 rpm (SPS-39A: 5, 7.5, or 15 rpm)
Antenna Dimensions: 165×167 in (including pedestal) (SPA-64: 165×160 in including pedestal)
Antenna Weight: 3200 lb (including pedestal) (SPA-64: 2950 lb)

These 3D radars are scanned electronically (frequency scanned) in elevation and mechanically in bearing. SPS-39 originally had a cylindrical-section antenna, but all ships now have the planar array, with a serpentine delay line on 1 side. Stabilization is achieved electronically. The antenna itself consists of a stack of 60 linear arrays. The early planar-array antenna (SPA-64) used 63 radiating slots per array; the later SPA-72 (for which most of the data above are given) uses 98. In each case, the antenna is tilted back at 25 deg, and total vertical coverage is 42 deg (41.6 deg for SPS-52B).

These radars use klystron transmitters. All have low-power modes (peak power 16 kW; but 14.4 kW, with 900 kW maximum, in SPS-52B) and variable pulse rates. SPS-39 and -39A have only 2-microsec (PRF 1850 pps) and 4-microsec (PRF 925 pps) pulse widths. SPS-39A's PRF is 488–2000 pps. In the order given above, SPS-52A's PRFs are 1220–2000, 488–2000, and 329–1050 pps. Presumably, the figures above are the usual values corresponding to the given pulse widths. Below-decks weights: SPS-52, 15,500; SPS-52B, 15,934 lb; SPS-52C, 14,040 lb.

The original SPS-39 was credited with a maximum range of 160 nm and a maximum altitude of 75,000 ft. The pulse data above refer to an improved (Series III) version introduced in 1963, with the planar-array antenna. The 3 modes were high-data-rate mode (i), with an instrumented range of 60 nm; high-angle mode (ii), 160 nm; and long-range mode (iii), 245 nm. Maximum elevation in the high-data-rate and high-angle modes was 42 deg (with an alternative limited angle of 13 deg in these

modes and in the normal long-range modes), and there was an alternative limited long-range mode with a 4.5-deg maximum elevation. The improved SPS-52 is credited with a maximum range of 240 nm and a maximum altitude of 100,000 ft (maximum elevation 42 deg).

SPS-42 was an SPS-39 modified to provide data directly to NTDS.

SPS-52 introduced the planar-array antenna now standard for both types, as well as a parametric amplifier and a wide-pulse feature for longer range. Stabilization is digital rather than analog. The computer was originally the Hughes H3118, but SPS-52B is generally credited with a standard navy UYK-15. SPS-52B introduced clutter rejection.

The current SPS-52C employs a UYK-20 computer. It is responsible for stabilization and beam control, target processing, and the interface with SYS-1. For ATD, a video extractor and control group (VECG) were added for radar-beam-control conversion functions, as well as a radar video converter (RVC) for SYS-1. The VECG can store up to 9 consecutive detections of the same object, find their centroid in 3 dimensions, and then pass that centroid's location to the IADT as a single target report, thus reducing the IADT's workload and increasing the overall system's accuracy. SPS-52C is also more reliable than its predecessor, with an MTBF (as reported in 1979) of 216 hr, compared to a requirement for 170 hr: a 14% improvement over SPS-52B.

SPS-52C has 4 modes: high-angle (moderate range and data rate); long-range (high-energy pulse); high-data-rate (quick detection and rapid update of close-in targets); and MTI (clutter rejection). For medium range, the radar has a 6-sec data rate (scan at 10 rpm); for long range and MTI, 8 sec (7.5 rpm); and for short range, 4 sec (15 rpm).

SPS-39 was first delivered in January 1960; it was the first operational U.S. frequency-scanning 3D radar. -39 suffered from limited reliability (in 1960–62 MTBF was only 14.3 hr, although figures as great as 67.4 hr were achieved on board some ships). SPS-52's development began about 1963.

SPS-52C's design began in 1973, and it (with SYS-1) was tested on board USS *Towers* beginning in December 1977; approval for service use was granted in 1978.

For details of the associated IFF antennas, see the entry for SPS-48 below.

SPS-52C was planned for installation on board all surviving U.S. ships equipped with the earlier SPS-39/52 (the frigates have SPS-52 or -52B; the destroyers may have retained SPS-39 or -39A). However, in August 1981 it was deleted from the planned modernizations of the *Brooke* and *Adams* classes (except for the 3 heavily upgraded *Adams*-class destroyers). It has been installed abroad, on board Australian and German *Adams*-class missile destroyers. The French *du Chayla* retains her SPS-39, as do the Italian *Caio Duilio*s and *Impavido*s. The Italian *Vittorio Veneto* apparently has SPS-52B, but the *Audace*- and *Animoso*-class missile destroyers appear to have SPS-52C. The Japanese *Hatakaze* class have SPS-52C, but the older missile destroyers have SPS-52B, as do the Spanish *Baleares* class.

Foreign navies did not always buy the same package, including the same computer, as the U.S. Navy. The Spanish SPS-52B (on board the *Baleares* class) is midway between a U.S. SPS-52B and -52C, with a Spanish-developed radar-integration system. The Japanese SPS-52C has special features. It also uses a new antenna, physically indistinguishable from its predecessors, but with its elements embedded in plastic (like the parts of a surfboard) rather than covered by a thin plastic sheet.

SPS-52C production ended in 1989, but several navies (including those of Australia and Canada) have since shown interest in purchasing it, and Hughes may yet license foreign production of a solid-state version, e.g., for modernization of the *Brooke*-class missile frigates and *Adams*-class destroyers now being transferred to foreign navies. Hughes decided to cease production because its improved version of TAS Mk 23 enjoyed much the same range performance as SPS-52, but with a much better data rate; it saw ITAS as the natural successor to SPS-52.



An SPS-52C antenna, on board USS *Tattnall* (DDG 19), the first ship so fitted. The bar above is an IFF interrogator. (Hughes)

◆ SPS-40

Band UHF: (400–450 MHz band) (10 channels)
Beam: 11×19 deg **Peak Power:** 200 kW (pulse compressed)
Gain: 21 dB **Pulse Width:** 60 microsec (compressed to 1.0)
PRF: 300 pps (jittered)
Scan Rate: 7.5 or 15 rpm (6 rpm in SPS-40 and -40A)
Antenna Dimensions: $216.0 \times 116.8 \times 111.0$ (deep) in
Antenna Weight: 1425 lb, including pedestal (1728 lb for SPS-40B and later versions) (3200 lb below decks; 3400 lb for SPS-40A; 3474 lb for later versions)

This radar and SPS-49 are the current standard U.S. 2D sets. SPS-40 is in effect a compromise between very long range (achieved by using low frequency) and reasonable definition; 400 MHz is about the minimum acceptable frequency for a current set, because the next lower band, around 200 MHz, cannot provide enough information.

The original SPS-40 was manufactured by Lockheed Electronics. SPS-40A, an improved version by Sperry, introduced a broad-band transmitter and some solid-state receiver changes. Peak power was increased to 255 kW. SPS-40B, by Norden, incorporated a new IFF (AIMS), for air control of friendly aircraft, a low-flyer-detection mode (LFDM), digital MTI (DMTI), and an automatic target detector (ATD) that allows the radar to feed into an automatic combat system (SYS series). DMTI provides clutter rejection over land. ATD employs a radar-video converter (RVC), which automatically detects targets and provides range and bearing data to the central combat-system computer. There are also ECCM improvements. SPS-40B and later versions have an alternative 3-microsec (short) pulse and alternative PRFs of 278 and 300. SPS-40C is a modified SPS-40A (to -40B standards), incorporating LFDM and reliability improvements. SPS-40D is a modified SPS-40A corresponding to SPS-40C standards. An improved antenna is under development, and Norden has developed a frequency-agility (FA) module. It selects an unjammed frequency and shifts frequency on a pulse-to-pulse basis. Other possible improvements are main and sidelobe cancelers; at present the antenna has fairly fat sidelobes (27 dB horizontal, 10 dB vertical).

Data above apply to SPS-40B; some models may compress the 60-microsec pulse to 0.6 microsec. Minimum range is 0.25 nm. Current MTBF is 252 hr; MTTR is 45 min. The transmitter is a tetrode tube.

The latest version, SPS-40E, incorporates a new Westinghouse solid-state transmitter (SSTx), intended for 90% probability of maintenance-free operation for 90 days, with no more than 11% reduction in range performance. The SSTx can also power up very fast so that the ship can operate with her radar shut down when in EMCON without risking loss of radar capability when it is needed. In addition, the SSTx automatically protects itself from damage due to battle damage to the waveguide or antenna; it shuts down, then powers up to the level allowed by the other components. Westinghouse offers a less expensive, lightweight (half power) SSTx for coastal defense.

◆ SPS-48

Band: S (2900–3100 MHz) **Beam:** 1.5×1.6 deg
Peak Power: 2200 kW **Gain:** 38.5 dB
Pulse Width: 3 microsec (per beam: 27 total)
PRF: 1250–2000 pps **Scan Rate:** 7.5 or 15 rpm
Antenna Dimensions: 194×228 in (including pedestal)
Antenna Weight: 4495 lb (including pedestal) (below-deck weights: -48, 18,211 lb; -48A, 19,651 lb; -48C, 20,548 lb) SPS-48E: 5684 lb above-decks (24,018 lb below-decks).

SPS-48 is the most sophisticated U.S. frequency-scanning radar, scanning multiple beams in elevation to combine long range with high data rate and multiple-pulse (i.e., high-probability) detection. Each stream of 9 pulses generates 9 beams, spread in frequency to give a total spread of 6 deg for the group. Successive groups elevate from 0 to 45 deg. In an alternative burn-through (antijam) mode, the entire 27 microsec are transmitted at 1 elevation angle, and pulse-compressed (with a ratio of 9:1). There is also a 9-microsec pulse. Instrumented range is 230 nm, and rated range is 220 nm, with a minimum ceiling of 100,000 ft. Vertical coverage is up to 45 deg. The transmitter is an amplatron.

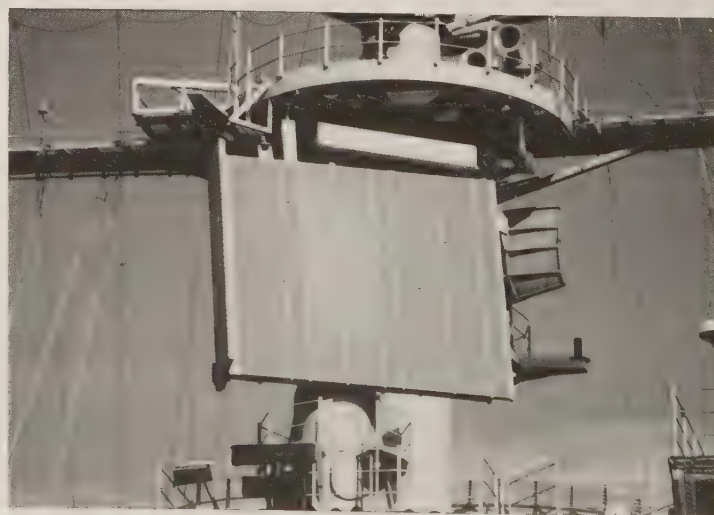
SPS-48C incorporates ADT.

SPS-48E (formerly SPS-48NTU), the current version, doubles the effective radiated power, reduces sidelobes (sidelobe level is -33 dB, compared to -23 dB for earlier versions of this radar), and increases the receiver's sensitivity. Maximum elevation angle is increased to 65 deg. Because the antenna incorporates ferrite phase-shifters, SPS-48E can combine pulse compression (i.e., frequency-swept pulses) with vertical phase scanning in frequency. The ferrites are interposed between the serpentine feed and the slotted arrays, compensating for the frequency sweep within each pulse. Pulse width is 27 microsec (compressed to 3 microsec). Input power: -48, 65.8 kVA; -48A, 72 kVA; -48C, 74 kVA; -48E, 112 kVA.

Associated with the New Threat Upgrade (NTU: SYS-2) program, SPS-48E incorporates a new cross-field amplatron trans-



SPS-40, with SPS-10 below it. (W. Donko, 1987)



SPS-48 on board the USS Enterprise, 1990. (A. Chiffolo)

mitter with twice the average output and greater reliability (it can continue to function despite some subcomponent failures, a technique called fail-soft), a digital receiver/frequency control, and a combined programmer/processor with half the equipment racks of previous versions. There is also a new single unified display group. The new transmitter permits snap-on/snap-off operation for simpler and more complete EMCON. All of these improvements have greatly increased the system's reliability. Predicted MTBF was 268 hr; but in a 146-day Sixth Fleet deployment, SPS-48E achieved an MTBF of 586 hr. The first ship to be fitted was USS *Biddle*.

Improved reliability is, in part, a result of a redesign that reduced radar part count by over 50% (280,000 to 126,000). The number of required adjustments has been reduced from 768 to 70, and the operator typically chooses among only 4 scan modes, with adjustments of 4 controls.

SPS-48E has 3 transmitter power modes (high, medium, and low power). Energy coverage modes are: equal angle coverage (EAC), maximum energy management (MEM), and adaptive energy management (AEM). In EAC mode, the highest power is concentrated at the lowest elevation angle, so that detection range is greatest at the elevation angle at which most targets are likely to appear. Cover is provided from the horizon to 45-deg elevation, and out to 220 nm (instrumented range). MEM provides high power in the lowest 4 elevation groups and medium power in the upper 4. AEM is automatically activated when SYS-2 generates a priority track gate or surveillance priority gate around a target or expected target area of particular interest. The radar adapts its power to the jamming environment and target's cross section. There are both 5-deg (in elevation) and 2-deg (chirp) modes. Both of these modes can be steered, whereas the other modes merely involve the preset elevation channels. The beam can also be scrambled to complicate countermeasures.

SPS-48D was the engineering development prototype for -48E and was tested on board USS *Mahan* in 1982-83, including operations off Lebanon.

Data refer to the AS-1686 antenna. The antenna, electronically stabilized against pitch and roll up to 20 deg, consists of 76 linear horizontal arrays. The new SPS-48E antenna has 95 linear arrays, each 18 ft long, with a total height of 18 ft.

SPS-48 is manufactured by ITT-Gilfillan.

Several IFF antennas can be used with SPS-48: AS-1065, AS-1688, AS-2188, and AS-3430. AS-1688 is intended as an integral part of the SPS-48 antenna; the others can be mounted either independently or on the antenna. Beamwidths: 9×45 deg for AS-1688, 7×48 deg for AS-2188, and 7.5×50 deg for AS-3430. These antennas are also used for other major U.S. radars.

In 1985 ITT-Gilfillan displayed a new GaAs/fiber-optic technology (then in its early stages) for a future phased- (active) array radar. In such a radar, the waveform is created, and phases are shifted and then transmitted via optical fiber into the bank of GaAs RF transmitters in the antenna. That scheme greatly reduces the usual power losses in such a radar; in a conventional radar, the phase shifters themselves cost 1.5-2 dB (and faster phase shifting consumes more power), not to mention the DC power required to run the diode phase shifters (typically tens of kW). In the fiber-optic radar, phase shifting is done at very low power. The other alternative, phase shifting by frequency scanning (as in SPS-48), is limited by microwave frequency. For widebeam steering, the antenna must use time-delay beam-forming; the beam must be many wavelengths across and very precisely made. By doing the beam-forming and beam-steering in the cabinet rather than in the antenna, the fiber-optic radar can use cut lengths of fiber and integrated optical switches to create the necessary time delays. In theory, then, an individual optical fiber would be used for each element; but wavelength multiplexing can give as many as 10 elements/fiber, so that the apparent requirement for about 6000 can be reduced to 600. The result should be less expensive high-resolution beam-forming with adaptive weighting for better beam-shaping.

SPS-48 was designed because SPS-39 had insufficient range for the Talos missile system; development began in 1959. The first production set went to sea on board the cruiser *Worden* in March 1965.

◆ SPS-49

Band: L (851-942 MHz) **Beam:** 3.3×9 deg

Peak Power: 280 kW

Pulse Width: 125 microsec, compressed (ratio 83:1); there is also a 2-microsec pulse for short ranges

PRF: 280 pps for long range, 800 or 1000 pps for short range

Gain: 29 dB **Scan Rate:** 6 or 12 rpm

Antenna Dimensions: 288×171 in (including pedestal)

Antenna Weight: 3040 lb (including pedestal)

SPS-49, manufactured by Raytheon, is the best current U.S. 2D air-search radar. It is currently replacing the SPS-37/43 series. Based on experience with the SPS-40, Westinghouse was (1988) conducting full-scale engineering development of a solid-state transmitter (SSTx) to replace the SPS-49's existing klystron (vacuum-tube) transmitter.

The radar is mechanically stabilized in line of sight and is adapted to ADT. Total below-decks weight is 13,791 lb.

Versions of SPS-49 are denoted by (V) numbers. (V)1 is the original version, e.g., on board *Perry*-class frigates. (V)2 was the version for New Threat Upgrade (NTU) modernization of cruisers. (V)3 is the Canadian version, with an embedded tracker (i.e., with ADT). (V)5 is the current ATD version, with a digital signal processor that requires its own cooling system. (V)7 is essentially the same radar without the cooling package, for ships such as *Aegis*, which provide cooling.

The (V)5 version employs digital pulse-doppler processing to reject clutter; the system has parallel coherent and incoherent processing channels, a mean-level digital CFAR processor, 5 finite-impulse-response (FIR) doppler filters, and amplitude clutter-map compensation in each channel. To reject jamming through the sidelobes, the system uses a 4-loop coherent sidelobe canceler (CSLC), and jammers' bearings are automatically detected and reported digitally. The PPI shows a jammer-direction-finder (JDF) strobe. There is a special antichaff mode, in which PRF is increased to improve doppler processing.



SPS-49 on board the USS *Fahrion*, 1984. (A. Raven)

The beam can be elevated (up-spotted) to help reject main-lobe jamming.

Peak power is increased to 360 kW (average power is 13 kW, compared to 10 kW for earlier versions described above), and the beam is $3.4 \text{ deg} \times 30 \text{ deg csc}^2$; antenna gain is 28.5 dB. Range accuracy is 0.03 nm, and bearing accuracy is 0.5 deg. Estimated MTBF is greater than 600 hr, and MTTR is less than half an hour. Total above-decks weight is 3165 lb, and below-decks weight is 14,004 lb; the power requirement is 86 kVA of 440 volt power and 10.1 kVA of 115 volt power. The internal space requirement is about 200 ft².

For details of IFF antennas, see the entry for SPS-48 above.

SPS-49 was conceived as part of the same frequency-diversity program that produced SPS-40; the prototype was tested on board the destroyer *Gyatt* between July 1964 and June 1965. Although this radar figured in many U.S. warship designs of the late 1960s, it was not bought in numbers. However, it was revived in 1970 in much modified form and then evaluated on board the missile cruiser *Dale* in 1976. SPS-49 was first bought in quantity to equip U.S. *Perry*-class missile frigates. As a measure of improvement in reliability since the mid-1960s, the original prototype showed an MTBF of about 60 hr, a tenth of the current figure.

Work is currently proceeding on an IADT (i.e., SYS-type system) for *Perry*-class frigates, to tie their air- and surface-search radar pictures together. Operational evaluation is scheduled for FY89.

Several major SPS-49 improvements are being considered, some under a Naval Research Laboratory program, SENRAD. One is an SSTx. The other may be an antenna upgrade, possibly a planar-array 3D antenna. The 2 goals would be reduced side-lobes and an agile beam. Any future agile-beam antenna would probably employ phase shifting for beam steering since the transmitter would have to employ pulse compression and would probably be frequency agile. Phase shifting might be done either at low power (before the signal passes through the amplifier) or at high power (in the antenna itself). Phase shifting at low power might be easier, but in that case the radar would have to pass multiple signals simultaneously through its rotary joint (otherwise the signals are multiplexed in the antenna, e.g., by stripping them from a serpentine waveguide that imposes phase differences). Westinghouse recently received contracts for both the SSTx and a 20-channel UHF rotary joint.

Westinghouse has been developing low-sidelobe UHF planar-array dipole antennas for some time. FASR (Fixed Array Surveillance Radar) is a $31 \times 12\frac{1}{2}$ -ft array consisting of 2 rows of vertical strip-line elements (27 per row). It was developed under contract for NRL. Another dipole array antenna was developed for the SPS-65 radar (see that entry).

As of 1989, the navy is also considering an improved SPS-49 processor, to take advantage of the new antenna. All of these projects are still in the experimental stage, but the French navy expects to replace its standard long-range 2D radar, DRBV 26, which is broadly analogous to SPS-49, with a long-range 3D

radar. That process would seem to meet the threat of high-altitude, steeply diving missiles such as AS-4/6, which may pass over the coverage of long-range 2D air-search radars.

Full-scale engineering development of the SPS-49 SSTx began under the FY88 program. The FY90 program includes development of signal-processing modifications and also of a phased-array antenna for SPS-49.

◆ SPS-53/60

Band: X **Beam:** (a) $1.6 \times 20 \text{ deg}$ (b) $1 \times 20 \text{ deg}$
Peak Power: 40 kW **Gain:** 30 dB average
Pulse Width: (i) 0.5 (ii) 0.1 microsec
PRF: (i) 750 (ii) 1500 pps **Scan Rate:** 15 rpm
Antenna Dimensions: (a) 5 ft (b) 8 ft
 AS-1652: $59 \frac{7}{8} \times 22 \frac{3}{8} \text{ in}$
 AS-2321: $59 \frac{7}{8} \times 21 \frac{1}{4} \text{ in}$
 AS-2322: $96 \frac{1}{4} \times 21 \frac{1}{4} \text{ in}$
 AS-2645: $96 \times 22 \frac{3}{8} \text{ in}$
Antenna Weight: (includes pedestal)
 AS-1652: 100 lb
 AS-2321: 87 lb
 AS-2322: 97 lb
 AS-2645: 100 lb

Sperry's high-resolution navigational radar is used by both the coast guard and the navy. The antenna is a slotted waveguide. In some ships it replaced SPS-5. Minimum range is 25 yd; maximum range is 32 nm. The current version is SPS-53M. Four antennas, all slotted waveguides, are used, two 5-foot and two 8-foot. AS-1652 (5 ft) is used with SPS-53, -53A, B, and H; AS-2321 (5 ft) with -53D, F, G, K, and M; AS-2322 (8 ft) with -53E and L; and AS-2645 (8 ft) with SPS-53J.

SPS-60 is a solid-state version of the vacuum-tube SPS-53E and uses a standardized 8-ft navy antenna. SPS-60 survives in U.S. service on board minesweepers and auxiliaries.

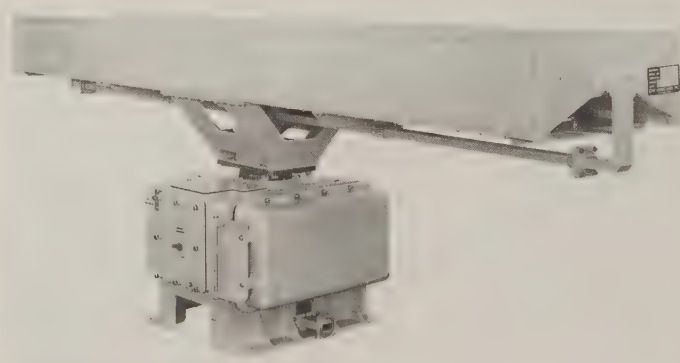
◆ SPS-55

Band: X (9.05–10.00 GHz) **Beam:** $1.5 \times 20 \text{ deg}$
Peak Power: 130 kW **Gain:** 31 dB
Pulse Width: (i) 0.12 (ii) 1.0 microsec
PRF: (i) 2250 (ii) 750 pps **Scan Rate:** 16 rpm
Antenna Dimensions: $80 \times 28 \text{ in}$ (including pedestal)
Antenna Weight: 195 lb including pedestal

SPS-55 is the X-band successor to the C-band SPS-10; the frequency was chosen to avoid interference with C-band missile trackers. The antenna consists of 2 slotted waveguides arranged back to back, the operator choosing either circular or horizontal polarization. The former helped to overcome rain clutter, as the rain drops tend to reverse the circular polarization of the waves they reflect, and the radar can reject signals of opposite polarization. More complex targets do not reverse polarization in so systematic a way; and their echoes are, therefore, not entirely rejected (although some target echo is lost). Each antenna consists of an array of 80 narrow slots skewed in angle (with alternating skew angles for squintless feed). Minimum range (short-pulse mode) is 50 yd; it is 300 yd in the long-pulse mode. Resolution: 75 and 650 ft, respectively. Reliability: 500 hr MTBF were required, 1200 hr demonstrated.



FASR antenna. (Westinghouse)



SPS-55 antenna, showing its back-to-back construction. (Cardion)

SPS-55 was developed by Raytheon but produced by Cardion; the first contract was let in June 1971. This radar was first used in quantity on board the U.S. *Spruance* class.

◆ SPS-58/62/65

Band: L (1215–1365 MHz)

Beam: 6×16 deg (12 deg in SPS-58) **Peak Power:** 12 kW

Gain: SPS-58A and -65: 23 dB, SPS-58: 26 dB

Pulse Width: 5 microsec (SPS-65: 7 microsec)

PRF: 2290 or 3050 pps (SPS-58A: 2285 or 3048 pps; SPS-65: 2315 or 3064 pps)

Scan Rate: 20 rpm (SPS-58A and -65: 15 rpm)

Antenna Dimensions: 126×76 in, with pedestal; SPS-58: 234×120 in

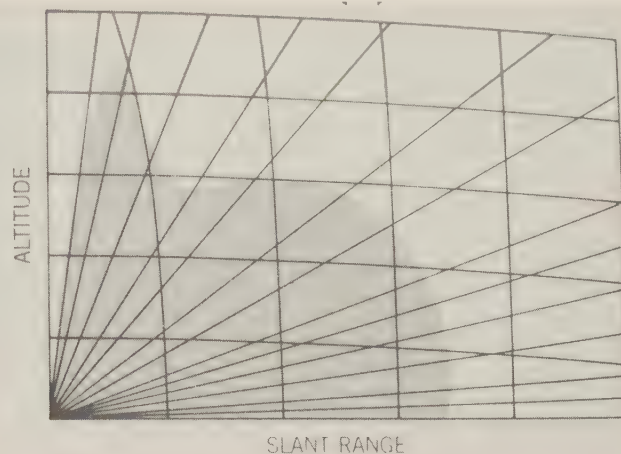
Antenna Weight: SPS-58A: 425 lb, with pedestal; SPS-58: 1200 lb; SPS-65: 439 lb. Below-decks weight: SPS-58: 2100 lb; SPS-58A: 1300 lb; SPS-65: 1594 lb

These short-range air-search radars, manufactured by Westinghouse, share the antenna of the standard SPS-10 surface-search set, the air- (actually horizon) search employing C- rather than L-band emissions. The transmitter is a 3-stage coherent klystron, for fully coherent operation (e.g., for MTI).

SPS-58 was developed at high priority after a series of studies of antiship-missile defense conducted in 1967–68. At that time Sea Sparrow was not considered effective against low-flying missiles because the associated search radar could not pick them out of the surrounding sea clutter. Sea Sparrow's CW doppler illuminator, however, could overcome clutter.

Contrary to published reports, the stimulus for the antimissile-defense program was not the sinking of the Israeli destroyer *Eilat* in October 1967. Rather, work on counters to Soviet antiship missiles began in January 1967, and the main stimulus seems to have been the need to protect shore-bombardment ships (Sea Dragon forces) off Vietnam. Presumably, the new threat consisted of shore-based missiles that could not be countered by carrier-based aircraft, the main earlier missile threat, the ASM, could be destroyed on board the bomber carrying it. A Fleet Anti-Missile Defense Executive Committee was formed in June 1967. Work continued through 1967, and undoubtedly the *Eilat* sinking encouraged this effort. It seems to have inspired special efforts to counter Komar- and Osa-class missile boats.

In 1967 all U.S. low-altitude naval search radars were simple pulse types, limited more by clutter than by the radar horizon. Even in calm weather, maximum range was typically 70% of the radar horizon, or about 14 nm for a destroyer. In rain or even moderately rough weather, clutter could preclude detection of a low-flying missile. The possible solutions were doppler, pulse doppler, pulse compression, and MTI radar; the performance of



Comparative coverage of SPS-65(V)ER (top) and SPS-65(V)1 and 2 (bottom). (Westinghouse)

the Tartar tracker (SPG-51) showed that pulse-doppler operation could succeed. In 1967 the main alternatives were modified fire-control systems (Mk 86 and the Signaal M20 series), a Westinghouse MTI radar, the Siemens pulse-doppler radar, an experimental Sanders radar called FAAR, and a power-driven version of the Sea Sparrow designator/illuminator.

The Siemens mobile pulse-doppler air-search radar (MPDR-45) was selected, for development by Westinghouse as SPS-58.

SPS-65 was first procured in FY75. In 1980 it was decided that all pre-FY75 U.S. SPS-58/58A/62 would be upgraded to SPS-65(V) capability through transmitter replacement and other field changes; all new carrier installations would be SPS-65(V)1s. SPS-58 was essentially a stand-alone system, but SPS-65 could feed directly into NTDS. It had ATD and was more reliable since the klystron of the earlier version was replaced by a solid-state driver. This radar also enjoys better ECM resistance. It employs MTI to reject clutter.

Early SPS-58s (and SPS-58Bs) used a separate antenna (AS-1067), but SPS-58A, -58C, and the subsequent SPS-62 and SPS-65 used the SPS-10 antenna, the usual feed horn of the surface-search device being replaced by a dual-feed waveguide horn. Maximum range is about 25 nm. SPS-58B and -58D have no displays but feed directly into NTDS, to trigger missile firing.

In 1979, Honeywell advertised the H-930 combat system, which incorporated an SPS-58 that automatically detected any target flying faster than an 80-kt MTI threshold. In this installation, the SPS-58 would have been mounted back to back with an SPS-55 surface-search radar. This SPS-58V radar had a 26-dB antenna (4×18 -deg beam) and an instrumented range of 125



SPS-65(V)ER antenna. (Westinghouse)

nm; scan rate was 15 rpm. Minimum range was given as 1 nm, and a 1-m² target could be detected at 66.4 nm. Azimuth accuracy was 0.5 deg, and range accuracy 1%. This version operated on any 1 of 6 selectable frequencies.

The Taiwanese Navy uses a stand-alone SPS-58, without any associated back-to-back antenna, as the missile detector for the Honeywell H930 fire-control system. This radar incorporates both MTI and ADT; the operator has only to press the firing switch. H930 Mod 1 has 3 channels, 1 Mk 35 optical system, and 2 CS/SPG-24 (similar to RCA HR-76) tracking radars. Reportedly the 2 SPG-24s are to be fitted with coaxial TV/IR trackers so that they can deal more effectively with sea-skimmers. These radars can also be used for low-level air search, to make up for the low data rate (19 rpm) of the SPS-58.

Westinghouse currently offers 3 versions of SPS-65: (V)1 for self-defense, (V)2 for fire control, and (V)ER for long (extended) range. All can be fitted with the company's solid-state L-band transmitter (SSTx), and all can be provided with a special anti-jamming frequency-agile mode (the radar automatically changes frequency based on its detection of the least-jammed frequency). (V)1 and 2 have a 25-nm instrumented range mode. The ER version has 3 range modes: 25, 50, and 100 nm.

As in the original SPS-58, these transmitters and signal processors can use the SPS-10 antenna. However, Westinghouse offers 2 alternatives. One is a dual-beam antenna for missile guidance, to detect high- or low-flying targets; this antenna requires additional signal processing. Another is a dipole-array antenna. In addition to the normal scan rates (15 rpm) for the 3 range modes, both the dual-beam and the dipole-array can be provided with an alternative high-speed mode.

(V)1 is the direct successor to the version originally developed as an acquisition radar for the Basic Point-Defense Missile System (SPS-58). (V)2 adds a fire-control interface group (FCIG) to (V)1, for ADT, manually initiated autotracking, NTDS symbology, target centroids, track history, and outputs suitable for gun and missile control. The (V)ER version, formerly SPS-58(LR), was announced in 1987. It has a higher-power solid-state transmitter and an enhanced signal processor. (V)ER can operate in short-, medium-, or long-range modes, and these modes may be timed for alternate scans. In long-range mode the radar uses a pulse-coded stretched pulse (pulse-compressed on reception); full MTI is provided out to 100 nm. The short-range mode is optimized for sea-skimmer detection within 25 nm.

SPS-65(V)1 and 2 use a 12-kW transmitter (average power 260 W); the ER version uses a 25-kW transmitter (average power 1200 W). Detection ranges on a 1-m² (Swirling case 1) target are, respectively, 23 and 61 nm. The ER version has an instrumented range of 100 nm, and it is frequency agile on a burst-to-burst basis. It employs digital MTI for clutter rejection. Elevation coverage is up to 16 deg in the (V)1 and 2 versions and up to 30 deg in the ER version. Accuracy is 1500 ft and 0.5 deg in (V)1 and 2, 608 ft and 0.5 deg in (V)ER. Resolution is 3000 ft in both cases, but azimuth (beamwidth) is 5.8 deg in the (V)1 and 2 versions and 3.5 deg in (V)ER. In all cases, the MTI improvement factor is 60 dB. The ER version employs variable PRF (300 to 625 pps), and the antenna's rotation speed is 10 or 20 rpm. Horizontal beamwidth is 3 deg.

Current MTBF for SPS-65(V)1 is 350 hr, and MTTR is less than 2 hr.

The new L-band transmitter can use existing SPS-6, -12, and -58 antennas, as well as the modified dual-frequency SPS-10 antenna used for earlier SPS-65 radars.

Data apply to a modified SPS-10B antenna. SPS-62, described officially as an "alarm radar," shared many SPS-58 components but had a modified receiver-processor and a new planar-array antenna (114 in wide, beam 5.5 × 21 deg, 12-kW pulses, 5 microsec long, PRF 2280 or 3040 pps). Development was abandoned in 1973 in favor of advanced versions of SPS-58. The relatively long pulse was probably compressed, for increased average power.

In U.S. carriers, SPS-58s with special separate antennas are being replaced by TAS Mk 23s (see below for description).

◆ SPS-64

Band: X (9345–9405 MHz) or S (3025–3075 MHz)

Beam: 4 alternative X-band slotted-waveguide antennas: (i) 1.9 × 22 deg (ii) 1.25 × 22 deg (iii) 0.9 × 22 deg (iv) 0.7 × 22 deg S-band slotted-waveguide antenna: (v) 2 × 25 deg

Peak Power: 3 alternative transmitters: (i) 20-kW fixed or tunable X-band, (ii) 50-kW X-band, (iii) 60-kW S-band

Gain: 28 dB **Pulse Width:** (a) 0.06 (b) 0.5 (c) 1.0 microsec

PRF: (a) 3600 (b) 1800 (c) 900 pps **Scan Rate:** 33 rpm

Antenna Dimensions: (i) 4 ft X-band only (ii) 6 ft (iii) 9 ft (iv) 12 ft (v) 6 ft **Antenna Weight:** (ii) 140 lb (iv) 332 lb

Raytheon's navigational radar for the army, navy, and coast guard has 3 alternative transmitters and 4 alternative antennas (as shown above). The main elements are (i) a high-powered S-band radar to detect surface targets out to 20 or 30 nm (AS-3195 antenna, RT-1241A transmitter-receiver); (ii) a high-resolution X-band navigational radar (6-, 9-, or 12-foot antenna); (iii) an interswitch unit that can connect any indicator/receiver/transmitter combination (so that the 12-ft antenna can be used for X- or S-band, for example); (iv) a RAYCAS V CIC indicator; (v) a RAYPATH indicator; (vi) an ESM interface; and (vii) a fire-control interface.

The RAYCAS V 16-in PPI is intended for use in a CIC; it is used in the (V)6 and (V)10 versions below. It can track up to 20 targets within 40 nm automatically, with direct readouts of target range/bearing and course/speed. Target true or relative vectors can be displayed on screen. Intercept course/speed are automatically calculated. Up to 20 ground-stabilized true marks (to permit on-screen marking of datum or reference points) can be displayed, plus up to 16 ground-stabilized navigational line segments (e.g., boundaries, fairways, danger zones). The indicator has automatic CFAR. As an option, programmable fairways/mapping stores up to 1500 geographic data points.

RAYPATH (12-in PPI, in the (V)11 version) automatically tracks up to 20 targets within 20 nm; automatically displays target CPA (TCPA), course/speed, and bow crossing distance; provides automatic warning when a target violates the CPA/TCPA threshold set by the operator; displays target true or relative vectors; and has true-motion and trial maneuver (to analyze proposed evasive action) modes.

RAYCAS and RAYPATH correspond to devices classified elsewhere as simple tactical data systems (e.g., CANE). Fire-control data can be transmitted to these indicators, and they in



SPS-64 on board the Coast Guard cutter *Bear*. The egg atop the bridge is a Mk 92 fire-control system for the 76-mm/62 gun forward. Also visible is the box containing an SLQ-32 ESM system, on a platform just aft of the bridge windows. The flat object atop the mast is a TACAN aircraft beacon. (U.S. Naval Institute)

turn can transmit data to a ship's fire-control system. A synchronization mode slaves X-band navigational radar transmission to the fire-control radar to avoid mutual interference.

The ESM interface (AM-6933) provides blanking pulse outlets for the X- and S-band radars, to avoid self-detection.

Versions (with Raytheon commercial designations in parentheses, where applicable):

(V)1 for the Coast Guard, with 6-ft X-band antenna (20-kW X-band transmitter) (RM 1220 6X). This is the radar in *Reliance*- and *Diver*-class cutters, and in patrol boats.

(V)2 for the Coast Guard, with 6-ft X-band antenna (two 20-kW X-band transmitter-receivers and 3 displays) (RM 1220 6X, RM 1620).

(V)3 for the Coast Guard, with two 6-ft X-band antennas (two 20-kW transmitter-receivers) (RM 1220 6X, RM 1220 6X RM16).

(V)4 for the Coast Guard, with one 6-ft X-band antenna and one 12-ft S-band antenna (20-kW X-band and 60-kW S-band) (RM 1220 6X, RM 1660 12S RM16).

(V)5 for the army, with one 6-ft X-band antenna (20-kW X-band transmitter) (TM 1620 6X).

(V)6 for the Coast Guard, with one 6-ft X-band and one 12-ft S-band antenna (50-kW X-band and 60-kW S-band transmitters and 2 displays) (RM 1250 6X, RAY CAS 1660 12S). This is the radar in *Hamilton*- and *Bear*-class cutters.

(V)7 for the Coast Guard, with one 6-ft X-band antenna (20-kW X-band transmitter) (RM 1225 6X).

(V)8 for the Coast Guard, with one 6-ft X-band antenna (20-kW X-band transmitter) (RM 1025 6X).

(V)9 for the U.S. Navy, with one 6-ft X-band antenna (20-kW X-band transmitter) (RM 1220 6X).

(V)10 for the Coast Guard, with two 6-ft X-band antennas (two 20-kW X-band transmitters and 3 displays).

(V)11 for the Coast Guard, with one 6-ft X-band antenna (20-kW X-band transmitter) (RAYPATH 1225 6X).

(V)12 for the army, a 10-kW X-band set (1210 4X).

(V)13 for the army, a 10-kW X-band set (1010 E 4X).

(V)14 for the army, a 10-kW X-band set using a radome (1010 E D).

(V)15 for the U.S. Navy, with one 6-ft X-band antenna (50-kW transmitter) (RM 1650 6X, RAY CAS V).

(V)16 for the army, with one 6-ft X-band antenna (50-kW transmitter) (RAYPATH 1650 6X).

(V)17 for the army, with one 12-ft S-band antenna (60-kW transmitter) (RAYPATH 1650 12S).

(V)18 for the U.S. Navy, with one 9-ft X-band antenna (50-kW transmitter) (RAYCAS 1650 9X NWU-51).

◆ SPS-67

This Norden solid-state radar is intended to replace SPS-10 on a one-for-one basis. SPS-67 uses the same antenna, the improvements being confined to the electronics of the transmitter, receiver, and display. The magnetron is the same as that of the SPS-55. SPS-67 is the first U.S. Navy radar built of standard electronic modules (SEMs) for commonality with future radars; Norden claims 92% SEM construction (including 46 types already approved, and only 29 new types), and 80% commonality to current navy sonars and to potential navy radars. Designed MTBF is 600 hr, and designed MTTR is 29 min, the short repair time being achieved partly by means of built-in test equipment.

The design provides for future addition of an automation module (digital MTI/ATD) to feed data into a combat system (IADT, as in SYS-1).

A new harbor-navigation mode (using a 0.1-microsec pulse) allows clutter-free detection of targets (buoys and small craft) at shorter range than is common with SPS-10. Tests have shown that buoys and small obstructions can be detected at 75 yd.

SPS-67 currently exists in 3 versions. (V)1 is the original type, essentially duplicating SPS-10 with more modern technology. (V)1 has demonstrated an MTBF of considerably better than 1000 hr and an MTTR of only 29 min. (V)2 replaces the original SPS-10 antenna with a nuclear-survivable (and much more reliable and maintainable) linear-array antenna. (V)2 should per-

form much better under conditions of extreme roll and pitch (e.g., in northern waters), and bearing accuracy is improved. (V)3, now under development for the *Arleigh Burke* class, has a 2/4-sec data rate, digital MTI (DMTI), ATD, and TWS. (V)3 is designed to provide digital data directly to fire-control, command-and-decision, and SYS systems. (V)3 shares the new (V)2 linear-array antenna.

◆ SPY-1/FARS

Band: S (3100–3500 MHz) (sustained coherent bandwidth 10 MHz, instantaneous 40 MHz) **Beam:** 1.7×1.7 deg

Peak Power: 4–6 MW (average power 58 kW) **Gain:** 42 dB

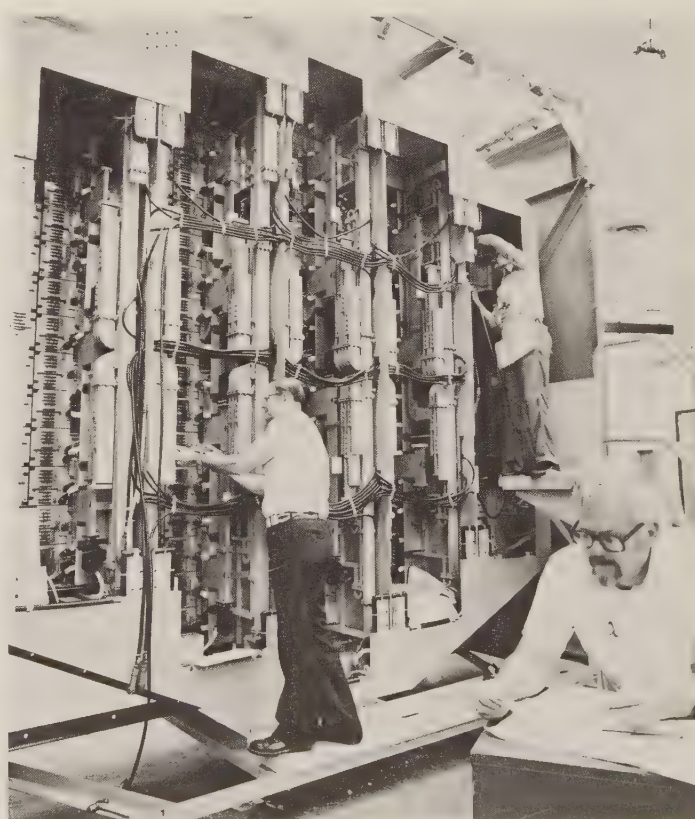
Pulse Width: 51, 25.4, 12.7, and 6.4 microsec (pulse-compression ratio 128:1) **PRF:** variable

Scan Rate: 1 horizon scan/min, 12 scans/min above horizon

Antenna Dimensions: 12 ft hexagon

Antenna Weight: 13,030 lb per face; below-decks weight 131,584 lb

SPY-1A, manufactured by RCA (as of 1988, this RCA division had been taken over by General Electric), is the S-band phased-array radar of the Aegis weapons system. Each of 4 faces is a 12×12 -ft [3.65×3.65 -m] octagon containing 140 array modules, each containing 32 radiating elements and phase shifters (a total of 4480; actually, because some modules are empty, there are 4096 transmitting and 4352 receiving elements, plus 128 auxiliary elements) driven by 8 transmitters. Array modules are paired to form receiving subarrays, and 2 such arrays are paired to form a transmitting subarray. Finally, these subarrays are grouped to form 32 transmitting and 68 receiving arrays, with separate receiving and transmitting terminals. Operation is monopulse. Total weight per face is 13,030 lb. The multiple beams are controlled by UYK-7 computers. The computer-controlled beam can update target positions several times per second, and over 200 contacts can be tracked simultaneously. The basic transmitter uses 32 crossed-field amplifiers, each with a peak power of 132 kW. Required power input is 490.9 kVA, compared to 64 kVA for the various versions of SPS-52, 65.8 kVA for SPS-48A and -48C, and 112 kVA for SPS-48E. For com-



Microwave "plumbing" in the back of an SPY-1 panel. See the illustration for SPG-62 (the associated target illuminator) for the outside of the radar. (U.S. Naval Institute)

parison, typical power inputs for 2D air-search radars are: 94.4 kVA for SPS-49; 15 for SPS-29/29E; 45 for SPS-37/37A; 21 for SPS-40; 27 for SPS-40A; 33.5 for SPS-40B,C,D; 45 for SPS-43/43A; 7 for SPS-58 and -65; 8.5 for SPS-58A.

SPY-1B (the first of which is on board CG 59) uses lighter-weight phase shifters, and the total weight per face is reduced to 7900 lb, compared to 16,970 lb for SPY-1 and 12,000 lb for SPY-1A. SPY-1D uses SPY-1B electronics but occupies only a single deckhouse, with a single radar transmitter. Each face of a SPY-1A has 4352 elementary radiators (subantennas) organized into 32 transmit subarrays and 68 receive subarrays. SPY-1B/D faces consist of 4350 radiators, plus 2 sidelobe-blanking antennas, but more compact wiring made it possible to divide the face into 2175 subarrays. Reducing each subarray from 64 to 2 elements eliminates grating lobes, making for sharper radar beams. Elements have 7- rather than 4-bit phase-shifting ferrites, for smoother electronic beam motion. The new array itself is much more nearly circular than the old one. As displayed in 1983, SPY-1B was expected to have 15-dB lower sidelobes and a better signal processor. Its transmitter tube was redesigned for a double duty cycle (with the same peak power), so SPY-1B could transmit longer pulses or more energy at higher elevation angles to counter diving missiles (such as AS-4/6) and jamming. The reduced sidelobes should reduce the effects of standoff jamming. VLSI electronics saves considerable weight and reduces the number of electronic cabinets from 11 to 5 (and weight from 14,700 to 10,800 lb). Better software should also improve ECM resistance against threats such as self-screening jammers and sophisticated repeaters.

SPY-1B introduces a new signal processor, smaller and lighter than its predecessors, but with improved performance and reliability; it is also less expensive, thanks to increased electronic integration. The new signal processor uses a channelized (parallel) architecture. Signals are received and processed in 4 separate channels: the main antenna reference (sum channel), azimuth and elevation difference channels, and a sidelobe-blanking antenna channel. Each channel is further divided into 4 parallel subchannels. All signals are digitized and processed for MTI, pulse compression, monopulse angle computation, main/sidelobe indication, missile processing, burn-through (ECCM) processing, and ECM analysis. This type of processing requires the use of VLSI electronics (the total number of separate digital modules falls from 3806 in SPY-1A to 1606 in -1B or -1D). A total of 11 microcomputers (16-bit Mil-Std-1750 type) are used.

The new SPY-1B transmitter consists of a TWT feeding 3 sets of paired crossed-field amplifiers, which in turn feed 2 sets, each of 16 crossed-field amplifiers, multiplexed to feed each pair of antennas (ultimately there is only 1 beam at a time). In SPY-1D, the 32 final crossed-field amplifiers are multiplexed between all 4 antenna faces.

SPY-1B introduces a direct missile up-link through the radar antenna, in place of the separate transmitters and antennas of the earlier -1A. SPY-1D will be the first version using the UYK-43 computer, which replaces the UYK-7 of the earlier versions. It also introduces the new standard display, UYQ-21, replacing the UYA-4 of the earlier SPY-1A. Late-production SPY-1Bs will also have UYK-43s and UYQ-21s.

GE is currently planning a post-processor upgrade for SPY-1B and -1D, in which a single module replaces 11 current modules and triples net performance. The upgrade should greatly reduce radar dwell time, hence allow the radar to track faster-moving targets. It employs an RCA control processor (RCP IIC), a Mil-Std-1750A computer using a special GE chip (CPU-SC-1750).

DDG 82 and later ships will be equipped with SPY-1E, which is intended for greater effectiveness against sea-skimmers.

The effect of electronic steering in both azimuth and elevation is to produce a very narrow pencil beam that can be steered randomly across the entire hemisphere. The radar can, therefore, search steadily, taking time out to track targets of interest by going back to dwell on the area around their last appearance.

SPY-1 reportedly scans a hemisphere of 175-nm radius while

using a single beam to search the horizon out to 45 nm for sea-skimmers.

Development began in 1965, and the system was first tested at sea in 1974. SPY-1A is the current production version, and SPY-1B is improved and simplified for later-production Aegis cruisers (from *Princeton*, CG 59, onward). SPY-1C was a proposed version for aircraft carriers. SPY-1D is the lighter-weight version for Aegis destroyers (*Arleigh Burke*, DDG 51, class).

The associated IFF interrogator is also electronically scanned. It is the Lockheed AIMS (AS-3134/UPX), which consists of 64 elements in a 12.5-ft ring (16 in high). The interrogator can operate in continuous, sector-scan, or jump-scan modes, shifting from beam to beam in 50 microsec. Beamwidth is 7×44 deg in any one of 1024 directions (so that a signal can be localized much more accurately than the beamwidth alone might indicate). The associated system is UPX-24(V), a central IFF (by Litton) that can integrate the outputs of as many as 4 unrelated radars.

FARS (Frigate Array Radar System) is an RCA proposal for an S-band system based on SPY-1, but with arrays only a quarter as large and a 2- rather than 4-channel signal processor. The transmitter will be driven by a TWT instead of the crossed-field amplifier of SPY-1, since less power is required. FARS was originally proposed for the projected German 4500-ton missile destroyer (which has presumably become Type 123); the company (now a division of GE) claims that FARS can fit ships as small as 3100 tons. FARS has also been proposed for the various NATO AAW programs. This system is compatible with both vertically launched Sea Sparrow and SM-2, and in 1987 RCA suggested that a mix of the 2 (4 Sea Sparrows per cell) was ideal for the Baltic. The SM-2s would keep most intruders out, and the Sea Sparrows were numerous enough to deal with leakers and with pop-up attackers. GE describes FARS's range as about 54% of SPY-1 (literally, the same number of units of range, but km rather than nm).

See also the Aegis system and the SM-2 missile entries below.

◆ UPS-3

Band: S **Beam:** 8×17 deg **Peak Power:** 230 W

Gain: 22 dB **Scan Rate:** 60 or 90 deg/sec

Antenna Weight: 56 lb (plus 45.2 lb pedestal and 25 lb quadrupod)

This lightweight radar, by Lear Astronics, was developed to alert Stinger operators assigned to provide forward-area air-defense for the U.S. Army's Light Divisions. UPS-3 is included here because it has been supplied to the navy to support Stinger missile operators on board ships. UPS-3 is designated TDAR (Tactical Defense Alert Radar) and can be set up by 2 people in less than 10 min. Maximum range is 20 km, and maximum target altitude 10,000 ft. Solid-state electronics makes for very high reliability (MTBF is 2180 hr). The antenna is a slotted waveguide. The LED display identifies a target as either a fixed or rotary wing aircraft, presumably on the basis of a moving target indicator (MTI).

This radar was based on the Israeli EL/M-2106 point-defense alert radar.

◆ Advanced Surveillance Radar: B-1B Radar

Under the FY89 program, work began on a feasibility study to test the B-1B X-band radar (Westinghouse APQ-164) at sea. This radar uses the TWT transmitter of the APG-68 radar of the F-16 plus a new processor and a new phased-array antenna, developed under the U.S. Air Force EAR (electronically agile radar) program. APQ-164 has a synthetic-aperture ground-mapping mode. The antenna is a 2D phased array, 559×1118 mm, controlled by 1526 phase shifters. In the B-1B, the antenna can be locked into 1 of 3 positions, the FOV being about 105 deg wide when pointed to either side, or 120 deg wide when pointed dead ahead. It scans ± 60 deg in elevation.

Presumably the B-1B radar is attractive mainly as an example of a new phased-array system. It is also relatively stealthy. As used by the bomber, it stores successive terrain maps in its computer, pausing between updates (which are typically made

at 3- or 4-sec intervals) rather than continuously scanning the ground. The memory suffices for terrain-following.

In the B-1B, the radar consists of 2 separate units with a single antenna, 1 unit on standby. It was first tested in July 1984. The APG-68 is a development of the earlier APG-66 (see W-160, below) with a programmable signal processor, a dual-mode transmitter, and a single-unit all-digital processor, all instructions being stored in a 512 kword EEPROM memory. It has 22 radar modes, presumably including Doppler beam-sharpened ground mapping (for a claimed eightfold improvement in ground mapping resolution). As an indication of computer power, TWS capacity is 10 targets.

Westinghouse has proposed a derivative of the B-1 radar for the 2-face phased array of its NAAWS radar.

◆ FAST, FLEXAR, MBAR

None of these advanced radars has been adopted. For details, see the previous edition.

◆ Furuno Radars

The U.S. Navy now uses Japanese commercial (Furuno) navigational radars, as in the past it typically used Pathfinder 1500s. Furuno radars are now very common in commercial service (e.g., on board fishing boats). The great advantage of using standard commercial radars on board combatant ships is that ESM surveillance systems cannot distinguish ships navigating with such radars from noncombatants. It seems likely that the Furuno was the Japanese radar planned for the abortive SWCM, the special warfare craft, medium.

U.S. aircraft carriers use the Furuno 904. Some Coast Guard cutters have Furuno 1510s. These radars are on board at least the submarine *Sunfish* (SSN 649), the destroyer *Hewitt*, the submarine tender *Emory S. Land*, and the tanker *Monongahela*. Some of the smaller Furunos are used on board coastal (special warfare) craft, such as 65-ft patrol boats and 36-ft Sea Foxes. These standard commercial sets have not been assigned AN/SPS designations.

Radar characteristics are listed here because, although the radars are of Japanese origin, their main military user is the U.S. Navy.

Model:	8050D	904
Band:	X	X
Beam:	(i) 1.8×25 deg (ii) 1.23×25 deg (iii) 0.95×20 deg	2.4×25 deg
Peak Power:	5 kW	3 kW
Pulse Width:	(a) 0.08/0.3 microsec (b) 0.3/0.6 microsec (c) 0.6/1.2 microsec (d) 1.2 microsec	(a) 0.08 microsec (b) 0.5 microsec
PRF:	(a) 2100 pps (b) 2100/1200 pps (c) 1200/600 pps (d) 600 or 500 pps	(a) 2500 pps (b) 840 pps
Scan Rate:	24 rpm	24 rpm
Antenna Width:	(i) 4 ft (ii) 6.5 ft (iii) 8 ft	3 ft 5 in

In this list, 8050D is taken as typical of small-ship Furuno radars. There are 3 alternative slotted-waveguide antennas, denoted (i) through (iii). Some models have higher-powered (10- and 25-kW) transmitters. The 1500 series matches 8050 series characteristics.

These radars use raster-scan (TV-like) displays rather than the previous standard PPIs. They are digitized, with sufficient memory to store the radar picture and display it in flicker-free form. Echoes are sufficiently persistent to show target tracks, and the radar controls are typically provided in touch-pad form. Display options in the 1510 include an off-centered display, a zoom display (the area of interest can be doubled without changing radar range [i.e., PRF]), and echo trail (as much as 1 min of target history can be displayed). Echoes are sorted into 8 brightness categories; the manufacturer claims that this feature prevents

targets from fading in and out, as in radars with a single displayed brightness level. Signal processing includes echo stretching and echo averaging, plus a radar interference rejector.

The 8000 series has a 12-in diagonal CRT, equivalent to a 180-mm (7.1-in diameter) PPI. The 904 has a 10-in diagonal 3-color CRT. The 1500 series has a 15-in diagonal CRT, equivalent to a 10-in diameter PPI.

◆ Pathfinder 1500

This Raytheon commercial radar was very widely installed on board U.S. warships during and after the Vietnam War, supplementing standard naval surface-search sets for navigational purposes. At the time Pathfinder was also an extremely popular civilian radar, and its use may have been intended to confuse some hostile ESM operators.

Typical characteristics (1500B): X-band, 7 kW, pulse width 0.14 microsec, PRF 750 or 1500 pps, 48-in slotted-waveguide, 2×20 -deg beam.

Raytheon also produced a radome-enclosed 1900, which was installed on board many lesser craft. Typical characteristics: X-band, peak power 5 kW, pulse width 0.16 microsec, PRF 2000 pps, scan rate 20 rpm, reflector 33 in wide, beam 3×27 deg.

◆ Raytheon R20/R40/R70/R80/ST Series Navigational Radars/SPS-69/Radar B

Band: X (9380–9440 MHz) **Beam:** 4×25 deg
Peak Power: 4 kW
Pulse Width: (i) 0.08 (ii) 0.25 (iii) 0.5 microsec
PRF: (i) 2250 (ii) 1500 (iii) 750
Antenna Dimensions: 24 in **Scan Rate:** 24 rpm
Antenna Weight: 20.9 lb

Data above apply to R40X. Mode (i) is used for 0.125-, 0.25-, 0.5-, 0.75-, and 1.5-nm range scales; (ii) for 3- and 6-nm; (iii) for 12-, 24-, and 32-nm (12-, 24-, and 48-nm in R41X). R41X's beam is 2.2×30 deg. R40X uses a radome-enclosed antenna; R41X is an open array (slotted waveguide). R20X and R21X have the same characteristics but use smaller displays (7 in rather than 10 in on the diagonal, but with the same display resolution). They have shorter maximum range (24 nm for R20X, 32 nm for R21X). Data for the larger radars of the series (R70, R80, and Pathfinder ST series) are given below.

These radars are being purchased by the navy and coast guard, largely under the navy's Radar B program (Radar A is the full surface-search set, such as SPS-55 or -67). In mid-1990 the U.S. Coast Guard awarded Raytheon a 3-yr contract for 758 R41X radars, to replace existing SPS-66s and -66As (Pathfinder 3100s). This program was originally designated SPS-XX. It is now SPS-69.

The navy's B-series radar is a navigational set with true-bearing capability. It is intended as the primary radar for smaller units such as tugs (ATS), salvage ships (ARS), and minesweepers (MSO), and as a secondary radar for larger combatants (carriers, cruisers, destroyers, frigates). As of the spring of 1990, the only authorized class B1 radar was SPS-64(V)9, replacing Pathfinders, LN-66, and RAYCAS radars. SPS-64(V)15 has not been approved, and sets installed will be replaced by (V)9 as soon as SPA-25G consoles with collision-avoidance capability are installed. However, the Pathfinder ST display is being married to existing SPS-64s (see below).

Category B2 is a low-power relative-bearing radar for coastal units such as LCUs, YTBs, and YOGs. Unlike B1, it has not been subject to centralized purchase. Instead, this type of radar is bought independently by type commanders. There were 2 attempts to formalize the process with an RFP. About 1982–83 a source selection was abandoned when Furuno protested. Late in 1988 the Raytheon R70A was very nearly chosen, but the navy decided instead to decentralize the B2 program. Most such radars are now Raytheon R40 (with a 24.4-in radome antenna) or R41 (with an open 46.1-in slotted-waveguide antenna). The current versions, R40X and R41X, were announced in March 1990. Both share the same transmitter and receiver. The raster-scan display (610×496 pixels) is 10 in along its diagonal and

shows data in 8 levels of brightness. Range resolution is up to 30 m [32.8 yd], and bearing accuracy is within 1 deg. The presentation can be off-centered by up to 66% of radius (except in maximum range scale). There is also a zoom mode: any area of the screen can be enlarged to fill the screen. A unique "sleep mode," in which the radar switches on and off for a periodic check on its surroundings, would seem to be particularly useful for submarine applications (it is intended for sailboats, which have limited power resources).

R41 is typically chosen for harbor craft and small boats, but it (as well as the smaller R20 series) is also used on board submarines as a backup to their BPS-series radars. On a submarine, a commercial navigational radar is also valued because it provides no military-style electronic emissions.

About 1000 R70As (basically updated SPS-66) are in service as small-boat radars in the navy and the coast guard. The R70 series has a common 12-in raster-scan display (525 × 640 pixels, 16 video levels), with different transmitters and antennas:

	Power	Radome	Beam
R70A	4 kW	3 ft	2.8 × 25 deg
R71	4 kW	3.5 ft	2.4 × 30 deg
R72	10 kW	3.5 ft	2.4 × 30 deg
R73	10 kW	4 ft	1.9 × 25 deg
		6 ft	1.2 × 25 deg
R74	10 kW	8 ft	2.6 × 30 deg
		10 ft	2.4 × 30 deg

Maximum range is 48 nm for 4 kW, 72 nm for 10 kW. All but R74 (S-band) are X-band radars. Beamwidths are given above. As in the R20 and R40 series, pulse width and PRF vary with range scale. There are normal and long-pulse operating modes:

For the 4 kW X-band transmitter (R70A):

Pulse Width	PRF	Range Scale
0.08 microsec	3072 pps	0.25–1.5 nm
0.25 microsec	1500 pps	3–6 nm
0.7 microsec	750/500 pps	12–24/48 nm
0.25 microsec	768 pps	1.5 nm (long pulse)
0.5 microsec	512 pps	3–6 nm (long pulse)

For R71, PRFs corresponding to these pulse widths and ranges are, respectively, 2000, 1500, 750, 500, 1500, and 750. These figures also apply to the 10-kW R72.

For the 10 kW radars (R73 and R74):

Pulse Width	PRF	Range Scale
0.08 microsec	2000 pps	0.25–1.5 nm
0.4 microsec	1500 pps	3–6 nm (1.5 nm long pulse)
0.8 microsec	750 pps	12–24 nm (3–6 nm long pulse)
1.2 microsec	500 pps	48–72 nm

Range resolution is better than 30 m [99 ft], and bearing accuracy is better than 1 deg.

The next step up, R81/R82/R84, has a maximum range of 96 nm. A few of these radars are in naval service, for workboats, ocean-going tugs, and patrol boats. R81 is a 10-kW X-band radar, R82 a 25-kW X-band radar, and R84 a 10-kW S-band radar. Each has 4 or 5 pulse lengths plus 3 long-pulse modes. Antennas: R81, 4 ft or 6 ft (1.9 or 1.2 × 25 deg); R82, 6 ft or 9 ft (1.2 or 0.8 × 25 deg); R84, 8 ft or 10 ft (2.6 or 2.4 × 30 deg). The display is a 928-line raster-scan CRT (14 in diagonal, with 16 video levels).

Pulse modes for R81:

Pulse Width	PRF	Range Scale
0.08 microsec	2000 pps	0.25–1.5 nm
0.4 microsec	1500 pps	3–6 nm (1.5 nm long pulse)
0.8 microsec	750 pps	12–24 nm (3–6 nm long pulse)
1.2 microsec	500 pps	48–96 nm (12–24 nm long pulse)

Pulse modes for R82:

Pulse Width	PRF	Range Scale
0.08 microsec	2000 pps	0.25–1.5 nm
0.25 microsec	2000 pps	3 nm (1.5 nm long pulse)
0.75 microsec	1000 pps	6–12 nm (3 nm long pulse)
1.0 microsec	750 pps	24–48 nm (6–12 nm long pulse)

Pulse modes for R84:

Pulse Width	PRF	Range Scale
0.08 microsec	3104 pps	0.25–1.5 nm
0.4 microsec	1552 pps	3–6 nm (1.5 nm long pulse)
0.8 microsec	776 pps	12–24 nm (3–6 nm long pulse)
1.2 microsec	517 pps	48–96 nm (12–24 nm long pulse)

The most sophisticated radar in the series is Pathfinder ST. This radar is currently being evaluated on board the coast guard cutter *Reliant*. Pathfinder ST is a series of S- and X-band ARPA radars with 25- and 34-cm ARPA PPIs capable of tracking 20 targets automatically. Targets are manually acquired using a trackball or automatically acquired using true or relative acquisition zones. Target true wakes are used to indicate target speed and direction. The S-band version can be fitted with a 30-kW below-deck or a 10-kW above-deck transmitter, and with a 12-ft antenna. The X-band version uses a 25-kW transmitter and a 7- or 9-ft antenna. Other characteristics:

	S-band	X-band
Antenna:	12 ft	9 ft
Beam:	1.9 × 30 deg	1.0 × 25 deg
Gain:	28 dB	28.5 dB
Scan Rate:	(all) 22/26 rpm (50/60-Hz power)	
Pulse Widths:	(i) 0.75 (ii) 1.0	(i) 0.08 (ii) 0.25 microsec
PRFs:	(i) 1000 (ii) 750	(i) 3000 (ii) 2000
Antenna Weight:	373 lb	144 lb
(aloft transmitter)	386 lb	158 lb
		148 lb
		161 lb

All use raster-scan displays (1024 × 768 pixels). Range scales: S-band: 6, 12, 24, 48, 96 nm; X-band: $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, $1\frac{1}{2}$, 3 nm. Minimum range is 27 yd in all cases, and range resolution is 0.3% or 4 yd, whichever is greater. Bearing accuracy is 1 deg, and bearing resolution is 0.3 deg.

The ST digital ARPA display is being married to SPS-64(V)10 radars on board several Atlantic carriers. At present the *America*, *Eisenhower*, and *Kitty Hawk* all have Pathfinder ST displays (M25 in the *Eisenhower*, M34 in the others).

◆ Danish Coastal Radar

ISC Cardion developed this unattended-site gap-filler radar for Denmark under a 1980 NATO contract. It searches for low-fliers and surface targets; its beam can be tilted by remote control. It has an 8 × 16-ft double-curvature reflector with an omnidirectional antenna for sidelobe suppression in the associated IFF. The transmitter is a TWT, and the waveform is coded for pulse compression. The transmitter (less than 100-kW peak power, 1% duty cycle) can operate at a fixed frequency, or in burst or frequency-agile modes; a different mode can be selected for any of 4 quadrant sectors. Processing includes digital MTI, and ADT can be added, and the radar can distinguish air from surface targets. As of 1988, 6 were in service and 2 more were ordered.

◆ Falcon

Falcon is ITT-Gilfillan's C-band pulse-compression (2 alternative compression ratios) coastal-surveillance radar. Development began in 1981, and by 1988 nearly 50 copies were on order (or had been delivered) for 5 countries. This radar was designed specifically for coast defense, the main desiderata being clutter rejection (against both rain and the sea surface) and reliability. High frequency and relatively short pulses make for high resolution so that the volume around the radar can be split into small resolution cells, to be processed individually. The man-



Cardion coastal radar. (ISC Cardion)

Manufacturer claims that relatively inexpensive solid-state electronics makes such processing economical. Dual feed horns (one 4 deg higher than the other) produce high and low beams simultaneously, for air and surface coverage. The high beam improves detection at short ranges and high elevation, where the



Falcon coastal radar. (ITT)

target would otherwise be in a low-gain part of the beam. Polarization can be chosen (horizontal or circular) to limit rain clutter, and doppler processing (biased toward low-velocity echoes) separates moving targets from background clutter. Targets are detected and tracked automatically out to 100 km (an optional extension to 160 km is available), and from sea level to 10,000 ft.

Falcon is frequency-agile over a 500-MHz band (48 channels). When doppler processing is being used, the radar hops in 4-pulse bursts. Radar characteristics: beam $1.25 \times \csc^2$ to 25 deg; peak power 60 kW (average 1.5 kW); instrumented range 100 or 160 km (corresponding to PRFs of 1500 and 9375 pps, respectively). Accuracy (resolution) is 20 (85) m, 0.2 (2.4) deg. Scan rate is 6 or 12 rpm. The system can maintain 100 target tracks simultaneously.

◆ UWB (Impulse) Radar

There was speculation that a new type of radar, UWB (ultrawide band), could be used to defeat stealth measures, following a June 1989 Los Alamos report prepared for NOSC. The premise of UWB is that, although an airplane or a missile may be stealthy over a limited band of radar wavelengths, any stealth scheme will break down if illuminated over a sufficiently wide bandwidth. Instantaneous radar bandwidth is inversely proportional to the width (duration) of the radar pulse, so a UWB radar is inherently a very short pulse radar, typical pulse widths being measured in picosec (thousandths of a nanosec, i.e., millionths of a microsec). Because its power is spread over so wide a frequency range, a UWB radar must produce a very high peak power, typically in the GW (thousands of MW) range.

Stealth shaping techniques, which are apparently inseparable from current stealth programs, defeat radars by diffusing their echoes. The echoing areas on the airplane or missile are several cm across, and the average shape suffices to limit direct reflection. A UWB would overcome this technique in 2 ways. At one end of its spectrum, its signals would have such short wavelengths that they would hit the inevitable small irregularities in the surface of the stealthy object, and some energy would be reflected. At the other end, they would be so large that their signals would be averaged over very large areas of the radar target, and they, too, would be reflected. The latter is an extension of the argument, made by stealth critics, that longer-wavelength radars will easily defeat stealth shaping and current radar-absorbing materials.

The UWB signal can, in theory, exploit any resonance or irregularity or edge in the target and, thus, may be able to return a large signal even from a carefully designed stealth aircraft or missile. Much depends, however, on how much energy is available in the usable radar band, and on how well the echo can be exploited. It might be argued that any particular stealthy object should be vulnerable to detection at particular unconventional radar frequencies and, therefore, that UWB is far too exotic to be worthwhile (at least for this purpose); however, it would be difficult to predict the precise characteristics of an enemy stealth airplane or missile.

UWB should have improved imaging capability because of its very short inherent range resolution (a result of its short pulses). The same characteristic should also make for reduced multipath through range-gating. Commercial UWB, which has been available for some time, has proven successful in penetrating foliage, earth, and even walls.

The principal technological issues in high-powered UWB (which does not yet exist) are probably the ability to switch very high power in a very short time (most likely using a short laser pulse) and the ability to exploit the resulting broad-band radar echoes, e.g., for imaging.

FIRE-CONTROL RADARS

◆ Mk 13

Band: X Beam: 0.9×3.5 deg Peak Power: 50 kW
Pulse Width: 0.3 microsec PRF: 1800 pps
Antenna Dimensions: 8×2 ft



The battleship *Iowa* shows her Mk 13 radar, in the long nacelle above her range-finder, 1986. The mast above carries SPS-49 and SPS-67 (for surface search). (Author)

The fire-control radar of the *Iowa*-class battleships is mounted atop their Mk 38 main-battery directors. Mk 13 is also installed on board the 2 reserve cruisers armed with 8-in guns. The antenna rocks back and forth inside its radome to scan in bearing over a 5.75-deg sector to either side (to achieve the 2D equivalent of conical scanning). Tracking range is 50,000 yd; range accuracy is 15 yd $\pm$ 0.1% of range. This radar (or Mk 8 Mod 3, its equivalent) also equips the Chilean cruiser *O'Higgins* (on her 2 Mk 34 main-battery directors).

◆ Mk 25

Band: X **Beam:** 1.6 deg **Pulse Width:** 0.25 microsec
Peak Power: 250 kW **Gain:** 39 dB **PRF:** 1320 pps
Antenna Dimensions: diameter 60 in **Antenna Weight:** 625 lb

Mk 25, the dish antenna radar associated with the World War II Mk 37 GFCS, employs spiral scanning (over a 12-deg cone) to acquire the target and conical scanning (over a 2.6-deg cone) to remain on target. Accuracy in bearing is 0.1 deg. For spotting, it has a 10-deg FOV. Angular resolution is 1.3 deg, and range accuracy is 15 yd $\pm$ 0.1% of range. Maximum tracking range is 100,000 yd. The antenna, but not the feed system, was also used in the later SPG-53.

Tests were completed in 1947, and over 400 of these radars were built. The only examples in current U.S. service are on board the 4 *Iowa*-class battleships, but Mk 25 equips many former U.S. destroyers in foreign service.

◆ Mk 26

Band: S (about 3000 MHz) **Beam:** 10 deg **Peak Power:** 50 kW
Gain: 26 dB **Pulse Width:** 0.5 microsec **PRF:** 540–660 pps
Antenna Dimensions: 36 in (truncated paraboloid)

Mk 26 is the range-only radar of the Mk 52 FCS, which survives on board some former U.S. destroyer escorts. Range on a bomber at 10,000 ft is 15,000 yd; range on a fighter at 1000 ft, 700–12,000 yd; range on a ship, 400–25,000 yd. Maximum tracking range is 27,500 yd. Range resolution is 200 yd (accuracy is 100 yd).



Mk 25 radar atop a Mk 37 5-in director on board the battleship *Wisconsin*, 1988. SRBOC chaff-launching mortars are visible to the right, on deck. (S. Terzibaschitsch)

◆ Mk 28

Band: X **Beam:** 6.5 deg **Peak Power:** 30 kW **Gain:** 27 dB
Pulse Width: 0.5 microsec **PRF:** 1800 pps
Scan: conical (2.3 deg) at 30 Hz
Antenna Dimensions: 45 in diameter

This U.S. World War II radar survives only on board the Chilean cruiser *O'Higgins* in her Mk 33 and Mk 57 (light anti-aircraft) directors. Mk 28 was a lighter alternative to the contemporary 5-in fire-control radar, Mk 12/22 (which was replaced by Mk 25). A fighter could be detected at 15,000 yd.

◆ SPG-34/Mk 34/SPG-50

Band: X (8740–9168 MHz) **Beam:** 2.5 deg **Peak Power:** 50 kW
Gain: 36 dB **Pulse Width:** 0.3 microsec **PRF:** 1800 $\pm$ 180 pps
Scan: conical (3.9 deg total coverage at 29 Hz)
Antenna Dimensions: 40 in diameter

SPG-34 is the radar of the World War II Mk 57 and Mk 63 FCSs; it appeared in 1953 as a revised version of the wartime Mk 34, with a larger antenna (40 vs. 30 in) and better facilities for target designation and acquisition. Targets are acquired using a 12.6-deg spiral scan (at 2 Hz). Tracking is by conical scan. Range resolution is 200 yd (accuracy is 15 yd $\pm$ 0.1% of range). Maximum displayed range is 60 kyd. Maximum range rate is 843 yd/sec (approximately 1500 kt). SPG-34 is similar to Mk 34 Mod 17 except for some repackaging below decks.

SPG-50 superseded SPG-34 in Mk 63s installed after about 1956. It has very similar characteristics, operating at a slightly higher frequency (8600–9600 MHz) and with a slightly shorter pulse (0.25 microsec) at a slightly higher pulse rate (2000 $\pm$ 200 pps). Total conical scan coverage for tracking is 4.1 deg, and targets are acquired by spiral scan over 12.6 deg. In contrast to SPG-34, SPG-50 uses a tunable magnetron as its power tube. Unlike SPG-34, it has automatic range designation and range

tracking; range and range rate are generated in the radar and sent directly to the gun sight. Typically, the ranging mechanism is controlled by a ship's target-designation system, but bearing and elevation data are inserted manually either by the director or the radar operator. Maximum range is 34,500 yd; minimum is 300 yd. Maximum range rates are -800 or $+350$ kt. SPG-50 has many components in common with SPG-53.

◆ SPG-35

Band: X (8.5–9.6 GHz) **Beam:** 2 deg **Peak Power:** 50 kW
Gain: 37.5 dB **Pulse Width:** 0.1–0.15 microsec **PRF:** 3000 pps
Scan: conical (3 deg) **Antenna Dimensions:** 48 in diameter

SPG-35 is the radar of the Mk 56 FCS. Accuracy is $20 \text{ yd} \pm 2.5\%$ of range. Resolution is 35 yd and 1.5 deg. Limits: tracking 100 deg/sec in train, 35 deg/sec in elevation. Maximum tracking range is 30,000 yd. In acquisition mode, the radar spiral scans over a 12-deg cone.

◆ SPG-51

Band: C (track) X (illuminate)
Beam: 1.6 deg (track)
 0.9 deg (illuminate) with 80 deg ancillary
Peak Power: 81 kW (track), 5 kW (illuminate)
Gain: 39.5 dB (track), 45 dB (illuminate)
Pulse Width: 2.1–3.2 microsec (track)
PRF: 4.1 kHz (surface mode), 9.5–16.7 kHz (air mode)
Antenna Dimensions: 92 in diameter

Data apply to SPG-51D (AS-2234 antenna). The radar consists of a C-band pulse-doppler monopulse tracker (with a 4-horn feed) and an X-band illuminator (CWI), both sharing a common reflector structure but using individual feeds and reflector surfaces (a horizontally polarized X-band wire-grid reflector embedded in dielectric material on its face). SPG-51 differs from other high-PRF radars in using multiple medium PRFs to combine conventional range tracking with doppler clutter rejection. The output of the monopulse cluster is fed into a rotating comparator, so in effect the radar tracks by conical scan on receive only (COSRO).

The ancillary antenna mentioned above provides the rear reference signal to the missile; it has a 12.5-dB gain.

The original SPG-51 had only a 2-kW CWI transmitter, which was marginal for the improved (17.5 nm) Tartar.

SPG-51A introduced a 5-kW CWI transmitter.

SPG-51B (1963) added a velocity tracking capability (speed gate) enabling the radar to track through clutter and at higher noise levels. The speed gate is an electronically tunable narrow-band filter (300 Hz rather than the original 7.1 kHz), which the

system uses to reject all signals outside a very narrow doppler pass band. Tracking range increases to 200,000 yd. SPG-51Bs in U.S. service were modified to SPG-51C standard. This radar survives on board the missile destroyer *Du Chayla* and on board the Japanese *Amatsukaze*.

SPG-51C introduced automatic acquisition and tracking, improved ECCM features, clutter rejection, and multiple target resolution as well as greater reliability. The data converter, which correlates all target information to make the logical decisions to acquire targets and maintain automatic 3D track, is solid-state rather than vacuum tube (as in SPG-51B) and has a new self-test feature. Maintenance adjustments are reduced from 83 to 6. The radar also has 2 new modes (reflecting contemporary concern with Soviet missile-attack boats and their weapons): surface acquisition and track, and horizon search. In surface-acquisition-and-track mode, noncoherent video is displayed on a B-scope to permit acquisition of a target too slow to be detected automatically by its doppler-shifted echo. The antenna is held fixed at 0-deg elevation, and PRF held at a value giving unambiguous range track out to the radar horizon. Horizon search mode is protection against low fliers (such as anti-ship missiles): the director scans the full 360 deg at a fixed elevation angle, with scan speed and range gate set to detect, acquire, and engage targets at Mach 1.2 or less without the delays inherent in the usual designation-and-acquisition process. The radar console has a second scope with a B-scan for use in the surface and horizon-search modes. The data converter of this version was designed for relatively simple conversion to all-digital fire-control operation.

Recent SPG-51C modifications are

Phase IIA: improved ECCM, solid-state, switchable, transmit-receive tube; improved maintainability

Phase IIB: improved CWI power supply; solid-state, stable master oscillator; replacement of klystron with permanent magnet-type tube

Phase IIC: improved DC gyros to eliminate 30-min warmup; replacement of amplidyne with solid-state drivers.

This version is standard in the *Adams* and *Brooke* classes, replacing the earlier SPG-51B. Peak power is 30 kW, and antenna (AS-2649) diameter is 91 in. This is the version on board the Spanish *Baleares* class, and it currently also serves in the Australian, French, German, Italian, Japanese, and Dutch navies.

SPG-51D, the latest operational version, was introduced with the Tartar-D (digital Tartar) FCS (*Virginia*, *California*, and *Kidd* classes). It introduced a new off-mount, frequency-agile, pulse tracking transmitter (which could change frequency up to 4 times/sec) with more than a fivefold increase in power over its predecessors; a new free-rotating, dual-frequency rotary joint; and a new antenna system with a fivefold increase in gain. SPG-51D employs a new pulse-shaping technique that makes for a cleaner spectrum and thus for less interference with other radars. This version is on board the Italian *Animoso*-class missile destroyers.

SPG-51 is unique in the fleet in using doppler to acquire targets and reject clutter and chaff. Transmitted frequencies are such that the operator can hear the doppler signature, and an experienced operator can use this aural signature to distinguish the type and number of targets. To make fullest use of the operator's capabilities, the console (at least in SPG-51D) allows overriding of the angle and range trackers of the system. Tartar-D continuously calculates expected target motion, assuming that the target is flying in a straight line, and uses measured range and angular position to update it. That reduces tracking bandwidths and, thus, reduces tracking line-of-sight noise. It also provides an automatic range computation when jamming denies range data (but provides angle data).

SPG-51E, which was not built in quantity, was intended as a "universal fire-control radar," to control Talos as well as Tartar (now Standard) missiles.

SPG-51 radars are manufactured by Raytheon.



SPG-51 Standard MR directors, USS *Mississippi*, June 1988. (Stefan Terzibaschitsch)

◆ SPG-52

Band: Ku (16.3–16.5 GHz) **Beam:** 5 deg
Peak Power: 50 kW **Gain:** 30 dB
Pulse Width: 0.5 microsec **PRF:** 1500 pps (modulation 400 Hz)
Antenna Dimensions: diameter 12 in **Antenna Weight:** 2 lb

SPG-52 is the radar associated with the Mk 70 GFCS. Manufactured by Lockheed Electronics, SPG-52 must have been one of the earliest practical applications of Ku-band technology. SPG-52 was a range-only radar, with no means of tracking, functionally equivalent to Mk 26, above. Maximum range was 10,000 yd. Total weight was 1177 lb, compared with 890 lb for Mk 26.

◆ SPG-53

Band: X **Beam:** 1.6 deg (spiral or conical scan)
Peak Power: 250 kW **Gain:** 39 dB
Pulse Width: 0.25 microsec **PRF:** 1000 pps
Antenna Dimensions: diameter 60 in
Antenna Weight: 163 lb (antenna only); total 5000 lb

Data apply to SPG-53A.

SPG-53 is the radar of the Mk 68 GFCS on board many U.S. frigates, destroyers, and cruisers; it was superseded by the SPG-60 and SPQ-9 of the Mk 86 system. This radar uses spiral scan (11.6-deg cone at 2 Hz) for target acquisition and conical scan (3.1-deg cone at 30 Hz) for tracking. There is a 4000-yd precision sweep.

SPG-53, for gun ships (*Forrest Sherman*-class destroyers), has an instrumented range of 50,000 yd. Peak power is 50 kW, and PRF is 1320 ± 132 pps.

SPG-53A, for missile ships, has a maximum instrumented range of 120,000 yd. Accuracy is $10 \text{ yd} \pm 0.025\%$ of range. Resolution is 80 yd and 1.3 deg. Tracking limits are 50 deg/sec in train and 30 deg/sec in elevation.

During the early 1970s SPG-53As were fitted with RSPE (radar signal processing equipment), a form of ATD intended to deal with faster targets (without RSPE, acquisition required the coordinated efforts of 3 operators). A target in the spiral-scan acquisition field of the radar is automatically detected and within 4 msec is gated in range. RSPE generates train and elevation error signals that drive the radar antenna. When the target is centered in the beam, the radar automatically switches to conical scanning, and the normal range and angle tracking circuits lock on. The entire process takes less than 5 sec. RSPE also incorporates antijam features; for example, it automatically rejects pulses with inappropriate pulse widths.

SPG-53B was SPG-53A with CWI for Tartar missile control. It was conceived for converted missile destroyers (DDG 31–34), which could not accommodate 2 SPG-51s. It was associated with GFCS Mk 68 Mods 9 and 10. The illuminating signal was provided by an off-mount version of the 5-kW SPG-51B illuminator, with improved reliability. The new antenna (AS 1868 rather than AS-515A) comprised 2 coaxial paraboloid antennas of different curvature and focal length and could, thus, accommodate 2 different feeds. CWI was fed through a horn mounted in front of the reflector, vertically polarized (it used the vertical wires of the front parabolic surface). Gain was 38 dB for the main (tracking) radar and 41.6 dB for the CWI antenna; diameter was 64 in (318 lb for the antenna alone). Mk 68 Mods 9 and 10 used an additional Mk 118 Mod 2 computer for launcher and missile orders.

SPG-53C is an analogous version for the Spanish missile frigates (*Baleares* class). In this case the CWI was an adapted SPG-51C module, matching that of the ships' main SPG-51C antenna aft. As in the U.S. ships, the frigates had a second Mk 118 Mod 2 computer, and WDE Mk 1 Mod 7 modified to accept data from an SPS-52 radar rather than from the digital SPS-48 with which WDE Mk 1 Mod 7 was associated in U.S. service. The U.S. FFG 1 class had no comparable CWI in their gunfire-control radars because they had Mk 56 rather than Mk 68 GFCS.

SPG-53D was SPG-53A modified with CWI to control semi-active Standard surface-to-surface missiles, on board 5 *Knox*-class frigates (see Mk 68, below). This version used a standard

SPG-51D illuminator, with a Mk 152 computer and a Mk 72 Mod 6 signal data converter.

SPG-53E is SPG-53A converted to monopulse tracking, for better capability against sea-skimmers and also for quicker reaction. Conversions were scheduled to begin about 1977, but SPG-53F was used instead.

SPG-53F is SPG-53E with simulated ECM input for training. This version replaces SPG-53A on board many destroyers and cruisers.

These radars are manufactured by Western Electric.

◆ SPG-55

Band: C (track) and X (CWI)
Beam: 1.6 deg (C); 0.8 deg (X); 72 deg auxiliary beam (X)
Peak Power: 1 MW (C); 5 kW (CWI)
Gain: 39 dB (C); 47 dB (X-band)
Pulse Width: 26 and 1.5 microsec **PRF:** 203–225 pps
Antenna Dimensions: 175×218 in (total); dish 96 in
Antenna Weight: 12,970 lb (total radar assembly)

Pulse width and PRF refer to operation in C-band target acquisition-and-tracking mode. In the Mk 76 Mod 6 FCS, SPG-55B has a tracking module, using a high pulse-compression ratio. Pulse widths are 12.7 (compressed to 0.1) and 0.1 microsec, PRF is 427 pps. All versions of SPG-55B also have a CW doppler tracker mode, using a separate receiver (a 30-in Cassegrain parabolic flat plate with 34-dB gain and 3.0-deg beam). Scan rate is 1.67 rpm horizontal and 10 deg/sec vertical for both the tracking module and the CW tracker. There is also an auxiliary short-range mode for antimissile defense, using a Custer horn (12×3 -deg beam) to illuminate short-range low-altitude targets and, at the same time, provide a rear reference beam. The Custer horn is used in sector-scan engagements and continuous boat-track modes.

SPG-55 controls SM-1(ER) missiles as part of the Mk 76 FCS. Originally, it controlled both beam-riding and homing versions of the Terrier missile, but the beam-riding feature (consisting of a guidance transmitter and a beacon tracker) was disabled when the last nuclear Terriers (BT(N) version) were retired.

SPG-55 replaced the original Terrier guidance radar, SPQ-5, which could control only the beam-riding version of the missile. SPG-55 is a monopulse tracker using a Cassegrain antenna and a 4-horn cluster. It was designed to acquire a 1-m^2 target at Mach 2 with 5-G maneuverability, at up to 100,000 yd, 10 sec after designation (assumed accurate within 2 deg in bearing,



A pair of SPG-55 fire-control radars, with Harpoon canisters visible in the foreground. (U.S. Navy)

within 3 deg in elevation, within 1000 yd in range). It was required to track with an average angular error not exceeding 0.2 mils. There were 2 acquisition patterns: long range for ranges beyond 30,000 yd, covering $4 \times 6 \text{ deg} \times 2900 \text{ yd}$, programmed by Computer Mk 119; and short range (using the capture antenna system), scanning a conical ($10 \text{ deg} \times 2900 \text{ yd}$) volume.

Besides the anti-air mode, SPG-55 was designed with surface-target and shore-bombardment modes. In the surface-target mode, the FCS computer controls radar elevation; the radar tracks automatically in train, corrected for cross-roll. Optimum angle is maintained to minimize multipath.

SPG-55A was part of FCS Mk 76 Mod 1. It has now been superseded entirely by SPG-55B. Total weight was 45,000 lb.

SPG-55B was originally introduced as part of FCS Mk 76 Mod 2. Total weight is 50,000 lb. This version survives on board the *Mahan* class.

SPG-55C is the current version on board Italian *Vittorio Veneto*- and *Andrea Doria*-class missile cruisers, USS *Bainbridge*, and the *Leahy* class.

SPG-55D is the version on board the missile cruiser *Long Beach* and the *Belknap* class. It is presumably the NTU version.

SPG-55 has been considerably modified since its introduction. A special counter-countermeasures program began in 1964. The radar already used frequency diversity, and the Terrier missile it guided had a home-on-jam mode. In 1963 the *Worden* tested SPG-55B with frequency diversity, and the *Pratt* (DDG 44) tested SPG-55A's acquisition and tracking of a CW noise-modulated barrage jammer.

The new threat was a combination of deceptive ECM and new countermeasures techniques, which were expected to be particularly effective in a coordinated mass raid. For example, low-level attackers might appear at the same time missile boats fired their weapons, bombers laid a chaff corridor, a stand-off jammer appeared, and high-altitude missile bombers maneuvered in formation while practicing barrage and deception jamming. The situation might be further complicated by rain and land clutter, and also by the presence of friendly carrier aircraft. An integrated counter-countermeasures program for the 3T missile systems (*Tartar*, *Talos*, and *Terrier*) was announced in the fall of 1964. The *Halsey* (CG 23) tested control of the radar-ranging system in jamming; operator control in passive angle tracking (i.e., in tracking a jamming source); rapid reacquisition of targets with blinking jammers; and manual range tracking of a jamming target. The next step (1965) was Ordalts to improve SPG-55A's operation in clutter and chaff, followed by a near-term R&D program (1967). The short-term improvements were made on board the *King*, *Wainwright*, *Sterett*, and *Fox* in 1967. They consisted of a sidelobe canceler, 3 modes of passive angle tracking (PAT), preselection of beacon recognition (to track the rising missile), a new control panel (which made it easier for the operator to follow the new counter-countermeasure doctrine), and special ECM simulators for training.

SPG-55B replaced SPG-55A as part of the *Leahy* class's modernization program (Terrier FCS Turn-Around Program), which began in 1965. At the same time Computer Mk 119 Mod 0 was replaced by Mod 5. *Leahy* was the first ship modernized, in 1967-68, and the program included the earlier *Mahan* class (SPG-55B replaced SPQ-5). The modernization program included improved system reliability. It was common for the complex high-powered radar transmitter to fail, and transmitter repair could be lengthy. Ships were modified so that 2 antennas could share the surviving transmitter, in a "power sharing" mode. Switching could be automatic and instantaneous, so a ship would not lose a track or abort a missile in flight. This mode increased the availability of dual channels by 18%. Modernization also included a radar silence mode to defeat enemy countermeasures. For example, the CWI transmitter was turned on only when ordered to guide an HT missile; the beam-rider transmitter (now eliminated) was turned on only when a beam-riding missile was fired. The transmitter tubes were not turned off when silence was desired; they radiated instead into dummy loads. Similarly, the transmitters could be tested without ra-

diating, so a ship could maintain her capability without revealing her presence or capabilities to an enemy listener.

All of these programs were directed mainly against classical air attack. By 1968, however, naval interest had turned toward the threat of missile boats. The boats were small and difficult to detect, and their missiles could appear very rapidly. The initial response was SAMID (Ships Anti-Missile Integrated Defense), a program emphasizing the most complete use of all shipboard assets, including the search radars. A SAMID Immediate program was designed for FRAM II-, *Adams*-, and *Belknap*-class ships deploying to Vietnam. It combined improved passive detection, improved active detection by clutter suppression, and quicker reaction time by providing fire-control radars with horizon or sector-scan search capability, using special links between these radars and the ship's CDS.

Belknap (CG 28 and later)-class ships had their SPG-55B radars modified for horizon and sector search, both for additional search capability and for quicker designation from search to fire control. A new continuous boat-track mode (tracking a surface target) was introduced. The ship's NTDS program was modified. The test ship was the *Jouett*. Further SAMID improvements were a narrow-pulse mode (to avoid clutter), a new digital range and beacon tracker, and the Custer horn.

In heavy jamming, the radar can track a jammer (passive-angle-track [PAT] mode) and can accept external range data (e.g., from NTDS). Alternatively, the operator can manually track the target using a range-rate control (local-range-track mode), the FCS computer maintaining the range rate at the value last entered. There is also a "coast" mode in which tracking is abandoned, but values of range and range rate are estimated using prejamming figures. Current SPG-55s also have a CWAT (continuous wave angle tracking) mode in which the radar tracks in angle using its CWI; it cannot track in range because the signal is continuous. The advantage of CWI is its very high average power, which can be used to burn through a jammer (the narrow pulse is only equivalent to 0.3 kW of average power, the long pulse to about 5.8 kW).

These improvements were in addition to changes from vacuum tube to integrated circuit to high-speed digital technology, for much greater reliability. The current Mod 10 (from FCS 76 Mod 10) upgrade, which will be completed in 1993, is part of the NTU program. Presumably, that entails target acquisition and tracking at greater ranges.

SPG-55 and its upgrades have all been produced by UNISYS (formerly Sperry).

◆ SPG-60

Band: X **Beam:** $1.2 \times 1.2 \text{ deg}$ **Peak Power:** 5.5 kW
Pulse Width: 0.27, 1, or 6 microsec **PRF:** 25,000-35,000 pps
Gain: 41.5 dB **Antenna Dimensions:** diameter 160 in
Antenna Weight: 4015 lb total

SPG-60 is the pulse-doppler tracking-and-illuminating radar associated with the Mk 86 FCS; SPG-60 operates in conjunction with the SPQ-9 TWS search radar. The radar tracks using a 4-horn monopulse assembly, the CWI feed being mounted on front of the horns.

Typically SPG-60 acquires targets designated either by SPQ-9 or by a search radar, searching the designated area and then tracking at ranges of up to 50 nm. SPG-60 can illuminate targets for both Sea Sparrow and Standard missiles. An associated computer is used to vary pulse width and PRF, to resolve the range ambiguities inherent in pulse-doppler operation.

This radar is made by Lockheed Electronics.

SPG-60 elevation limits are $+85/-30 \text{ deg}$. The FOV of the associated television is continuously adjustable from 2.1 to 21 deg; output is a 729-line signal. Instrumented range is 100,000 yd; the radar can detect a 1-m^2 target at 85,000 yd. Maximum instrumented range rate is Mach 3. Range granularity is 5 yd. CWI: 5 kW injected, sufficient to engage a 1-m^2 Mach 2 target at 20,000 yd with a Standard Missile (SM-1 MR). Specified MTBF was 300 hr.



Two SPG-62 illuminators are visible above the after face of the SPY-1 radar on board the USS *Ticonderoga*, 1983. The large circular structure is the IFF associated with the Aegis system; above it are the TACAN (the flat radome at the masthead) and the LAMPS data link. (DoD)

◆ SPG-62

Band: X **Average Power:** 10 kW
Antenna Dimensions: diameter 90 in

SPG-62 is the illuminator associated with the SPY-1 (Aegis) radar and its Mk 99 MFCS. Unlike SPG-51, which SPG-62 resembles, it does not track its targets. The Aegis system points the illuminator at targets detected and tracked by the main radar, during the last few seconds of missile flight, to provide terminal guidance for the SM-2 missile.

SPG-63 was the alternative tracker-illuminator, using the same antenna, with C-band (42.5 kW, PRF 10,400–10,800 pps) tracking. SPG-63, however, was unnecessary: SPY-1 provided sufficiently accurate track data that SPG-62 could be slaved to it, with no tracking feedback.

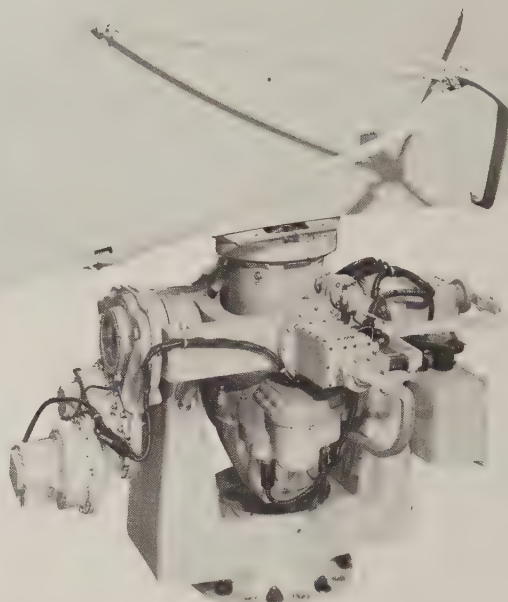
◆ SPQ-9

Band: X **Beam:** 1.35×3 deg **Peak Power:** 1.2 kW
Gain: 37 dB **Pulse Width:** 0.3–16 microsec
PRF: 3000 pps **Scan Rate:** 60 rpm
Antenna Dimensions: 80.5×30 in (radome 120×96 in)
Antenna Weight: 1185 lb (including radome)

SPQ-9 is the surface-search and target-acquisition radar of GFCS Mk 86; this radar can also acquire and track low-flying aircraft. SPQ-9 is a TWS pulse-compression radar; the entire Mk 86 system reportedly can handle 120 tracks simultaneously. SPQ-9 was 1 of the earliest applications of optical pulse compression (16.4 microsec compressed to 0.12 sec, also given as 167:1 ratio). One source gives a peak power of 3 kW.

Maximum range is 20 nm, minimum 150 yd. There are 2 versions: 1 for surface search and very limited (2000 ft) air search, 1 for air search (with integral IFF) up to an elevation of 25 deg. Only the pure surface-search version is dome-enclosed. The operator can choose among 5 operating frequency ranges, using pulse-to-pulse frequency agility to defeat ECM. SPQ-9 is a digital radar, with digital MTI. The antenna is stabilized against roll and pitch.

Maximum instrumented range is 40,000 yd (PD 0.90 for a 1-m^2 target at 30,000 yd). Range resolution is less than 50 yd and range accuracy is $10 \text{ yd} \pm 0.025\%$ of range. In 1967 MTBF was given as 784 hr.



SPQ-9 radar without its radome. See also the illustration for the Mk 86 FCS. (Lockheed Electronics)

The alternative version, for combined air- and surface-search, had a 25-deg (elevation) fan beam and an IFF antenna and was generally mounted on deck. No production versions of this antenna appear to have entered service.

Current work is concentrated on an MTI/low-noise front end (LNFE). MTI should counteract chaff and heavy weather; LNFE should reduce the minimum radar cross section of a target to a quarter of the present value.

◆ VPS-2 (Sharpshooter Radar)

Band: X (9200–9250 MHz; 6 crystal-controlled frequencies)
Beam: 4-deg conical beam **Peak Power:** 1.4 kW (average 10 W)

Lockheed Electronics's coherent pulse-doppler MTI radar is used in the Spanish Meroka system. It is also used in U.S. Army Vulcan air-defense guns. In the Vulcan system, the radar is servoed to an optical line of sight. It searches automatically for the target for accurate tracking. Search range is 5000 m; the radar tracks targets moving at 15–310 m/sec.

◆ STIR

Separate Target Illumination Radar was designed for the Mk 92 FCS of the *Perry*-class frigates. STIR has no separate AN-series designation. Thanks to its greater diameter (i.e., higher gain), the STIR antenna can be used to track targets at ranges beyond those of the Mk 92 with which STIR operates. It also has a CWI to guide SM-1 (MR) missiles. Tracking is by monopulse, and in the CWI mode the antenna functions as a Cassegrain, the illumination being reflected off a subreflector at the monopulse cluster, and focused by the main dish. A CW fill-in horn is mounted in front of the monopulse cluster. The dish is pierced for 2 aligning telescopes and also for a coaxial television tracker (which, however, has not been fitted). Diameter is 100 in (turning radius 78 in), and height, including pedestal, is 138 in. This antenna is designated UD 417. UD 417 is substantially smaller than the Mk 39 antenna of SPG-60 (diameter 160 in), which is also a monopulse tracker with CWI and which is very similar in appearance.



STIR on board the USS *Rodney M. Davis*, 1987. (F. Jentsch)

◆ TAS (Target Acquisition System) Mk 23

Band: L **Beam:** 3.3×75 deg **Peak Power:** 200 kW
Gain: 21 dB **PRF:** See below **Scan Rate:** 15 or 30 rpm
Antenna Dimensions: 231×129 in (including pedestal)
Antenna Weight: 1950 lb topside, 10,000 lb total

The Hughes Target Acquisition System Mk 23 is the search radar and associated combat-control system with the Improved Point-Defense Missile System (NATO Sea Sparrow Missile System) in U.S. Navy service. The designation parallels that of Aegis, except that there is no separate designation for the search radar (analogous to SPY-1). The TAS radar is a range-gated pulse-



Hughes's Improved TAS three-dimensional radar. (Hughes)

doppler type, mounted back to back with an IFF antenna, and is intended to locate, acquire, track, classify, and designate missiles diving or popping up 30–60 sec before impact. The broad (vertical) fan beam covers missiles diving at steep angles, and the doppler processor can separate moving low-level targets from the surrounding clutter of the sea return. The beam is shaped so that most of its energy is transmitted at low elevation angles.

The waveform is ramped FM.

The radar automatically detects and tracks, feeding data into an associated combat-system computer. TAS is broadly equivalent to the British Type 967/968 associated with the Sea Wolf point-defense missile system. Mk 23 can track up to 54 targets simultaneously. The manufacturer claims that it can reject over 50 dB of clutter around a moving-target return. ECCM features include the ability to switch rapidly on and off (for EMCON, without risk of being unable to switch back on); and doppler processing helps TAS overcome jammers, both on and off axis. Range-gating makes it possible for a ship to concentrate on targets without accidentally tracking nearby friendly aircraft or surface ships (when, for example, an ASW ship is stationed between a carrier and a suspected-submarine contact). The operator selects a controlled-reaction zone, in which the radar picks up targets either automatically or semiautomatically, the latter method allowing the operator to override friendly or neutral tracks and so to prevent the system from engaging them.

The 2 primary operating modes are normal (automatic point defense, 20-nm scale) and medium-range (surveillance and air control beyond 90 nm). They can be mixed for combined point defense and air surveillance. PRFs corresponding to the 2 modes would be, respectively, about 4000 and about 900 pps. A PRF of 4000 corresponds to a first blind speed of about 1900 kt.

The radar antenna consists of 26 flared feed horns, plus 1 for sidelobe blanking and 1 for sidelobe cancellation. Total weight is 10,000 lb (2,000 lb topside). TAS radars are connected to general-purpose standard navy computers (UYK-20), which determine whether targets are threats (using IFF), rank them, and then designate weapons to engage. The computer can maintain more than 50 target tracks, each of which requires 20 words of the 60k memory. Reaction time is typically 60–80 sec, but the minimum is less than 30 sec. The operator uses a standard NTDS console (UYA-4).

Originally Mk 20 to 24 were developed, sophistication increasing with Mark number. Mk 24 incorporated an infrared sensor. Mk 23 was tested at sea on board the destroyer *Downes* in 1975. Mod 0 was the engineering-development model. Mod 1 is integrated with NTDS, for the *Spruance* class; Mod 2, for major auxiliaries, is a stand-alone model, with its own NTDS-type UYA-4 console.

In 1984 TAS was modified so that it could be connected directly to the SLQ-32 ESM warning system. TAS is currently being updated with UYK-44 computers, the associated memory being increased from 60k to 512k. The UYA-4 console is replaced by the new standard UYQ-21.

Hughes announced an updated version, MTAS (multimission TAS) in 1985, and a prototype has been in operation since 1986. The antenna consists of a 26×6 -dipole array controlled by diode phase shifters. It can produce either the sort of fat fan beam used by a conventional TAS or a fat elevating lobe beam as in a conventional electronically scanned antenna (such as SPS-52). However, because the array is phase-phase controlled, the beam can be moved electronically in both elevation and in azimuth. Normally a target would be detected in the 2D fan-beam mode. At shorter range the radar would shift to 3D operation to obtain target elevation. The elevating beam is fat because it is essential to obtain full coverage at short range and at very steep angles; pencil beams do not provide enough "paints" of the target to give a high probability of detection at short range. Phase-phase steering is necessary to allow the radar to return very quickly to a target detected in 2D mode, before the antenna has turned completely away.

The combination of normal 2D operation with 3D operation only as required explains Hughes's description of the radar as "2½D." Hughes also calls MTAS a "4D target designation radar" (bearing, range, elevation angle, and range rate).

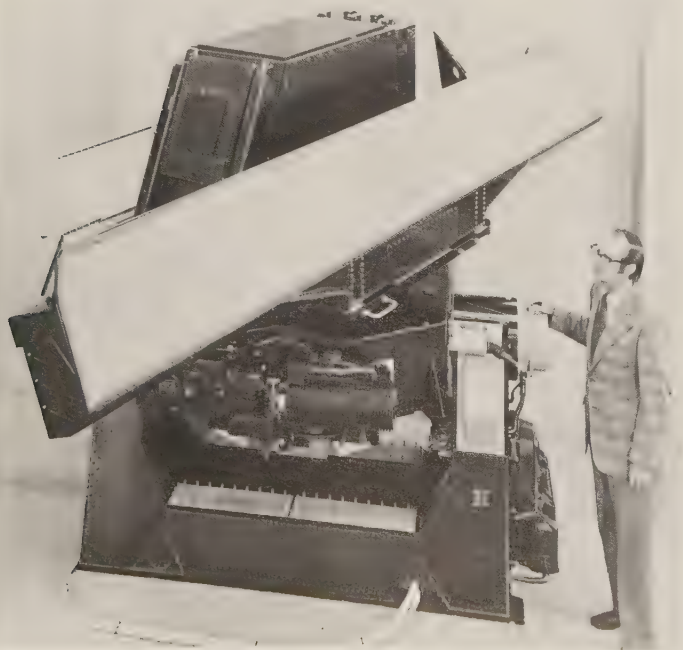
As of early 1989, the conversion of a TAS system to improved TAS is a U.S. Navy-approved ORDALT, which can be carried out at pierside in 10 days. Conversion entails installation of the new antenna, reprogramming of the displays, and insertion of some new electronic cards in the equipment cabinets. No such conversions have, however, been carried out. When MTAS was first announced in the spring of 1985, Hughes expected its incorporation in the sixtieth TAS to be delivered (1987).

Hughes has offered a version of the improved TAS radar as the MFR of the NAAWS program. Instead of elevating the entire beam, this version would maintain a fixed lower lobe pointed at the horizon, the same radar antenna simultaneously conducting horizon and hemisphere searches.

Hughes also offers a small-ship version of TAS, with a smaller transmitter and antenna, at a total weight of 6000 lb (compared to 10,000 for the basic TAS).

The FY86 program included a new requirement to integrate the SAR-8 IR search-and-track device (IRSTD) with Mk 23 and SLQ-32 via the Mk 23 computer. IR-to-radar and IR-to-ESM track associations will be used to complement the radar-to-ESM association already being developed. The Mk 23 integration will permit a demonstration of IR designation to NATO Sea Sparrow in support of SAR-8 tests. The NATO Sea Sparrow office is currently trying to fit the fully integrated TAS/SLQ-32/SAR-8 system into Sea Sparrow ships; this system can also designate targets to the RAM missile. The result is a relatively inexpensive system with impressive track-handling capability, which some in the office have called "Polish Aegis." The system includes a Hughes-designed TEWA (threat evaluation and weapons assignment) component, which decides whether a given threat should be engaged by hard- or soft-kill systems, and, if hard-kill, by RAM or Sea Sparrow.

As of early 1989, the NATO Sea Sparrow office had just given permission to integrate a Hughes FLIR and a Ball Aerospace LLLTV into the overall system. The FLIR, originally developed for the Abrams tank, is the nonradar tracker of the system. The Ball LLLTV is installed atop the Mk 91 director. One problem in this installation was that director slew was too coarse for the LLLTV, with its very narrow FOV; Ball had to dampen director motion to keep the LLLTV on target. These electro-optical sensors will both be integrated with the TAS, to increase detection



TAS Mk 23 antenna. (Hughes)



TAS Mk 23 on board the carrier *Ranger*, July 1986. It is the bar antenna on the mast, above the large flat plate of SPS-48C. The radar on the after side of the mast, just below it, is SPN-43, a short-range air-search set for carrier air control. (Hughes)



UYA-4 display of the TAS Mk 23 system, on board the carrier *Ranger*, July 1986. The display consists entirely of processed rather than raw video. (Hughes)

range, particularly when long radar range operation is precluded. SAR-8 is likely to be a future feature of this system.

Current versions of TAS Mk 23 are:

Mod 0 Original version, with a Mk 158 computer.

Mod 1 UYK-20 computer and OJ-451(V)9/UYQ-21 display; this version could control up to 3 NATO Sea Sparrow launchers.

Mod 2 UYK-20 computer and OJ-194(V)3/UYA-4 display for non-NTDS ships (production version of Mod 0).

Mod 3 UYK-20 computer and OJ-451(V)9/UYQ-21 display (modified Mod 1).

Mod 4 UYK-20 computer and OJ-451(V)9/UYQ-21 display (modified Mod 2).

Mod 5 As Mod 1 but UYK-44 computer (for *Spruance* class).

Mod 6 As Mod 2 but UYK-44 computer.

Mod 7 As Mod 1 but UYK-44 computer.

Mod 8 As Mod 2 but UYK-44 computer and new OJ-451/UYQ-21 display.

As of the spring of 1990, the improved version of TAS is known as TASI, and its future is tied to that of the NAAWS program. Although the radar is thoroughly tested and suited to pier-side installation (with some new cards to be installed in the below-decks electronics cabinets), the expected installations did not materialize. An ORDALT for conversion was approved, but the necessary funds went to NAAWS instead. Now it seems likely that existing TAS radars will slowly be converted. It is possible that TAS will figure in the version of NAAWS finally selected.

◆ R76/HR76

Band: X (12 preselected frequencies over 800 MHz)
Beam: 2.7 deg **Peak Power:** 250 kW
Gain: 32 dB **Pulse Width:** 0.25, 0.5, or 1 microsec
PRF: 1000–3000 pps **Antenna Dimensions:** 1 m
Antenna Weight: 205 kg (1200 kg total; 360 kg including TV)

RCA's small-ship fire-control radar uses distributed microcomputers connected by a data bus rather than the usual central computer. Their functions include target tracking, operator console interface, and ballistic computation. RCA argued that such a distributed system was relatively easy to update, since changes in any function would tend not to disturb programs running in another computer, and also since additional functions generally required their own microcomputers. A typical installation included as many as 8 microcomputers: 1 for track radar, 1 for the track console, 1 for gunfire control, 1 for the search console, 1 for data extraction, 1 for the ship interface (to other sensors and weapons), 1 for bus control, and 1 to control EAROM (electronically alterable ROM, in which constants such as magazine temperature are entered manually). The 16-bit bus operates at a 100-Hz frame rate. The data bus design is such that the system can, at least in theory, be extended into a fully integrated tactical data system, although in fact that has not been done by any user.

R76 was originally offered with a single system computer, a 16-bit 32-kword UYK-28. By 1984 the system was provided with 2 types of microcomputers, an RCA control processor (RCP) (a floating-point Mil-Std-1750A machine) and a Rolm 1664 (in effect a UYK-19 with hardware floating-point arithmetic, a superserset of UYK-19). The system uses 16 microprocessors on a common bus with ROMs, each on a separate printed circuit module in a drawer, for redundancy. One processor is used for mode control, 1 for target range, 1 for target angle, etc. The system bus as a whole could accommodate up to 64 microcomputers, far more than the system was ever likely to need.

Early in 1982 the Royal New Zealand Navy selected R76C5 for frigate modernization because its basic technology was more modern than those of alternative systems (Ferranti WSA 400, Marconi ST802, Philips 9LV200, and Signaal WM20-series). The first contract was signed in June 1982, and the first installation began in February 1985 (HMNZS *Wellington*). HR-76 is the fire-control tracking radar of the Taiwan navy's *Wu Jinn I*-type destroyers. (See also the description of the H930 Mod 1 tactical command/control system in the Surveillance and Control section.) Some examples of this version have also been installed in coastal defenses.

The antenna is gyro-stabilized for horizon search. It is a par-

abolic reflector with a 4-horn Cassegrain feed for monopulse tracking. The mount also carries an electro-optical contrast tracker (TV or IR), and a separate electro-optical director carries a tracker with a laser range-finder and a remote-control zoom lens (with an FOV variable from 30 to 1.5 deg). Acquisition range on a 1-m² target is 40 km [43,700 yd], and accuracy at 20 km is 10 m in range and 1 mrad in bearing/elevation. Search-scan period is 4 sec (15 rpm), and reaction time from designation to tracking averages 3.5 sec. To track a target less than half a beamwidth above the horizon, the antenna is held at a fixed elevation, and the target is tracked off-axis.

R76 could be adapted to track an airplane or a helicopter while receiving down-linked data from a coded beacon, for OTH missile targeting.

The display is a 16-in PPI showing synthetic and raw video.

RCA offered a variety of versions: the basic R76, R76C for large patrol boats and destroyers, R76M for guided-missile ships, R76D to control drones and RPVs, R76LB for land-based guns for coast defense, and R76P for small patrol craft. At least in some versions, R76C uses a radome-enclosed antenna and has a higher-power transmitter. R76M uses the same components but has a 2-operator console, the second position for missile control. Missiles are guided by modulating the tracking beam, the missile being tracked by the second channel of the 2-channel monopulse receiver. R76D has a 2-operator console (1 operator for drone control), and the 2-channel receiver and coding capability of the transmitter are used for drone operation. Maximum instrumented range is 160 km, to track a beacon-equipped drone or RPV. R76LB has an instrumented range of 80 km, to take advantage of the greater horizon range of a cliff-mounted radar.

HR76 was derived from RCA range-instrumentation radars and airborne satellite-tracking antennas.

◆ W-120/W-1200

Westinghouse's private-venture shipboard fire-control radar is based on the APQ-120 of the F-4J. Target acquisition is by automatic search either around an externally provided target position or around the last known target position (if track is broken). Typically a 4000-yd acquisition window is placed around the designated range. The radar acquires a target in 20 msec after designation. If automatic track is lost, the radar attempts to reacquire the target. There is also a mode for detecting low fliers. Peak power is 165 kW (pulse widths 0.4 and 2.0 microsec, PRFs 1000 and 500 pps). Westinghouse claims that W-120 can detect a 1-m² target at 30 nm; that range accuracy is 0.01% to 2.5 nm, then 2% at greater ranges; and that angular accuracy is better than 2 mrad. The antenna is a radome-enclosed 32-in paraboloid (gain 34.5 dB) that can elevate/depress to +90/–30 deg. Beamwidth is 2.8 deg. Search patterns are 10-deg azimuth × 30-deg elevation scan; 10 × 15 deg scan; spotlight or fixed beam position. Reliability: 300 hr MTBF. The antenna/pedestal assembly weighs 860 lb, and the display/controls 100 lb.

Westinghouse offered several optional features: CW guidance for Sea Sparrow; 250-kW peak power; MTI/MTT (moving-target track) noncoherent mode (which was particularly useful against low fliers and could be entered automatically whenever the space-stabilized elevation angle fell below a preset angle of about 2.5 deg; this mode improved signal-to-clutter ratio by about 20 dB); and a new slotted planar-array antenna (lower sidelobes).

W-1200 was a series of modular FCSs developed by Westinghouse to compete with the H930 series; the associated tracker was W-120. W-1200 itself had no tracker; it was broadly equivalent to EX-93 (see that entry). W-1200 employed an optical director, an LN-66HP radar, a UYK-19 computer, and a Westinghouse UPA-62 display. It could control 35- and 40-mm guns. W-1200 seemed to have been the only one in the series sold (to South Korea for the *Paek Ku* class). W-120 was sold as part of the H930 system for Korea and Taiwan. W-160, announced in 1982, is the successor to W-120 in these systems.

◆ W-160

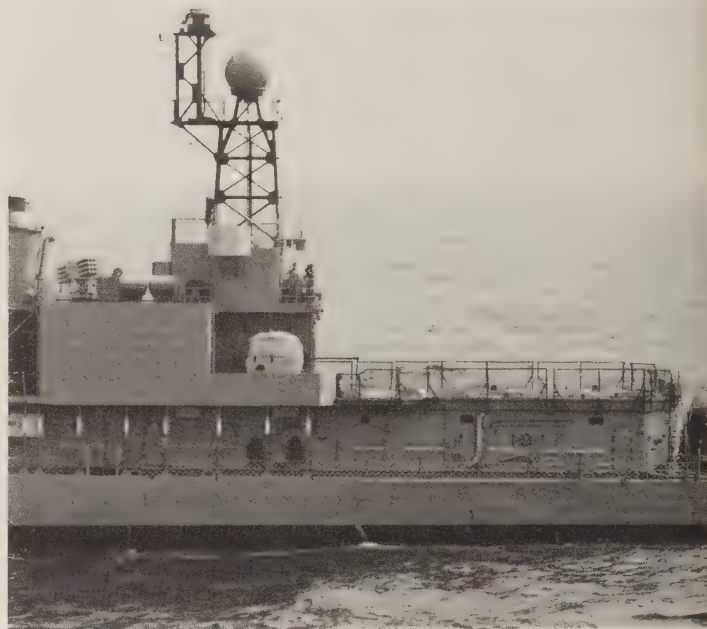
Westinghouse's private-venture shipboard fire-control radar is based on the APG-66 fire-control radar of the F-16 fighter. The X-band pulse-doppler radar, using a 42-in reflector (effective aperture 36 in; gain 36 db) has a range of 25 nm on a 1-m² target, claimed MTBF being 600 hr (30 min). Tracking is by monopulse (6-, rather than the usual 4-, horn feed for greater countermeasures resistance). Tracking accuracy is better than 1 mrad in angle and 15 m in range. An alternative 6-ft antenna (42-db gain) extends range to 46 nm. A digital computer takes angular data from the radar and computes a target's position in 3D. The computer controls the antenna both for search and for tracking and is powerful enough to calculate gun ballistics, making the system self-contained. The radar is compatible with guns of up to 5-in caliber and with NATO Sea Sparrow and SM-1 missiles.

Radar characteristics: peak power is 16 kW; pulse width is 1 or 10 microsec; PRF can be 1 of 8 between 1000 and 14,200 pps; beamwidth is 2.5 deg (1.25 deg with 6-ft antenna). The transmitter is coherent, so it is suited to moving-target indication (MTI), using an FFT to extract the frequency characteristics of the returned echo. That ability is important both for tracking and for clutter/jamming rejection. The radar can operate in either a search mode (low elevation, 360 deg at 15 rpm) or in its primary tracking mode. At low elevation angles, off-bore-sight tracking is used to avoid multipath propagation (mirror images off the sea).

W-160 has 9 search modes (5 surface search, 4 air search) and 6 track modes (2 surface and 4 air). It detects sea-skimmers on the horizon by its good subclutter visibility. Six special sub-modes offer missile-launch detection, projectile spotting, and kill assessment. Instrumented range is 75 km. The airborne origin of the system shows in its light weight (750 kg) and its limited power consumption (13 kW). The associated computer has 16 kwords of RAM and 48k of ultraviolet EPROM, using 16-bit words.

W-160 is the fire-control tracking radar of the Taiwanese navy's *Wu Jinn III*-type destroyers. (See also the description of the H930 MCS tactical command/control system in the Surveillance and Control section.)

Chien Yang is fitted with an H930 modular combat system. She is fitted with a Signaal air-search radar, SPS-10/SPS-58, for surface and low-altitude air search, and a Signaal STIR fire-control radar, which also provides illumination for her SM-1 surface-to-air missiles. The masthead radome is a TACAN. (F. S. Mei)



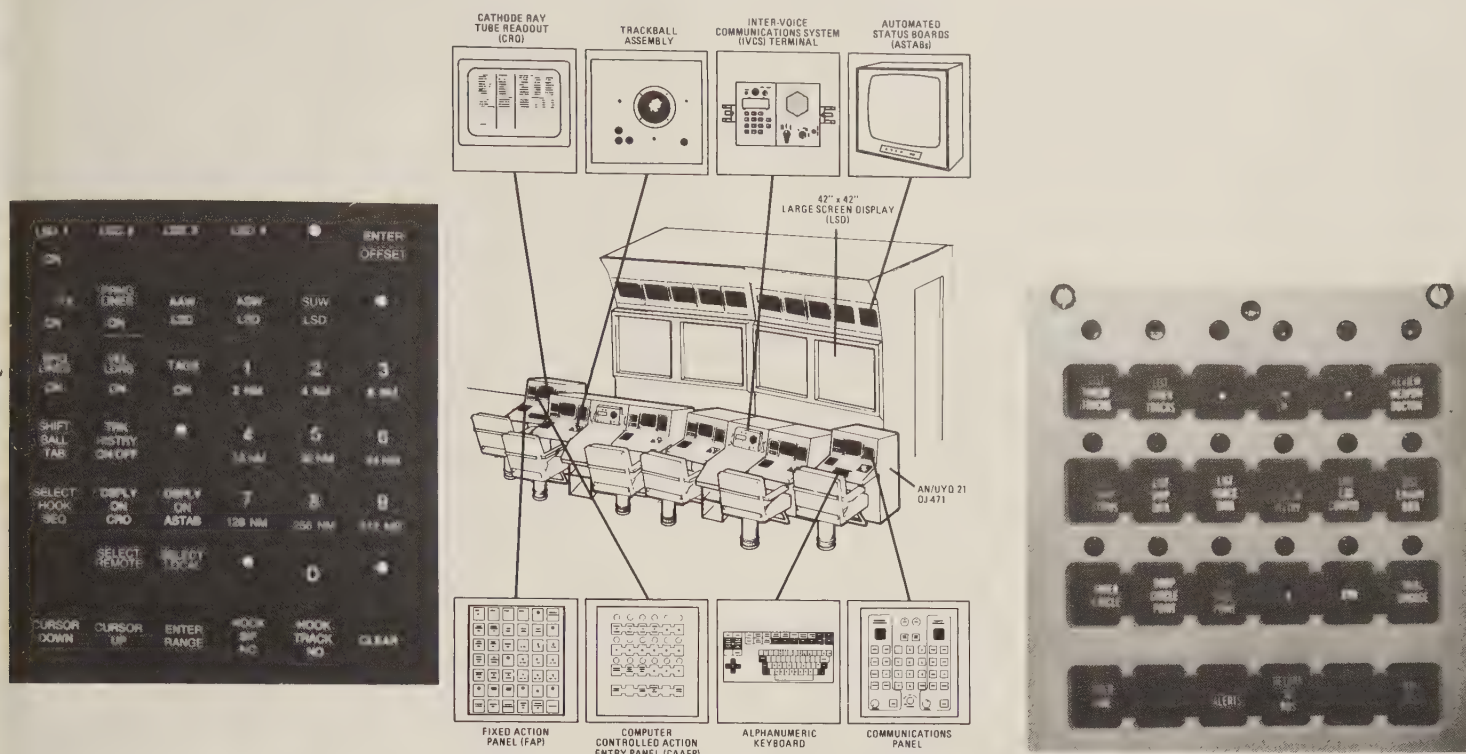
The W-160 "golf ball" on board the Taiwanese destroyer *Chien Yang*, a *Gearing* subject to WS-III modernization. The box at the base of the mainmast is 1 of 2 Chang Feng III (Hughes MEWS) arrays; note the chaff launchers atop the deckhouse, forward of the array. The radome at the top of the mainmast, not entirely visible here, is probably the Argos 680. The boxes hold SM-1 missiles. (F. S. Mei)

RADAR INTEGRATION

◆ Aegis

Aegis is the overall weapons system (Weapons System Mk 7) that uses a SPY-1 radar to control SM-2 anti-aircraft missiles. Mod 2 was planned for the abortive U.S. strike cruiser (CSGN). Mod 3 equips *Ticonderoga*-class missile cruisers. Baselines: (1) *Ticonderoga*; (2) CG 52-58, with the vertical launching system, Tomahawk, and ASW upgrades; (3) CG 59-64, with SPY-1B and UYQ-21 consoles; (4) CG 65-73, with UYK-43/44 computers and increased battle-group capacity in the Aegis display system. The *Arleigh Burke* (DDG 51) combat system is a combination of (2) and (3); baseline 4 builds on DDG 51 and introduces the UYK-43/44 computers. The baseline-2 program was demonstrated at the Aegis land test site in FY86, and the ASW upgrade was added to the program in September 1986.





The Aegis display system. (RCA)



Aegis large-screen decision displays. (RCA)



Aegis large-screen displays on board the cruiser *Vincennes*. They are paired: 1 set for the embarked group commander, 1 for the ship's CO or TAO. In this case the pair of screens shows the same scene (the southwestern coast of the United States) in 2 different scales. The *Arleigh Burke*-class destroyer, which is not designed to carry an embarked group commander, has only 1 pair of screens. (Hughes)

Tomahawk was integrated into baseline 2 in FY87. Baseline 3 was demonstrated in June 1987. Baseline-4 integration and demonstration were scheduled for March 1988 through February 1989 (as of January 1987).

Aegis replaces the NTDS/WDS combination of earlier U.S. missile cruisers. Aegis is built around Command and Decision System Mk 1, Aegis Display System Mk 1, and Weapons Control System Mk 1, the first and last replacing, respectively, NTDS and a WDS (the original Aegis test ship, *USS Norton Sound*, had WDS Mk 12). All of these systems are built around UYK-7 computers. In the Mod 3 version, Aegis employs 16 UYK-7s, 11 UYK-20 minicomputers, and 1 UYK-19 computer.

The display system has 4 very large (42 × 42 in) paired screens and is entirely new. In principle, 1 pair of screens is for the ship's captain and 1 for the embarked group commander. Each pair of large screens is supported by 2 command-display consoles, a data-input console, and 5 automated status boards (ASTABs). In addition, 2 ASTABs are on the bridge.

The large screens display processed, rather than raw, radar video as tracks, NTDS symbols, and Aegis symbols, in white

on a blue background. Each screen can operate individually, at its own range scale; and controls allow for irrelevant tracks to be suppressed, for tracks to be tagged (track numbers or alphanumeric labels of up to 24 characters in 3 lines), and for offsets from a display centered on the ship. Additional information is supplied on the associated command-display consoles and the ASTABs above the large screens. In principle, the commanding officer and TAO sit at the 2 command-display consoles, with a data-input assistant at the adjacent input console.

Because the 2 displays of either group can show the same situation at radically different scales (calling up the same computer data base), operators can position their ball tabs on either large-scale display (LSD), and operators working to different

scales or in different warfare areas can share the same target data without changing screens or even manually pointing (as in standard NTDS systems). Important tracks and symbols can be highlighted without being tagged.

The display system can also store up to 40 patterns, such as formation diagrams, anchorages, and amphibious boat lanes. It can automatically initiate up to 16 simultaneous track histories until ordered to stop doing so. It can also provide digital maps of the area in which the ship is operating, refreshing own-ship position every 2½ sec.

Aegis as a whole is credited with the ability to handle 128 tracks. The SPY-1 radar can actually handle more, the extra capacity being used to avoid overflow. The most important limit on track capacity is the interface with the track file in the associated command/control system. The margin in the radar prevents overflow when numerous long-range tracks of little immediate interest are present.

The Aegis display system is to be the basis of a future battle-group AAW display group, which will allow an embarked battle-group AAW commander to control the force.

Versions (Aegis baselines):

Baseline 1 CG 47-51: original version

Baseline 2 CG 52-58: Vertical Launching System, Tomahawk, ASW upgrades

Baseline 3 CG 59-64: SPY-1B, UYQ-21 displays

Baseline 4 CG 65-73: version that converts computer programs to UYK-43/44 computers and provides increased battle-group capability in the Aegis display system. This version includes a special UYK-43 version of the Mk 86 FCS.

The FY90 program included integration of the SPS-49(V)7 air-search radar, the Mk 86 Air Gun Mode, and Ship Signal Exploitation System (SSES) upgrades into the Aegis combat system.

Work is currently proceeding on an expanded display system, under the Command Support At-Sea Experiment. It includes both color graphics and an auxiliary screen that can be used to preview large-screen displays, or to show such auxiliary information as the *altitude* track history of a designated target (presumably a capability required after the *Vincennes* incident). This experiment is described in greater detail in the Surveillance and Control section.

The FY91 program includes upgrades (both hardware and software) for increased capability against sea-skimming missiles, to enter service on board an FY94 missile destroyer.

◆ BGAAWC

Battle-Group AAW Coordination is a program to tie together all the ships of a battle group. Aegis data will ultimately be disseminated throughout the group so that non-Aegis ships will be able to use that information for firing. That dissemination requires both more efficient use of existing sensors and better gridlock within a force, since without good gridlock ships cannot use one another's data. By 1986 an SPS-48 detection data converter had been tested and deployed. A surface-gridlock system was installed on board the *Ticonderoga* class, solving a 20-yr-old problem. An airborne-gridlock system was under test on board an E-2C. Air gridlock was demonstrated in the *Vinson* battle group, and Aegis autogridlock technology was transferred to non-Aegis ships. These efforts together constituted Phase I of the BGAAWC program.

Phase II concerns force-control items to place weapons on target, e.g., improved gridlock using the GPS satellites and improved Aegis displays.

Phase III initiates cooperative engagement capability, in which CDS (Aegis command) fire-control-quality data are exchanged, and missiles are remotely fired. This capability has already been demonstrated by an Aegis ship and a Terrier ship; the next stage is the remote firing of an SM-2 Block II missile on board a vertical launcher ship, by another Aegis ship, against a real target.

The effect of BGAAWC is to increase the efficacy of fleet air defense substantially, since non-Aegis (even non-AAW) ships can become, in effect, spare magazines for Aegis ships, which can order launches and control the missiles in terminal engagements. That capability in turn is possible because SM-2 is fired into a preset basket and only intermittently command-guided.

Aegis's use for remote missile operation is of 2 types: remote track launch on search (RTLOS) and, at a more primitive level, transmission of Aegis data by Link 11 to designate a target to a fire-control radar. In RTLOS, a missile is launched by a ship that is not emitting at all, the Aegis ship carrying out the entire fire-control function. The firing ship, then, can be (in effect) in ambush, since an oncoming airplane may well be unaware that it is within attack range. In theory, RTLOS could be extended to include control (or at least designation) from an airborne platform.

RTLOS was first tested in the summer of 1985, using the missile ships *Mahan*, *Yorktown*, and *Richmond K. Turner*, and 2 BQM-34 drones. *Yorktown*, an Aegis ship, tracked both drones with her SPY-1. Track data were turned over to 1 of the other ships, which used her own SPG-55 for the final engagement with an SM-2 missile. Early in 1986 RTLOS was conducted using an Aegis ship, an E-2 airplane, and an NTU ship.

◆ New Threat Upgrade (NTU)

NTU is an AAW upgrade for U.S. missile cruisers and *Kidd*-class destroyers. Existing air-search radars are replaced by SPS-48E and SPS-49(V)2, and a new SYS-2 IADT feeds NTDS, which in turn feeds a new WDS Mk 14. The existing SM-1 missile system is replaced by the autopilot-controlled SM-2 Block II. That replacement makes for greater range because of the option of flying missiles along the most efficient possible paths. Another reason is that each missile can home on a more distant target. SM-1 must receive substantial illumination energy virtually at the time of launch; indeed, missiles are designed to self-destruct if they do not receive the reflected illumination within a few seconds of takeoff. Because reflected energy at the launcher falls off as the fourth power of range, every increase in range is extremely expensive. If, however, the missile can approach close to its target before having to pick up much reflected energy, then effective range depends on the level of energy at the target, not at the launcher, and that energy falls off only as the square of the range. Finally, because the SM-2 autopilot can be programmed in flight, missiles can be guided into appropriate homing baskets even near maneuvering targets. The result is not quite Aegis—without SPY-1 accuracy the SM-2s cannot be guided very close to their targets before requiring illumination—but is far better than earlier SM-1 systems, in increasing range and allowing multiple engagements. Because SM-2(ER) is the longest range SM-2, NTU is particularly valuable when applied to extended-range ships (formerly Terrier ships). SM-2(ER) will become less important only when the boosted version of SM-2 Block IV enters service.

In the NTU system, the ship tracks the target only, transmitting the target's position to the missile. The missile computes the trajectory required to hit the target. In contrast, Aegis, which has a more precise tracking radar, tracks both missile and target, commanding the missile into position.

In Tartar ships, NTU uses CW acquisition and tracking to improve performance against high altitude, supersonic, steeply diving missiles.

As of March 1987, the U.S. Navy planned to upgrade 31 ships (9 nuclear cruisers, 9 *Belknap* class, 9 *Leahy* class, and 4 *Kidd* class) in FY85-93. However, this program may be reduced because of budgetary problems.

Work on CG/SM-2 and NTU for extended-range ships began in FY86, for the *Belknap*- and *Leahy*-class conventional cruisers; the nuclear cruisers *Long Beach*, *Bainbridge*, and *Truxtun*; and the *Mahan*-class destroyers. The *Mahan* was the test ship. The *Bainbridge*, *Truxtun*, and the *Mahan* class were dropped from the program, as they are to decommission in the early 1990s. The first NTU (ER) ship was the USS *Biddle* (1987). The

Tartar (or MR) version of NTU is to be applied to the *California*- and *Virginia*-class nuclear cruisers and to the *Kidd*-class destroyers; the prototype is the USS *Scott* (DDG 995).

◆ RAIDS

Rapid Anti-Ship Missile Integrated Defense System is a near-term improvement to the *Spruance* class. The project was begun by NSWC early in FY88 in response to fleet requests (i.e., presumably in response to experience in the Persian Gulf, including the *Stark* incident). The problem in the case of the *Stark* seems to have been excessive false alarms, which tended to reduce alertness when the attack actually developed. Nor was it clear that an unusual signal, which turned out to be that of an Agave attack radar, was properly interpreted. Reactions were just too slow, and there was no useful guide to the sort of integrated maneuver and chaff-launching reaction that was needed. Appropriate maneuvers depend on too many variables to be extemporized.

As of early 1990, a demonstration was scheduled for October 1990. RAIDS was formally established as an acquisition program in FY89. This very rapid development required that RAIDS use existing equipment; it is essentially a better means of exploiting the sort of information already available to the ship, to control on-board weapons. Software was developed using 386-based laboratory computers, and rapid development requires that the shipboard hardware use the same Intel 80386 chips.

The Phase 1 system generates tactical recommendations (e.g., turn to course 295, fire chaff) based on an automated evaluation of the tactical situation. The current NTDS installation drives hard-kill weapons, such as the NATO Sea Sparrow and the 5-in guns, in a reasonably timely fashion, but there is no corresponding automated control of ESM and decoys. Nor is there any system that recommends the maneuvers appropriate to (or necessary for) the use of the decoys, e.g., to minimize a ship's radar cross section in the direction of the threat missile. No such system can be fully automated because no officer will surrender maneuver control to a computer. That is why RAIDS is a recommendation system. It carries threats designated to hard-kill weapons as constraints on its tactics (e.g., the ship cannot be turned to mask a hard-kill weapon). It displays hard-kill engagement envelopes.

A further Phase 2 includes automated reactions, both by countermeasures and by antiship missile defense (ASMD) weapons. Additional sensors will be added. As of early 1990, Phase 1 is to be introduced into the fleet beginning in FY93. Phase 2 is a preplanned product improvement, applicable to frigates and to other classes, as well as to the *Spruances*.

RAIDS has 2 elements. One is the integration of ESM information and other ship sensors in what amounts to a new combat data system. The other is the automation of tactical recommendations, using a software "tactics engine."

Currently, NTDS ties together the ship's main active sensors but does not really embrace the passive ones. In a *Spruance*, the existing SLQ-32(V)2 and the ULQ-16 pulse analyzer are individual stand-alone devices. The EW officer maintains a status board and reports orally to the CO and to the TA in CIC. EW data are analyzed manually, using classified publications listing emitters. This procedure cannot possibly keep up with an approaching missile; it is designed, presumably, to deal with submarine emissions and also with the requirements of long-range missile targeting, neither of which is likely to be very time-urgent. RAIDS ties the SLQ-32 and the ULQ-16 together by means of a dedicated digital bus to reduce the operator's problems in resolving identification ambiguities. The new EWS (EW supervisor) console provided by RAIDS shows a filtered NTDS threat picture overlaid on the emitter picture, making for easier interpretation of the latter.

RAIDS has 3 elements: the sensors providing the ASMD picture, the sensors used primarily to determine whether soft kill succeeds, and the display/analysis element. All are connected by a data bus (an LAN). The ASMD sensors are NTDS (CDS) itself (i.e., the main search radars and off-board data provided

via Link 11), SLQ-32/ULQ-16, and the radars of the 2 Phalanx guns. The main soft-kill evaluation sensors are the Mk 86 FCS radars and the Mk 23 TAS. Presumably, the latter are used because they are needed to initiate the alternative hard-kill measures. All of the sensors are connected to the system via RAIDS interface units (RIUs) incorporating 386 chips. CDS and SLQ-32/ULQ-16 share a common RIU via a T-bar switch; Mk 86 and Mk 23 share a common RIU. The 2 Phalanx each have their own RIU.

The main computing element is a track manager, based on 386 chips. It is responsible for reducing the high false-alarm rate that has plagued earlier automated ASMD systems. RAIDS avoids the problem by associating radar tracks formed in the ship's NTDS with particular emitters, using both factors (range/range rate in NTDS and emitter character) to decide which tracks merit reaction. If a missile seeker is not detected, RAIDS guesses the most likely platform and provides a synthetic missile track with estimated impact time. Threats are ranked according to which is likely to hit first. The ship's officers can insert the weights they consider appropriate (depending, e.g., on where the ship is operating). The SLQ-32 can be preset to report radars of particular interest.

The RAIDS displays are located next to the SWC (surface warfare coordinator)/TAO console in CIC, next to the SLQ-32 console in CIC, and near the centerline pelorus on the bridge (i.e., convenient to the OOD ordering evasive maneuvers). Each display is a color CRT showing a threat evaluation (in PPI form), recommended actions, and a timeline showing just how urgent those actions are.

Maneuver recommendations are based on factors such as wind, chaff-cloud size and development time, ship cross section (on a given bearing), and sensor and weapon blind arcs.

◆ RVP/SIDS

Radar-video processors are used to provide existing radars with an ADT capability. One such system, the Hughes CV-2834/UYA-4(V), was applied to the DDG 2 combat system about 1972 at the NTDS Development and Evaluation Site, Mare Island, as part of a projected DDG 2-class NTDS installation. This system was not applied to U.S. *Adams*-class destroyers, but it was installed on board the 3 Australian ships of this class. Trials were conducted between June and July 1975 on board HMAS *Perth*. The system was extended to the SPS-52 3D radar, and fully automatic control and surface tracking was added in 1976. In this system, radar-video processing could be applied to 1 radar (SPS-10, -40, or -52) at a time.

Initially (1974-75) the main mode of operation was manual track initiation, followed by automatic tracking; and there was no surface-tracking mode. The RAN asked for fully automatic tracking, the CV-2834 program being modified for ATD (with manual override). After these modifications, the radar operator's task was reduced to choosing a radar, setting the optimum video level, and then turning on the RVP autocontrol; the operator would then monitor RVP performance. By 1981 the Australians typically operated their RVP in automatic control 90% of the time, finding that tracking was much better than earlier manual methods, with excellent target resolution at long range, and (because the system does not lose alertness as its operator tires) with a sevenfold improvement in probability of detection for a given opportunity. Reaction time is dramatically reduced: the estimated range at which a Mach-2 target must be detected to provide enough reaction time so that the target can be killed before passing inside minimum missile range is about half that required by the original system in totally manual mode.

In the *Perth* system, ADT data are checked by a tracking program, to see whether they correspond to realistic target motion, and those that are evaluated as real are retained in a target track file. In exercises about 1980 HMAS *Perth* was able to exercise primary tracking responsibility for a force whose other members were all non-ADT NTDS ships. One result of the success of the *Perth* system was that the RAN specified RVP/ADT for its *Perry*-class frigates. The German *Adams*-class (*Lutjens*-

class) missile destroyers have been fitted with SYS-1, as have 3 U.S. *Adams*-class destroyers.

SYS-1 and -2 differ from the *Perth* system by fusing data from all the shipboard radars; there is no operator selection of which radar to use.

The Sensor Interface Data System (SIDS) uses a CV-2834 and a computer to provide an existing radar with ADT, providing track data to the shipboard command/control system as would a manual operator. It is driven by a UYK-20 computer fed by raw data from an SPS-49 or -55; it services command/control either directly (as in FFG 7) or through a sensor synthesizer called SIDS (CGN 9 and CG 26 class). The RVP/UYK-20 combination is also incorporated in the Hughes TAS Mk 23.

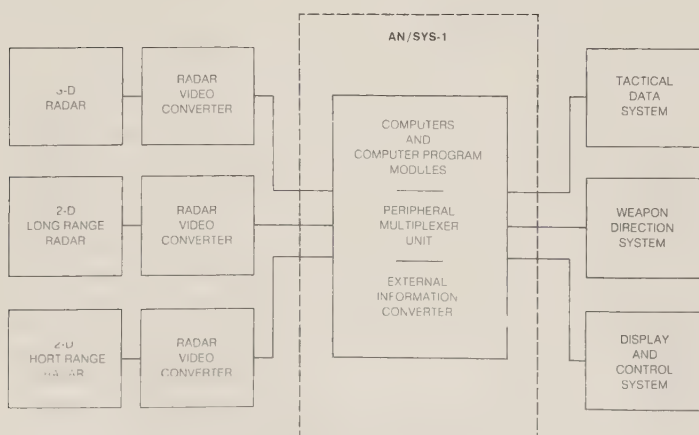
◆ SYS-1/2

The Integrated Automatic Detection-and-Tracking (IADT) System is intended to integrate the disparate radars on board a missile destroyer into a single system. Video inputs (contacts) from the individual radars (SPS-65, SPS-40, SPS-52C) are correlated to form unduplicated tracks, the computer tracking the apparent centroid of an array of blips associated with a single target.

Each radar is fitted with a radar-video converter (RVC). The raw radar video is passed through a video processor consisting of an integrator, an automatic detector, and a data extractor. The integrator sums echoes from a single target. The automatic detector estimates background clutter and noise and compares them with this sum, deciding that a target is present when a set threshold ratio (intended to hold the false-alarm rate to a preset value) is exceeded. That comparison suppresses much of the surrounding clutter. The associated data extractor computes the associated target's range and bearing and puts these data into a form appropriate to the TWS computer, which correlates these data with existing tracks.

This technique can be used to refine the target's position on a beam-to-beam basis, in 3D. The SPS-52C radar carries out this refinement internally, in its video extractor and control group. Conversely, false targets can be rejected when they fail to reappear on a beam-to-beam basis. The system can also adjust its detection criterion depending on circumstances; for example, the system can increase detection probability in a high-threat area by accepting a higher rate of false alarms.

SYS-1, which uses 2 UYK-20 computers, supports 2 NTDS-type (OJ-194(V)3/UYA-4) consoles, whose operators include the radar-control (RC) and detector-tracker-monitor (DTM) operator. Track symbols and vectors are shown on the PPI together with a track-history display (THD) on tracks requested by the operator. The THD is a time-compressed display of about 1 min of track history. There is also a digital display of track data, radar environment parameters, and program status. Both consoles are driven by 1 of the SYS-1 computers, the other serving as a backup.



SYS-1 block diagram. (Norden)

The single-target tracks are transmitted directly to the tactical data system (TDS), a specialized destroyer system in missile destroyers upgraded with SYS-1, and NTDS in the case of cruisers fitted with SYS-2. The TDS operators decide which tracks the system supplies to the WDS, which in turn assigns guns and missiles to the targets. There is an alternative quick-reaction mode in which the SYS system passes its data directly to the WDS, to respond quickly to short-range and pop-up attackers. In the late 1970s it was claimed that SYS-1 more than halved reaction time.

SYS-1 may function either as an ADT or as an IADT system. In a *C. F. Adams*-class destroyer, SYS-1 integrates data from SPS-52C and SPS-40C/D; SYS-1 has provision for later integration with SPS-67 with AM. The integrated tracks flow into the DDG-TDS command/control system, which also receives IFF and sonar data. SLQ-32(V)2 data are entered by keyset, and the system also receives data links (Link 11 and Link 14). The system, in turn, provides data to the weapons systems and their specialized computers.

SYS-1 was designed specifically for DDG 2-class missile destroyers, using SPS-40 and SPS-52C radars as its primary sensors. Land tests began in October 1977, and these systems were then tested successfully on board the missile destroyer *Towers* in December 1977–September 1978. This program was part of the *Adams*-class modernization. Only 3 ships were fitted: the *Tatnall*, *Goldsborough*, and *Benjamin Stoddert*, the first at Philadelphia (August 1981–November 1982), and the other 2 at Pearl Harbor (April 1983–July 1984 and April 1984–August 1985).

SYS-2 is an IADT designed for CG/CGN/DDG 993. It integrates the SPS-48E and SPS-49(V)5 radars instead of SPS-52C and SPS-40, and interfaces with an NTDS computer instead of with DDG-TDS, and with WDS Mk 14 rather than Mk 13. SYS-2 incorporates a Kalman tracker and is being installed as part of the New Threat Upgrade (see above).

SYS-2(V)2 is the IADT for the *Perry*-class frigates. SYS-2(V)3 is the IADT of the *Wasp* (LHD 1) class.

SYS-3 is a system procured for the Israeli *Sa'ar-V* class under the U.S. assistance program.

SYS systems are currently in service in the U.S., Australian, Italian, and German navies. Norden is currently developing a next-generation system, IRDIS (Integrated Radar Detection and Identification), for an unnamed foreign customer's corvettes (presumably the new Israeli *Sa'ar-V* class now being built in the United States). IRDIS will automatically integrate nonradar data, such as ESM data, with the radar-generated track files. IRDIS-type systems should become increasingly important as ships operate more frequently under conditions of radar silence.

◆ SAMID/ASMD

Ships Anti-Missile Integrated Defense program and Anti-Ship Missile Defense program were conducted in the late 1960s and early 1970s, but their fruits remain in the current fleet, and their structure explains several current efforts. SAMID was established in July 1967 to meet the threat of Soviet-supplied antiship missiles (Styx, Shaddock, and the coast-defense Samlet) in Vietnam. This was well before the sinking of the Israeli destroyer *Eilat* by a Styx (October 1967), and SAMID was applied only to ships operating in Southeast Asia. The object was to improve a ship's reaction speed, but without purchasing much new hardware (so that a useful capability could be created in a short time). As in the past, this capability would be directed via CIC. However, in the interest of very quick reaction, SAMID also included a reflexive mode for bypassing CIC. Presumably, the reflexive mode was also a casualty mode, in the event CIC was hit.

Despite the reference to the long-range Shaddock, SAMID was conceived primarily to deal with short-range missiles approaching at relatively low altitude, hence visible only as they crossed the horizon. Hence the emphasis on quick reaction and on maximizing missile detection (e.g., by pressing fire-control radars into service as auxiliary horizon-search sets).

SAMID was conceived as a combination of immediate, near-term, and long-term phases; the near- and long-term elements later became the basis of the ASMD program. The immediate program, approved by the CNO late in 1968, emphasized doctrine and training, with a minimum of new hardware; it was intended for installation on an emergency basis on board *Adams* (DDG 15), *Belknap* (CG 28), and FRAM I (*Gearing*-class) ships deploying to Southeast Asia. It improves passive intercept detection, analysis, and display capabilities for immediate threats by modification or replacement of intercept receivers; it improved active detection by search radar through clutter suppression; and it reduced reaction time by providing horizon/sector scan in fire-control radars (see the entries for SPG-51 and -55), by using intersystem and intrasystem data links (integrated hardware and software), and by adopting specialized operational procedures.

The *Leahy* class's package consisted of (i) horizon search/sector scan for SPG-55B, which provided both additional search sensors and a means to reduce the system's overall reaction time; (ii) functional integration of the chaff-dispensing and other EW systems with missile and gun systems; (iii) shipboard operator and team training, using devices such as the radar video recorder (RAVIR). Equivalent modifications to the weapons systems of the DDGs and the gun destroyers were also provided. The cruisers and missile destroyers were provided with radar video processors (probably among the first ATDs in U.S. naval service) and with threat-warning receivers. Only the cruisers had NTDS, and their programs were modified. All of the ships were fitted with chaff launchers, which at that time meant chaff rockets. The gun destroyers were fitted with a new warning system, QRC 68/9 (the threat reactive system, SLG-19), and they received IR fuzes for their 5-in guns. RCA's SLQ-19 was shelter-housed, and it could automatically recognize and respond to the main-threat missiles (*Styx*, *Shaddock*, *Samlet*). When integrated with NTDS, it was redesignated SLQ-26.

Neither the DLGs nor the gun destroyers had automated CICs. That in itself limited their potential reaction time (apart from 7 ships, the DDGs still lack automated CICs). SAMID, therefore, provided simple intersystem data links for quicker reaction time, which allowed rapid graphic communication between EW and weapons systems and command and control. The basic system was designed for DDG 15, then modified for CG 28 and FRAM I. It consisted of 5 units: (i) a passive intercept unit in the EW area of CIC; (ii) an active ECM station in the EW area of CIC; (iii) an evaluator's station in the display-and-decision area of CIC; (iv) a weapons-control station (WCS) in the display-and-decision area of CIC; and (v) a unit at the passive ECM (chaff) remote-control station. The system was rigged so that passive intercept could pass an alert/threat bearing directly to FCS in the reflexive mode, as well as bearing/threat to the evaluator. It could also receive bearing/threat/search request from the evaluator, who could get threat data from FCS radars operating in search mode. Active ECM provided bearing/activity/radiation to and also received these data from the evaluator. The evaluator passed bearing/threat/assignment and FCS/chaff/fire-chaff-order/weapons-free to the WCS; and received threat/salvo-in-flight/chaff-fired. The WCS assigned FCS to a target in the reflex mode, assigned targets to chaff, and received chaff information (ready/fired/loaded).

Because SAMID had to be installed quickly, it could not entail major rewiring of CICs, or the installation of new computers. Most data were, therefore, transferred by synchro (i.e., analog bearing data) and by signals (relay closures) illuminating information indicators.

The cruisers, which had NTDS, were already (in effect) wired for the sort of information transfer and processing that SAMID provided. Their SAMID packages, therefore, did not include either a WCS or a separate evaluator.

The major entirely new hardware was the SLD-1 threat DF, which made reflexive action possible. The missile ships' active jammers (ULQ-6B) were modified.

SAMID was tested between October 1968 and February 1969

against simulated Soviet missiles, using small craft as simulated missile boats (*Komars*). In a cruiser, the search radar's reaction time (to weapon designation) was reduced, on average, from 107 to 33 sec; in a missile destroyer, from 97 to 43 sec. The fire-control radar's reaction time was reduced from, respectively, 51 to 17 and 23 to 14 sec. EW's reaction time was reduced from 107 to 23 sec and from 119 to 24 sec, respectively. The success of these tests led to a decision to install SAMID on board 20 ships: 4 cruisers (CG 30, 31, 33; CGN 35), 3 missile destroyers (DDG 9, 13, 14), and 13 FRAM I gun destroyers (DD 717, 718, 784, 806, 808, 832, 836, 851, 852, 869, 875, 886, 887). SAMID was designed for installation within 2 weeks, without a major shipyard availability, all to be completed between January and July 1969 at the rate of 1 missile ship and 2 gun destroyers per month.

By 1970 the near-term version was planned for larger ships as well as for destroyers: CVA 31, CVS 38, CGN 9, CLG 4, CG 11, CG 29, CG 30, CG 31, CLG 4, and DLG 11 (now DDG 42), for completion by mid-1971. SAMID Intermediate (for completion by the end of 1972) was planned for CVA 59 (now CV 59), CLG 7, CG 16, CG 17, CG 26, DDG 4, DDG 13, DDG 22, DDG 35, and AOE 1.

For the CG 28-class missile cruisers, the near-term version included a clutter suppressor and automatic threat detector for the SPS-10 surface-search radar, a minimum range kit for SPS-37/43, Mk 28 chaffroc launcher, improved EW (see below), a threat announcer system, radar-signal processing equipment (RSPE) for the GFCS (Mk 68/SPG-53) to reduce target acquisition time and improve ECCM, specialized training, and programming of a third NTDS computer (CP-642B) to include a SAMID module. The EW improvement was a new Threat Recognizer/Programmer, the American Electronic Laboratories SLQ-21, an automatic threat-recognition device for H-, I-, and J-bands. SLQ-21 programmed the appropriate countermeasures into the modified ULQ-6B. The system included an automatic threat library, probably embedded in the NTDS computer itself. The ships were fitted with a new multibeam-intercept antenna system (feeding WLR-1/3 receivers) and with combined passive-intercept receivers, as well as with an SLA-10 signal blanker (to protect the system against own-ship radiation). The SPG-55 radars were modified for continuous boat track and horizon/sector scan.

Again, the lack of a central combat-direction computer was a major drawback in non-NTDS ships. This time there was more scope for modification; non-NTDS ships were to be fitted with a data correlation-and-transfer system, DATACORTS, built around a CP-967 digital computer communicating with all the sensors and decision and action stations. DATACORTS was analogous to NTDS except that it did not include Link 11. It received inputs from all sensors, correlated and displayed their data, performed threat analysis, and recommended action. It also provided the necessary controls to initiate action; it recommended and assigned fire-control channels, active and passive ECM, and weapons, all based on the type and degree of the threat, the threat bearing, the availability of defensive weapons, and doctrine on rules of engagement.

The 2 test ships for this SAMID 70 were the *Jouett* (CG 29, for the NTDS version) and *Little Rock* (CLG 4, for the non-NTDS version).

Apart from this program, ASMD improvements were also made in large amphibious ships (LPD and LPH).

At about the same time a more integrated approach to greater radar effectiveness was under consideration: combination of all radar data in a single computer. This concept was practicable because so much work had already been done on automatic radar detection (ATD), partly in connection with SAMID. The different radars had very different characteristics, so their net probability of detection could be much greater than the capability of any 1 set. Once radar track data were in a computer, they could be compared to known flight profiles for quick threat identification and reaction. When it was begun in 1968, this approach was called the New Threat Upgrade, and ultimately

it led to SYS-1. The automated-threat-response ideas were also reflected in the design of the *Perry*-class CDS, which was intended largely to counter pop-up submarine-launched missiles (SS-N-7).

The next stage was a long-term ASMD program. As of 1970, it was expected that some form of ASMD would be installed on board about 250 ships by 1977. The first stage included the installation of what amounted to NTDS (a system called JPTDS, the Junior Participating Tactical Data System) on board 4 missile destroyers under the FY71 program.

Other ideas were also tested. On 30 August 1971 the *Lawrence* (DDG 4) was designated an ASMD test platform (FY72) under a quick-procurement program called Hip Pocket. She tested Sea Chaparral (which was later deployed in Southeast Asia on an emergency basis on board FRAM I destroyers), Redeye (the predecessor of the current Stinger), an IR search-and-track system (the predecessor of SAR-8), an interrupted-CW threat-warning radar (which might be considered the forerunner of TAS Mk 23, sharing the SPS-10 antenna), IR shielding to her funnels, a chaff mortar (the first test of RBOC), and a flame-thrower (an IR decoy) on her fantail. She used a computerized threat library to sound an automatic alarm in CIC. Hip Pocket was evaluated in February–June 1972. Hip Pocket II was authorized in September 1972 for the *Hoel* (DDG 13) and *Coontz* (DLG 9, now DDG 39). This program also included the prototype of the SQR-18 escort towed array. For the DDG, Hip Pocket II included Alert II ESM on the SPS-10 antenna mount, a passive engagement system (PES) in CIC, a shipboard IR surveillance system (SISS), a dual-spectrum imaging sensor (DSIS), an IR threat acquisition-and-verification system (ITAVS), an active-passive range-gated television (including a laser for ranging and dusk/night operation), and LLLTV. The SPS-10 was modified with an incoming-target alarm and a video clutter suppressor (it reacted to threats closing at Mach 0.5–3.0). The primary new weapon was a Hybrid Missile System carrying Chaparral, Hornet (laser-guided), and dual-mode Redeye missiles, with a TV/laser tracker on the mount. The ship also carried RBOC mortars and IR and radar decoys. The ship's SPG-53 GFCS radar was modified for better low-angle performance. The *Coontz* tested active defense by the army's Vulcan 20-mm cannon, controlled either by a lead-computing sight or by the Mk 68 FCS. The more elaborate Phalanx was already under development, under a QRC contract awarded to General Dynamics in 1969.

The strong emphasis on electro-optics reflects both the fear that radar could not deal effectively with low fliers and the experience built up during the Vietnam War. Presumably, experience in the 1973 tests showed that this technology was not yet sufficiently mature for production, but thatIRST was worth further effort (in the form of SAR-8).

ASMD fell victim to post-Vietnam finances. Many of the ideas tested in Hip Pocket were indeed pursued, but more slowly than might have been imagined under the intense pressure of the missile threat in Southeast Asia. The 4 FY71 DDGs were fitted with JPTDS, but not the remaining (planned) units. The new standard integrated jammer (to combine the threat-recognition and automatic-reaction features of SLQ-19 and -21 with the jammer to replace ULQ-6), Shortstop (SLQ-27), proved too expensive and had to be canceled in 1974 (the prototype was removed from the *Biddle* in 1979). The next-generation version of the wartime SLQ-19 was TRUMP (the Kuras-Alterman threat reactive upgrade modernization program), 2 of which were bought to upgrade existing ULQ-6B and -6C jammers and provide them with channelized receivers (SLR-12), at a unit cost of \$250,000 (FY75 dollars). SLQ-30 seems not to have been bought in any quantity by the U.S. Navy, but it was recommended to foreign navies using ULQ-6, and it may have been bought by Greece and perhaps Iran.

By about 1974, the ASMD EW program had led to DPEWS, the design-to-price EW system intended to replace Shortstop. SLQ-32 ultimately won this competition (in February 1977). At that time DPEWS was intended for smaller surface ships, for LAMPS III helicopters, and for some fixed-wing aircraft (prob-

ably P-3s and S-3s). Planned ship installations were: 60 ships with threat warning, wide-area, electronic surveillance and deceptive ECM (unit cost \$1.4 million in FY75 dollars); 115 ships with threat warning and wide-area surveillance (unit cost \$500,000); and 125 ships with threat warning only (unit cost \$300,000). At that time initial installations were planned for 1977. In addition, the program called for installation of SRBOC mortar-delivered chaff rounds, for 5-in chaff rounds, and for development of a long-range, dilution, decoy chaff rocket carrying RBOC (to succeed the Vietnam-era Chaffroc, which had been canceled because of technical problems).

By this time priorities had shifted. The preferred solution to the fast attack boat was offensive action, e.g., using the new Harpoon missile. The greatest perceived Soviet missile threat was the big air-launched antiship missile (AS-4 in particular). Longer-range active counters, such as improved Standard Missiles and NTU, seemed much more valuable. Chaff rockets could be abandoned because the missile-carrying bombers would have the fleet under observation for long enough to negate their confusion effect. Chaff mortars were more important as a contribution to last-ditch defense. Warning, in the form of SLQ-32, was terribly important, as was targeting assistance for Harpoon, in the form of improved DF systems such as Outboard and its ilk.

From the Falklands War (1982) on, however, the small fast attack boat and the short-range air-launched sea-skimmer became more and more important. Virtually the same solutions first proposed in SAMID and in ASMD are now being suggested (e.g., RAIDS). They are also now more practicable and less expensive. Given the number of ships in existence without any semblance of automated combat direction, systems like DATACORTS become much more interesting.

AIR-TRAFFIC-CONTROL RADARS

◆ SPN-35

Band: X (9000–9160 MHz)

Beam: (e) 3×1.15 (scans in 10- or 35-deg sectors) (a) 1.1×3.5 (tilted -1 to $+25$ deg)

Peak Power: 175 kW **Gain:** (e) 34 dB (a) 36.5 dB

Pulse Width: 0.2 or 0.8 microsec **PRF:** 1200 pps

Antenna Dimensions: (e) 30×152 in (a) 78×159 in

Antenna Weight: 3500 lb (total for radar, including radome)



SPN-35 (in the radome) on board the Spanish carrier *Principe de Asturias*, 1989. (S. Terzibaschitsch)

Although not strictly an air-defense radar, SPN-35 is included in this section because, as a blind-approach radar, it helps make all-weather carrier air operations possible. SPN-35 is typically enclosed in a radome and consists of separate antennas to measure the elevation (AS-1669) and azimuth (AS-1292) angles of an incoming airplane. In the table above, these antennas are distinguished as (e) and (a), respectively.

SPN-35 is a shipboard version of the land-based TPN-8 blind-approach control radar, mounted on a stable platform. First evaluated at sea in 1963, SPN-35 was designed to enable its operator to direct a pilot along a predetermined glide path to a point a mile from a ship, after which the pilot could land visually. SPN-35 was installed on board virtually all U.S. carriers, including amphibious ships, but it is being removed from full-deck carriers as part of the SLEP modernization program; the standard combination of carrier landing radars is SPN-41, SPN-42 (or -46), SPN-43A, and SPN-44. SPN-35 is manufactured by ITT-Gilfillan. It survives on board U.S. amphibious ships and on board the Spanish *Principe de Asturias*.

◆ SPN-43

Band: S (3590–3700 MHz) **Beam:** 1.5×45 deg
Peak Power: 850 kW **Gain:** 32 dB
Pulse Width: 0.6 or 0.25 microsec **PRF:** 1125 pps
Scan Rate: 15 rpm **Antenna Dimensions:** 120×150 in
Antenna Weight: 3400 lb (including pedestal)



SPN-43 is the solid antenna above the larger SPS-49 on board the carrier *Enterprise*, 1987. The tub below SPS-49 carries SPN-42, and the 1 below that carries a Mk 91 Sea Sparrow missile director. (J. Kuersner)

SPN-43, manufactured by ITT-Gilfillan, is the marshal or air-search component of the carrier-controlled landing system. SPN-43 can also function as a secondary or backup air-search radar. Maximum range in clear weather is 50 nm (35 nm in rain), and minimum range 250 yd. The antenna can be tilted from 2.5 to 6.0 deg.

◆ SPN-46/SPN-42

This planned low-probability-of-intercept (LPI) ATC radar is to replace SPN-42. Two SPN-46s were authorized in FY86, with



SPN-42 on board the carrier *John F. Kennedy*, 1986. (S. Terzibaschitsch)

engineering demonstration due in FY89. SPN-46 uses an existing radar antenna and standard navy computers. LPI will be achieved by frequency agility, which should also increase the effective echoing area of incoming aircraft and thus eliminate the need for radar augmentation in the form of the corner reflector currently used. LPI is essential because the ATC radar is the only system specific to the carriers; all other carrier radars are common to other ships. Thus the carriers can be identified passively only through their ATC emissions.

SPN-46 can control 2 landing aircraft at once. It has a 10-nm operating range and monitors a 4-nm approach-control zone. The radar operates both in Ka-band (33.0–33.4 GHz) and in X-band (9275–9345 MHz) at a peak power of 50 kW (pulse width 0.2 microsec, PRF 2000 pps). It scans at 12 scans/sec, searching over a 25×1 -deg box 1200 ft deep in range. Minimum range is 150 ft, and range resolution is 2 ft. Azimuth and elevation resolutions are 0.00274 deg, for accuracy in glide-slope calculation. Elevation coverage is $+30/-15$ deg, and azimuth coverage is ± 155 deg. The system uses two 4-ft dual-band antennas, with conical scan in Ka-band and monopulse operation (Cassegrain feed) in X-band. The associated computer is AYK-14, and the elements of the system are tied together by a 1553B bus. There are 3 operating modes: (I) closed-loop automatic landing, (II) ILS approach (position data are shown on the cockpit display), and (III) talk-down. The system is called PALS (precision approach and landing system).

SPN-46 is manufactured by Bell Textron. As of April 1990, it had been installed on board the carriers *Abraham Lincoln* and *John F. Kennedy*, and it was being installed on board the *Kitty Hawk* and *George Washington*.

SPN-42, of which SPN-46 is an LPI equivalent, is a dual-channel automatic-aircraft-landing system, each channel of which can handle 1 airplane at a time. Each channel employs a pair of antennas, a Ka-band dish (AS-1347/SPN-42) and a smaller X-band beacon receiver (AS-2407/SPN-42) rigidly mounted to the dish. The main dish tracks by conical scanning, using a 0.57-deg beam scanning at 6000 rpm. SPN-42 tracks the incoming airplane and transmits track data to NTDS; the system transmits course corrections back to the incoming airplane via Link 4A. There are 3 alternative operating modes: automatic, in which commands are sent directly to the autopilot of the airplane; semiautomatic, in which the pilot responds to corrections sent via a pointer in the cockpit; and a manual (talk-down) mode.

OPTRONIC SYSTEMS

◆ Mk 24 Target Designation Transmitter/WDS Mk 11

Mk 24 is the standard U.S. Navy optical target designator, transmitting target elevation and bearing to a ship's combat system. It consists of a pair of counterbalanced binoculars atop a pedestal. Elevation limits: $+90/-20$ deg. The transmitter proper weighs 210 lb and is 70 in high, with a swept radius of 12 in. A below-decks control unit (Mk 79) adds another 95 lb. When combined with a data transmitter, Mk 24 is part of WDS Mk 11, incorporating 4 (Mod 2 or 3) or 2 (Mod 4) Mk 24s.

◆ Mk 35 Optical Director/Model 985

This Kollmorgen periscope system was designed for the U.S. post-Vietnam small-combatant program of the early 1970s, for FCS EX-93. Mk 35 has been incorporated in the Korean *Paek Ku* class and in H930 Mods 0, 1, and 2. The periscope carries day/night stabilized optics plus a television. The operator can estimate range by stadimeter (i.e., by an angular measurement of a known distance on the target), or the director can track in bearing while radar is used for ranging.

Although this director is primarily optical, and primarily driven by the operator's joystick, Mk 35 has provision for automatic tracking using the television camera. Elevation FOV limits are $+80$ and -30 deg, the FOV itself being 8×32 deg. The director can slew at 80 deg/sec (e.g., when accepting designation from another source). Resolution is 0.2 m at 3000 m, or 0.9 m at 15,000 m in daylight; corresponding night figures (clear with quarter moon) are 1.5 and 7.5 m.

Model 985 is a slightly lighter and less expensive version of the Mk 35 developed by Kollmorgen; Model 985 is in the Taiwanese *Hai Ou* class, where it feeds a locally developed FCS based in part on H930. The operator's position is a desk with 2 handgrip controls, the eyepiece of the periscope being fixed above the control panel, 7 ft 2.25 in above the deck. There are 2 FoVs (wide for acquisition, narrow for engagement). The periscope can be fitted with a 1-in vidicon (silicon, target type) TV tube. Tracking accuracy is 1 mrad. Elevation limits are $+70/-25$ deg, and slew rate is 80 deg/sec (acceleration 120 deg/sec²). Low power: magnification $2\times$, FoV 30 deg, focus 10 m to infinity. High power: $8\times$, 7.5 deg, 50 m to infinity. The total system weight is about 235 kg.

Kollmorgen announced a more elaborate remote periscope system, Model 875, in 1980, but it seems not to have been sold.

◆ Director EX-46 Mod 0

Kollmorgen's electro-optical director for the *Arleigh Burke* class won a competition against Norden/SAGEM. It feeds data into the GFCs, whose only other sensor is the ship's SPY-1D radar. The director carries a television and a Kollmorgen Micro-FLIR; the latter scans a SPRITE array both horizontally and vertically (it is a hybrid-serial FLIR). There is no laser, neither for range finding nor for target designation. The above-deck unit is about 30 in wide and 28 in high and weighs about 300 lb. This contract was awarded in June 1990.

EX-46 replaces the abortive EX-121 Seafire electro-optical FCS, described in the previous edition of this book. Alternatives

closed out in favor of Kollmorgen and Norden were Contraves (Sea Hawk II, see Switzerland), Lockheed (offering the Swedish 9LV-series), Hughes (using a version of the Italian NA-18L carrying Hughes sensors), and McDonnell Douglas.

◆ CWDD (AN/KAS-1)

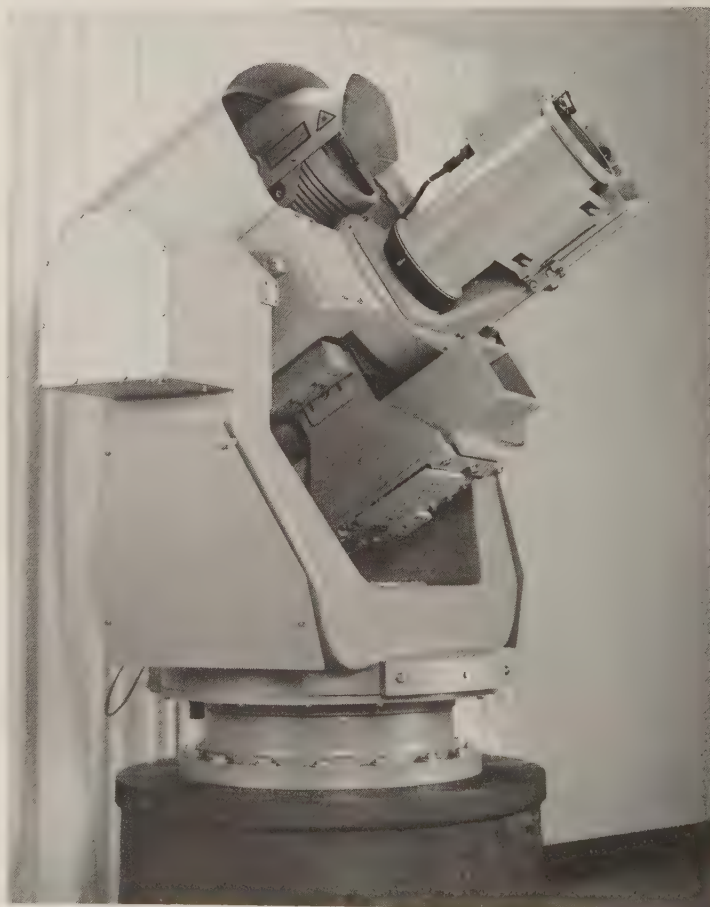
Texas Instruments's Chemical-Warning Directional Detector is a modified army TAS-6, mounted on a ship's railing or TDT pedestal. CWDD is a binocular direct-view FLIR that can also be used for intelligence collection and gunlaying. Production began in 1982.

◆ H930 Optronic Sensor (Modular Combat Optronics System)

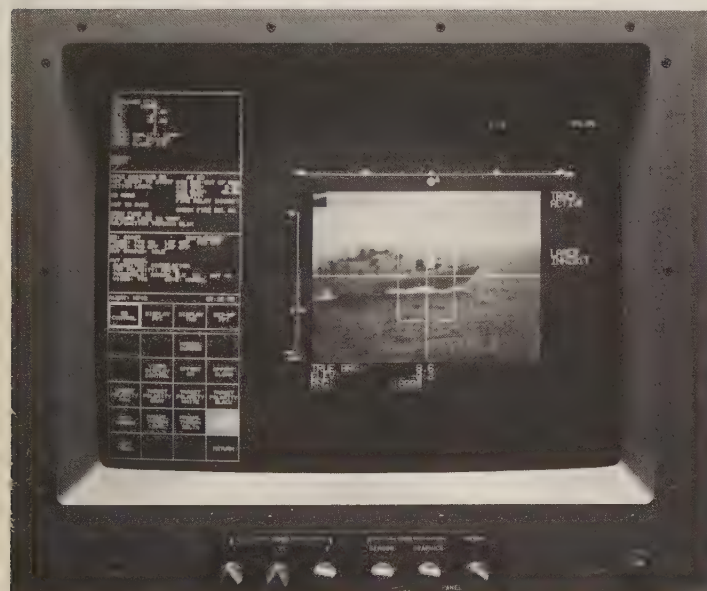
This sensor is part of the H930 on board Taiwanese *Wu-jinn III* destroyers. It can receive designations from other shipboard sensors, or it can be used to designate targets to other sensors. The system operator chooses among correlation, centroid, and edge tracking modes. The horizon-stabilized platform on its pedestal carries a television camera, a laser, and a FLIR. A below-decks joystick positions the pedestal; switches on the joystick control functions such as zoom control, entering auto-track, laser firing, entering manual mode, FLIR control, and automatic video tracker control. Television and FLIR images are displayed on a common raster-scanned monitor on the below-decks console.

◆ Hughes E-0 Sensor (HIRE)

Hughes is developing a FLIR, HIRE (Hughes IR Equipment), for the export market, using the Selenia NA-30, NA-18L, or Medusa Mk 3 lightweight stabilized pedestal. The sensors have been selected specifically for the NA-18 pedestal. Hughes envisages a variety of optics in the 8–14-micron band for different applications. As part of this effort, NA-30 was tested on board the destroyer *Rodgers* (under the Foreign Weapons Evaluation program).



The optronics portion of the Hughes (H930) modular combat system and its display. The console carries a series of switches and a joystick, and the display is raster scanned. (Hughes)



The optronics portion of the Hughes (H930) modular combat system and its display. The console carries a series of switches and a joystick, and the display is raster scanned. (Hughes)

Hughes currently offers 2 alternative 3–5-micron sensors. One is a developmental HgTE focal-plane-array FLIR with a thermo-electric cooler, weighing about 6 lb, which should be useful in high-humidity conditions. Its alternative FOVs are about 2.5 and 6 deg, and it can detect a 0.1°C difference in temperature. This is a 2D second-generation array, scanning over a scene rather than staring. It was developed under the Thermal Weapons Sight program.

The alternative is a 512 × 512-element platinum-silicide staring array. It was developed as part of the low-cost focal-plane-array initiative.

HIRE is a more austere 8–12-micron common-module FLIR using a 60-element HgCdTe detector and a dual-mode tracker (correlation and centroid).

The Hughes laser is an eye-safe Raman-shift unit (1.54-micron wavelength), capable of both low and high (10 pps) pulse rates, the latter to track fast targets.

◆ LSEOS Mk II

Texas Instruments's Lightweight Shipboard Electro-Optical Sensor was announced in 1990. It is currently being tested at sea. LSEOS is based on a high-resolution thermal imager already in service with Chaparral missile batteries (and in production since 1983). LSEOS has already been tested on standard navy radar pedestals and integrated with an FCS; Texas Instruments states that it is currently being used in an unspecified naval application. LSEOS operates in the 8–12-micron range, has dual FOVs (15 × 20 and 2.0 × 2.65 deg), and weighs 80 lb (plus 20 lb for the control panel and 80 lb for the electronic interconnect unit). Resolution: 0.82 mrad using the wide FOV, 0.11 mrad using the narrow field.

◆ Model 975

Kollmorgen's TIS (thermal imager system) director, the sensor of which is mounted in a 2-axis stabilized turret, feeds a desk-type console below decks. The FLIR has wide and narrow FOVs, for target acquisition and for target identification and tracking. Wide FOV: magnification 3.75×, 8.5 × 1.6 deg, focus from 50 m to infinity. Narrow FOV: 14×, 2.1 × 6.4 deg, focus from 50 m. Elevation limits: +80/–20 deg. Slew rate is 0–80 deg/sec (acceleration 360 deg/sec²). Tracking accuracy is within ±1 mrad (stabilization is within 0.1 mrad).

The FLIR is a hybrid parallel-serial type developed by Kollmorgen (Model 208S MICROFLIR) using an 8-element SPRITE detector. A 30 × 10-m target can be detected at 20 km and recognized at 11 km in a light haze (10 km optical visibility, 70% humidity).

The director box is 20.75 in long and has a square cross section. Above the FLIR, it has space for a CCD television or an Nd-YAG laser range-finder. Other options are a slave mode (or radar tracking), a lead-angle computer for small-caliber weapons, and an interface to an FCS.

The single-sensor box can be replaced by a wider one, carrying a FLIR and a television camera side by side, with the laser range-finder above; in this form Model 975 is a full optronic director.

◆ Mast-Mounted Sight (MMS)

McDonnell Douglas's Mast-Mounted Sight was originally developed for army OH-58D helicopters. During 1989, however, it was fitted to *Perry*-class frigates operating in the Persian Gulf, primarily to detect floating mines. Human lookouts had proved ineffective because of the heat, dust, and humidity. Reportedly, it was also quite useful against fast attack craft and low-flying aircraft, in effect as an interim substitute for SAR-8. The USS *Crommelin* and at least 1 other ship were fitted, and as of September 1989, 7 more units were on order. The spherical turret of the sight is mounted on a bridge pedestal on the centerline, controlled by an operator in CIC. There are also 2 other displays, 1 of them on the bridge. As installed on board the *Crommelin*, the sight is used only for target acquisition, but it can be modified to control weapons as well. The U.S. Navy first experimented with the MMS in 1987, testing it on board a *Knox*-class frigate.

The spherical turret carries a FLIR, a daylight television camera, and a ranging/designating laser; tracking is digital. Its unique value in a helicopter is that it is mounted above the rotor, so that the helicopter can function from ambush, its body and even its rotor hidden by trees. Principal navy changes were: deletion of the laser range-finder/designator and optical bore-sight assembly, and control and display installation for ship adaptation. A redesigned laser range-finder is now an option.

Turret slew rate is 60 deg/sec; bearing limits are ±190 deg and elevation limits are ±30 deg. The FLIR (8–12 microns, 6.6-in aperture, 120-element common module HgCdTe detector) has 2 alternative magnifications, 3× and 10.35× (corresponding FOVs are 9.6 and 2.8 deg). Resolution is 240 lines, processed by a digital scan converter to 875 lines. There is also a television sensor (TVS) using a low-light silicon vidicon (1-in-diameter tube) operating in the 0.65–0.9-micron range, with



The Mast-Mounted Sight on board a *Perry*-class frigate. (McDonnell Douglas)

700-line resolution in an 875-line video format; aperture is 4 in, shared (in the army version) with the laser range-finder/designator. Alternative TVS FOVs are 2 and 8 deg. Total turret weight is 73 kg (161 lb).

In army tests, the criterion to detect a target was to get 2 lines on it; recognition took 12 lines.

MMS growth options proposed by McDonnell Douglas are: installation of a laser range-finder, a manually trained day/night gunsight for 0.50 cal/25-mm guns, integration with the Mk 92 fire control for 76-mm-gun fire control, an improved mounting position (presumably on a mast), a better control/display (for faster operator response, target acquisition, and failure detection/correction), improved protection using ship services such as chilled water, increased gimbal travel (for better air search/track and better operation in high sea-states), and better magnification for greater effective range and better defense against sea-skimmers.

McDonnell Douglas Electronics is marketing an improved version as Euro-Sight, adding a TOW tracker, an improved thermal imager, and a multitarget tracker. Euro-Sight incorporates a GEC TICM II thermal imager. The GEC camera reportedly provides 50% more range than the U.S. Common Module unit in the current sight, with only half the electronics. The Euro-Sight can track up to 4 targets simultaneously. McDonnell Douglas hopes to halve the cost of the sight (to under \$1 million), partly by using VHSIC chip technology to cut the number of circuit cards from 32 to 12 or 13, at the same time increasing processing power from 1 to 7.5 MOPS. Both the air force and the U.S. Navy have reportedly shown interest.

As of mid-1989, 142 MMS (out of an army requirement for 592) had been delivered.

◆ Rockwell Tactical Imaging Sensor

Rockwell (Autonetics) showed a FLIR at the U.S. Navy League show in 1990; it will go to sea on board a *Spruance*-class destroyer as an adjunct to existing point-defense sensors. It uses

a 256×256 -element, 3–5-micron staring array; the wavelength was chosen for maximum target contrast. The system is fully automatic and has a digital output. No weights or dimensions were given.

◆ Sea Tiger

Texas Instruments's optronic FCS was tested by the South Korean navy in 1985. The stabilized cylindrical body, on trunnions, carries a laser range-finder/designator next to a day television camera, above a larger-diameter thermal imager (as used in Night Chaparral). There is an automatic video tracker, which can use either the television or the infrared image. The 1-operator console is below decks. Sea Tiger was originally designed to control guns and surface-to-surface missiles, but it can also control SAMs, since it can elevate to 70 deg. Frigates can be acquired and tracked at up to 14 km. The pedestal-mounted director weighs 270 kg and has a working circle (radius) of 60 cm.

Sea Tiger itself was not commercially successful, but a few derivatives (Sea Dragon) were sold in the Far East, presumably in Korea. Sea Tiger was intended for use with the Sea Ray laser-guided surface-to-surface missile.

◆ TIMS

Texas Instruments's thermal imaging multisensor (FLIR, CCD daylight camera, and CO₂ laser) is for land and sea applications in trackers and FCSs. TIMS has a stabilized 2-window turret with a stabilized mirror inside. The FLIR has wide ($\frac{1}{2}$ mrad, 2.3×3.1 deg, f/2.0) and narrow ($\frac{1}{8}$ mrad, 6.9×9.2 deg, f/1.9) FOVs. Field of regard is $+75/-20$ deg in elevation (360 deg in azimuth). The television is a high-resolution CCD type (245×780 pixels), with an FOV similar to that of the FLIR. The laser is integrated with the FLIR. Range is about 10 km. Tracking is digital.

See also electro-optical enhancements to the Mk 68 GFCS, below.

GUN AND MISSILE FIRE-CONTROL SYSTEMS

The new *Arleigh Burke* (DDG 51) is the first U.S. surface combatant without any independent gunfire-control system as such. The SPY-1D radar is sufficiently precise to track targets and shells, for improved accuracy and reaction time. A gun-mount processor and display provides an alternative method of gun computing and a backup mode. The gun weapons system as a whole is designated Mk 34, consisting of the Mk 45 gun (5-in/54) plus a Mk 160 computer (which does the ballistic computation).

◆ Mk 33

This antiaircraft director survives only on board the Chilean cruiser *O'Higgins*; it was the predecessor to the Mk 37 of World War II. Unlike Mk 37, Mk 33 incorporates its computer (Range Keeper Mk 10) in its above-decks rotating structure. This system cannot cope with modern aircraft, and is presumably relegated to controlling 5 in/25 guns against surface targets. Maximum target speed is probably 380 kt (there is a special "dive attack" feature to deal with targets diving at up to 400 kt). Including a $\frac{1}{4}$ in shield, Mk 33 weighs about 15,500 lb.

◆ Mk 37 (GFCS)

The standard U.S. dual-purpose FCS of World War II was designed primarily to control 5-in gunfire. In the U.S. Navy, Mk 37 survives only on board the 4 battleships and the 2 reserve cruisers (*Des Moines* class). It also survives on board many ex-U.S. destroyers in foreign navies. All existing versions employ the Mk 25 fire-control radar. These directors carry 15-ft stereo range-finders. Mk 37 was the first U.S. antiaircraft FCS to employ a below-decks computer (Mk 1A), separate from the above-decks optics and, later, the radar. Mk 37 is a linear-rate system, most effective at relatively long range. Post-1945 improvements included automatic radar tracking, high peak power (250 kW in the Mk 25 radar), and 800-kt maximum target speed.

Mk 37 was superseded by Mk 67 and then by the very similar Mk 68. For a typical version, Mod 62, operating limits were a lead angle of 30 deg and a range rate of ± 450 yd/sec. Detection and tracking ranges were 100,000 yd, and maximum computed range was about 20,000 yd. Total weight was 40,150 lb including the below-decks computer, and the working circle radius was 100 in. Elevation limits: $+110/-25$ deg.

◆ Mk 38 (GFCS)/Mk 34/Mk 54

The *Iowa* class's 16-in GFCS was the first U.S. application of amplidyne drive. Mk 38 incorporates a stable vertical (Director Mk 41) and a long-base (26 ft 6 in) stereo range-finder, as well as a ranging/spotting radar (Mk 13). The main functions of the aloft director are to obtain target range and bearing, and level angle and cross-level (which are also supplied by the below-decks stable vertical). Weight is 50,450 lb above decks and 10,305 lb below decks, with 12 crew above and 20 crew below decks (2 plotting rooms). The associated computer is Range Keeper Mk 8. The director operates in primary control (observed target bearing transmitted directly to Range Keeper in plot). The director can be manually driven (by hand wheels) or power driven.

Because the computer is electromechanical, it requires a special cam for each combination of projectile and velocity. Cams exist for the 2700-lb AP shell (2500, 2300, and 1800 ft/sec) and for the 1900-lb HC shell (2690, 2525, and 2075 ft/sec). The latter shell did not enter service until late 1942, and ships did not receive the necessary cams until late in the war or postwar. Calculating limits are 45 kt (target speed) and 50,000 yd.

Ships were completed with a Mk 40 standby director in their conning towers, connected to a small radar. In addition, the turrets (Nos. 2 and 3) have their own long-base (46-ft) stereo range-finders and Mk 3 analog fire-control computers.

A Mk 48 shore-bombardment computer was added to the forward plotting room in the 1950s; a second unit was added aft upon modernization (in the *New Jersey*, for service in Vietnam). In addition, upon modernization 2 HP-85 digital computers were added, 1 to estimate initial velocity for each shell on the basis of erosion, powder temperature, and previous shell velocities from that gun; the second to correct for trunnion height, target height, earth curvature/rotation, and temperature. In addition, the system can correct for errors in the cams of the Mk 8 Range Keeper.

The system as a whole is less than satisfactory because it still relies on a few pre-cut cams to deal with a wide variety of current

and new shells and ballistic conditions. The ships will, therefore, be modernized with new Mk 160 computers (as in the new *Arleigh Burke* class) tied to the existing 16-in FCSs.

As an interim measure, commercial microcomputers have been used, at least since the mid-1980s, running software developed for more modern fire-control computers.

Mk 34, essentially a smaller-caliber equivalent to Mk 38, survives only on board the Chilean cruiser *O'Higgins*. This director carries a Mk 13 (or the equivalent Mk 8 Mod 3) radar. Mk 34 carries an 18-ft range-finder and weighs 41,300 lb (topside) plus 10,742 lb (below decks). Topside crew is 16, with 5 more below decks. The associated computer is Range Keeper Mk 8 (which is also used in the similar Mk 38 battleship director). Maximum target speed is 45 kt.

Mk 54 is the GFCS on board the 2 surviving *Des Moines*-class cruisers. It was designed to replace the earlier, cramped Mk 34 and to provide some antiaircraft capability (against targets with speeds up to 800 kt). Like Mk 34, Mk 54 incorporates a Mk 8 Range Keeper (to track surface targets), but it also includes 2 antiaircraft computers, Mk 1A (as in the dual-purpose Mk 37 system) and Mk 48 Mod 1. As in the earlier system, the associated radar is Mk 8. Total topside weight is 40,452 lb, and below-decks weight is 13,792 lb; it requires 10 topside personnel and another 20 (for 2 plotting rooms) below decks. Mk 54 carries a 26.5-ft range-finder.

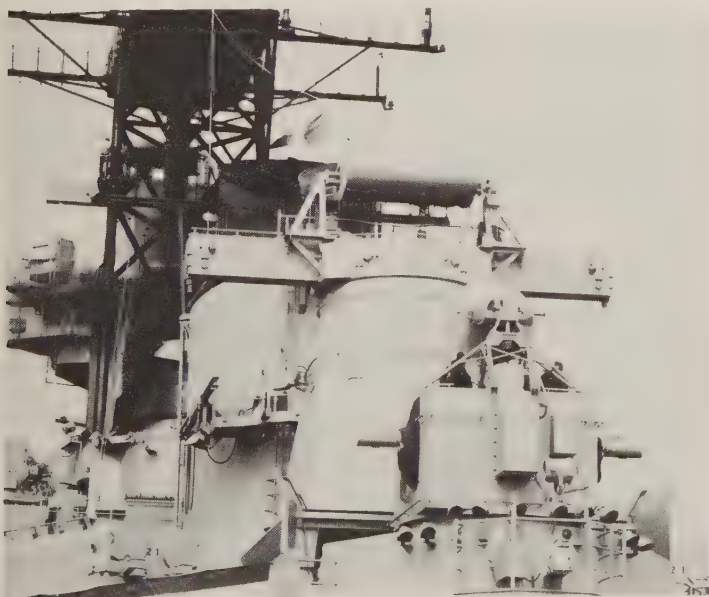
◆ Mk 51/52/63/70 (GFCS)

Mk 51, essentially a remote lead-computing gunsight, was the most successful World War II light director. Mk 52 was a modified Mk 51 carrying a Mk 26 range-only radar, primarily for destroyer escorts. The typical weight of Mk 51 was 710 lb above decks. Mk 52 weighed 1710 lb above decks and 1320 lb below decks. Mk 52 incorporated Computer Mk 6 for surface fire. Operating limits for Mk 52: lead angle 20 deg, target speed 350 kt, range for surface fire 12,000 yd, range for AA fire 7000 yd.

Mks 51 and 52 survive in some foreign navies.

Mk 63 is essentially a Mk 51 with a tracking radar (Mk 34 or SPG-50) on the gun mount itself. Typical weights: Mod 23, 3900 lb; Mod 24, 4000 lb; Mod 28, 5300 lb; Mod 29, 5400 lb. Operating limits: detection range about 37,000 yd; tracking range about 35,000 yd; computing range about 7000 yd. Maximum lead angle 20 deg, maximum range rate $+350$ kt, -800 kt. Range limits are 800 and 7000 yd. The above-decks director pedestal (carrying a Mk 29 sight) weighs 1300 lb.

Mk 70 was a modified Mk 63 in which radar range was introduced automatically, rather than manually, into the lead-computing gunsight. Mk 70 was installed on board the helicopter carrier *Iwo Jima*, to control twin 3-in/50 guns Mk 33.



Mk 38 director (with Mk 13 radar) on board the USS *Wisconsin*, 1988. In the foreground is a Mk 37 director carrying a Mk 25 radar, turned toward the main battery director. (S. Terzibaschitsch)



Mk 52 gunfire-control system with Mk 26 range-only radar, on board a destroyer escort. (Naval Historical Center)

The other ships of the class had Mk 63 directors. Mk 70 had an SPG-52 radar, and maximum target speed was 650 kt.

Mk 70 Mod 2 equips the former U.S. *Claud Jones*-class escorts in Indonesian service.

◆ Mk 56 (GFCS)

This standard U.S. postwar 3-in/50 blind-fire director also incorporated 5-in/38 or 5-in/54 ballistics. Unlike Mk 37, Mk 56 is a relative rate, i.e., a medium-range, system. In such a system the overall fire-control problem is approximated by concentrating on the motion of the target relative to the firing ship at any given moment; the faster the targets, the less the effect of omitting the motion (other than roll and pitch) of the firing ship. The firing solution is generated within 2 sec of beginning tracking a target. Mk 56 carries a Mk 35 (SPG-35) radar and employs a Mk 30 below-decks computer. Mk 56 was the first U.S. blind-fire director without an optical range-finder. Operating limits: lead angle 30 deg, range rate ± 260 yd/sec. Maximum detection-and-tracking ranges are 30,000 yd, and maximum computing range is 15,000 yd. Elevation limits: $+82/-23$ deg. Total weight: 17,000–26,000 lb, with a 51-in (radius) working circle. Above-decks weight is 9809 lb.



Mk 56 gunfire-control system, in this case controlling 5-in/38 guns on board a U.S. *Essex*-class carrier, now discarded. (U.S. Naval Institute)

◆ Mk 68 (GFCS)

Mk 68 is a 5-in linear-rate GFCS, found on board many U.S. cruisers, missile destroyers, and frigates. It employs the SPG-53 radar and was succeeded by Mk 86. Mk 68 carries an 11-ft stereo range-finder and uses 2 below-decks computers, Mk 47 and Mk 116. Mk 47 was an electronic/electromechanical analog replacement for the electromechanical Mk 1 of the Mk 37 FCS; and Mk 47 provided faster, smoother solutions. It was first employed in the postwar Mk 67 director. Mk 68 was essentially a Mk 67 modified to handle supersonic targets. Limits: detection range about 90,000 yd, tracking range about 100,000 yd, computing range about 18,000 yd. Maximum lead angle 50 deg, maximum range rates ± 1125 yd/sec. Elevation limits $+85/-20$ deg. Above-decks weight is 15,300 lb (working-circle radius 80 in). Total installed weight: 26,600–28,000 lb.

Texas Instruments produced 2 electro-optical adjuncts to Mk 68. In 1972, under the Quick Reaction (QRC) program, over a dozen Mk 68s were modified to include a FLIR, laser range-finder, displays, and the necessary control electronics. The system could then operate at night or in low visibility without emitting radar signals. Ships so modified were used extensively during the closing stage of the Vietnam War; because existing equipment was used, the first installation was completed 8 weeks after contract award.

In 1973, based on the QRC work, Texas Instruments was awarded a contract for a Mk 68 Electro-Optical Sensor System



Mk 68 director, with its SPG-53 radar (USS *Pharris*). (U.S. Navy)

(EOSS), as part of the Navy Gun Improvement Program. The Mk 68 optical range-finder was replaced by a high-performance FLIR plus a laser designator/range-finder, and an automatic video tracker was installed. The tracker pointed the laser, which could track to better than 0.2 mrad independent of the director. The EOSS could receive designation from other ship sensors or could acquire targets independently during conditions of radar silence. The system was installed on board the missile destroyer *C. F. Adams* and was used for 3 yr. EOSS could be recognized by the installation of the laser and television camera alongside the director turret, on its left-hand side.

Versions:

Mod 0 Original version for *Forrest Sherman* class, using the Mk 47 Mod 3 computer. Total weight was 28,000 lb. Mod 1, for the same class, used a modified computer (Mk 47 Mod 4). Mod 3, for later *Forrest Shermans* and for the *Mahan* class, had a modified computer (Mk 47 Mod 5) and added computer Mk 116. All of these versions had dual ballistics (5-in/54 and 3-in/50). In Mod 3, for the first time the radar transmitter-receiver was located in the director shield instead of below decks. Mods 1 and 3 weighed 28,800 lb.

Mod 4 *Adams*-class version equivalent to Mod 3.

Mod 5 Replacement for Mod 1 with radar moved to director shield, for DD 940–944.

Mod 6 *Mahan*-class version with computers Mk 47 Mod 7 and Mk 116 Mod 0 and SPG-53A rather than -53 radar (1961). There was a similar Mod 7 for this class.

Mod 8 *Belknap*- and *Truxtun*-class version using SPG-53A radar and computers Mk 47 Mod 9 and Mk 116 Mod 4. It controlled the 5-in/54 gun against both surface and air targets, and 3-in/50 guns against surface targets only (1962).

Mod 9 For *Mitscher*-class destroyers converted to missile ships with SPG-53B radars (which had provision for CW injection, for missile control). The computers were Mk 47 Mod 8 and Mk 116 Mod 3 (1965). These ships no longer exist.

Mod 10 For *Forrest Sherman*-class destroyers converted to missile ships with SPG-53B radars; the computers were Mk 47 Mod 5 and Mk 116 Mod 0 (1965). These ships no longer exist.

Mod 11 For *Knox*-class frigates (FF 1052-1077) with SPG-53A radars and computer Mk 47 Mod 10 (no Mk 116), to control 5-in/54 guns. This version was also used on board Spanish *Baleares*-class frigates.

Mod 13 For *Joseph Hewes* (FF 1078), with provision for RAP (rocket-assisted shell) fire, using the Mk 47 Mod 11 computer. The radar was SPG-53A, and there was no Mk 116 computer (1969).

Mod 14 For *Knox* class (FF 1056, 1068, 1072, 1075, 1078, 1079), to provide them with a surface-missile capability (Standard ARM, the Interim SSM), using ORDALT 6010A. These ships are also fitted with ORDALT 6948, to allow them to fire RAP rounds. The computers are Mk 152 Mod 1 and Mk 47 Mod 10, and the ship is also fitted with a Mk 154 Mod 9 range computer (digital ranger ORDALT 6894). The radar is SPG-53D (1972).

Mod 15 Was a special electro-optical system fitted on board the USS *Adams* in July 1975 and removed in June 1979. It employed an EX 160 Mod 0 computer and electro-optical sensor set EX 1 Mod 0 (which included a laser ranger) with radar SPG-53F. This experimental system temporarily replaced the ship's Mk 68 Mod 4.

Mod 16 For the USS *Adams* and *Belknap*, using computer Mk 160 Mod 1 (1 gun) or Mod 2 (2 guns) and radar SPG-53F (1979).

Mod 17 *Belknap*-class system replacing Mod 8 (replaces Mod 16 on board *Belknap*) using computer Mk 160 Mod 3 and radar SPG-53F (1979).

Mod 18 *Mahan*-class system to replace Mod 6, using computer Mk 160 Mod 3 and radar SPG-53F (1979).

Mod 19 *Adams*-class system (for DDG 2-16, 18, 21, i.e., those that were not fitted with Mk 86) to replace Mod 4, using computer Mk 160 Mod 3 and radar SPG-53F (1979).

Mod 20 *Knox*-class system to replace Mods 11 and 13, using computer Mk 160 Mod 3 and radar SPG-53F (1979).

♦ Mk 69

GUNAR fire-control system is extinct in the U.S. Navy but still in use in the Royal Canadian Navy. Mk 69 could handle supersonic targets. Tracking range was 40,000 yd (computing range 10,400 yd); maximum target speed was 1250 kt, and maximum lead angle was 30 deg. The director was intended for use against air targets only, controlling guns firing proximity-fuzed ammunition. Typical topside weight was 5000 lb, with another 8400 lb below decks, and working-circle radius was 36 in. Personnel: 2 in the director and 2 below decks. Mk 60 is the Canadian designation for the solid-state version now being substituted for the original U.S. Mk 69 (with the SPG-515 radar).

♦ Mk 74 (MFCS)

Mk 74 is the SM-1(MR) GMFCS in U.S. and foreign service. It consists of the SPG-51 radar on a Mk 73 director plus a computer, originally Mk 118 (1 per radar). The computer aids the tracking radar in acquiring a target and projects the target's position ahead for rate-aided tracking. It generates orders for the Tartar launcher (and, at least in the case of an *Adams*-class destroyer, can simultaneously generate orders for two 5-in/54 mounts). It also generates Tartar missile orders and the display data for target evaluation in the WDE. The associated WDS is Mk 4 (Mk 11 when it is integrated with NTDS).

The elevation limits of the 2-axis-stabilized Mk 73 director are +83/-30 deg. It carries both the SPG-51 radar antenna and an LLLTV camera (Mk 15).

The prototype was completed in 1958, and the current Mod 2 appeared in 1969. It incorporated solid-state electronics and direct-drive motors rather than the earlier amplidynes (and vac-

uum tubes) of Mods 0 and 1. Mod 3 was never produced, and Mod 4 was developed into a Mk 80 director for Aegis (the abortive version with a tracking rather than a slaved illuminator). Mods 5 and 6 are modernized versions of Mods 0 and 1 (Mod 6 is a modernized version for *Adams*-class missile destroyers, first delivered in September 1979). The current Aegis slaved director (Mk 82) is a lightweight (2680 vs. 7600 lb) version of Mk 73, capable of higher angle rates.

FCS Mk 74 is primarily for missile control, but it can also provide tactical data to the associated WDS (Mk 4 or Mk 13). Normally, the WDS controls the GFCS and the 2 Mk 74 MFCSs separately, but the 2 systems interconnect through the WDS. The Mk 68 on board most SM-1 ships can track targets sufficiently accurately to slave the 2 SPG-51s if their tracking elements fail. The Spanish *Baleares* class, with only a single SPG-51, has a second Mk 118-2 computer associated with the Mk 68 GFCS to provide a second missile-control channel. This computer accepts target position and rate functions from the Mk 47-12 computer of the GFCS.

The most important development in this series was Tartar D (digital Tartar, using SPG-51D: Mk 74 Mods 4 and 5). Tartar D was conceived in response to a revised SOR. Its extended tracking range more nearly matched the extended range capability of the SM-1(MR), compared to the earlier Tartar.

Capabilities of the original Mk 74 system (Tartar missile, predecessor of SM-1(MR)): acquisition range, 120 kyd (on an F6F airplane); reliable tracking range, 20 kyd; minimum range, 500 yd; range rates, 50-1320 kt; angle rate, up to 120 deg/sec.

About 1975 the Tartar FCS was credited with a tracking capability between 2000 and 200,000 yd; targets were acquired at 120,000 yd (the associated 3D radar could detect targets at 160-240 nm, and the associated 2D radar could detect them at 20-285 nm, depending on the radar).

Versions:

Mod 0 Original version for missile destroyers, using an analog computer (Mk 118). The radar was SPG-51.

Mod 1 Version for the 3 *Albany*-class missile cruisers, using the Mk 118 analog computer and SPG-51 radar. Total weight was 19,000 lb.

Mod 2 *Brooke* (FFG 1), DDG 31, and DDG 35-class version, with WDS Mk 4. The computer was Mk 118 Mod 2, and the radar was SPG-51B.

Mod 3 Revised version for missile destroyers and frigates, with SPG-51C radar.

Mod 4 Tartar-D (digital) version, for the *California* class (1969), with NTDS (WDS Mk 11, SPG-51D). It was similar to Mod 3, but with a digital (Mk 152) rather than an analog computer, with SPG-51D rather than -51C, and with a Mk 73 Mod 2 director. Estimated total weight was 65,000 lb. The *Californias* were the first ships to have SPG-51D.

Mod 5 *Virginia*- and *Kidd*-class version (1969) of Tartar-D, with Mk 26 dual-purpose launcher (WDS Mk 13).

Mod 6 Mod 0 with a digital computer (Mk 152 Mod 1), the digital update for DDG 2-24 (1969); total weight was about 19,000 lb. The radar was SPG-51C.

Mod 7 Tartar system for DDG 31-34 conversion, similar to Mod 6 (Mk 152 computer, SPG-51C radar).

Mod 8 Similar to Mod 6 but WDS Mk 4 is upgraded to Mk 13 Mod 1/JPTDS (Junior Participating Tactical Data System). The WDS Mk 13 computer is integrated with the Mk 152 Mod 1 computer (1971). This is the FY71 ASMD program upgrade, for 4 DDGs (DDG 9, 12, 15, and 21). The radar is SPG-51C.

Mod 9 The Mk 152 computer is replaced by UYK-7 (1974); this version is smaller and lighter than earlier ones (for the *Arkansas* and projected further ships of that class).

Mod 10 *Perry*-class version with UYK-7 computer (1974).

Mod 11 Mk 152 (digital computer) version for *Adams*-class destroyers (DDG 2-15), 1974. The radar was SPG-51D (Tartar-D).

Mod 12 Mk 152 (digital computer) version for the *Brooke* (FFG 1) class, 1974. The radar was SPG-51D (Tartar-D).

Mod 13 Derived from *Mod 8*, and similar to it, for modernized *Adams*-class destroyers (SM-1 missiles). It was designed to work with WDS Mk 13, and it used the SPG-51C director, and LLLTV Mk 5.

Mod 14 CGN/SM-2 version (1983). The radar is SPG-51D. This version includes an OJ-194 console for FCS supervision. Total weight: 42,665 lb.

Mod 15 *California*-class NTU Baseline, with CWAT (CW acquisition and tracking). Total weight: 44,835 lb.

◆ Mk 76 (MFCS)

Mk 76 is the SM-1(ER) GMFCS in U.S. and Italian (*Vittorio Veneto*— and *Andrea Doria*-class cruisers) service; it was formerly on board the Dutch cruiser *de Zeven Provinciën*. Mk 76 is broadly analogous to Mk 74, consisting of a radar (SPG-55) atop a Mk 74 director with a computer (originally Mk 119). Originally controlling Terrier missiles, Mk 76 could track targets at speeds as great as Mach 2 and with angle rates as great as 120 deg/sec (60 deg/sec in elevation). The maximum acceptable range rate was 40,000 yd/sec. The original SPG-55 radar could track targets out to 60 nm. By 1975 the maximum tracking range had been increased to 120 nm and the maximum target speed to more than Mach 2.5. At that time the system could control SM-1 missiles against targets out to 80 kyd and at altitudes of 50,000–80,000 ft. Total system reaction time was given as 60 sec, including target-data processing, threat evaluation, launcher loading, and weapons assignment. The launcher (Mk 10) took 45 sec to fire its first salvo and 30 sec between later salvos.

Unlike the earlier Mk 71, 72, and 73 Terrier FCSs, Mk 76 could be retrofitted for CWI (originally 2 kW, later 5 kW). By 1965 all *Mod 0*s had been retrofitted to the dual-mode *Mod 1* version (SPG-55A); from 1964 on all could fire the nuclear beam-riding version of the missile. Mk 76 may also have been designed from the first for ultimate integration with NTDS.

Mk 76 differed from Mk 74 in that it had no gunfire-control capability. Its Mk 119 computer was very similar to Mk 118 but was designed to control longer-range Terrier missiles. The system was designed to control its beam-riding Terrier missile in shore bombardment and in surface-to-surface fire. Unlike Tartar, Terrier seemed suitable for such operation because it was command-guided (in its beam-riding form). There were 2 surface-to-surface beam-rider modes, 1- and 2-director. In 1-director mode, the radar tracked the target in azimuth only, and the missile was programmed in elevation to the target (the radar had to elevate to guide the missile, and the target therefore had to be in the lower portion of its beam). In the 2-director mode, 1 director tracked the target, and the associated Mk 119 computer provided the other director with missile orders. In shore bombardment, 1 director could track a beacon ashore while the other controlled the missile. In the absence of command guidance, a semiactive missile could still be fired at a ship, but only at short range; hence the interest, in the mid-1970s, in active and ARM versions of SM-1. Command guidance (in SM-2) restores the capability for longer-range surface-to-surface fire.

The associated WDSs are Mk 3 for the *Farragut* class, Mk 6 for the cruiser *Long Beach*, Mk 5 for the carriers (all now removed), Mk 7 (missile cruisers CGs 16–35), and Mk 11 (ships refitted with NTDS integrated with their FCSs).

Versions:

Mod 0 Version for *Farragut*-class destroyers (DDG 37 class) with SPG-55 radars and the Mk 119 *Mod 0* computer, first on board *Coontz* (DDG 40) in 1959. In 1964 Mk 119 *Mod 0* was modernized into a configuration equivalent to *Mod 3* or *Mod 4* to ac-

commodate the new PEP (performance extension program) Terrier missile, which had the new Mk 30 sustainer motor. The computer was provided with new missile-control functions to aid the missile's speedgate in quickly locating target Doppler and to provide optimized homing trajectories in longer-range flights. The first 4 ships of this class were completed with the earlier Mk 73 FCS (with SPQ-5A radars) but were modernized with Mk 76.

Mod 1 Dual-mode version (SPG-55A radar) with Mk 119 *Mod 0* computer. All *Mod 0*s were upgraded to *Mod 1* configuration. Total weight: 29,400 lb (11,000 lb topside, 18,400 lb below decks). That included 25,400 lb of radar and director and 4000 lb of computer. This was the version initially installed on board the cruiser *Long Beach* and the carriers *Kitty Hawk* and *Constellation* (now removed).

Mod 2 Upgraded version with SPG-55B radar and Mk 119 *Mod 0* computer. *Mod 2* was first installed on board the *Worden* (CG 18) in 1963. This radar enjoyed better CCM through purely random PRF jitter, extra-high tracking power (5 kW average), and pulse compression.

Mod 3 Version with SPG-55B radar and Mk 119 *Mod 3* computer, for the *Belknap* class and the carrier *America* (CV 66, now removed). *Farragut*-class destroyers were upgraded to this version.

Mod 4 Version with SPG-55B radar and Mk 119 *Mod 4* computer for the *Wainwright* (CG 28) class (integrated with NTDS). Total system weight was about 30,000 lb.

Mod 5 Version with SPG-55B radar and Mk 119 *Mod 5* computer for the *Leahy* class as modernized from 1968 on, with NTDS and WDS Mk 11.

Mod 6 Version with SPG-55B radar modified with CW Acquisition and Track (CWAT) and Mk 152 computer (in place of the analog Mk 119 of *Mods 3, 4, and 5*). CWAT provides an additional tracking channel for the SPG-55 radar. *Mod 6* was first installed in the *Belknap* class. This designation was first applied in March 1972.

Mod 7 Version with SPG-55B plus a tracking module (for better C-band performance, especially in sea return) and a Mk 152 computer (in place of the analog Mk 119) for the *Dahlgren* (DDG 43) as modernized. *Mod 7* is the baseline for the CG/SM-2(ER) system (*Mod 9*). This version was installed on board the *Belknap* (CG 26) as repaired in 1976.

Mod 8 Version with SPG-55B, CWAT, and a tracking module, the Mk 152 computer for the *Bainbridge* (CGN 25) as modernized. This version incorporates a UD-1230 console for ECCM, has a single scan mode for target acquisition, and self-monitors missile casualties.

Mod 9 SM-2(ER) version with new Mk 152 computer (adds 500 lb), February 1974. The associated SPG-55B radar has a new X-band mode and serializer, a rear reference antenna, and X-band frequency agility for SM-2(ER). This version deletes the beam-riding Terrier capability from *Mod 8*. *Mod 9* was intended for all the Terrier (now SM-1(ER)) ships. This version could control the SM-2(ER) missile but was not the full New Threat Upgrade.

Mod 10 New Threat Upgrade version, to control the SM-2(ER) missile, using the Mk 152 computer. System weight is 31,000 lb. Capture and guidance facilities are deleted from its SPG-55B radar. This is the Terrier Ordalt Program (TOP), providing the director with an improved servo subsystem and a new power drive for accurate slewing and acquisition.

◆ Mk 80/84/85 (MFCS)

The Polaris FCS is obsolete in the U.S. Navy.

Mk 84 was the Polaris A-3 missile-control system for *Lafayette*-class missile submarines, replaced by Poseidon fire control (Mk 88). British Polaris submarines are equipped with Mk 84

Mod 2 (Mod 1 was a version introduced to control the Mk 2 Mod 1 version of the missile-guidance system with the Mk 5 Mod 1 missile). Mk 84 uses Computer Group Mk 146.

Mk 85 was an abortive Polaris FCS for cruisers.

See also the entry for Polaris in the Strategic Strike Systems section.

♦ Mk 86 (GMFCS)

The Lockheed Mk 86 gun-and-missile fire-control system employs the SPQ-9 TWS radar, the SPG-60 tracker-illuminator, and an electro-optical sensor (closed circuit television or LLLTV). A laser range-finder can be mounted on the stabilized television camera platform or on the SPG-60 antenna, and bore-sighted to the television tracker. An IR sensor can be mounted over the television and laser range-finder to track multiple targets, detect gun flashes, and provide a passive image of the area around the ship. The 2 radars operate independently and are linked only by the computer. SPQ-9 provides surface search and low-altitude air coverage. SPG-60 automatically scans to acquire a target but can also provide horizon search. The system can accept data from other standard U.S. systems such as NTDS or ITAWDS (for amphibious fire support) or the Mk 74 MFCS, and Mk 86 can accept data from other shipboard sensors and from 1 of 4 target-data transmitters (TDTs).

Mk 86 grew out of an Operational Requirement issued in 1961 for a new surface-to-surface GFCS to support amphibious operations. BuOrd issued a contract to Lockheed Electronics in 1964. Mk 86 was required to track 4 targets and to engage 2, and also to be compatible with the variety of guns in the fleet (3-in to 8-in). It had to interface with NTDS. All of these requirements pointed toward the use of a general-purpose (programmable) digital computer. Mk 86 was tested in this surface-only form (as Mod 0) in 1965 on board the *Barry*, using only the SPQ-9 radar. About 1967 requirements for antiaircraft fire control and CWI (for missile control) were added, requiring a separate monopulse air-track antenna (SPG-60) with its transmitter and receiver. New versions introduced at this time were Mod

1 (surface and air gunnery) and Mod 2 (surface and air gunnery and CWI for missile control). The CWI mode could be used as a backup Tartar (now replaced by Standard Missile [MR]) control channel.

Mod 1 was for the *California* class (superseded by Mod 3). Mod 2 was for the test ship *Norton Sound*.

Because surface fire and AA fire used separate antennas, the modified Mk 86 could engage 2 targets simultaneously (it has 2 separate gun-control consoles). It used a more powerful computer, a Univac 1219 (Mk 152) in place of the Univac 1218 (Mk 150) of the original system. This doubled memory capacity (to 32k 18-bit words, with 16 I/O channels) and permitted simultaneous use of the fast and slow channels. Using the Mk 152 Mod 2 computer, Mk 86 could track 5 targets, engaging 2 simultaneously. Computing range was 131 kyd, maximum angular rate (air targets) was 12 deg/sec, maximum range rate (air) was Mach 3, required MTBF was 416 hr, and required MMTR was less than 18 min. In this form Mk 86 could communicate directly with NTDS and with the Tartar (now Standard Missile) system without special buffers.

Capabilities of the existing versions are:

	VERSIONS					
	Mod 3	Mod 4	Mod 5	Mod 8	Mod 9	Mod 10
Surface/low-fliers tracked	4	4	4	4	4	4
Air targets tracked	1	1	1	1	2	1
Simultaneous surface/low-flier engagements	2	3	2	2	2	2
Simultaneous air-target engagements	1	1	1	1	2	1
Semiactive illumination	No	No	Yes	Yes	No	No
Visual trackers	2	3	2	1	1	2

Versions:

Mod 1 was for the *California* class (superseded by Mod 3).

Mod 2 was for the test ship *Norton Sound*.

Mod 3 (*Spruance* and *California* classes) uses the Mk 152 computer.

Mod 4 is on board *Tarawa*-class assault ships.

Mod 5 is in the *Virginia* and *Kidd* classes; it uses a UYK-7 computer. Total weight is 14,200 lb.

Mod 6 is a version with a UYK-20 computer. Total weight is 11,734 lb.

Mod 7 is a Mod 0 with a new-generation computer (UYK-20). Total weight is 7200 lb.

Mod 8 was the version for modernized *Adams*-class destroyers; the program was canceled after the first 3 had been installed. Mk 86 did replace the earlier Mk 68 system on board the West German *Adams*-class destroyers, and a similar program is underway for the Australian ships of this type. The computer is UYK-7. Total weight is 14,750 lb. Fitted with a UYK-7, a Mk 86 can track up to 120 targets simultaneously.

Mod 9 is the version for Aegis ships. It has no SPG-60 radar, using Aegis data for gunfire control against air targets. The computer is UYK-7, and total weight is 10,000 lb.

Mod 10 is a replacement for Mod 3 with a UYK-7 computer, for *Spruance*-class destroyers; it was conceived partly as an adaptation of Mk 86 to fire laser-guided shells (Deadeye; see the discussion under the Mk 42 5-in/54 gun, below). The standard gun-control console was replaced by a Mk 113 weapons-control console, providing an interface between fuze-setting and func-



The 2 radars of the Mk 86 GFCS on board the USS *Mississippi*, June 1988: radome-enclosed SPQ-9A above, SPG-60 below. The hole in the SPG-60 antenna is for the television tracker. (Stefan Terzibaschitsch)

tion-setting, selecting ammunition, calculating ballistics for the guided shell, and designating the target to the Seafire laser designator. The computer is UYK-7, and total weight is 15,507 lb.

Mod 11 (1983) supersedes *Mod 4* in the *Tarawa* class; the computer is UYK-7. Total weight is 15,507 lb.

Mod 12 is a UYK-7 version for the *Kidd* and *Virginia* classes.

In November 1989 Lockheed Electronics delivered the first of a series of Ordalt kits developed under a 1985 contract, providing a digital MTI and a low-noise front end (LNFE) for the SPQ-9A radar. The LNFE is built around a solid-state low-noise amplifier; fitted with it, the radar can detect smaller targets at greater ranges. The FY90 program includes improvements to SPQ-9A so that it can detect small radar targets more effectively, in response to requests by the Middle East Force. Presumably, the LNFE was intended primarily to deal with air targets; the new program concerns small attack boats such as Boghammers.

The FY88 program also included an emergency improvement to the Mk 86 system to engage fast, radically maneuvering surface targets (such as Boghammers), which were then being encountered by the Middle East Force.

Current SPG-60 improvement programs include a sidelobe canceler (to solve problems recently experienced by the fleet), a product improvement package for greater effectiveness against sea-skimmers (FY90), and addition of a CW injector so that the radar can function as a second track/illuminate channel for NATO Sea Sparrow missiles on board *Spruance*-class destroyers and large amphibious and auxiliary ships (FY90).

Conversion of Mk 86 systems on board U.S. cruisers to the UYK-43 computer began in FY88.

Under the FY91 program, the Mk 86 Video Processor Mk 2 is being improved to provide false-alarm filtering, adaptable video thresholds, a capability to track 10 or more targets, and also full-range Low-Altitude Detection/Acquisition (LAD/A) coverage.

◆ Mk 88/89

Mk 88 is the Poseidon C-3 strategic-missile FCS. Mk 89 is the corresponding land test-facility FCS.

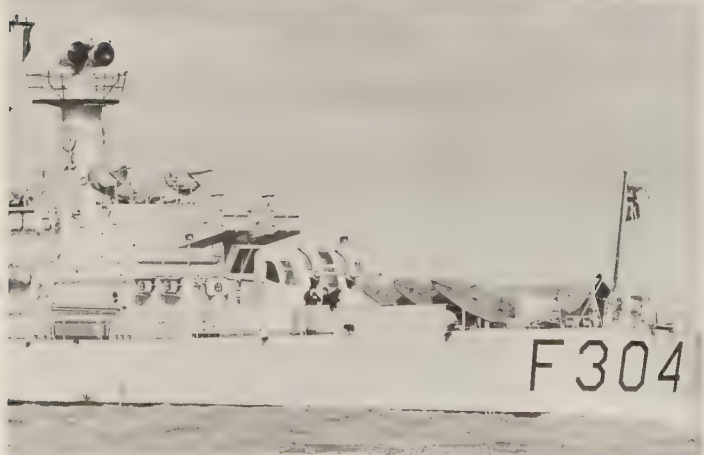
See the entry for Poseidon in the Strategic Strike Systems section.

◆ Mk 91

Band: X **Peak Power:** 2 kW (average, CW)

Antenna Dimensions: 100 × 96 in **Antenna Weight:** 3315 lb

Mark 91 is the U.S. FCS associated with the NATO Sea Sparrow Missile System (NSSMS). Mk 91 succeeded BPDMS (Mk



NATO Sea Sparrow on board the Norwegian frigate *Narvik*, March 1985, showing the radar of the Mk 91 fire-control system atop the raised platform at the left, and the 8-cell box launcher below and abaft it. The gun is an enclosed version of the standard U.S. twin 3-in/50, and the containers hold Penguin antiship missiles. (L. Van Ginderen)

115) and, like the earlier system, uses separate transmitting and receiving CW antennas. Targets are automatically designated from either SPS-58/65 or TAS Mk 23 radars, the Mk 95 radar of the Mk 91 FCS tracking the target automatically and illuminating it. Unlike BPDMS, NSSMS incorporates a wide-beam antenna to provide the missile with a reference beam. That reference in turn makes it possible for the missile to use proportional navigation, which is more efficient than a direct pursuit path.

Both transmit and receive antennas are 39 in in diameter; the transmitter is a parabolic dish, the receiver a Cassegrain twist reflector.

Mod 0 is the single version, *Mod 1* the dual version as used by the Danish, Norwegian, Italian, Japanese, and U.S. navies. There is also a special "Netherlands" configuration used by the Belgian, West German, Dutch, and Spanish navies employing the Dutch M25 fire-control system.



NATO Sea Sparrow launchers and Mk 91 illuminators (radar Mk 95) on board the carrier *USS Ranger*, July 1986. An electro-optical tracker is located between the 2 radomes of the radar illuminator-tracker. (Hughes)

◆ Mk 92 and Mk 94

Band: X **Antenna Dimensions:** (search) (track) 96-in diameter

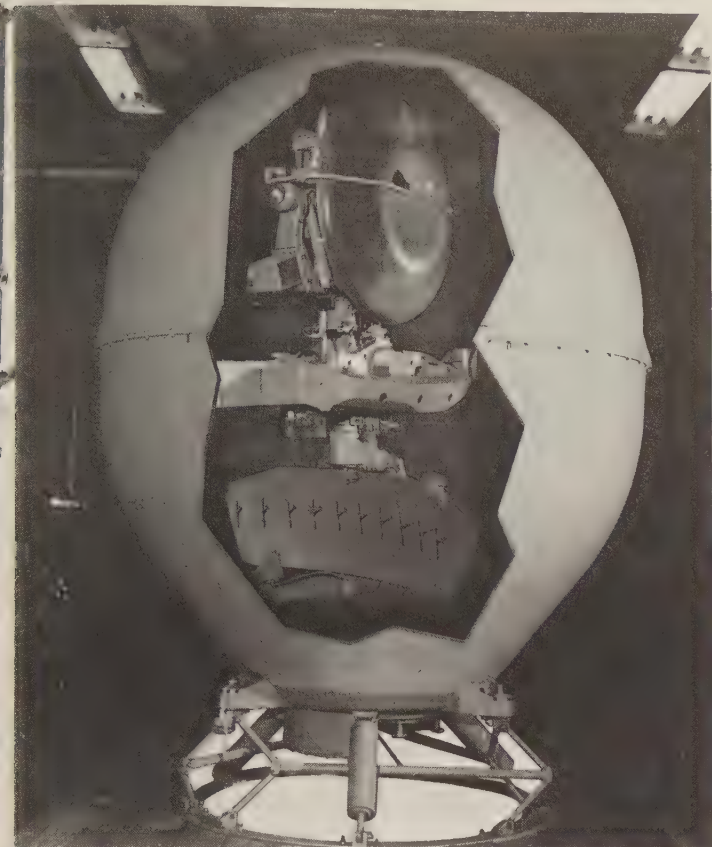
Antenna Weight: 6300 lb (topside weight)

Mk 92 is a U.S. version (produced by Sperry) of the Dutch Signaal WM 28 fire-control system. The associated TWS radar, which employs 2 antennas (the combined antenna system [CAS], UD 401) inside an egg-shaped radome, has no separate designation and is, therefore, described here. As installed on board *Perry*-class missile frigates, Mk 92 controls both the designator in the egg and a separate tracker/illuminator, the STIR (UD 417). Mk 92 controls both Standard Missiles (SM-1) and a 76-mm gun. As installed on board *Pegasus*-class missile hydrofoils, the Mk 92 is limited to the CAS and controls only a 76-mm gun.

The single console (weapons-control console Mk 106) provides a PPI for tactical display and 2 track displays (A- and B-scopes). Tracks are designated by means of a ball on the console, an acquisition gate being placed around the target blip on an A-scope. Once the target is being tracked, the A-scope displays engagement limits around the target blip so that the operator can gauge when to engage. The time-shared B-scope indicates designation or track error by the position of the target blip relative to the scope's center. Maximum instrumented range on the PPI is 128 nm (on the A-scope, 64 nm).

Versions:

- Mod 0*: 1 air-engagement channel, 2 TWS surface channels, missile and gun control; 1905 lb topside/9086 lb below decks.
- Mod 1*: 1 air-engagement channel, 2 TWS surface channels, guns only, for *Pegasus*-class PHM and *Bear*- and *Hamilton*-class coast guard cutters; 1905/5637 lb. *Mod 5* (Saudi PCC/PCG) is similar.



The antennas inside the Mk 92 Combined Antenna System (CAS). (Sperry)

- Mod 2: 2 air-engagement channels (i.e., 1 STIR), 2 TWS surface channels, missile and gun control; 6318/15,848 lb. This version is installed in the *Perry* class and requires a separate Mk 107 console, incorporating a PPI, for STIR control. Existing Mod 2s were subject to a "near term improvement" program when ships were equipped with SM-1 Block 6 missiles. The test ship was the *Stephen W. Groves* (1983).
- Mod 3 is a proposed version, not as yet sold, Mod 6 without the STIR.
- Mod 4 was not used as an official designation. It may have been the abortive Phase III with the phased-array radar.
- Mod 5 Version for the Saudi PCG and PCC programs, similar to Mod 1 above but with a higher proportion of American-made parts. There are also about 15 design improvements enhancing safety, reliability, and maintainability. Total weight is about 7835 lb.
- Mod 6 CORT upgrade, see below. In this version the Mk 106 Mod 1 weapons-control console is replaced by Mod 2, and the Mk 107 STIR-control console is replaced by Mk 107 Mod 1. Total weight is about 24,000 lb.

All versions use the UYK-7 computer, which replaces the Mk 159 (a Signaal computer) of the Mk 94 prototype system (an imported WM 28). In Mod 2 and Mod 6, CWI (for missile control) is available on 2 channels (using SPG-51D transmitters), in both the "egg" and in the separate STIR. The Mod 2 version of the system includes an OJ-194(V)/UYA-4 PPI display (not in Mod 1) plus consoles Mk 106 and Mk 107. The Mk 106 console is the system control center, with displays for target detection, acquisition, and tracking, as well as controls for target assignment, selection, weapons utilization, and means for data entry. The displays show IFF returns. In Mod 2 the console displays firing channels 1, 4, and 5. The Mk 107 STIR console is similar to Mk 106 except that surface track-and-search controls have been eliminated; it carries displays for detection, acquisition, and tracking of air targets by the STIR, as well as controls for

target assignment, target selection, and weapons utilization. Both of the air channels (2 and 3) are controlled from the Mk 107.

The 2 CAS antennas, a search antenna below and a tracker above, share a common feed and time-share their power. The search antenna scans at 60 rpm, a rate rapid enough to allow for TWS tracking of up to 2 surface targets. The search antenna provides a measure of height-finding, by spiraling the beam up in 3 revolutions (4 beamwidths), then down again in half a revolution, for interlaced coverage.

The parabolic dish at the top of the egg is used for 3D (i.e., air) target acquisition and monopulse track. Like the search antenna below, the parabolic dish can track up to 2 air targets while searching for more. This array is designated Mk 53.

The 100-in-diameter STIR antenna tracks targets out to greater ranges. It employs a modified Mk 39 antenna, with a monopulse cluster and CWI fill-in horns, on an SPG-60 pedestal. The STIR antenna is designated Mk 54.

Mod 1 is the version on board the hydrofoils, controlling only a 3-in gun. Mod 2 is on board *Perry*-class frigates. Mod 5 is mounted on board Saudi PCG- and PCC-class gunboats built in the United States.

Mk 94 was the functional prototype, an imported HSA system. It has a Mk 159 computer; Mk 92 has a UYK-7.

Several improved versions of the basic Mk 92 have been proposed. Phase I is a near-term get-well program, and it is being carried out. Phase II adds a new coherent receive/transmit (CORT) transceiver to counter heavy jamming, clutter, and STA clutter (i.e., targets just beyond instrumented range that are so large that their STAEs swamp echoes from small nearby targets). CORT is, unfortunately, quite massive, and it is not likely to be very widely applied. As of 1988, the U.S. Navy planned to buy 6 sets of CORT electronics. The *Ingraham* (FFG 61), the last of the *Perry* class, has a unique combat system combining CORT with an IADT. Phase III, proposed by Sperry (now UNISYS), is a much more ambitious program, adding a new high-elevation array. Phase III is intended to counter high-altitude targets in a heavy jamming environment. The navy has argued that Phase III is too expensive and too massive for ships that are already almost overloaded. Congress kept the program alive, but as of 1988 it had been canceled.

The Engineering Development Model (EDM) of the coherent receiver-transmitter was tested on board the *Estocin* in November 1986, and production of hardware was authorized in August 1987. The EDM was removed from the ship and installed at the combat-system test center in January 1987; integration testing was completed in October 1988. The upgraded Mk 92 with a production CORT was scheduled (early in 1988) for tests at sea on board the *Ingraham* in the third quarter of FY90. She has the SYS-2(V)2 IADT and an SPS-49(V)5 radar. The FY88 program included studies of how CORT might be backfit into ships lacking these systems.

As of 1990, UNISYS claims that CORT doubles the detection and tracking range of the Mk 92 system within the same space and weight. The radar can acquire and track targets with a radar cross section only 10% that of the smallest that Mod 2 can acquire and track. In addition, new components double system MTBF. The first ship to be retrofitted (to be completed in the spring of 1991) is the *Taylor* (FFG 50), to be followed by batches of 4 ships per year, beginning in FY92. Besides the *Ingraham*, 5 CORT upgrades were funded in FY88 (FFG 50, 51, 53, 55, and 56) and 3 in FY90. The upgrade includes replacement of the existing UYK-7 and UYK-20 computers by UYK-43s and -44s, and installation of SQQ-89 (full-spectrum towed-array processing). Spain and Taiwan have bought the CORT upgrade package (ORDALT 15-535) for their *Perry*-class frigates (in the Spanish case, only for the last 2 ships in the class).

◆ Mk 93 (GFCS)

The Honeywell gunfire-control system of the CPIC-prototype export coastal-attack boat is associated with the EX-74 (Emerlec-30) gun and uses Kollmorgen's Mk 35 periscope director.

This system appears in modified form on board other small combatants built for foreign navies, armed with the Emerlec-30 and using the periscope director. The radar is a Litton LN-66HP, a lightweight computer permitting 2-target TWS operation. The optical director can provide 2 more target tracks. The lightweight (1100-lb) computer can handle ballistics for 20-mm through 76-mm calibers.

EX-93 was the progenitor of the Honeywell/Hughes H930 series (hence the latter's name). Two somewhat similar systems were developed, Kollmorgen's Sea Serpent and the Westinghouse W-1200. Sea Serpent combined its optronic periscope director with a navigational radar (in this case a Raytheon Pathfinder) and a UYK-19 computer. Up to 20 targets could be tracked (TWS), and the laser mounted with the director optics provided accurate range data. Westinghouse combined the periscope director (Mk 35) with an LN-66HP radar and a UYK-19 computer. It also developed a series of progressively more powerful versions. Both seem to have originated in the mid-1970s, required for a system for Ethiopia. Honeywell won the contract (for H930 Mod 0), but the company's CEO decided to reject the system (a fortunate decision since Ethiopia soon had an anti-Western revolution). It seems likely that Kollmorgen and Westinghouse developed their own systems partly to compete for this particular contract; both were announced in the late 1970s.

◆ Mk 98 (MFCS)

Mk 98 is the Trident FCS for *Ohio*-class submarines (Mk 88 Mod 2 is Trident C-4 on board earlier submarines). Mod 0 is for Trident I. Mod 1 is for Trident II (D-5 missile). Mod 2 (identical to Mod 1 except that it controls 16 rather than 24 missiles) is the British version, and Mod 3 is the land-based test version.

◆ Mk 99 (MFCS)

Mk 99 is the Aegis AAW FCS. The Aegis system as a whole is designated Weapons System Mk 7. Versions:

Mod 0 is the 2-illuminator test version built for the *Norton Sound*, using separate guidance (Mk 90) and tracking (Mk 91) radar sets with 2 standby illuminators. (1970)

Mod 1 is the prototype production version for the *Ticonderoga*, using SPG-62 illuminator-only radars. The corresponding Aegis version was Mod 3.

Mod 2 is the production version for the *Ticonderoga* class (Aegis Mod 4).

Mod 3 is for Aegis Mod 6, using SPG-62A radars (1985); it was a test configuration on board the *Norton Sound*.

Mod 4 is for Aegis Mod 7; it is similar to Mod 3 but has 4 SPG-62As.

◆ Mk 100-114

Mks 100-114 are ASW fire-control systems.

◆ Mk 115

Band: X

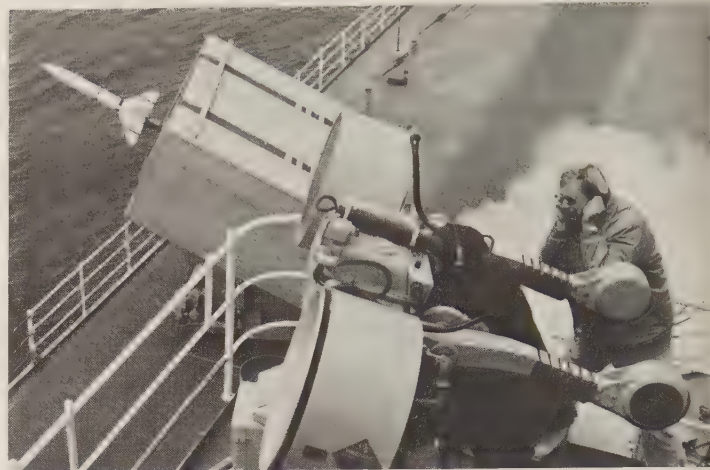
Antenna Dimensions: total 79 × 84 in (including pedestal)

Antenna Weight: 1800 lb

Mark 115 is the FCS associated with the Basic Point-Defense Missile System (Sea Sparrow); at this writing BPDMS installations are being replaced by Phalanx close-in defensive guns and also by NATO Sea Sparrow missile systems. Because the associated radars have no separate designations, they are described here.

Fire is controlled from the CIC, where a fire-control panel monitors the system. The operator there turns on launcher and radar and selects and fires the missiles. Interception range is described as 4+ nm.

The missile homes on CW energy, so the radar cannot employ a single antenna to receive and to transmit. The Mk 33 transmitter is a 2-ft parabolic dish. The Mk 19 receiving antenna is



Sea Sparrow Basic Point-Defense Missile System handlebar director (Mk 115), with its missile launching. (U.S. Navy)

a 2-ft planar array using 52 slotted waveguides in 4 sections, and is electronically conically scanned to track a target.

Tracking is manual: errors detected by comparison of transmitted and received signals are displayed in a gunsight atop the modified director pedestal, and the operator moves the "handlebars" to keep the error signal centered in the optical display. Manual pointing was adopted because the targets were expected to have high closing velocities but little angular motion relative to the ship being attacked. Even so, the person in the loop makes for a relatively long reaction time.

Work on this system began in 1963, and production began in 1967. The Mark number is higher than that of the later NATO Sea Sparrow System (Mk 91) because this quick-development system was inserted into the series numbered Mk 100 and above that is otherwise restricted to underwater fire-control systems.

◆ Mk 116-119

Mks 116-119 are ASW fire-control systems.

◆ Weapons Direction Systems (WDS)/Target Designation Systems (TDS)

Weapons Direction Systems mediate between CIC and the missile fire-control system. They are all outgrowths of post-World War II work on automatic and semiautomatic Threat Evaluation and Weapon Assignment (TEWA) systems; the TEWA was needed to decide, very rapidly, whether a given target could be or should be engaged, i.e., to take into account the effective engagement capabilities of the weapons on board the ship. A ship's actual target-handling capacity depends on the capacity of her WDS, since directors are cued, not directly from CIC, but rather from the series of tracks held by the WDS, itself fed by the same radars feeding CIC. Only with the advent of NTDS is the WDS fed directly from the automated track file in CIC, since in earlier nonautomated ships the grease-pencil track data in CIC are not accurate enough for such assignment. Thus, the difference in target capacity between an NTDS ship and a non-NTDS ship is enormous, the pre-NTDS ship being limited to perhaps 4 or 8 targets. This limitation is entirely separate from the limitation imposed by the number of missile directors, i.e., of fire-control channels. Once a particular fire-control channel has completed its engagement with a particular target, it obtains its next target, not directly from CIC, but rather from the WDS.

Non-NTDS ships with computer-driven combat systems, such as the *Perry*-class FFG, are equivalent to NTDS ships in this sense: they can maintain very large numbers of tracks ready for designation to fire control. Precomputer ships must generally assign a tracking console to each target, and the number of such consoles is very limited. As in NTDS, tracking on each console is rate aided; but the consoles do not communicate, and each carries only a single track. The pre-NTDS missile systems in current U.S. service are on board *C. F. Adams*-class missile destroyers.

A WDS consists of a designation system (which takes target information from CIC, maintains a series of target tracks, and assigns targets to FCSs and launchers) and the associated auxiliary components, mainly optical target-designation transmitters (TDTs) and 1 or more casualty weapons-direction and firing panels. In some cases the WDS also includes a separate coordinate converter with its associated computer. Early missile WDSs were built around Designation Equipment (DE), which was superseded by Weapons-Direction Equipment (WDE). WDS fully integrated with NTDS needs no separate DE or WDE since the enveloping NTDS holds all the potential target tracks.

All of the WDS systems are outgrowths of a series of automated target-designation systems conceived by Bell Laboratories in 1945-47 under a Bureau of Ordnance project, FCS Mk 65, intended to deal with future fast jet aircraft. The reader may sense a certain convergence between Mk 65 and NTDS; the latter, however, was a Bureau of Ships project. One might see Aegis as the final merger between NTDS and WDS. Bell's major contribution was to see that some form of TEWA and some form of accurate tracking were needed to mediate between search and fire-control radars. The original concept, then, was to provide a highly accurate short-range air-search radar (SPS-3) for mediation, together with an ATEWA. In fact SPS-3 failed, but SPS-39 was conceived as the replacement.

The earliest Bell-type system, Target Designation System (TDS) Mk 3, was installed on board the command cruiser *Northampton*. The TDS series also included a much simpler category of equipment, intended to permit a CIC to designate directly from search radar to gun directors. These TDSs were the electronic equivalents of optical target data transmitters (TDTs) used by an officer to assign a visible target to a director. Until the end of the Korean War, targets were typically designated from CIC by sound-powered phone, the radar in the director finding its target by searching around the location reported by CIC. However, as aircraft speeds increased, this system no longer sufficed, and more direct means of transferring data directly from CIC to director were required.

The chief systems in service by the mid-1950s, some of which probably survive on board ex-U.S. warships in foreign navies, were TDS Mk 5, 6, and 7. Mk 5 was designed for destroyers, Mk 6 for carriers, and Mk 7 for missile cruisers. Mk 5 employs a horizontal PPI with 4 joysticks, for a supervisor and 3 designators. The PPI is a PPI repeater (actually a television), and the joysticks move 4 designating hooks (semicircles on the screen). They transmit designations to the directors, which provide repeat-back hooks to show the directors' own positions. The horizontal display can also be used for grease-pencil marking (e.g., to enter nonradar data, such as lookouts' reports). The designator who hooks a target tracks it manually (with the joystick) until it is picked up by the director.

The PPI is, in effect, an integrated tactical display (albeit of only 1 search radar), and in this case threat evaluation is entirely manual. In such systems, maximum displayed range is generally 30 nm (60 kyd). Although the system as such does not impose any limit on target velocity, clearly it cannot easily serve as a link to the directors if the targets are very fast, as in that case they cannot easily be manually tracked, no matter how good the joystick operator.

There was also a rather more ambitious TDS Mk 1 on board the frigates (actually large destroyers) of the *Norfolk* and *Mitscher* classes, and on board contemporary destroyers converted for ASW (*Basilone* and converted *Fletcher* classes). These TDSs were essentially manual target-designation switchboards, capable of tracking 2-3 targets simultaneously and of controlling 2-8 directors. Mk 1 could not assign weapons to targets.

TDS Mk 3 was the first U.S. automatic target tracker, handling twice as many targets as directors, automatically tracking all of them (in an early application of TWS), and automatically evaluating the threat each target presented. Directors and guns were assigned automatically. The entire system weighed 23,905 lb in its 4-director installation on board USS *Northampton*. Mk 3 included an integrated target display and could

deal with target ranges as great as 30 nm (60 kyd). TDS Mk 3 is worth describing here because it was the basis for subsequent forms of WDS. An evolved version, TDS Mk 7, was installed on board the first 2 U.S. missile ships, the cruisers *Boston* and *Canberra*.

It turned out that the automatic TEWA system incorporated in TDS Mk 3 was impractical. The later WDSs descended from Mk 3 all used manual threat evaluation, which generally meant the operator would decide which target would enter engagement range first. Only when the WDS was integrated with the powerful computer of the NTDS system could threats be evaluated automatically.

WDSs:

Mk 1 System for the first U.S. missile ships (*Boston* class), built around DE Mk 7 (GMFCS Mk 71).

Mk 2 System for light cruisers converted to Talos ships, now extinct. Mod 0 was in CLGs 3 and 4, Mod 1 in CLG 5. Mk 2 used DE Mk 8-0.

Mk 3 Terrier system. Mod 0 was for the first 4 *Farragut*-class missile destroyers, with Mk 73 FCS. The designation equipment was Mk 9-0. Mod 1 was in light cruisers converted to Terrier ships, now extinct (FCS Mk 73). Mod 2 (with DE Mk 9-1) was the version for *Farragut* (DDG 37)-class destroyers equipped with FCS Mk 76. It used DE Mk 9-1. An unusual feature of this version was that the 2 visual target-designation transmitters Mk 24 could be used to reassign missile directors already tracking other targets without intervention at the radar console. At least in this version the WDS could interchange information between the underwater FCS and the missile-tracking radars; the radars could be used to track outgoing ASROC missiles and thus to correct for the effects of the wind. In this mode the sonar target's position could be displayed at the DE Mk 9, and a director was assigned to track the outgoing ASROC to its point of water entry. This WDS was also in the *Leahy* class.

Mk 4 Tartar system for *C. F. Adams*-class missile destroyers and *Brooke*-class frigates. Mod 0 is in DDGs 2-14 (WDE Mk 1-0), Mod 1 in DDGs 15-24 (WDE Mk 1-1) and the Italian *Audace* class, Mod 2 in the FFG 6 class (WDE Mk 1-2), Mod 4 in DDGs 35-36 (WDE Mk 1-7), and Mod 5 in DDGs 31-34 (WDE Mk 1-7) and the Spanish *Baleares* class. Mk 4 is also the system in the Italian *Impavido* class and in the Japanese *Amatsukaze*-class destroyers. Mk 4 was deleted from French and German missile destroyers when they were fitted with automated CDSs not quite equivalent to NTDS (the Germans and Italians developed their own equivalents to WDS Mk 13). Ships fitted with NTDS had their Mk 4 analog systems replaced by the digital Mk 13.

Mk 5 Terrier system for carriers, now extinct. Mod 0 was in the *Kitty Hawks* (WDE Mk 3-0), Mod 1 in the *America* (WDE Mk 4-2).

Mk 6 Cruiser system for the *Long Beach* (Talos/Terrier) and *Albany* class (Talos/Tartar), with WDE Mk 2 (Mod 0 in the *Long Beach*; Mods 1, 2, 3 in the *Albany* class, now extinct). When the *Albany* was rebuilt with NTDS, she could carry 128 tracks, compared to 24 with her previous WDE.

Mk 7 System for Terrier (SM-1(ER)) cruisers (replaced by Mk 11). Mod 0 (WDE Mk 4-0) was in the *Bainbridge* before her modernization with NTDS. Mod 1 (*Leahy* class, with WDE Mk 4-1 rather than Mk 4-0) increased the value of the range scales, doubling the range to conform to SPG-55B rather than -55A. Estimated weight is 17,500 lb. Mod 2 is a digital system, connected to NTDS via the converter SYA-3. Mod 3 is in the *Belknap* class (WDE Mk 8-1).

Mk 8 Terrier/SM-1 system, roughly equivalent to Mk 3 and 4.

Mk 9 Projected Typhon system, canceled.

Mk 10 Projected system for later heavy missile cruisers (CG 13 class), canceled.

Mk 11 WDS designed for integration with NTDS in a missile cruiser carrying SM-1(ER). Typically, a target is detected by a detector/tracker in NTDS, who enters the track into the computer. A separate identification operator decides that the track is hostile, and it is then passed to a track supervisor, who makes sure that the rate-aided tracker stays on the blip. The ship's weapons-systems coordinator (SWC) decides that fleet aircraft cannot intercept and, thus, that the target must be handled by the ship's missile system. The SWC alerts the ship's FCS and at the same time passes the target to a special tracker, who refines target position by using an expanded (4-nm) scale on the PPI. The tracker in turn passes the target to an FCS coordinator, who passes it to a particular FCS. At this stage a missile and launcher are selected. The FCS and launcher feed back to the FCS coordinator and the associated engagement controller. There are 4 consoles: OJ-166 FCS, OJ-167 for the launch system, OJ-194 PPI, and the Mk 80 system casualty. Mod 0 is in the *Belknap* class (CGs 28-34 as completed); Mod 1, the *Truxtun*; Mod 2, the *Leahy* (CG 16) class and the *Bainbridge*; Mod 3, the *California* class; Mod 4, the modernized *Farragut* (DDG 37) class.

Mk 12 System for Aegis (part of the overall Aegis weapons system). Mk 12 schedules and controls the firing of SM-2 missiles, computes missile orders, and schedules target illumination. It determines whether a given target can be intercepted, schedules assignments, and solves fire-control problems. The WDS communicates directly with the Mk 26 launcher in digital format for the first time in a U.S. Navy system.

Mk 13 System for Tartar (SM-1(MR)) ships with NTDS (GMFCS Mk 74 Mod 6). Mod 0 is in the *Virginia* and the *Kidd* class; Mod 1, the *Adams* class, as modernized with JPTDS (DDs 9, 12, 15, and 21); Mod 2, the *Perry* class; Mod 3, the *Adams* class modernization (as projected in 1977: DDG 17 would have been the prototype but was not done); and Mod 4, the *Adams* class modernization (DDGs 19, 20, and 22) and modernized Australian *Adams*-class destroyers. Consoles: 2 OJ-194(V)3 PPIs, Mk 90 or 91 launch-system console, Mk 218 casualty weapons-director panel, and Mk 129 casualty battery-control unit. There is no launch-system console in the *Perry*-class version.

Mk 14 System for Terrier ships with NTU, beginning with the *Mahan* in 1979. This system is unique in being able to handle both (MR) and (ER) missiles. It incorporates 2 UYK-20A or -44 computers and 2 or 3 OJ-194(V)4 consoles. Mod 2 is Terrier NTU. Mod 3 is for the *Long Beach* and the *Leahy* class. Mod 4 is for missile cruisers. Mod 5 is for missile destroyers.

Designation Equipment:

Mk 4 Part of TDS Mk 4. Maximum range is 60 kyd, and it is capable of tracking 4 targets (manual designation, estimated elevation). Total weight of the Mod 2 version is 2080 lb (TDS Mk 4-2 weighs 3845 lb).

Mk 5 Part of TDS Mk 5. Maximum range is 60 kyd, and it is capable of tracking 4 targets (manual designation, estimated elevation). Total weight of the Mod 1 version is 660 lb (TDS Mk 5-7 weighs 2100 lb).

Mk 6 Part of TDS Mk 6. Maximum range is 60 kyd (maximum range displayed is 240 nm); 4 targets are tracked simultaneously (joystick tracking, estimated elevation). Mk 6 controls 8 directors, weighs 6640 lb (TDS Mk 6-0, 9200 lb), and has 4 operators.

Mk 7 Part of WDS Mk 1-0 of the *Boston*-class missile cruisers (now extinct). Mk 7 weighed 45,000 lb (out of 51,470 lb for the WDS) and required 24 operators in the WCS, 1 in CIC, and 10 in the AA station. Maximum range was 120 kyd. DE Mk 7-0, on board the *Boston* class, was the predecessor of the later Mk 8 and Mk 9 on board Terrier and Tartar ships. Like its successors, Mk 7 divided the weapons-assignment task into 3 phases: display/detection/tracking, evaluation/FCS assignment, and reevaluation/weapons assignment. There were 6 target-tracking consoles Mk 17-0, each equipped with a PPI and a pantograph

by means of which the operator could enter the coordinates of a point on the screen. Normally 2 consoles were assigned to the ship's missile battery and 4 to her guns. The operator at a console could enter a target into 1 of 16 TWS channels (i.e., into 1 of 16 channels that would project ahead the position of a range-gated target). Later, less ambitious designation equipment used rate-aided tracking, in which the system projected ahead by assuming that the target did not maneuver, and an operator monitored that projection to correct for maneuvers. Targets were tracked in 3D. Each Mk 17 console provided only range and bearing, but target elevation could be displayed and inserted at 1 of 2 Mk 16 consoles. Mk 16 showed elevation for any or all of the TWS channels; the operator positioned a cursor, and the height-finding radar then automatically tracked in altitude. This complication was deleted from later systems, which provided a very limited altitude display at the left-hand side of their target-tracking consoles. There were separate consoles (Mk 21) to accept target data from target-bearing transmitters, comparing their assignments to radar data. For the second phase, the TWS channels fed into a target-assessment console Mk 18, and 3 director-assignment consoles (2 Mk 21s for gunnery, 1 Mk 23 for missiles). The Mk 18 could display all 16 channels, and its operator could select those targets of particular missile interest, in effect editing the displays of the director-assignment consoles. The missile-director-assignment console had 2 displays side by side, a synthetic PPI picture of the missile-engagement channels alongside a series of electronically generated bar graphs to indicate target suitability and urgency. Finally, for Phase 3 there were a weapons-assignment console (Mk 22) and launcher-status consoles (Mk 19).

Mk 8 Part of WDS Mk 2-0 (converted cruiser system). Maximum displayed range is 240 nm, and maximum designation range is 300 kyd; Mk 8 handles 6 targets simultaneously. Weight is 9160 lb out of a total of 11,300 lb for the WDS. There are 18 operators in the WCS, 3 in CIC, and 4 in the AA Station. Mod 0 was Mk 6 modified for target evaluation, designation, and control for Talos missiles (now extinct). Mods 1 and 2 were versions for converted U.S. cruisers, now extinct. Mod 3 is the Terrier system on board the Italian cruiser *Vittorio Veneto*. The Mod 0 version could engage up to 6 raids. There were 2 plotter repeater loops, with stations in CIC and the WCS for raid identification and plotting; 1 loop was for long-range targets, the other for short-range targets. There was also a designation indicator to display raid positions, director positions, ship's heading, clear areas, and an indication of when the assigned director was at the designated position. Basic raid information, special (nuclear) threat warning, and missile-warhead-type (conventional/nuclear) recommendations were sent electronically by CIC to the WCS via the 2 plotter loops. The CIC operators wrote in the raid-identification letters adjacent to the radar pips they chose, and this written-in video was transmitted to the WCS; the appropriate WCS plotter-repeater operators copied the plotted information and began tracking. The WCS-plotted information appeared on the main WCS display and was repeated to CIC via the loops so that CIC could monitor the progress of the plotting. The main display in the WCS was a pair of 16-in vertical CRTs (Designation Indicator Mk 5), each operating at either a 60- or a 240-kyd range scale, showing radar video, written-in data, designator symbols, and director repeat-back numerals. Overlays could be rotated to show either ship's course or a trial course-change proposed at the WCS control panel. The main console in WCS could assign raids to a pair of target-engagement consoles that could track targets, designate raids to the radar directors, and compute missile-intercept points. This system incorporated a separate elevation-tracking console (Mk 46, with three 7-in CRTs with E-type displays, showing elevation angle on a vertical scale). The other consoles were director assignment (Mk 42, with a 12-in CRT) and target entry (Mk 44, with two 12-in dual-gun CRTs for long- and short-range air-search radar video, and one 5-in expanded-offset display). WDS Mk 2-1 (using DE Mk 8) controlled Talos and Tartar batteries for the converted

Albany-class cruisers. In this version the elevation console Mk 46 had an additional CRT so that the system could handle 8 rather than 6 target channels.

Mk 9 Part of WDS Mk 3-1. Maximum range was 120 kyd. There were 10 operators in the WCS, 1 in CIC, and 10 in the AA Station. Mk 9 was the forerunner of WDE Mk 1, 3, and 4 (for the *Adams* class, the converted light cruisers, the *Leahy* class, and the *Bainbridge*). Up to 6 targets could be selected, manually rate-aided, and tracked. They could be evaluated and designated to either guns or missiles. The operator at a console in CIC assigned targets to 1 of the 6 channels by moving a pantograph over the target blip on the PPI, then pushing a button. The system could also store a standard keep-out range (the range at which the incoming target could be assumed to be releasing its weapon), and the value of this range could be varied from target to target. Once a target had been selected, it could be tracked with rate-aiding by 1 of 2 similar consoles in the WCS. The track channel developed and stored target velocities based on successive position corrections introduced by the tracker in the WCS. Each console operator was expected to track 3 targets in 3D (i.e., to correct the rate-aided track in both PPI and height, the latter as shown on the left-hand edge of the CRT). Targets were evaluated and assigned to directors at a pair of director-assignment consoles, each carrying both a synthetic-video CRT and an electronic graph (target speed, height, time remaining for engagement, remaining busy time for track radars currently engaged). Mod 2 is in the Italian *Doria*-class cruisers.

Weapons-Direction Equipment (WDE):

Mk 1-0 Tartar (later SM-1(MR)) WDE for *Adams*-class destroyers, used to select hostile targets and assign missiles and guns to the most threatening among them. Mk 1-0 is based on the earlier DE Mk 9. Up to 6 targets can be selected for engagement, manually rate-aided, and tracked. They can be prioritized. As in contemporary systems, there are 2 target-selection and -tracking consoles Mk 37-0, 1 director-assignment console Mk 47-0, and 1 weapons-assignment console Mk 48-0. All are located in CIC. Raw video from 1 of the 2 search radars (2D and 3D) appears on 1 of the Mk 37s, and each target is input into a channel by means of a pantograph. Once a target has been entered into a channel, further tracking is the responsibility of 1 of the 2 Mk 37 operators, each of whom is expected to track 3 targets (however, each may be responsible for all 6). Height is displayed at the left edge of the PPI for tracking in 3D. If height information is not available, the fire-control radar itself (SPG-51) searches in elevation to acquire a target. The Mk 47 console shows a PPI on its left and a multipurpose plot (electronic graph) on its right; the PPI shows synthetic video (generated by the system's Mk 118 computer) for all 6 targets being tracked so that the console operator can compare them. It also displays the ship's track and the missile system's blind zone; it can display the velocity vector of any 1 of the 6 targets. The graph shows target speed, target height, time interval for missile-director assignment (assignments resulting in earliest and latest intercepts), and remaining busy time for MFCSs currently assigned. The console operator uses these data to assign fire-control channels; the computer slews the 2 directors in response and performs an acquisition search. The remaining console is used to assign the launcher to the highest-priority target; the operator is responsible for the final evaluation of the blind zones and of the range, altitude, and seeker-angle limitations of the missile. The operator actually fires the missiles.

Other versions of Mk 1 were

Mod 3: version for the Italian destroyers *Impavido* and *Intrepido* (1962)

Mod 4: projected version for the carrier *John F. Kennedy*, superseded by NTDS

Mod 5: projected version for Canadian frigates (1965), abandoned when Tartar was deleted from these ships

Mod 6: version for the *Mitscher* class's refit as DDGs, replaced by Mod 7 for these ships and also for the *Forrest Sherman*-class conversions

Mod 7: version for destroyers converted to missile ships, now extinct

Mod 8: Mod 1 integrated with NTDS.

Mk 2 Dual-purpose WDE to control both long-range (Talos) and short-range (Tartar or Terrier) missiles, in the *Long Beach* and the converted *Albany*-class cruisers. The *Long Beach* had the Mod 0 version, with 15 manned consoles. Targets were transmitted to the system via a target-entry console (Mk 44-0) in CIC. It carried 2 side-by-side radar PPIs (1 for long range, 1 for short), plus a third display to show a magnified portion of either radar's picture; NTDS data were superimposed on the radar video. There were 24 target-tracking channels. As in NTDS, the operator used a joystick to hook a radar pip and thus to insert a target into 1 of the channels. The system had 6 target-tracking consoles (Mk 45 Mod 0), each with 4 displays so that all 24 channels could be displayed simultaneously. Operators at the displays used their joysticks to enter tracking errors. Two elevation consoles (Mk 46 Mod 0) were used to track targets in elevation; each had 3 displays, which were time-shared among the 24 channels. Time-sharing was interrupted when a particular channel was assigned to an FCS. Operation was supervised by a second Mk 44 Mod 0 console manned by the tracking supervisor (e.g., to resolve crossing targets or to reassign unevenly distributed targets). Targets were assigned to directors by a pair of consoles (1 for Talos, 1 for Tartar or Terrier), each with a pair of displays (PPI and electronic bar graph). Finally, there were 3 launcher-assignment consoles (2 Terrier, 1 Talos in the *Long Beach*). The *Albany* class's version, Mk 2 Mod 1, was similar but with Mod 1 consoles. It was not embedded within NTDS.

Mk 4-0 WDE for the *Leahy* class, superseded when these ships were fitted with NTDS. Mod 1 had different scale overlays to accommodate the longer-range SPG-55B radar. Mod 3 was Mod 1 modified to receive digital input from an SPS-48 radar, using height-tracking console Mk 70-0. This console had two 4-gun CRTs, each of which showed gated (range and azimuth) height information for the targets assigned to the track channels, for a total of 8 channels (1964).

Mk 6-0 WDE for the abortive Typhon ships (WDS 9-0), (MR) and (LR).

Mk 7-0 WDE for the projected CG 13. It could track up to 24 targets.

Mk 8-1 WDE for WDS Mk 7-3 in the first 2 *Belknap*-class cruisers; superseded when they were converted to NTDS.

◆ Sharpshooter

Lockheed Electronics's on-mount digital-radar FCS for 20–40-mm guns was announced in 1974 and incorporated in the Spanish Meroka close-in weapons system. Sharpshooter embodies some Mk 86 FCS technology. This system was offered in 4 versions: Mk 1 (on-mount, as in Meroka), Mk 2 (off-mount, with stabilized optical sight), Mk 3 Mod 0 (off-mount, with television tracker but without an optical sight, and with dedicated tracking radar), and Mk 3 Mod 1 (off-mount, with television tracker combined with its stabilized optical sight, but without a dedicated tracking radar).

The X-band pulse-doppler monopulse radar is a developed version of the range-only radar used in the U.S. Army Vulcan system, but with greatly improved clutter rejection (and with tracking capability). There is also a stabilized optical sight with zoom magnification, slaved to the radar; and the control panel has 2 handgrips (1 for mode control—local/remote track, the other with the firing trigger and joystick). The gunner uses the optics and joystick to acquire the target and monitors the track. Maximum target lock-on range is 7000 m, and accuracy is 1.5 mrad and 30 ft in range. Maximum radial target speed is Mach

1.8. The director's angular rate in both axes is 2 rad/sec. Elevation limits: +90/-25 deg.

Total weight of Mk 1 is 1323 lb; of Mk 3 Mod 0, 1778 lb; of Mk 3 Mod 1, 350.7 lb.

AIRBORNE RADARS AND FIRE-CONTROL SYSTEMS

FRANCE

◆ Vigil

Vigil is Thomson-CSF's project for an X-band early-warning radar for the next generation of French aircraft carriers. It is to enter service in 1992. It uses the programmable signal processor and waveform developed for the existing RDY fighter radar, plus an electronically scanned antenna. Total weight, exclusive of consoles, will be 450 kg. The radar will be installed on board refurbished Grumman Tracker aircraft (originally built for carrier-based ASW) in a belly radome; the aircraft will be re-engined with turboprops. There will be 2 operators, the radar automatically detecting and tracking targets and automatically computing intercepts. Thomson-CSF, the manufacturer, estimates that Vigil will detect a 5-m² target at 110 nm, based on performance already achieved by RDY (using a smaller antenna).

RDY itself is a multifunction (air-to-air, air-to-ground, and air-to-sea) radar, achieving this capability by means of a programmable signal processor (as in the U.S. APG-65). For air-to-air operation, it can use 1 of 3 waveforms (high, medium, and low PRF). It can track 8 targets while scanning, each target being assigned a priority label. Simultaneous fire-control solutions can be computed for several targets, so that a fighter equipped with RDY can engage several simultaneously using active missiles. Alternatively, the radar can be used to illuminate a target for a semiactive missile. The air-to-ground modes of operation are ground mapping (RBGM) and doppler beam sharpening (DBS) for navigation; and air-to-ground ranging (AGR) and detection and tracking of fixed (HTT) and moving (GMTI/GMTT) targets. The radar is also designed for sea search, using a variety of waveforms to cancel clutter at different sea-states.

RDY is a pulse-compression radar (with a variable compression ratio), using 2 different peak-power levels (dual-mode operation). The transmitter uses a TWT.

The radars of current French maritime-patrol aircraft all have some air-to-air capability to provide surface ships with limited support.

USSR

The new Soviet aircraft carriers *Tblisi* and *Riga* will be equipped with MiG-29 (Fulcrum) and Su-27 (Flanker) fighters, both of which have air-to-air radars. It is not clear whether the Yak-41, the follow-on to the current Yak-38 (Forger), will have any more radar than its predecessor, but in the past the Soviets have tended to assign odd numbers to fighters and even numbers to bombers.

◆ Slot Back (RP-29)

Slot Back is the doppler look-down/shoot-down radar of the Su-27 and the MiG-29; it is not definite, however, that both aircraft carry exactly the same version. Reportedly, Slot Back incorporates APG-65 technology (1 report suggests that it is a copied APG-65, a wag suggesting that some of the assemblies can be replaced part-by-part by APG-65 parts). Reports of capabilities vary; at the Farnborough air show in 1990 a Soviet designer claimed a range of 80 km [43.7 nm], which is short of earlier estimates (100 km [about 54 nm]). RP-29 is the Soviet service designation (NO-193 is the maintenance designation).

A report of 130-nm search range and 100-nm tracking range, sometimes claimed for Slot Back, more likely refers to Flash Dance, the MiG-31 strategic interceptor radar.

UNITED KINGDOM

◆ Blue Fox

See the Strike/Surface Warfare section.

◆ Blue Vixen

See the Strike/Surface Warfare section.

◆ Searchwater

See the Strike/Surface Warfare section.

UNITED STATES

◆ APG-65/APG-73

The Hornet (F/A-18) dual-purpose fire-control radar (air-to-air and air-to-surface) was developed by Hughes. It is now in service in the U.S. Navy and also in Canada, Australia, and Spain. This radar has also been adopted by West Germany for the F-4F improved-combat-efficiency (ICE) upgrade program.

The most important new feature is a high-speed (7.2-MFLOP) software-programmable signal processor (PSP), which makes the radar flexible. Doppler-filter and range-gate configurations are defined by software, whereas in previous fighter radars these configurations were hard-wired.

The antenna is a low-sidelobe planar array with direct electric drive rather than the hydraulic drive of earlier airborne radars.

Air-to-air modes are velocity-search, range-while-scan, TWS, single-target-track, raid-assessment (expanded coverage of a target to resolve a raid into individual aircraft), air-combat-maneuvering, and gun-director. There are also a narrow-beam vertical-scan mode and a bore-sight-acquisition mode in which the pilot points the airplane at a target. In the acquisition mode, the radar searches the entire volume equivalent to the heads-up display (HUD) and locks onto the first target detected. The gun-director mode uses pulse-to-pulse frequency agility to reduce target scintillation, for highly precise tracking. As in AWG-9, the longest range is achieved in velocity search (high PRF giving only velocity and bearing data). The range-while-scan mode uses a combination of interleaved high and medium PRF waveforms, the high-PRF waveform giving some range data and the medium-PRF waveform permitting the use of range-gate processing. TWS gives the shortest ranges. Single-target-tracking uses monopulse angle logic and can extrapolate the target's position while the target fades out of view during violent maneuvers; this mode employs a special high-PRF waveform for Sparrow guidance.

Air-to-surface modes are real-beam-ground-mapping, doppler-beam-sharpening (sector or patch), synthetic-aperture, fixed-target-track, sea-surface-track, terrain-avoidance, precision-velocity-update, and air-to-surface-ranging. Doppler-beam-sharpening achieves a 19:1 improvement in sector scan and a 67:1 improvement in patch mode.

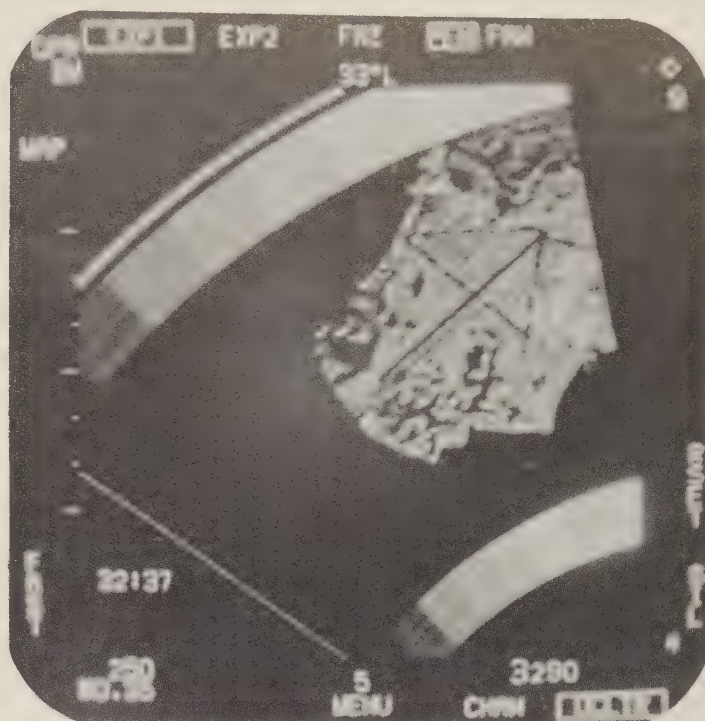
The claimed MTBF is more than 100 hr. The entire system weighs 340 lb (exclusive of rack) and occupies less than 4.5 ft³. In comparison, the APG-63 of the F-15 weighs 483 lb and occupies just less than 9 ft³, exclusive of the antenna. Digital operation greatly reduces field adjustments; Hughes claims that built-in test equipment can detect 98% of all faults.



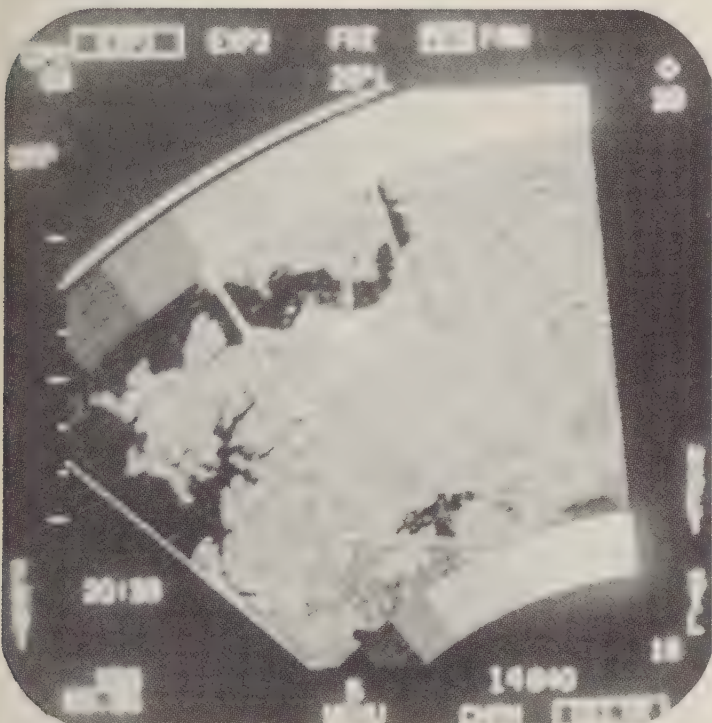
APG-65 prototype, showing the microwave plumbing behind the flat slotted-array antenna. (Hughes)



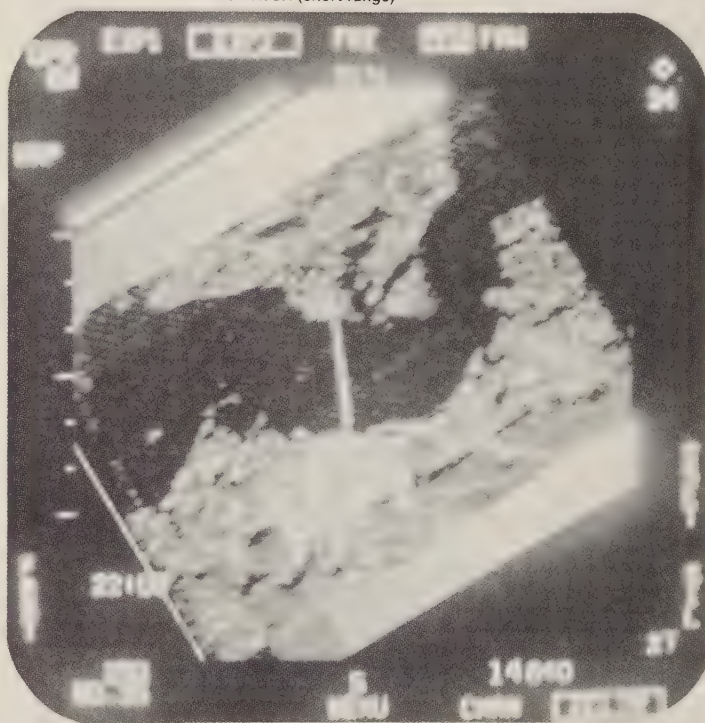
GROUND TRUTH



DOPPLER BEAM SHARPENING PATCH (short range)



DOPPLER BEAM SHARPENING SECTOR



DOPPLER BEAM SHARPENING PATCH (long range)

Effect of Doppler beam sharpening in an APG-65 ground-mapping display. (Hughes)

The current APG-65 upgrade (the operational requirement was promulgated on 27 January 1988) exploits APG-70 and -71 development work and uses parts of those radars. Hardware design is to begin during FY90, rooftop integration of hardware and software following in FY91, with flight tests in FY92.

In early 1989 the marines chose APG-65 as their preferred Harrier (AV-8B upgrade) radar, despite some legal obstacles (the radar project was not subject to formal competition, although the marines did fly several alternative radars first). The new radar is part of a more general Harrier II Plus program. As of August 1990, the projected FY91 program called for 20-27 new Harrier II Plus, and the marines hope to upgrade 193 existing AV-8Bs, beginning with 12 each in FY92 and FY93, then 24 per

year from 1994 on; the Harrier II Plus is to enter service in 1993. Spain plans a similar upgrade (and will buy 6 new Harrier II Plus), and Italy is to buy Harrier II Plus for the carrier *Giusseppe Garibaldi*. Reportedly, Japan is considering buying Harrier II Plus for the JMSDF.

The radar must be modified to fit the Harrier; like the Blue Vixen in a Sea Harrier, it has to be spread out through the fuselage (the signal processor and data processor are moved to the rear fuselage). The antenna is reduced in diameter to about 22.8 in.

APG-73 is a modernized F/A-18 radar by Hughes Radar Systems. Work began in 1989, and the first development radar is to be completed in mid-1991; Hughes hopes for a production contract in October 1991, with first deliveries in 1994. APG-73 should appear in time to be installed on 600 new F/A-18s, and it may be used to retrofit night-attack F/A-18s, providing them with greater computer capacity. APG-73 retains the transmitter

and antenna of the APG-65 but replaces the signal-processor, data processor, and receiver/exciter of the earlier radar.

APG-65 is being installed on German land-based F-4F Phantom fighters as part of an upgrade program. An evolved version was proposed, but not chosen, for the projected European Fighter Aircraft.

◆ APG-71

This replacement for the AWG-9 in the F-14D upgraded Tomcat incorporates some APG-70 (F-15C/D/E) technology but retains features of the original AWG-9. The first production unit is scheduled for delivery in September 1989. The signal processors of the APG-70 and -71 are 86% common.

APG-71 began as a digital version of AWG-9; Grumman and Hughes tried to introduce a digital signal processor into AWG-9 Block V; the proposal went as far as the technical-evaluation stage, but it was never completed. When it was finally adopted, the change in designation from AWG-series to APG-71 reflected a fundamental change: Hughes became a subcontractor to Grumman, the builder and aircraft-system integrator, rather than the prime contractor of a separate system.

Most analog radar functions are replaced by digital equivalents, and this digital operation made it possible to introduce a programmable signal processor (for multimode operation), by means of which the system as a whole could be modified by software. In addition, the antenna was now digitally controlled and, therefore, could be scanned in a pattern chosen by the radar computer. Operating in TWS mode (which requires target illumination every 2 sec), the antenna can be commanded to "steal" an occasional scan to look at other targets of interest. Because the radar signals are carried in digital form, the computer can analyze them in greater detail, for noncooperative target identification.

Because the existing AWG-9 is still the most powerful airborne fighter radar, APG-71 retains its transmitter and power supply. However, it has a new broad-band master radar oscillator. There is also a new receiver, with better Doppler resolution, for better track accuracy and discrimination between nearby targets. The receiver employs a new high-speed analog-to-digital converter to achieve a combination of spectral purity and dynamic range. There is also a new digital raster-scan display, which can show infrared video as well as raw and processed radar video.

Thanks to the digital processor, the new radar has better overland performance and can operate in ground-mapping and ground-attack modes. Overland performance will be improved further by a future medium-PRF mode. The radar should also enjoy broader velocity search coverage (eliminating the need for separate settings depending on whether the target is approaching or retiring), a more flexible target-engagement zone, a new long-range passive-identification mode (to count closely bunched aircraft), and programmable ECCM and clutter control.

One consequence of the new antenna control is that the radar is no longer constrained to fixed 2- and 4-bar patterns, which in the past had prevented it from detecting some targets that were widely separated vertically. In bar scanning, the radar sweeps across a bar before shifting to the next bar below. In the new mode, the scan can be interrupted to track a target (even if it is outside the normal pattern), then return to scanning.

Presumably APG-71 incorporates the new radar waveform projected for the APG-70: range-gated high PRF. In the past, the choice has always been between low PRF for long-range and high PRF for good doppler performance but short unambiguous range. Moreover, high PRF is best for an airplane approaching at high speed, whereas medium PRF is best for a tail chase. Typical fighter radars interleave the 2 PRFs in a "4 bar" search, leaving some gaps in coverage. APG-70 uses a combination of range gates and doppler filters (20,000 filters, 500 per range gate); the PRF is 200,000. The new technique should also make raid assessment much more accurate.

The new signal processor has 4 units compared to 3 in the

F-15 and operates at 40 MCOPS. The associated digital data processor operates at 3.2 MIPS.

APG-71 flight tests, on board a converted TA-3B, began in July 1987.

◆ APQ-104

Band: X **Beam:** 4.5 deg **Peak Power:** 160 kW **Gain:** 31 dB
Pulse Width: 0.7 microsec **PRF:** 1200 pps
Scan Rate: 71 deg/sec horizontal, 30 scans/min vertical
Antenna Dimensions: diameter 20 in
Antenna Weight: total weight 537 lb

The radar for the U.S.-built French F-8E(FN) replaces the APQ-94 of earlier U.S. versions of this airplane, for compatibility with the French R.550 missile. APQ-94 was presumably similar; its characteristics are listed above. APQ-94 used a magnetron transmitter and hence was not a pulse-doppler radar. Presumably the modification represented by APQ-104 was a CW injection mode.

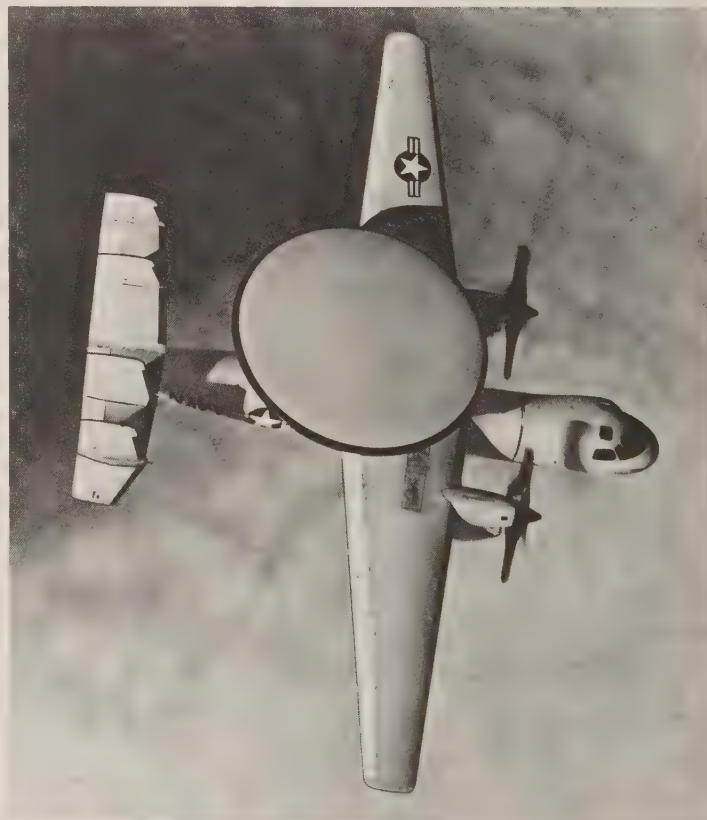
APQ-94 was built by Magnavox.

◆ APS-120/125/138/139/145

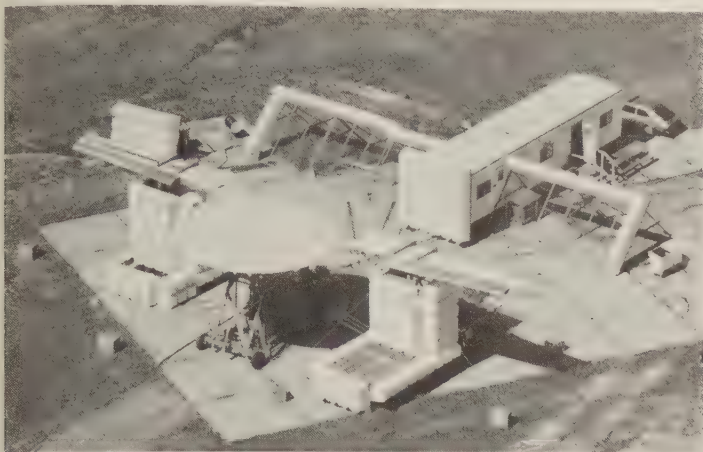
Band: UHF (400–450 MHz) **Beam:** 7 × 20 deg
Peak Power: 1 MW **Gain:** 21.5 dB
Pulse Width: 13 microsec (compressed to 0.2 microsec)
PRF: 300 pps **Scan Rate:** 6 rpm
Antenna Dimensions: 2.5 × 24 ft (in rotodome)
Antenna Weight: 1700 lb

Data are for APS-96, the predecessor to the current APS-120/125/138/139, to give some idea of overall characteristics. APS-96 is no longer in service. These characteristics are quite comparable to those of the UHF shipboard radar, SPS-40.

The standard U.S. naval airborne early-warning radar, installed on the Grumman E-2C Hawkeye, the General Electric APS-125 is now also in service in Egypt, Israel, and Japan. Lockheed is marketing an alternative installation on board converted P-3 airframes for land-based naval air surveillance, perhaps by Australia and Norway; this look-down P-3 is now entering service with the U.S. Customs Service. Although APS-125 and



The Grumman Hawkeye carries an air-search radar comparable in size to that found on board a major surface ship. (Grumman)



Since 1986, Grumman has been testing a conformal (active phased-array) radar to replace the rotodome of the current E-2C. Arrays occupy leading edges of the wings, and others could be installed in the leading edge of the tail. The test rig, which includes a rotodome, is shown. Grumman expects to have a flying system by 1992 or 1993, for service introduction in the late 1990s. The array has to adapt its beam form as the wing flexes, and Grumman achieves this adaptation by means of rapid feed-back calculations at each of the thousands of antenna elements. The system has been tested by running a propeller just ahead of the wing. The company points out that, quite apart from the advantage of reducing airframe drag, a conformal array is not limited to a steady scanning rate. Instead, the array can concentrate on areas of particular interest. Such operation might help separate a stealthy target from its background; reportedly the ability to dwell on areas of interest may, by itself, add 20–30% to the effective detection range. Reportedly, too, the new conformal array uses instantaneous radial-velocity measurement (presumably by FFT applied to returning echoes) to separate targets of interest from sea clutter. (Grumman)

its relatives are primarily intended for air search, they have a very significant surface search capability, and aircraft equipped with these radars can control antiship attacks. The functional predecessor radar, APS-20, is now used exclusively for surface search. (See the Strike/Surface Warfare section for details.)

UHF frequency was chosen for maximum ability to detect small targets at long range (based partly on available transmitter power) and for sea-clutter rejection (transmitter stability, pulse compression for high resolution, and single-delay analog AMTI). The selection of UHF paralleled the shift to such UHF shipboard radars as SPS-17 (which led to SPS-37/43). The first such U.S. AEW radar, APS-70 (425 MHz, 2 MW), was designed for airship use, and in tests it achieved 40% greater range than comparable earlier S-band sets. The E-2 radars were conceived about 1957 as the carrier-based equivalents of the big airship radar. The earlier AEW radars (APS-20 and -82) operated at S-band and, although they had considerable transmitted power (e.g., 1 MW in APS-82), they also suffered greater transmission losses. Thus APS-96 was credited with somewhat greater range than APS-82 at the same transmitted power. Maximum range, as limited by PRF, was over 200 nm, about twice the nominal range of APS-82.

The current (APS-138, or TRAC-A) antenna is an array of 2 rows each of 8 yagis (1 row of 12 in earlier versions) in a rotodome (a rotating radome) 24 ft in diameter and 2.5 ft deep rotating at 6 rpm. It uses monopulse processing to achieve narrow beam definition in the horizontal plane, dividing the antenna in half and comparing sum and difference signals, which are separately pulse-compressed. There are also 2 auxiliary antennas used for sidelobe cancellation. Previous versions of the radar used an array of 12 yagis in the rotodome. The radar measures target altitude by comparing pulses reflected directly by the target to pulses that have reflected off the surface as well as the target (either coming or going or both). This technique is probably effective mainly at sea, where the surface is highly reflective. In contrast, it appears that the APY-1 radar of the Boeing E-3 AWACS produces a beam narrow in both azimuth and ele-

vation, sweeping the beam vertically for height-finding. That scheme reflects that radar's primary function, which is air search over land.

APS-96 did not incorporate the AMTI initially specified (primarily to detect small low fliers at long range). The method employed, comparison of echoes on a pulse-to-pulse basis (the differences being detected as beat frequencies in filter banks), required very stable transmitter frequency. Existing klystrons were too massive for airborne use, so a special tetrode amplifier tube was developed. APS-111 (1963) introduced AMTI into this radar series. This AMTI was ineffective in eliminating land clutter, and further measures were necessary. AMTI processing is now digital, and the radar is sometimes described as pseudo-pulse Doppler.

APS-125 is a modified successor to APS-96, the original E-2 radar, via the APS-111 of the E-2B and the APS-120 of early E-2Cs. APS-111 had improved clutter rejection for overland operation, including special circuits to cancel out the clutter that was frequency shifted by aircraft operation and that would have interfered with both moving target indication and pulse compression. There were also new techniques for sidelobe suppression. APS-111 was tested in 1964–68, and APS-120 incorporated these improvements plus an automatic radar detector, linking the radar to the tracking-and-intercept computer (airborne ADT). The computer seeks a constant false-alarm rate (CFAR) and sorts radar returns before presenting them to the intercept operators. APS-120 also had a more stable (and more reliable) radar transmitter.

APS-125 uses 2 MTI techniques in succession, cancellation and pseudo-doppler. Both use the doppler shift imparted to a signal returned from a moving target, but in different ways. For cancellation, the effect of the doppler shift is approximated by a change in the overall phase of the returning signal. That signal can be compared to a reference signal, to eliminate (cancel) non-moving targets (clutter), i.e., targets showing no phase shift. This form of MTI is mathematically equivalent to analyzing a signal for doppler shifts. Like any pulse-doppler radar, an MTI radar has a series of blind speeds proportional to its PRF (when the phase shift reaches 360 deg, it is equivalent to zero). Any real system, moreover, finds it difficult to detect phase shifts near the blind speeds; these areas of small response are called notches. One of the blind speeds is at zero relative velocity, and the object of the phase comparison (cancellation) is to leave as much of the clutter as possible in the notch around zero. APS-125 uses a triple canceler.

In the case of a moving airborne radar (like APS-125), the clutter has an average velocity centered around the speed of the airplane. The MTI canceler can shift the notches so that the center speed of the clutter lies in a notch. TACCAR (time-averaged-clutter coherent airborne radar) automatically centers the notch at the average doppler frequency of the clutter. Clutter is worst at short ranges, the altitude of the airplane determining the point at which detection markedly improves. This point is at a range of about 170 nm for an E-2C at 23,000 ft over land.

After pulse compression, APS-125 converts its signals into 10-bit digital words (60-dB dynamic range), the word rate out of the converter being 5 MHz. They are passed through a 3-pulse canceler that eliminates the bulk of the clutter (the very stable radar transmitter is said to make for a 55-dB improvement in signal-to-clutter ratio at this stage).

Then comes pseudo-doppler processing. The digital signals are passed through a 16-point FFT. Each FFT output (i.e., each velocity signal) is individually threshold-detected, and these signals are subject to processing (beam splitting, velocity ambiguity removal, selectable low-speed target censoring, blanking).

This form of doppler processing is very different from that in typical pulse-doppler radars. The frequency range in the chirped pulses has already been eliminated by pulse compression. Because the radar's PRF is very low (to achieve long unambiguous range), the first blind speed is also very low, and velocity (obtained by using the FFT) is ambiguous. A nominal PRF of 300

pps corresponds to a first blind speed of 200 kt. However, because the antenna rotates slowly, a target will be painted many times while it is in the main beam (dwell period), and the radar can estimate its velocity by noting the change of range during each dwell. This estimate is then used to remove the ambiguity in the output of the FFT (velocity is ambiguous because the PRF is limited, to obtain unambiguous ranges). This processing is possible because the radar transmitter is extremely stable on a pulse-to-pulse basis.

Given doppler processing, the system defines a series of optimum velocities centered between the pairs of notches. As the target velocity falls farther and farther below optimum, the signal involved falls into the notches. In the case of APS-125, the nominal PRF, 300 pps, corresponds to 200 kt between blind speeds. The flat part of the response curve extends about 65 kt above or below the optimum velocity, and detection becomes marginal when the target velocity is within about 25 kt of a blind speed. Presumably, this problem is solved by periodically shifting the PRF, hence shifting the blind speeds and the corresponding notches.

The APS-125 digital (rather than the previous analog) processor is called ARPS (Advanced Radar-Processing Subsystem). It provides better clutter rejection and false-alarm control, for fully automatic overland operation. It also has lower sidelobes (to suppress sidelobe jamming). ARPS tests began in December 1972, and an APS-120 retrofit program began in 1977. APS-125 is said to be able to track 300 targets simultaneously, out to a maximum range of 250 nm. This capability is the ATD modification to the basic radar. After tests, the operational-test-and-evaluation force recommended that the system be modified to alert the operator if performance was degraded for any reason. Such degradation (e.g., through jamming) must be a major worry in automatic detection systems. It was also suggested that some rapid means be provided to clear the detector processor of alerts without shutting it down (i.e., as a means of clearing saturation that results from false targets).

The next improvement was APS-138, which has a new low-sidelobe antenna (total radiation aperture control antenna, TRAC-A). The first was delivered to Grumman in December 1982. All 84 existing APS-125s are being brought up to -138 standards. APS-138 can reportedly track a cruise missile at a range of 150 nm. Goodyear (Loral) claimed that, equipped with an array processor, an E-2C equipped with TRAC-A can track over 600 targets simultaneously, and can direct more than 40 simultaneous interceptions. However, TRAC-A was initially unsuccessful, the operational-test-and-evaluation force calling for broad-band TRAC-A in all 10 radar channels and improvement to match ARPS performance levels. The system passed an operational test in June 1983 but still suffered from excessive weight.

APS-139 is a further improvement with better ECCM and better surface-search performance. Scheduled to enter service in 1988, this radar can reportedly maintain over 2400 tracks simultaneously. It will be introduced in aircraft number 122.

APS-145 further rejects overland clutter, using environmental processing, in which radar sensitivity is adjusted cell by cell (range interval $\times$ beamwidth) on the basis of the clutter and traffic in that cell. PRF is being reduced to permit detections at ranges as great as 350 nm, and the scan rate is being reduced from 6 to 5 rpm. PRF may be varied during operation to eliminate target blind speeds. APS-145 was under test in 1988 and is scheduled to enter service in 1990. APS-125 and its successors all transmit on 10 channels. In early versions, channel selection was manual. However, in APS-145 channels are monitored and automatically selected, to avoid jamming signals; channels are selected on a scan-to-scan basis (every 12 sec). Grumman and GE tested a 100-channel version for the U.S. Navy, but that version was not deemed necessary. Automatic channel selection was important for the 1986 GE bid for the British AEW (Nimrod 2) contract; APS-125 was initially rejected because it would have interfered with some other NATO signals. GE argued that the new automatic selection system would avoid such

interference. Similar problems had already been overcome in Japan (where there was fear of interference with the taxi-radio band).

These radars initially fed their data into a magnetic-drum computer, which was replaced by a Litton L-304 digital computer in the late 1960s; and in 1972 the Litton OL-77/ASQ was introduced. It was initially built around 2 L-304s with eight 8k memory units. As of 1982, about 50% more capacity had been added.

The new airship is initially to carry a modified APS-138 or -139 with a 40×10 -ft antenna, for operational testing. However, advocates of the airship for fleet air defense have proposed a longer-wavelength (for antistealth operation) antenna wrapped around the airship envelope.

All of these radars are manufactured by General Electric.

For some years Grumman and General Electric have been working on a next-generation conformal-array AEW radar. A passive receiver in a wing structure passed ground tests during the summer of 1984.

See also ATDS, the airborne tactical data system fed by the E-2C's radar (described with NTDS in the Surveillance and Control section).

◆ AWG-9

Band: X **Beam:** 2.3 deg

Peak Power: 10 kW (average: up to 7 kW in pulse-doppler mode, up to 500 W in pulse mode)

Pulse Width: 0.4 and 50 microsec (pulse) 0.4, 1.3, 2.0, 2.7 microsec (pulse doppler)

Scan Rate: horizontal: 80 deg/sec
vertical: 2 scans/sec

Antenna Dimensions: 36 in (gain 37.5 dB)

Data above date to the early 1970s, and current AWG-9 characteristics have probably been modified.

The F-14 Tomcat's radar is built by Hughes. It weighs about 1300 lb, and volume is about 28 ft³. The antenna is a 36-in slotted-plate planar array, with 12 (6×2) IFF dipoles on its face. AWG-9 uses a variety of raster-scan patterns, designated by their horizontal sweep width and by their vertical extent in "bars"; they range from 8 bars and 65 deg (to either side of the airplane every 13 sec) down to 1 bar and 10 deg every quarter-second. Other azimuth limits are 20 and 40 deg; search in elevation can cover 1, 2, 4, or 8 bars. There is also a vertical-scan lock-on (VLS) mode in which the radar sweeps a 4.8-deg-wide beam up and down over a 40-deg vertical sector, which can extend from -15 to +25 deg, up to +15 to +55 deg.

There are 6 pulse-doppler modes: pulse-doppler search (PDS, giving only range rate and bearing: 5-m² target detected at 115 nm); range-while-search (RWS, to 90 nm, giving range, range rate, and bearing); TWS (to 90 nm, forming a complete track file, and limited to 2 bars/40 deg or 4 bars/20 deg to achieve sufficient data rate); pulse-doppler single-target-track (PDSTT, including both velocity tracking and jam-angle tracking, JAT). There is also an associated slaved mode for use with an IR tracker, permitting illumination of a selected IR target. Pure pulse modes are pulse search (PS, out to 63 nm) and pulse single-target-track (PSTT, out to 49 nm). There is also a slaved pulse mode. Finally, there are 3 mixed modes: pilot-rapid-location (PRL, a lock-on using a 2.3-deg beam centered on the pilot's line of sight), vertical-scan lock-on, and manual rapid lock-on. Each is effective out to 5 nm, presumably using the spacing of the doppler pulses. The TWS mode is used only for Phoenix missile launch, the radar achieving a 2-sec data rate.

The radar intercept officer (RIO) in the F-14 back seat has 2 displays, a 5-in multimode display of raw radar video, plus a 10-in processed data display using NTDS symbology, and including target tracks.

Reportedly, AWG-9 achieves 2.5 times the range of the AWG-10 installed at about the same time in F-4J Phantoms. AWG-9 can track 24 targets simultaneously. A measure of its radiated power is its ability to guide an AIM-7F Sparrow at a range of 38 nm, compared to 24 nm for earlier radars.

AWG-9 is being replaced by APG-71 in the F-14D upgraded Tomcat.

In the new F-14D, AWG-9 is replaced by a digital version, APG-71 (see the separate entry).

◆ AAAWES

Advanced Airborne Anti-air Warfare Weapons-Engagement System, a project for airborne cooperative engagements, is similar in concept to BGAAWC. AAAWES is a 2-yr (1989-91) exploratory program at Point Mugu. A sufficiently broad-band digital link should enable several aircraft to share a common tactical picture. One airplane could control missiles fired by another; it could also operate in radar silence, using another's radar picture. Some forms of jamming could be overcome because they are so directional. Current data links (Link 4A and Link 11) cannot carry sufficient information for the deployed fighters to share the tactical picture in enough detail. Ultimately, the fighters will share multisensor data. The full program will probably take at least 10 yr to field. Hughes Radar Systems Group won the test/demonstration contract in July 1989. At this stage perhaps the most important program issue is the development of sufficiently capacious LPI communications, presumably achieved in part by using highly directional antennas.

◆ IRSTS

General Electric's infrared search and tracking device is for use in the F-14D fighter. The production decision was to be made in the fall of 1989. IRSTS is conceived as complementary to the AWG-9 or APG-71 radar, allowing the F-14 to passively detect and track aircraft at long range. IRSTS flight tests began on board an air force F-15 in the summer of 1988 and continued on a modified F-14A.

Compared to a search radar, an IRSTS has a wider field of view and a narrower effective beamwidth, although IRSTS cannot determine a target's range. The narrow beam makes it possible to distinguish aircraft within a distant raid, and current systems can track multiple targets simultaneously, on a TWS basis. In theory, an IRSTS could be used to set up a missile fire-control solution, the firing aircraft using its radar (or a laser range-finder) only for a 1-time check on the target's range. Such practice would be analogous to the submariners' technique of passive tracking plus single-ping ranging and would greatly reduce the warning provided by an enemy's radar receiver. On the other hand, infrared radiation does not pass through clouds and other weather, so a pure infrared sensor system is unlikely to be satisfactory.

The current IRSTS operates in the mid-infrared (3-5-micron band) and uses a linear focal plane array of 256 indium-antimonide detectors. The focusing IR optics scan this array, in effect, over the scene outside the fighter to form an image. Compared to staring FLIRs, this system scans a very narrow beam over its array, providing greater range. Software is used to reject

clutter and such hot spots as solar reflections off clouds. Future detectors may use 4×256 or 8×256 arrays. Both General Electric and Martin Marietta have also experimented with longer-wave (8-12-micron band) mercury-cadmium-telluride arrays; 1 is to fly on board an F-14A at Point Mugu in May 1989. The longer-wave system is expected to provide longer range, as well as better performance against targets with reduced IR signatures, such as slow aircraft and cruise missiles. As of early 1989, it will probably be the one chosen for production.

As currently designed, the IRSTS gimbaled infrared optics weigh 85 lb and have a diameter of 9 in. The system consists of 2 weapon replaceable assemblies (WRAs), the sensor head and the processor.

IRSTS appears as navy fighters move from the current analog cockpit arrangement to a new "glass cockpit," in which all of the single-purpose dials are replaced by multipurpose digital CRTs. In such a cockpit, the pilot can use the same CRT to view radar or IRSTS (or TCS—see below) images. In theory, the CRT could also be arranged to superimpose or compare such images, to simplify the pilot's task of interpretation. Simplified interpretation has certainly been the effect of analogous developments in surface ships' systems.

The IRSTS chin pod was originally designed to be interchangeable with the television chin pod (TCS), but it has been decided that F-14Ds will all have dual pods.

Airborne infrared sensors have had a long history in U.S. fighters. In the mid- to late 1960s, many IR sensors were carried by North American Air Defense Command aircraft such as F-106s, and the F-14 originally incorporated such a sensor. These devices were abandoned because their range was very limited, because they provided very limited data, and because their false-alarm rates were high. F-14As were initially produced carrying a chin-mounted ALR-23 infrared detector, whose seeker head could slew independently of the fighter's radar. ALR-23 was not an imaging device. It operated in the 3-5-micron band and used an indium-antimonide detector cooled by a closed-cycle Stirling refrigerator. Reportedly, ALR-23 was provided largely to detect the Soviet MiG-25 Foxbat, which would have presented a very hot target image against a cold sky. The sensor proved ineffective and was soon deleted from the F-14. Many aircraft were completed without any chin pods, but the pod originally designed for the ALR-23 was used instead for a television, the TCS.

By the late 1970s a new generation of IR technology was available. A new air force IRSTS program was begun in 1981, and the U.S. Navy joined in 1984. Official justifications for IRSTS include the claim that the sensor may help to detect aircraft with low (i.e., stealthy) radar cross sections.

The new-generation IRSTS was first flight-tested in 1985, but the air force reduced its participation in the program in February 1986. Reportedly, the air force considered the sensor less effective than expected in a look-down situation. The navy, planning to use the sensor in the outer air battle (where the targets would generally be at considerable altitude, against a cool sky), remained in the program and approved full-scale development in 1986. Recent improvements in IRSTS have satisfied most air force concerns, although there are still no plans to place the sensor on F-15s.

General Electric is prime contractor; Martin Marietta was selected as second-source contractor in June 1987. As of early 1989, production was expected to begin in FY90. In January 1989 the U.S. Navy requested industry proposals for an integrated long-wave IRSTS/laser range-finder, for large aircraft such as P-3s, capable of tracking multiple targets at ranges beyond 100 km. Such a system might also be applicable to the E-2 or to a future unmanned fleet early-warning airplane.

◆ TCS (AXX-1)

Northrop's television camera sight for the F-14A incorporates a stabilized long-range telescope in a chin pod. The TCS was introduced to provide fighters with a means of positively identifying targets even at very long range, so that the planes could



IRSTS infrared sensor under the nose of an F-14A for tests. The operational version will be 1 of 2 identical under-nose pods, side by side, the other containing the television camera sight (TCS). The protrusion under the chin pod is an ALQ-100 jammer. (GE Aerospace)

use their long-range air-to-air missiles effectively. Prior to the advent of the TCS, typical rules of engagement required the fighter virtually to fly alongside its target before firing. That handicap was unacceptable when enemy aircraft carried long-range air-to-air missiles.

The optics have to be stabilized to keep the very distant object in view as the F-14A moves. TCS can be used independently, e.g., in an automatic search and target-acquisition mode (in analogy to shipboard optronics), or it can be slaved to the AWG-9 radar for target identification. The TCS image is captured by a video recorder on board the fighter. The telescope has a magnification of 10 and can scan over a 30-deg FOV. The instantaneous FOV is selectable as either narrow (0.44 deg) or wide (1.42 deg); the black-and-white image is presented on the pilot's vertical display indicator and on the radar officer's tactical information display.

The television pictures of the battle between navy F-14s and Libyan MiG-23s in January 1989 were taken by TCS. TCS production began in 1981, and as of 1988 all F-14As were equipped with this pod.

TCS is descended from the U.S. Air Force TISEO, target identification system, electro-optical (ASX-1), which was developed in the early 1970s as part of the Rivet Haste and Combat Tree programs. TISEO's camera and stabilized telescope are mounted in the left wing's leading edge on some air force F-4E fighters, with the video processor and power supply in the body of the airplane; and the video image is shared with the back-seat radar display. Over 500 TISEOs were delivered during the 1970s. They allowed a pilot to identify potential targets well beyond normal visual range and, thus, to use long-range air-to-air missiles (Sparrows) even under stringent rules of engagement, solving one of the major problems of air combat in Vietnam.

Navy tests of an adapted version, TVSU, the television sight unit, began in 1977. Typical effective range was 9 nm, compared to 2 or 3 for the unaided eye; reportedly observers could even decide what sort of stores the observed aircraft were carrying. That was certainly the case for the TCS-equipped F-14s in the 1989 Libyan incident. TVSU was tested at sea, on board the carriers *Kennedy* and *Constellation*, in the summer of 1978, proving particularly successful in reconnaissance. An airplane detecting a ship on radar could slave TVSU to the radar image and obtain a usable ship image at a range as great as 50 miles. TCS is a fully navalized version of TVSU.

SURFACE-TO-AIR MISSILES

BRAZIL

◆ Avibras SSA-N-1

Dimensions: 15 cm × 2.72 m [5.9 × 107 in]
Weight: 85 kg [187 lb] **Warhead:** 12 kg [26.4 lb]
Propulsion: Rocket **Speed:** Mach 2.0+
Range: max 6 km [6600 yd]

Data apply to the air-to-air Piranha missile (MAA-1).

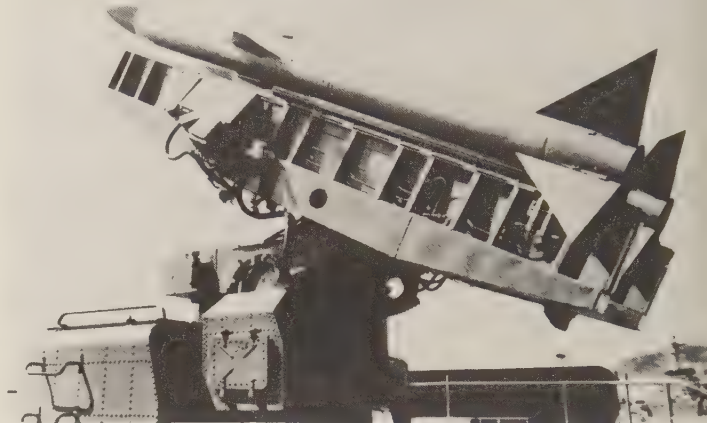
SSA-N-1 is a ship-launched version of the Piranha (MAA-1) air-to-air missile, which is replacing Sidewinders in Brazilian service. SSA-N-1 is manufactured by the Centro Tecnico Aeroespacial (CTA) of Brazil. Concept studies were conducted in 1975, and development began in March 1976. However, the army and navy withdrew from the program late in 1977, returning only in mid-1982. The first trials were completed in mid-1984, and the air-to-air weapon entered service in 1987. Reportedly, there were initially some problems with motors, and at least 6 French-built motors were provided for the prototypes.

The naval version was to have armed later-production Brazilian patrol frigates, which will be built during the 1990s. Since the missile itself broadly resembles Sidewinder, presumably the surface-to-air version would have been comparable to Chaparral. However, this system was canceled in 1987 when the Brazilian military budget was cut by 20%. Given the erratic history of the program, it may be revived later.

CHINA (PRC)

◆ RF-61/SD-1

Dimensions: 28.6 cm × 3.99 m; span 1.166 m [11.3 × 157 × 45.9 in] **Weight:** 320 kg [705 lb]
Warhead: continuous-rod warhead
Propulsion: single-stage rocket (boost-glide) **Speed:** Mach 3
Range: 10 km against a low-flying target; maximum altitude is 8 km; maximum range at that altitude, about 5.5 km [10,900; 8700; 6000 yd]



HQ-61. (U.S. Naval Institute)

RF-61 is a ship-launched short-range surface-to-air missile. Guidance is semiactive, using a tracker-illuminator and a rear reference beam for proportional navigation.

The missile's configuration broadly matches that of the U.S. Sparrow, although RF-61 is a much larger weapon. It is unique among rail-launched surface-to-air missiles in lying atop, rather than being suspended from, the (twin) launching rail.

RF-61 was first exhibited in 1986 although it has not yet been offered for export. The missile is made by CPMIEC, the commercial arm of the Ministry of Space Industry. Development seems to have been protracted; only 2 ships carrying this weapon have been built, and they were completed in the early 1970s.

RF-61 is the ship-launched version of the ground-launched HQ-61; missile weight is 320 kg, rather than the 300 kg of the ground version.

In September 1990 CPMIEC distributed brochures describing a new version of this missile, designated SD-1. However, the photograph illustrating the missile had previously been printed with the earlier HQ-61 and RF-61 designations. The ground-launched version is now designated SD-1A.

CPMIEC announced a new low-altitude missile, FM-80, at Farnborough in 1990. It is probably in the Roland or Crotale class. Although the brochure did not mention any naval application, one is likely, given the dual role of HQ-61/RF-61/SD-1.

FRANCE

◆ Crotale Naval/Crotale NG

Dimensions: 15 cm × 2.89 m; span 54 cm [5.9 × 113.7 × 21.3 in]
Weight: 80 kg [176 lb] **Warhead:** 15 kg [33 lb]
Propulsion: boost-glide rocket (SNPE Lens III motor; burn time 2.3 sec) **Speed:** Mach 2.3 (800 m/sec; 2624 ft/sec)
Range: 8.5–13 km [6.5 km vs. a sea-skimmer; 700 m minimum]. Effective range is 10+ km against an airplane and 13+ km against a helicopter. Altitude: 150–12,000 ft [9300–14,200 yd; minimum 765 yd]; see below for anti-sea-skimmer modification.

Crotale is now the standard French point-defense missile system, installed on board the 2 carriers and 10 escorts (3 F67- and 7 C70-class frigates); it is also carried by the 4 French-built Saudi *Al Madinah*-class frigates. The typical installation is an 8-round launcher and 16 reloads, manually reloaded. Reload time for the entire launcher is about 5 min. There is also a



Crotale Naval launcher with colocated fire-control radar. The IR tracker is to the left of the radar dish. (Thomson-CSF)

lightweight 4-rnd launcher, tested on board a French aviso about 1986; it replaced the ship's 100-mm gun.

The system is fired from CIC. In large ships the fire-direction radar (with associated TV camera and IR telescope) is mounted on the launcher, the missile tubes being grouped to either side. In a smaller ship, the director can be off the mount, the electronics in a deckhouse underneath. The version for small ships is modular; a larger ship uses the compact version, in which the electronics are carried in a deckhouse under the launcher/director. Thomson-CSF claims that the modular launcher is about the same size and weight as a single 40-mm gun.

Compared to the land-based version, Crotale Naval has larger-diameter tubes for launching missiles, to keep the missile's fins from striking the sides of the tube when launching in rough weather, and lighter caps.

Guidance is command to line of sight, using a radar tracking the transponder on the missile. Upon firing, the missile is gathered into the radar's line of sight by an IR tracker (FOV 5 deg). Steering is by measurement of the error angle between missile and target, using a fin-mounted transponder on the missile and a Ku-band digital data link. The monopulse doppler tracking radar has a range of 20,000 m. A second IR tracker can be used to fire a missile at a second target in anticipation that the main command channel will become free when the first target is destroyed. This anticipation-firing mode makes for quicker engagement of multiple targets, even when they are not very close together.

Reaction time is 4.5 sec from reception of the target-designation signal. Because the missile is command-guided, the system can deal with only 1 target at a time. However, Thomson-CSF points out that a really fast missile with a high single-shot kill probability can destroy several targets in rapid succession (almost certainly with the important caveat that the targets are approaching as a stream attack). For example, Mach 0.9 sea-skimmers can be intercepted successively at 8500, 4500, and 1900 m. The manufacturer claims that anticipation firing increases the engagement rate, so that 5 targets can be engaged and killed in quick succession, before they pass within the minimum engagement range.

Designed to counter missiles flying at 50-m altitude or above, Crotale originally did not have an anti-sea-skimming capability. At very low angles of elevation the tracker beam can suffer from reflections off the surface of the water (image effect). The solution was an infrared tracking/guidance system (SEID, *Système d'Ecartométrie Infra-rouge Différentielle*), which can help

Crotale engage a sea-skimmer at up to 8500 m (depending on atmospheric conditions). The system using SEID is termed EDIR, *Ecartométrie Différentielle Infra-rouge*.

Fitted with SEID, Crotale is considered effective against Mach-2.0 targets at altitudes as low as 4 m. Because tracking is by IR, the missile must be fired offset from the target so that the missile's own IR signature does not blank out the target's. Typically Crotale is made to dive at the target at a 1-deg angle. Evaluation gates around the target are used to counter possible IR countermeasures, and the manufacturer claims that interception accuracy is 0.1 mrad in a 20×30 -mrad lobe. The system evaluates the quality of the different tracking sensors available to it, choosing automatically the one most suited to the engagement.

Moreover, an improved version of the radar tracker, using special filtering, can track a missile by comparing the direct- and reflected-image (off the sea surface) radar signals, out to 3000 m. This mode is important because under some weather conditions the infrared tracker would be ineffective.

Crotale is the entire system, not the missile. The current missile is the Matra R.440N, described above, but the next-generation Crotale NG uses a new missile, the LTV VT-1 (see below).

Very low level operation also required modifying the missile's proximity fuze to reject sea clutter. Thomson-CSF claims that the combination of a proximity fuze and a directed-blast warhead (into a plane perpendicular to the missile's axis) makes for very high kill probabilities: 0.82 for an airplane at a range of 10,000 m and 0.90 for an antiship missile at a range of 8500 m. These figures are probably conditional on successful target acquisition and missile guidance.

The current motor accelerates the missile to Mach 2.3 in 2.3 sec, and the missile reaches 5 km in 10 sec and 8 km in 20 sec, by which time it is subsonic; it takes another 26 sec to get to 13 km. Matra is developing a new motor, which will enable the missile to reach 15 km in 25 sec; only beyond that range will Crotale be subsonic.

This missile was originally called Murene and was designed to engage targets at ranges between 1500 and 9000 yd. Development of the basic land missile, Crotale, was largely (85%) financed by South Africa, beginning in 1964, the British government having refused a South African order for Bloodhound missiles. The first unguided round was fired in 1965 (the first guided round was fired in September 1967). Development of the naval version began in 1972, the French navy ordering 10 systems in May 1974. The first sea-based test was in November 1978, the target, a CT20 drone, being hit at 6-km range. Trials were completed in October 1979, and series production began in January 1980. On board the carriers, 2 Crotale Naval launchers replaced the original 3.9-in battery in 1986/87, the navy having expressed concern about possible sea-skimming missile attacks when the ships were deployed off the Lebanese coast.

A next-generation version, Crotale NG, is currently in production. It was derived from the modular Crotale Naval but uses a new missile, the VT-1, developed by the U.S. firm LTV. VT-1 is to arm the new *La Fayette*-class frigates; it is not entirely clear how much more of the Crotale NG system they will have. As announced, the French navy's order was the first French sale of Crotale/EDIR, which had previously been sold to the PRC and the UAE.

The Crotale NG program began in 1985 (under the name Liberty), to meet the U.S. Army FAADS-LOS-L-H requirement (the competition was won by the Oerlikon ADATS). Crotale NG has now been adopted by Finland and by the Dutch Air Force. In this form it uses a new 200 W Signaal C/X-band radar, Varibeam, which can process up to 20 targets simultaneously, maintaining 8 tracks. The associated frequency-agile, pulse-compressed, pulse-doppler tracker can detect hovering helicopters or Mach-2 aircraft. There is also an optronic tracker. Some of these sensors would presumably be used in the naval version.

The new VT-1 missile is 2.4 m long and weighs 75 kg (95 kg for a complete round); its maximum range is 11 km at an alti-

tude of 6000 m, and its maximum speed is Mach 3.6 (average speed Mach 2.3, covering 8 km in 10 sec). At 8-km range it can maneuver at 50 Gs, compared to 20 Gs for the current Crotale missile. VT-1 has a new pseudo-randomly pulse-modulated, broad-band prox fuze developed from that of Crotale Navale; it operates between 0.2 and 0.5 sec before interception. The missile has been under development by LTV since 1986, on contract from Thomson-CSF. Production began in 1989, and the first weapons are to be delivered, for Finland, in 1991. VT-1 completed test firings in France late in February 1989.

Crotale NG uses the same multisensor (radar and IR) control approach as Crotale Naval but differs from previous Crotales in that all sensor data are sent to 1 computer, which processes them and determines guidance orders after filtering interference. Thus radar and optical modes normally operate together, checking each other constantly. The trackers define a window containing target and missile as well as false targets already detected. Each target is surrounded by a measuring window, within which measurements made by different sensors are correlated. All data are sent to a 2D filter.

Crotale NG uses a new 12-rnd, 2.6-ton launcher (6 rnds on each side, compared to 4 for Crotale). The associated director (900 kg) carries a Ku-band, pulse-Doppler, frequency-agile radar, an LLLTV, and a FLIR; it should be able to detect very low flying targets beyond 18 km [19,700 yd]. The computer processes up to 20 targets and selects the 8 most threatening; it also selects the optimum modes of target tracking and missile guidance. The operator validates the choice of most threatening target and fires; Thomson claims that only 6 sec need elapse between target detection and firing.

◆ Masurca

Dimensions: 406 mm × 5408 mm; span 1277 mm; booster length 3222 mm and tail span 1500 mm. The missile penetrates 114 mm into the booster, so total length is 8516 mm. [16 × 212.9 × 50.2 in; 126.9 × 59.0 in; total length 335.2 in]

Weight: 840 kg; booster 1858 kg [1850/4095 lb]

Warhead: 120 kg [264 lb]

Propulsion: booster (burn time 4.5 sec) plus sustainer (burn time 30 sec); booster thrust about 35 tons, sustainer thrust 2300 kg [5070-lb thrust] **Speed:** 900 m/sec max [2952 ft/sec]

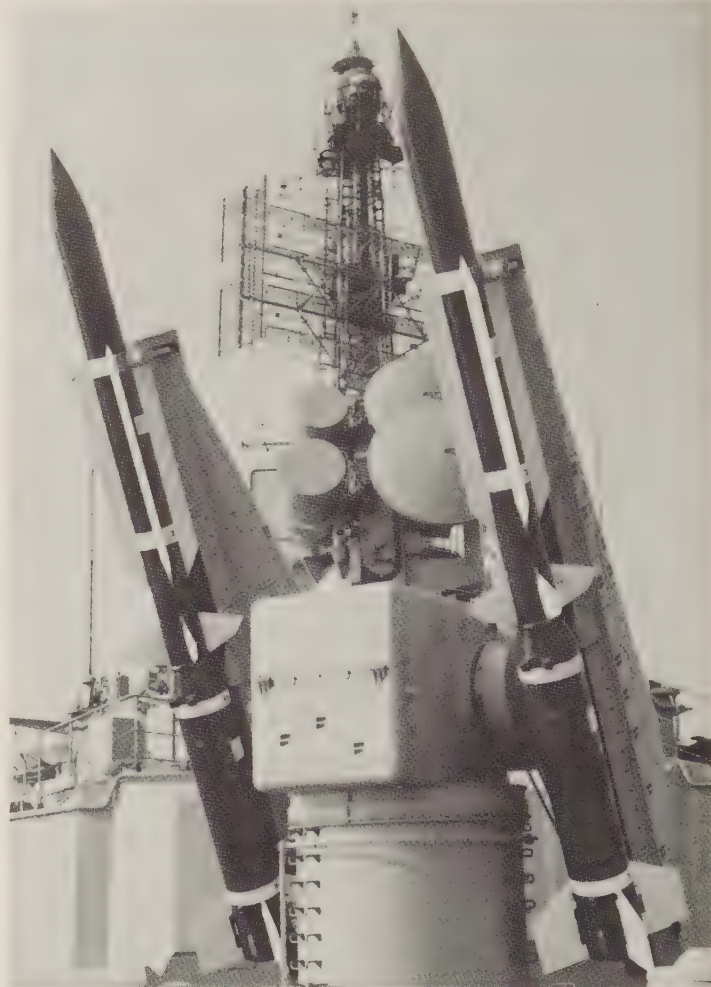
Range: 40,000 m; kinematic range 62,000 m [43,700/67,800 yd]

Masurca is an area-defense weapon broadly comparable to the U.S. Terrier/SM-1(ER). The configuration is similar, but the French missile is larger and heavier. There were both semiactive and beam-riding (Mk 2 Mod 2) versions; currently only the semiactive Mk 2 Mod 3 remains in service. Fire control is by a DRBC 51 tracker-illuminator. The design requirement was to intercept two 1-m² targets at altitudes of up to 18,000 m and at ranges of 25,000 m (beam-rider) or 35,000–40,000 m (semi-active).

Like Terrier or SM-1(ER), Masurca is stowed horizontally, on a revolving drum, without the long booster fins, which are fitted by hand before firing. The rate of fire is one 2-missile salvo every 30 sec. The launcher carries a total of 46 missiles (18 per drum plus 10 missiles in reserve, broken down with missile and booster separate). Total system weight: 111.5 tons for fire control, 31.5 tons for the launcher itself, 202.0 tons for the loading system, and 105.0 tons of missiles, 450 metric tons in all.

The 3 remaining systems, on board the 2 *Suffren*-class destroyers and the cruiser *Colbert*, were modernized 1983–85 to maintain the system until the end of its scheduled life in 1998–2000.

Masurca was 1 of 5 French naval missiles whose development began in the first postwar decade: 3 anti-aircraft missiles (Masurca, Maruca, and Masalca), 1 ASW missile (Malafon), and 1 antiship missile (Malaface). Each designation indicated the role and manufacturer: MA for *marine* (navy), then the manufacturer (SUR, for Supersonique RUELLE), then the mission (CA, for *contre-avion*, anti-aircraft). For Malafon, the only other survivor of the program, LA indicated Latecoere, and FON indicated underwater (FACE was *surface*). The program was drastically reduced about 1958, as finances tightened: Masurca had



Masurca on board the cruiser *Colbert*. (ECP Armées)



DRBR 51 directors for the French Masurca missile. (*Ships of the World*)

the highest priority, and Malaface was killed on the theory that the carrier's strike aircraft had made the missile unnecessary. Masalca, developed by Latecoere, was a longer-range (95-km) anti-aircraft missile intended for a cruiser, a French equivalent of the U.S. Talos. Presumably, the related cruiser project was dropped about 1960.

◆ Mistral (Sadral and Simbad Systems)

Dimensions: 90 cm × 1.81 m [3.5 × 71.3 in]

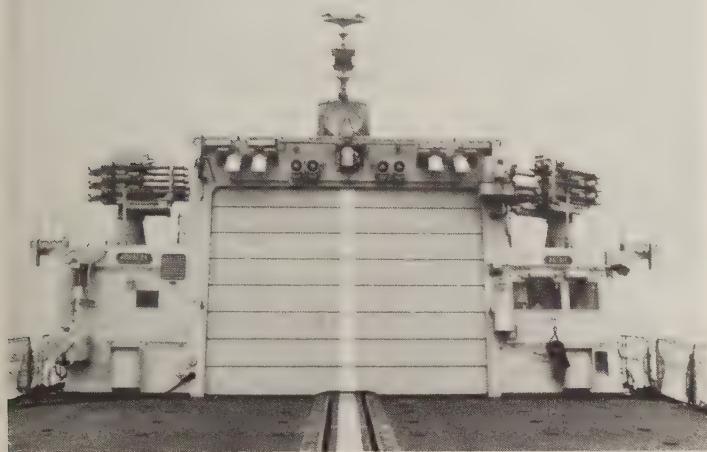
Weight: 17 kg [37.5 lb]

Warhead: 3 kg (1800 tungsten balls) [6.6 lb]

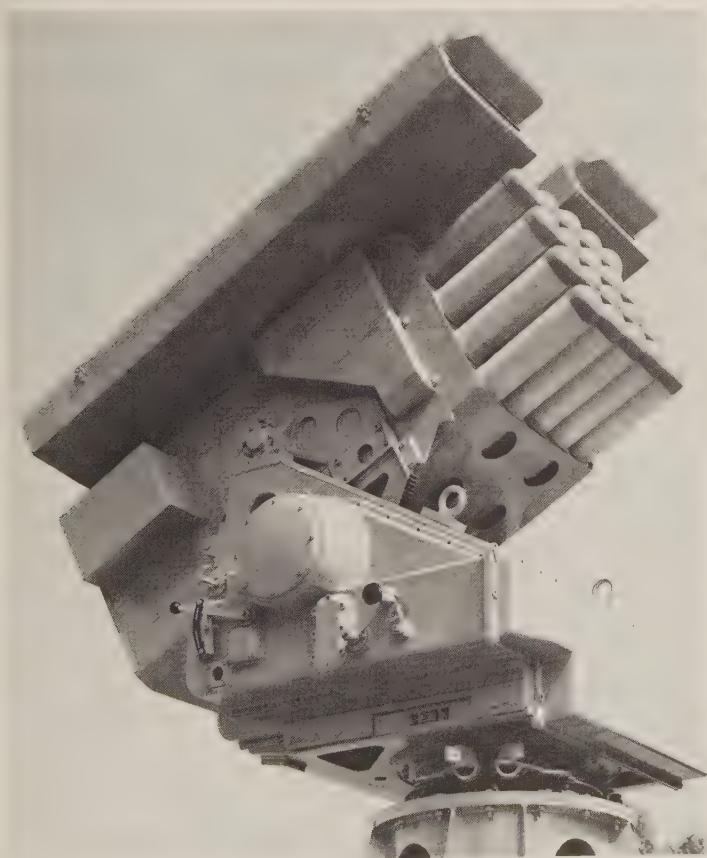
Propulsion: boost-sustain rocket (The booster burns only inside the launch tube, accelerating the missile to 40 m/sec [131 ft/sec], and the sustainer ignites 15 m away; the motor is based on that of the Super 530 air-to-air missile.) **Speed:** Mach 2.6

Range: 6 km against aircraft; 4 km against helicopters; 6 sec to 4000 m. Minimum range: 500 m [6600/4400 yd; minimum 550 yd]

The Matra Mistral is a short-range defensive missile used in several naval systems. Matra describes the weapon as the first shoulder-fired Mach-2.5 defensive missile. It uses an all-aspect infrared seeker and a laser proximity fuze, and the manufacturer claims that Mistral can attack helicopters with reduced IR signatures. Unlike many previous IR-guided missiles, Mistral employs proportional (rather than pursuit) navigation, using a gyro as a reference. One effect of such guidance is to reject flares ejected from the rear of a target.



Sadral anti-aircraft launchers (for the Mistral missile) on board the destroyer *Cassard*. (Matra)



Breda's combined Mistral missile and SCLAR chaff launcher, 1989. (Breda)

Mistral uses a 2-color IR seeker made by SAT. The warhead uses both impact and laser fuzes. On the launcher, the missile runs up its seeker and gyro in 2 sec; total reaction time is 5 sec.

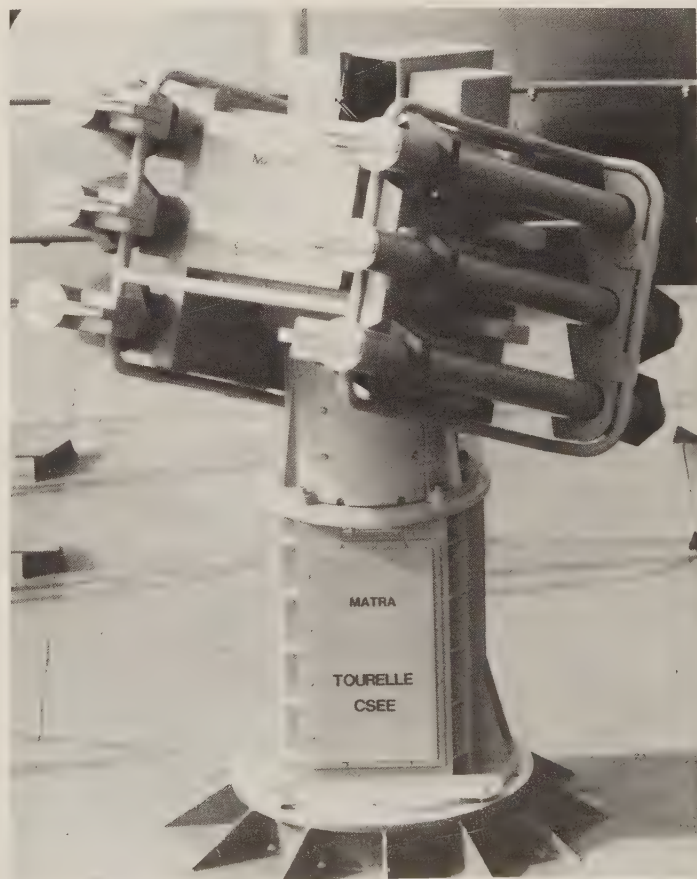
Sadral (*Système d'auto-défense rapprochée anti-aérien légère*) is a close-in 6-rnd defensive system for second-line ships, using Mistral. There is also a lightweight 2-rnd launcher, Simbad (*Système intégré de Mistral bimunition pour l'auto-défense*). Simbad is a modified 20-mm pedestal mount (a configuration that in itself explains the function of this and analogous weapons) carrying a simple optical sight.

The Sadral launcher is stabilized, elevating and training. It carries a television camera and an IR camera for night firing. The missile is locked onto the target before firing, presumably to limit the amount of background visible to the seeker, thus improving the effective signal-to-noise ratio. An audio signal indicates that the missile has locked on before it is launched. A more elaborate version of the basic Sadral mount, Lama, carries 4 or 6 missiles and an optical target designator that can act as a secondary director for other shipboard weapons.

Tests of the basic Mistral missile were completed in March 1988, with firings against low-flying CT20 drones. One firing resulted in a head-on hit at 5 km.

Sadral is in service on board French anti-aircraft frigates (C70 AA type) in a version called SATCP (*surface-air, à très courte portée*), using a CSEE automatic director and a 6-missile rapid-reload mount. Mistral is also combined with a close-in defensive gun in the proposed Samos/SAGEM close-in weapons system. An air-to-air version, A/HATCP, is planned for French Air Force helicopters; Santal is used by ground forces, and the basic man-portable infantry version is SATCP.

This program began with feasibility studies in 1978, Matra being selected as prime contractor in August 1980. The naval version was announced in October 1980, and tests began early in 1985. Deliveries of Mistral began in June 1988. As of 1988, the estimated cost per missile, including the kevlar launch tube, was \$60,000–\$100,000.



Sadral 6-missile launcher for Mistral. (Matra)



Simbad 2-missile shipboard launcher for Mistral. (Matra)

Naval users are France, Brunei, Finland, and Norway. As of late 1990, a sale to a Persian Gulf navy, probably that of the UAE, was reported as imminent. Both Finland and Norway are developing their own missile mounts. The Finnish navy is to use a converted Soviet-type, 25-mm, unstabilized, hydraulically operated, locally controlled mounting (which receives only target-designation data from the ship's CDS). The 2 guns are replaced by 6 Mistral tubes arranged in an arch above the FLIR and TV camera. Total weight is about 1500 kg. These weapons are to arm Finnish fast attack craft and minelayers. Norway ordered several hundred Mistrals in September 1990 to arm the *Storm-* and *Snogg-*class fast attack boats, with options for more for the *Hauk* class and the new mine-countermeasures craft. The attack boats will probably be armed within the 6-tube Sadral mounting, the minecraft with the 2-tube Simbad. Mistral may also be the missile chosen for the new Norwegian system described below.

◆ SAAM/ASTER

Dimensions: 18 cm × 2.6 m [7.1 × 102.4 in]; booster 36 cm × 1.6 m [14 × 63.0 in]

Weight: 100 kg [220 lb]; booster 200 kg [440 lb]

Warhead: 10–15 kg focused fragment [22–33 lb]

Propulsion: rocket

Range: 5–15 km (see below)

Data are for ASTER 15. The seeker is the AD4A used in the Matra MICA air-to-air missile. The standard 8-rnd launcher module weighs 12.5 t.

This French advanced point-defense (antimissile) missile is under development by Thomson-CSF and Aerospatiale and is the weapon of the FAMS system. The overall system is called SAAM (*Système de défense surface-air antimissile*), and the missile is ASTER. The potential targets are Mach-2.5 (15-Gs) sea-skimmers, diving antiradar missiles, and fighter aircraft. Claimed performance is a range of about 10 km against supersonic and maneuvering missiles, or 15–17 km against high-altitude aircraft and subsonic missiles. The same upper-stage missile is to be developed for land service as SAMP (*Sol-Air Moyenne Portée*). The land-based SA-90 (ASTER 30) is to be ramjet-powered; the sea-based SAN-90 (ASTER 15), rocket-powered. Otherwise, these versions have most systems in com-



ASTER with its booster. (Author)

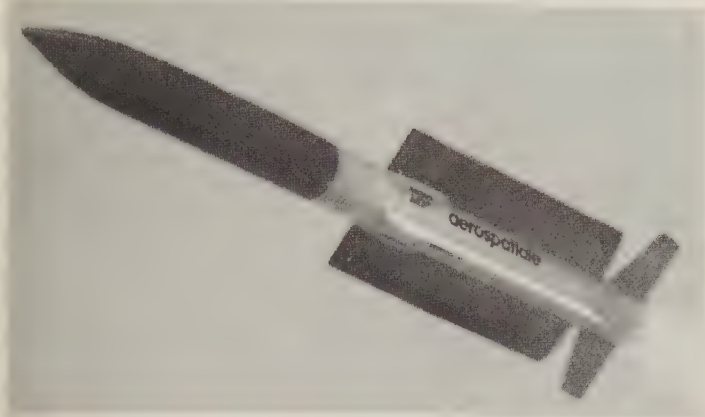
mon, requiring radar acquisition ranges of, respectively, 25 and 10 km [27,300 and 10,900 yd].

Key design requirements are very short reaction time, multiple engagement capability, great agility, and a very short guidance time constant. Quick reaction is ensured by a combination of vertical launching (from the canister tube in which the weapon is shipped) and highly automated operation. As in the U.S. Aegis system, a flat-face phased-array radar (in this case a single rotating face), the Thomson-CSF Arabel, tracks both missile and target. The missile is sent into a terminal "basket" by a command up-link programming the autopilot. The system is designed to handle 10 targets simultaneously. Unlike the U.S. Standard Missile, however, ASTER will use active terminal guidance, requiring no dedicated illuminators. Presumably ASTER has that capability because the missile is intended to engage its targets at short range: there would not be enough time to share a few illuminators.

The designers expect that violent missile maneuverability (up to 50 Gs) will allow the weapon to approach within 2 m of its target. At that range the missile can achieve catastrophic structural damage even with a relatively light warhead. A light warhead in turn makes it possible to package high maneuverability within a reasonable volume.

The missile itself consists of a separate booster and a guided vehicle incorporating a sustainer motor. By separating booster and sustainer, the designers again reduce terminal homing weight. They achieve maneuverability by a combination of aerodynamic forces and direct-force control (i.e., rockets firing perpendicular to the axis of the missile), a system they call PIF-PAF. Direct-force control has previously been used only in antiballistic-missile weapons. For ASTER, the claimed virtues of direct-force control are that it can operate even at very high altitude and, at any altitude, can permit violent maneuvers even at low angles of attack.

As in the U.S. SM-2 Aegis (ER), the booster employs thrust-vector control to tip the missile into the appropriate trajectory.



The ASTER missile in flight. (Aérospatiale)

ASTER, however, is finned. The booster's size controls the missile's range. The naval version of the system is designated ASTER 15 (15 km); the land version, with a larger booster, is ASTER 30. At the end of acceleration, ASTER 15 should have a velocity of 1000 m/sec; ASTER 30 will be somewhat faster. The naval version will be fired from a vertical launcher employing 8-weapon cells.

Reportedly, the French credit current systems with a reaction time of 15–20 sec; using the Arabel radar, ASTER is to have a 5-sec reaction time.

The RFP for a collaborative European missile (the French government is seeking partners for SAAM/SAMP development) was issued in 1980/81, with a 31 December 1981 deadline; the Aérospatiale-Thomson-CSF development contract was announced in August 1983. The SAN-90 design was frozen in 1984 (and a model displayed at Le Bourget in October 1985). ASTER was selected over the Matra SAMAT (which is, however, being continued as a backup) early in 1986.

As of 1988, ASTER was due to enter French navy service by 1996, on board the new carrier *Charles de Gaulle*, and SAMP was due to enter French army service in 1998. The first missile test, which demonstrated PIF-PAF maneuvering, was at the French CEL test range, 17 June 1987. About 1987 the estimated unit price of an ASTER was \$400,000–\$700,000.

The overall ASTER weapons system is designated Syrinx (Système Rapide Interarmées à base d'Engins et Fonctionnant en Bande X). See also FAMS, below.

INDIA

◆ Trishul

Trishul is a quick-reaction low-level missile, developed under the Integrated Guided-Missile Development Program approved in July 1983. It is a triservice weapon, intended to be effective against sea-skimmers. As of mid-1989, it had made 8 successful flights. Production weapons were to be delivered in 1990. Trishul uses a dual-thrust rocket motor and has a range of 9 km. It employs a combination of command guidance and some form of terminal homing. A modified surveillance radar is used to intercept one target at a time, and a modified Signaal Flycatcher provides guidance. Flycatcher is an mm-wave TWS radar, made under license by Bharat Electronics.

The 1983 program also included, in its first stage, the Prithvi SSM (250 km). The missiles of the second stage, to be operational by 1993, are the medium-range Akash SAM and the Nag third-generation antitank missile.

Akash is a ramjet missile, probably similar to the Soviet land-based SA-6, which has a blended rocket-ramjet power plant. It is to be guided by a phased-array radar, which permits simultaneous engagement of several targets. A photograph of a model shows 3 missiles on a tracked launcher, similar to that used for SA-6. Presumably, Akash, like Trishul, is a triservice project, so there will probably be a naval version.

INTERNATIONAL

◆ FAMS

FAMS stands for Family of Antiair Missiles; FAMS was developed in parallel with, and as an alternative to, NAAWS. The current production partners are France, Italy, and the United Kingdom, and the missile is the French ASTER described above. Each system employs 2 radars, a long-range unit for area air search and a shorter-range tracker. Late in 1989 the French Astral was chosen as the FAMS long-range radar. There are 2 versions of the basic naval system, the short-range SAAM chosen by the French navy and the medium-range SAMP/N chosen by Italy (using the ASTER 30 missile to engage aircraft at 30 km and missiles at 12 km). Neither quite corresponds to the British LAMS requirement, which falls between them. The French variant of the system uses Arabel as its shorter-range radar; the Italian variant uses EMPAR. No British radar has been chosen, but Marconi is the lead British contractor and is a partner in EMPAR.

All FAMS systems will use Selenia's MARA computers and MAGICS consoles (each of which accommodates up to 2 MARA computers) linked by the Italian MHIDAS bus (10 Mbit/sec). MARA currently uses an 80286 processor, and in 1990 Selenia was reported to be experiencing some difficulties with the modular software it was writing. It expected these problems to be solved with the introduction of 80386 processors. Other internal MARA boards are MON (0.5 Mbytes of RAM), ERB (768 kbytes), EPROM (64 kbytes), BSU1 (bubble memory, 0.5 Mbytes), and ECM memory extension (2 Mbytes of RAM).

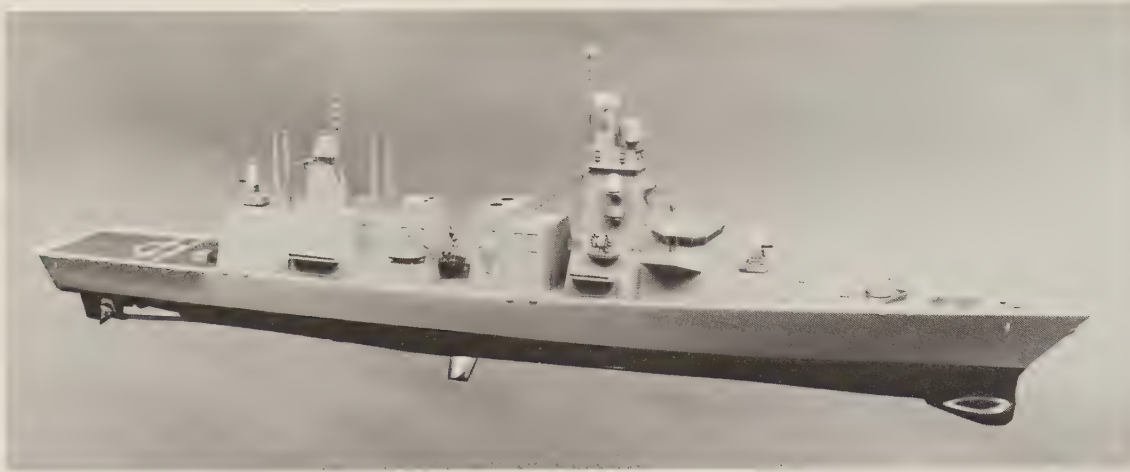
A FAMS consortium, Eurosam, has been formed by Aérospatiale, T-CSF, and Selenia. In October 1988 the French and Italian defense ministers agreed that their nations would collaborate on FAMS. In December 1989 the British officially chose FAMS as their next-generation naval air-defense system.

There are still some difficulties. The British wanted a local-area missile system, sufficient for limited area defense. Reportedly, they consider FAMS/ASTER much more a point, or single-ship, defensive system. In mid-1990 the British were reportedly confronting much higher costs and a much longer schedule than they had originally wanted, and there were reports that Britain was considering rejoining NAAWS. More probably, the British government hoped to improve the terms of British participation in FAMS, including the extent of industrial participation. Again, it was reported in mid-1990 that both the British and the Spanish governments were dissatisfied that the architecture of the system had already been determined, to the extent that neither country could expect much in the way of high-technology participation.

◆ NATO AAW Missile System

The NATO AAW Missile System is a U.S.-led project to replace the existing Sea Sparrow and to arm the NATO frigate. The primary requirements are quick reaction and multitarget handling, to deal with salvos of very fast low-altitude weapons like SS-N-22. The system must also be able to counter steep divers. In theory, that requirement might demand something like Aegis controlling a new, very high energy missile. However, like Sea Sparrow, NATO AAW is conceived as a secondary system for ships intended primarily for other purposes, such as ASW. Therefore, NATO AAW has to be relatively small and, it is hoped, inexpensive.

NAAWS has suffered badly from administrative indecision. It was originally part of the abortive NATO frigate program, and it was pushed quite urgently because of fears that Sea Sparrow was becoming obsolete in the face of SS-N-22 and similar weapons. Thus at one point contractors were required to have test systems running in 1989; this requirement in turn tied them to existing hardware, at least on an interim basis. However, as of late 1990, the formal RFP was expected in March 1991. At the same time, the program fell victim to internal warfare over U.S. defense cuts. It was formally deleted from the FY92 budget, but that was most likely only a maneuver, as the secretary of de-



The Westinghouse model of a possible NATO AAW frigate, showing trainable phased-array radars fore and aft, displayed at the U.S. Navy League show in 1990. (Westinghouse)

fense was most reluctant to abandon this multinational program. The deletion from the budget particularly upset the other partners, Canada and the Netherlands, who had stayed with NAAWS (rather than FAMS) despite the collapse of NFR-90. As of late 1990, Spain was still a participant in NAAWS but seemed very likely to choose FAMS instead. However, the Dutch were expected to collaborate with the Germans in developing a new air-defense ship in the late 1990s, and it would most likely be armed with NAAWS. Thus the Germans were likely to reenter the program.

Some of the delay was the result of difficulties in obtaining authority to release U.S. technology to the European allies. That was ironic because NAAWS was originally conceived as a way of transferring Aegis technology to other NATO navies. As of late October 1990, it seemed likely that the NAAWS MoU would have been signed at the end of 1990. At that time technology transfer was still an issue within the U.S. Navy (lists of the relevant technology were submitted in March 1990). Delays in settling the transfer issue delayed the issue of the RFP for 2 months, to early February 1991 (as estimated in October 1990; March 1991 as estimated a few months later). Proponents of a liberal release policy argued that in some areas, such as GaAs-chip technology for future radars, the Europeans were actually in the lead. A Technical Documentation Package was issued in May 1990. When issued, the full RFP had to be answered within 90 days. Reportedly, the MoU would commit the partners to the next phase of the program, Dem/Val and FSED of an interim system. As of late 1990, the U.S. Navy expected to fund only one consortium through Dem/Val in hopes of holding down the cost of the Block 0 system. As of the end of 1990, it was not clear how much a Block 0 missile would vary from Sea Sparrow. The program office claimed that it would be much more capable but would be of the same size, drawing on experience with Standard and with AMRAAM.

The key elements of the NAAWS requirement are the ability to deal with fast surface-skimmers and the ability to handle saturation attacks. The typical building blocks of the system, then, are a horizon-search radar (to pick up surface-skimmers with a very high probability, albeit at relatively short range), a hemisphere-search radar sufficiently accurate for fire control (generally termed an MFR, or multifunction radar), 1 or more electro-optic or infrared sensors integrated with the radars, a combat system core, and a vertically launched missile (for very quick reaction, even at very short range). All the competing consortia include radar and missile builders on both sides of the Atlantic. The consensus seems to be that the most successful (i.e., saleable) NAAWS will have to be adaptable to several quite different radar/missile suites, even though the U.S. Navy is

pushing for definite selections. In turn, the most innovative and important element of NAAWS should be a highly adaptable, modular computer combat system, programmed in the software equivalent of the hardware of the German MEKO frigate. Such flexibility has been most publicly identified with the Ferranti WS500 series (see the Surveillance and Control section), but all of the NAAWS competitors have probably adopted something roughly comparable.

This need for flexibility probably explains the reticence of 2 of the 3 current NAAWS competitors, who have steadfastly avoided mentioning specific sensors or weapons in advertising. The sole exception is Raytheon, which has suggested a developed version of its Sea Sparrow. Reportedly, Raytheon was initially dropped from the NAAWS competition because the company's proposed system was insufficiently advanced over existing ones (i.e., because it was too specific). The company's rejoinder is that anything much less specific cannot possibly meet the NAAWS deadlines (delivery of operational systems by 1998) and that, moreover, full development of a completely new set of systems will break any realistic NAAWS budget.

It is also possible that some developments financed under NAAWS will be applicable to existing ships and systems. For example, Raytheon's newly developed Sea Sparrow, with a new motor and multimode guidance, was intended for launching from the existing vertical launcher; the company argued that up to 64 missiles could be fired from a standard 16-cell vertical launcher (Mk 41). FMC demonstrated "4-pack" Sea Sparrow launching (4 Sparrows in 1 VLS cell) for the first time in June 1988. The company described this success as its contribution to NAAWS (at the U.S. Navy League show, March 1989). In the past, in connection with proposed German ships (presumably Type 123), RCA (now GE) has commented that the ideal weapons suite would be a combination of Standard Missiles and Sea Sparrows in a common vertical launcher.

Several alternative NAAWS configurations have been published. At the U.S. Navy League show in March 1989, GE (which absorbed the RCA division that manufactured SPY-1) showed a possible NATO-frigate design employing a 4-face fixed phased-array radar, with 2 illuminators (similar in shape to the Dutch STIR or STING), and an electro-optical sensor between them. Presumably, the fixed radar would carry out both the horizon and hemisphere-search roles (as SPY-1 does in Aegis ships), and the illuminators would be slaved (as in Aegis). GE would probably use the improved Sea Sparrow as its interim missile, choosing later between new U.S. and European weapons.

Raytheon has published a sketch showing 2 radars, a relatively low frequency rotating unit to detect and track long-range targets (the company's sketch seems to show stacked waveguides), and a higher frequency fixed array to deal with shorter-range targets.

Hughes has suggested the improved version of its TAS Mk 23 as a potential MFR.

The usual published sketch of the NATO frigate shows only

1 MFR, a rotating back-to-back pair of flat-faced arrays atop the ship's tower foremast. That MFR presumably represents Arabel or EMPAR.

The original competing consortia were:

—GE (RCA), with British Aerospace, CSC (which developed the Aegis tactical software), FMC, General Dynamics, Inisel (Spain), Marconi, Siemens, Signaal, and Thomson-CSF.

—Martin Marietta, with Hughes, ITT, Lockheed Electronics, Magnavox, Norden, HSA (Signaal), Bazan, Litton of Canada, AEG, Krupp Atlas, and Plessey.

—Raytheon, with AEG, Fokker, Plessey Radar, Bristol Aerospace, Martin Marietta, ERIA (combat direction software), and MBB.

—Westinghouse, with Hughes Aircraft, LTV, Martin Marietta, McDonnell Douglas, MCR, ORI (analysts), Vitro, Canadian Marconi, MEL, Oerlikon (of Canada), SPAR, AEG, BGT (the German missile manufacturer), Contraves, Dornier, Philips (ELCOMA, of the Netherlands), Bazan, Ceselsa (Spanish radar systems house), Babcock Power (UK), Ferranti, Short Brothers, and Thorn-EMI. This group is called UNISAMS.

By September 1988, the Martin Marietta and Raytheon proposals had been dropped. However, Raytheon protested, and by early 1989 it had been reinstated in the NAAWS program.

At this stage the NATO frigate was still alive, and the main competition was between the French-led FAMS, which was conceived as a stand-alone AAW system, and the U.S.-led NAAWS, which was conceived as an Aegis-like combat system, integrated with most ship sensors and with the ship's tactical data system. NAAWS would also be integrated with the ship's electronic countermeasures. In September 1989 Britain and then France and Italy dropped out of the NATO frigate program, leaving only Spain as a possible participant requiring FAMS rather than NAAWS. At that time France and Italy agreed to join in FAMS. Although Britain was still considering its options, its withdrawal from the NATO frigate made withdrawal from NAAWS likely; that followed in December. The official British reasoning was that the NAAWS schedule ran some years later than what they needed. At that time the Germans, too, withdrew from NAAWS because its capability was beyond their requirements.

These withdrawals left NAAWS as a U.S.-Canadian program with possible Spanish participation. It is still essential as a gap-filler since the United States will have to operate numerous non-Aegis ships against Third World countries increasingly well armed with sea-skimming antiship missiles. At present Aegis is probably the only effective counter to such weapons, thanks to its automated reactions and its very effective main radar.

The withdrawals, particularly by the British, left the contenders in chaos, since British-supplied systems were essential elements of their proposals. The following notes describe the systems, to the extent that information was available late in 1989. At that time it appeared that 2 teams would be chosen for 4-yr demonstration and validation contracts in June 1990.

Unisams was led by McDonnell Douglas Missile Systems. Ferranti was to have supplied the data system, a variant of its System 500. The proposed missile was new, 4 fitting a standard Mk 41 vertical-launching cell, and it used a dual-mode active/passive seeker. A lightweight modular launcher was planned for smaller ships.

The GE team was still built around the FARS radar, but other partners included BAe Dynamics and Marconi Radar.

Raytheon still planned to use its tail-controlled Sparrow derivative, this time with a combined X-band semiactive radar and IR seeker. The planned radars were an S-band MESAR, for volume search and target designation/track, and a smaller Raytheon X-band phased array for target illumination and horizon search. The 2 would be superimposed on a single rotating mounting. In this team, Martin Marietta was expected to provide the core architecture and the vertical launcher; AEG the radar seekers, missile-guidance systems, and ship's combat-systems integration; MBB the fuzes and warheads; ERIA (Spain)

the combat system software; Bristol Aerospace the missile motors and control; and Fokker the missile-control systems and shipboard launchers.

Given the withdrawal of the NATO partners, NAAWS may well be recast as a U.S. Navy program. Alternatively, it may be down-scaled so that it can replace the existing NATO Sea Sparrow on a system-for-system basis.

As of mid-1990, no official RFP had yet been issued. However, the broad concept of NAAWS has not changed. A multifunction radar (MFR) is to be used for both horizon search and fire control. Its beam must be accurate enough to shoot on search, since by definition the system will have little time to shift from detection to firing mode. Ideally, the radar should be accurate enough to control both guns and missiles, although that may conflict with the requirement for rapid search. Current U.S. Navy planning calls for development in 2 stages, first with the existing Sea Sparrow missile but a new command/control core and a new search radar, and then, if money is available, with a new missile. The argument is that even a new missile cannot overcome the inherent limits of existing radar and command/control, whereas better command/control may make the existing missile worthwhile. The current order of priorities, then, is the core (command/control), then the MFR, and only then the missile.

NAAWS apparently differs from previous approaches to the ship-defense problem in integrating all defensive resources, both hard- and soft-kill. Its TEWA, then, must be able to compare, for example, chaff, jamming, missiles, and close-in guns. In theory, NAAWS will be an expert system capable not only of engaging but also of recommending course and speed via a bridge console. To some extent RAIDS (see separate entry) is an approach to this problem.

As of mid-1990, there were 3 active teams: McDonnell Douglas-Westinghouse (Unisams), GE/RCA, and Raytheon. None had a concrete design, at least for public discussion.

McDonnell Douglas had bought the Ferranti System 500 computers it had originally planned to use for the core of its system (System 500 had been used in the concept-exploration phase). At this time it seemed possible that McDonnell Douglas would continue to use System 500 despite the British withdrawal and would buy the associated code. As of 1990, the company was concentrating on evaluating different generic missiles and sensors in standard scenarios, as preparation for the next round of bids. The main test threats are a supersonic high diver and a sea-skimmer. Reportedly, the system is required to achieve a 0.7 probability that the target ship will not be hit.

McDonnell Douglas was also considering using Hughes Ground Systems to develop a new core. Presumably, such a core would be related to the H930 CDS and its successors. Hughes was also attractive because it was already under contract to integrate the TAS radar with combat systems. It, therefore, already had a TEWA and experience in multiweapons assignment.

Unisams was looking at a new Hughes-McDonnell Douglas missile with better performance than Sea Sparrow, using a tri-mode seeker (probably IIR, semiactive, and command). Imaging IR was needed to minimize the miss distance. The projected missile would have been 3 times as fast as Sea Sparrow, shaped like a slimmed-down SM-2 to minimize time constants (i.e., maximize maneuverability).

RCA/GE was also reportedly considering Hughes as a command/control core developer.

Raytheon was still developing a full-up system. As of early 1990, the company was marketing a new line of militarized VAX computers and had developed its own TEWA to run on them, or on its CWS workstation. Presumably this development was fallout from the NAAWS exercise, but it also presented possibilities for future CDS development, possibly in combination with Plessey (Nautis).

◆ NATO Sea Sparrow

See Sparrow (U.S. air-to-air missile) below.

◆ Polypheme-SM

Aerospatiale (France) and MBB (West Germany) are privately developing a submarine-launched, fiber-guided, anti-aircraft missile, Polypheme-SM. As of 1989, the 2 companies claimed that the system could be made operational within 5 yr, should either the French or the German navy fund full-scale development. Range would be 10 km against typical ASW helicopters; presumably, it would be shorter if the missile were fired against higher-performance fixed-wing aircraft. Maximum altitude is



Polypheme-SM emerges from the water, its canister falling away. The after rocket motor is burning. (Aerospatiale)



Polypheme-SM in flight, trailing its fiber-optic guidance link. The forward rocket motor is burning. (Aerospatiale)

5000 m (about 16,000 ft). The 43-kg missile (carrying a 3-kg fragmentation warhead) would be carried in a pressurized 62-kg capsule, which would carry it free of the water. The capsule could be fired at a depth as great as 300 m (about 1000 ft); it would follow a preprogrammed underwater trajectory, at a speed of 15 m/sec, emerging from the water about 1 km from the launch position, to protect the submarine from disclosure of its position.

The missile employs a boost-sustain motor and has 2 flight speeds: 150 m/sec for target search and 250 m/sec for attack. The missile carries 2 separate rocket motors for the 2 phases of its flight. It employs 4 canard steering fins and 4 fixed stabilizing fins at its tail.

Polypheme is compact because, like the U.S. FOG-M land-based missile, it contains virtually no guiding intelligence. Its seeker is optronic, and the seeker output travels down the optical fiber to the launching submarine. The operator aboard the submarine flies the missile to its aerial target.

There are 2 operating modes. If target range and bearing are fairly well known (e.g., if the helicopter is detected by the sound of its blades or by the pinging of its dipping sonar), the missile can search a 3-km-wide path as it flies. Alternatively, if target position is only very approximately known (e.g., by the splash of sonobuoys entering the water), the missile can fly an ascending spiral search pattern, with a radius of 1 km.

Polypheme-SM is interesting because it minimizes the exposure of the firing submarine. However, it still limits the extent to which the submarine can escape after firing. The ideal submarine self-protection weapon is a deterrent to any close approach (for localization) and can be deployed while the submarine runs, and that requires more, rather than less, intelligence inside the missile (infrared guidance is an interesting option here). Otherwise, the use of the missile tends to confirm that a supposed submarine contact is indeed a real one. On the other hand, any effective submarine-launched surface-to-air weapon will greatly reduce the value of current airborne ASW systems.

As of mid-1989, Polypheme-SM is a technology-study program. Hardware development to date has been limited to work with optical fibers; an SS 12 missile has flown 8 km trailing such a fiber. Initially, Aerospatiale used fibers coated with Kevlar, but currently only the hairlike fiber itself is used. Images have been transmitted successfully over a 60-km distance.

◆ RAM (RIM-116A)

See RAM under U.S., below.

◆ VSRAD

A 12–14-month prefeasibility study of a future NATO Very Short Range Air-Defense system began in June 1990. The major partners are Germany, Italy, the Netherlands, Spain, and the United Kingdom, with OTO Melara leading the industrial team reporting to the new Project Group 36. The United Kingdom already has a VSRAD project (see the UK section, below); reportedly, the navies of Germany, Spain, and Italy were planning similar efforts. The current observers are Belgium, Denmark, France, Norway, and the United States. An outline NATO staff target (ONST), already approved by the partners, reportedly calls for a maximum range of about 3 nm. All current hard-kill techniques (cannon, missiles, unguided rockets, lasers, and particle beams) are to be evaluated (the British VSRAD has already chosen a hypervelocity missile, Seastreak).

ISRAEL

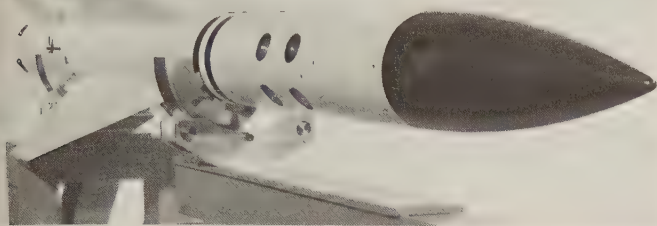
◆ Barak I

Dimensions: 170 mm × 2.175 m; span 0.68 m [6.7 × 85.6 × 26.8 in] **Weight:** 98 kg [216 lb]

Warhead: 22 kg [48.5 lb]

Propulsion: triple-thrust (boost/sustain/terminal engagement) rocket **Speed:** 580 m/sec [1900 ft/sec]

Range: 0.5–10 km [550–10,900 yd]



Barak. (IAI)

Israel Aircraft Industries's point-defense missile for small fast attack craft is designed to achieve very short reaction time (time to maximum range less than 30 sec). Barak is vertically launched, and guidance is by automatic command to line of sight. There is also a backup optical command-to-line-of-sight tracker using a laser range-finder. Engagement is fully automatic (with operator veto).

Control immediately after launch is by thrust vanes (which flip the missile over in 0.6 sec, at 25 Gs, i.e., 10 rad/sec), which are jettisoned once the missile has accelerated sufficiently for aerodynamic control. Total angular coverage is from -25 to $+85$ deg (and 360 deg in bearing). The missile maneuvers at 45 Gs. In 1987 Barak was successfully tested against a TOW missile representing a low-cross-section sea-skimmer.

The rocket motor has 3 thrust levels, presumably initial boost (to avoid damaging the launching ship), then high-energy boost, then sustain. There is no conventional proximity fuze because the weapon may often have to engage sea-skimmers; instead, it uses a special Rafael adaptive proximity fuze with an integrated altimeter to control the sensitivity of the downward part of the fuze envelope.

The weapon is carried in 8-missile cells, and 1 control system can accommodate up to 32 missiles. Each vertical launch unit can be split into pairs of 2-8 missiles, either in above- or below-deck launchers. The radar and fire control weigh 1300 kg, and one 8-cell unit weighs 1700 kg. Canister size: $2550 \times 376 \times 300$ mm [$100.4 \times 14.8 \times 11.8$ in]. Barak was conceived for the *Reshef* class, which has a total armament weight of 40 tons. A more conventional self-defense weapon would have consumed a quarter of that weight.

Barak was announced at the June 1981 Paris Air Show, and a model displayed in 1983; tests began in May 1984. Development was reportedly accelerated because of the experience of the Falklands War. The development contract reportedly requires delivery to the Israeli navy from the end of 1988, with the system operational during 1989. However, as of 1988 sea trials were expected only that year, with the system becoming operational in 1990. Chile has bought Barak (the sale was announced early in 1988). Barak will probably arm the Singaporean *Victory* class. Barak will probably also enter Israeli service in 1991. Reported unit price (1987) was \$200,000.

A land-based version of this missile is called Adams. It is described as having a limited ATBM capability, presumably against short-range tactical weapons (such as the FROGs that the Soviets have supplied to many client states).

ITALY

◆ Aspide

Dimensions: 20.3 cm $\times$ 3.7 m $\times$ 80 cm (100 cm in the air-to-air version) [8 in $\times$ 12 ft 2 in $\times$ 2 ft 7.5 in/3 ft 3.4 in]

Weight: 200 kg [485 lb] **Warhead:** 35 kg [77.2 lb]

Propulsion: single-stage solid-fuel rocket

Speed: Mach 4.0 (AAM role) **Range:** 15+ km [16,400 yd]

Aspide is an Italian-designed alternative to the current Sparrow and Sea Sparrow. The airframe is derived from that of AIM/RIM-7H, but the internal systems are new, including an X-band monopulse seeker for snap-up/snap-down firing and for better

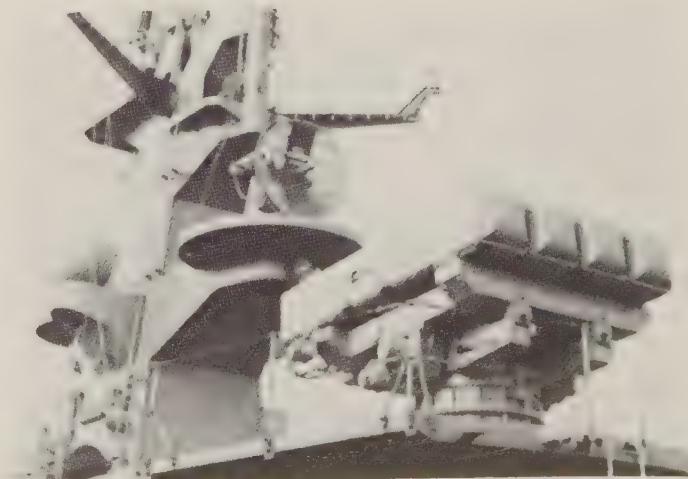
countermeasures and clutter resistance. The missile enjoys better endurance than Sparrow, using closed-loop rather than open-loop hydraulics. It also has a new SNIA motor with higher thrust and specific impulse, for greater velocity and range. There is a home-on-jam guidance mode.



Aspide in flight. (Selenia)



Sixteen-missile automatic loader for Aspide. This system and the Canadian Tribal-class Sea Sparrow are the only Western point-defense missile systems not reloaded by hand. (Selenia)



Four-cell Aspide launcher for corvettes. The Orion tracker-illuminator is visible above the launcher. (Selenia)

This missile is widely used as a naval point-defense weapon, and there is also a tactical ground-defense version, Spada. In the naval version, the associated overall system is Albatros, developed by Selenia. Albatros can also accommodate the Sparrow missile and predates the appearance of the navalized Aspide. Aspide's box launcher is much like that of NATO Sea Sparrow, and the substitution of one missile for the other involves only a change in circuit boards and programming, which can even be done at sea. However, unlike Sea Sparrow installations, Albatros/Aspide can accommodate a semiautomatic reloader (and a 16-missile below-decks automatic reloader is under development). There is also a lightweight quadruple launcher for small ships of less than 300 tons (4000 rather than 9000 kg for the launcher, and 1600 kg for the fire-control system); this launcher has been ordered by Ecuador.

The associated radars are usually the Selenia RTN-10X tracker and the Sirio RTN-12X illuminator (but Albatros Mod/10/0, using a Marconi 1802AS, has been developed by Marconi and Selenia-Elsag).

Development of the air-to-air version began in 1969, with trials in 1974-75. Albatros was developed in parallel (initially using the Sea Sparrow missile), with sea tests in 1973. Aspide's production began in 1977, and the first Albatros/Aspide system was exported to Peru in October 1978. The first Italian navy firing of the Aspide missile (from a modified NATO Sea Sparrow launcher) was in July 1979. In 1986 unit price was about \$250,000. By that time over 2000 were on order worldwide, and about 1000 had been delivered.

In 1984 Selenia announced that it was developing a vertically launched derivative of Aspide with an active radar seeker. This derivative was announced as the new Idra missile in April 1985.

However, Idra was dropped in favor of Italian participation in the French-led FAMS systems (for details on Idra, see the previous edition of this book).

In 1986 Selenia began to consider applying the Idra active seeker to Aspide. The active Mk 2 version should enter production in 1995, and deliveries are to begin in 1996.

NETHERLANDS

◆ Sweeper

In April 1988 Signaal and Bofors jointly announced what they describe as a new naval surface-to-air missile system, Sweeper. It appears to be a further development of the 4-missile system jointly announced in 1986 (see RBS 70 below), using the longer-range RBS 70 Mk 2 and the Signaal LIOD electro-optical director. Operation is entirely automatic, no above-deck operator being required.

NORWAY

◆ Norwegian Automatic Short-Range Air-Defense System

NFT has developed this system primarily for small combatants, such as the projected new fast attack boat. This system uses a combined auto-tracker/launcher (3 launch tubes on either side of the director) controlled by a KMT-340 console. The launcher maneuvers on 3 axes, with a maximum elevation of 120 deg. It carries a Ku-band tracking radar and electro-optical trackers. The French Mistral is under consideration as the weapon. The KMT-340 console is a reduced version of the new MSI-340 CDS planned for the new Norwegian fast attack boat.

SWEDEN

◆ RBS 70 (Rayrider)

Dimensions: 10.6 cm × 1.32 m; span 32 cm [4.2 × 52.0 × 12.6 in]

Weight: 15 kg [33 lb] (system weight 250 kg [551 lb])

Warhead: 1-kg prefragmented (with tungsten pellets) using impact and laser proximity fuzes [2.2 lb]

Propulsion: boost-sustain rocket (booster burns only in launch tube; sustainer ignites at a safe distance)

Speed: Mach 1.0+

Range: 5,000 m [5500 yd]; 6000 m in the Mk-2 version. Height coverage is 3000 m [9480 ft].



RBS 70 Missile Mk 2. (Bofors)

Rayrider is the naval version of the Bofors laser-guided infantry weapon; RBS 70 is currently used on board Swedish *Land-sort*-class minesweepers and Finnish *Helsinki-II*-class fast attack craft. The missile is a laser beam-rider; Bofors claims that the missile is unjammable because it receives its information from the launcher, not the target. Laser beam-riding automatically confers forward-aspect capability. In contrast, most short-range SAMs, which home on a target's infrared radiation, typically fly toward a target's tail. Thus they cannot hit an approaching attacker. Only very sophisticated infrared weapons, such as Stinger, can match RBS 70's forward-hemisphere performance. The laser transmitter/tracker is already gyro-stabilized for use on light trucks and is, therefore, automatically adaptable to a moving ship. The current standard installation is a single missile-launcher tube on a pedestal, which also carries the operator's seat. Reaction time is 4-5 sec.

The current RBS 70+ (Mk 2) version has a greater range and a better laser receiver, increasing the defended area by 30-50%. Mk 2 uses digital guidance (which takes up less volume than the earlier analog electronics and, thus, leaves more space for a warhead), a 50% larger warhead (shaped charge plus fragmentation pellets), and a larger sustainer. Finally, Bofors describes Mk 2 as armor-piercing and, therefore, capable of dealing with armored missiles and aircraft such as helicopters (and, presumably, thin-skinned armored vehicles). Mk 2 is fully interchangeable with Mk 1. Early in August 1988 Bofors tested a Mk 2 against a sea-skimmer approaching at an altitude of 5 m [about 16 ft]. The target was destroyed at a range of 1800 m. The target's dimensions were 40 cm [16 in] in diameter and 4.5 m in length. Mk 2 entered production during the winter of 1988-89. Effective range is 7000 m.

In 1986 Bofors and Signaal (HSA) announced a more elaborate system, combining a quadruple RBS 70 launcher with the pedestal, processor, and console of the Signaal LIOD director. Targets would be designated by 1 or 2 optronic designators, each carrying a coarse sight and a 7 × 50 binocular. Targets would be tracked by the Signaal LIOD in the launcher itself, using a



Sweeper launcher. (Bofors)

daylight television with a 3-deg FOV, with an effective tracking range of 11,000 yd (and effective up to a target speed of 875 yd/sec). The 2-pod quadruple launcher weighs 425 kg, plus 85 kg for each target designator and 375 kg for the control console.

A new version, RBS 90 (formerly RBS 70M Nightrider), combines the Mk 2 missile with a new remotely controlled twin launcher with a laser transmitter and TV and IR cameras on board. Although RBS 90 is intended for land use, it has obvious naval application.

Work on the basic missile began in 1967, and Bofors received a development contract in 1969 and a production contract in June 1975. The naval version was tested in February 1984, and a vertically launched version was demonstrated on 9 September 1986 (tests completed November 1986). In 1988 the estimated cost per missile was \$90,000–\$100,000. The Iranians used RBS 70 extensively during the Gulf War and reportedly shot down about 45 aircraft with it.

SWITZERLAND

◆ ADATS

Dimensions: 6 × 81 in **Weight:** 113 lb

Warhead: 26.5-lb frag-HEAT; active laser proximity fuze and impact fuze

Propulsion: solid-fuel rocket **Speed:** Mach 3

Range: 1000–8750 yd; to altitude of 16,500 ft

The Oerlikon Air-Defense Antitank System was designed for land operation, but reportedly the Thai navy is considering it. As its name implies, ADATS provides substantial surface-to-surface capability in addition to low-altitude air defense. Oerlikon is the system integrator; the missile is made by Martin Marietta.

The missile achieves its dual capability by laser beam-riding, with receivers in 2 of the tail fins; the burden of dual-purpose guidance falls on the optronic director. The current optronic package is similar to that of the AH-64 attack helicopter. The missile has dual fuzing—impact for antitank, laser proximity (4 lasers and 4 receivers) for antiaircraft. Missiles are delivered in sealed 143-lb containers, 9.45 × 86.6 in.

The standard ADATS turret, including 8 missiles, weighs 9920 lb. Presumably, this is much the same as the weight of a possible shipboard version. The stabilized turret carries a FLIR, a television, an NeYAG laser range-finder, a CO₂ guidance laser, and an optronic missile tracker; in addition, it carries a Contraves Italiana X-band, dual-beam, pulse-doppler, TWS radar for initial target acquisition. The latter searches out to a range of about 22,000 yd and up to an altitude of about 16,000 ft. The manufacturer claims that, encountering 8 aircraft flying at 900 km/hr at 2-sec intervals, the system can detect them at 14,000 yd and kill 5 before they fly over, and 3 more as they depart.

Development began in 1979, and missile trials in June 1981. The first full-system trial followed in 1982. ADATS has been adopted by both the Canadian and U.S. armies (the latter as its LOS-FH).

About August 1990 Oerlikon sold the ADATS system to Martin Marietta (which had developed the missile), retaining marketing rights outside North America. At that time it was uncertain whether the U.S. Army would actually purchase the system that it had selected.

TAIWAN (GOC)

Although current service missiles (Sea Chapparral and Standard) are all of U.S. origin, there are 2 indigenous programs for possible future naval missiles, Tien Chien and Tien Kung.

Tien Chien (Sky Sword) is a generic term for air-to-air missiles. Tien Chien I is an IR missile comparable to Sidewinder AIM-9L/M, and a prototype has been fired from a ship, probably using a modified Sea Chapparral launcher. Tien Chien II is broadly comparable to advanced versions of Sparrow.

Tien Chien I is being developed to replace the current AIM-9N/P; it reportedly enjoys better acquisition and tracking at low altitude and near the sun and has a seeker similar to that of the AIM-9L. Compared to AIM-9L, it has double-delta canards with a higher aspect ratio. Production is to begin in 1990, and 700 are planned, initially for fighters but probably later for shipboard use.

Tien Chien II is a longer-range missile, initially conceived in 3 versions: medium-range semiactive radar, active radar, and ARM. The last version no longer enjoys a high priority, although seeker technology demonstration work is continuing. The semiactive version is comparable to AIM-7M, and in 1990 it is nearly at the end of full-scale engineering development. The airframe and motor are based on those of AIM-7F, but Tien Chien II is to have a higher-thrust, impulse, boost-sustain motor and better aerodynamics. The inverse-monopulse seeker has been test-flown (although the missile as a whole has not), and reportedly the missile will have a digital autopilot and on-board digital processor similar to those in AIM-7M. The warhead will probably be blast-fragmentation with a laser proximity fuze.

The semiactive missile is considered an interim step toward full active homing, as in the U.S. AMRAAM. An initial version will replace the semiactive seeker in the semiactive version with an X-band active radar, but will lack any data link. Effective range will be about 20 nm. The ultimate version is to incorporate a data link controlling the missile in mid-course via a new controllable autopilot, as in AMRAAM. In its airborne version, the missile will be controlled by a variant of the U.S. APG-67 radar, which has a 30-nm look-up range and a 22-nm look-down range. Missile speed has been reported as between Mach 3 and Mach 6, depending on trajectory.

As of 1990, it was expected that the interim active version would be ready about 1994, and the ultimate version about 1996–97.

The Taiwan navy has expressed interest in the weapon as an alternative to NATO Sea Sparrow for the new frigates now (1990) planned. These ships were initially to have been French FL 3000s equipped with the French Tavitac 2000 tactical data system and with vertically launched Sea Sparrows. However, early in January 1990 the French government canceled the sale of the ships, and it is no longer clear what the design ultimately adopted will be.

The other major anti-aircraft missile program is Tien Kung (Sky Bow), the surface-to-air series. Tien Kung I is similar in outline to the U.S. Patriot but employs semiactive homing derived from that of Improved Hawk. Although Hawk homes continuously, Tien Kung reportedly uses a mid-course data link with semiactive terminal homing. It would then be more like the U.S. New Threat Upgrade or even the Aegis system. The current land-based version employs the General Electric (RCA Division) ADAR-2 phased-array radar, which is linked to several illuminators.

Tien Kung I is about the same size and shape as Patriot; the latter is 16 × 204 in and 2200 lb; the blast-fragmentation warhead weighs 200 lb. Patriot's slant range is 60 km and maximum altitude is 78,750 ft. Like Hawk and Patriot, Tien Kung I has a dual-thrust rocket motor. It has a blast-fragmentation warhead probably comparable in size to that of Patriot. Speed at burn-out is Mach 4 to Mach 5, and maximum range is about 35 nm, with an effective ceiling of 60,000+ ft. Like Patriot, Tien Kung I is designed for very high maneuverability, reportedly for sustained 30–35-G maneuvers, with an ultimate limit of 60 Gs.

The missile is fired from a quadruple launcher, and a 16-rd vertical launcher is being developed. The latter may ultimately equip Taiwan navy frigates. The land-based version is currently operational using Improved Hawk fire control.

An extended-range version, with a separate booster rocket, is being developed as Tien Kung II. This is a less ambitious version of the original program, which included active terminal radar guidance and an integral rocket-ramjet motor.

As of mid-1990, Tien Kung II has been redesigned with a ramjet power plant. Trials of the original rocket-powered version were disappointing, because of bubbles in the propellant. Taiwan, therefore, bought Bloodhound missiles from Singapore (to acquire superior solid-fuel technology), only to find that they, too, suffered from the internal bubble program.

As for current programs, the SM-1 version aboard Wu-jinn III (modernized *Gearing*)-type destroyers is now operational. For details of this system, see the description of the Modular Combat System (MCS), a variant of the U.S. H930, under tactical data systems in the Surveillance and Control section of this book. In October 1989 a Wu-jinn III successfully fired an SM-1 against a Beech drone at a range of 27 km at medium altitude. This success followed some initial failures. The main problem seems to have been breaking radar track. Given the nature of the MCS, that problem may be due to the limited effective data rate through the data bus, and thus to excessive dependence on extrapolation.

USSR

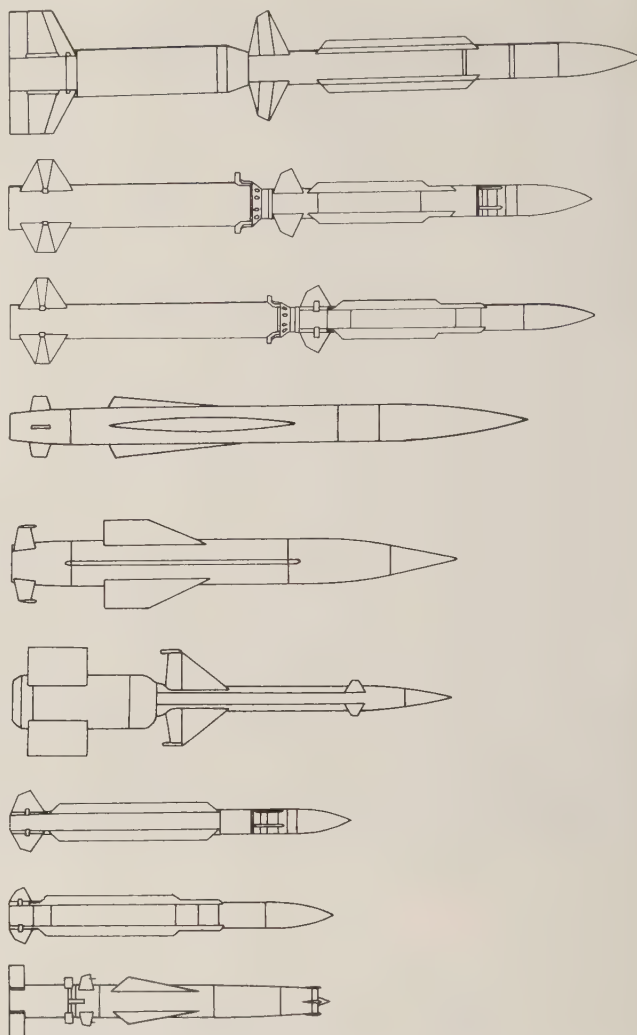
◆ SA-N-1 Goa

Dimensions: 37 cm × 6.1 m; span 1.2 m; booster diameter 55 cm and span (folding fins) 2.3 m [14.6 × 240 × 47 in; 21.6/90.6 in]
Weight: 950 kg [2090 lb] **Warhead:** 60 kg (132 lb)
Propulsion: separate booster (burn time 3 sec) and sustainer (19 sec); boost-glide flight
Speed: maximum Mach 3.5
Range: 18.3 km, minimum 2.4 km; altitude limits 45 m to 18.3 km [2600–20,000 yd; 150–60,000 ft]

Data are for the land-based SA-3.

A navalized version of the land-based SA-3, SA-N-1 was the first Soviet naval surface-to-air missile to enter widespread service. The land-based SA-3 is known as Neva (S-125) in Soviet service and was developed by the Lavochkin design bureau. SA-3 was conceived as a low-altitude complement to the SA-2, which had been designed primarily to attack bombers at high altitude. SA-3 was the first Soviet surface-to-air missile to use solid fuel for both stages, a consideration that would have made the missile much more attractive than the massive SA-2 for naval use. Prototype testing of SA-1 began at Sary Shagan in 1959, and that missile became operational in 1961.

The naval missile, SA-N-1, is designated M1 Volga-M in Soviet service; the Soviets may use the name Volga for the missile itself within the land-based Neva system. The first test platform



Typical area-defense missiles. Top to bottom: Masurca, Terrier, SM-2(ER), SA-N-6, SA-N-3, SA-N-1, Tartar, SM-1(MR), Sea Dart. (*Ships of the World*)

was the Kotlin-class destroyer *Bravyy*, which ran trials in June 1962. This system arms Kashin-class destroyers and Kynda- and Kresta-I-class cruisers. The roughly contemporary SA-N-2, a navalized SA-2, was employed only on board one now-discarded ship and seems to have been an unsuccessful experiment.

SA-N-1 is command-guided, with 1 double Peel Group director per twin-armed launcher. The director can, therefore, engage only 1 target at a time; the doctrine is presumably to fire 2



An SA-N-1 missile on its dual launcher. (TASS from SOVFOTO)

weapons per target. The system presumably operates as command to line of sight, measuring an error between the line of sight to the missile and to the target, and sending correction signals. That scheme is probably also characteristic of SA-N-3, -4, and -9.

The missile has a canard configuration, with relatively large fixed wings, and there is a short booster, whose fins fold out as the missile leaves its launcher.

SA-N-1 (like all other Soviet naval surface-to-air missiles) is credited with a secondary antiship role. As estimated in 1973, surface-to-surface range is 3–9 nm. This missile (and the other Soviet naval SAMs) is normally proximity fuzed; design for antiship attack would require an additional impact or delayed-action fuze.

Standard magazine capacity per launcher is 16, the missiles being carried in two 8-missile race-tracks.

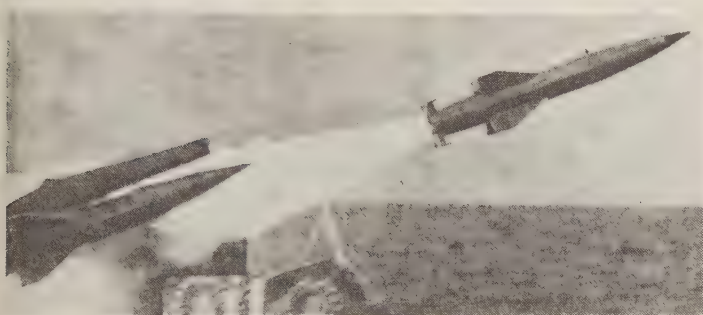
◆ SA-N-3 Goblet

Dimensions: 60 cm × 6.1 m; span 1.4 m [23.6 × 240 × 55.1 in]

Weight: 545 kg [1200 lb] **Warhead:** 80 kg [176 lb]

Propulsion: boost-sustain rocket motor **Speed:** Mach 2.5

Range: 32,800 yd (improved version, in *Kiev*, 60,100 yd) (altitude 300–80,000 ft)



SA-N-3 missile being launched, with another on the launcher. (*Ships of the World*)

SA-N-3 is unique among Soviet naval surface-to-air missiles in having no army equivalent; reports that Goblet was related to the semiactive SA-6 proved erroneous. SA-N-3 is command-guided (Head Lights is the radar director), with 1 director per twin launcher. The missile has shallow delta wings, perhaps adopted for lengthened surface-to-surface range, for something approaching dual-purpose performance. The rear fins carry fixed antennas that probably carry the command link.

Reportedly, SA-N-3, like SA-N-1, was developed by the Lavochkin/Grushin design bureau, and a proposal for this weapon was prepared for Khrushchev in 1961.

In 1973 SA-N-3 was credited with a surface-to-surface range of 2–20 nm.

Missile capacity per launcher is 36 (it may be 22 in some ships).

◆ SA-N-4

Dimensions: 21 cm × 3.2 m; span 64 cm [8.2 × 126 × 25.2 in]

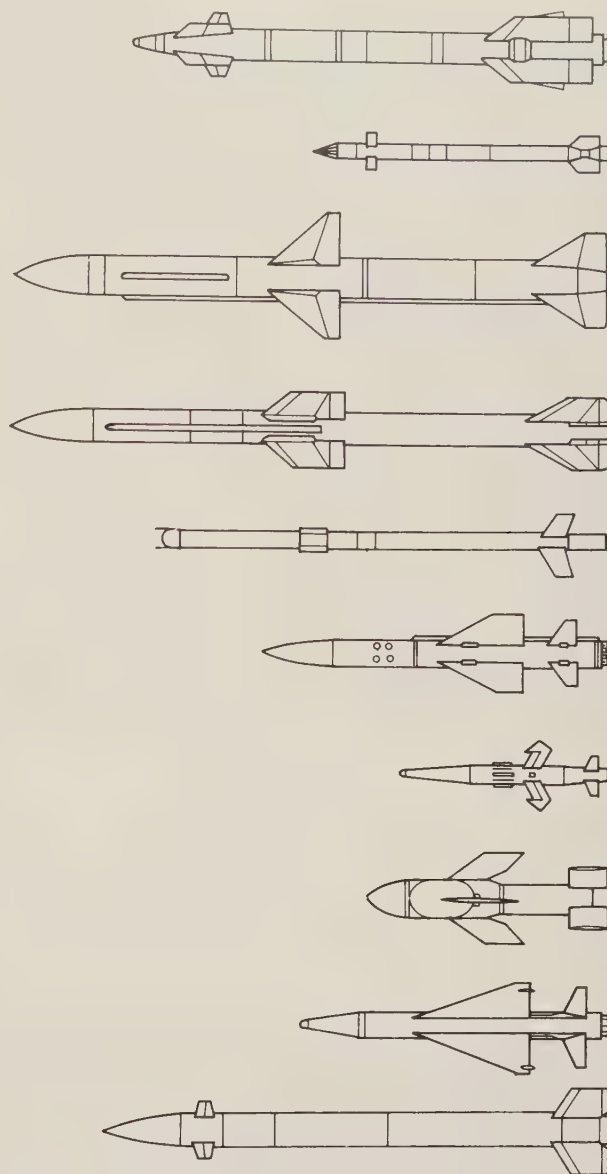
Weight: 168 kg [370 lb] **Warhead:** 18 kg [40 lb]

Propulsion: boost-sustain rocket (burn times 2 and 15 sec)

Speed: Mach 2+

Range: 13 km (minimum 1.6–3 km) [14,200 yd; minimum 1750–3300 yd]; altitude limits 30–20,000 ft

The Soviet designation of this point-defense missile system is Osa-M; the Soviet launcher designation is ZIF-122. SA-N-4 is a naval equivalent of the land-mobile SA-8 (Gecko). Apparently the naval version entered service first. SA-N-4 is broadly comparable to the U.S. Sea Sparrow or to Crotale Naval. Missiles are housed nose-down in the protective silo. The twin-arm



Short-range naval air-defense missiles. Top to bottom: Crotale Naval, Mistral, Sparrow, Aspide, RAM, Barak, RBS 70, Sea Cat, Sea Wolf, SA-N-4. (*Ships of the World*)

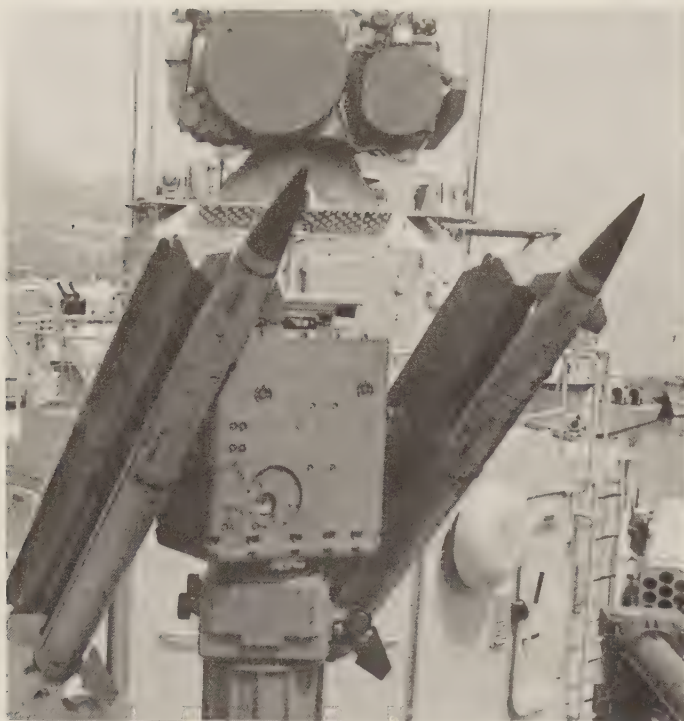
launcher is normally housed; it emerges before firing and retracts to pick up reloads. Missile capacity per standard 4.2-m diameter silo is 20, on 4 revolving drums, each carrying 5 rnds. The nose-down position reduces the distance missiles must be lifted into firing position and may be required for fuzing before firing. This arrangement would also simplify protection against a cook-off, since all that would be required would be to open the door to vent.

SA-N-4 is command-guided (by the Pop Group radar) and can be used against surface targets.

The missile details above refer to the land-based equivalent, SA-8. At the Defense Services Asia Exposition (Kuala Lumpur, March 1990) the Soviets provided official details of the land-based missile. Detection range of the land-based radar (similar to, but not identical to, Pop Group) was given as 35 km, tracking range as 25 km, and missile range as 1.5–10 km (1640–10,900 yd); altitude range was given as 10–3500 m (33–11,500 ft). Firing rate was given as 1 missile every 45 sec, and ready-to-fire time as 26 sec.

In 1973 SA-N-4 was credited with a surface-to-surface range of 1.5–4 nm. Reportedly, the Soviets frequently exercise this capability.

SA-N-9 is the replacement for this system.



SA-N-4 missiles on their twin-arm launcher.

◆ SA-N-5 Grail

Dimensions: 70 mm × 1.34 m [2.76 × 52.8 in]
Weight: 9.2 kg [20.3 lb]
Warhead: 1.1 kg (370 g RDX/AP) [2.4/0.82 lb]
Propulsion: boost-sustain rocket
Speed: 385 m/sec (Mach 1.13) [1260 ft/sec]
Range: 3.6 km; min 800 m, altitude limits 50–3500 m [875–3900 yd, 165–11,500 ft]



A standard quadruple SA-N-5 mounting. Many Soviet submarines carry single SA-N-5 tubes.

SA-N-5 is a naval version of the ubiquitous SA-7 shoulder-launched surface-to-air missile. Grail is either hand-held or fired from a special quadruple launcher. SA-N-5 is widely distributed on board Soviet patrol and amphibious craft, much as the U.S. 20-mm gun once appeared wherever space was available. Many Soviet submarines reportedly carry 1 or more in the sail, for self-defense when surfaced. Compared to the U.S. Stinger, SA-N-5 is reportedly less effective against anything but a hot tailpipe and is easier to counter.

The basic missile is called Strela or 9M32 in Soviet service; development was reportedly inspired by the revelation of the U.S. Redeye in 1959. The naval version is called Strela 2M in Soviet service.

The SA-7 is produced in China as HN-5; HN means Hong Nu, or Red Cherry. The current HN-5A is an improved HN-5 with a more powerful warhead and a better seeker, the latter for greater detection range and better discrimination against clutter. Slant range is 0.8–4.4 km. This missile is carried on board fast attack craft and small auxiliaries.

For some time there have been reports of Soviet interest in submarine antiaircraft missiles. In 1990 it was reported that Typhoon and Kilo-class missiles carry a 4-ft-diameter pressure-proof container that can be extended upward. The container carries 12–18 SA-N-5 or -8 IR missiles, and the report claims that a hinged blast deflector is clearly visible on the sails of both types of submarine.

◆ SA-N-6 Grumble

Dimensions: 45 cm × 7 m [17.7 × 276 in]
Weight: 1500 kg [3300 lb] **Warhead:** 90 kg [198 lb]
Propulsion: rocket **Speed:** Mach 6
Range: 100 km; max altitude 30.4 km, min altitude 300 m [about 109,000 yd, 984–99,700 ft]

SA-N-6 is a naval version of the land-based SA-10 area-defense missile. The land-based weapon was reportedly designed in the late 1960s or early 1970s to deal with a new generation of high-speed threats, presumably including the new U.S. SRAM short-range ballistic stand-off bomber missile. In naval service, SA-N-6 supersedes the SA-N-3 area-defense missile and provides (in theory) the ability to counter much faster threats and, probably, pop-up threats (thanks to the vertical launcher). However, because Grumble almost certainly cannot engage incoming threats around a 360-deg arc, SA-N-6 is not a true anti-saturation system like the Aegis system.

Reportedly the missile is extremely energetic.

The land-based system was developed by the Grushin design bureau, and tests began in 1972. In land service, the missile is associated with a large S-band surveillance-and-tracking radar (Big Bird), a pulse-doppler target tracker, and a flat-plate X-band



An SA-N-6 launcher on board the cruiser *Marshal Ustinov*. In contrast to Western vertical launchers, only 1 missile can be launched at a time (only 1 section opens); the triple circular plates over other missile positions are apparently blow-out plates. (S. Zaloga)

control radar. It seems likely that the naval Top Dome radar combines the tracking and missile-control functions in a single device, and that the Big Bird surveillance/acquisition function is carried out by Top Sail or a similar 3D search set.

The naval test ship, the cruiser *Azov*, appeared in 1977. SA-N-6 is the primary anti-aircraft armament of *Kirov*- and *Slava*-class cruisers. Missiles are carried in 8-rnd vertical revolver launchers. Since each Top Dome director covers only a limited arc, and since all the missiles can fly in any direction, it seems likely that each director can control weapons against the maximum number of targets. In that case the 12 missile launchers on a *Kirov*-class cruiser would suffice to deal with 6 targets (on the usual Soviet basis of 2 missiles per target), and each director would be able to engage up to 6 targets simultaneously, over a limited arc.

A Soviet brochure describing the equivalent land-based system (S-300 PMU) was released late in 1990. The system is credited to the Almaz design/production bureau. It consists of a command vehicle and 3 launcher vehicles, each carrying 12 missiles, i.e., it is equivalent to the 12 launchers (and 1 of the Top Dome radars) of a *Kirov*-class cruiser. The brochure claims that the radar can handle 6 targets (2 missiles per target) simultaneously and that it can intercept air targets at any operational altitude above 25 m [about 80 ft], i.e., well above sea-skimmer altitude. The single-stage missile uses solid fuel and has a fragmentation warhead; it is cold-launched and ignites well above the launch canister.

◆ SA-N-7 Gadfly

Dimensions: 40 cm × 5.6 m, span 1.2 m [15.9 × 220 × 47.2 in]

Weight: 650 kg [1433 lb] **Warhead:** 80 kg [176 lb]

Propulsion: solid rocket **Speed:** Mach 3

Range: 30 km, min 3 km [3300–33,000 yd]; altitude limits 100–46,000 ft

SA-N-7, a navalized SA-11, is the first Soviet naval semiactive missile. SA-11 was itself derived from SA-6, a semiactive weapon inspired by the U.S. Hawk. As in the U.S. Standard system, SA-N-7 uses a single-arm fast-firing launcher, but it uses multiple Front Dome illuminator-trackers located near each launcher. *Sovremennyy*-class destroyers are arranged so

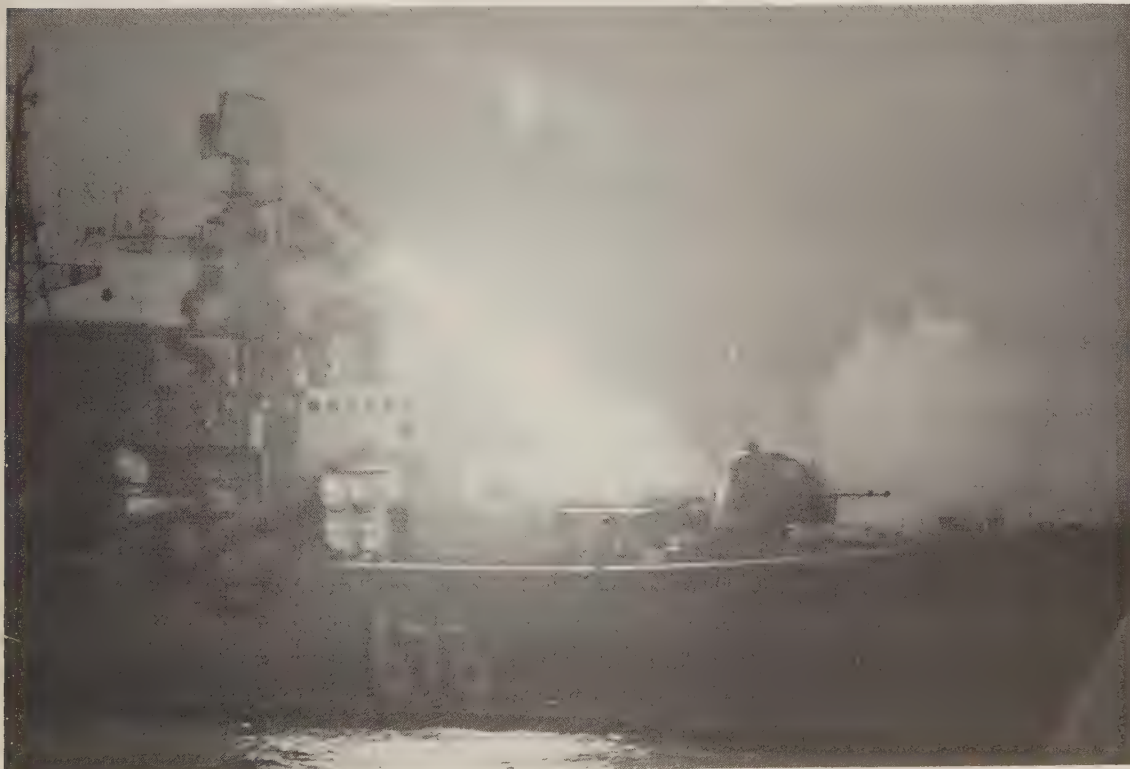
The destroyer *Sovremennyy* fires an SA-N-7 missile. (West German MoD)



An SA-N-7 missile on its launching rail on board a *Sovremennyy*-class destroyer. The resemblance to the U.S. Standard Missile is apparent. (German Ministry of Defense)

that 2 Front Domes are located on each side of each launcher, with 2 more on the sides of the ship near the forward launcher. An electro-optical device, presumably associated with the system, is located on each side near a Front Dome near each launcher. At least 2 Front Domes, therefore, bear on each heading (3 on the broadside). This pairing would seem to correspond to the previous Soviet practice of providing 2 missiles per target (on 2 launcher arms of a slow-firing launcher). However, the 2 launchers must share 1 Front Dome when they engage targets approaching from directions near the broadside. Presumably, the Soviets could not adopt the typical U.S. solution, to place the illuminators on the centerline, because these ships are extremely limited in centerline space. The trials ship, *Provornyy*, has 8 Front Domes, giving her a pair on each quarter. Presumably, *Sovremennyy* is too short to allow for this arrangement (the after position equivalent to 1 of the 2 forward Front Dome positions is occupied by the Light Bulb data link antenna).

Reportedly, SA-11 uses an energy-efficient up-and-over trajectory similar to that of SM-2. That would seem to imply the



use of a data link, in which case the SA-N-7 system would be somewhat equivalent to the U.S. NTU. Reported characteristics include a maximum speed of Mach 3.0 and the ability to maneuver at 23 Gs. These figures compare with Mach 2.5 and 15 Gs for SA-6.

The land-based SA-11 appeared about 1979; the naval test installation (on board the destroyer *Provornyy*) appearing in 1981. The missile itself is similar in external configuration to the U.S. Standard Missile series. Only 1 ship per year is being built to accommodate this missile.

The standard launcher holds 20 (also reported as 22) missiles. Its Soviet designation is probably 3S90. The Soviet name for this system is their word for "Tornado."

◆ SA-N-8 Gremlin

Dimensions: 75 mm × 1.4 m [2.9 × 55.1 in]
Weight: 10.5 kg [23.1 lb] **Warhead:** 2 kg [4.4 lb]
Propulsion: boost-sustain rocket **Speed:** 600 m/sec [1970 ft/sec]
Range: 6 km, min 600 m; altitude limits 10 m and 5500 m [660–6600 yd; 33–18,000 ft]

A follow-on to SA-N-5, SA-N-8 uses the next-generation Soviet hand-held weapon, SA-14. Reportedly SA-14 introduces a more sensitive IR detector but still lacks full forward-aspect capability and, thus, does not quite compare with the U.S. Stinger. The next type, SA-16, reportedly can attack an approaching target and is probably also in naval service.

This weapon apparently entered service about 1980.

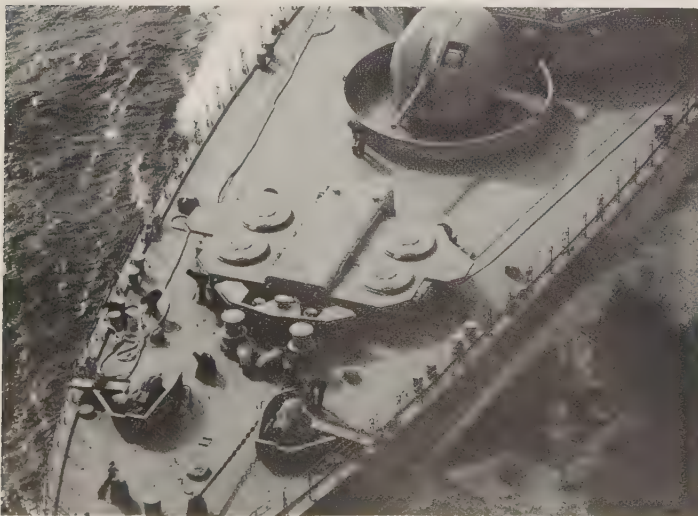
The Soviets displayed SA-16, which they designate Igla (Needle), at the Defence Services Asia Exposition at Kuala Lumpur in March 1990. The IR seeker has a 40-deg FOV, compared to the 5 deg of earlier equivalents (i.e., it probably uses an imaging IR seeker), and maximum range is 5000 m [5500 yd]. Targets can be engaged at altitudes of 10–3500 m [33–11,500 ft], and maximum target speed is 360 m/sec [700 kt]; average missile speed is 570 m/sec [1100 kt]. Reaction time is 5 sec.

◆ SA-N-9

Dimensions: 20 cm × 3.5 m [7.9 × 103 in]
Weight: 200 kg [441 lb] **Warhead:** 20 kg [44 lb]
Propulsion: boost-sustain rocket **Speed:** Mach 3
Range: 15 km; maximum altitude 12 km [16,400 yd; 39,000 ft altitude]

This vertically launched missile is the successor to SA-N-4. SA-N-9 first appeared in the destroyer *Udaloy* and is to be fitted in the cruiser *Frunze*, the carrier *Novorossisk*, and presumably in other future construction. SA-N-9 is found on board the carrier *Baku*. Reportedly, SA-N-9 is a naval version of the land-based SA-15, which has superseded SA-8 in Soviet ground forces. Data above describe SA-15.

The associated radar director is Cross Sword.



Four SA-N-9 revolver launchers on board a *Udaloy*-class destroyer. Presumably, they are loaded via the large centerline hatch. The shrouded objects farther forward are twin chaff launchers. (Sea Power)

At San Diego in 1990 the Soviets stated that each SA-N-9 vertical launcher loads a missile into the central position and fires it from there; it can fire its 8 missiles within about 1 min.

A Soviet brochure describing an equivalent land-based system (Tor) was released late in 1990. The system is credited to the Antey design/production bureau. The vehicle-mounted Tor carries 8 vertically launched missiles in a rotating turret, with a planar radar and a search radar on the same turret. Neither really resembles any element of Cross Sword, but performance is presumably comparable. Two system operators sit at a pair of consoles carrying a large CRT (presumably for the search radar), a medium CRT (presumably for the EO adjunct), and a small CRT (at the other operator position, presumably the display for the engagement radar).

In this system the C-band pulse-Doppler/pulse-compression search radar has a range of 25 km, and its beam is 32 deg high (covering 0–32 or 32–64 deg; no horizontal beamwidth is given in the brochure). It can acquire up to 48 targets, initiate tracks on 10, and evaluate threats automatically. The K-band pulse-Doppler/pulse-compression, phased-array, tracking radar operates over a 15 × 15-deg sector, tracking 2 targets simultaneously at velocities of up to 700 km/sec [1380 kt]. The complementary EO system can detect targets at 20 km.

Reaction time from the first target detection is 5–8 sec.

The missile has a maximum range of 12 km [13.1 kyd] and can engage at altitudes between 10 and 6000 m [33–19,600 ft]. Maximum missile speed is given as 850 m/sec, and the fragmentation warhead (which uses a proximity fuze) weighs 15 kg [33 lb].

◆ SA-N-10

This lightweight twin-arm automatic launcher for IR-guided missiles is found only on board the nuclear-powered auxiliary SSV-33. The missile may be SA-N-8 (SA-14 or -16).



SA-N-10 launcher (upper center) on board the intelligence-gathering ship SSV-33. It is 1 of 3 on board (2 are aft). Immediately abaft it are a Kolonka remote visual sight and a pair of Tin Man remote optronic devices; forward is a 76-mm gun. The launcher presumably reloads automatically from below. (Sea Power)

◆ SA-N-11

This is the missile component of the CADS-1 system described in the gun section below. The missile, launched from a dispos-

able tube, is a navalized SA-19. The mount carries up to 8 missiles, plus guns. The missiles may be auto-reloaded from a below-decks magazine, perhaps in analogy to the standard Soviet bombardment rocket launcher.

UNITED KINGDOM

◆ Javelin/Starstreak

Dimensions: 3 × 54.7 in (fin span 10.8 in) **Weight:** 28 lb

Warhead: 6 lb (1.3 lb HE) **Speed:** Mach 1

Propulsion: boost-sustain rocket

Range: 5000 yd vs. jet aircraft, 6000 vs. helicopter; minimum range about 500 yd; effective altitudes 30–10,000 ft

Data above apply to Javelin.

These are hand-held anti-aircraft rockets comparable in role to the U.S. Stinger, the Soviet SA-7, and the Swedish RBS 70. Javelin can be used for small ship's self-defense; the manufacturer, Short Brothers, has tried from time to time to sell multiple lightweight mounts. The Royal Navy first purchased Javelin in June 1984, following trials on board HMS *Phoebe*. A 5-rnd mount is being developed. Sea Javelin was formally announced in September 1985, and in November 1986 it was revealed that British minesweepers in the Persian Gulf had been armed with Javelin for self-protection. Javelin is also carried in a 3-barrel launcher on the Omani royal yacht. No GWS designation has been announced. The Royal Navy used the predecessor missile, the Short Brothers Blowpipe, as an emergency point-defense weapon during the Falklands War and may have deployed some to the Persian Gulf. However, none are currently (1990) deployed, and on land British Blowpipes have been limited to Territorial (reserve) forces.

Blowpipe has survived as a war-reserve weapon. It was carried on board Canadian warships assigned to the Persian Gulf in August 1990; these ships were also fitted with elderly Boffin single 40-mm mounts (which were intended for the new Canadian coastal mine-countermeasures craft). The Canadians later bought Javelins to supplement or replace their Blowpipes.

The Javelin missile is command-guided to line of sight, the aimer using a sight and thumb controls to maintain the apparent coincidence between missile and target. The missile is auto-



Triple Javelin. (Short Brothers)

matically gathered into the FOV by an infrared sensor, and that process reduces minimum range to 300 yd. Time of flight to full range is 14 sec. Javelin uses semiautomatic command-to-line-of-sight control, the operator merely keeping the target in the aiming sight, and the missile being tracked automatically. This scheme increases accuracy and reduces minimum intercept range. Javelin also has a higher impulse motor for greater range (5.5 km [6000 yd]), and a blast-fragmentation rather than a shaped-charge warhead (2.72 vice 2.2 kg). Dimensions match those of Blowpipe, except that the missile is slightly heavier, and the total system, including the clip-on aimer, weighs 24.1 rather than 20.25 kg.

As of 1988, estimated costs per missile were \$8000 for Blowpipe and \$12,000 for Javelin. Blowpipe was sold to at least 14 countries, and production probably amounted to about 36,500 rnds, with one clip-on aiming unit for every 5–10 mds.

The successor missile is Starstreak, which uses a boost-sustain rocket to attain Mach 4.0 and has a range of 7 km (7700 yd); minimum range is about 300 m. Dimensions are 127 mm × 1397 mm (launch tube diameter 274 mm). No weight figure is available, but the manufacturer has tried to keep total on-shoulder system weight below the Javelin's 24.3 kg. Unlike any previous British anti-aircraft missile, Starstreak fires 3 separate warheads (darts), each about 2 × 45 cm, which are described as both explosive and kinetic-energy penetrators. Each carries



This model of a naval Starstreak (Seastreak) mounting was displayed by Short Brothers at RNEE in 1989. (Author)



Javelin on shipboard. (Short Bros.)

about 1 kg of high explosive. Since the motor is Javelin-derived, it would appear that the very high speed is achieved by using very light darts, perhaps analogous to the use of sabots in conventional guns.

The Starstreak command unit contains 2 laser diodes, 1 scanning horizontally and 1 vertically, to establish a 2D matrix of beams pointing toward the target. The darts are, in effect, beam-riders, using steerable fins to hold formation within this matrix. They are designed to penetrate before exploding. Guidance is semiautomatic, the operator placing a stabilized aiming circle on the target using the continuous-zoom telescope. The operator tracks it briefly to establish azimuth and elevation lead angles before firing, then keeps the circle on the target until the darts hit.

Short Bros. displayed a private-venture naval version, Sea Streak, at the RNEE exhibition in 1989. A 1-ton powered stabilized mounting carries 24 missiles, a mm-wave surveillance radar (scanning in both bearing and elevation to detect targets at up to 15-km range) at its head, electro-optical tracker and guidance sensors on 1 side, and radar tracker and guidance sensors probably operating in mm-wave) on the other. The surveillance radar provides threat warning and evaluation, and the entire system can operate automatically. Salvo size is based on automatic threat evaluation, e.g., 1 missile against an airplane, or 3 against an antiship missile. The naval Starstreak missile would differ from the land-based version in having a single-stage motor and boost-phase guidance.

◆ Sea Cat (GWS 20, 21, 22, 24)

Dimensions: 7.5 × 58.3 in; span 25.6 in **Weight:** 138 lb
Warhead: 45 lb (38-lb HE) in Mod 1; Mod 0 is a 31-lb continuous-rod warhead (5-lb HE); both mods have both impact and IR proximity fuzes. **Propulsion:** boost-glide
Speed: Mach 0.6 (average at the end of boost)
Range: 5000 yd, minimum 1500 yd; max altitude 3300 ft

Sea Cat was the first point-defense missile to enter naval service. Sea Cat was conceived (by Short Brothers and Harland) as a 1-for-1 replacement for the existing twin 40-mm Bofors gun and was based on the Malkara antitank missile. Sea Cat is command-guided by an operator using a joystick (Mk 20 Visual Guided Weapon Director); the operator first captures the missile after launch using sighting binoculars, then tracks it to the target. This version is used by Australia (early River class) and Nigeria (*Erin'ni* class).

GWS 21 is controlled by the Type 262 radar originally developed for 40-mm gun control. This version is used by Indonesia (Tribal class).



A quadruple Sea Cat launcher on board the British frigate *Argonaut*, 1975. (U.S. Navy)

GWS 22 employs a modified radar director originally designed for medium gunfire control, MRS 3 (the British equivalent of the U.S. Mk 56), with Type 904 radar and a Type 323-series closed-circuit television. In this MEASL system, ordered by the Royal Navy in 1972, the television, which is slaved to the target-tracking radar, tracks the missile automatically. This version is used by Chile (County class and *Leander* class), India (*Leander* class), New Zealand (*Leander* class), Pakistan (County class and *Leander* class), and the United Kingdom (surviving non-Sea Wolf *Leanders*).

GWS 24 employs the WSA-4 FCS with Type-912 radar (*Amazon*-class frigates). This version is also used by Brazil (*Niteroi* class).

Sea Cat could also be controlled by the Contraves Sea Hunter, the Selenia NA-9, and the Signaal M45 systems. Only the last survives in Australia (later River class), Chile (*Almirante Williams* class), India (some *Leanders*), and Indonesia (*van Speijk* class). The Sea Hunter version was adopted by Iran, but Sea Cat was removed from her Vosper corvettes (replaced by Soviet-type 23-mm cannons).

Sea Cat was modified in 1977 with a special altimeter, for the antiship-missile-defense role; Sea Cat carried out sea-skimming trials late in 1980 and was ordered (as a target) in September 1980.

The standard launcher carries 4 missiles, with the command-guidance antenna in the center. The launcher weighs about 6600 lb. A lightweight (2800 lb) 3-missile launcher was adopted by the Iranian and Nigerian navies. It is controlled by a set of binoculars atop a single manually operated pedestal director.

Because of its low speed and short range, Sea Cat cannot engage supersonic targets. Development of a proposed Sea Cat 2 was dropped in favor of Sea Wolf; the much greater sophistication of the latter system testifies to the complexity of the supersonic sea-skimming-missile problem.

◆ Sea Dart (GWS 30; CF 299)

Dimensions: 16.5 × 172 in, including booster; span 36 in
Weight: 1200 lb **Warhead:** 50-lb HE/continuous rod
Propulsion: ramjet with rocket boost **Speed:** Mach 2.5–3.0
Range: 25–30 nm (altitude 100–60,000 ft)

Sea Dart is the standard British area-defense missile, a semi-actively homing ramjet. Like the defunct U.S. Talos, Sea Dart uses 4 interferometer aeriels (polyrods) for guidance, rather than a dish. They provide monopulse tracking; the missile has a reference antenna pointing back and flies a proportional-navigation path. Guidance is provided by 2 Type 909 tracker-illuminators. This radar is cued by a Type 992Q high-definition (target-indication) radar, which in turn is cued by a Type 965 or Type 1022 broad-beam search radar; only the illuminator searches in elevation.

Because it employs vacuum-tube technology, this system is reportedly not entirely reliable. A Sea Dart 2 program, announced in November 1977, reportedly amounted to a British equivalent of the U.S. 3-T "Get-Well" program of the 1960s. However, Mark 2 would also have had thrust-vector control (and a more powerful booster), new wings and fins to allow the missile to engage higher-altitude targets, more fuel tankage, and a higher proportion of solid-state circuits. Presumably solid-state circuitry would also have applied to the guidance radars, which had the most serious reliability problems. Moreover, using the separate search and target-indication radars in combination increased the system's response time. Marconi proposed, then, to replace the obsolescent 965/992 combination with a single search/target-indication radar, STIR. Sea Dart 2 would also have had a programmable autopilot (as in the U.S. NTU). This major upgrade was reportedly ordered after the system failed against a simulated saturation attack off Australia. By 1980 the Sea Dart 2 program had been reduced to ECCM improvements, including the new radars. However, the program (including the new Type 909M and STIR radars) was killed in 1981 as part of the Nott Defense Review. This program seems to have been revived following the Falklands War, without the



A Sea Dart launcher (Mk 30) on board the missile destroyer HMS Glasgow, 1990. In contrast to U.S. vertically loaded launchers, the blast doors project well above the ship's deck. (Author)

Mk 2 designation. Modernization will include replacement of existing Type 992Q radars with the new Type 996 for better targeting.

A new blast warhead (GMk 39A1) was delivered beginning in 1987. Presumably this warhead is a response to the problem of intercepting fast passing targets.

Missiles are loaded in 2 stages. Stowed vertically in a magazine below the water line, missiles are then carried up (by chain hoist) into an intermediate position, warmed up (for 30–60 sec), hoisted into an upper-deck position, and only then rammed hydraulically onto the launcher: this process is analogous to the 2-stage hoists used by many heavy naval guns. This practice should increase safety (the Royal Navy has been extremely con-

scious of safety requirements for magazines since World War I) but may also reduce the rate of fire. Reportedly, at least 1 Sea Dart ship found in the Falklands War that her blast or flash (outer hoist) doors did not close properly at times. Typically 2 missiles are held in readiness below the launcher, with another 2 in the intermediate position. The intermediate position is probably required to fit the booster, just as in Terrier/SM-1 and Masurca. The cumbersome magazine arrangement may explain proposals for box-launched Sea Dart. However, reportedly HMS *Invincible* was able to fire 6 Sea Darts in 2 min on 1 occasion, or 1 salvo (2 missiles) every 40 sec. HMS *Bristol* is equipped with a heavy Mk 30 (i.e., GWS 30) Mod 0 electrically driven launcher, whereas later ships have the lighter-weight Mod 1. Missile capacity: HMS *Bristol*, 22 missiles; Type 42 (all versions), 22 missiles; *Invincible* class, 36 missiles. The 22-missile figure is often rendered 20, and the difference may be test missiles.

Development began in August 1962, with full development approved in May 1963, tests in 1965, and production announced in November 1967. The 500th missile was fired by HMS *Bristol* in November 1986. Using Sea Dart, HMS *Invincible* shot down a Petrel target drone on the Hebrides missile range in November 1985.

Argentina was the only export customer, for its 2 Type 42 destroyers. As of 1986 estimated production was 1600 (plus 60 for Argentina), and estimated unit price was \$300,000. A new production contract, reportedly for 100 missiles with the new warhead, was let in August 1986.

Sea Dart was the major British naval area-defense missile used in the Falklands War and is credited with having shot down 7 Argentine aircraft. Unfortunately several other firing opportunities were lost because of the system's unreliability, e.g., because magazine doors did not always allow missiles to be loaded promptly. The system was also degraded by its surveillance and acquisition radars, which reportedly lacked the MTI required to detect and track Argentine aircraft popping up over the nearby shore.

A box-launched Lightweight Sea Dart system was announced in 1978, using the Marconi ST805 tracker-illuminator (ranges are reportedly 60 km on an airplane and 14 km on a missile, the former increasing to 80 km with a larger dish). The missile has also been promoted as a surface-to-surface weapon with a range of 25–30 km, climbing steeply after launch, then diving at 30 deg to build up momentum for deep penetration of a target. Thus far none has been sold. A land-based version, Guardian, for defense of the Falklands, was offered in September 1982 but was not purchased.

◆ Sea Slug (GWS 1)

Dimensions: 16.1 in × 20 ft (19 ft 8 in for Mk 1); span 56.6 in

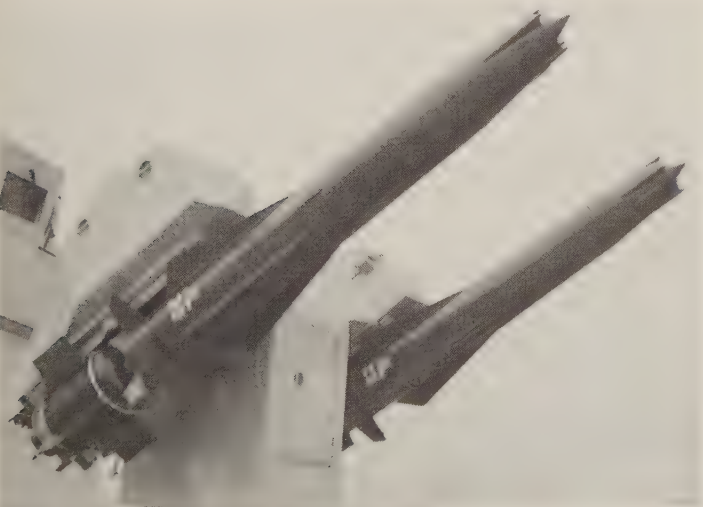
Weight: approx 4400 lb total (1980 lb without boosters)

Warhead: approx 200 lb

Propulsion: strap-on boosters with sustainer rocket

Speed: Mach 1.8 **Range:** Reported range for Mk 2 is 24.3 nm.

Sea Slug is obsolete; it is the survivor of the initial postwar generation of Western command-guided (beam-riding) surface-to-air naval missiles. The U.S. equivalent, now extinct, was the beam-riding version of Terrier. The original requirement, defining Sea Slug Mk 1, was that the missile be able to engage a high-



Sea Dart. (Sea Power)



HMS *Devonshire* fires a Sea Slug. The cylindrical radar just forward of the helicopter platform is Type 901; forward of the after funnel are the Type 278 height-finder and the Type 965 (AKE-1 antenna) search radar. (U.S. Naval Institute)

altitude 650-k bomber at 30,000 yd (15 nm), i.e., at about 50% greater range than the contemporary U.S. Terrier. Sea Slug Mk 1 development trials were completed in 1961.

Sea Slug Mk 2 was intended to achieve 20% better performance than Mk 1, to be much more lethal against low-flying aircraft, and to have an operating range of 70,000 yd and a maximum altitude of 65,000 ft. It also had new design features for antiship use. To achieve this performance, it had more powerful Gosling boosters and a more powerful Deerhound sustainer. There were alternative warheads, although the standard was still a continuous-rod antiaircraft type. It had 3 independent fuze systems: an IR proximity fuze, an impact fuze (for antiship effect), and provision for command detonation.

The Sea Slug guidance radar (Type 901) produces 3 beams: a gathering beam, a target-tracking beam, and a separate missile-guidance beam. The last makes possible up-and-over attacks against low-flying aircraft (the guidance beam is elevated, and the missile commanded to dive) and against surface targets (at ranges of up to 40,000 yd). This type of guidance was somewhat similar to that adopted for the U.S. Talos, except that terminal guidance was by command rather than by semiactive homing. The missile, therefore, could not follow violently maneuvering targets, and its accuracy declined with range. These limitations were acceptable for a weapon designed, like the contemporary U.S. Terrier, to deal with large subsonic bombers (Sea Slug was originally made large enough to accommodate a homing antenna, but none was ever made for it). The lack of terminal homing became crippling as targets became more agile. Thus, although 2 ships, the *Antrim* and *Glamorgan*, carried Sea Slug into the Falklands War, the missile was not used for fleet air defense. HMS *Glamorgan* did fire hers against Port Stanley airport.

Work on Mk 2 began about 1957, and tests were completed in 1965. However, in fleet firings the missile tended to break up when its boosters blew away (they separated 1 by 1 as they burned out, and subjected the missile to heavy but unbalanced loads). The problem seems to have been solved in 1971–72.

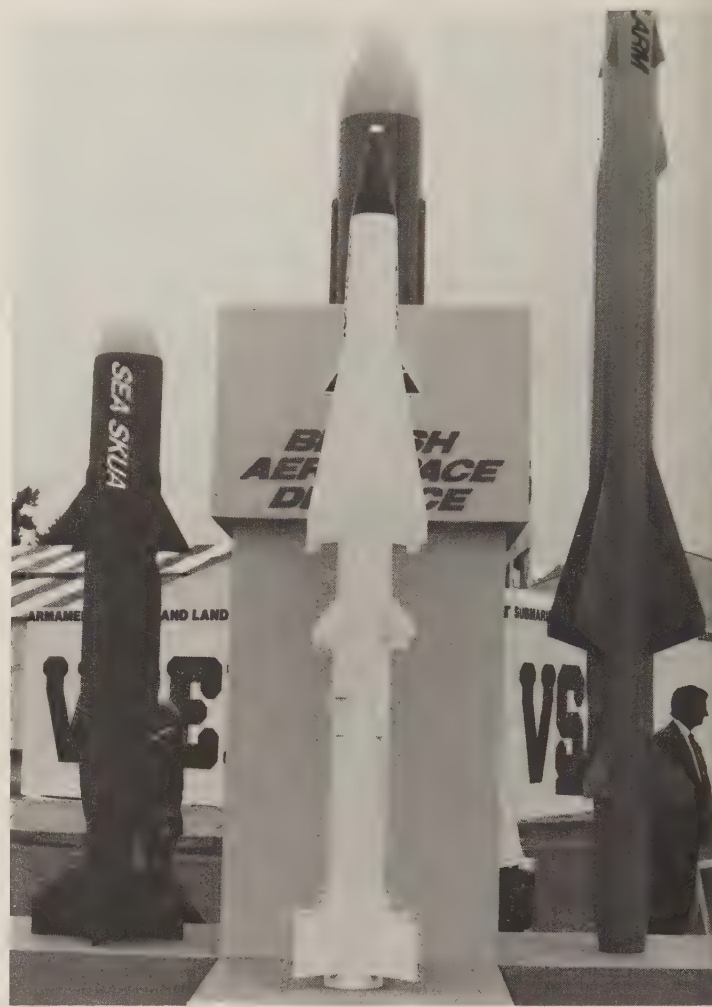
This missile was carried only by British "County"-class destroyers. Except for the disarmed accommodation ship HMS *Kent*, the only surviving units have been sold to Chile and Pakistan. The Chileans elected to retain Sea Slug in 2 of their 4 ships; in 1986 they bought the remaining spare parts and spare missiles.

Sea Slug is unique in having its 4 strap-on boosters attached around its nose rather than its tail. The wings and control surfaces are attached at 45-deg angles. The missile was designed to be stowed horizontally, rather than vertically (as in the first U.S. Terrier launchers); and in "County"-class destroyers the centerline magazine takes up much of the total length of the ship, resembling the hangar of a small carrier. Capacity is 39 missiles. The earliest County-class ships stowed all their missiles ready for service (i.e., finned) on 2 parallel tracks for a total capacity of 28. Later ships, however, carried about 18 ready-service rounds, with about 20 more forward requiring winging and finning before they could be fired (there was a winging/finning compartment forward of the launcher). Because the wingless missiles were much narrower, they could be stowed more densely.

◆ Sea Wolf (GWS 25, 26)

Dimensions: 18 cm × 2 m; span 56 cm [7.1 × 75 × 22 in]
Weight: 82 kg [180 lb] **Warhead:** approx 14 kg [31 lb]
Propulsion: boost-glide; burn time 2–3 sec
Speed: Mach 2 **Range:** approx 5 km [5500 yd]

Sea Wolf is a point-defense missile, normally carried in a 6-round trainable launcher. Guidance is by command to line of sight, using either a radar or a television tracker. The missile is gathered into the tracking beam and command-guided up the beam until intercepting the target. A ship carries 1 radar per missile launcher, so that (for example) a Type 22 frigate has 2 engagement channels. The tracker operates in I-band, the command link in J-band; individual trackers operate in different



Vertically launched Sea Wolf. (Author)

frequencies, so that a ship can guide 2 missiles independently toward the same (or alternative) targets simultaneously. Missile launch is entirely automatic (subject to operator veto), the weapons system ranking and engaging threats in turn. During the Falklands War, this system (on board Type 22 frigates) was used for the close-in defense of the British aircraft carriers. It was discovered that the automatic threat-ranker tended not to deal with crossing targets, and new software had to be provided on the spot. This experience shows both the inherent flexibility of software-based digital systems, and also the effect of the assumptions (in this case, that the system was purely for self-defense) written into that software.

Targets are acquired and tracked by back-to-back Type 967/968 radars, and the associated guidance radar is Type 910. The search/track radars are 2D, the target being located in elevation by the Type 910 tracker itself.

A lightweight version (GWS 25 Mod 2) is being developed for the *Invincible*-class carriers and Type 42 Batch III destroyers, using a 4-barrel launcher and a lightweight tracker (Type 911, the Marconi 805SW); the contract award was announced 1 February 1988. The Type 911 tracker had already been tested on board HMS *Brave*, in November 1986. All subsequent Type 22s are so fitted. This system is GWS 25 Mod 3. Besides Type 911, Mod 3 employs upgraded Type 967/968 radars. The lightweight Mod 2 system uses a launcher based on that developed for Sea Cat; Mod 2 fires containerized missiles. Total weight is 2.5 tonnes, compared to 7.5 tonnes for the earlier 6-barrel launcher. Each containerized missile weighs 170 kg.

A vertical-launch system (GWS 26) is being developed for the new Type 23 ("Duke"-class) frigates, a Sea Wolf with a booster already having been launched from an obsolete frigate (September 1982). It appears that British Aerospace was interested in vertical launch at a much earlier date, since 7 Sea Wolf-type



Sea Wolf being loaded. (British Ministry of Defence)

missiles were launched and turned over to normal flight mode in 1978 in Project SINNER. The first British official development contract was let in the fall of 1983. Vertical-launch Sea Wolf installations will use a new Type 911(2) tracking radar, an improved version of the Type 911(1) now being installed. In the vertical-launching system, the missile itself is provided with a long, finned booster with thrust-vector control. The booster reportedly adds about 50% to the range of the missile, for a maximum of about 8 km.

A development contract for a more sophisticated version of the system, GWS 27, was let in 1986. It was later canceled. GWS 27 would have used an active seeker and a phased-array tracker, the Marconi S1805SW Multifire. Reportedly, 1 goal of the GWS 27 program was to more than double the range of the missile, to beyond 10 km. Missiles would have been command-guided into a terminal homing basket, or else fired with pre-programmed inertial mid-course guidance autopilots. The Marconi seeker intended for GWS 27 was displayed at RNEE 1985.

British Aerospace has also marketed a lightweight Sea Wolf using the Signaal VM40 tracking radar.

Sea Wolf was initially conceived as a faster follow-on to Sea Cat, to engage supersonic targets. In June 1967 a contract for what was then designated PX430 (CONFESSOR) was let to British Aircraft Corporation. The initial production contract followed in July 1968, and the first missile was fired in 1973. A Sea Wolf hit a Mach-2 Petrel target in 1974 and a 4.5-in shell in June 1977. This missile proved quite successful during the Falklands War. On 1 occasion, 4 Argentine aircraft attacked a frigate. Two were shot down, and a third crashed trying to evade a Sea Wolf. Only the fourth escaped. In all, Sea Wolf was credited with having shot down 5 aircraft during the war.

This system was ordered by Kuwait, but in March 1988 the British Ministry of Defence blocked the sale on the grounds that the technology involved might be transferred further.

In 1988 British Aerospace offered a modified vertical-launch Sea Wolf, named Wolverine, as a near-term land-based anti-tactical-ballistic-missile weapon. The initial Wolverine proposal was a boosted missile with an elongated nose carrying flechettes and an active radar seeker, which was derived from the seeker originally proposed for an active version of the Sky Flash air-to-air missile. With the disappearance of the Soviet SS-20 (because of the INF Treaty), the remaining threat was considerably less demanding, and BAe was able to discard active guidance. The current proposal employs MRCLOS (Missile Ref-

erence Command to Line of Sight). MRCLOS uses an inertial reference unit in the missile, reducing the number of updates required by a pure command to line of sight (CLOS) system. That reduction, in turn, permits a single fire-control unit to guide several missiles on a time-shared basis. BAe currently claims that MRCLOS would suffice against weapons such as the upgraded Soviet SS-23 and SCUD B, although an active missile seeker will still be needed to deal with future weapons. Presumably MRCLOS would have a potential naval application.

In mid-1989 the British MoD funded a BAe/Marconi Sea Wolf mid-life update, Marconi concentrating on the radar. Tenders for competitive project definition were to be issued in 1990, for completion in 1992. An initial production contract may be issued in 1993.

The first Sea Wolf VLS missile was handed over to the Royal Navy in 1989.

◆ SDMS

Support Defence Missile System would be used by a missile ship to defend the adjacent 2 or 3 ships, as the Type 22 frigates defended carriers in the Falklands. It is conceived as the successor to current area-defense missiles (Sea Dart) and will presumably arm the next-generation air-defense destroyer (the Type 42 successor to be purchased in place of the NATO frigate). ARE accepted much shorter range in view of the rise of sea-skimmers that approach at short range only, making classical area air defense impossible. The project, therefore, stresses fast reaction and high rate of fire. SDMS will almost certainly be the FAMS missile, but in 1990 there were reports that the existing ASTER did not meet British requirements. Prior to British acceptance of FAMS, a likely candidate had been GWS 27, Sea Wolf with an active seeker and with command mid-course guidance.

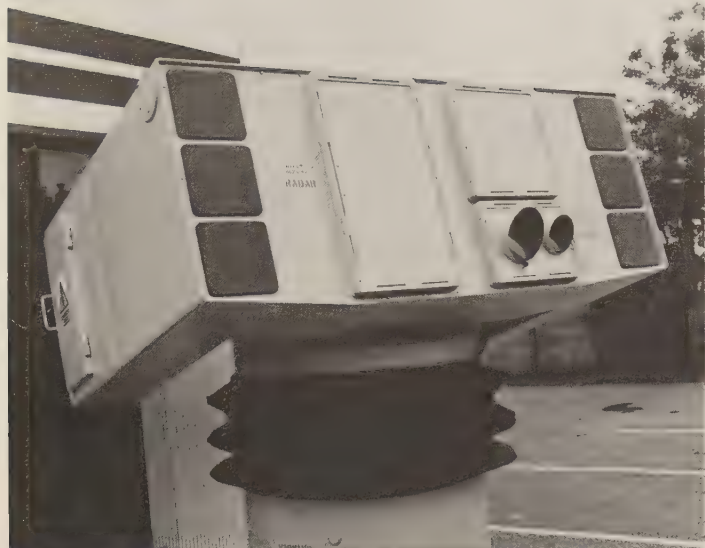
SDMS is 1 of 3 parallel ARE programs for next-generation air defense; the others are VSRAD and the active decoy.

◆ VSRAD-2000

Very Short Range Air Defence is an ARE-sponsored program parallel to SDMS. It is conceived as a last-ditch point defense, a short-range hypervelocity weapon that can be accommodated on board merchant ships (STUFT), but that can also be connected into a ship's central command/control system. ARE prefers a missile to a gun because it doubts whether a gun can destroy the incoming missile at sufficient range, and also because it doubts the ability of GFCs to deal with future maneuvering targets. Several alternatives are under consideration, including the potential for international collaboration (see VSRAD in the international section). ARE has displayed 1 based on the Short Seastreak, as well as an alternative using a retractable 4-rnd firing ramp. Seastreak itself was developed as part of a VSRAD contract with MoD.

◆ Rascal CIWS

At the RNEE exhibition in the fall of 1987, Rascal displayed a mock-up of a new private-venture close-in weapons (missile) system the company is developing, for introduction about 1995. The system consists of a box launcher on a stabilized platform, with a noncleaving radome on top. The box (about 1.7 m wide, 1.8 m long, and 0.7 m high) carries 3 missiles on each side, stacked vertically, with electronics and hydraulics between and with windows for 2 optronic sensors in the front. The radome carries a K-band CW search radar, scanning at high speed, and covering an 80-deg arc in elevation. Presumably the radar detects targets by their doppler. Threats are automatically evaluated and passed to an M-band tracking radar using an array antenna (to form both a wide beam for missile gathering and a narrow beam for command to line of sight). Very fast missiles are to be used, so that even though engagement range will be short there will be time for at least 1 re-engagement should the first fail. Maximum delay from detection to interception will be 3 sec. Total system weight is to be no more than 1.5 metric tons. Reportedly the missile will be an adaptation of the British



The Racal CIWS mock-up, on display at RNEE 1987. (R. Cheung)

Aerospace Thunderbolt, the unsuccessful competitor with Starstreak for a British Army contract.

The Racal system is interesting because it suggests a movement away from current gun-based CIWS systems back toward missiles, which should have a high unit-kill probability, but which are often ineffective inside a substantial minimum range. Although the system was described as a private venture, the Racal proposal may reflect the requirements of VSRAAD 2000.

UNITED STATES

◆ Aegis

See radar integration under AAW radars above.

◆ RAM (RIM-116A)

Dimensions: 5 × 111 in; span 17.25 in **Weight:** 162 lb
Warhead: 5 lb **Propulsion:** solid-fuel rocket
Speed: Mach 2.0+ **Range:** 5 nm

The Rolling Airframe Missile (RAM) is a new point-defense weapon developed as a joint U.S. (General Dynamics)–West German (RAM GmbH)–Danish (Per Udsen) program.

Unlike Sea Sparrow, RAM is a fire-and-forget weapon, homing either on the infrared signature (forward-aspect glint) or the emissions of the homing radar of the incoming weapon. RAM uses a Sidewinder motor, warhead, and fuze, a Stinger infrared seeker, and a new 2-antenna RF seeker. The missile spins as it flies, so that 2 canard control fins (and 2 RF antennas) do the



RAM (RIM-116A) firing. (General Dynamics)

work that 4 of each do in a nonspinning missile. Four tail fins keep the missile spinning.

In theory, the missile is fired in response to radar (or passive electronic intercept or passive electro-optical) warning, launched on a selected bearing and elevation. RAM flies toward its target on the basis of RF mid-course guidance. The missile shifts to infrared terminal guidance but can continue on RF if weather conditions (e.g., too little sun to provide too little glint) provide too little IR signature. In theory, this fire-and-forget operation should make it possible for even a small combatant to deal with multiple attackers.

There are 3 alternative launchers: a standard 21-rnd EX-31 for patrol boats up to large amphibious ships (using the same base and turning mass as a Phalanx mount), a modified NATO Sea Sparrow launcher (2 cells occupied by a total of 10 RAMs), and a special RAM Alternate Launching System (RALS) carrying 10 rnds in 2 arms. RALS has been designed specifically for small craft, and it has been proposed to the Royal Danish Navy for installation on board Standard Flex-300 and *Niels Juel*-class ships.

Planned U.S. EX-31 installations: 2 LCC, 5 LHA, 7 LPH. The Sea Sparrow change will go into aircraft carriers, LHDs, AORs, and the *Spruance* class.

LAUNCHER CHARACTERISTICS

	Standard	RALS
Above-Decks	11,424 lb	7200 lb
Below-Decks	2,105 lb	
Working Circle	129 in	
Elevation	–25/+80 deg	–25/+85 deg
Capacity	21	10

RAM production was suspended because of test and cost problems, which have delayed the system about 5 yr in all. However, on 30 March 1987 U.S. Secretary of Defense Caspar Weinberger certified that the missile had passed its tests and would, therefore, enter production. At that time it was expected that the first 500 would cost \$145,000 (FY86) each, cost averaging \$100,000 for the remaining 4500 planned U.S. weapons. An MoU for U.S.-German production was signed in August 1987, at which time the United States planned to buy 30 launchers, and Germany planned 58 launchers (1923 missiles). The German producer will be RAM GmbH, and it and General Dynamics are to compete for up to 70% of the annual binational purchase.

The first 117 U.S. production missiles were authorized under FY86, FY88, 240; FY89, 260 (U.S. production only). The January 1989 U.S. budget request showed 580 RAMs in FY90 and 540 in FY91. The FY91 budget (January 1990) showed the figure for that year cut to 405, at a projected unit cost of \$174,000.

As of 1990, the Royal Danish Navy is considering buying RAM. Drawings of the new Japanese 1900-ton frigate show RAM; presumably, the Japanese plan to manufacture the missile under license.

RAM is limited in that some missiles, particularly divers, use IR or semiactive-radar rather than active-radar guidance and, hence, will not provide the necessary RF signature. The projected solution is a more sensitive IR seeker, for search as well as terminal homing. The new version is RAM II; a development contract was signed in December 1989.

The new IR seeker is to be sufficiently sensitive for the missile to acquire targets before launch, without any RF signature being present. The existing reticle (point) seeker is to be replaced by an image-scanning seeker (as in a FLIR), and the IR mode and search pattern will be selectable from the launcher. RAM II will retain the dual-mode guidance capability, and a missile launched in RF mode will default to IR search if RF acquisition is lost. This program was initially known as IRMU (IR Mode Upgrade), and it was demonstrated over water early in 1990. As of May 1990, the RAM II seeker had not yet been chosen.

There are several new launcher concepts. The U.S. program for modernizing protection of shipping (POS) ships, described in the ASW section, includes improved hard-kill self-defense, which means RAM missiles. This program affects *Spruance*-class destroyers and *Knox*- and *Perry*-class frigates. Funding, at least for the first 2 classes, is likely to begin during FY91. *Perry*-class frigates are to have their Mk 13 launchers modified so that they can load twin RAM canisters (on hardbacks) as single rounds, in place of single SM-1 missiles. NSWC/Dahlgren has proposed Sideshooter, in which RAM launchers are mounted on the outside of a 5-in Mk 45 gun mount. The mount can carry two 21-rnd, four 5-rnd, or two 5-rnd launchers.

General Dynamics has proposed using a ship GFCs to designate RAM targets. More generally, RAM can be integrated with a ship CDS through a computer-based self-defense module interface. The module should be effective with any ship CDS (presumably, it was developed as part of the larger integration effort now underway); using it, RAM should be able to exploit fire-control radar, Phalanx radar, ESM, or IR tracks. This idea was tested on board the destroyer *David R. Ray*, the ship's Phalanx detecting and acquiring the target. General Dynamics argues that Phalanx and RAM are complementary since RAM will generally kill targets at ranges that preclude debris from hitting the ship, while Phalanx can deal with leakers at its shorter range.

The FY89 program began work on RAM utilization of CIWS radar information and also on the IR seeker upgrade to deal with passive targets. The FY90 program began work on a Block I upgrade, including launcher modifications and system evaluation. The planned FY91 program includes design work on RAM launch from Mk 13 launchers.

As of mid-1990, plans to carry RAM missiles in modified Sea Sparrow launchers had been dropped because of cost and technical difficulties. That leaves the EX-31 launcher and probably a modified Mk 13. RALS, the Danish lightweight launcher, has been tested, but the missile has not yet been adopted by the Royal Danish Navy.

The RAM operational requirement was issued in May 1975, followed by an MoU with Germany for advanced development in 1977 (with Denmark in 1979) and by an MoU for full-scale engineering development in March 1979. RAM first flew in 1978.

◆ Sea Chaparral

See Sidewinder (U.S. air-to-air missile below).

◆ Sea Sparrow

See Sparrow (U.S. air-to-air missile below).

◆ Standard Missile-1 (Medium Range) (RIM-66A and -66B)

Dimensions: 13.5 × 176 in; span 42.5 in

Weight: 1240 lb (1390 lb for RIM-66B)

Warhead: 137-lb continuous rod

Propulsion: boost-sustain rocket **Speed:** Mach 1.25–3.5

Range: 35,000 yd, minimum 3000 yd for air targets; maximum intercept altitude 65,000 ft (maximum intercept range 50,000 yd, maximum altitude 80,000 ft for RIM-66B)

Data are for RIM-66A except as noted.

The Standard Missile replaced the earlier Tartar and Terrier, using as many parts in common as possible for, respectively, the medium-range (MR) weapon with a boost-sustain motor and the extended-range (ER) weapon with a separate booster and sustainer. The design was adapted from that of the TRIP (Tartar Reliability Improvement Program) weapon, which had also been specified for the abortive Typhon program. Reliability improvements included all-electric design (hydraulic power for control surfaces was eliminated) and solid-state electronics with the first battery power in a U.S. missile (which drastically reduced warm-up time, from 26 sec to 1/15 sec). Those improvements in turn eliminated the requirement for shipboard check-out, missiles being shipped as "wooden rounds" good for a 3-yr no-test cycle. The Standard Missile also incorporated a single-



The Taiwanese destroyer *Chien Yang* fires an SM-1 missile, 1989. The "golf ball" contains a W-160 fire-control radar. (F. S. Mei)

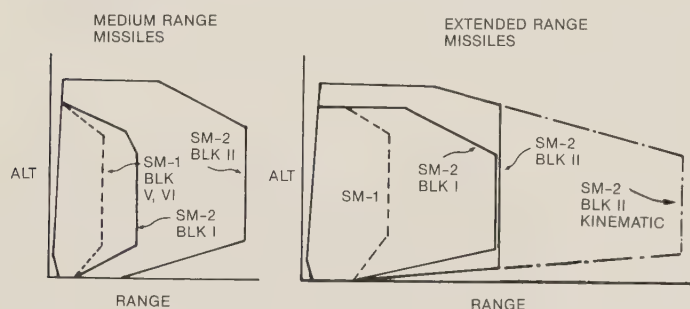


A twin Standard Missile launcher on board a Taiwanese WJ-III (modified FRAM *Gearing*) destroyer. This type is unique to the Taiwanese navy. (F. S. Mei)

sideband receiver (for improved ECCM and clutter rejection) and "doppler offset" to improve discrimination among multiple targets. An increase from 12 to 19 guidance channels reduced ship-to-ship interference. While RIM-66A was an interim weapon that used the existing Mk 27 Tartar motor, RIM-66B introduced a new Mk 56 dual-thrust rocket motor, to achieve 45% greater intercept range, 33% greater peak velocity, 25% greater intercept altitude, and greater terminal maneuverability. RIM-66C is SM-2(MR) (see below).



Standard Missile (Medium Range) being fired from a Mk 26 launcher. The SM-1, SM-2, and Tartar missiles are virtually identical in appearance, though quite different in capability. (U.S. Navy)



Improvements in the Standard Missiles' intercept envelopes resulted from the change from semiactive to command guidance. (General Dynamics)

The original design requirements for the SM-1(MR) missile were a maximum range of 25 nm and a maximum intercept altitude of 80,000 ft. By 1971, however, an (MR) missile at White Sands had successfully intercepted an augmented target at a range of 38 nm. That was without using the energy-efficient trajectory of the SM-2 missile system; at the time it was estimated that SM-2(MR) would be able to engage targets at a range of 40 nm, using the original SM-1 motor and airframe. Longer range meant a lengthier flight, and the electric battery had sufficient energy for 200 sec of operation.

Standard differed from its Terrier/Tartar predecessors in using an adaptive autopilot, i.e., an autopilot that could adapt to changes in missile velocity (e.g., after burnout) and atmospheric pressure (e.g., as it climbed into thinner air). The missile continuously measured its own aerodynamics by sensing the strength of an intentionally induced roll oscillation. In 1971 it was claimed that the existing autopilot could deal with altitudes from sea level up to 100,000 ft, with payload variations of up to 1000 lb (i.e., with a fully burnt-out motor), and with speeds as great as Mach 5.

The original 1964 design allocated space and weight for an RF up/down link for mid-course guidance and also for the inertial reference system for the autopilot, which it needed to exploit the link. Both capabilities were used in the SM-2 version of the missile.

From FY72 on, missiles were bought with a new proximity fuze, TDD (target detecting device) Mk 45. By this time targets were so varied that conventional proximity fuzes no longer sufficed. They formed a cone-shaped sensing pattern whose length equaled the range cutoff. The warhead exploded a fixed time after a target penetrated the outer edge of the cone. The time

delay and the range cutoff were related to the size of the target: if the delay was too long, for example, the blast of the warhead might pass beyond an approaching small target. Until about 1970 it was possible to choose a compromise fuze design (cone angle, range cutoff, and time delay) that could hit roughly amidships on large targets without missing small ones. That was impossible when targets, such as antiship missiles, became very small (particularly when, if they were crossing targets, the fuze would approach broadside-on, seeing their body diameters as their effective lengths). The solution was to use a pair of beams that, in effect, measured target length and permitted the fuze to adjust the time delay to match. Mk 45 was also specially adapted to low-altitude conditions (it could, therefore, trigger overhead bursts against surface targets), and it incorporated new ECCM features. Advanced development work began in FY65, and it was completed at the end of FY69. Engineering development began late in 1969, and Mk 45 was first delivered to the fleet in 1973.

Other weapons in the series were designed for specific anti-surface applications: RGM-66D was Standard ARM (ship-to-ship, homing on the target's radar emissions); RGM-66E was a Standard ARM adapted for firing from an ASROC launcher; RGM-66F was a Standard Active antiship missile. AGM-78, Standard ARM (see Strike/Surface Warfare section), is an air-launched antiradar version, now being replaced by HARM, AGM-88A (see Strike/Surface Warfare section). In the surface-to-surface mode, Standard ARM follows an up-and-over trajectory and thus achieves a range of 35–40 nm (minimum range 7000 yd) carrying a 219-lb warhead (102-lb high explosive). Standard ARM (shipborne) was fitted to 2 U.S. patrol gunboats; it is carried by the Korean *Paek Ku 51* (ex-USS *Benicia*) and *Paek Ku 52–55* of the PSMM-5 class. Standard was fitted to the Iranian destroyers *Babr* and *Palang*, in box launchers (4 per ship, with 4 reloads) as a surface-to-air missile, not Standard ARM (and so is limited to horizon range for surface-to-surface fire). It seems likely that the Standard installation on board the third Iranian destroyer, *Damavand*, is for antiship use only, given the nature of her FCS (Sea Hunter 4). The interim surface-to-surface missile (ISSM) program was initiated in FY70, and the first of 5 *Knox*-class frigates fired Standard semiactive missiles in February 1972 (the *Trippe*). She used 2 of her 8 ASROC cells for antiship missiles. ISSM was replaced by Harpoon in U.S. service.

The West German navy reportedly bought Standard (at that time, Tartar) for German missile destroyers because the weapon promised a useful surface-to-surface capability. For a time General Dynamics was developing a version of the missile armed with a Bullpup warhead, specifically for the antiship role, to be carried on board German fast attack craft. This weapon was tested, but the Germans chose Exocet instead.

Development of the Standard Missile began in FY63, with tests in FY65–67, and procurement from FY67 onward. Procurement of SM-1(MR) ended in FY85 (700 in FY84, 600 in FY85). Consequently, in the future ships firing off their SM-1 missiles will have to use SM-2(MR) with its programmable autopilot disabled; that use should lengthen the SM-2's production run and cut that missile's unit cost. Total SM-1(MR) production was reportedly 12,000. The Standard Missile concept, unifying the design of the Tartar and Terrier follow-ons, was proposed in October 1963 by the Surface Missile Systems Project Office, and development was approved by the secretary of the navy on 10 April 1964. Because of the standardization of both (ER) and (MR) versions, unit cost was well below that of the earlier Tartar and Terrier until the introduction of the more complex fore-and-aft fuze (TDD Mk 45) in FY72 missiles.

Developments of the basic RIM-66B are incremental and are denoted by block changes. The current version is Block VI; the first production version was Block II. Versions were

Block III First 1194 production units.

Block IV Next 1665 production units. Upgrades included ECCM improvements, reduced minimum range, and shorter acquisi-

tion time against surface and crossing targets. Block III missiles were upgraded to Block IV standard from about 1970 on.

Block V Next 2141 production units. This program began in mid-1967 to achieve substantially better maneuverability and improved ECCM. These missiles were better able to engage surface targets because they reduced the effect of glint (target scintillation) by using a modified scanning system (sequential plane scan, SPS, rather than conical scan). The new integrated-circuit autopilot reacted more quickly, and the seeker head was driven directly rather than through gearing.

Block VI The current units add the SM-2 monopulse seeker, for better resistance to countermeasures, and a new proximity fuze (target detection device [TDD] Mk 45 Mod 4), but the guidance section is interchangeable with that of Block V. Both Block VI and SM-2(MR) Block II are 10 in longer than earlier versions to accommodate the new Mk 56 motor described above. Block VI also has a new dual-initiated warhead for greater fragment velocity and density to deal with targets closing at higher speed. Acceptance trials were completed in March 1983, and Block VI began to replace Block V in procurement in FY80.

The termination of SM-1 production has had 2 important consequences. First, to the extent that the current effort at battle-group AAW coordination is successful, SM-1 ships carrying SM-2 missiles can act as spare magazines for Aegis ships, contributing to the overall firepower of the battle group. Second, since the United States is not yet willing to export SM-2 technology, it is unable to provide further missiles to those NATO allies currently operating SM-1. The U.S. decision reportedly contributed, in part, to the French choice not to build the planned second group of SM-1-armed missile destroyers (*Casard* class).

For details of the predecessor Tartar (RIM-24) missile, probably now extinct, see the previous edition of this book.

◆ Standard Missile-1 (Extended Range) (RIM-67A)

Dimensions: 13.5 × 160.182 in (wing span 24 in, fin span 42.48 in) plus booster (18 × 156.6 in, with 62.25-in fins)

Weight: 1148.27 lb plus 1876.7-lb booster (2969 lb total for RIM-67B)

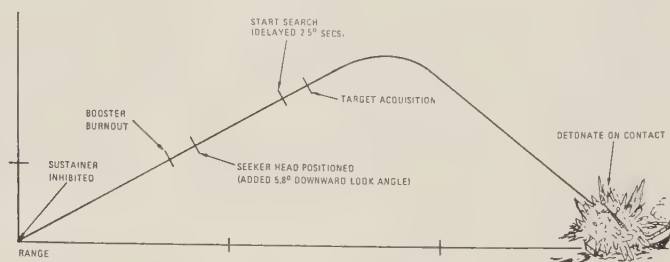
Warhead: approx 250 lb

Propulsion: sustainer rocket with separate booster

Speed: Mach 3.0

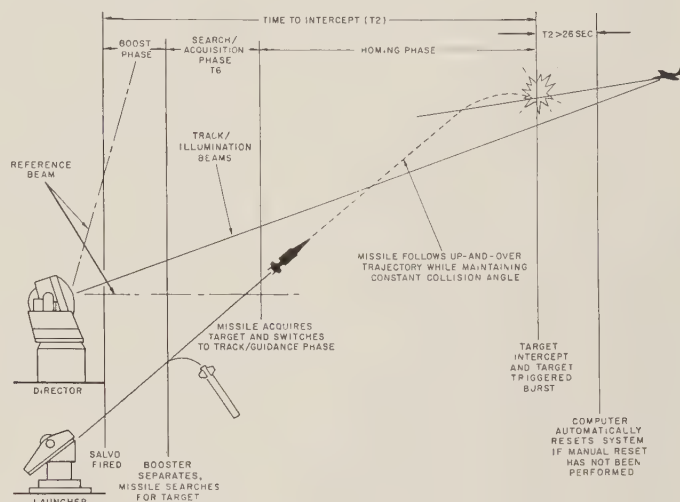
Range: 40 nm (minimum 7000 yd, altitude limits 50–80,000 ft)

This successor to Terrier (RIM-2) incorporates many components in common with RIM-66 SM-1(MR), but with a different rocket motor capable of greater range. Procurement of the SM-1 Block II (ER) version ended after 1983 (1095 ordered FY82, 375 FY83). Compared to Block I, Block II has a more energetic motor



DIFFERENCES FROM AA MODE

1. SUSTAINER IGNITION INHIBITED
2. DELAYED SEEKER ACQUISITION
3. DISABLES THE PROXIMITY FUZE



Standard Missiles' flight paths.

(for higher intercept altitude), a more lethal warhead, and better resistance to countermeasures.

The original design of the SM-1(ER) missile called for a range of 40 nm and a maximum altitude of 80,000 ft. However, by 1971 a missile fired at White Sands had intercepted an augmented target at 70 nm. At that time it was estimated that SM-2(ER)'s range (using the original motor and airframe) would be 90 nm.

The nuclear version of Terrier, the only version of the predecessor to SM-1(ER) remaining in service, has now been retired. See the previous edition of this book for details of this weapon.

◆ Standard Missile-2 (RIM-66C and RIM-67B)

SM-2 adds a programmable autopilot to the basic SM-1 missile, so that SM-2 can be command-guided into a homing "basket" near the projected position of the target. SM-2 was the first tactical missile to incorporate inertial navigation, to guide the missile from the launching ship up into the designated homing "basket." Semiactive illumination is needed only toward the end of the missile's flight. SM-2 is the basis of the Aegis system, which counters saturation by time-sharing illuminators. SM-2, in both (MR) and (ER) versions, is also part of the New Threat Upgrade (NTU) to existing missile systems. NTU ships do not enjoy the tracking precision of the SPY-1 phased-array radar, so illumination must be provided for a longer period, but even so they can engage more targets per unit time.

Like SM-1, SM-2 exists in 2 versions: a single-stage Medium Range (MR) weapon (RIM-66C), and a 2-stage Extended Range (ER) version (RIM-67B). Both share the same programmable autopilot. Aegis ships fire only the (MR) version because their rapid-fire launchers cannot accommodate the manual finning required by the (ER) weapon. The big boosters of these missiles require large fins; the smaller tail fins of the (MR) missiles fold during stowage. Missile cruisers with Mk 10 launchers can fire the (ER) version after undergoing NTU modernization.

The addition of command guidance increases a missile's range



SM-1(ER) being launched. (U.S. Naval Institute)

in 2 ways. A conventional semiactive missile homes all the way to its target: the illuminator must, therefore, provide enough energy for a sufficient amount to be reflected all the way back to the missile on its launcher. In contrast, a command-guided SM-2 requires illumination only near its target. The illuminator must still provide sufficient energy to reach 1 way, but only a fraction of the way back. The combination of command and semiactive is preferable to pure command because tracking (both of missile and of target) is unlikely to be precise enough to bring the missile within lethal range at many tens of miles, while the target maneuvers violently.

The missile also gains range because it can fly a more energy-efficient path than the direct chase of a semiactive weapon. When SM-2 replaced SM-1 (without any change in rocket motor), effective range approximately doubled (the stated improvement in the (MR) version was 60%). SM-1(MR)'s range was probably about 25 nm, so this improvement probably brought the range of SM-2(MR) to about 40 nm. In the case of SM-2(ER), the improvement was 50% or more. Altitude performance also improved. Published diagrams of SM-2(ER) Block I/II's range suggest a maximum range of 90 or even 100 nm. Maximum missile range against a given target is ultimately determined by terminal energy, as the missile glides after its sustainer engine burns out.

SM-2 Block I introduced a monopulse seeker, which counters self-screening jamming.

SM-2 Block II had an improved rocket motor, to deal with faster and more maneuverable targets. This motor doubled the effective range of the (MR) missile, probably bringing it up to the limit imposed by illuminator power. The (ER) Block II missile could fly much farther (i.e., enjoyed a much greater kinematic range), but its effective (illuminator-limited) range is presumably about the same as that of (MR) Block II (which in turn is about the same as that of (ER) Block I). In this case the advantage of the new motor was increased maneuverability against more difficult targets.

Block II also adds digital signal processing and a high-velocity fragmentation warhead (to kill targets passing at very high speeds). Block II was developed in response to a 1975 directive by the secretary of defense, who called for a faster, i.e., more energetic, weapon (in both (MR) and (ER) versions). In March 1981 an SM-2 with the new Mk 70 booster set an altitude record for the interception of a drone.

Missiles procured from FY88 on are Block III, with an improved low-altitude fuze. Development of another new motor, the dual-thrust Mk 104, was announced in the FY86 budget. Mk 104 is presumably intended for an SM-2(MR) Block V, an unboosted equivalent to Block IV.

SM-2(ER) required a data link back to the launching ship. The link was first tested on board the destroyer *Mahan* in FY79, and installation of the link is associated with the NTU program (see the entry under shipboard AAW radars above).

SM-2 Block I procurement ended in FY83. Block II (ER) was approved for service use in May 1983, and the (MR) version in December 1983. Block III, which incorporated low-altitude improvements developed under a 1984 Standard Missile Improvement Program, entered production in 1988 in both (MR) and (ER) versions. A new warhead and further fuze enhancements will be introduced in Block IIIA. As of early 1990, a "dramatically advanced guidance system" is to be retrofitted into missiles during FY91 as Block IIIB, and all-up Block IIIB missiles are to enter production in FY92.

In December 1985 it was estimated that 13,560 SM-2 missiles would be required; another estimate shows 8119 (MR) and 7270 (ER) missiles. The difference may reflect estimates of test and practice firing. Unit costs, as of FY82, were \$513,333 for (MR), \$572,333 for (ER). Total Standard Missile procurement (all versions): FY84, 1190; FY85, 1380; FY86, 1316. SM-2(MR) procurement began with 30 in FY80; then FY83, 150; FY86, 846; FY87, 844; FY88, 1310; FY89, 1310; as of January 1989 the U.S. budget request was 590 for FY90 and 900 in FY91. SM-2(ER): FY80, 55; FY86, 470; FY87, 350; none in FY88 or FY89.

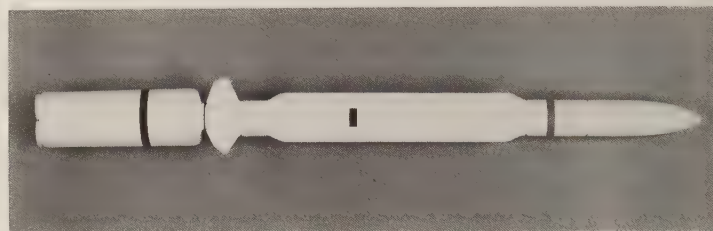
The FY91 budget request (January 1990) included 600 SM-2 Block IIIA missiles. The FY90 budget had included 940 (i.e., more than had been requested), at a unit price of \$415,000.

A Missile Homing Improvement Program (MHIP) is to begin in FY91, for both Standard and Sparrow.

The Navy's proposal for a nuclear version, denoted SM-2(N), using a W81 warhead, was rejected in the FY80 budget but reinstated in FY81 (for procurement of test rounds). However, (N) was deleted from the FY86 budget by the congressional conference committee in favor of a nonnuclear solution. The chief argument in favor of SM-2(N) was the threat of steeply diving nuclear-armed air-to-surface missiles such as the Soviet AS-4/6. If a weapon could intercept such a missile only as it dove, a conventional weapon might tear off wings without destroying an armored nuclear bomb; and the Soviet weapon, tumbling, might still destroy its target by a near miss. The nonnuclear alternative was presumably a higher-energy missile (Block II or even Block IV), which could attack the incoming weapon farther out, before it began to dive, and bring it down outside any damaging range.

◆ SM-2 Aegis (ER) (SM-2 Block IV)

Dimensions: 13.5 × 256 in (booster: 21 × 72 in)
Weight: 3076 lb (total)



An SM-2 Block IV (Aegis ER) missile, with its short finless booster. (Raytheon)

SM-2 Aegis (ER) is a boosted version of SM-2(MR) designed specifically for Aegis ships equipped with Mk 26 or Mk 41 launchers, to deal with very fast or very high altitude targets. Added energy should make the weapon more agile, particularly at the edges of its flight envelope. The missile should also achieve greater range. Aegis ships could not use the regular SM-2(ER) configuration because their launchers are automatic (for high rates of fire) and, therefore, cannot accommodate the manual finning of the usual Mk 10 (SM-2(ER)) system. In 1987 the contract for SM-2 Block IV development was given to Raytheon; General Dynamics Pomona had been responsible for all SM-1/2 development up to that time.

Block IV is designed specifically for vertical launching, so the new missile's short (finless) booster uses thrust-vector control. Modifications to the missile itself include a slip-cast silica radome, a modified antenna with a new signal processor, an improved autopilot, and modified dorsal and tail fins (the latter with new actuators and a new clamp). Raytheon claims that the new aerodynamic surfaces will give considerable improvements in lift and control.

The FY91 budget request included the first 300 production SM-2 Block IV missiles.

◆ Sea Chapparral

See the entry for the Sidewinder air-to-air missile.

◆ Sea Sparrow

See the entry for the Sparrow air-to-air missile.

◆ Stinger (FIM-92)/FIF-2

Dimensions: 2.75 × 60 in **Weight:** 34.5 lb
Warhead: 6.6 lb (proximity fuze) **Propulsion:** 2-pulse rocket
Speed: Mach 2.0 **Range:** about 5500 yd

This surface-to-air missile was intended for use on land (e.g., by the marines), but since 1984 Stinger has been issued to many



A Stinger is fired from shipboard. Note the supporting ring. (General Dynamics)

U.S. warships and auxiliaries for point defense, particularly in Middle Eastern waters. For example, movies of the missile cruiser USS *Vincennes* showed a Stinger operator on deck. Target acquisition was initially entirely visual (via head phones), but the navy is now buying UPS-3 battlefield radars for this purpose. Compared to other hand-held infrared missiles, Stinger is said to have a greater capacity to home on the forward aspect of an incoming target. SA-7, for example, seems to be more limited to tail-aspect attacks and is more likely to be vulnerable to relatively simple infrared countermeasures.

Special features include a dual-color (IR and ultraviolet) seeker (for resistance to countermeasures) and a rosette-scan seeker (in Advanced Stinger) for target discrimination, e.g., between an airplane and a flare.

Recent procurements: FY84, 1205 navy; FY85, 2360 navy; FY86, 3439 navy; FY87, 536 navy; FY88, 425 navy, 3067 marines; FY89 request, none for navy, 3115 for marines. It was reported in April 1988 that purchases of Stinger by the navy had ended, with about 150 fewer than the 685 originally planned. Because it was designed for use on land, Stinger incorporated no shielding against the electromagnetic radiation typically present on shipboard. This problem is typical of land-warfare weapons placed on ships without special adaptation. In addition, the missile's launch blast could damage the ship's structure.

At the U.S. Navy League show in 1989, General Dynamics exhibited a shipboard firing platform for Stinger, a ring allowing the gunner to rest the launcher when not in use, with plastic poles to prevent firing in a direction that would damage the ship. The poles are analogous to the pipe rails fitted to many light antiaircraft guns during World War II, to keep their gunners from firing into their ships' superstructures. This is a problem for any manually controlled weapon since there is no automated FCS that incorporates the appropriate cut-offs.

This missile arms the new West German mine-countermeasures craft (Types 332 and 343), each of which has 2 Stinger positions (as well as 40-mm guns). The German designation for Stinger is Fliegerfaust 2 (FlF 2); Redeye was FlF 1.

Stinger was extremely successful in Afghanistan, against Soviet helicopters and ground-attack aircraft.

◆ ASAT

The antisatellite weapon is a new program begun in FY90, with a proposed budget of \$218.9 million for the first 2 years. The United States has had active antisatellite programs through the Reagan Administration, but in the past they have been an air force responsibility. The navy has argued that the satellites of most immediate tactical significance are relatively low flying Soviet naval reconnaissance craft, and that their prompt destruction may be essential in battle group operations. For example, destruction of a radar satellite just prior to launch can disrupt an Oscar's SS-N-19 missile attack by denying the submarine vital last-minute information. This tactical move is precisely analogous to destroying a Bear-D radar airplane to disrupt an SS-N-3 attack.

This type of attack is quite distinguishable from an attack on an early-warning (or, probably, signals intelligence) satellite in a higher orbit. It seems at least arguable that the Soviets cannot afford to place their tactical radar satellites in very high orbits, particularly if the U.S. Navy uses decoys and cross section-reduction techniques to make radar tracking of its ships more difficult. There will, then, generally be a very clear distinction between attacks on naval-related tactical satellites and attacks on satellites that might be considered more strategic in character. That distinction in turn should help differentiate naval ASAT, as a tactical operation, from strategic-warning ASAT, which some might consider destabilizing.

Reportedly, the decision to allow the navy to develop a sea-based ASAT reflects OSD agreement, late in 1988, that space should not be controlled by a single (i.e., air force) manager, but rather that at least some space defense tasks should be considered natural outgrowths of air defense at lower altitudes.

Reportedly, too, the navy's program is a response to rejection of the air force's ASAT program, which many in Congress considered strategically destabilizing. The air force's weapon was a miniature homing vehicle, carried aloft by an F-15 and then fired into orbit atop a rocket. The same weapon could be carried by an F-14; in each case, the fighter must fly a precisely defined high-energy trajectory, acting as the first stage of the interceptor rocket. A navy ASAT might also be fired out of a shipboard vertical launcher. As of the late spring of 1989, it appeared that tactical ASAT, which had been carried in budget documents as a joint army-navy program, would be developed by the army, presumably by ABMDA, the old Army Ballistic-Missile Defense Agency, at Huntsville, Alabama. The joint nature of the program would presumably be reflected in a requirement that the missile fit the standard navy vertical-launcher cell. Any possibility that the weapon would be carried aloft by a navy fighter thus seems to be ruled out. It may be that limitations on the size of the tactical ASAT missile will be reflected in inherent performance limitations sufficient to convince potential congressional critics that the weapon cannot be used against strategic warning satellites.

As Chief of Naval Operations, Admiral C. A. H. Trost chose the surface-ship VLS rather than the strategic-submarine missile tube as the preferred launcher. As of 1989, ASAT was planned as a kinetic-energy (direct-collision) weapon, with an undetermined sensor.

◆ Outer Air Battle Missile(s)

Since the 1970s the U.S. Navy has sought a longer-range, higher-energy replacement for the SM-2 series. Ideally, this replacement would be able to engage Soviet bombers before they could launch their antiship missiles, during what is now called the Outer Air Battle.

For a surface-launched weapon, the problem is twofold. First,

some means of guiding a missile, perhaps beyond the fleet's horizon, is needed. Second, the missile requires sustained high power. The second problem is more easily solved, since very long range hypersonic weapons already exist. In the 1970s it seems to have been assumed that the solution would be an integral rocket-ramjet, and the new Mk 26 launcher developed for Aegis ships was deliberately designed to fire future larger weapons with this type of propulsion. Because the current Vertical Launching System (Mk 41) is designed to accommodate Tomahawk cruise missiles, it can also accommodate a future long-range surface-to-air weapon.

Guidance is a much more serious problem. The most obvious solution is active homing rather than the semiactive homing of SM-2, but a small missile-borne active radar is unlikely to be able to overcome terminal countermeasures, as the targets will enjoy much greater power resources. It might be possible to use a combination of active radar and infrared "glint." One alternative is to limit the missile to a specific mission, the destruction of the escort jammers that generally accompany Soviet antiship air strikes. The missile could then home on the jamming emissions; the threat of the missile might force the Soviets to shut down their jammers, thus opening the platforms to shorter-range weapons. Another alternative is to use a platform closer to the target to provide guidance, a technique once called Forward Pass. One version is the Surface-Launched Air-Targeted (SLAT) missile, for which ships carry the heavy missiles and air platforms the relevant radars. In 1984 Martin Marietta proposed that OTH guidance be furnished by a dedicated radar satellite, but this idea was apparently too radical (and probably far too expensive).

Several extremely long range surface-to-air missiles were proposed through the 1970s, usually using rocket-ramjet power to achieve a combination of range and terminal maneuverability. The usual choices for guidance were concentration on Soviet escort jammers (home-on-jam) and Forward Pass (SLAT). LORAINÉ (see below) represents yet another, and quite different, alternative. A very long range home-on-jammer project, SOJS (Stand-Off Jammer Suppression), was canceled in 1981 with the announcement that, as important as this threat was, some new technical approach was needed.

At about this time there was also official reference to a ramjet-powered Long-Range Dual-Mission Missile (LRDMM), which could attack surface targets (at Mach 2.5) as well as very distant air targets (at Mach 4.5). As of 1978, the navy hoped that LRDMM could enter engineering development in April 1983. LRDMM would extend Aegis's range and might rely on E-2Cs for OTH engagement of targets such as Backfires and stand-off jammers. There was some interest, at the time, in commonality with the air force ASALM ramjet cruise missile, and some hope that the army would join in a triservice program. The ramjet missile Martin Marietta proposed for ASALM later surfaced as a possible Outer Air Battle alternative, and then became the SLAT supersonic target (and a Harpoon follow-on candidate—see Harpoon II in the Strike/Surface Warfare section).

Another project of the late 1970s was Thor, an abortive Martin Marietta project using a Sprint (ABM)-like very high acceleration missile. The Thor concept seems to have been applied both to very long and to very short range projects of this type, since the very high acceleration could boost a weapon to considerable range, or allow the missile to engage short-range targets that were maneuvering very violently.

A series of Outer Air Battle studies was carried out in the early 1980s, the objective being a pair of missiles, one for surface ships (to replace SM-2) and one for aircraft (to replace Phoenix). Ideally, both would use many of the same components.

A unitary Outer Air Battle Missile program began under the FY81 program, under the designation SM-3. Research efforts included improvements in IR guidance to supplement semiactive homing; more maneuverable aerodynamic design; the development of a linear autopilot (superior for high altitudes); and a directional, aimable warhead (for greater lethal radius and better effect against hardened targets). The Outer Air Battle study,

which was completed on 15 June 1983, set development milestones (a breadboard design in FY84, with wind tunnel tests and design review, followed by an FY85 concept definition competition). An RFP issued on 4 February 1985 included such guidance concepts as Forward Pass (see above) and called for commonality between the advanced air-to-air missile (AAAM) and the surface-to-air missile (ASAM). Reportedly ASAM was conceived as an 800-nm, Mach-4.5 ramjet.

Concept contracts were awarded on 31 May 1985 to Hughes, Martin Marietta, McDonnell Douglas, and Raytheon; study contracts were also awarded to General Dynamics and Grumman. Submissions were due in the first quarter of FY86. A navy program review during the summer of 1986 concluded that it was impossible to develop a satisfactory unitary missile and, moreover, that it was unwise to develop a totally new very long range surface-launched surface-to-air weapon. Instead, effort would be concentrated on a new long-range air-to-air missile (AAAM) and on an evolutionary improvement of SM-2, which became SM-2 Aegis (ER). AAAM was separated from ASAM.

◆ LORAINÉ

LORAINÉ is an experimental program sponsored by DARPA: the letters mean Long-Range Aircraft Interceptor Experiment. LORAINÉ is intended to attack targets at very long range with nonnuclear weapons and, therefore, is a candidate technology for the navy's Outer Air Battle project. There are also possible air force applications, for example, as part of the Air Defense Initiative (ADI, the air-breathing complement to SDI). In common with other DARPA projects, LORAINÉ is a technically risky attempt to achieve a dramatic improvement in overall performance.

From the sketchy information available, it appears that LORAINÉ is a ballistic weapon sized to fit the standard launching cell of a Mk 41 vertical launcher. LORAINÉ boosts its reentry vehicle (the "boost-glide vehicle") above the atmosphere. As the vehicle falls back to earth, the active conformal-array radar searches over a wide area matched by its kinematic footprint. The missile has sufficient energy to connect with any conventional air-breathing craft; speeds of Mach 8–10 have been mentioned. The homing footprint might be so wide that the weapon could use target-designation data from a sensor as crude as an OTH radar. Reportedly the reentry vehicle might use a multimode seeker (e.g., active radar, antiradar, and home-on-jam). One technical problem would be to distinguish the target from the surrounding ground clutter; this problem would be for LORAINÉ a worse version of the usual look-down/shoot-down question.

Because the missile is relatively small (limited by vertical cell dimensions to roughly Tomahawk size), it is potentially quite mobile and can be carried by aircraft (Tomahawk was considered as an alternative air-launched cruise missile). Given the missile's mobility and flexibility of basing, DARPA saw LORAINÉ as a means of rapidly improving national air defenses in a crisis.

The program began formally in FY86 (\$2.5 million) as a continuation of earlier exploratory work (the SWERVE III experiment). The SWERVE III vehicle was apparently assembled at the Sandia National Laboratory (which normally concentrates on nuclear weapons and which would, therefore, be familiar with the problems of ballistic reentry vehicles); and under the FY85 program a SWERVE III test vehicle flew 600 nm to Johnston Island (20 April 1985) to verify electrical, mechanical, and thermal performance. This project was tentatively killed off in DARPA cuts for the FY86 budget, but the money was restored when another project, Teal Ruby, had to be delayed.

In FY87, \$20 million was provided, and the request for FY88–90 is \$52 million (\$18 million for FY88, \$22 million for FY89, and \$12 million for FY90) to bring the weapon to full-scale development stage. A test flight against a drone is planned for 1991. The key technology is a radar array capable of operating at very high temperature and at high speed. In the FY87 budget Congress rejected a navy request for \$16.3 million for a

study of a hypersonic wide-area-defense missile on the grounds that the LORAINÉ technology would be superior.

The original SWERVE was the Sandia Winged Energetic Re-Entry Vehicle, a Sandia-DARPA project dating from late 1979, and conceived as an application of DARPA work on a sensor-navigation problem. SWERVE was derived from several years' work to achieve standoff maneuvering capability for tactical aircraft carrying nuclear weapons. The Sandia tactical inertial-guidance and extended-range (Tiger) program used test nuclear-weapon shapes with wings, movable canards, and solid-propellant propulsion. SWERVE was a hypersonic theater-defense missile that could be surface-launched into a ballistic (exo-atmospheric) trajectory, then reenter and maneuver to attack aircraft and cruise missiles, with a large footprint at a range of 1000 nm. Initial flight tests from Kauai, Hawaii, in September 1980 used a Thiokol Strypi (XM-33 Castor I as first stage, augmented by 2 XM-19 Recruit rocket motors). The second stage ignited after the vehicle was above the atmosphere and headed downward to accelerate the SWERVE vehicle to the desired speed. SWERVE leveled off at 25,000 ft and maneuvered. Reentry speed was about 10,000–12,000 ft/sec, about half that of a ballistic missile reentry vehicle.

◆ T ASD

Rockwell's target-acquisition ship-defense system was first displayed at the U.S. Navy League show in March 1989. A sketch showed a box missile launcher surmounted by a radar dome containing a pair of radars, operating in Ku- and W-bands. Rockwell argues that guns cannot expect to destroy incoming missiles at sufficient range to avoid damage from their fragments. The next best alternative is command to line of sight-guided missiles. Rockwell's proposal shows 2 radar dishes side by side on a single pedestal, the 2 frequencies being used together to solve multipath and glint problems. Both dishes would transmit simultaneously, and the associated control system would also use data from other ship sensors, such as ESM and electro-optical devices. Rockwell has already tested the radar concept; the company's stand showed a photograph of the dual dishes (which are the same size) side by side on a test pedestal.

TASD was a product of a congressionally mandated Balanced Technology Initiative (BTI), which was intended to apply new strategic-defense concepts to tactical problems. The TASD contract was signed in the summer of 1988.

By the spring of 1990 TASD had apparently been reduced largely to a sensor program. Drawings displayed at that time showed that initially the 2 coherent radars shared a common antenna, but that the proposed production version had side-by-side antennas. At this time Rockwell claimed that the system as a whole enjoyed 100-microrad accuracy, and that its dual frequency made it effective against low-fliers and in adverse weather. The dual radar could also provide a Ku-band up-link for a command-guided missile. Rockwell proposed it as a fire-control sensor for a 5-in gun or an electro-thermal gun (ETG). One drawing suggests a final configuration in which an electro-optical sensor is mounted atop the 2 radar dishes.

Further data were not available; it is not clear whether Rockwell has a specific command-guided point-defense missile in mind.

◆ MIRACL

Although not currently a satisfactory weapon, the Mid-Infrared Chemical Laser has shot down drones in tests, and presumably it is intended as the forerunner of future U.S. naval laser weapons. In 1985 Congress rejected a navy request that MIRACL be developed as the basis for a future naval tactical directed-energy system; the laser project was left alive largely by its connection with the SDI program. In current form, MIRACL reportedly occupies several acres.

The first successful test was on 18 September 1987 against a target drone flying at 500 kt and at an altitude of 1500 ft. On 2 November MIRACL shot down a BQM-34S drone at twice that first range; figures were not disclosed.

On 23 February 1989 MIRACL, using a Sea Lite beam director, destroyed a supersonic drone (later identified as a Vandal, a converted Talos ramjet missile) at what was described as a realistic tactical range. MIRACL had destroyed subsonic targets in the fall of 1987 but never a supersonic one. The press release issued at the time stated that the laser lethality demonstrated in the test had been predicted and tested against static missile parts but never against a real high-speed target. The 1989 test was the culmination of a 2-yr program. MIRACL itself is much too massive to use at sea, and Sea Lite is also quite massive, but the successful test, conducted at White Sands Missile Range, may provide motivation for a usable tactical system.

The tactical problem is quite different from the strategic or space-based laser problem. A missile warhead damaged in space may well burn up as it reenters the atmosphere, so relatively low damage levels may suffice. On the other hand, that damage must be imposed at very great ranges, on the order of thousands of miles. In contrast, a tactical laser hits its target at relatively short range, but the lethality must be very great, since a pinhole fatal in space may have no effect whatever on a large aerodynamic missile. The destruction of the Vandal is particularly impressive because it is so large and robust a missile. The precise damage mechanism involved is still of interest. For example, if the laser destroyed the Vandal by igniting its fuel tanks, then the result may not be generally applicable. If, however, the laser literally melted large areas of the missile's surface, the result is much more significant. The possibility of countermeasures such as defensive types of missile construction remains open in either case, however.

Proponents of a naval air-defense laser can point to the massive power supply available on board ship and to a ship's great reserves of space and weight. For example, much of the weight of the laser might be carried well below decks, with only the optical path of the beam emerging into a beam director above decks. Compared to a conventional missile, the laser promises lethality down to zero range. Compared to a small-caliber gun, the laser greatly simplifies the fire-control problem, presumably destroying the target so thoroughly that there is no danger of fragments traveling on to damage the ship. The 3 great technical issues are probably propagation through the water vapor-laden air near the sea's surface (e.g., shooting down sea-skimmers); the rate of fire (i.e., providing enough energy for quick multiple engagements); and the sheer mass of the beam director.

The MIRACL test against the Vandal drone was conducted under the congressionally mandated Balanced Technology Initiative (BTI), an attempt to apply SDI technology to conventional warfare.

The MIRACL laser was developed by TRW and uses a Hughes beam director (Sea Lite). Sea Lite was conceived for research toward a laser CIWS, as the culmination of a series of navy studies of chemical and gas dynamic lasers. The navy had also worked on at least 2 particle-beam weapons, Seesaw and Chair Heritage. In 1973 TRW won a competition with a deuterium-fluoride CW laser, operating at 3.8 microns (350 kW). It shot down a TOW missile in 1978, exciting navy interest in a laser CIWS. Hughes received a contract for a pointer-tracker. In FY81, however, the program was moved back from advanced to exploratory development, and about a third of the requested appropriation was cut by the House of Representatives. The move to White Sands Missile Range began in FY82, and MIRACL moved from the naval tactical program to the SDI program. In September 1985 it destroyed the second stage of a Titan missile booster on the ground at a reported range of about half a mile. The laser first ran at full power on 19 August 1986. In the successful Vandal test, the laser destroyed vital components, causing the missile to spin into the ground.

The laser fuels are ethylene, hydrogen, and NF₃; TRW estimates the cost per kill at \$10,000.

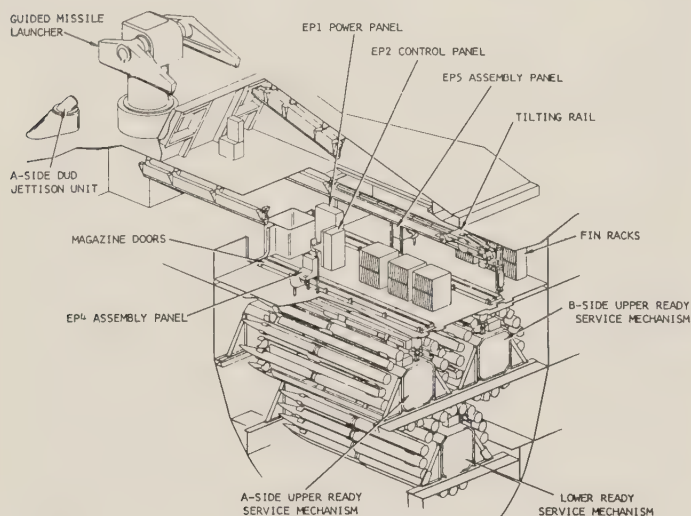
As of 1990 the 2 developing companies were attempting to convince the U.S. Navy to test a defensive laser at sea. TRW displayed a model of a possible ship-defense laser at the 1990 U.S. Navy League show. Although MIRACL itself stretches over

a considerable desert area, TRW claims that a practical version would be no larger than a 5-in/54 gun or a vertical missile magazine. It would not displace the gun or the missiles, since the gun would still be needed for shore bombardment, and the missiles to deal with targets above cloud cover. The laser would be aimed by an imaging tracker telescope.

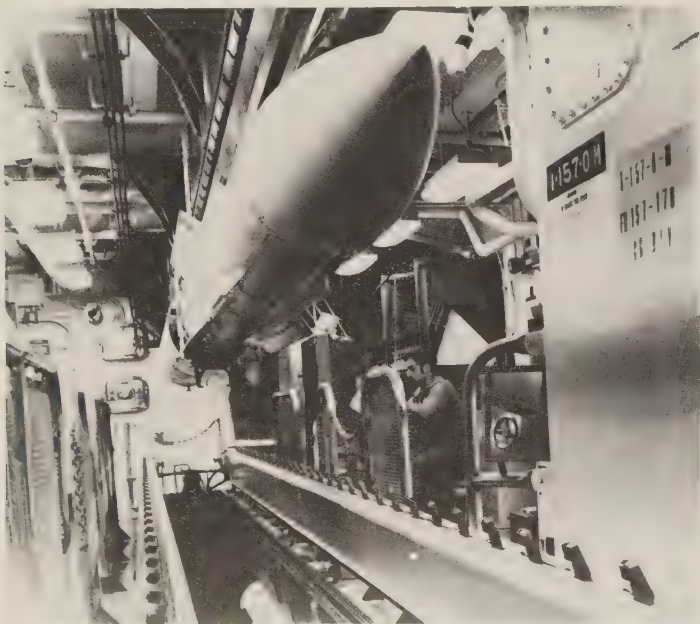
◆ U.S. Missile Launching Systems

The principal current types are Mk 10, 11, 13, 26, 29, 41, and 43.

Mk 10 standard DDG and CG Terrier launching system, for SM(ER) (originally Terrier) missiles. The missiles are stowed horizontally without their booster fins, in 20-missile rotating rings. They are raised onto parallel monorails for ramming onto the launcher (through armored doors), and the boosters are finned manually. Rate of fire: 4 rnds per minute (1 missile every 30 sec per rail); typical weight, including missiles and fluids, 400,347 lb (275,875 lb without missiles). Mod 1 has 2 rings; Mod 2, the superfiring launcher in the cruiser *Long Beach*, has



Mk 10 missile launcher. The ready service mechanisms are the rotating rings carrying the missiles. Other versions of the Mk 10 launcher employ 2 or 4 rings.

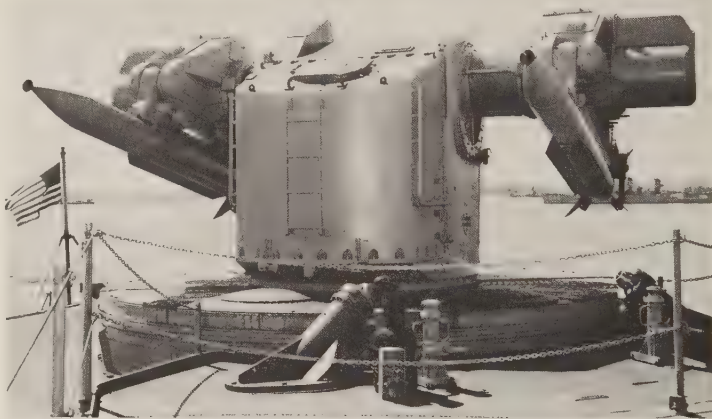


A missile in a Mk 10 launcher, waiting to be finned before being rammed out onto the rails. Below it can be seen the blast doors leading to the rotary magazine; the stations at either side are for the men who ram the fins onto the missile booster. The fins are too large to fold for stowage, and the operation of finning slows the firing rate of the launcher. (U.S. Navy)

4 (80 missiles: 695,329/450,857 lb); Mods 3 and 4 were for the carriers *Kitty Hawk* and *Constellation* (now removed); Mods 5 and 6 (2 rings, 40 missiles) are on board *Leahy*-class cruisers. Mods 7 and 8 (*Belknap*-class cruisers) have 3 rings (60 missiles) and fire both surface-to-air missiles and ASROC (20 ASROC can be interspersed with the missiles on the 2 upper rings). This system was called ASTER. Weight: 546,734/361,994 lb. Complement: 16. Dimensions, for a 2-ring installation: 360 × 395 in (magazine, not counting launcher). Train rate: 30 deg/sec (elevation rate 20 deg/sec; limits +90/-10 deg).

At the U.S. Navy League show in 1990 FMC displayed possible new applications for the existing Mk 10 launcher: firing a ballistic rocket, or firing a flechette rocket (80 flechettes per round) for antiship missile defense. Interest in shore bombardment recalls a late 1960s project for a shore-bombardment missile, which would have been fired from the missile launchers of obsolescent missile cruisers.

Mk 11 twin-arm SM(MR) (originally Tartar) launcher, virtually automatic because the missiles did not have to be finned. Mk 11 was, however, considered unreliable, and it was superseded by Mk 13. The 42 missiles are stowed vertically in a 196-in diameter (209 in high) magazine. Total weight: 201,370 lb loaded, 148,450 lb empty. Crew was 3, and rate of fire one 2-missile salvo every 18 sec. This launcher can also fire Harpoon missiles.

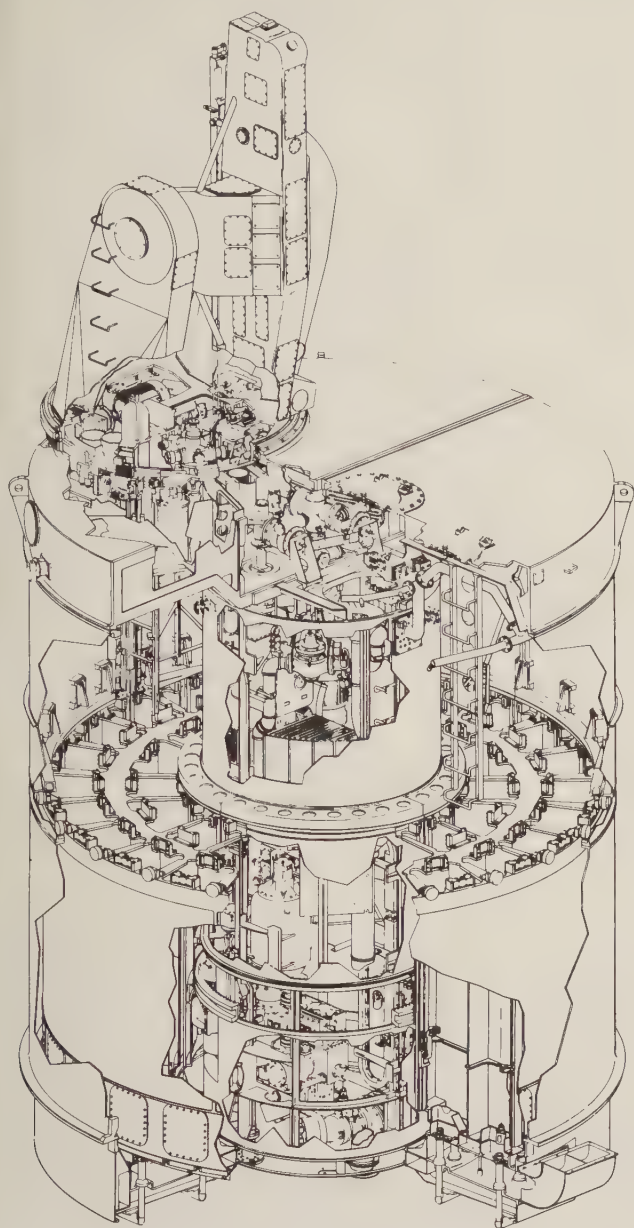


Mk 11 missile launcher. (U.S. Navy)

Mk 13 current standard SM(MR) launcher, with a single arm, first installed in late *Adams*-class missile destroyers. Mk 13 fires 1 missile every 10 sec (continuous salvo rate is 1 missile every 7.47-7.82 sec in the Mod 4 in the *Perry* class). The 40 missiles are stowed vertically, in 2 concentric rings (Mk 22, below, is in effect the inner ring of a Mk 13). Both the rings and the launcher rotate, the blast door is fixed. Train rate: 90 deg/sec (elevation rate 45 deg/sec); elevation limits are +95/-15 deg (+93/-15 for Mod 4). Diameter: 203 in. Weight (Mod 4): 134,704 lb empty. Mod 4 was designed specifically to fire Standard Missiles, which require no warm-up, and, therefore, lacks the warm-up connectors of earlier versions. This launcher can fire Harpoon missiles.

Besides the elimination of all the warm-up circuits and hardware, Mod 4 has a new solid-state (rather than relay) control system and a means of automatically identifying the missile in each magazine position (which is necessary for a launcher firing different types of weapons). Mod 4 can identify any 7 out of a possible total of 64 missile types. Two zener diodes within each missile have reverse breakdown voltages related to binary codes assigned to missile versions based on their warhead, fuzing, guidance, and propulsion. The missile automatically identifies itself to the guide arm as it is loaded onto the launcher.

Mk 16 ASROC "pepperbox," carrying 8 missiles in 2-missile cells elevating separately. Maximum rate of fire is 3 missiles/



Mk 13 Mod 1 missile launcher. The missiles are carried in the two concentric rings surrounding the central column. (FMC)

min. Elevation limits: $+85/-3$ deg. This lightweight launcher is often criticized for its vulnerability to weather damage. Most versions are reloadable; in *Knox*-class frigates the magazine is under the bridge, abaft the launcher, and the missiles are stowed horizontally. In *Spruance*-class destroyers, the magazine is under the launcher, the missiles are stowed vertically, and the launcher elevates to 90 deg to reload. The *Spruance* version was designed specifically so that it could later be replaced by Mk 26 Mod 0. Instead, these ships are being fitted with 61-cell vertical launchers to hold 45 Tomahawks and 16 Vertical-Launch ASROCs.

Mk 21 The Polaris A3 missile-launching system survives only in the Royal Navy. Unlike its predecessors, but like all later U.S. strategic-missile launchers, it uses a gas generator to expel missiles.

Mk 22 lightweight single-arm SM(MR) launcher, for *Brooke*-class frigates and for the Spanish *Baleares* class, carrying 16 missiles in 1 fixed vertical storage ring (the blast door revolves). Rate of fire: 7/min. Train rate: 85 deg/sec (elevation 45 deg/sec); elevation limits: $+85/-10$ deg. Magazine diameter is 146 in. Weight (empty): 94,003 lb.

Mk 24 Poseidon C-3 launching system.



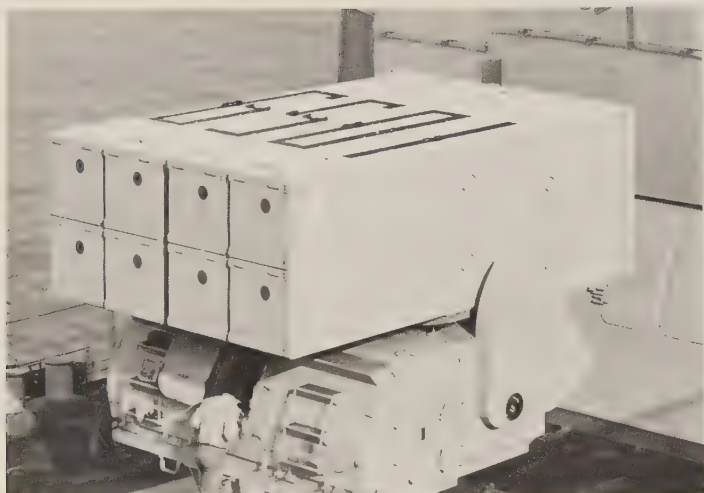
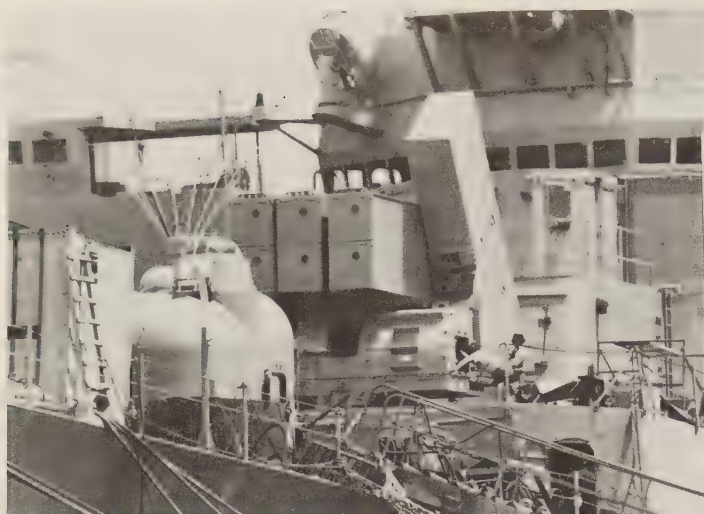
FMC is currently studying a variety of modified standard launchers, including the proposal to mix Standard Missiles and 2-RAM strongbacks in a Mk 13 magazine, illustrated here. The RAMs could be ripple-fired, and the strongback ejected as soon as they had been fired. FMC has proposed similar modifications to Mk 10, 22, and 26 launchers. The Mk 13 project is being funded as part of the *Perry*-class improvement program. (FMC)

Mk 25 BPDMS (initial Sea Sparrow) launching system, consisting of ASROC boxes on a former 3-in/50 twin mount (2 outboard, 2 between the vertical arms of the mount), all elevating and training as a unit, carrying 8 Sea Sparrows and firing them at a minimum interval of 2 sec (all in 16 sec). There is no means of automatically reloading. Training rate: 30 deg/sec (elevation rate: 24 deg/sec); elevation limits $+65/-15$ deg). Total weight: 31,500 lb. Mod 1 has frangible doors.

Mk 26 twin-arm dual-purpose (SM and ASROC) launcher, used in place of Mk 13 on *Virginia* and *Ticonderoga* classes. Missile length limit is 200 in (diameter 14.75 in, weight 2200 lb, compared to 13.5×186.45 and 1500 lb for Mk 13). Missiles are stowed vertically, in 2 parallel chains running fore and aft under the launcher. Rate of fire per arm reportedly approximates that of Mk 13 (in theory a Mk 26 can fire 2 missiles every 10 sec). Train rate: 90 deg/sec (elevation: 50 deg/sec). Three versions: Mod 0, 24 missiles (193,022 lb/162,302 lb empty, largely for ASROC); Mod 1, 44 missiles (264,897/208,577 lb); and Mod 2, 64 missiles (337,031/255,111 lb).

Mk 29 NATO Sea Sparrow launcher, more compact than Mk 25 and considerably lighter (12,768 lb), firing 1 round every 2 sec. Train rate: 40 deg/sec (elevation 65 deg/sec), elevation limits $+85/-5$ deg.

Mk 32 Standard Missile box launcher, for *Asheville*-class gunboats (Mods 0 and 1) and for the Iranian destroyers *Babr*, *Palang*, and *Damavand* (Mod 2). Mk 32 is fixed in train and elevates to an angle of 25 deg for firing, with a maximum rate of fire of 2 rnds/min (2 rnds per launcher, in a magazine forward of the launcher proper). Total weight: 22,420 lb. The launcher is 205



Mk 16 is the standard ASROC launching system, shown on board the frigate *W. S. Sims* (1986) and on board the missile destroyer *Farragut* (1987). Each pair of cells elevates independently. (S. Terzibaschitsch and W. Donko)

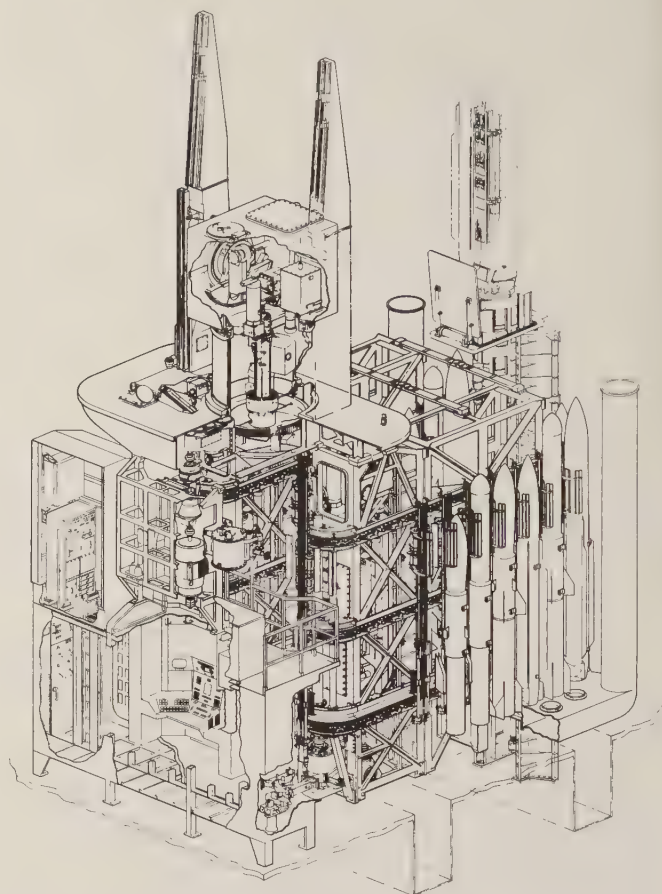
in long, with a 203-in magazine, and the launcher itself is designated Mk 134.

Mk 35 Trident C-4 launcher for strategic submarines.

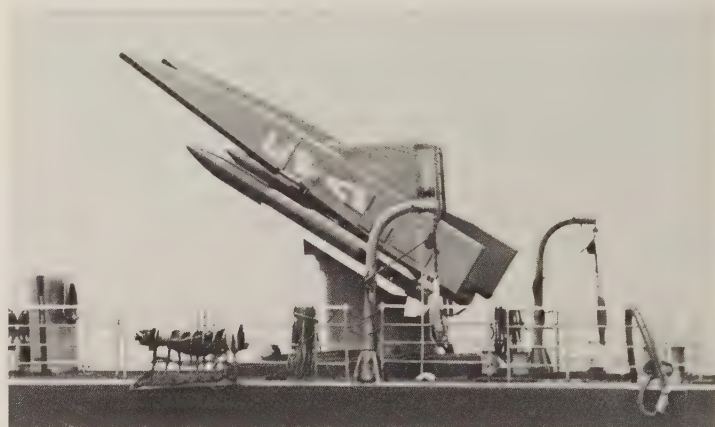
Mk 36 SRBOC chaff launcher (130-mm, 40-lb cartridge). The launcher itself is Mk 137.



A standard Mk 25 launcher for the Basic Point Defense Missile System, on board the helicopter carrier *Tripoli*, July 1984. The girder in the background carries a ULQ-6 jammer. (Zeitlhofer)



Mk 26 Mod 1 missile launcher, showing a variety of weapons (Standard, 2 kinds of ASROC, and Harpoon) and the strike-down hatch at the right, with a Standard Missile being loaded. The missiles are carried on a pair of vertical conveyors, 1 for each launcher arm. (FMC)



Standard Missiles on a Mk 26 launcher, USS *Callaghan*, 1988. (W. Donko)



A Mk 29 Sea Sparrow launcher on board the frigate *Van Kinsbergen*, 1990. (L. van Ginderen)

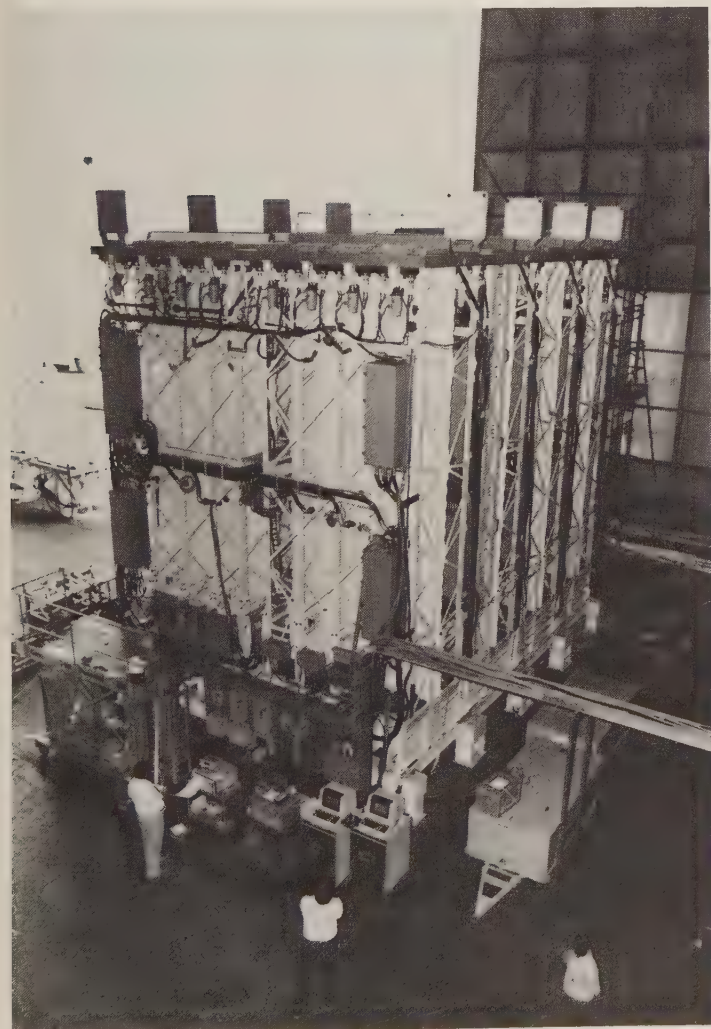
Mk 37/38/39 launchers for CAPTOR mines from, respectively, surface ships, P-3 aircraft, and submarines.

Mk 40 Training launcher system for Iranian Navy (to train on Mk 32 launching systems).

Mk 41 Vertical Launching System (VLS), conceived in 1976, and first installed operationally on board the cruiser *Bunker Hill* (CG 52). The system was originally designed to fire only Standard Missiles, using a 228-in canister (which allowed for future expansion). However, it was decided that all VLS would also be able to launch Tomahawk missiles, so the standard canister slot was enlarged, to a length of 264 in. Standard Missiles are, therefore, loaded in short canisters with a 37.5-in adapter; all canisters are 25 in² in cross section. There is also a short canister, 144 in long, e.g., for Vertically Launched Sea Sparrow (4 missiles per canister space). This canister has not yet been used but has been proposed for the NATO frigate. Maximum missile size is 22 × 220 in (2500 lb).

Launchers are assembled from modules (8 cells each, in 2 rows of 4; but each group also includes one 5-cell module with a 3-cell strike-down crane). The usual combinations, then, carry either 29 or 61 missiles. Each module carries its own launch sequencer, motor control panel, and gas exhaust system. When a missile is fired, it exhausts through the canister blowout cover into the plenum and then up through the deck between the 2 rows of cells. The plenum can withstand 7 firings per cell plus a restrained firing from any other cell. The Mk 41 is said to cost half as much as a Mk 26 (cost per missile) and to require fewer crew (8 guided-missile mates on the *Bunker Hill*, 11 on an earlier Aegis cruiser).

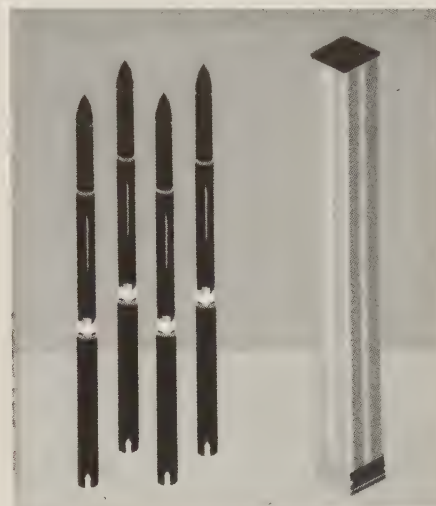
Rate of fire is reportedly 1 missile/sec.



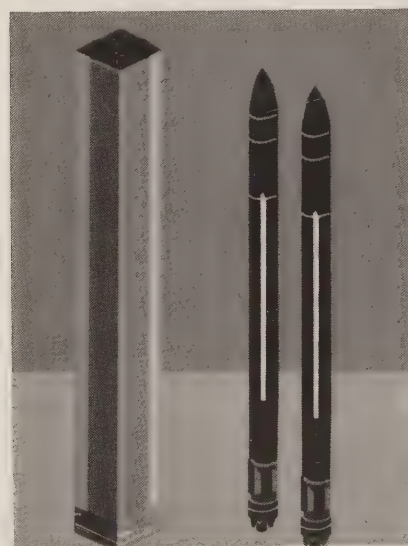
Vertical-launcher cells ready for installation.

Because the cells are large enough to accommodate a Tomahawk, they are considerably larger than a Standard Missile. At the 1990 U.S. Navy League show, FMC, the manufacturer, displayed a cell holding 2 slightly slimmed SM-series missiles (arranged diagonally), which were described as a General Dynamics proposal for a possible follow-on to the current SM-2(MR) for the mid-1990s.

Successful 4-pack launching of Sea Sparrow missiles was demonstrated as part of the NAAWS program. Given sufficient reserves of topweight, an Aegis ship could presumably stuff some of her vertical cells with the new version of Sea Sparrow (RIM-7P), which has an up-link compatible with that of SM-2.



FMC's concept for 4 boosted Sea Sparrows in a single vertical launcher cell. (FMC)

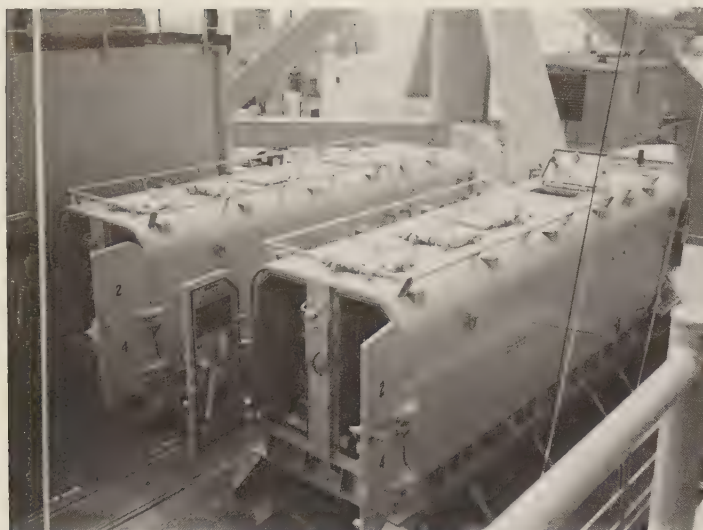


The FMC/GD "dual pack" proposal: to pack 2 of a more compact version of SM-2 in a single vertical launcher cell, doubling a ship's missile capacity. (FMC)

Mk 42 Countermeasures launching system.

Mk 43 box launcher for 21 RAM (RIM-116) point-defense missiles on a Phalanx chassis, part of ASMD Weapons System EX-31 (the system is often described as EX-31).

Mk 44 Tomahawk armored box launcher (for Tomahawk Weapons System Mk 32). Mod 1 was the ground-launched system (GLCM), now obsolete, and Mod 2 is the shipboard launcher.



Mk 44 armored box Tomahawk launchers on board the battleship *Wisconsin*, 1988. (S. Terzibaschitsch)

Mk 45 Tomahawk vertical launching system for submarines.

Mk 45-46 Trident D-5 launchers.

Mk 48 Sea Sparrow vertical launching system (using the Mk 164 launcher). Mod 0 is in the Canadian "City"-class frigates; Mod 1 is in the Dutch M-class frigate; and Mod 2 is in the Greek MEKO-200 frigate. Mk 48 has now (1989) been chosen for LHD 5, planned for the FY91 program. Mod 0 consists of 2 individual cells with exhaust uptakes between them. Mod 1 has paired cells with uptakes alongside. Mod 2 is 16 cells concentrated in 4 rows, with paired uptakes between the first and second and the third and fourth rows. The Mod 0 and Mod 1 installations are designed to be placed along a ship's side; Mod 2 is a centerline installation. Mod 0 dimensions: total height 190 in, total width 89 in, depth 52 in. These figures include the dual manifold between the 2 cells. The total weight of a 16-missile system is 34,393 lb. For the basic 2-cell launcher, 2 canisters weigh 1450 lb, 2 missiles 1100 lb, exhaust control 725 lb, ship-board mounting interface 800 lb; the total for 2 cells 4075 lb. The system as a whole requires one missile-launch controller (825 lb) and one electrical interface (242 lb). The total is 34,393 lb. Each controller can accommodate 2 fire-control systems, 16 missiles, and 8 electrical interface units.

Mk 49 RAM (RIM-116) box launcher (21 rnds) for large amphibious ships, which use canisters longer than those of the Mk 43. Total weight is 8960 lb.

Mk 50 Launching system for SLQ-49 "rubber duck" decoy. Even-numbered Mods (0, 2, 4) include 2 Mk 166 launchers, 1 on each side (total weight is 600 lb). Odd-numbered Mods (1, 3, 5) include 2 Mk 166s on each side (total weight is 1200 lb).

Mk 52 Decoy launcher for the PBC patrol boat, including two 6-barrel Mk 137 SRBOC launchers.

AIR-TO-AIR MISSILES

FRANCE

◆ Super R 530

Dimensions: 26 cm × 3.54 m; span 90 cm (530D: 26 cm × 3.8 m × 87.5 cm) [10.2 × 139.4 × 35.4 in {10.2 × 149.6 × 34.4 in}]
Weight: 250 (265) kg [551 {584} lb] **Warhead:** 30+ kg [66+ lb]
Propulsion: dual-thrust rocket (2-sec boost, 4-sec sustain)
Speed: Mach 4.5 (5.0)
Range: 35 (45) km; ceiling 21,350 (24,400) m [38,300 {49,200} yd; 70,000 {80,000} ft]

Data refer to 530F, with 530D data in parentheses as shown.

R 530 is the standard French heavy air-to-air missile, currently carried by Crusader carrier-based interceptors. R 530 is



A Super 530D missile, with Magic 2 in the foreground. (Author)

broadly equivalent to the U.S. Sparrow. The 530F version is semiactive and is carried by the Mirage F-1 fighter with its Cyrano IV X-band monopulse radar. The 530D is carried by the Mirage 2000, which has an RDM multimode radar (for export) or an RDI radar (for the French Air Force).

The Super 530 missile can maneuver at up to 20 Gs (at 17,000–18,000 m in altitude) or 6 Gs (27,000-m altitude). The 530F version can snap-up (rising 9000 m to 27,000 m). The 530D can also snap-down.

Work began in 1958, and the original R 530 was in service in 1963. Design of the improved Super 530 began in 1968; development began in January 1971, and trials of the AD 26 seeker in September 1972. The first guided firing was in 1975, and production began in 1980. The first Super 530D with RDM pulse-doppler radar was delivered in May 1983, and the missile became operational (on board Mirage 2000 fighters) in mid-1986.

◆ Magic (R 550)

Dimensions: 16.4 cm × 274.8 cm; span 66 cm [6.4 × 108.2 × 26.0 in]
Weight: 89 kg (Magic 2: 90.7 kg) [196.2 {199.9} lb]
Warhead: 12.5 kg (including 6-kg HE) [27.6 {13.2} lb]
Propulsion: single-thrust rocket, 1.9-sec burn
Speed: Mach 2+
Range: 10 km (minimum range 300 m) [range 1000–11,000 yd]

Magic is France's current, standard IR-guided missile, carried by Super Étendard strike fighters and by Crusaders. It can be launched at airspeeds of up to 700 kt and is credited with a maximum maneuverability of 30 Gs. The IR seeker is nitrogen-cooled. Typical range is 2.5 km [2750 yd] at medium altitude, or 10 km at high altitude.



The French Rafale fighter carries Magic 2 missiles on its wing tips, with 4 Matra MICAs under its body. (MATRA)



Magic 2. Unlike Sidewinder, Magic 2 has no air-driven gyros on its tail fins. (Author)

The improved Magic 2 entered production in September 1984. It has a better detector (80–100 times as sensitive) and can be slaved to the aircraft's fire-control system. The maneuverability limit is increased to 50 Gs. In February 1990 a Magic 2 was fired by a fighter flying at Mach 1.3 at 20,000 ft, pulling 8 Gs, which was reportedly close to the edge of its flight envelope.

Magic was conceived as a private-venture replacement for Sidewinder. Concept and feasibility studies were carried out in 1966–68, and the French government let a development contract in 1969. The first guided launch was in January 1972. The 1000th missile was delivered in December 1976, the 2000th in November 1977, the 3300th in March 1979, the 4500th in August 1980. More than 8000 have been manufactured for at least 18 countries; 75% of total production is for exports. Magic was first used in combat, in the Persian Gulf War, in August 1980. There, Magic is carried by French naval aircraft and Indian Sea Harriers.

In 1988 estimated cost per missile was \$175,000 (\$200,000–\$250,000 for Magic 2).

◆ MICA

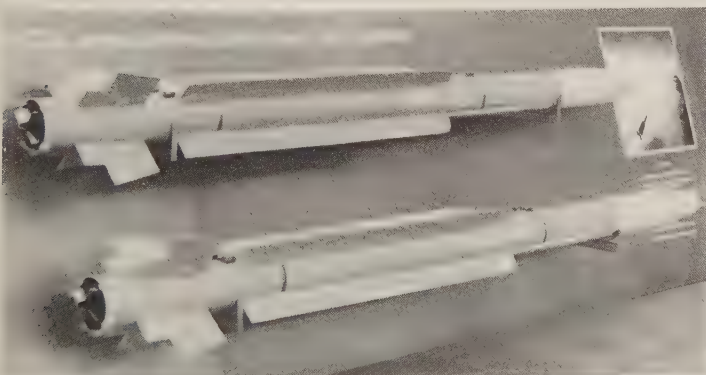
Dimensions: 16 × 310 cm [6.1 × 122 in]

Weight: 110 kg [242 lb]

Warhead: 12 kg [26.4 lb]

Propulsion: solid-fuel rocket

MICA is to replace both Magic 2 and Super 530; it will arm the next-generation French Rafale naval fighter. The missile has 2 interchangeable homing heads, active radar and IR. Data above refer to the radar version. Like its competitor, the U.S. AMRAAM, MICA has a preset autopilot and an inertial reference system, for multitarget engagement with mid-course update. Matra claims that its long wings particularly suit it to flight at high angles of incidence, for steep climbs and dives (snap-up and snap-down shots). The seekers are designed to lock onto targets far off bore sight at short range. The missile steers



The 2 versions of MICA, radar (top) and IR (bottom). Note that the tail fins are very similar to those of Super 530. Control vanes are visible in their exhaust nozzles. (Author)

by a combination of aerodynamic (tail control) and direct-thrust control (using 4 vanes in its nozzle). Modes: multitarget engagement at long range (mid-course update), medium-range multitarget engagement (no mid-course update, but the missile may lock on after launch), dogfight, and self-defense. In the last mode the missile automatically locks onto targets as much as 90 deg off bore sight, so a strike airplane need not turn away to engage an enemy aircraft. Matra is prime contractor, with radar guidance developed by Electronique Serge Dassault (ESD) and Marconi Defence Systems (which has a 30% share); the IR seeker is being developed by SAT and Matra. Matra points out that MICA is so light that it can be carried on wing as well as fuselage. Rafale should be able to carry 6 (wing tips and under body), and similarly an F/A-18 should be able to carry 6 (underwing and under body; the Matra brochure does not show MICAs at the F/A-18's wing tips).

Matra offered a modified MICA with an IR seeker as an alternative to the ASTER series (which was adopted as the SAAM/FAMS missile). Several such missiles could fit a single Crotale tube, just as several RAMs can fit a single Sea Sparrow cell.

Studies of the next generation French air-to-air missile began in 1979–85, and Matra was awarded a development contract late in 1985. The missile was ground-qualified in 1989, and air-to-air firings began in 1990, from a Mirage 2000. As of mid-1990, the active radar version of MICA was scheduled for availability at the end of 1993.

INTERNATIONAL

◆ ASRAAM (AIM-132A)

ASRAAM, or Advanced Short-Range Air-to-Air Missile, was the Sidewinder replacement envisaged in an August 1980 MoU among the United States, Britain, and Germany. Under this MoU, the United States would develop the parallel Sparrow replacement, AMRAAM, and it would agree to adopt an Anglo-German Sidewinder replacement, ASRAAM. However, as of 1990 the future of the missile project was extremely uncertain, the German government having pulled out of the project in July 1989. Germany would have provided more than 40% of total development funds. Its withdrawal was due largely to the escalating cost of other programs such as PAH-2 and EFA. The U.S. Air Force closed its ASRAAM project office in 1990 as part of its FY90–91 budget cuts, but as of the spring of 1990 it was not yet clear whether the United States still plans to buy some ASRAAMs as its part of the MoU.

Norway joined the program in 1986, and Canada in 1987. France has observer status. Germany was to have contributed over 40% of the total, with a similar share from Britain, 10%



ASRAAM mock-up on a British Sea Harrier. The United States is trying to avoid using the launch-rail adapter. (British Aerospace)

from Norway, and 3–4% from Canada. Italy and Spain had shown some interest earlier, but in 1989 neither was directly involved in the program. Planning was based on a U.S. requirement for 40,000 missiles, compared to 15,000 in all for Britain, Germany, Norway, and Canada. The German share was 4495 rnds, at a projected unit cost of DM 200,000 (something less than \$100,000).

During 1988 the national armaments directors of the United Kingdom and West Germany decided to transfer prime responsibility from Germany to Britain. The decision did not affect work shares, but the ASRAAM became more clearly a leader-follower program. In return, Euram, the company responsible for AMRAAM production in Europe, moved from Britain to Germany; the partners in Euram are MBB, AEG, BAe, and Marconi Defence Systems.

BAe, which had already carried out considerable development of projected Sidewinder replacements for the Royal Air Force and the Royal Navy, under the SRAAM (short-range air-to-air missile) program, was prime contractor, with the German firm, BGT (which had manufactured Sidewinder under license) as the main subcontractor. When the Germans withdrew, BAe sought new partners, and Thomson-CSF reportedly offered to develop a new seeker, in place of BGT. Early in 1990 BAe was negotiating with Hughes to form a new ASRAAM consortium.

SRAAM used thrust-vector control and had a dual-mode (radar and IR) seeker. Published photographs of the ASRAAM model show fin control. Reportedly, the missile will use a triaxially stabilized IR seeker capable of all-aspect acquisition and tracking, and of discrimination among multiple targets. The missile will be slaved either to the aircraft's search radar or perhaps to the pilot's helmet, and will probably be locked on before launch. There may also be a lock-on-after-launch mode, the missile being fired outside its FOV. The missile's seeker may also be used as an alerting IR sensor while searching from its launch rail, e.g., for an airplane not equipped with a search radar (or not using its radar, for electronic silence). Photographs show a wingless missile, presumably using body lift in flight; and the motor will probably be a boost-sustain type to provide sufficient energy for terminal maneuvers.

ASRAAM is to have an IIR head, but it has not yet been decided whether it will be strap-down or gimballed. Current British seekers provide a picture consisting of 64×64 pixels; Hughes has demonstrated a 256×256 -pixel array. This level of imaging makes jamming difficult, and also makes it easier to provide off-boresight capability. As of mid-1988, reported performance includes: 20–50-deg off-boresight capability, speed about Mach 2.5, 10-G maximum maneuverability. Reportedly, this performance may be within the capability of an updated Sidewinder.

The U.S. DoD has complained about the slow pace of ASRAAM development. DoD also wanted ASRAAM and AMRAAM to be interchangeable on an airplane's pylons. That requirement ruled out the Missile Support Unit (MSU) planned for ASRAAM (the MSU contained interface electronics and cooling pack). The U.S. DoD argued that at the least an MSU would have to be tested after firing an ASRAAM, because it could be damaged by the hot gases of the launch. BAe has, therefore, had to integrate the MSU with the missile, and that integration, in turn, has protracted development. As of mid-1988, completion of development was scheduled for 1989.

As might be imagined, given the very large prospective U.S. order, U.S. objections carried great weight. ASRAAM was substantially redesigned, its diameter increased from 150 to 163 mm to accommodate the equipment otherwise carried on the MSU. As a consequence, the seeker could operate longer and the nose profile was more efficient aerodynamically. The missile was given a boat tail to reduce drag. The fatter missile was stiffer, hence better able to resist whipping when fired from a wing tip, but it was also very near its weight limit. Given repackaged electronics, the fatter missile could carry a larger warhead, and there was some interest in redesigning its motor to take more propellant, by replacing the carbon-fiber casing. Even

so, there were reports in 1989 that projected ASRAAM performance (which would not enter service for some years) was no better than the performance actually being achieved by existing product-improved Sidewinders.

Late in 1989 GEC (which owns Marconi Defence Systems) proposed an ASRAAM alternative using MICA technology, both in the seeker and in the motor, which it called MICASRAAM. MICASRAAM would use thrust-vector control and a wide-angle seeker for far-off-boresight shots. It would use a cooling engine rather than 1-shot gas bottles, to activate and maintain the missile seeker throughout flight. The missile can, then, function as a surveillance device to supplement the aircraft radar. Using the inertial guidance system of the MICA missile, MICASRAAM could be locked on after launch. For example, it could be commanded into a curving path, flying under inertial control until the target entered the seeker's FOV. MICASRAAM would weigh less than 90 kg [less than 198 lb] and would be able to accelerate laterally at over 50 Gs. GEC and Matra claimed in 1990 that it can be available in 1995. In theory, the British government cannot take up this proposal until the ASRAAM MoU is abandoned or until it lapses in 1994.

In March 1988 it was reported that the United States might be developing an alternative "black" (code-word) missile that might even be ready for service before ASRAAM, which is unlikely to be available before 1995 at the earliest (despite an initial schedule requiring production in 1983 or 1984). According to these reports, the black Sidewinder-replacement program has been proceeding for some years, and there are even test airframes. ASRAAM was described as too heavy and as requiring too many modifications to the aircraft intended to carry it. Reportedly, the U.S. alternative program is classified partly because the U.S. services do not want other multinational programs, such as the Modular Stand-Off Weapon, jeopardized.

USSR

The new Soviet carrier *Tblisi* will probably carry a mix of Su-27 (Flanker), MiG-29 (Fulcrum), and Yak-41 (Forger follow-on) fighters, of which the Su-27 and MiG-29 both have long-range doppler radars and carry a variety of air-to-air missiles. The current Yak-38 (Forger) is credited with the ability to carry the AA-8 Aphid only, the Soviet equivalent of Sidewinder.

Su-27 is a long-range national air-defense (PVO) fighter and has also been used to escort Su-24 (Fencer) attack bombers. Its likely naval roles would be bomber escort (to prevent U.S. F-14s from executing their outer-air-battle mission) and possibly a contribution to the national air-defense system. The latter role has often been discussed by Soviet writers but may well owe more to current official interest in "defensive insufficiency" than to any operationally realistic scenario. However, unless the Soviet carrier operates AEW aircraft (which will be difficult in the absence of a catapult), any interception role will have to depend on cooperation with land-based aircraft. That is not impossible; the U.S. Navy operated land-based AEW aircraft (EC-121 Warning Stars) until the early 1960s, i.e., until it could obtain sufficiently sophisticated carrier-based types. U.S. naval forces currently enjoy cooperation from land-based AWACS aircraft.

Su-27 is not quite equivalent to the F-14, since the Soviet plane has only a single seat and lacks a very long range equivalent to the U.S. Phoenix. However, in the PVO it replaces the very large, very long range Tu-28 (Fiddler), which was a 2-seater.

An Su-27 carries up to 10 missiles, including pairs of AA-10 A/B/C and 4 AA-8s (Aphids) or AA-11s (Archers).

MiG-29 is a much shorter range and much more maneuverable airplane, more like the U.S. F/A-18 in size and in character. Armament is 6 AA-10s or AA-11s underwing, plus provision for AA-8s and AA-9s.

Both aircraft also carry 30-mm cannon.

Soviet air-to-air missile development practice is to provide parallel IR and semiactive radar versions of the same airframe. Standard doctrine is to fire 2 missiles to achieve a reasonable probability of kill, and to mix the 2 main guidance techniques

for the same reason (partly on the theory that countermeasures will be deployed against one or the other, but not against both). Typically, then, a fighter will fire an IR missile first (otherwise the IR missile would home on the tail of the semiactive one). However, the IR missile cannot be locked on nearly as early as the semiactive one (note the comparative ranges, where figures are given), and a typical U.S. view would be that the mixed tactics unduly limit a fighter's maneuvers.

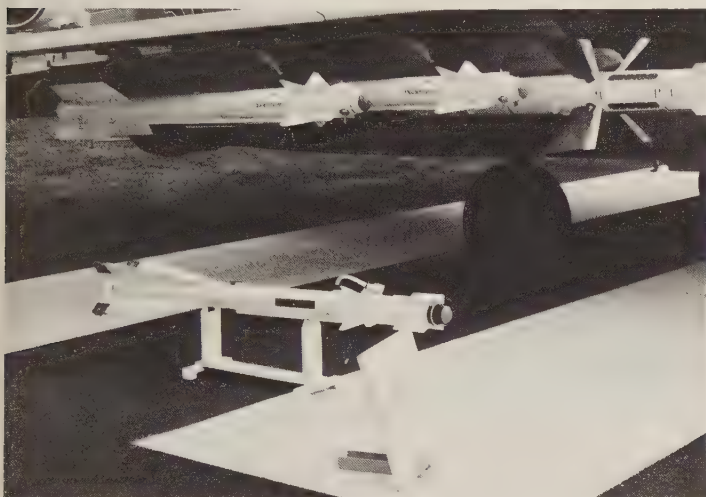
♦ AA-8 Aphid (R-60)

Dimensions: 13 m × 2.0 m; span 52 cm [5.1 × 78.7 × 20.5 in]
Weight: 55 kg [121 lb] **Warhead:** 6-kg HE [13.2-lb]
Propulsion: solid-fuel rocket **Speed:** Mach 3.0
Range: 7 km [7650 yd]

AA-8 is the Soviet equivalent of the modern versions of Sidewinder, replacing the earlier AA-2 Atoll. Although Aphid exists in both IR and radar-guided versions, only the IR version is probably carried by Forger carrier-based VTOL fighters.

There is some evidence that AA-8 lacks lethality. For example, in October 1988 an AA-8 failed to kill a British Aerospace 125 business jet carrying the president of Botswana, when the missile was fired by an Angolan MiG-21. The missile is smaller than a Sidewinder and cannot be launched head on.

The current version is R-60MK. This missile is now being replaced by a new R-73 (AA-11).



An AA-8 (R-60) missile on display at Farnborough, 1990. In the background are AA-11s and an AA-10. (Author)

♦ AA-10 (Alamo, R-72)

Dimensions: 7 × 158 in (126 in for short-range versions) [18.5 × 400/320 cm]
Weight: 441 lbs (342 lb short-range) [200/155 kg]
Propulsion: solid-fuel rocket; boost-sustain in long-range version
Speed: Mach 4.0 (Alamo B: Mach 3.5)

This missile replaces the AA-5 (Ash) carried by the previous heavy PVO fighter, the Tu-28, as well as the AA-3 (Anab) of the single-seat Su-15 (Flagon) PVO fighter. MiG-25/31 interceptors carry a much larger missile, AA-6 (Acrid). The AA-10's configuration is unusual, with inverse-tapered wings abaft small strake foreplanes, and with the usual (but short-span) tail fins. It is officially described as conferring good maneuverability at high angles of attack.

There are 4 versions:

- | | |
|---------|--|
| Alamo A | Short-range semiactive-radar (standard in MiG-29) version. |
| Alamo B | Short-range IR version. |
| Alamo C | Long-range semiactive-radar version. |
| Alamo D | Long-range IR version. |

The difference between long and short range is in the length of the rocket motor, hence its burn time. The longer-burning



An AA-10 (R-72R) missile on display under the wing of a MiG-29 at Farnborough, 1990, with AA-11s outboard. Note the characteristic inverse-tapered wings. (Author)

motor may also be used to provide the missile with greater terminal maneuvering power at constant range. In the radar version, the longer motor is probably intended to take advantage of the higher illuminating power available in an Su-27. Since AA-10 is a very new missile, it is apparently assumed that it uses an inverse-monopulse seeker, like that of current Sparrows.

In 1988 it was reported that in recent U.S. Air Force exercises the head-on range of Alamo was assumed to be 6–8 nm, rather than the 20 nm of late models of Sparrow. However, later estimates were 30 km [16.5 nm] for the A and B versions and 45 km [25.5 nm] for the C and D versions. At Farnborough in 1990 a Soviet aircraft designer credited AA-10 (presumably the radar version, which was on display) with a range of 60 km [32.8 nm].

The earlier Soviet AA-7 (R-23) missile, which arms the MiG-23, is a 1970s missile broadly equivalent to the original Sparrow III, albeit much larger (8.75 × 181 in, with 42-in span; 705 lb with an 88-lb warhead). Range was about 20 nm or 22 nm in the semiactive version (R-23R), and 12 nm in a look-down mode. As in other programs, there is also an IR version (R-23T). Presumably, the difference between AA-7 and Sparrow is explained by much less compact Soviet electronics, and also possibly by much less efficient solid fuels (it takes a larger motor to get worse performance, in this case Mach 3).

AA-10 entered service in 1984, and initially it was described in the West as a developed version of AA-7. However, it has an entirely different configuration.

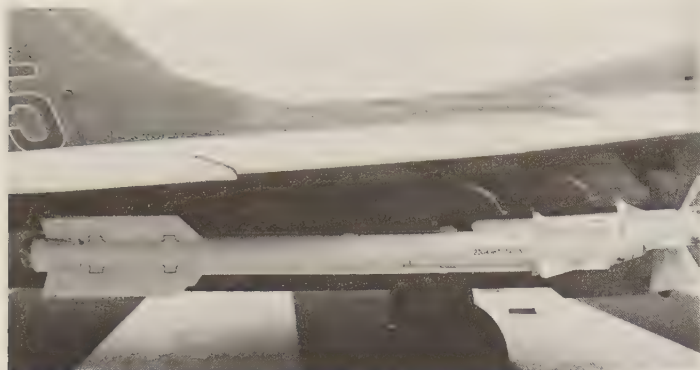
Soviet military designations: R-72R and -72T are the radar- and IR-guided versions of the basic missile; R-72ER and -72ET are the longer-range versions. The industrial designator is Izdeliye (Object) 470. The R-27 designation sometimes published for this missile is probably a misprint.

♦ AA-11 (Archer; R-73)

Dimensions: 130 mm × 2.13 m [5.1 in × 7 ft]
Weight: approx 45 kg [100 lb]
Propulsion: solid-fuel rocket (boost only)
Speed: Mach 2.5

This new short-range, dogfight missile was first reported in 1986; it replaces AA-8 and is probably broadly equivalent to recent Sidewinders (AIM-9L/M), to which it is similar in size and configuration. However, at least 1 report credits it with thrust vectoring for very high maneuverability. It should offer better lethality than AA-8, and also better performance (including forward-aspect attack).

At Farnborough in 1990 a Soviet aircraft designer credited this missile (presumably the IR version, which was on display) with a range of 20 km [10.9 nm], a capability to maneuver at 60 Gs, and a seeker that could turn 60 deg off bore sight (this last figure may be the seeker's full FoR). The missiles on display showed



An AA-11 (R-73) missile under the wing of a MiG-29 at Farnborough, 1990. (Author)

what may have been vanes in their nozzles, for a degree of thrust control.

UNITED STATES

◆ AAAM

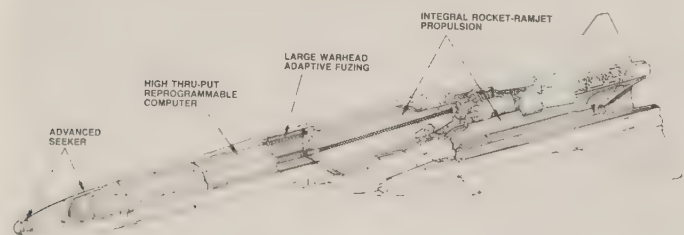
The Advanced Air-to-Air Missile is intended to replace Phoenix (see below) with a Sparrow-sized weapon. Two competitors have emerged: a General Dynamics–Westinghouse team and a Hughes–Raytheon–McDonnell Douglas team. Proposals were submitted in May 1987, and both contractors received demonstration/validation contracts for FY88–90, the winning team to receive its contract in FY91. Funding may make it impossible to carry both teams all the way through to flight tests.

Reportedly, the navy wanted an AAAM with a diameter of less than 9 in and a weight of less than 650 lb, with a unit cost of less than \$750,000, to attack crossing and violently maneuvering targets at ranges of 100 nm. The hope was that an F-14, which can fly with 6 Phoenix and land with 4, could land with at least 8 AAAM on board. The navy has specified a maximum AAAM-system weight of 5303 lb for the F-14D, on the basis of acceptable carrier-landing weights.

The General Dynamics project dates to the mid-1970s and began as a private venture. The company proposes a combina-



The General Dynamics version of AAAM, being fired by an F-14. (General Dynamics)

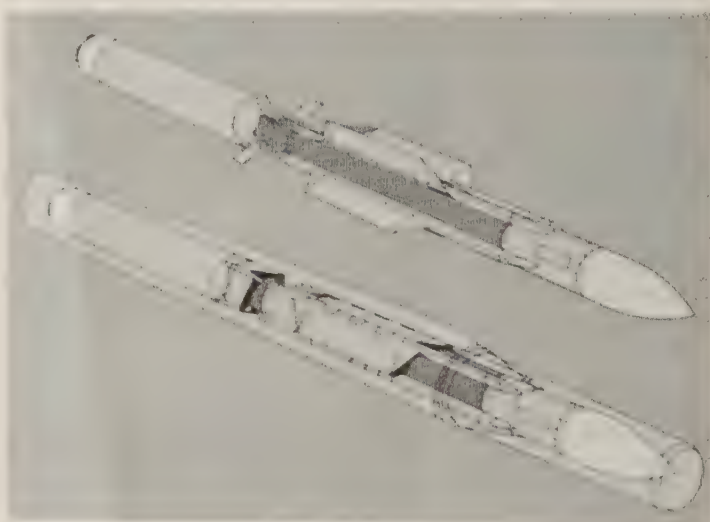


The Hughes version of AAAM, an integral rocket-ramjet. (Hughes)

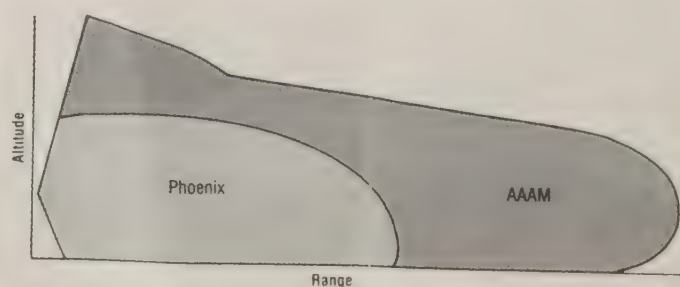
tion of a small long-range 2-stage rocket missile (380 lb; 5.5 × 144 in) and an external multifunction airborne track-illuminator or ATI (16 × 142 in, 750 lb), the 2 communicating through the standard internal digital data bus already used for pods such as laser-trackers. The ATI would have a limited search capability, although usually targets would be designated to it by the aircraft's main search radar or main IR search/tracker. The ATI would have front and back antennas, so it could continue to track while the airplane maneuvered freely. Once the target(s) had been designated, the ATI would track them and compute engagement envelopes. The aircrew would select and fire missiles, which would fly out using mid-course inertial guidance. The missile's autopilot would be updated via a signal time-shared between the missiles. Missiles would transition to semi-active terminal guidance (interrupted continuous wave), and in at least some cases missiles might home by infrared (perhaps mm-wave) using a common-aperture dual-mode seeker. Missiles homing semiactively would time-share a common illuminator, just as Phoenix does.

The General Dynamics missile is so small that the company estimates that an F-14 can carry as many as 15 AAAMS, normally 6 to 9. The missiles themselves would be stowed in universal launch tubes, with their fins and wings folded. The motors would have selectable burn, i.e., they would be able to reserve fuel for terminal maneuvering. The missiles would use a combination of aerodynamic and thrust-vector control for violent maneuvering. General Dynamics claims that this approach and the ATI's ability to function as a (limited) acquisition radar make it possible to provide almost any airplane with an advanced very long range air-to-air capability.

The alternative Hughes-Raytheon missile is powered by an integral rocket-ramjet, for a high-power output throughout the flight. Hughes's missile would use a combination of infrared



The General Dynamics/Westinghouse AAAM, stowed in its universal launch tube and deployed. The ogival radome is radar transparent and would be discarded if the missile went into IR-homing mode (there is an internal hemispherical dome over the IR seeker). (General Dynamics)

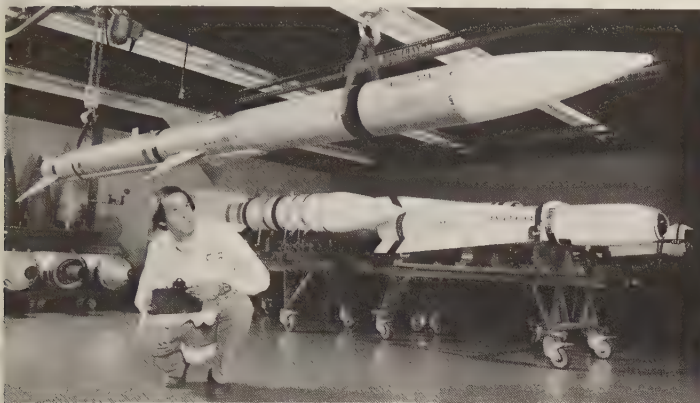


AAAM envelope compared to that for Phoenix. (General Dynamics)

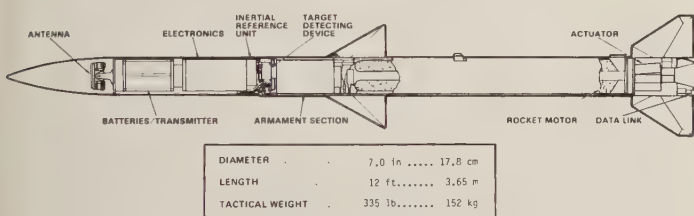
imaging and active-radar homing. Like Phoenix, the missile uses semiactive mid-course guidance. No dimensions (other than a length of 12 ft) are given, but Hughes describes the missile as Sparrow-sized with Phoenix or better performance ("stand-off ranges that are up to 4 times greater than current systems"). Engagement modes include launch-and-leave and silent- (pure-passive) engagement.

◆ AMRAAM (AIM-120A)

Dimensions: 7 × 144 in (wing span 21 in, tail span 25 in)
Weight: 335 lb **Warhead:** 50-lb class
Propulsion: solid-fuel rocket **Speed:** reported approx Mach 4.0
Range: reported 60,000–80,000 yd



AMRAAM (AIM-120A) with Phoenix and Maverick in the background. (Hughes)



AMRAAM's inboard profile. (Hughes)

The Hughes Advanced Medium-Range Air-to-Air Missile is intended to replace Sparrow. Much lighter than Sparrow, AMRAAM may be carried in greater numbers. More importantly, it is a fire-and-forget weapon, providing a fighter with a capacity to engage multiple targets. The missile is sent into a homing basket on the basis of data fed in before firing, supplemented by data-link data supplied by the launching fighter. Approaching the target, AMRAAM switches on its X-band pulse-doppler seeker. Long range and good maneuverability are assured by a boost-sustain motor, which replaces the boost-glide motor of the Sparrow.

In 1982 Raytheon was chosen as a second-source supplier. Although an air force project, the missile has several vital naval applications. It provides F/A-18s with the capability to engage multiple targets, and AMRAAM will probably provide late-production A-6 Intruders (A-6G and later) with a self-defense or even fleet radar-picket capability. In addition, AMRAAM has been chosen as the armament of the modernized Royal Navy Sea Harrier fighter.

AMRAAM has always suffered from very high unit cost. Hughes, the prime contractor, has suggested from time to time that the missile is the natural successor to Sea Sparrow as well as to Sparrow itself. Raytheon has suggested that the missile can never be made inexpensive enough to supplant Sparrow entirely, and that a developed Sparrow will be the basis of the next-generation NATO naval air-defense system.

The first production AMRAAM missile was delivered on 26 October 1988. The initial production lot (for navy and air force) is 180 missiles, 105 from Hughes and 75 from Raytheon.

The U.S. Navy FY89 program included 26 AMRAAMs, and the January 1989 budget proposal showed 150 in FY90 and 800 in FY91. The current AMRAAM export price is \$475,000. There is some question as to whether these missiles will be manufactured in Europe by the Euram consortium because the U.S. manufacturers, Hughes and Raytheon, are asking a 13% licensing fee. Euram may, therefore, be unable to offer a competitive price. However, during the 1989 Paris Air Show, MBB announced that it would license-produce AMRAAM, delivering the first units in 1993. This production will include weapons for Royal Navy Sea Harrier 2 fighters.

The only current foreign naval customer is the Royal Navy, which plans to carry AMRAAMs on board its Sea Harrier FRS.2 fighters, and which cannot substitute any existing medium-range semiactive radar missile. The reported current British requirement is at least 330 missiles. Very large numbers of AMRAAMs are required to replace Sparrows in current service with European air forces.

Concurrent with initial AMRAAM production, there is an AMRAAM product-improvement program. Replacement of the current electronics by custom VLSI chips should drastically reduce the number of circuit boards, and heat production is to be reduced by 90%. The current mechanical gyro is to be replaced by laser ring gyros.

Early in 1989 the Norwegian government signed a study contract with Hughes and with Norsk Forsvarsteknologi (NFT) to develop a mobile land-based surface-to-air missile system using AMRAAM, to be called NASAMS (Norwegian Advanced Surface-to-Air Missile System). Each battery will consist of 3 radars, 3 fire-control centers, and 9 six-missile launchers, the controlling radars being based on the current Hughes TPQ-36. Should NASAMS proceed to production, the modified AMRAAM developed for it would presumably become available for naval service.

Navy procurement: 26 in FY89, 85 in FY90, 550 requested (January 1990) for FY91 (unit cost \$767,000).

◆ Have Dash-2

This stealthy missile, intended as the forerunner of an AMRAAM successor, is currently under development. Ford Aerospace is conducting a 38-month program that is to end in 6 flight tests (by 3 vehicles) in March–September 1992. Although the program is being managed by the U.S. Air Force Munitions Systems Division, a missile derived from Have Dash-2 may well follow AMRAAM into naval service. Have Dash-2 is to be carried externally, blending into the skin of an airplane without destroying its stealthy shape. It, therefore, has a flat underside, 13 in wide (it is to be carried above, rather than below, the fuselage), and it also provides some body lift. For most of the missile's length its 2 upper sides are also flat (it has a triangular cross section). It, therefore, belongs to the new class of faceted stealthy missiles, the faceting reflecting most radar signals away from the transmitting antenna. Given its greater body lift, Have Dash-2 dispenses with the mid-body wings of Sparrow and AMRAAM and is limited to 4 folding tail fins. The combination of body lift, fin configuration (as in the proposed tail-control Sparrow), and new bank-to-turn autopilot should permit Have Dash-2 to maneuver at 50 Gs, compared to 35 Gs for current weapons.

The missile's length is limited to 12 ft (144 in, as in AMRAAM) to avoid interference with trailing-edge control surfaces and access doors on the F-15s and F-16s that may ultimately carry it (the test flights will be made from an F-111E equipped with a 2-piston ejector). Total weight is 400 lb. The drawing released in July 1990 shows a pointed nose similar to that of the existing AMRAAM. This shape is inherently stealthy in that it reflects radar signals away from broadside. However, if it houses a conventional planar antenna, the shape the incoming radar signal is likely to see will be the flat shape of that antenna. A conformal array might encounter fewer problems but would be more difficult to use. Have Dash-2 will not be testing new-generation stealthier sensors. It will incorporate an

inertial reference system (like that required by AMRAAM) and a new navigation-intercept computer. An operational missile derived from Have Dash-2 would use a combination active/passive radar and IR seeker. Plans originally called for Have Dash-2 to be powered by either a ducted or a pulsed rocket, in either case stealthier than the current boost-sustain engine (because its IR signature is either greatly reduced, in the case of the duct mixing air with the exhaust, or intermittent). However, in the interest of economy, flight tests will be made with AIM-7E Sparrow motors.

In July 1990 Brunswick Defense received a contract for 3 graphite-polyamide (composite) airframes for the recoverable prototypes; they are probably the first nonmetallic, supersonic missile airframes. Reportedly, 1 of the 2 major issues in the flight tests will be whether such materials are strong enough to withstand the expected speed of Mach 4+. The other question is the extent to which the unusual shape and autopilot can achieve the desired agility.

Have Dash-1 was described officially as a missile-to-airframe integration program.

◆ Phoenix (AIM-54)

Dimensions: 15 in × 13 ft (span 36 in)
Weight: 1008 lb (985 lb for AIM-54A) **Warhead:** 133 lb
Propulsion: solid-fuel rocket (single-pulse)
Speed: Mach 5.0 (Mach 4.3 for AIM-54A)
Range: 80 nm (minimum 2.0 nm) (AIM-54A: maximum 72.5 nm, minimum 2.1 nm)
Launch Altitude: 60,000 ft maximum (-54A: 48,800 ft)
Missile Max Altitude: 100,000 ft (-54A: 81,400 ft)



Phoenix missiles carried by an F-14A fighter. (U.S. Navy)

Data apply to AIM-54C version.

Phoenix, manufactured by Hughes, is the longest-range air-to-air missile in operation; stated maximum range is 86+ nm. Phoenix is carried only by F-14 Tomcats and is guided by their AWG-9 radar. The missile incorporates a programmed autopilot to fly into a basket near the target; Phoenix then picks up semi-active illumination from the launching airplane. Not needing that illumination at launch time, Phoenix can fly a more energy-efficient (up-and-over) trajectory. Moreover, not needing to pick up reflected energy at very long range, the missile can make use of an illuminating radar of reasonable power (the missile is closer to the target when illumination is needed). Illumination is intermittent, and the missile uses its X-band active seeker for terminal guidance. The combination of precomputed/data-linked initial trajectory and terminal active homing makes it possible for several missiles to time-share a single tracker-illuminator; an F-14 can engage 6 targets simultaneously.

AIM-54A was manufactured from 1972 through 1980. The only foreign customer was Iran, and it seems likely that the missile was compromised during or after the fall of the Shah. No reliable reports of Phoenix engagements during the Iran-Iraq War have come to light, but it has been reported that the Iranians have used their F-14s as airborne radar-control platforms.

AIM-54C was the second production version, incorporating 5

major improvements: digital rather than analog circuitry so that the missile can be programmed for target discrimination in stream raids, improved beam (crossing-target) capability, and improved capabilities to engage an opening target from its rear quarter; better resistance to ECM; greater range and altitude; greater maneuverability; and a fuze (target-detecting device) better adapted to detonating on small targets or very low altitude targets found in clutter such as chaff. Deliveries began in 1981, and the last of 330 were delivered in September 1986. Deliveries of AIM-54C Plus began in March 1986. This last version incorporates internal heaters.

A further improved AIM-54C Plus began development in August 1987; it incorporates a high-powered TWT (adapted from that of AMRAAM, giving 10 times the power of the earlier version), a reprogrammable memory (RPM), and a new low-sidelobe antenna with better electronics. The new memory replaces 45 chips with 6 new ultra-high-speed ones. The RPM and new software were tested in shots in September and December 1989, and the full upgrade was first tested in August 1990. The full upgrade will be incorporated in new-production missiles and will also be available in retrofit kit form.

Although designed primarily as an outer-air-battle weapon, to attack bombers rather than their missiles, Phoenix can shoot down antiship missiles. In June 1983 it was reported that in a test Phoenixes had shot down 11 of 11 Harpoons.

Current U.S. Navy policy is to maintain 2 competing suppliers of all major weapons; Raytheon was chosen as the second source, making initial deliveries early in 1988.

Like SM-2, Phoenix is designed to deal with saturation attacks. During the early 1970s, Hughes proposed a sea-based version, which some saw as a less expensive alternative to Aegis. This version was also substantially less capable, and it did not progress very far. Phoenix is ultimately to be replaced by AAAM, which is Sparrow-sized.

The basic concept of a very long range air-to-air missile was developed in 1960, and Hughes was selected in August 1962. The first guided flight (from an A-3) was in May 1966. AIM-54C's engineering development began in October 1976, with first deliveries of development missiles in August 1979. Production began late in 1982, and AIM-54C was operational in January 1984. Approximate unit costs: AIM-54A, \$750,000; AIM-54C in FY83, \$796,000, but in FY84, \$681,000. Reported inventory objectives are: 2932 AIM-54A, 7249 AIM-54C (including 45 for RTD&E). The 1000th AIM-54C was delivered 27 October 1988; this figure includes more than 600 AIM-54C+. The FY89 program included 450 Phoenix missiles; and in January 1989 the U.S. budget proposal showed 420 in each of FY90 and FY91. Current plans call for completion of Phoenix procurement in FY93, although there is some question as to whether that will make second-source production (by Raytheon) uneconomical.

Four engagements give some idea of AIM-54/AWG-9 capability. In one case, an F-14 (at Mach 0.7, 31,500 ft) intercepted 5 targets simultaneously. Four missiles were launched from 30-nm range at 4 of the 5, flying (at Mach 0.6 at 20,000–25,000 ft) in a wave-front formation 20 nm wide. One target was hit directly, and the other 3 missiles passed within lethal range.

In a second exercise, an F-14 began to track a BQM-34E drone that was using ECM (Mach 1.5 at 50,000 ft). The missile was launched into an up-and-over trajectory at a range of 110 nm, reaching a peak altitude of 103,500 ft, and flying 72.5 nm to intercept the target. The drone had been augmented to present the radar cross section of a bomber.

A third exercise simulated an engagement with a MiG-25 Foxbat (simulated by an AQM-37A at Mach 2.2 at 82,000 ft). The F-14 fired from a range of 35 nm, the missile climbing about 36,000 ft to destroy the drone.

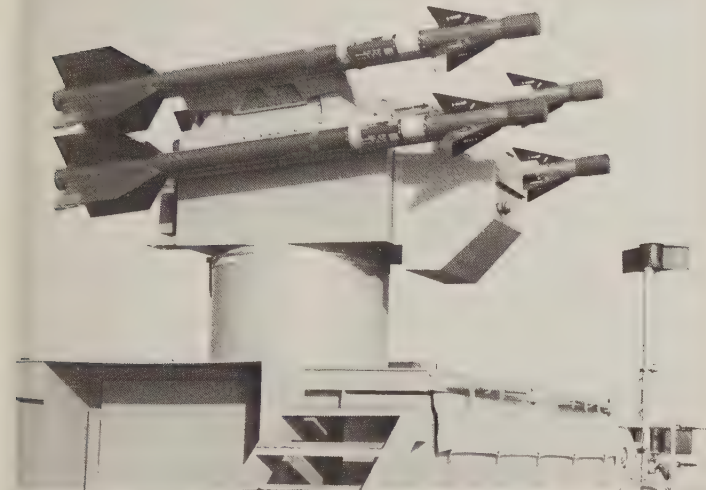
Finally, the F-14 engaged a BQM-34A simulating a cruise missile that was flying at 50 ft. The fighter flew at 10,000 ft, and its radar operated in TWS mode; it killed the missile at a 22-nm launch range.

◆ Sidewinder (AIM-9)/Sea Chaparral

Dimensions: 5 × 112.2 in (canard span 15 in, wing span 24.8 in)
Weight: 188 lb **Warhead:** 25 lb **Propulsion:** boost-sustain
Speed: Mach 2.5 **Range:** 10,000–20,000 yd



Sidewinder (AIM-9L). (U.S. Navy)



Sea Chaparral on board a Taiwanese destroyer. (Republic of China Navy)

Data apply to AIM-9L version.

The Sidewinder is virtually the Free World's standard short-range air-to-air missile. It has also been copied by the Soviets and by the Chinese. Several other countries have developed externally similar weapons. The current version, used by the U.S. and Royal Navies, is AIM-9L/M, to which the figures above apply. Because Sidewinder (and its brethren) need very little support by the airplane carrying them, they are the natural missile armament for attack aircraft and for fighters without long-range radars, such as current Sea Harriers.

Guidance is passive infrared, with proximity and contact fuzing (the early version had only a contact fuze). There was also a semiactive-radar-guided version, AIM-9C. Stocks of this weapon have been converted to Sidarm short-range antiradar missiles (see the Strike/Surface Warfare section). AIM-9L introduced full-aspect homing, using the heat generated by high-speed flight and also the forward-aspect "glint" of sunlight on an airplane. The basis of current versions, AIM-9L is the version that proved so successful in the Falklands War, when the missile was carried by British Sea Harriers defending the fleet against Argentine air attacks.

AIM-9A (AAM-N-7) was the prototype, development of which began in 1950 at China Lake; it was conceived as a guided version of the 5-in, high-velocity aircraft rocket. The contract for seeker development was let in 1951, and the first missile flew on 11 September 1953. In September 1958 Sidewinder became the first missile to shoot down another airplane in combat, over

the Taiwan Straits. A dud brought home by a PRC MiG fighter was apparently the basis for the Soviet AA-2 (Atoll, or K-13).

AIM-9B (Sidewinder 1A) was the first production version. It became operational with the U.S. Navy in July 1956, and production ended only in 1962. Total -9B production was 80,900 by Philco-Ford plus about 15,000 under license in West Germany by Fluggeraetewerk Bodensee GmbH (now Bodenseewerk Geraete Technik) for NATO air arms. About 10,000 missiles were later updated (see AIM-9F, below). Missiles updated from 1982 on have been fitted with DSU-21/B laser proximity fuzes, described below under AIM-9L. In the early 1960s an AIM-9B cost about \$2500.

The basic mode of operation was the bore-sight attack, in which the missile seeker was caged to look dead ahead. When an IR source entered that FOV, the missile generated a tone. In theory, the pilot would then check whether the target was within the missile's kinematic flight envelope and fire. In some aircraft the missile could begin to track the target before leaving the rail, generating a chirping tone in the pilot's earphones. These audio cues, standard for all Sidewinders, were essential since the pilot could not look away during a dogfight. Only with the advent of HUDs have Sidewinders introduced visual cues (a digital display of seeker-head position and an "in range" cue based on programmed launch-zone equations).

AIM-9B had a 25-lb blast-fragmentation warhead containing 10.5 lb of high explosive (producing about 1500 fragments moving at 6000 ft/sec, lethal to 30-ft range) and contact and IR proximity fuzes. Maximum range at high altitude was about 2.6 nm, using a 4000-lb-thrust motor burning for about 2 sec; maximum speed was Mach 1.7. Range decreased to 4000 ft at low altitude. This version had an uncooled lead-sulphide (PbS) seeker with a 3.5-deg FOV, a maximum look angle of 25 deg, and a 70-Hz reticle; it could track at 11 deg/sec.

The seeker operated at short wavelengths (about 2 micron); and peak sunlight, reflected sunlight, cloud edges, and the horizon all fell into its bandpass. The dead zone around the sun was 20 deg wide. The sensitivity of the overall system imposed a 2-G limit, beyond which it could not track (maximum G-loading at launch was 2 Gs below 40,000 ft and 1.6 Gs above that altitude). The missile on the launcher rail had its seeker head caged in the dead ahead (bore-sight) direction, so it could acquire targets only within its FOV. The maximum look angle was the angle through which the seeker head could track a maneuvering target, once the missile had locked on. Most AIM-9Bs were converted to AIM-9E or equivalent standard.

Dimensions: 5 × 111.5 in, span 22 in, weight 155 lb. Maximum allowable launch range: 2.6 nm at high altitude, 4000 ft at low altitude (but see test results listed below). Minimum range is 3000 ft (reduced or increased by 300 ft for every 0.1 Mach difference in speed). These figures are for subsonic tail attacks in which target and launcher are flying at the same speed and altitude.

AIM-9Bs modified with reduced-smoke motors, for training or for special missions, are designated -9B2.

In Vietnam it was discovered that Sidewinder IA was ineffective against maneuvering targets. The missile had originally been designed to deal with Soviet bombers attacking carrier battle groups, and only in 1964 was it tested against fighterlike targets (BQM-34A drones and QF-9Gs). The attacking aircraft locked on with their radars and had to assume proper attack speed and range before firing. Of 2 missiles fired at BQM-34As in 45-deg turns at 40,000 ft, 1 missed by about 200 ft, and 1 caused only minor damage. Of 9 fired at QF-9G drones (ex-fighters) in 3-G turns at 15,000–20,000 ft, 2 failed for undetermined reasons and 7 failed to guide. All had been fired in the heart of the calculated envelope, at angles-off of 5–10 deg and at slant ranges of 3000–5000 ft. In 5 cases, the missile guided initially but failed to follow the target through the turn. One missile did succeed in killing a QF-9G at 5000 ft. Worst of all, it was extremely difficult for pilots to keep their airplanes within the heart of the Sidewinder envelope as defined by these unsuccessful tests.

By 1964 some of these problems were already being overcome in the AIM-9D (which had been designed well before the problems were known): it was much more maneuverable, and its seeker operated in a much less cluttered part of the IR spectrum. AIM-9B tactics also improved. During 1 period in 1966, for example, the air force fired 21 missiles, achieving only 5 hits. However, of the others, 6 had been fired without any tone in the earphones (in effect, jettisoned), 4 were out of range, 1 was launched at 6 Gs, 1 was too close to arm its fuze, and 4 apparently never armed because they were too close or overtook the target too rapidly. In a 1967 operation, of 12 launched, 7 guided, and all either killed or probably killed their targets. Of the other 5, 2 were fired at a target that disappeared into clouds before they could hit, and 3 were fired to break up an attack on a friendly fighter (i.e., to force evasive action).

The net effect of improvements, in versions such as -9D and -9E, was to turn the relatively sluggish Sidewinder into a snapshot dogfight weapon. That was partly because it could be fired and forgotten, whereas the alternative, Sparrow, requires the launching airplane to continue to illuminate the target. Partly, too, because no illumination is needed, a properly designed version of Sidewinder can follow a target through convoluted maneuvers.

In all, 452 Sidewinders were fired in combat in Vietnam, for a net single-shot kill probability (as published in 1980) of 0.18. In 1980, using AIM-9L, the U.S. Navy expected a single-shot kill probability of 0.50, the U.S. Air Force 0.285. That year OSD estimated that Sidewinder kill probability was 0.15 against a low-flying fighter and 0.30 against a high flier; comparable estimated figures against a bomber were 0.20 and 0.40. Recent experience suggests that these are rather conservative estimates.

AIM-9C (Sidewinder IB) was the radar semiactive-homing (in X-band) version, suitable for head-on attacks; it could also home on jammers. Many were later converted to Sidearm antiradar missiles. This missile was developed in parallel with AIM-9D, with which it shared a common airframe, a 25-lb continuous-rod warhead (radius 17 ft, using PBXN-3 rather than HBX-3 explosive), and a more powerful (14,200 vs. 8450 lb-sec specific impulse) longer-burning (5 rather than 2 sec) motor, with a correspondingly longer-burning gas generator (60 vs. 20 sec; 38 sec for the -9C), which increased range to 11.5 nm. AIM-9C performance was slightly worse than that of -9D because it was slightly heavier, had greater drag (because of its hemispherical radome), and had shorter guidance time. It had a slightly greater minimum altitude. Maximum seeker look angle was 55 deg.

AIM-9D (Sidewinder IC) was redesigned, the lead-sulphide seeker being nitrogen-cooled. It had a new magnesium-fluoride (instead of quartz) dome, better streamlined (3-in rather than 5-in hemisphere). It had a 2.5-deg angle of view, 40-deg maximum look angle, and a 125-Hz reticle; and it tracked at 12 deg/sec. The smaller field reduced background noise since the target necessarily occupied more of the total field. Compared to -9B, -9D could be used at greater angles to the target's tail. This capability was exploited by providing broader-chord fins for better maneuverability. This version was credited with limited head-on capability. About 1000 AIM-9Ds were made for the U.S. Navy. AIM-9D was, in effect, the first second-generation Sidewinder.

Test results for AIM-9B vs. AIM-9C (1963) showed:

Aspect	Fighter (Mach)	Target (Mach)	Altitude of Both (ft)	Range (ft)	
				-9B	-9D
Tail	0.8	0.8	500	5400	14,000
Tail	0.8	0.8	20,000	10,500	22,000*
Tail	0.8	0.8	40,000	19,700	40,000*
Tail	1.0	1.0	50,000	23,100	47,800*
Nose	1.12	1.68	Fighter: 40,000 Target: 53,000	no cap	53,000*
Max Altitude for firing				67,000	85,200

The asterisks indicate figures that were expected to be bettered in later firings. Maximum range increased at higher alti-

tude, where the target was much brighter against less background radiation.

Both AIM-9C and -9D entered service in 1965, and several thousand were made for the U.S. Navy and for Britain.

AIM-9E was a modified -9B for the U.S. Air Force, under a Low-Altitude Performance (LAP) program suggested by the manufacturer, Philco, in 1965. Improvements included a new thermo-electrically cooled (Peltier cycle) lead-sulphide seeker and revised electronics and wiring. About 5000 missiles were converted to this type, about 1967. The detector had a 40-deg look angle, a 100-Hz reticle, 16.5-deg/sec tracking, and a reduced solar dead zone. Cooling increased sensitivity, particularly against high clutter at low altitude; the wider seeker angle improved attack, and faster tracking made for better low-altitude performance. The European Sidewinder consortium produced the parallel FGW Mod 2, the lead-sulphide detector being carbon-dioxide cooled; the solar dead zone was reduced to 5 deg. Silicon replaced the glass radome. AIM-9B and -9E missiles were further updated to -9J standard (see below). AIM-9E2 has a reduced-smoke motor. AAM-1 is a Japanese version, somewhat smaller and lighter than the U.S. version (102.4 in long, 154.3 lb vs. 118.1 in, 164 lb).

AIM-9F was a new-build -9B (FWG 2) manufactured by the European consortium (BGT), with a more sensitive lead-sulphide seeker and a more powerful motor. Sweden uses this weapon under the designation RB 24.

AIM-9G was the U.S. Navy equivalent to -9E, developed under the SEAM (Sidewinder Expanded Acquisition Mode) program, permitting off-boresight target acquisition and lock-on. The seeker was slaved to the fighter's radar as it scanned, so the missile could acquire a target within the maximum look angle (or the maximum look angle of the radar, whichever was smaller). Maximum range is reportedly 19,360 yd. Dimensions: 5 × 113 in, span 24.8 in, weight 191 lb. Production of this version ended in 1970.

AIM-9H replaced -9G, and nearly 5000 were made. This version is credited with limited all-weather capability, i.e., with the ability to continue to attack a target through haze and light cloud cover. The seeker is described as forward-biased, which probably means that proportional navigation (using a gyro as reference) has replaced the earlier pursuit navigation. Forward-biasing will cause the missile to hit an airplane near its cockpit, where the target is most vulnerable. It will also greatly reduce the value of any decoy projected aft from an airplane. This version introduced solid-state electronics in the seeker, and it has a faster-tracking seeker (20 deg/sec) and double-delta wings, the latter for better maneuverability. AIM-9H was the last purely naval version of the missile. Production of 7720 AIM-9H began in 1972, the missile entering service in 1973. Weight is 186 lb.

AIM-9J was a -9B or -9E rebuilt for the air force, with partially solid state electronics and double-delta wings with more powerful actuators, plus a longer-burning gas generator (for flights lasting up to 40 sec, but not the 60 sec of the -9D and its descendants). Maximum range is reported as 15,850 yd. Overall range is sacrificed for high acceleration to deal with fast targets. About 6700 were delivered by Ford Aerospace, about 1970. AIM-9J1 is a new-build missile, -9J2 a converted -9B, and -9J3 a product-improved version. Dimensions: 5 × 120.9 in, span 22 in, weight 172 lb.

AIM-9JUL1 is an upgraded AIM-9J/N/P developed by Bodenseewerk, to achieve performance and reliability comparable to that of AIM-9L at a significantly lower price. Highly reliable AIM-9L subassemblies such as the all-aspect seeker, the guidance electronics, and the coolant-bottle section are combined with the control-servo section of the AIM-9J/N/P to form a new guidance and control unit, which is attached to the unchanged body of the AIM-9J/N/P missile. BGT claims that AIM-9JUL1's performance matches that of AIM-9L, except for minor limitations due to the earlier missile's smaller control-servo torque and slightly lower thrust. The company also claims that the frontal acquisition range of the all-aspect seeker and the thrust profile of its rocket motor provide it with surface-to-air capa-

bility comparable to that of AIM-9L/SHORAD. As of the summer of 1990, JULI was still a private-venture proposal, BGT promising first deliveries 26 months after contract award (missiles would be delivered for modification 18 months after contract award).

AIM-9K was an alternative to AIM-9L developed by China Lake but not produced.

AIM-9L is described as a third-generation missile (-9B was the first, -9D the second) developed on a joint-service basis. It was based on AIM-9H but was effective at all aspects, capable of engaging violently maneuvering targets, and effective against fast aircraft even at medium range. It has a new active-laser proximity fuze (DSU-21) consisting of 8 GaAs laser diodes plus 8 photodiode receivers. The warhead is a new 20.8-lb annular blast-fragmentation type, using preformed rod fragments.

A magnesium-fluoride window covers an argon-cooled indium-antimonide detector that operates in 2 colors (i.e., at both long and short wavelengths). The new seeker head was originally developed by Bodensee (the European Sidewinder manufacturer) for the abortive German Viper short-range air-to-air missile. Unlike previous missiles, this one uses a fixed reticule, with a moving tilted mirror (rotating Cassegrain system) performing a conical scan modulated in both frequency and amplitude (presumably a variant of a rosette scan). This arrangement improves sensitivity and tracking stability, and it also allows for later incorporation of a more elaborate detector, e.g., imaging infrared (since the relation between reticule and detector is now fixed). There is a new guidance and control group (DSQ-29). The missile has an internal coolant tank, so it can be carried by air force aircraft (U.S. naval aircraft have coolant bottles in their missile launch rails).

There were several other improvements to the seeker electronics. Because the seeker scans conically, it does not see a target dead ahead; normally, then, the pilot would hear no tone at all when the missile was perfectly boresighted. An ingenious audio enhancement bridges this dead zone so that the pilot can register when the optical axis of the missile is precisely aligned with the target. The missile must be limited in initial maneuverability since otherwise there is a chance that it will acquire the launching airplane. In this version the seeker is partly caged for the initial phase of its flight; it can make full use of increased maneuverability later on. Instantaneous seeker FOV is reduced to decrease the effect of background noise. Since that also reduces the probability of target acquisition, a scan mode is provided to increase the missile's effective FOV. The radar-slaved SEAM mode also improves the chance of initially acquiring a target.

In 1980 it was reported that a combination of modified signal processing and a new seeker reticule would improve background discrimination by a factor of 3, and that new tracking software would greatly improve performance against glinting targets, i.e., against targets visible only by the reflection of sunlight on their surfaces. This program began in 1977. It is sometimes denoted ALASCA (all-aspect attack capability). AIM-9L was the version used so successfully by the British during the Falklands War; 100 were supplied, and they shot down at least 25 aircraft. In Swedish service this missile is designated RB 74.

AIM-9L/I is a modified AIM-9L, developed by BGT. One of 4 electronic modules is changed, for better countermeasures resistance, comparable to or better than that of AIM-9M. AIM-9L/I was tested for the first time at China Lake in the summer of 1990, achieving 3 successes out of 3 shots.

AIM-9M is the current U.S. production version, with improved countermeasures resistance and clutter rejection. It incorporates a Hughes closed-cycle cooler. Production began in 1981. Weight is 189.6 lb. The new motor is smokeless.

AIM-9N is a rebuilt -9J (formerly designated -9J1) intended for foreign military sales. Three of the major circuit boards of the earlier version were redesigned. About 7000 of these missiles were made.

AIM-9P is an export version of the current -9M, either a rebuilt AIM-9B/E/J or new production. AIM-9P1 introduced a

laser proximity fuze in place of the earlier IR fuze. -9P2 has a reduced smoke motor. -9P3 has an IR fuze, a reduced-smoke motor, and a stronger warhead and guidance/control section; this version employs a new explosive that is less sensitive to high temperatures. -9P4 has increased IR acquisition and guidance capability and an optimized fuze. Weight is 170 lb.

AIM-9R is the next-generation version, a product-improved -9M. Ford was awarded the contract in April 1987, and the missile should enter service in 1992. -9R has a new IIR detector, using CCDs that do not have to be cooled. The array detector should increase range and simplify support. Weight is 193 lb, and range is reportedly 21,125 yd. Work on this version, originally called AIM-9M(PIP), began in 1986. Current navy plans call for conversion of 5000 AIM-9M to -9R standards. The U.S. Air Force is testing a new control system developed by Elbit (of Israel) to provide off-bore-sight capability. This control system slaves the seeker head to the aircraft radar or to a helmet sight. Tests were completed in March 1988.

AIM-9R was first fired in April 1990. The U.S. Air Force claims that it is too expensive and does not meet requirements. It has proposed an alternative AIM-9M Plus; but as of mid-1990, DoD was trying to determine whether this duplication of effort was justified.

AGM-87A (Focus) was a slightly modified Sidewinder intended for night attacks against visible IR emitters such as truck headlights; it was quite successful during 1969-70.

In FY85 flyaway unit cost was \$55,000. Recent procurement by the navy: FY84, 350; FY85, 1000; FY86, 2120; FY87, 627; FY88, 288; none in FY89. Total production run, approximately: AIM-9B, 80,000; -9C, 2000; -9D, 12,000; -9E, 5000; -9G, 2120; -9H, 7700; -9J, 10,000; -9L/M about 14,950. Reportedly, it would take about 4 months and \$18 million to triple the current production rate under mobilization conditions.

AIM-9L is manufactured in an improved form by a European consortium (West Germany, Norway, Italy, and Great Britain) headed by BGT, which made earlier forms of the missile; in addition, Mitsubishi has been manufacturing AIM-9L under license since 1981. Reportedly, the West German army has evaluated AIM-9L (with a modified microchip) as a short-range surface-to-air missile, and 5 test firings were conducted in August 1986. Although no naval application was reported, such a missile might serve as an emergency alternative to RAM.

The U.S. Navy uses Sidewinder only in an air-to-air version. However, the Taiwan navy uses a surface-launched version, Sea Chapparral, a seagoing version of an army missile, work on which began in 1959. The U.S. Navy did mount 9 Chapparrals on board *Gearing*-class destroyers in 1972 (they were removed in 1973) as a form of close-in defense during the Vietnam War. Chapparral had been tested on board a large amphibious ship in 1963, and it was proposed (as the 10,000-lb Seawinder) in 1967-68 as an interim defense against Styx missiles. At that time, Seawinder was rejected in favor of longer-range offensive missiles, particularly Standard Active and Standard ARM, which could be used to destroy the Styx platforms before they came within range. The Sea Chapparral mounting was never standardized by the U.S. Navy, and details are not available. The mounting can be controlled either remotely (using a camera in the mounting) or locally. It arms Taiwanese (ROC) destroyers and frigates, as well as the LSD *Cheng Hai* and the new replenishment ship *Wu-Yi*.

Sea Chapparral is fired from a 4-rnd turret, with 8 more missiles stowed for ready use. The operator locks onto the target using an optical sight, and the system can be improved by adding a FLIR; targets can also be designated by other ship sensors. Range is about 2.2 nm.

The missile is MIM-72; the first version, MIM-72A, was equivalent to AIM-9D. The first production missiles were delivered in 1969, and the system entered combat in the 1973 Middle East War. MIM-72B has a more powerful warhead and a better seeker and fuze. MIM-72C, developed in 1970-74, has an all-aspect seeker, a larger warhead, and a radar (doppler) proximity fuze. The addition of a 2-color rosette-scan seeker (as in

AIM-9L) and a smokeless motor resulted in MIM-72C/R (rebuilt MIM-72C) and the production MIM-72F; -72D and -72E were test versions for the improved seeker and a new directional-doppler proximity fuze. The current version is MIM-72G, with a combination of 2-color rosette-scan seeker and scanning spatial discrimination, using digital programmable electronics. The seeker can be reprogrammed (to adjust to different countermeasures) up to the moment of launch. Reportedly, the Taiwanese versions are MIM-72C, -72C/R, and -72F. Probably, these weapons will ultimately be supplanted by an indigenously developed air-to-air missile, broadly comparable to AIM-9L/M, Tien Chien (Sky Sword) I.

Ford had proposed a Chapparral II with a new reduced-drag airframe, tail rather than nose control surfaces, and a new motor, for an effective range increase to 11,000 yd. The new missile would also have a new dual-mode (IR and antiradar) homing system.

Sidewinder is to be succeeded by a British-developed ASRAAM (AIM-132). However, ASRAAM development has been protracted. Hence the decision to place AIM-9R in production in 1990, as an interim weapon.

A new Sidewinder seeker was displayed at the Association of Old Crows (EW association) meeting at Boston in September 1990. It incorporates a new AMT massively parallel computer (described in the Addendum), which is powerful enough for multispectral image processing. At least as displayed at the show, the seeker employs a large-diameter gimballed Cassegrain mirror (i.e., with a sensor at its center and a small mirror forward of it to reflect the image from the large mirror back into the sensor). The modified Sidewinder was described as robust against current countermeasures (i.e., against flares and IR suppressors, as well as flashing lamps), satisfactory for day/night operation, and effective against helicopters (and not against their exhaust plumes). It was also described as low cost and low risk. The implication was that this was a staring array using processing so powerful that it could distinguish the relatively cool skin of a helicopter against the cooler sky or even the ground. The logical suggestion is that, at least in clear weather, this sort of seeker can easily distinguish stealthy aircraft and missiles since they cannot cool themselves below ambient temperatures.

Next to the Sidewinder front end was another missile nose marked SRM (presumably Short-Range Missile), with an acutely pointed (rather than rounded) and faceted (6-sided) nose, carrying a larger-diameter mirror virtually filling its diameter (which was about that of the Sidewinder). SRM is presumably a formerly black Sidewinder successor project. It will be faster than Sidewinder (hence the need for the pointed nose). The facets are presumably needed to minimize optical distortion.

These missiles are part of Martin Marietta's attempt to win a contract to develop the next-generation air-to-air missile, either as a new version of Sidewinder to succeed AIM-7M or as a new missile altogether. Because the company had no previous experience of similar weapons, it felt compelled to produce some prototype hardware. As of September 1990 the next-generation requirement had not yet been funded, and other companies were also interested in the potential for such a program, which the air force would lead. They, too, are using imaging IR seekers associated with massive computing power.

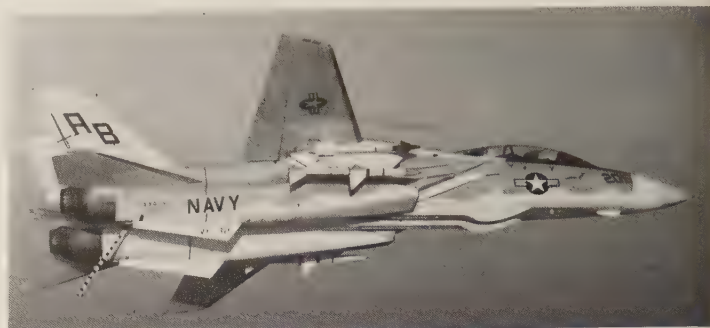
◆ Sparrow and Sea Sparrow (AIM-7/RIM-7)

Dimensions: 8.03 × 141.5 in (wing 24.65 in folded, 40.6 in open; tail span 24.3 in) **Weight:** 500 lb

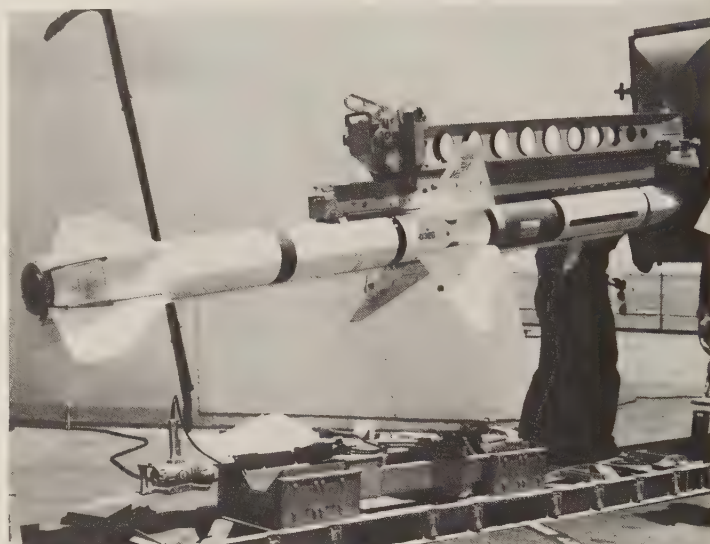
Warhead: 67-lb continuous-rod (17.9-lb DATB explosive) in 7E version; 86-lb continuous-rod WEU-3/B in AIM-7M

Propulsion: rocket boost-glide **Speed:** Mach 4.0

Range: depends on guidance radar (24–28 nm air-to-air for AIM-7M). Sea Sparrow's range (7E version) was 12,000 yd (1500 minimum); maximum altitude was 18,000 ft. Maximum speed was 1600–1800 ft/sec, and warm-up/reaction time was 8 sec/9–16 sec. These data are now obsolete, but they give some idea of the system's performance. The current NATO Sea Sparrow range is reported to be 8–14 nm (16,000–28,000 yd).

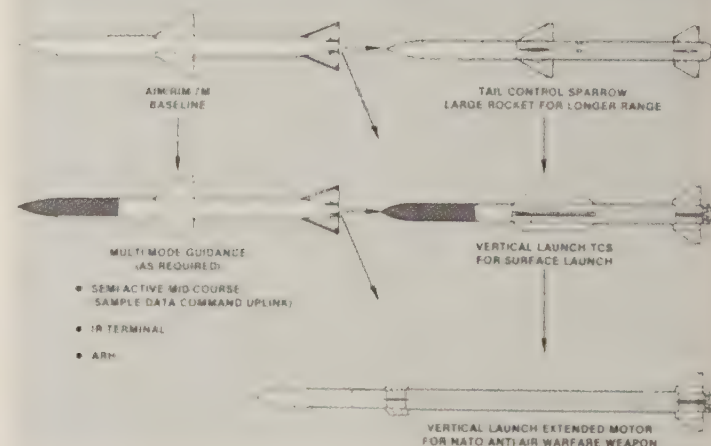


Sparrows and a Sidewinder carried under an F-14. (U.S. Navy)



Sea Sparrow being loaded into 1 cell of its launcher. Only the Canadian version of Sea Sparrow (on board Tribal-class destroyers) is power-loaded; the NATO version and the earlier Basic Point-Defense Missile System both use hand-loaded 8-cell launchers. (U.S. Navy)

Sparrow Configuration Evolution



Raytheon's proposals for advanced Sparrows, 1988. (Raytheon)

Data apply to RIM-7M; AIM-7M has longer wings.

Sparrow (AIM-7) is the current standard U.S. radar-guided air-to-air missile, supplemented by Phoenix (AIM-54) only on F-14 fighters. Sparrow arms F/A-18 Hornets. Because it is semiactively guided, Sparrow requires a large illuminating radar on the fighter, and the firing airplane must illuminate the target all the way from launch to kill. For these reasons Sparrow cannot be carried by lighter naval aircraft such as the Harrier/Sea Harrier and the A-6 Intruder; Sparrow also cannot be used effec-

tively against saturation raids. In theory, AMRAAM (AIM-120) solves both problems, by combining a data link and an active seeker. However, AMRAAM is quite expensive; and Raytheon, which manufactures Sparrow, believes that AMRAAM will continue in development for some time.

Sparrow is the West's primary, current, beyond-visual-range missile. In Vietnam this capability was something of an embarrassment since without very reliable IFF a long-range missile would inevitably destroy numerous friendly aircraft (which were, after all, the great majority of all aircraft in the area). Hence the development of the long-range AXX-1 television described in this section.

The overall Sparrow single-shot kill probability in Vietnam was only 9%. By 1980, however, the U.S. Navy estimated Sparrow's single-shot kill probability as 35%, and the corresponding air force estimate was 28.5%. OSD estimated 15% against a fighter at low altitude, 35% against a fighter at high altitude; corresponding figures against a bomber were 20% and 56%. Figures from recent combat, e.g., in the Israeli air force, have not been published.

Sparrow was conceived as a radar beam-riding guided version of the 5-in high-velocity aircraft rocket, Hot Shot (by analogy with a parallel British project, Long Shot); the guidance system drew on work being done on contemporary surface-to-air weapons (the now-extinct Talos and Terrier). In May 1946 Sperry was asked to submit a proposal for a weapon with a maximum range of not less than 2000 yd, and a minimum range of not more than 1000 ft, fast enough to attack a Mach 1 target. The original 5-in airframe was too small, and Douglas was asked to design the 8-in airframe ultimately adopted. The contract was awarded in May 1947, and the weapon named Sparrow. The first target was intercepted on 3 December 1952, production already having begun because the bomber threat to carriers was considered so urgent. The Sparrow I (AIM-7A) beam-rider entered fleet service in 1956. Although beam-riding was unacceptably inefficient, about 2000 of these missiles were manufactured before production ended in 1962.

Sparrow II (AIM-7B) was an abortive active-radar version, ultimately intended to arm the Canadian Arrow (CF-105) interceptor. It was much too far ahead of its time and died with the airplane project.

Sparrow III (AIM-7C) was the successful version, using CW semiactive homing similar to that applied to Terrier and Tartar (the forerunners of the Standard Missile ER and MR versions). Deliveries began in January 1958. About 2000 were made.

AIM-7D, the first version to be used in combat, could be fired at supersonic speeds. It could home from the forward hemisphere, i.e., could accept very high closing rates, and it could also home on a jammer. Compared to AIM-7C, it had a storable liquid-fuel motor (specific impulse 15,000 lb-sec over 1.9 sec) instead of the earlier solid-fuel type, increasing effective range by about a third and ceiling by 10%, to 30,000 ft. The warhead was a 65-lb continuous rod (circle radius was 56 ft, and lethal range was 125 ft).

Although the notes on guidance that follow apply specifically to AIM-7D and -7E, they still apply to other Sparrows and to similar semiactively guided missiles.

This missile (and its successors) had receivers on its tail fins, so it could measure relative target velocity by comparing this reference signal with the signal reflected from the target. When the missile was fired, the speed (doppler) gate swept a frequency band until it detected the appropriate preset target doppler. The gate within which the target doppler had to be could be set wide or narrow, the narrow setting being much better for rejecting clutter such as chaff. In the narrow setting, the gate swept 5 kHz to either side of the preset frequency, 1 kHz corresponding to a speed of about 30 kt (so that the total sweep corresponded to 150 kt). The wide speed was 6–138 kHz (150–4100 kt), corresponding to a total lack of presetting information. Aside from the likelihood that the missile would lock on to the wrong target, the sweep over the wide gate took so long that the missile might fail to lock on altogether.

AIM-7D used proportional navigation, the autopilot obtaining both relative target speed (via doppler) and line-of-sight rate. Since flight characteristics would change with altitude, the control system had a set of preset altitude bands. The missile could be fired in 1 of 2 modes, full-system and bore-sight (snap-shot). In the full-system mode, the computer of the firing fighter provided the narrow-gate doppler and the initial lead angle. Bore-sight was intended for use when the target was so close that radar could not be locked on. The radar is caged to the boresight axis of the airplane, so the target will be illuminated when tracked within the 50 mil optical sight. There is no lead-angle indication, and the missile must be fired with a wide gate, since the fighter FCS is not engaged.

Many AIM-7s were fired in bore-sight mode in Vietnam, and few worked properly, given the limitations of the wide doppler gate. A third method, "manual boresight," was therefore invented. The missile is locked onto an imaginary target, and a closing speed manually set; the typical value for a tail chase was 150 kt. Although simple in theory, manual boresighting was difficult in practice because all of the interlocks designed for use in the full-system mode had to be cut out. A joint air force/navy task force on AIM-7 effectiveness recommended that aircraft carrying the missile be provided with a Target Aspect Switch providing 4 different closing-attack inputs, depending on the situation. For a head-on attack, the closing rate would be the fighter's speed plus 450 kt; for the forward quarter, head on plus 240 kt; for a tail chase, fighter's speed minus 240 kt; and for zero closing speed, zero input.

Tests in 1965 showed that the Target Aspect Switch provided Sparrow with a useful capability against low-altitude and maneuvering targets, although it was still difficult for the pilot to estimate the proper firing range. In the 1965 tests, manual boresighting made for about 50% successes. If the missile could be fired in full-system mode, it could attack a nonmaneuvering target at altitudes as low as 5000 ft. Properly used, it could also be extremely effective against maneuvering targets, demonstrating (in 1965 tests) a success rate of 41% (55% when adjusted for failures due to aircraft and missile malfunction) against subsonic maneuvering targets.

Reality in Vietnam was much less happy. For example, during a short period in 1966, 13 AIM-7D were fired. One hit. Four were deliberately fired out of the launch envelope to break up an enemy attack, 4 were fired in the allowable launch envelope but failed to guide, 3 motors failed to fire, and in 1 case the guiding radar broke lock after the missile had been launched. About 7 months later, 18 AIM-7E missiles were fired during 1 operation (BOLO, 2 January 1967); 2 more failed to launch altogether. Two more missiles were lost because the firing airplane's guiding radar broke lock after launch. However, of the remaining 16, only 8 guided properly, making 4 confirmed kills and 1 probable.

These figures meant that reliability, rather than some conceptual flaw in the missile, was the major issue, and therefore that Sparrow would become extremely effective as electronic technology improved. Discounting missile failures due to unreliability, the BOLO result was a kill rate of at least 50% among missiles for which the fire-control radar functioned properly.

Because AIM-7D was a boost-glide missile, its effective range depended very much on the speed of the launching aircraft (which was, in effect, its first stage).

About 7500 were made. Dimensions were 8 × 144 in (weight 398 lb, wingspan 40 in, tail span 32 in).

The next version, AIM-7E, was produced between 1963 and June 1973; it was the basis of most other Sparrow variants. About 25,000 were made. AIM-7E was widely used in Vietnam and hampered there because its maneuverability was limited by low terminal energy. It had the same dimensions as -7D but weighed 435 lb, most of the extra weight being its more powerful motor.

The new pure-sustainer (total impulse 22,100 lb-sec, burn time 2.9 sec) rocket motor added about 75% to the missile's

range. In 1963 the manufacturer, Raytheon, credited -7E with an effective intercept range (against a 5-m² target at 50,000 ft) of 16 nm, assuming that the launching aircraft was flying at Mach 2, with a time of flight of 40 sec. In 1968 the U.S. Air Force credited the missile with a maximum range, in a frontal attack against a fighter, of 13 nm (3 nm in a stern chase). Typical minimum ranges were 5000 ft for a stern attack, 12,000 ft head-on. The most important limitations were fuze-arming and time to make guidance corrections; another was the strength of the illuminating radar.

The other main improvements were increased seeker range, improved speed (doppler) gate circuitry for low closing and opening range rates, and improved ECCM.

AIM-7E2 (and the related RIM-7H, the first Sea Sparrow) was a modified and more reliable version introduced in 1969. It had a "dogfight" guidance mode (faster tracking and stronger flight-control responses) and an improved fuze (with shorter arming time, for shorter minimum range), and it could fly at higher altitudes. Minimum range was reduced, the guidance system locking up more quickly after launch. The missile could tolerate a higher G-load. AIM-7E3 had an improved fuzing circuit and was more reliable. AIM-7E4 was protected against the "spillover" radiation of powerful fighter radars.

Raytheon proposed an "Advanced Sparrow III" as early as 1963 as an alternative to Phoenix; it would have a programmed fly-out to permit launch at the aerodynamic launch limit, which would itself be increased by using a new dual-thrust (boost-sustain) motor, burning for 3.5 sec (total impulse 30,800 lb-sec, total weight 200 lb compared to 156 lb for -7E). The missile could fly for as long as 75 sec, and it could reach 52 nm; more typically, it would double -7E's range, to about 30 nm. As in Aegis, effective guidance range depends in large part on the point at which the missile requires usable amounts of radar energy reflected from the target. A missile that can fly a considerable distance before requiring this illumination energy can guide onto a more distant target, using the same illuminating radar. Raytheon did not propose any kind of mid-course update, so this guidance mode presupposed a relatively sedate target.

The other new features proposed at this time were more compact electronics, freeing space forward of the wings for a heavier warhead (90 lb) and for the enlarged motor. Advanced Sparrow would have been compatible with pulse-Doppler, rather than CW, radar.

The main Advanced Sparrow capability, much greater range against a bomber, was not very attractive during Vietnam. It was revived later, and development of the new AIM-7F began officially in January 1972. It incorporated the new motor, and range was 24 nm using the Phantom radar (38 nm using the more powerful radar in the F-14); the proposed fly-out mode was abandoned. A new seeker was considered more effective against low fliers and multiple targets, and the new motor (Mk 58 rather than Mk 52) provided more energy for snap-up shots. AIM-7F also incorporated the new heavy warhead (Mk 71 rather than Mk 38) that had been proposed in 1963. The new guidance electronics were solid-state units in replaceable modules, for easier maintenance and better reliability.

The guidance technique was changed to adapt the missile to the new generation of pulse-Doppler radars. AIM-7F measures the range to the target by comparing the FM signal received on its rear (reference) antennas with the FM signal reflected from the target. The frequency difference is proportional to target range (this technique is analogous to the pulse-doppler radar-ranging technique described in the Prefatory Notes on radar). The missile receives target range from the fighter's fire-control radar, and it updates range by calculating target velocity (doppler). A range gate is used to reject countermeasures. AIM-7F was approved for production on 1 October 1974, the first production award (to Raytheon) following on 31 October 1975; the projected requirement was 6864 for the navy and 5415 for the air force.

AIM-7G had a new seeker but was only a prototype (1970).

The -7H designation was reserved for Sea Sparrow (see below), and there appear to have been no -7J, -7K, or -7L versions.

Instead, the next version was designated AIM-7M, the M standing for an inverse monopulse seeker, the principal improvement in the new missile (for better resistance to countermeasures). This version also has an active (presumably laser, rather than radar) fuze, a missile-borne digital computer, and an autopilot. The effect of the autopilot is to allow the missile to fly a considerable distance without requiring illumination. Thus missiles can be fired at several different targets in sequence, illumination being used only for mid-course and terminal homing. The autopilot permits the missiles to fly an energy-efficient trajectory. The combination of proportional navigation with a preset autopilot flies the missile in such a way that it almost never points directly at the target. The antenna points to one side. In theory, therefore, there is space alongside for an IR seeker, an option not incorporated in -7M missiles, but tested recently. Although in theory the autopilot allows for intermittent command guidance, there is no provision for a data link. Full-scale production of AIM-7M was approved on 12 December 1982, the first missile having been test-fired in April 1980.

In 1985 the U.S. Navy reportedly proposed a next-generation Sparrow, AIM-7X, as an alternative to AMRAAM (AIM-120A). In 1987 Raytheon won a \$19.6 million contract for this product-improved version, now redesignated AIM-7P. The new version incorporates current low-altitude fuzing modifications and has new guidance electronics (using VHSIC technology) capable of accepting mid-course guidance commands (with software modifications).

Production: AIM-7A, about 2000; -7B, 100; -7C, 2000; -7D, 7500; -7E, 25,000; -7F, 5000. In March 1987 the reported requirement for these missiles was 7988 for the navy and 6321 for the air force. Recent navy procurement: FY84, 695; FY85, 1671; FY86, 1948; FY87, 1716. None were requested for FY88, but Congress directed that the navy buy 600 because of delays in the designated successor program, AMRAAM. The navy's FY89 program included 450 Sparrows. The navy also plans to upgrade 4000 AIM-7F to -7M standards. It was reported in 1987 that the maximum production rate from 2 sources is 250 missiles per month. Unit cost (FY83) was \$198,209.

Sparrow has been very widely exported, and it is license-built by Selenia and by Mitsubishi. The Selenia Aspidé (see above under SAMs) uses much the same airframe but with different internal components, both for air-to-air and for surface-to-air use. The British Sky Flash, which has also been adopted by Sweden, is a modified Sparrow.

Sky Flash is a modified Sparrow (AIM-7E). British Aerospace has been marketing a proposed X/K-band active version since 1985, originally with a Marconi seeker. The current seeker contractor is Thomson-CSF; this seeker may be similar to, or identical to, seekers in the active version of Aspidé and also in the surface-to-air ASTER missile. The missile is being offered to countries that will not be permitted to buy AMRAAM; British Aerospace claims that it can be in service as early as 1992.

RIM-7, Sea Sparrow, is a ship-launched self-defense variant, the current version being RIM-7M. It is used in 3 major systems: the Basic Point-Defense Missile System (BPDMS), which uses the Mk 115 FCS and is being replaced by Phalanx guns (replacement of all 72 was announced 1981, to be completed by the end of FY88, but this target has not been met); the NATO Sea Sparrow System (Mk 91 director); and some examples of the Italian Albatros system (though most such systems fire the Italian Aspidé missile). BPDMS was developed from 1963 on to fire a folding-fin version of AIM-7E designated RIM-7H; it was first tested in May and June 1965. An alternative RIM-7F was derived from the AIM-7F air-to-air missile. Modifications consisted of rapid run-up, folding wings, and clipped tail fins. All versions of BPDMS were considered deficient against low-flying attackers.

NATO Sea Sparrow (the Improved Point-Defense Missile Sys-

tem) uses the same missile but a very different overall combat system. The director is automatically trained, on command from CIC. The NATO Sea Sparrow program was reportedly inspired by the sinking of the Israeli destroyer *Eilat* (the first combat casualty caused by a surface-to-surface guided missile) in 1967. Later that year a NATO Project Group prepared an MoU; it was signed by Denmark, Italy, Norway, and the United States. Belgium and the Netherlands joined the consortium in 1970, West Germany in 1977, and Canada and Greece in 1982. Raytheon was awarded the prime contract in September 1969. A production contract followed in August 1973.

An 8-cell box launcher (Mk 29) with frangible panels at the ends of each cell, was developed; it replaces the modified AS-ROC launcher of the U.S. BPDMS system. Raytheon, which manufactured the air-to-air weapon, was awarded the prime development contract in September 1969. The other development firms were Terma Electronisk of Denmark (microwave receiver), Selenia of Italy (firing officer's console/display module), and Kongsberg Vapenfabrikk of Norway (director controller, director pedestal, and computer). The system was first tested on board the frigate *Downes*, a second model going on board the Norwegian frigate *Bergen*; and all evaluation was completed by the end of April 1973. The first production systems were delivered in 1975. A full NATO Sea Sparrow system employs 1 or 2 Mk 91 directors. Typically the 8-cell launcher is manually reloaded. At this writing (1988) a standard modification is in train to fill 2 of the 8 cells with RAM point-defense missiles.

RIM-7H-1, the initial NATO Sea Sparrow missile, is AIM-7E-1 with a rapid run-up (RRU) modification, folding wings, and clipped fins. RIM-7H-2 is equivalent to AIM-7E-2, with RRU, folding wings, and clipped fins. RIM-7H-5 is RIM-7H-2 with a point defense fuze fix.

NATO Sea Sparrow Block I uses the RIM-7H-5 missile (modified AIM-7E). Operational evaluation was completed in February 1974. Development and operational testing of the full Block I system was completed in December 1977, with full-scale development following from June 1978. Block II uses the RIM-7M monopulse missile, which was introduced into the system in 1978. A projected Sea Sparrow version of the AIM-7F was abandoned in favor of a version of the monopulse-guided AIM-7M. Some consideration was apparently given to developing a missile specifically for Sea Sparrow use, with a simpler seeker (CW only, since the shipboard radar illuminator is not pulse doppler) and, therefore, a simpler and less expensive radome, a new autopilot, and simpler and less expensive aerodynamic features. This project was also abandoned; RIM-7M is a modified AIM-7M. Modifications to the missile include fuzing better adapted to low-altitude clutter, the ability to discriminate between multiple targets in a stream attack, and a self-destruct feature to protect friendly ships onto which the missile may inadvertently lock. The missile is also capable of discriminating between different illuminators since a ship may have several directors, and several nearby ships may fire Sea Sparrows together, most likely by sensing coding in the illuminator signal.

Total system weight, including 8 RIM-7M missiles, is 28,648 lb (13,676 lb for the loaded launcher, 3431 for the director and its television camera).

The Sea Sparrow system is triggered by a main search radar, such as the U.S. TAS Mk 23 or SPS-65. The radar designates a target to the Mk 91 director. The director then scans and acquires the target, modulating emissions for ranging and angle tracking. If the target fades during track, the director coasts in range, bearing, and elevation until it reacquires. During the target-tracking process, the Sparrow's time of flight to the target is computed; and the operator is alerted if the target is engageable. Shortly before the target comes within range the launcher is automatically assigned to the appropriate radar director and aimed at the predicted intercept point. In automatic mode, a salvo is fired when the target becomes engageable. In semiautomatic mode, the operator issues a firing command. Typically the U.S. Navy operates its Sea Sparrows in semiautomatic

mode. European navies tend to use the automatic mode. This distinction reflects a difference in operating conditions. Except in wartime, when they would face submarine-launched missiles anywhere at sea, U.S. ships probably would not face air attack unless they approached hostile shores. European warships are almost always within range of potentially hostile air or missile attack.

RIM-7M differs from AIM-7M only in that the former's wings are folded and tail fins clipped, for launcher stowage. Wingspan is 40 in (25 in folded) and tail span is 24 in. In addition, the rocket motor is remotely armed. The warhead is a WAU-17/B blast-fragmentation type, chosen over the earlier continuous rods (WAU-10/B) to destroy a nearby target passing at very high speed.

The current (1988) Sea Sparrow is RIM-7M, which is adapted for vertical launching. This version has improved surface-to-surface capability, improved surface look-up capability, and improved performance and reliability. Vertical- and box-launched missiles are identical, apart from the additional jet-vane control (JVC) unit bolted onto the tail of the vertically launched weapon. Both have a new active fuze, which incorporates a target-range gate and a sea-range gate, the latter to keep the missile from detonating against the sea at low altitude. The jet-vane control unit incorporates an inertial strapdown navigation computer; it pitches the missile over onto a course toward the target. Missiles fired from vertical launchers begin to tip over 0.7 sec after launch and do not rise above 200 ft when fired against low-altitude targets. The missiles are fully tipped over by the time they are 250 ft from the ship.

Compared to the standard trainable-launcher version, the VLS version provides more ready missiles (against saturation attack), quick launch after target detection, reduced topside space and weight, and quick engagement of fast sea-skimmer or pop-up missiles.

Like AIM-7M, RIM-7M incorporates an autopilot and, thus, has the potential for multiple engagements if that autopilot is set at launch time. Since the missile can fly for a considerable time before needing to detect energy reflected from the target, Raytheon has proposed engaging multiple targets by floodlighting: using a broad-beam radar (e.g., 45-deg beam) to illuminate several incoming targets simultaneously, and using an engagement radar to compute autopilot settings. The floodlight would illuminate each target only weakly, but weak illumination might be enough if the missile does not need to pick up radiation until fairly close to the target. In this way a single search radar and a very simple floodlight might bridge the gap between the current single-target Sea Sparrow system and a much more sophisticated system meeting the NATO AAW requirements. This floodlighting system has not been tested, and presumably it was the one rejected when Raytheon was dropped from the NATO AAW System program. However, the company argues that any substantially more complex solution will be prohibitively expensive. The Raytheon illuminator has 8 apertures, each producing a 45×75 -deg beam, plus a zenith horn (60×60 -deg beam). The system transmits through 1 selected illuminator at a time, power being 2 kW average (gain 10 dB). The beams are so wide that no mechanical stabilization is needed. The full pattern covers the entire hemisphere, down to 15 deg below the horizon (to allow for rolling motion).

The floodlight technique is already operational in the army's Hawk missile, in a program called LASHE (Low-Altitude Simultaneous Hawk Engagement). In this case the illuminator has a beam broad in azimuth but relatively narrow in elevation. As of mid-1990, the Raytheon NAAWS proposal still incorporates the floodlight technique.

A version of Sea Sparrow using a Signaal FCS was developed independently for the Canadian *Iroquois*-class destroyers; that version employs launching rails that deploy from the sides of the ship.

A vertically launched Sea Sparrow prototype was tested at sea in 1981, and a formal NATO Sea Sparrow ORDALT issued in

1981. Canada decided to purchase the vertical-launch system for its "City"-class frigate in 1983, Raytheon receiving the contract the following year. The vertically launched RIM-7M was successfully tested at White Sands in 1985. Test launches included shots at simulated low-altitude targets, at mid-range and off-axis, the missiles avoiding the simulated ship's superstructure; there were also low-altitude short-range shots. The Royal Netherlands Navy bought this system for its M-class frigates in 1985, and Greece chose it for the new MEKO-200 frigate in 1988. Delivery of 6-launcher ship sets for Canada was completed in 1987, and production deliveries of 155 Canadian units was completed in 1988. A total of 256 missiles are on order for the Netherlands navy, as of 1988.

In 1988 the expected total production run of RIM-7M was 2950 missiles, and unit cost in FY85 was \$214,000.

In 1988 Raytheon announced a program for further Sparrow evolution, using the RIM-7M as a baseline. For improved aerodynamics against violently maneuvering targets, the missile was redesigned for tail control. With this modification, the missile can carry a larger rocket motor with increased thrust and can maintain its current vertical-launch capability. The missile's existing reprogrammable computer is adaptable to multimode guidance (semiautonomous mid-course, IR terminal, and anti-radar homing). This wingless Evolved Sea Sparrow (ESS) offers twice the maneuvering power of the winged missile. ESS would have a new autopilot, all-boost rocket motor, and tail controls. The forepart (seeker and warhead) would match RIM-7P (see below), but the after part would be necked out to 9-in diameter; total weight would be 245.1 kg (540 lb), and length would be 145.7 in [3.7 m]. Evolved Sea Sparrow could be in service by 1994. Raytheon claims that ESS will have 2 to 4 times the energy of the existing Sparrow and that ESS can easily be backfitted on board ships now equipped with NATO Sea Sparrow.

A further stretched version, the Long Ship-Defense Missile (LSDM), which Raytheon claims could be in service by 1998, would offer Mach-3 speed and twice the current range. ESS and LSDM would share common control and tail-fin (jet-vane) systems. The missile would receive mid-course guidance through the illuminator, whose signal would be modulated.

Raytheon proposes a 4-missile canister launcher for these weapons, each cell of which would be about 11 in across (total width 25 in).

The ESS/LSDM combination was Raytheon's candidate for the NATO Antiaircraft Warfare missile system. The company argues that this system may well be adopted when the alternative, more sophisticated, systems prove too expensive.

Meanwhile, RIM-7P is likely to be the next version of Sea Sparrow. Tests began in 1989, and production was approved in October 1990. The main changes from earlier versions are improved low-altitude performance, an advanced reprogrammable (VLSI) missile-borne computer, an up-link capacity, and the ability to accept delayed lock-on.

The higher-capacity computer is a major change, allowing the missile to execute a much greater variety of maneuvers, and also allowing for more fuzing options. Existing Sparrows fly an up-and-over trajectory, but RIM-7P can fly an offset path (the horizontal equivalent of up-and-over). For example, the missile can fly out in front of an approaching target. Beginning with the 7M version, the Sparrow flight path has varied with target type (e.g., sea skimmer, helicopter, surface ship, aircraft), but -7P has a richer repertoire.

The up-link provides the system with the potential for Aegis-like operation, if a ship is equipped with a suitable 3D radar. That should apply to a variety of foreign ships with radars such as the Dutch SMART. It also opens the possibility that the U.S. Navy will adopt RIM-7P as a shorter-range supplement to SM-2, 4 Sparrows occupying a single cell of the Mk 41 launcher (a capacity already tested as part of the NAAWS program).

Delayed lock-on was originally required to adapt the missile to vertical launch since the missile could not enter the guidance beam until it pitched over. Now all Sparrows can fly for a time before they must see energy reflected by the target. The set

delay is no longer fixed by the missile's trajectory requirement; instead it is determined on the basis of target trajectory. For example, the target may be outside the seeker angle when the missile is launched. A time delay also allows the missile to maneuver to intercept a maneuvering target, if the illuminator is initially masked.

Several component improvement programs are currently in progress. The navy's conventional munitions program includes work on a dual mode (RF/IR) fuze and fuzing against low observable (i.e., stealthy) targets. The 2 projects are closely related, and they were merged in FY88. Raytheon has been conducting a Sparrow low-altitude-fuze product-improvement program (PIP). The preliminary design review was conducted in January 1988, and the first development-test missiles were delivered in October 1988. There is also a Sparrow Missile Homing-Improvement Program; a seeker survey was conducted under the FY89 program.

RIM-7P was operationally evaluated in June 1990, and as of August, a production decision was expected by the end of the summer. The new version should be more effective against low fliers. Work is currently proceeding on the tail-controlled RIM-7R.

SHIPBOARD GUNS AND GUN SYSTEMS

The terms gun and mount are often used nearly interchangeably in this section. In a few cases, the same gun (barrel and breech mechanism) is used in different gun mountings, and the distinction is worthwhile. In most cases, however, a particular combination of gun tube and breech and loading mechanism is always associated with the same mounting, and no distinction is worth making. The term "mount" (or mounting) is generally taken to include the guns it carries, so that one describes a weapon as, say, a twin 40-mm mounting or a twin 40-mm gun.

CHINA

China continues to use a derivative of the Soviet 130-mm twin semiautomatic mount described in the Soviet section; the Soviet guns were used only on board "Kotlin"-class destroyers, now being discarded.

◆ ENG-2

Caliber: 100-mm/56 **Rate of Fire:** 25 rnds/min/barrel
Muzzle Velocity: 916 m/sec [3004 ft/sec]
Maximum Range: 22,500 m [24,600 yd] (maximum altitude, 15,000 m [49,000 ft])
Training Rate: 25 deg/sec (elevation 20 deg/sec)
Elevation/Depression: +85/-5 deg
Ammunition Capacity: 52 rnds ready-service
Weight: 34 tons

This new twin auto-loading 100-mm gun has supplanted the single 100-mm/56 in Chinese production. It arms Jianghu-II- and -III- and Jiangdong-class frigates and has been offered for export on board a projected frigate designation EF30. The mount is servo-controlled by a director. Traverse limits (left and right) 225 deg. Acceleration: 23 deg/sec²/in elevation, 20 deg/sec²/in traverse.

There has been some speculation that the Chinese would manufacture the French 100-mm Compact gun or a derivative, having bought 2 from France.

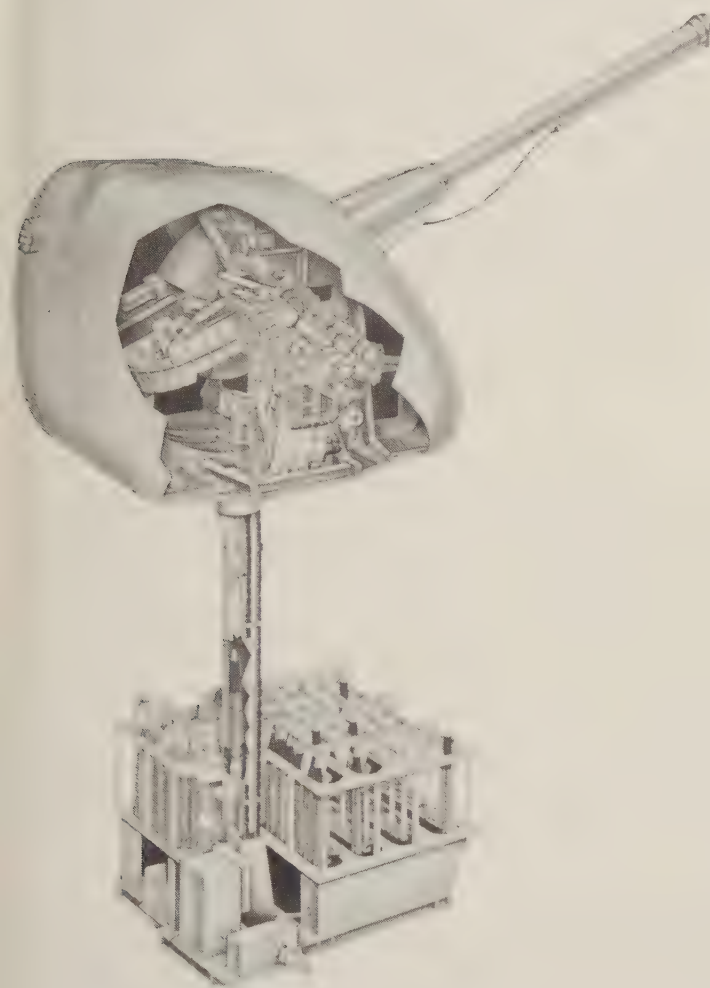
FRANCE

◆ 100-mm

Caliber: 3.9-in/55 (13.5-kg projectile)
Rate of Fire: 90 or 40 or 10 (selectable) rnds/min
Muzzle Velocity: 870 m/sec [2850 ft/sec]
Maximum Range: 17,500 m; maximum effective range 12,000 m for surface fire, 6,000 m for antiaircraft fire [19,100/13,100/6600 yd]
Training Rate: 50 deg/sec (elevation 32 deg/sec)
Elevation/Depression: +80/-15
Ammunition Capacity: 66 or 114 (ready-use)
Weight: 13,500 kg [29,750 lb]



Two 100-mm gun mounts on board the destroyer *Duguay-Trouin*, 1982. (L. Van Ginderen)



The 100-mm Compact mount, showing the ammunition fan feed up the side of the mount and the conveyor that elevates with the gun. (Creusot-Loire)

The 100-mm is the standard French dual-purpose gun mount; the larger 127-mm (5-in) gun formerly mounted on board cruisers and destroyers is no longer in service. In effect the 100-mm replaced both the 127-mm and the contemporary twin 57-mm anti-aircraft gun (see below for details of the surviving mounts) with a single weapon. This 100-mm gun fires a shell heavy enough for shore bombardment but light enough for the gun to achieve a rate of fire high enough for useful anti-aircraft work. 100-mm was the first French-designed fully automatic medium-caliber gun and follows an earlier (Model 1945) twin 100-mm weapon (mounted on the battleship *Jean Bart*). Development of

the 100-mm gun superseded work on a projected 105-mm/60 twin triaxially stabilized mount, which would have used surviving stocks of German ammunition.

Data refer to the export (Compact) version, used in the Portuguese, Saudi Arabian, and Malaysian navies; 2 copies were sold to China (PRC). Most have a 42-rnd magazine; those for Malaysia had 90-rnd magazines. In addition, 18 rds are carried in an intermediate magazine next to the gun (see below for an explanation of these figures).

The Compact mount is a lighter-weight (7.5 tons saved) version of the standard French 100-mm Model 1953 or 1968, Model 1968 being a somewhat lighter version of Model 1953. Model 1968 weighs 22 tons, and its training rate is 40 deg/sec (elevation 25 deg/sec). The rate of fire is 78 rds/min in recent weapons (60 in older ones). Claimed maximum effective range is 15,000 m against surface targets and 8,000 m against air targets, presumably reflecting better steadiness in the older mount. The 1968 version has a 35-rnd ready-use magazine.

The 100-mm Compact can fire preselected 1-, 2-, 3-, or 6-rnd bursts. Ammunition feed is arranged so that rounds can be passed back down into the magazine when others are selected. The ammunition supply consists of a main magazine below the gun, with a 12-rnd secondary magazine (but Creusot-Loire offered 36 rds to the Canadians, for the "City"-class frigate). Both magazines are modular, in 24-rnd palletized units. Rounds are carried up horizontally, by a fixed hoist (duct), into an intermediate 18-rnd magazine that elevates with the gun. From this magazine they are transferred down and around (in a horizontal fan) so that they can be rammed into the breech. Typically the intermediate magazine carries 12 rds (so that it and the secondary magazine carry a total of 24, explaining the figures above). Shells are paired, with an empty space between each pair. The intermediate magazine, which is more typical of smaller-caliber guns, brings the gun into action more quickly and makes for rapid access to alternative types of ammunition.

All of these guns are water-cooled (barrel life 3000 rds), and all have a fuze-setter that allows for adjustments just before a round is loaded into the breech.

Model 1953 (*Jeanne d'Arc*, *Suffren* class, *La Gallissonnière*, *Surcouf* T47 ASW destroyers, and *Commandant Rivière* class) uses an analog FCS with electro-mechanical computer. Model 1968 (*Colbert*, *Tourville* class, *Georges Leygues* class, *Aconit*, *Duperré*, A-69 class) uses a digital FCS. At least in the Compact version, the mount is fully automatic, requiring no on-mount personnel.

In 1980 DTCN announced developmental work on an IR-homing round for this weapon, using a staring IR sensor. DTCN did not expect the IR sensor (which drove fins at the base of the shell) to be sensitive enough to ensure a hit on an approaching sea-skimming missile. Instead, the shell was provided with a proximity fuze and a relatively large warhead. The homing round project was canceled in 1990.

At Bourget Naval in October 1990 Creusot-Loire showed a remotely controlled Compact Mk 2 mount with short reaction time ("power on" to first shot in less than 10 sec). Maximum rate of fire is 90 rnd/min using a 13.5-kg ball prefragmented shell with high-performance fuze. The mount stores 66 ready-use rounds in its basic version (42 of 1 type, 12 each of 2 others) or 114 in a large-capacity version (90 of 1 type, 12 each of 2 others). It allows for instant selection among 3 types of ammunition, has an automatic and reversible reloading system, and has 3 selectable rates of fire (90 [reducible to 85], 45, and 20 [both of the latter are adjustable] rnd/sec). Barrel life is 6000 rnd (3000 heavy rnd). Elevation rate is increased to 35 deg/sec. Standard deviation in firing is less than 0.5 mrad. The main improvements in the design are in operability and reliability.

Creusot-Loire also showed a modernization program, 100TR (*tourelle à technologie renouvée*) with a reduced radar cross section. This version is considered good for at least 7 yr without servicing. Local wear is reduced by remotely locking the movable components when they are at rest (they unlock automatically when the turret starts up).

◆ 57-mm M1951

Caliber: 57-mm/60 (5.73-lb projectile)
Rate of Fire: 120 rnds/min/barrel
Muzzle Velocity: 865 m/sec [2840 ft/sec] [originally 3018 ft/sec]
Maximum Range: 13,000 m (5,000 m effective antiaircraft) [14,200/5500 yd] **Elevation/Depression:** +94/-10 deg
Ammunition Capacity: 80/rnds/barrel **Weight:** 16 tons



A French 57-mm/60 twin gun mount on board the missile destroyer *Dupetit Thouars*, 1964. The radars are U.S.-supplied SPG-51s, to control the Tartar missile shown on its launcher. (U.S. Naval Institute)

The gun is the postwar Bofors 57-mm/60, a scaled-up version of the wartime 40-mm/60. The mount is of French design but retains Bofors's fan-feed system for supplying ammunition. The fan feed is joined at the trunnion axis by an inverted-U feeder-hoist extending down to an automatic-feed ready-service box on the deck of the mount; the total of 80 rnds per gun includes box, feeder hoist, and fan feed. The ready-service box in turn is refilled by hand (at 40 rnds/min) from a hoist turning with the mount, extending down to a handling room below. Bofors produced its own mounting, described in the Swedish section. This once-common gun survives on board the French cruiser *Colbert* and the missile destroyers *du Chayla* and *Dupetit Thouars*, having been superseded in French service by the single automatic 100-mm gun (which is not much heavier).

◆ 30-mm (CAS 62 mounting)

Caliber: 30-mm/70 (0.42-kg projectile)
Rate of Fire: 650 rnds/min
Muzzle Velocity: 1000 m/sec [3280 ft/sec]
Effective Range: 2800 m [3000 yd; maximum range 9300 yd]
Training Rate: 50 deg/sec (elevation 40 deg/sec)
Elevation/Depression: +83/-18 deg
Ammunition Capacity: 215 rnds
Weight: 3620 kg [3920 kg including ammunition] [7980/8640 lb]

This power-operated mount, carrying the HS 831A gun, is found only in the frigates *Balny*, *E. de V. Henry*, *Protet*, and *Victor Schoelcher*. These data may refer to a modified version of the mounting in the *Commandant Rivière* class, since these ships originally had an ammunition capacity of 300 rnds per gun, loaded hydraulically. Other ships in this class are armed with single 40-mm guns.

◆ SAMOS

SAGEM's close-in weapons system (SAGEM Anti-Missile Optronic System) uses the General Electric 30-mm GAU-8/A Gatling gun, the same weapon as in the Dutch *Goalkeeper* (see entry below for details). SAMOS competes with *Satan* for the French Navy CIWS requirement and was announced in 1986. There is no associated radar; the gun relies entirely on electro-optical tracking by a Volcan FCS. That tracking avoids multipath reflections from the sea but is presumably subject to limitations of weather and daylight. The Volcan weighs about 150 kg, containing a biaxially stabilized optical sight for tracking,



SAMOS test-firing. (SAGEM)

plus fixed television, IR, and laser sensors. Gun elevation/depression is limited to +83/-19 deg.

The 30-mm gun can be supplemented by 4 *Sadral* missiles atop the gun mount, to extend maximum range from 2-3 km out to 6 km.

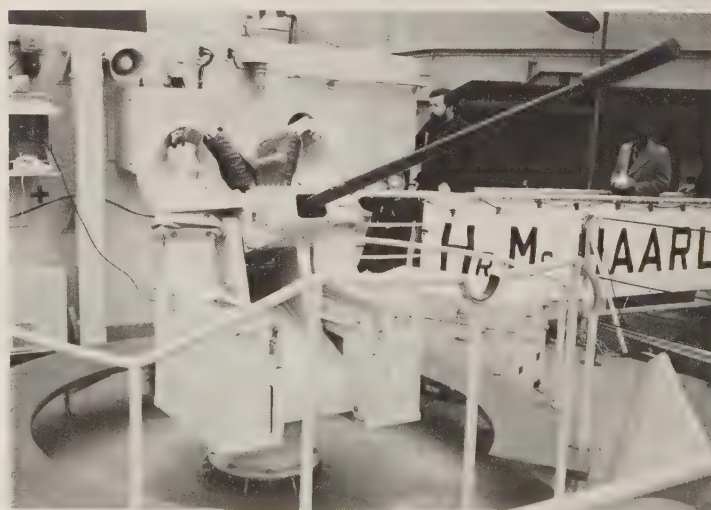
SAMOS was demonstrated at the French navy's Gavres range in October 1987, against a *Rushton* target. The target was engaged at 1100 m, and the first hit was made at 850 m, in the area of the IR flare at the rear of the target. The acoustic miss-distance indicator was destroyed on the 28th round, and the system made at least 3 hits before the target disappeared.

Thomson-CSF ceased to market the competing weapon, *Satan*, when it acquired *Signaal* and the rights to *Goalkeeper*. For the details of *Satan*, see the previous edition.

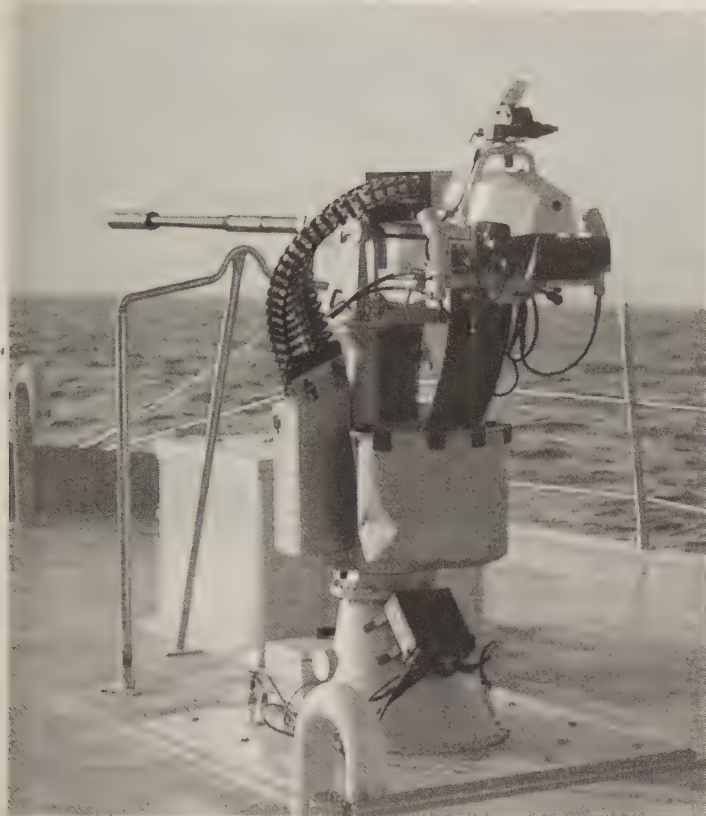
◆ GIAT 20-mm

Caliber: 20-mm/90 (255-g projectile)
Rate of Fire: 650-720 rnds/min
Muzzle Velocity: 1050 or 1250 m/sec [3440/4100 ft/sec] (HE/AP)
Maximum Range: 10,020 or 6,770 m depending on ammunition [10,960/7400 yd]; effective range 2000 or 1200 m [2200 or 1300 yd]
Training Rate: manual
Elevation/Depression: +60/-15 **Ammunition Capacity:** 300
Weight: 336 kg [741 lb] empty **Working Circle:** 2.23 m

The DCAN gun mount for the new GIAT-CN-MIT-20F2 gun has two 150-rnd magazines. This weapon arms the Tripartite minesweepers, and there are also army and air versions. This gun is based on the GIAT CN-MIT 20 M693 (Canon Mitrailleur 20-mm Modèle 693), formerly the Hispano Suiza 820. The naval version entered production in 1983 and is currently used by France, Belgium, the Netherlands, and Indonesia.



A GIAT 20-mm gun (20F2) on board the Dutch minesweeper *Haarlem*, 1987. (R. Cheung)



The French GIAT Affut 15 mounting for the 20-mm M621 gun. The gun fires 750 rounds/min, the mount carries 160 rounds. Elevation limits are $+45/-10$ deg, and total weight (without ammunition) is 167 kg. (GIAT)

At Farnborough in 1988 GIAT displayed a naval version of its M621 20-mm low-recoil gun, which had previously been shown only on land and air mountings. It is typically carried by helicopters and small aircraft. Muzzle velocity is 980–1030 m/sec [3215–3380 ft/sec], depending on the type of ammunition, and cyclic rate is 750 rds/min (an alternate rate, 300 rds/min, is available in the aircraft version). The naval mounting is similar to a land mounting (Army 15A) already shown and carries 160 rds (total weight, presumably without ammunition, is 184 kg [406 lb]), with elevation limits of $+45/-15$ deg. A collimator sight is provided. Recoil is minimized by a muzzle brake and a shock-absorbing mount. Total gun length is 2.207 m [86.9 in], and without the mount the gun weighs 47 kg [104 lb] in its aircraft version.

In contrast to the 20F2, this weapon is 73 calibers long. Development began in the late 1970s, and naval installations began in the mid-1980s. Fifty have been sold, to 4 navies. French-supplied 20-mm guns are used by the Belgian, Djibouti, Gabonese, Indonesian, Madagascar, Mauritanian, Moroccan, Dutch, and Senegalese navies, but many of these weapons may be older 20-mm guns originally made in Britain or in the United States.

◆ GIAT AAT 52 and NF-1

Caliber: 7.5-mm (NF-1, 7.62-mm)
Rate of Fire: 700 rds/min (900 in NF-1) (effective rates: 200–300, 250–300, respectively)
Muzzle Velocity: 832 m/sec (NF-1: 830 m/sec)
Maximum Range: 2000 m (see below)
Elevation/Depression: $+55/-30$ deg
Ammunition Capacity: 200-rnd box
Weight: 17.6 kg empty (25.10 kg loaded) (NF-1)

These are standard auxiliary weapons in the French navy and in the navies of the former French colonies; they are equivalent in function to the U.S. 0.50. The 7.5-mm AAT 52 (*Arme Automatique Transformable Modèle 52*) was the standard postwar French light machine gun; it entered naval service in the late

1950s. The navy uses the heavy-barrel version (with a 23.5-in barrel, rather than the 19.3-in barrel of the light version). The belt feed and delayed-blowback action are derived from those of the wartime German MG42.

NF-1 is a NATO-caliber (7.62-mm) version. These guns are sighted out to 2000 m, but effective range is 1200 m.

The French navy uses a standard pedestal mount (14A) bracketed to a bulwark (data above). There is also a series of Creusot-Loire pintle mounts, designated P127A for the U.S.-supplied 0.50-caliber Browning M2 HB, CP 80A for the 7.62-mm FN machine gun, and CP 52A for the NF-1. With a gun, P127A weighs 82 kg empty and 125 kg loaded. Elevation limits are $+50/-15$ deg.

◆ Laser Weapon

The French weapons development organization, DGA (*Délégation Générale de l'Armement*), is testing a laser weapon, LATEX (*Laser Associé à une Tourelle Experimentale*), a 40-mW laser coupled to an Aerospatiale aiming system. DGA began the program in 1986. In November 1989 it was reported that a laser weapon had been fired at a range of 700 m against a missile head and an aircraft fuselage panel. DGA claims that the laser produces sufficient power, 10 kW/cm², to seriously damage an aircraft fuselage. In 1990 the laser is to be fired at a target flying at 250 m/sec at 2000 m. DGA is seeking European partners for a further laser-weapon program.

GERMANY (WEST)

◆ Mauser Vierling

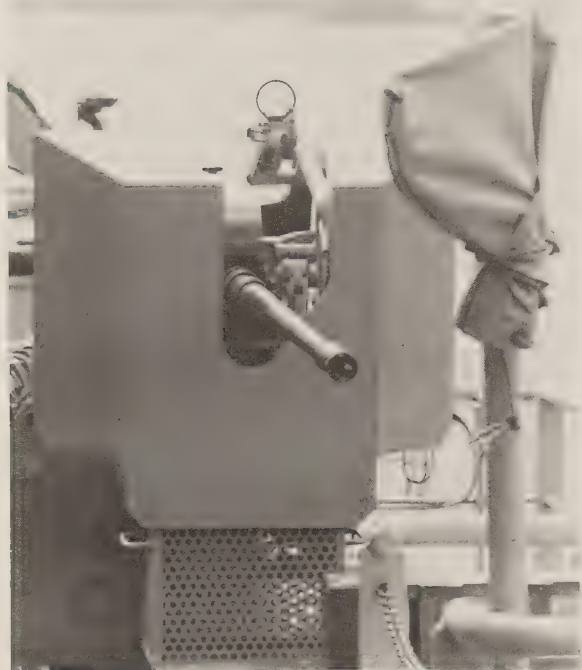
Caliber: 27-mm/63 (1700-mm barrels) (HE, TP, APFSDS ammunition)
Rate of Fire: 1700 rds/min/barrel
Muzzle Velocity: 1200 m/sec [3940 ft/sec]
Training Rate: 150 deg/sec (elevation 150 deg/sec)
Elevation/Depression: $+80/-15$ deg
Ammunition Capacity: 1440 rds
Weight: 3500 kg (including ammunition) in lightweight version (heavier version, approx 4000 kg)

Development of the quadruple 27-mm CIWS (Vierling) based on the Mauser aircraft gun began as a private venture in 1987. The Mauser does not need the half-second warm-up period of other CIWS because it is gas operated rather than electrically operated. A new APFSDS round was developed specifically for this application. The first prototype was completed in 1989. It showed 4 barrels in diamond formation. The magazines (375 rds/gun) are fixed to the base of the mount, feeding their belts to the elevating mass. The project was shelved early in 1990, but it was revived during the year (with some funding from Diehl), and a model of a lightweight mount (with no deck penetration) was displayed at Defendory in October 1990. Its barrels are in 2×2 arrangement, in a massive turret that very nearly covers the guns altogether. Most of the protruding length of each barrel is encased in a box that covers all 4. Although the German navy has been unable to provide development funds, sea trials on board a German fast attack boat are scheduled for 1991. Ultimately, the Vierling may arm German ships without any other specialized antimissile weapon, as well as any future German fast attack boat.

◆ Rhinemetall 20-mm Mk 20 Rh202

Caliber: 20-mm **Rate of Fire:** 1000 rds/min
Muzzle Velocity: 1050 m/sec (HEI-T, TP-T ammunition) or 1100 m/sec (API-T ammunition) or 1150 m/sec (APDS-T) [3440/3770 ft/sec]
Maximum Range: 2000 m effective range [2200 yd]
Elevation/Depression: $+55/-10$ deg
Ammunition Capacity: 200 rds, linked, in 2 boxes
Weight: 408 kg total; 74 kg ammunition [899/163 lb]
Working Circle: approx 2.45 m [96.5 in] radius

This gun was developed in the early 1960s, and a naval version was announced in 1973 on the S.20 pintle fork mounting.



20-mm Rhinemetal gun on board the Irish *Eithne*, 1986. (Author)

The gun is gas-operated, with a rigid bolt, fed by a belt from its right-hand side. On land, it is carried by the Marder APC. The gun is designed to minimize recoil forces and for long barrel life. As offered in 1973, it had only a speed ring sight, although a lead computing sight was offered as an option. Users are West Germany, Greece (on a Wegmann mount), the Bahamas, Barbados, Indonesia, Ireland, and Thailand.

Norway uses the same low-recoil gun in a different mounting designated KV-SK/20 (derived from the FK20-2 field-gun mounting). Elevation limits are $+70/-15$ deg, and the working circle is 1730 mm. Total weight is 400 kg without ammunition. This gun is manufactured by Kongsberg (now renamed Norsk Forsvarsteknologi). Norway also uses this gun in its coast defenses, to protect larger guns from close-in air attack and from infantry.

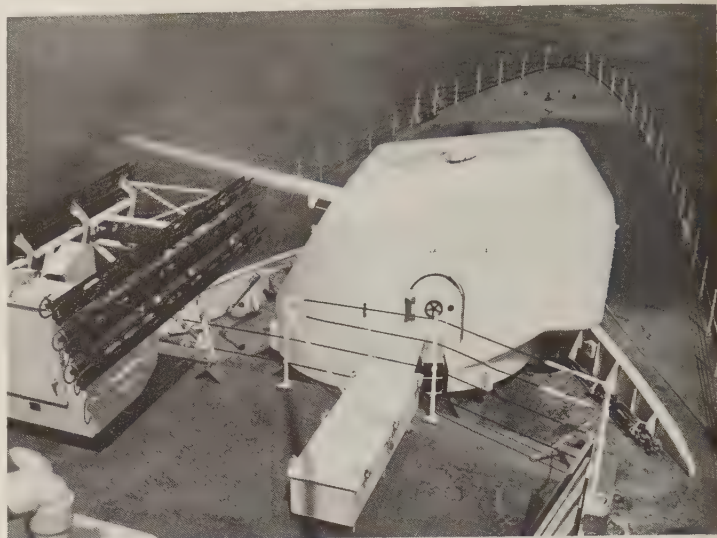
ITALY

◆ OTO-Melara 127-mm/54 LW

Caliber: 5-in/54 **Rate of Fire:** 45 rnds/min
Muzzle Velocity: 807 m/sec [2650 ft/sec]
Effective Range: 15,000 m surface; 7000 m antiair [16,400/7660 yd]; maximum range 23,680 yd
Training Rate: 40 deg/sec (elevation 30 deg/sec)
Elevation/Depression: $+83/-15$ deg
Ammunition Capacity: 66 rnds (3 drums) **Weight:** 37.5 tons
Working Circle: 6.108 m [240.5 in]

This gun is a lightweight equivalent of the U.S. Mk 45, enjoying a higher rate of fire and capable of higher elevation for antiaircraft use. The light weight is achieved by using light alloys and a fiberglass shield. The gun is fitted with a muzzle brake. 127-mm/54 loads from 2 drums, a third being loadable while the gun fires. Each drum can, therefore, be loaded with a separate type of ammunition. The type of ammunition (surface, air, pyrotechnic, or chaff) can be selected during firing. Two oscillating arms (which include fuze-setters) strip rounds from the vertical hoist and place them on loading trays. Mounting reaction time is 5 sec. The ammunition is the standard U.S. semifixed type, the ammunition being brought together only at the bottom of the 2 fixed-structure hoists.

This weapon has been exported to Argentina, Canada, and Nigeria, and is to arm the new Japanese Aegis destroyers.



HMCS *Athabaskan* fires her OTO-Melara 5-in/54 gun, 1980. (Canadian National Defence HQ)

◆ 4.7-in

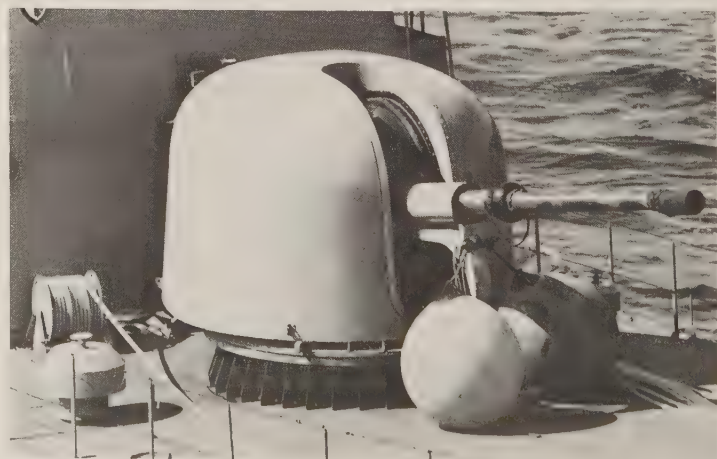
Caliber: 120-mm/45 **Muzzle Velocity:** 850 m/sec [2790 ft/sec]
Maximum Rate of Fire: 7 rnds/min **Training Rate:** manual
Elevation/Depression: $+33/-10$ deg
Maximum Range: 14,500 m [15,900 yd]
Working Circle: 3.96 m radius [155.9 in]
Weight: 16,900 kg [37,250 lb]

This pre-World War II weapon survives only on board Paraguayan *Paraguay*-class gunboats built by Odero in 1931. Presumably the 4.7-in is the 1924 twin destroyer mount carrying the Vickers-Terni gun, data for which are given here.

◆ OTO-Melara 76-mm/62 Compact Mounting

Caliber: 3-in/62 **Rate of Fire:** 85 rnds/min
Muzzle Velocity: 925 m/sec [3034 ft/sec]
Maximum Range: 8000 m surface; 4000–5000 m antiair [8700/4400–5500 yd]
Training Rate: 60 deg/sec (elevation 35 deg/sec)
Elevation/Depression: $+85/-15$ deg
Ammunition Capacity: 80 ready-service (drum magazine)
Weight: 7.35 tons **Working Circle:** 208 in (radius)

76-mm/62 is one of the most successful recent medium-caliber weapons, widely exported. This gun is manufactured under license in Spain and in the United States (as the Mk 75). The single feed drum, holding 70 rnds, surrounds the screw feeder hoist (6 rnds) leading up to a station below the left trunnion. Two arms alternately pick up rounds and place them on a loading drum (4 rnds) at the breech. The drum feeds rounds into a loading tray, which receives the spent cartridge case as



The OTO-Melara 76/62 Compact, on a fast attack boat. (L. Van Ginderen)

the gun recoils. As the gun runs out after recoiling, the tray feeds in the next round. The drum around the base of the hoist can be reloaded while the gun fires. Light overall weight is achieved by using light alloys and a fiberglass shield. Recoil forces are reduced by a small muzzle brake.

The latest version, "Super Rapido," was designed specifically for antiship-missile defense. It weighs 7.5 tons and carries 85 rnds on the mount (selectable 1, 10, or 120 rnds/min; on trials, a gun achieved 139 rnds/min). To achieve much higher rates of fire, OTO-Melara modified the ordnance itself, as well as the feed, the ammunition, and the fuzing. The recoil length and the firing cycle have been shortened. Ramming is no longer part of the sequence in which the spent cartridge is ejected. In redesigning the feed, care had to be taken not to chamber the round at excessive translational speed (which could have damaged it). Some operations are now performed in parallel instead of in series (as in the original Compatto). Because the magazine is now independent of the turret, the feed can be interrupted to insert different types of ammunition, a feature that makes the guided shells described below more attractive. Total firing cycle time has been reduced from 0.7 to 0.5 sec. Accuracy has been improved, partly because the moving parts (which affect accuracy) have been made lighter. The loading tray is particularly critical, in that it moves transversely and thus can shake the gun off aim. In the Compatto, it weighs 50 kg and travels 280 mm, but these figures are reduced to 18 kg and 140 mm in the Super Rapido. Such improvements reduce the standard deviation of shots at 1000 m to 0.3 mrad, some recent small-caliber ASDM weapons have dispersions of over 2 mrad at that range.

Because the feed in the Super Rapido is quite different from that of the earlier Compatto, the earlier guns cannot be converted to the later standard. However, there is a retrofit kit that converts the earlier gun to 100 rnds/min; kits have been supplied for evaluation to the Italian, German, and U.S. navies. The Royal Netherlands Navy has bought 2 kits and has purchased the Super Rapido gun for its M-class frigates. Super Rapido has also been purchased to arm Danish Standard Flex 300s, to arm Singaporean 62-m fast attack craft, and to be the main gun armament of the rebuilt Canadian "Tribal"-class destroyers. The Super Rapido has been adopted for the new Italian *Animoso* class and for the mid-life modernization of the *Audace* class. In the case of the *Animoso*, the Super Rapido replaces the twin fast 40-mm gun of earlier ships of this type.

In the course of developing the Super Rapido, OTO-Melara considered introducing a new low-RCS turret, but decided not to abandon the current shape. The company did harden the turret shell (to resist an overpressure of 1 rather than 0.5 kg/cm²).

OTO-Melara developed a new prefragmented round for the new gun, filled with tungsten cubes rather than the spheres used in earlier shells. This filling shifts more of its total mass toward the outer body as it spins, making for a greater moment of inertia about the projectile's axis and thus for better stability in flight. The shell body is machined inside and outside rather than forged, so the actual center of gravity is very close to the theoretical location, on the shell axis; that makes firing more predictable. This prefragmented shell, made by OTO-Melara and by SNIA-BPD, weighs 6.3 kg and has a lethal radius of 10 m. It incorporates a new proximity fuze to ensure that it will burst ahead of an incoming missile. OTO-Melara is developing a new IR fuze to replace the current doppler type.

There are also 2 new projectiles for surface engagement: SAPOM (6.35 kg, with 0.455 kg of Compound A3 HE) and extended-range SAPOMER (6.5 kg, 0.480 kg HBX-1). Both are semi-armor piercing with base fuzes.

The Italian navy considers Super Rapido an effective anti-missile weapon, as witness its abandonment of the twin Fast Forty in the new *Animoso*. OTO-Melara estimates that, using a Dardo FCS, Super Rapido could begin engaging incoming missiles at about 6000 m, the first rounds arriving at about 5500 m. Given such a long first-engagement range, a single gun should be able to deal with 4 subsonic sea-skimmers, arriving on courses 90 deg apart, before any reached 1000 m.

There is also an older 76-mm/62 (from which the Compact mount was developed), with a muzzle velocity of 850 m/sec, which fires 60 rnds/min. The older gun is recognizable by its more angular gunhouse. This weapon is currently in service only in its single version; a twin mount, with barrels stacked vertically, was its predecessor.

Two course-corrected 76-mm shells are being developed.

OTO and BAe (later joined by Selenia/Elsag and Ferranti) are developing CCS (Course-Correctible Shell); BAe provides the on-board electronics package. First tests were conducted in 1987, then firing trials in 1989, with trials on board an Italian warship scheduled for 1991. There are 6 small thrusters at the shell's center of gravity (the original design called for 10), and 4 fins deployed from the base of the shell reduce the spin rate to the point at which the rockets can be effective. This round can be mixed with conventional unguided rounds. Guidance (for a 1-shot correction of up to 10 deg) is by radio command or modulated laser. The projectiles are not tracked; rather, their course is predicted by the ship's ballistic computer based on known conditions. Projectile length is increased 51%, 355 to 536.5 mm, but the use of light alloys keeps the weight down to 6.3 kg. Fin span is 270.3 mm. Explosive charge is reduced from the present 0.73–0.75 kg, but better accuracy should make for greater lethality. Since the total length of the projectile plus charge cannot be increased, propellant must be reduced, and shell speed is reduced by about 85 m/sec. Effective range is 4–6 km, and shells can be made to deviate up to 400 m laterally from their original points of aim. These shells will be fired at a probable point of interception, then flown toward any new probable point. The cost per round was 15–20 times less than the cost of a point-defense missile such as Mistral. This shell is compatible with the NA 20 and NA 25 FCSs.

Signaal, in collaboration with Diehl of West Germany, is developing CORAS (Correctable Ammunition System). Signaal claims that kill probability vs. incomers is improved by a factor of 4, at less than 25% of the cost of a missile system such as RAM or Sea Sparrow. The shell controller unit is coupled to the ship's FCS, which continuously computes a predicted hitting point (PHP), and relays data to all shells in the air via a simple radio link. The shell corrects course by releasing gas, as in the Bofors corrected-course 40-mm shell. The major problem is the lack of a horizon reference; it was solved by having the shell measure the strength of the up-link electro-magnetic field. As of mid-1989, Signaal was seeking further partners, such as OTO-Melara, Martin Marietta, and Bofors. The ammunition electronics is still under development; in computer simulations, Signaal claims to have improved the range for effective single-shot hit from 600 to around 2500 m. CORAS thus forms a complement to Goalkeeper, filling the gap between close-in gun range and effective missile range (about 3000 m). Several potential customers, including Dutch and FRG navies, expressed interest, and firing trials were conducted in the latter part of 1989.

As of late 1990 it seemed likely that the 2 teams would merge.

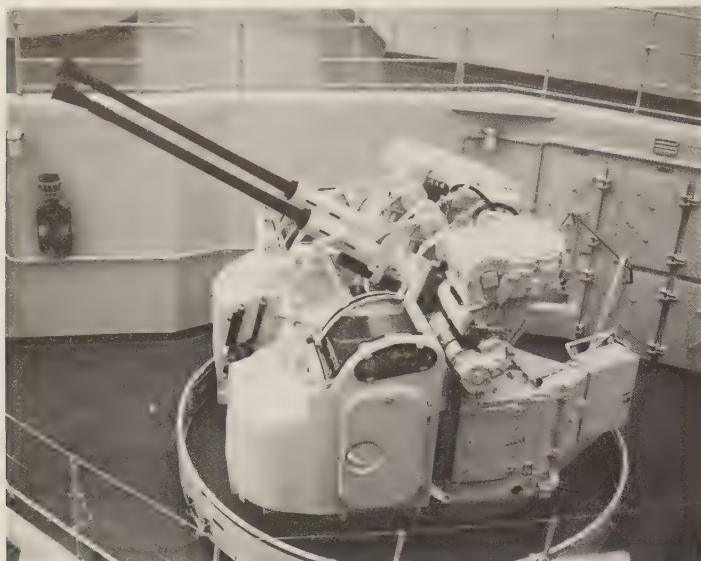
OTO-Melara also offers a dual-purpose (antiship and anti-aircraft) MOM (Multirole OTO-Melara) round. It has a proximity fuze and contains tungsten cubes embedded in the casing. An extended-range round is under development, and there is a new base-detonating delayed-action fuze.

◆ Breda 40-mm

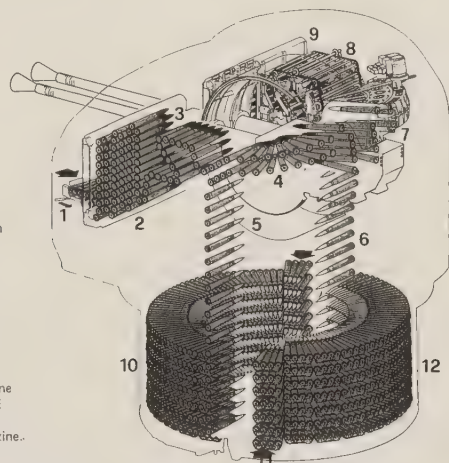
Caliber: 40-mm/70 **Maximum Recoil Length:** 100 m [3.94 in]
Muzzle Velocity: 1025 m/sec (HE) [3362 ft/sec] 1350 m/sec [APFSDS] [4428 ft/sec]
Maximum Horizontal Range (HE): 12,500 m [13,700 yd]
Maximum Altitude: (HE) 8700 m [28,500 ft]
Rate of Fire: 900 rnds/min/mount
Maximum Elevation/Depression: +85/-13 deg
Working Circle: 2.902 m [114.3 in]

Data are for the Twin Fast Forty.

Breda produced 2 versions of the twin 40-mm/70 (see Bofors, below). One was a compact twin mount. It in turn was suc-



A Breda twin 40-mm gun on board the German training ship *Deutschland*, 1985. (R. Cheung)



Ammunition flow in the Breda twin Fast Forty (40-mm) gun. (Breda)

ceeded by the Twin Fast Forty. The main features of the new mount are a new recoiling mass, a dual-feed system, and digital servo control. The new recoiling mass reduces the recoil stroke by better than half to speed the firing cycle. The dual-feed system employs a lower magazine, under the mount platform, plus an upper magazine split between the 2 guns. Both upper and lower magazines feed into each gun.

The Fast Forty exists in 2 magazine versions, Type A (736 HE rnds in 7 horizontal layers) and Type B (444 rnds in 4 horizontal layers). In each case, the upper magazine contains 200 APFSDS (Armor-Piercing Fin-Stabilized Discarding Sabot) rnds.

The Compact version has a similar ammunition capacity and is rated at about 600 rnds/min (300 per gun). Total weight without ammunition is 5500 kg for Type A, 5300 kg for Type B (7300 kg in Type A, 6300 kg Type B, with ammunition). Training and elevation rates are 90 and 60 deg/sec. Breda claims that this weapon shows a much shorter reaction time than the earlier Bofors gun and saves considerable manpower. However, at least when the Compact version is used in the antimissile role, the most important improvement is much greater accuracy. In June 1976 official Italian navy trials showed a mean dispersion of 1 mrad, compared to the manufacturer's estimate of 1.8 mrad. Breda/Bofors calculated that, given an error rate of 3 mrad (which is very conservative), and missile accelerations of 2.8 Gs in the vertical and 4.7 Gs in the horizontal, the gun should have a 30% probability of destroying an incoming air target outside

900 m (i.e., outside the range at which ballistic fragments would be a problem).

In Italian service the usual FCS is Dardo, with an Orion RTN-20X radar (see above under shipboard radars and FCS).

Breda also manufactures conventional open-topped 40-mm mountings carrying air-cooled guns. Type 106 is a twin 40-mm/70; Type 107 is the corresponding single mount. Each gun carries a 32-rnd Breda autofeeder that elevates with the gun, or it can be loaded with the usual 4-rnd clip. Train and elevation speeds are both 95 deg/sec. Type 106 serves in the West German navy (e.g., in the *Hamburg* class).

Type 64 is a twin mount, each gun carrying a 100-rnd automatic magazine. Total weight without ammunition is 7900 kg, and training and elevation rates are 85 and 95 deg/sec.

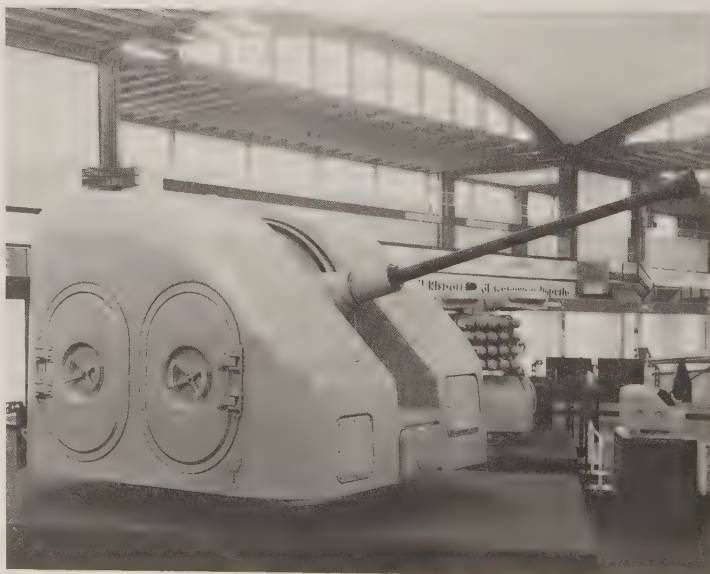
Type 564 is a single 40-mm/70 carrying a Model 1971 144-rnd automatic magazine. This weapon is also marketed as the Breda-Bofors 350P. Total weight without ammunition is 3300 kg. Training and elevation rates are 80 and 45 deg/sec.

For defense against sea-skimming missiles, these guns use ammunition with a special Fratelli Borletti proximity fuze that adjusts its fuzing range to the altitude, to avoid premature bursts. At 40 m above the sea, the burst range is 4.5 m; at 20 m, about 3 m; and at 5 m, about 1 m.

Breda exhibited the prototype of a new single-barrel Fast Forty



Breda twin 40-mm/70 compact naval guns. (Breda)



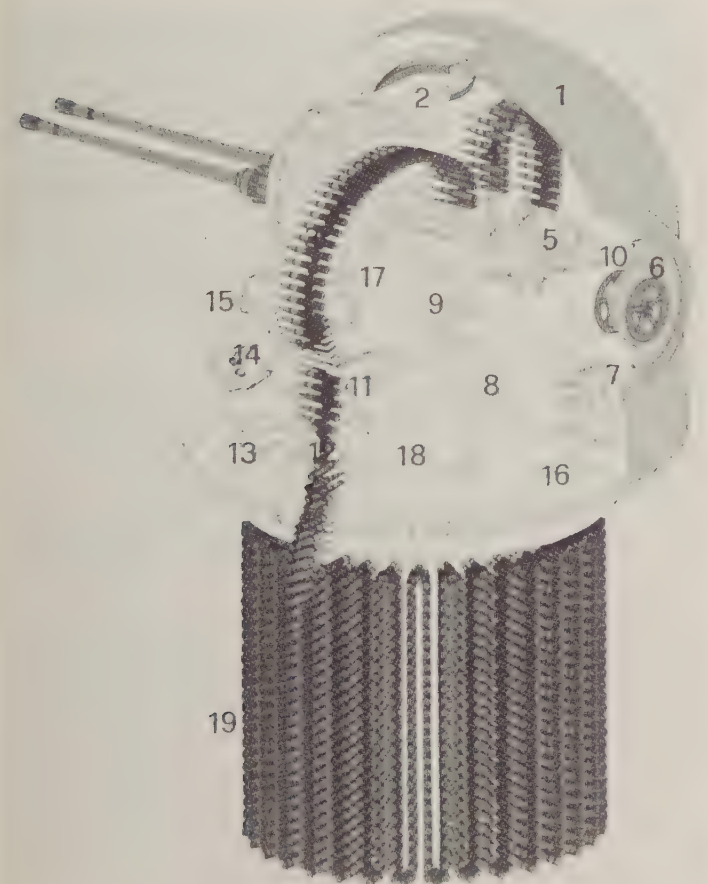
Breda's single Fast Forty mount, on display in 1989. Behind it is the combined chaff and Mistral launcher. (Breda)

antiaircraft cannon at the Mostra Navale exhibition in Genoa in May 1989. There are 3 versions: remotely controlled (Type A) and locally controlled (Types B and C). Type B uses a simple on-mount FCS. In Type C the mount is provided with a micro-computer-based FCS employing a stabilized television line of sight independent of the line of fire and a laser range-finder. Power is provided in part by a converter that accumulates recoil energy as the gun fires. Compared to previous 40-mm/70 weapons, this one uses a new oscillating mass (designed by Breda) that substantially reduces recoil distance (from 230 to 100 mm) and time, allowing a higher rate of fire (450 rnds/min compared to the previous 300 rnds/min). Changes include a new rammer taking the round directly from the feed position to the breech-block closing position. The mount carries two 42-rnd magazines, and 5 more rnds are accommodated in the gun feeder and hopper, for a total of 89 rnds on the mount. Elevation limits are $+83/-13$ deg.

Breda claims that a twin Fast Forty, firing 900 rnds/min, can kill an incoming supersonic missile, flying a straight path, using proximity-fuzed bursts, at a range as great as 3000 m. At such ranges it is probably sufficient to destroy the missile's control surfaces. The mount automatically shifts to the heavier APDS rounds when the missile reaches a range of 1000 m.

◆ Oerlikon/OTO 35 mm

Caliber: 35 mm/90 (1.56-kg round, including 550-g shell) [3.43/1.21 lb]
Rate of Fire: 1100 rnds/min (550 rnds/min/barrel)
Muzzle Velocity: 1175 m/sec (3850 ft/sec)
Maximum Range: 6000 m (5000 m air target) [6600/5500 yd]
Training Rate: 120 deg/sec (elevation 70 deg/sec)
Elevation/Depression: $+85/-15$ deg
Ammunition Capacity: 800 (400/barrel)
Weight: 6400 or 6600 kg with ammunition (through- or above-deck version) [14,100/14,500 lb]
Working Circle: 3500 mm [137.8 in]



1 - Gunhouse of reinforced fiberglass. 2 - Mantlet plate. 3 - Left feed belt. 4 - Right feed belt. 5 - Mauser elevating mass. 6 - Access door. 7 - Training power drive. 8 - Spent case and link deflector chutes. 9 - Elevation toothed sector. 10 - Firing mechanism. 11 - Booster. 12 - Guide. 13 - Firing limiting device. 14 - Elevation power drive. 15 - Spent case and link evacuation tubes. 16 - Training lock. 17 - Elevation lock. 18 - Auxiliary junction box. 19 - Magazine.

Breda twin 30-mm compact mounting. [Breda]

This Oerlikon type GDM-C can be compared to the Oerlikon-Bührle GCM-A01 manufactured under license in Britain (see British guns below). 35-mm was produced as a private venture, and its design emphasizes light weight. Unlike the Swiss mount, the OTO-Melara mount carries its 2 guns on either side of a central mass. A special dual feed allows a choice, for each gun, between the main ammunition container and a separate container holding 20 rnds of special ammunition. The 2 guns are KDAs, slightly lighter than the clip-fed KDCs of the Swiss mount.

To reduce weight, OTO-Melara used aluminum extensively in the mount and also used a watertight fiberglass shield. The unit as a whole is interchangeable with the OTO-Melara 76/62 Compact gun. The design emphasizes quick reaction, and time from off to fire is 2.6 sec. High muzzle velocity and low drag make for short time of flight, e.g., 6 sec to 4400 yd.

This gun was very nearly selected as the main armament of the U.S. *Perry*-class frigate, but the OTO-Melara 76/62 (U.S. Mk 75) was chosen instead. Similarly, 35-mm was nearly selected for the *Pegasus*-class hydrofoil. The U.S. Navy bought 1 mount for evaluation, but no trials were conducted.

◆ Breda 30-mm

Caliber: 30-mm/82 (369-g projectile) [0.813 lb]
Rate of Fire: 800 rnds/min
Muzzle Velocity: 1040 m/sec (HE) [3410 ft/sec] 1220 m/sec (APDS) [4000 ft/sec]
Maximum Range: effective range 3000 m (time of flight 5.36 sec with HE round) [3300 yd]
Training Rate: 140 deg/sec (elevation 80 deg/sec)
Elevation/Depression: $+85/-13$ deg
Ammunition Capacity: 160 rnds
Weight: 1200 kg empty/1330 kg loaded [2640/2930 lb]
Working Circle: 2.72 m [107.1 in]

This Breda single mounting for the German Mauser MK 30-mm Model F gun uses a dual feed and standard NATO ammunition (as in the U.S. GAU-8). In effect 30-mm is a scaled-down version of the Breda twin 40-mm gun. The 30-mm gun was announced in 1984. A new locally controlled version was announced in 1986. It is gyro-stabilized and joystick controlled using optics that are line-of-sight stabilized. Aim-off is automatically calculated while the target is kept in sight. Breda claims that the new version should be effective against surface targets at up to 3000 m.

There is also a twin compact version, announced in 1980, carrying 1100 (Type B) or 2000 (Type A) rnds. Training and elevation rates are 130 and 75 deg/sec. Elevation limits are



Breda single compact 30-mm mounting. [Breda]

+80/-13 deg, and the working circle has a radius of 2.523 m. Marconi and Breda jointly proposed a close-in version of the twin 30-mm mount using a collocated Marconi 440-series radar mounted atop the shield, under the designation Sea Cobra. This weapon was tested in England (on the Fraser Gunnery Range) in the early summer of 1988, against Rushton targets. The first operational installations were made in 1987, for the Italian Customs Service.

◆ Breda-Oerlikon 25-mm KBA

Caliber: 25-mm/80 **Rate of Fire:** up to 600 rnds/min
Muzzle Velocity: 1100-1360 m/sec [3600-4460 ft/sec]
Maximum Range: see below
Training Rate: manual (power-assisted)
Elevation/Depression: +50/-15 deg
Ammunition Capacity: 200 rnds
Weight: 660 kg without ammunition [1455 lb]
Working Circle: radius 2.31 m [90.9 in]

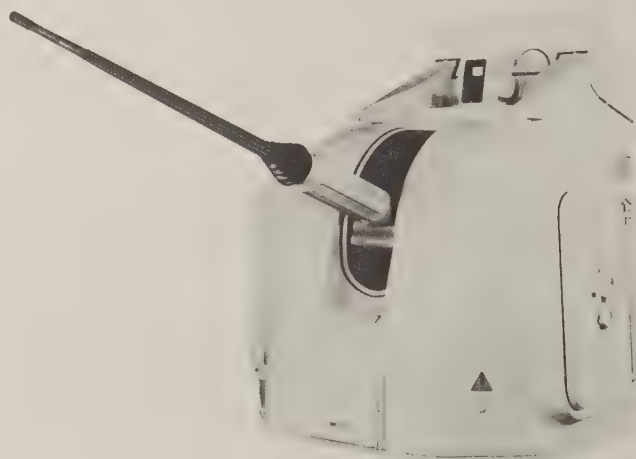
This weapon, announced in 1988, is the first result of a new collaboration between Breda and Oerlikon Italiana. KBA is intended as a direct replacement for the earlier manual 20-mm gun. Firing much more powerful ammunition, it is too heavy to handle entirely manually, particularly on board a lively ship. The mounting, therefore, provides hydraulic power assistance, not at all times, but only when power is needed. Power assistance is triggered by the amount of inertia resisting the gun's movement. In effect, the power assistance cancels out the unpredictable inertial forces due to ship motion, so that the gunner always applies only the degree of force that would be needed if the ship were not moving at all. The gunsight, which is ranged out to 2000 m, is fixed to a parallelogram system: the gunner can remain standing at any gun elevation, instead of having to crouch uncomfortably as in earlier manually operated guns. Light alloy construction is used to hold down the total weight of the mounting. This weapon retains the dual-feed system of the earlier land-based KBA gun, permitting the mounting to be reloaded while it is still available to fire.

Breda has now mounted the Oerlikon 25-mm KBB gun in versions of its existing 30-mm and 40-mm mounts. The first such weapons were displayed at the Mostra Navale exhibition in Genoa in May 1989: single and twin mountings.

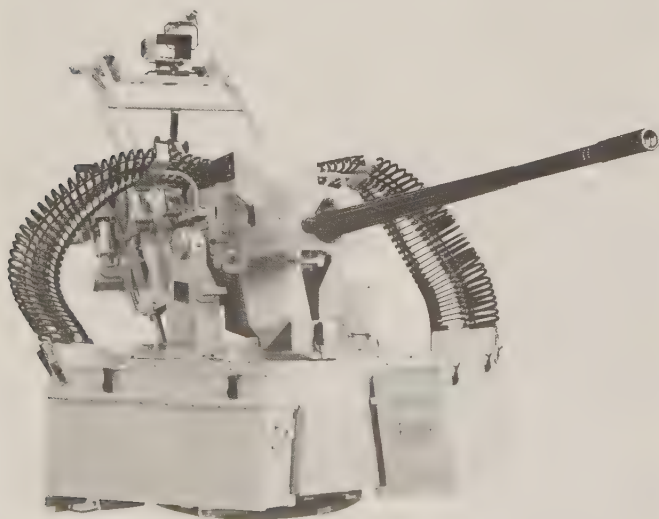
The single mounting employs dual-feed (two 80-rnd boxes) and on-mount buffer batteries sufficient for up to two hundred 360-deg rotations (or their equivalent in elevation and depression). They are charged by the ship's power, and they permit gun operation to continue in the event ship's power is no longer available. The locally controlled mounting employs a Breda



The Breda twin 25-mm mounting. (Breda)



The Breda single 25-mm mounting in locally controlled form. (Breda)



The Breda-Oerlikon 25-mm KBB gun. (Breda)

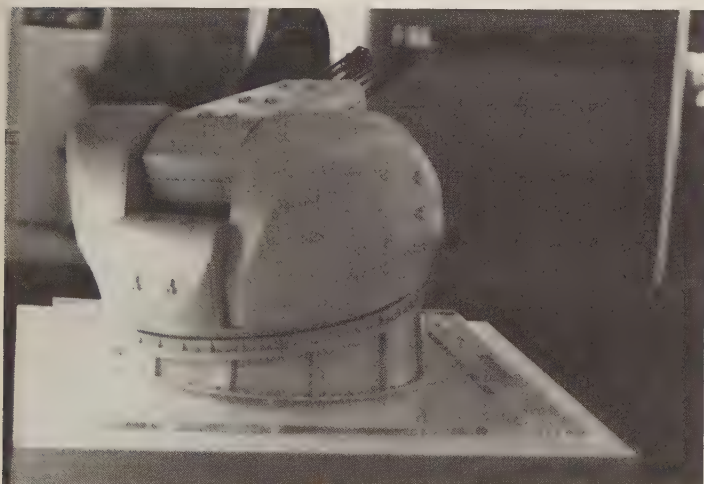
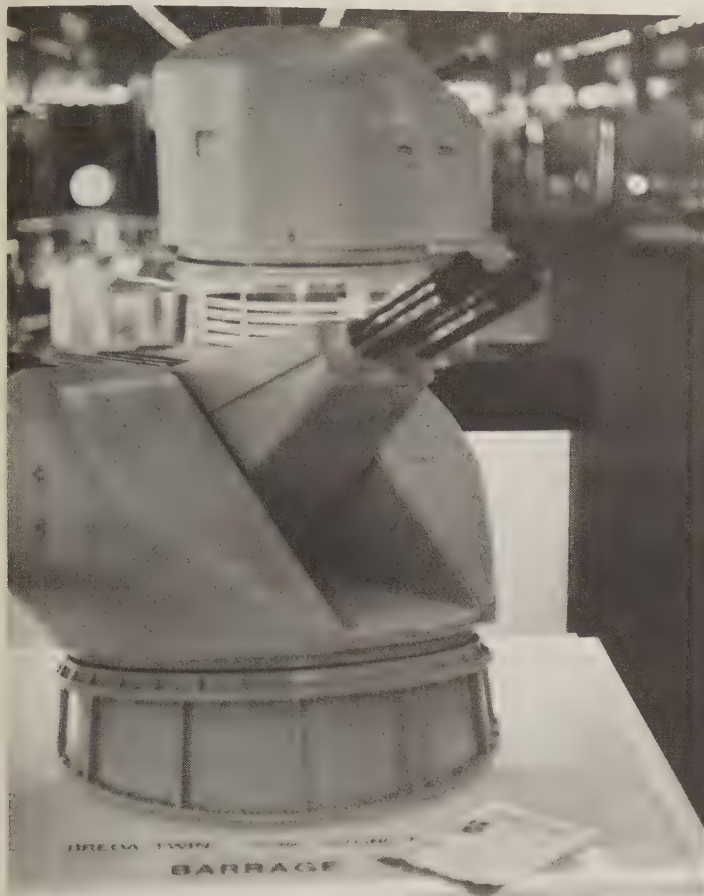
Hawkeye micro-FCS, employing an independent stabilized line of sight. Target tracking is computer-aided (the computer projects ahead a straight trajectory), and range is estimated by using precalibrated reticules (for example, the operator opens fire when the target image coincides with a circle of predetermined lens magnification). The mount can be fitted with an LLLTV in place of the usual daylight television camera, and it can be controlled remotely.

The twin 25-mm mounting employs a specially designed Breda cradle, the bore axes being set unusually close together for accuracy. There are 3 alternative magazine arrangements: Type A (2000 rnds), B (1000 rnds), and C (500 rnds, on the rotating platform).

◆ Myriad

Caliber: 25-mm **Rate of Fire:** 10,000 rnds/min
Muzzle Velocity: 1270 m/sec **Maximum Range:** effective range 1000+ m
Training Rate: 3.0 rad/sec (train 2.5 rad/sec)
Ammunition Capacity: 2000 rnds
Weight: 7700 kg (including ammunition)

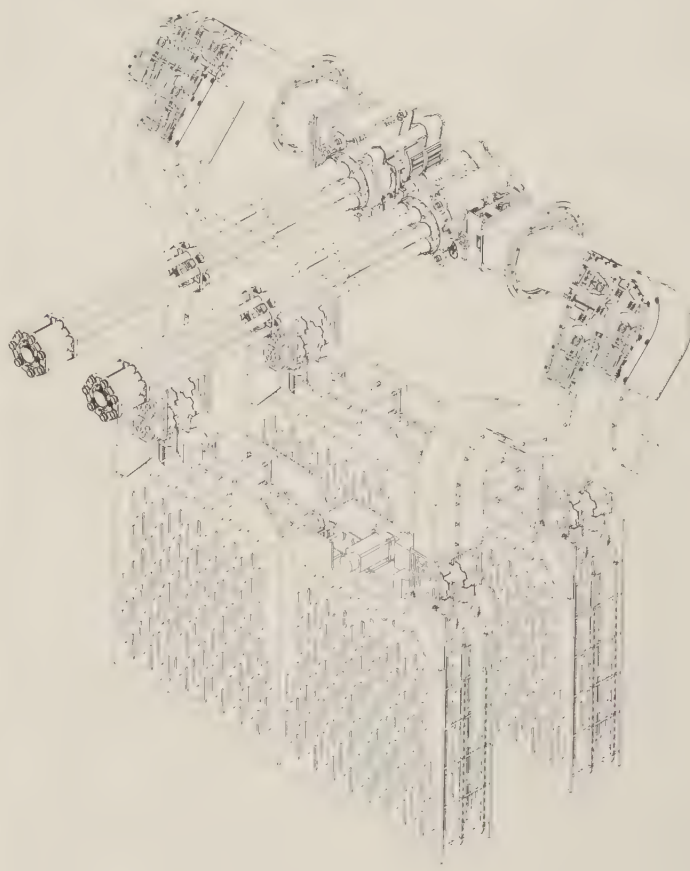
This new CIWS, first displayed at Mostra Navale in Genoa in 1989, is a joint venture by Breda, Contraves Italiana, Elsag, and



A model of the new Myriad close-in defensive weapon, at the Paris Air Show, 1989. The canted platform is similar to that employed in the Seaguard system (which Contraves manufactures). As in Seaguard, the director is separate from the mounting. (Author)

Selenia. It employs a pair of Oerlikon 7-barrel 25-mm KBD Gatling guns, which fire the high-velocity ammunition of the Oerlikon KBB gun. KBD is the first application of the Gatling principle to Oerlikon weapons. The associated director carries a pair of radars, a Ka-band (35 GHz) set for acquisition and a W-band (95 GHz) set that takes over at short ranges. With a much narrower beam, the W-band radar suffers less from multipath (reflected in radar nodding).

The logical basis of Myriad is the contention that next-generation antiship missiles will be both supersonic and highly maneuverable, so they may well evade weapons whose FCSs have to predict target motion. Hence, it will be impossible to hit an incoming missile at any great range. The Myriad devel-



Twin 25-mm Gatling guns of a Myriad mounting, showing ammunition feeds. (Breda)

opers argue that, no matter how it maneuvers, a missile must attack a ship through a relatively constricted window close to the ship. The Myriad FCS, built by Elsig, uses known aerodynamic features of the missile to predict the location of the window, 500–1000 m from the ship. The very high rate of fire developed by the twin guns, 10,000 rnds/min, saturates this window. The ammunition is a special AMDS (antimissile discarding sabot) type, using a tungsten-alloy rod penetrator 14.5 mm in diameter (mass 156 g). As in the U.S. Phalanx, the kill mechanism is penetration of the missile warhead to ensure its detonation; the manufacturer argues that only such destruction will ensure against missile fragment damage to the ship. Muzzle velocity of the AMDS round is 1270 m/sec (1285 m/sec for the APDS-T round). Remaining velocity at 500-m range is 1190 m/sec; time to 500 m is 0.41 sec. Remaining velocity at 1000-m range is 1113 m/sec (time to 1000 m is 0.84 sec).

The gun itself has a new patented antihangfire safety mechanism, which precludes firing ammunition from an unlocked breech.

Like the existing Seaguard weapons, Myriad is mounted on a tilted platform, so it can engage zenith attacks. The mounting carries 2000 rnds in 4 boxes, 2 per Gatling (so that each gun can switch between 2 types of ammunition). Total weight, including ammunition, is 7700 kg. Each of the 2 guns weighs 1600 kg, including its 1000 rnds of ammunition.

Gun and director are connected to a standard MAGICS console via the standard 10-Mbit/sec data bus (MHIDAS); the system is arranged so that many trackers and many guns can be interconnected through a single bus. The system can accept search-radar data and conduct its own threat evaluation before firing.

The Myriad program started in 1988, and the prototype should be completed in 1990, with integration and testing completed by the end of 1991, and firing trials in 1992. It may be offered to the Italian navy to replace Dardo in new ships.

NETHERLANDS

◆ Goalkeeper (SGE-30)

Caliber: 30-mm **Rate of Fire:** 4200 rnds/min
Muzzle Velocity: 3318 ft/sec (3900 ft/sec firing discarding sabot ammunition, MPDS)
Maximum Range: Engagement range about 2000 m [2200 yd]
Training Rate: 100 deg/sec (elevation rate 80 deg/sec)
Elevation/Depression: +85/-25 deg
Ammunition Capacity: 1200 rnds
Weight: 14,018 lb loaded plus 7766 lb off-mount
Working Circle: 100 in

This close-in weapon developed by Signaal and General Electric uses the latter's 30-mm 7-barrel GAU-8/A Gatling gun. A linear-array X-band search radar on the mount (1.5 × 30/60-deg beam, scanning at 60 rpm) relays the target's range and bearing to the dual-frequency (X- and Ka-band) tracking radar (which uses a Cassegrain dish) on the gun mount. The beamwidth of the X-band tracker, 2.4 deg, is larger than that of the acquisition radar, to assure very rapid acquisition without search. Once the X-band tracker has acquired the target, the 0.6-deg beam of the Ka-band tracker takes over. In automatic operation, the radar limits itself to targets in a 2-7 km range bracket, and with radial speeds of over 150 m/sec. Total reaction time against a Mach 2 sea-skimmer, including automatic detection, IFF interrogation, 90-deg tracker slew, tracker elevation, X-band lock-on, and computer run-in, is about 5.5 sec, the engagement beginning at 1.5 km with maximum kill probability at 300 m. The radar is derived from the Signaal Flycatcher ground AA unit.

The system, using data from its radars, automatically and continuously evaluates and prioritizes targets. Signaal claims that the use of Ka-band (8-mm wavelength) provides a very narrow beam that avoids reflections off the sea (even against sea-skimmers) and, thus, produces no deceptive mirror images. The broader X-band tracker radar captures the designated target, and the signal/noise ratios of the X- and Ka-band tracker radars are continuously and automatically compared to reject clutter and jamming. Both radars have standard anticlutter and ECCM features, such as pulse compression, pulse-to-pulse coherence (for doppler-MTI tracking), frequency diversity, and flexible waveforms (adaptive transmission). Tracking is by monopulse in both frequency bands.

This system employs closed-loop spotting of the type used in Phalanx.

The 30-mm Gatling gun in its EX-83 mount is also the basis of the French close-in weapons, SAMOS and Satan. Signaal chose the GE Gatling gun in preference to the Mauser 30-mm gun, for which Goalkeeper was originally designed, because the quadruple Mauser (SEM-30) could not meet a Dutch navy requirement for 1.7-mrad dispersion; SGE-30 demonstrated 1.2-mrad dispersion in a 6-sec burst (420 rnds).



Goalkeeper on board HMS *Invincible*, 1990. (E. Grove)

Signaal demonstrated the GAU-8/Flycatcher combination in November 1979, against targets at a range of about 1000 m; Goalkeeper is the result, the Dutch navy choosing the GE gun over the Mauser gun in mid-1980.

In 1983 the Royal Navy chose Goalkeeper rather than the VSEL Sea Dragon, a similar EX-83 gun controlled by a masthead Sea Giraffe 150HC and an on-mount tracker derived from the DN181 millimeter-wave radar of the Rapier blind-fire system. Reportedly, this choice was based more on political and economic than on technical factors.

NORWAY

◆ NFT Armored Turret

The projected Norwegian fast attack boat will use a version of the new NFT armored turret developed for vehicles; it is also used (in more heavily armored form) in Norwegian coast defenses (carrying a Rhinemetal 20-mm gun). The power-driven turret, which is controlled by joystick, can carry a 20- or 25-mm gun. It can also operate manually if power is interrupted. The FPB version will carry more ammunition than the standard vehicle version described here.

The NFT turret was developed (with Hagglund of Sweden) for the M 113 armored personnel carrier; initially, this single-operator, welded-steel turret carried an Rh 202 cannon. Ultimately, it carried a Mauser 25-mm Model E cannon with a coaxial 7.62-mm MG 3 machine gun. The combat weight of this version (including 1000 rnd) is about 1000 kg. The bearing ring diameter is 1.2 m. Elevation limits are +50/-10 deg. Power train (not elevation) is up to 90 deg/sec. A newer version, with a higher profile (height 0.605 m above the vehicle roof), carries a dual-feed Rh 202 (200 rnd of 20-mm) and a coaxial 7.62-mm MG 3 (400 rnd) and weighs 850 kg. There are 2 speeds for manual train (there is no power option). Swept radius is 2.3 m.

◆ Raufoss Antiship Warheads

These delayed-action penetrators were developed for the Royal Norwegian Air Force and Navy and are intended to pass through 3-12 mm steel at 0-60-deg impact angles, exploding 2 or 3 m inside the target (average detonation delay is 5 msec). The usual explosive (composition A3) is supplemented by persistent incendiary material in the shell and is intended to ignite diesel oil, bunker fuel, and lubricating oil. The current family consists of:

M78 for 3-in/50 naval guns. This is the only member of the family that lacks incendiary material.

RA79 for 2.75-in aircraft rockets, carrying 460 g of explosive and 70 g of incendiary. Total warhead weight is 5.91 kg. This warhead is designated HEISAP, high-explosive incendiary semi-armor piercing.

M85 for 105-mm coastal artillery, carrying 1.7 kg of A3 and 60 g of incendiary; total weight is 15.1 kg.

M88 for 127-mm coastal artillery, carrying 3.2 kg of A3 and 60 g of incendiary; total weight is 28 kg.

Raufoss also makes training projectiles (TP) for 3-in/50 and 105-mm guns and for the 2.75-in aircraft rocket.

These warheads were first exhibited in 1990. They follow earlier Raufoss work on armor-piercing/incendiary machine-gun and machine-cannon rounds. See the U.S. 0.50-cal machine gun entry for details (the 0.50 is probably the most interesting naval application).

SPAIN

◆ Meroka

Caliber: 20-mm/120 (round weight 320 g, including 102-g projectile) [0.71/0.225 lb]
Rate of Fire: 2 bursts/sec (9000 rnds/min during burst that lasts 0.080 sec)
Ready-use Ammunition: 720 rnds (60/barrel) (2160 in future version)

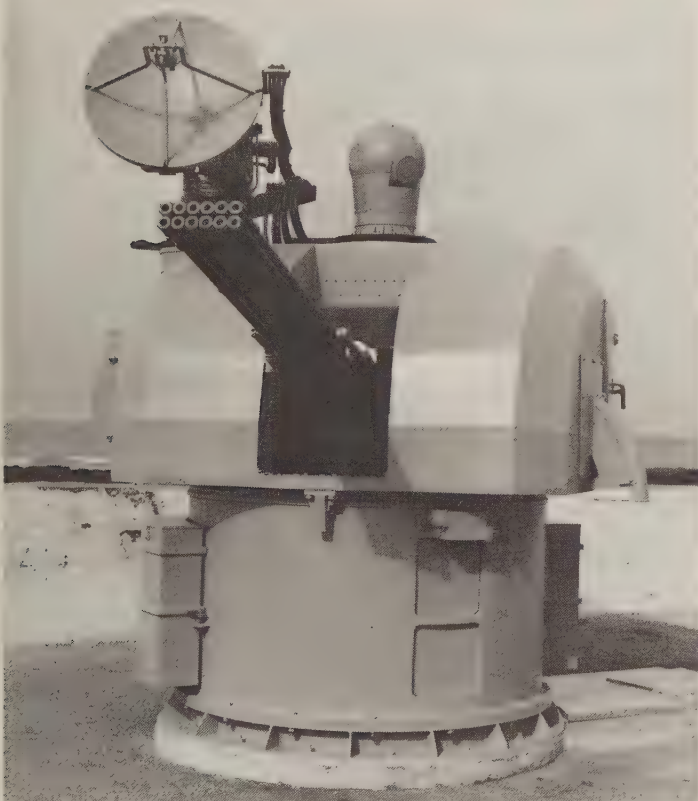
Muzzle Velocity: 1300 m/sec [4260 ft/sec]
Maximum Elevation/Depression: +85/-15
Weight: 4500 kg on mount; plus 421 kg off mount [9920/928 lb]

A close-in weapons system developed by the Spanish manufacturer Bazan, Meroka is mounted instead of the U.S. Phalanx on board Spanish equivalents of U.S. warships (*Perry* class and the Sea-Control Ship *Principe de Asturias*). Meroka is designed to operate on the basis of target detection (by an associated search radar) at 15,000 m, using its own I-band tracking radar to acquire targets at 5000 m, and achieving first impact at 1500 m and target destruction at 500 m [16,400/5500/1640/550 yd].

Targets are tracked by monopulse, using an on-mount Lockheed Electronics PVS-2 Sharpshooter. In current Spanish installations, targets are designated via a Selenia RAN-12L/X search radar via a Selenia PDS-10 tactical-data console. There is no closed-loop spotting. An optronic system is provided for backup in a jamming environment, and there is an off-boresight tracker to deal with extremely low targets.

Bazan claims that the ammunition is a special hard-core type, for maximum penetration of missile bodies.

The twelve 20-mm barrels are arranged in 2 horizontal rows, very close together.



Meroka. (Bazan)

◆ Sardin

Sardin is a Meroka replacement now under development by Bazan. Reportedly, it will be a hybrid weapon (presumably, guns and missiles); presumably, this project was the reason Spain entered the NATO VSRAD consortium.

SWEDEN

◆ Bofors 6-in DP

Caliber: 152-mm/50 (101-lb shell, 71.8-lb cartridge)
Rate of Fire: 12-15 rnds/min/gun **Muzzle Velocity:** 2950 ft/sec
Maximum Range: 28,400 yd
Elevation/Depression: +60/-10 deg
Weight: 113 tons (no ammunition)

This dual-purpose cruiser gun was designed beginning in 1937, primarily for the Dutch navy. When the Netherlands was

overrun, twin and triple mounts were diverted to the Swedish *Tre Kronor*-class cruisers. These ships have now been discarded, but twin mounts remain on board the 2 former Dutch *de Zeven Provinciën*-class cruisers in the Peruvian navy. Those mounts represent 1 generation of technology beyond the Soviet's triple 6-in mount (*Sverdlov* class) and are roughly comparable to U.S. wartime automatic heavy guns (6-in/47, now discarded, and 8-in/55, in the *Des Moines* class).

This weapon is unusual in that the shell and cartridge case are stowed separately (for ease of handling) but are rammed together into a single round on a cartridge carrier before hoisting to the gun; the weapon, therefore, enjoys the advantages of fixed-round loading. The breech is a vertical sliding wedge, and the loading tray elevates with the gun for all-elevation loading. The design was criticized by British observers on the grounds that the ramming together of shell and cartridge case demanded extraordinarily close production tolerances.

Armor: 4.9-in face and rear, 2-in roof, 1.2-in sides.

◆ Bofors 4.7-in/50 (120-mm)

Caliber: 120-mm/50 (21-kg HE shell; 40-kg complete round) [46.3/88.2 lb]
Rate of Fire: 45 rnds/min/barrel
Muzzle Velocity: 850 m/sec [2790 ft/sec]
Maximum Range: 13,000 m surface fire; 7000 m antiaircraft [14,200/7700 yd]
Training Rate: 25 deg/sec (elevation 40 deg/sec)
Elevation/Depression: +85/-10 deg
Ammunition Capacity: 104 rnds (52/gun)
Weight: 55 tons (67 including rotating platform and ammunition)

Data refer to the twin destroyer mount, which was manufactured for the Swedish, Dutch, and Colombian navies. This gun survives in the 2 Dutch *Tromp*-class destroyers and in several ex-Dutch destroyers transferred to the Peruvian navy. The Swedish and Colombian ships have been discarded.

The twin 4.7-in gun was developed by Bofors (beginning in 1944) as an intermediate weapon between the 6-in/50 and the 57-mm/60. Bofors developed 3 types of loader, a horizontal fan (which was used in the 57-mm mount), a vertical fan, and a pendulum swinging up from the vertical ammunition hoist to the breech. In each case, the loader had to be able to accept rounds at any elevation and then shift them to the elevation of the breech. The pendulum was chosen for this mount. Its arm is pivoted at the trunnion, and it swings between the top of the hoist and a loading position behind the breech; rounds are rammed from the top position directly into the breech. After ramming, the round debullets, i.e., the shell separates from the cartridge case and seats. Bofors claims that this process decreases barrel wear and also retains the cartridge case more firmly in the chamber until the breechblock has closed sufficiently.

Each of the 2 hoists has two 26-rnd hoppers at its bottom, so that both surface and AA ammunition can be carried. It takes 5-15 sec to switch ammunition by turning the hoppers to line up the unused one.

This mount was considered extremely advanced when it appeared in 1950, and about 1953 the Royal Navy considered adoption. The mount was rejected: it was too heavy, too noisy, and not flash- or gas-tight. Reportedly, the Dutch navy found the mount rather too heavy (and vibrations too violent during rapid firing) for the 2700-ton destroyers.

Bofors also developed a single automatic mount of this caliber, designated TAK 120L/50-93, for destroyers or frigates. In Swedish service, this mount would have replaced the twin 120/50 in a later-generation destroyer, but that project died when Swedish naval policy shifted to an emphasis on small coastal craft and submarines. Rate of fire was 70 rnds/min (with a water-cooled barrel), using twin-drum magazines below the mount; range was 21,000+ m (time to 10,000 m was 19.2 sec). Elevation limits were +78/-10 deg. Training speed was 40 deg/sec (elevating speed 30 deg/sec). Total mount weight was 57 tons, including the foundation (with control room) and 300 rnds, and the gunhouse was built of 10-mm steel. Each round weighed



The Dutch cruiser *de Ruyter* (now Peruvian) shows both the Bofors twin 6-in and twin 57-mm/60 (superfiring above the 6-in turrets) guns. (U.S. Naval Institute)

40 kg. The entire mount could be laid by 1 operator, and the gun was liquid-cooled so that it could sustain a high rate of fire. The turret had an unusually low profile. Ammunition feed was by a dual swinging arm (as in the twin 4.7-in gun). The crew was limited to 3. Work began about 1956, the goal being a single self-contained unit including on-mount fire control (as in the contemporary U.S. GUNAR), firing 60 rnds/min. This weapon is interesting as an example of what might be possible if the Swedish navy continues toward larger craft, as it now seems to be doing.



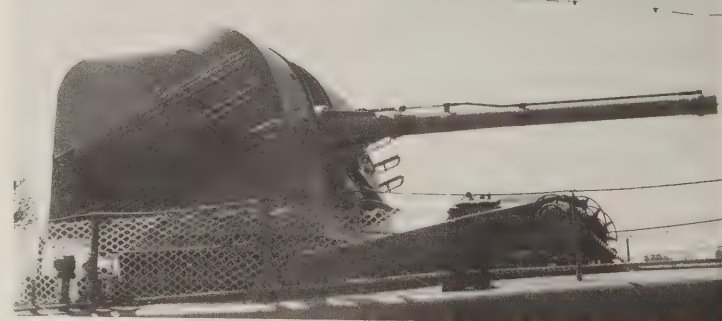
Bofors 4.7-in/50 on board the Dutch destroyer *Friesland*, now discarded (however, sisters are retained in the Peruvian navy). The surface-search radar is the Signaal ZW-01 (now replaced by ZW-06 in the surviving ships); the radar on the foremast is DA-01, and the big air-search antenna aft belongs to LW-02. The fire-control radar is M 1. The foremast carries the standard British DF antennas: FH 4 at the foretop and UA-2 below, for HF and UHF, respectively. (U.S. Naval Institute)

◆ Bofors 4.7-in/46

Caliber: 120-mm (21-kg HE shell, complete round is 35 kg) [46.3/77.1 lb]
Rate of Fire: 80 rnds/min
Muzzle Velocity: 800 m/sec [2620 ft/sec]
Maximum Range: 18,500 m [20,200 yd]
Training Rate: 40 deg/sec **Elevation/Depression:** +80/-10 deg
Ammunition Capacity: 52 rnds ready use (plus 16 in mount)
Weight: 28.5 tonnes (without ammunition or flare launchers)
Working Circle: 6.33 m [249.2 in]

This dual-purpose enclosed gun, for large fast attack craft displacing 600 tons or more, is currently in service only on board 2 Finnish corvettes of the *Turunmaa* class, the minelayer *Pohjanmaa*, and the Indonesian *Fatahillah* class. The barrel is water-cooled, and the gun has a vertical sliding breechblock. There are 2 magazines, 1 fixed to each side of the breech. Each magazine has 5 ammunition channels (5 rnds each), and the gun feeds alternately from each magazine into the ammunition chamber of the autoloader. The dual-magazine arrangement permits loading with 2 kinds of ammunition, so that the type can be switched instantly without interrupting the loading cycle. The enclosure is 4-6-mm steel for splinter protection.

Development (on a private-venture basis) began in 1963, and the first prototype was tested in 1967. This weapon is an adapted antiaircraft field gun. The Bofors designation is TAK 120.



A single Bofors 4.7-in/46 on board the Finnish *Turunmaa*, 1986. (S. Terzibaschitsch)

◆ Bofors 76-mm

Caliber: 3-in/50 (5.9-kg [13-lb] Mk-27 ammunition)
Rate of Fire: 30 rnds/min
Muzzle Velocity: 823 m/sec [2700 ft/sec]
Maximum Range: 12,600 m at 30 deg elev [13,800 yd]
Training Rate: 25 deg/sec (elevation: 25 deg/sec)
Elevation/Depression: +30/-10 deg
Ammunition Capacity: 16 ready-use rnds on the sides of the hoist frame **Weight:** 6.5 tonnes empty

This fully automatic single gun is intended primarily to deal with surface targets. It is controlled by an external director and



Bofors 76-mm gun on board the Norwegian patrol boat *Hvass*. The radome conceals a Signaal WM-26 fire-control radar, and the search radar above it is a Decca TM 1226. The missiles aft are Penguins, and the gun aft is a Bofors 40-mm L70. (G. Koop)

is unmanned, for a low silhouette. The gunhouse is 6 mm thick. This gun is used only on board Norwegian *Storm*-class fast attack craft and on board Singaporean 110-ft "Type B" patrol boats. In both cases the associated FCS is the Signaal WM-26, a "half-egg" incorporating a single TWS radar.

◆ Bofors 57-mm/60

Caliber: 57-mm/60 (5.73-lb shell, 6.27-lb cartridge)
Rate of Fire: 130 rnds/min/gun **Muzzle Velocity:** 3018 ft/sec
Maximum Range: 15,880 yd
Training Rate: 30 deg/sec (elevation 30 deg/sec)
Elevation/Depression: +90/-10 deg
Weight: 68,300 lb (no ammunition)

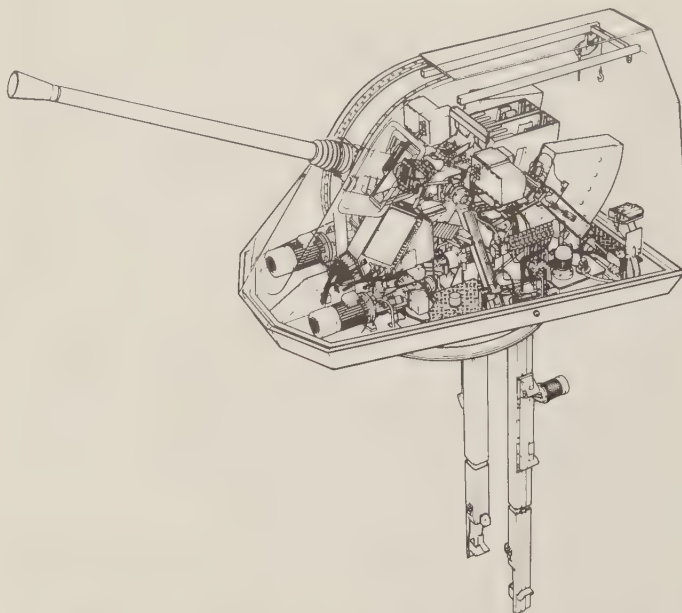
Bofors developed the 57-mm gun during and after World War II as the natural successor to the 40-mm/70 then under development; the 57-mm/60 is a scaled-up version. The French Model 1951 uses a Bofors-manufactured gun in a French mounting. This gun was also adopted, in a Bofors-designed mounting, by the Dutch and Swedish navies, as a secondary-battery weapon, in an enclosed twin automatic mount. The 57-mm/60 survives on board one ex-Dutch Peruvian cruiser.

With this weapon, Bofors abandoned the 4-rnd clip of the 40-mm gun, theorizing that fire could not be fast enough, and that clips would be far too heavy. Instead, loaders drop rounds into ammunition boxes, which in turn feed 2 fans (quadrant-shaped hoppers). The fans are mounted at the gun trunnions, so that the position of the gravity feed is always constant (horizontal, perpendicular to the gun's axis). The fan itself elevates with the gun, and rounds move along the fan from the perpendicular position to a position directly over the breech. Similar fan feeds can be seen in other postwar Bofors and Breda-Bofors weapons.

◆ Bofors 57-mm/70 Mk 2

Caliber: 57-mm/70 (6.1-kg [13.1-lb] round)
Rate of Fire: 225 rnds/min
Muzzle Velocity: 1025 m/sec (PFHE; 950 m/sec for HCER) [3360/3120 ft/sec]
Maximum Range: 17,000 m [18,600 yd]
Training Rate: 55 deg/sec (elevation 40 deg/sec)
Elevation/Depression: +75/-10 deg
Ammunition Capacity: 120 rnds in cupola, 40 rnds ready to fire
Weight: 6500 kg without ammunition [14,300 lb]
Working Circle: 4.325 m [170.3 in]

Bofors claims that this gun is truly dual-purpose: that it is accurate and agile enough to destroy sea-skimmers (by using proximity-fuzed ammunition and by attempting to set off their warheads); and that, with penetrating (delayed action) HE rounds (HCER, or high-capacity extended-range), it puts more explosives into a surface target in the first 30 sec than any other gun of up to 100-mm caliber. The company claims that 57-mm/70 should be an effective shore bombardment weapon because it can pepper an area with shell fire before the targets can move or take cover. The delayed-action fuze should permit penetration of 20 mm of steel before the round bursts about 2 m inside the target. Bofors claims, too, that using better steel allows reduced shell thickness, so that the shell carries 40% more explosive than its predecessors.



Bofors 57-mm/70 Mk 2.

The loader and the gun mount are 2-sided, so that 2 types of ammunition can be handled simultaneously. Ammunition comes up from the magazine into two 20-rnd cassettes, mounted on a rail behind the gun. When filled, they move into position above, and discharge their ammunition down into, the ready-use magazines. There are also 2 intermediate cassettes, each holding 20 rnds, so that the cupola (turret) carries 60 rnds (2 cassettes and the ready-use magazine above the gun itself) on each side, the total of 120 being sufficient for 15 or 20 engagements.

Bofors particularly emphasizes a new servo system that greatly reduces aiming errors and damping time, for greater accuracy when engaging air targets. Compared to the earlier Mk 1 (see below), Mk 2 uses a special monobloc steel barrel that does not require water cooling, and the turret of Mk 2 has a reduced radar cross section (10-20% lower than that of the earlier mount).

This weapon is used on board Swedish corvettes (*Spica-III* class) and has been selected for the Canadian "City"-class frigates.

Mk 1 is a less sophisticated version, for offshore-patrol vessels, coast guard vessels, etc. In Swedish service Mk 1 arms *Hugin*-class missile boats and *Spica*- and *Spica-II*-class missile boats. Mk 1 is also used by the Malaysian and Yugoslav navies. The rate of fire is 200 rnds/min, and elevation limits are +78/-10 deg (training rate 55 deg/sec, elevation 20 deg/sec). Am-

munition capacity is 128 rnds plus 40 ready-use rnds in the dual hoists.

Work on the 57/70 began in 1972, based largely on experience with the earlier 57/60. The major improvements were a higher rate of fire (200 vs. 130 rnds/min), the use of new ammunition with proximity and/or impact fuzes, an improved water-cooling system for the gun tubes, reduced weight (by using light alloys more extensively), and a new electro-hydraulic system for rapid slewing and elevation.

Reviewing this weapon, the U.S. Navy's Foreign Ordnance Review Team considered the 57/70 Mk 2 heavy compared to the OTO-Melara 35-mm and 76-mm weapons.

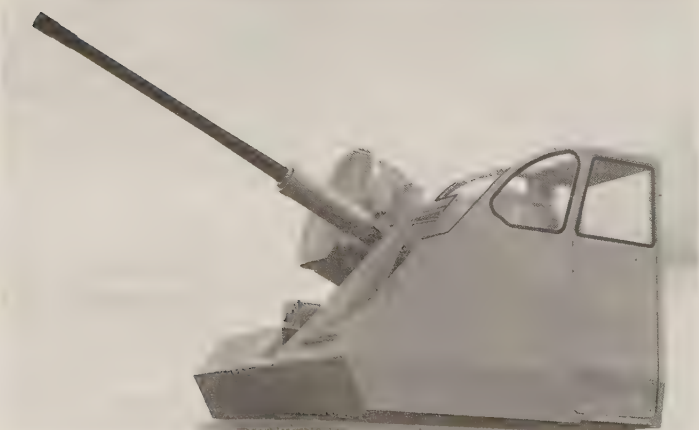
◆ Bofors 40-mm L70/Trinity

Caliber: 40-mm/70 **Rate of Fire:** 300 or 330 rnds/min
Muzzle Velocity: 1005–1025 m/sec [3300–3360 ft/sec]
Effective Range: 4000 m [4400 yd]
Training Rate: 85 deg/sec (elevation 45 deg/sec)
Elevation/Depression: +90°–10 deg
Weight: 2.8, 3, or 3.3 tons without ammunition

This weapon was conceived by Bofors to replace the World War II L60 gun. In various forms the 40-mm/70 has been in production since the late 1940s. All current production versions are single air-cooled guns. The current versions are SAK 40L/70-315, which is hand-operated; SAK 40L/70-350, which is power (electro-hydraulic) operated, gyro-stabilized, and remotely controlled; and SAK 40L/70-600, which employs the Trinity 99-rnd magazine (2 more rnds are in the intermediate feed position and in the ramming position). All 3 versions employ open-topped shields (for which GRP weather covers are available), the -600 version (Trinity) being recognizable by its special magazine. All of the Bofors-built 40-mm guns, then, use gravity-feed magazines directly descended from those of the earlier World War II Bofors 40-mm/60.



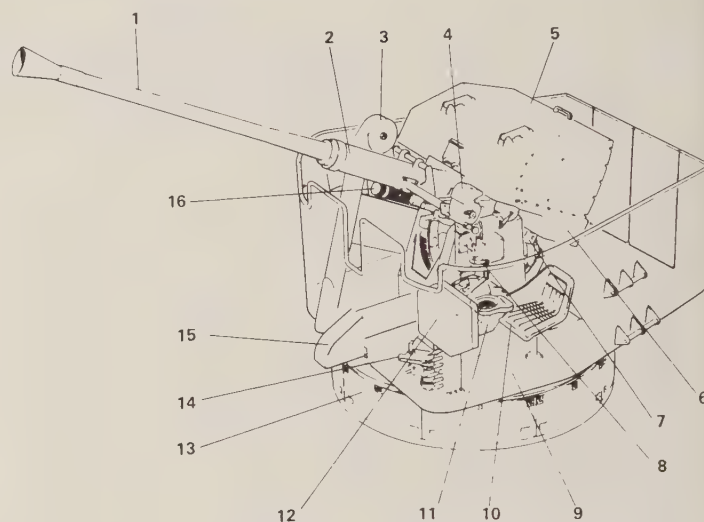
Bofors 40-mm L70 on board a Yugoslav Type-80 fast patrol boat. The launchers forward of the gun are for chaff/illumination. (U.S. Naval Institute)



Bofors Trinity 40-mm/70 gun. (U.S. Naval Institute)



Bofors 40-mm/70 fitted with a new Trinity 99-rnd magazine, as in West German service. (Bofors)



- | | |
|-------------------------------|-----------------------|
| 1. Barrel with flame guard | 9. Platform |
| 2. Breech casing | 10. Layers seat |
| 3. Balancing gear | 11. Laying unit |
| 4. Sight | 12. Control panel |
| 5. Magazine | 13. Protecting screen |
| 6. Lateral feed device (left) | 14. Firing pedal |
| 7. Automatic loader | 15. Empty case chute |
| 8. Elevating crank | 16. Recoil buffer |

The Bofors 40-mm/70 with a Trinity 99-rnd magazine. (Bofors)

In August 1986 the West German navy awarded Bofors a contract to upgrade the existing German 40-mm/70 guns, using the new high-capacity magazine and elevating mass that had been developed for the Trinity (-600) version of the gun. The modernized guns have a higher rate of fire. Ships involved include the Type 343 minesweeper and the Type 148 missile attack boat.

The Royal Navy planned single-, twin-, and 6-barreled versions of the 40-mm/70, but all were canceled in 1957 in favor of the Sea Cat missile; the gun was used by the British Army. Projected British naval designations were Marks 10, 11, and 12, respectively.

Breda has produced the Bofors 40-mm/70 under license since 1969. The company has specialized in automatic loading mechanisms, which are described under the entry for the Breda Twin Fast Forty, above. The Breda 144-rnd automatic feed system is also manufactured under license by Empresa Nacional Bazan of Spain, for the Spanish navy.

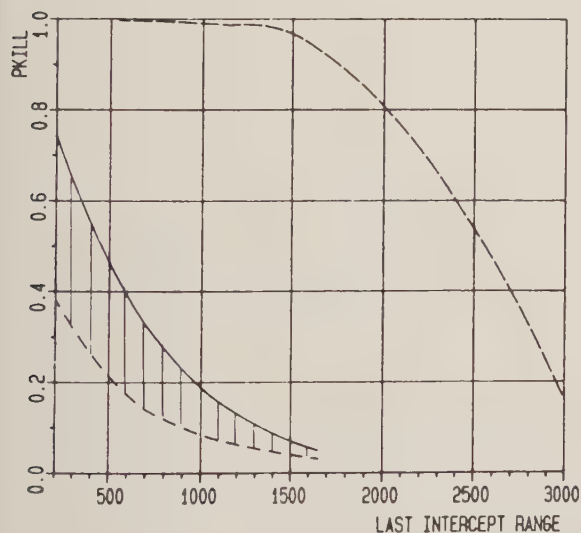
Bofors has developed a variety of ammunition. The 40-mm/70 originally fired either armor-piercing (AP) or high-explosive with tracer (HE-T). Bofors developed the first production prox-



Trinity test-firing on board the Swedish minehunter *Landsort*. The small objects to either side of the gun mount are Elma ASW launchers. (Bofors)

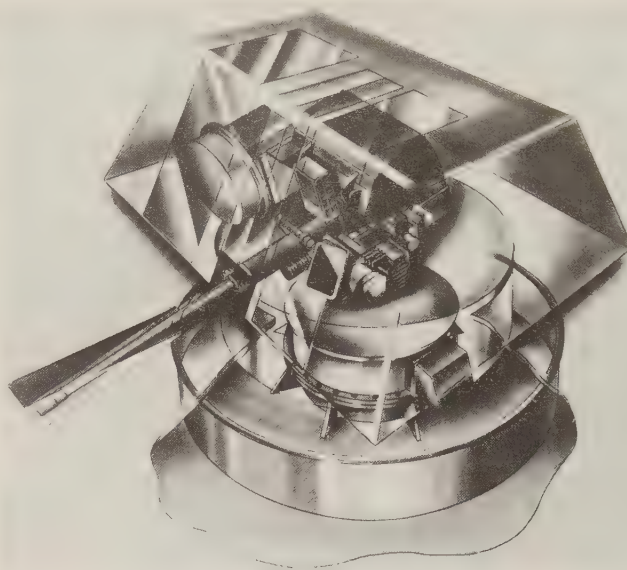
imity fuze for a 40-mm shell, for the L70 gun, beginning large-scale production in 1975 (40-mm proximity fuzes are also manufactured by Borletti in Italy and by Thomson-CSF in France). Bofors has recently developed a similar fuze for the older 40-mm/60, many of which are still in service. In 1982 the company announced a proximity-fuzed prefragmented HE (PFHE) shell to deal specifically with low-flying aircraft and sea-skimming missiles. The shell contains 650 carbide-tungsten pellets, each of which can penetrate 14 mm of duraluminum. They surround the core of octol (HMX/TNT) explosive and are projected outward when it bursts. The steel body of the shell itself produces another 2400 fragments. The shell body is boat-

EFFECT AGAINST SEASKIMMING MISSILE.
KILL PROBABILITY AS A FUNCTION OF LAST INTERCEPT RANGE (M).
MISSILE ALTITUDE=5M. MISSILE SPEED 300 M/S. ACCELERATION=0.16.
TIME FOR TARGET MOVE RELATIVE TO THE FIRING
OF FIRST ROUND=0. (MOST DIFFICULT CASE.)
TRINITY FIRING WITH OPTIMIZED BURST PATTERN.
TIME OF FIRE 2 SEC.



— 30 MM APDS CIWS
- - - 40 MM TRINITY
... 20 MM APDS CIWS

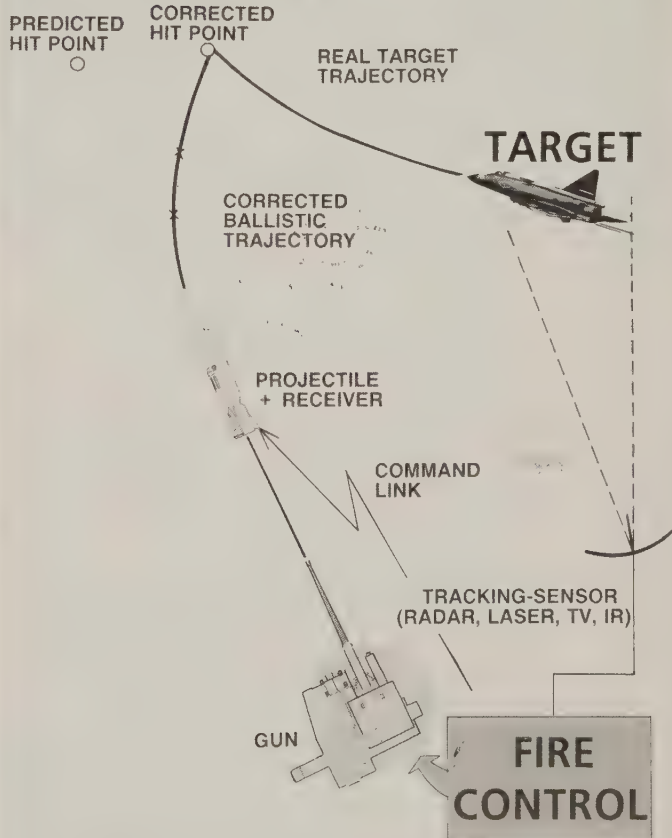
Bofors' argument in favor of proximity-fuzed antimissile ammunition. This is the company's estimate of missile kill probability as a function of last intercept range, in meters, assuming a missile altitude of 5 m and a speed of 300 m/sec. It is assumed that the gun fires a 2-sec burst. The closer the kill, the more likely it is that fragments of the missile hit the ship. The dashed line on the right is for Trinity; the full line is for a 30-mm CIWS like Goalkeeper, and that below it is for a 20-mm CIWS such as Phalanx. (Bofors)



Trinity in a "stealth" mounting. (Bofors)

tailed for optimum splinter spread. Lethal radius is 6.5 m against aircraft and 4.5 m against missiles. Bofors argues that such a shell is more effective than a penetrator such as that used by the Phalanx or Goalkeeper systems, because the PFHE shell has a better chance of destroying an incoming missile. Although the overall rate of fire of the 40-mm/70 is much lower than that of a Gatling gun, Bofors argues that 1 of its shells is broadly equivalent to a burst fired by the Gatling.

TRINITY



PRINCIPLE FOR GAS JET CORRECTABLE AMMUNITION SYSTEM

Proposed 40-mm course-corrected shell. (Bofors)

The PFHE shell uses a doppler proximity fuze with special ECCM features; the shell can also explode on impact. Bofors claims that a 10-rnd PFHE burst is as effective as 50–75 rnds of HE-T. In theory, the doppler feature prevents the shell from bursting prematurely when it nears the sea surface.

There is also a high-capacity HE round (HCHE) using a point delay fuze, which allows the shell to penetrate a target for 0.3 msec (equivalent to 20 mm of armor) before bursting. Bofors claims that the large charge inside its HCHE shell provides blast effects equivalent to those of a conventional 57-mm shell.

An Italian firm, SNIA BFD, has developed an armor-piercing fin-stabilized discarding sabot (APFSDS) 40-mm shell, and this company has also developed a preformed fragmentation (PFF) round.

Bofors is currently developing a course-corrected 40-mm shell, which the company is convinced will be needed to deal with next-generation targets. The shell would carry enough propellant to allow several corrections in sequence, on the basis of command signals. Such a shell would have to be somewhat heavier (hence slower) than the Trinity 3P shell (see below), but Bofors argues that course correction would make up for any reduction in initial accuracy caused by lengthier time of flight.

The new 40-mm 4P GJC (gas-jet controlled), course-corrected shell was tested for the first time (against static targets) late in 1989. It is controlled by a radio link from the Trinity FCS. Using a 6-gas-jet auxiliary propulsion system, it can make several corrections in flight. Fins at the base of the shell reduce its spin rate to make corrections more effective. An entire 5–10-rnd burst can be shifted about 50 m. The command link can also set (delay) the proximity fuze so that a shell can penetrate a target.

Trinity is a modernized 40-mm/70 gun, conceived primarily as a close-in antimissile weapon, competing with systems such as Phalanx. As with Phalanx, the fire-control radar is mounted directly with the gun. The Bofors view was that, rather than rely on bursts of small-caliber projectiles, it would be better to use smaller numbers of larger-caliber ones, which would have predictable trajectories, and each of which would have much greater lethal effect. The company also determined that any future close-in gun would have to achieve much greater range than existing weapons. Work began about 1982, and Trinity was announced at Farnborough in 1984. Initial tests were conducted in 1985–86.

The name Trinity is derived from the synergistic combination of ammunition, weapon, and fire control.

Bofors argues that 40-mm is very nearly the ideal caliber for such a weapon since that size makes for a larger and hence much more lethal shell than the 20–35-mm weapons in use elsewhere; yet 40-mm can be fired much faster than the next natural size, 57-mm. Trinity's development began with an improvement in the ammunition. Higher-energy propellant was used to slightly increase muzzle velocity while increasing projectile weight by 25%. The new 3P shell weighs 1.1 kg (compared to 0.88 kg for the earlier PFHE and 0.96 kg for the old HE-T) and is slightly longer, for better aerodynamics. Explosive content is about 25% greater than that of the PFHE; upon bursting, the 3P produces more than 3000 fragments, including 1000 tungsten-alloy pellets. The weight of a complete round is 2.8 kg, compared to 2.4–2.5 kg for older 40-mm/70 rnds. Because the new shell is much more energetic than the older ones, the gun must absorb greater recoil forces; it uses a muzzle brake.

The fuze is programmable: it can be set, as it enters the breech, for proximity or point detonation. The burst pattern can also be preset: for example, a circular pattern to attack a high-altitude airplane or a fan pattern against a sea-skimming missile. The FCS is designed to position a 10-rnd burst around a missile, the pattern measuring 15–20 m across, with each fuze programmed individually during firing so that the pattern can be arranged to keep the lower rounds from triggering off the sea. Trinity can also fire a new AP shell.

There is a new high-capacity (99-rnd) magazine, holding 45

rnds to the left and 54 to the right of the gun, in 11 vertical rows. This division allows the gun to carry 2 kinds of ammunition at the same time. Only 1 side is used at a time, its outer row being emptied first. Typically, the gun carries 101 rnds, 99 in the magazine and 2 in the gun. Bofors assumes that the gun will typically fire 5–15 rnds per engagement. The gun is rated at 330 rnds/min, and claimed dispersion is 0.7 mrad.

The mounting as a whole is largely nonmagnetic since Swedish minesweepers are a major likely application. Elevation limits are +80/–20 deg, and the working circle radius is 2.974 m [117 in]. Total weight is 3700 kg [8155 lb].

The Trinity mount incorporates a specially built Bofors microprocessor, a radar, a laser range-finder, a gyro-stabilized reflex sight, and an image intensifier for night operation. The computer determines the number of rounds to be fired, the fuze setting, the programmed burst pattern, and the actual moment of firing for greatest effect. As of mid-1990, it still was not certain whether the radar would be the Ericsson Ku-band Eagle or the BEAB Ka-band radar, which had been preferred earlier.

Claimed effective range is 2000–3000 m against a low-flying fast attack airplane, or 2500 m against a sea-skimming missile.

A remotely controlled version, Trinity Spartan, has also been designed; it incorporates the same ammunition and weapon, but the fire control is off-mount. Bofors conceived Trinity as an integrated system using its own sensors. However, the company has also offered to combine Trinity with existing fire-control radar systems, such as that employed in the Dutch Goalkeeper.

Trinity was tested on board the Swedish minesweeper *Land-sort* in the winter of 1988. Trinity was to be integrated with a new Ericsson Eagle coherent-doppler tracking radar.

Trinity was first demonstrated in public in September 1988. Sea Trinity was shown engaging a helicopter hovering behind a curtain of trees at 2600-m range, then firing bursts against a simulated maneuvering target, then firing against armored containers. The gun then fired a burst of 8 rnds, each set for a different mode (to demonstrate the programmability of the 3P round); and then the gun fired 100 rnds against a target container at 1100-m range.

In 1988 the Swedish Defense Procurement Administration commissioned Bofors to study a "stealth" version of Trinity, for use on board a future warship. Trinity is already shaped to reduce its overall radar cross section and incorporates radar-absorbing material to cover openings and cavities. The gun also has a low magnetic signature, and Bofors claims that the basic design allows for further signature reduction by computer-controlled active compensation. A sketch released at the time shows the basic Trinity enclosed within a cupola with flat sides angled inward to reduce radar reflections.

Trinity was first ordered, for the Swedish navy, in May 1990 to arm the new Swedish stealthy surface-effect ship. Plans initially called for the gun to retract into the deck, but the planned elevator was not rigid enough, and the gun mounting was considered stealthy enough to be left above decks.

◆ Bofors 40-mm (old types)

Caliber: 40-mm/60 (barrel length is actually 56 calibers) (0.9-kg [1.98-lb] shell) **Rate of Fire:** 120 rnds/min
Muzzle Velocity: 800–880 m/sec [2620–2890 ft/sec]
Maximum Range: 10,000 m; effective range 3000 m [10,900/3300 yd]
Elevation/Depression: +90/–5 deg
Ammunition Capacity: 4-rnd clip

The Bofors 40-mm/60 was the standard Allied heavy automatic anti-aircraft gun of World War II, remaining in service in some numbers, both in single and in twin mounts. See the British and U.S. sections, below, for details of their 40-mm mounts. Postwar, Bofors developed a higher-velocity 70-caliber gun, which was adopted by many navies. Breda developed a series of automatically fed 40-mm/70s (see Italian entries above).

The original Bofors guns all used 4-rnd clips that were gravity-fed into the gun from above. All subsequent Bofors 40-mm and 57-mm guns continue to use the same basic gun mechanism,

which is fed from above. Land-based (and some single naval) versions were air-cooled; naval twins were all water-cooled.

Bofors currently offers a variety of modernization options for the 40-mm/60. Although generally described in connection with land-based guns, these options are applicable to surviving naval units. Bofors claims that the effect of modernizing the 3 main components of the weapon—the gun itself, its sight, and its ammunition—improves kill probability against a typical fighter-bomber by 50–80% (e.g., kill probability at 1 km rises from about 18 to nearly 100%), based on a 9-rnd burst. The gun's rate of fire is increased by about 50%, from 120 to 180 rnds/min; the hopper at the top of the gun is enlarged to hold 20 rnds (so that 2–3 targets can be engaged between reloadings; the rounds are still carried in clips of 4, for easy handling); and power laying is introduced (for guns on land; naval mountings are generally already power operated).

The earlier point-detonating ammunition is replaced by PFHE proximity rounds similar to those developed for the L70 gun (see above). Bofors claims that the effect of the proximity fuze is to increase the effective bursting area of the target (i.e., the probability that a shell will burst) by a factor of 50–300. Maximum bursting range is 5.5 m (reducible by automatic sensitivity control to 1–2 m for use against missiles flying at low altitude). Muzzle velocity is 860 m/sec [2820 ft/sec], and total shell weight is 980 g [2.16 lb], including 90 g of octol explosive. The gun is fitted with a proximity fuze disconnecter, so that the shells can still function in the point detonating mode if required. The disconnecter is attached to the front of the ammunition hopper atop the gun. The gun can also fire HET (high-explosive tracer; in this case HE means greater penetrating power rather than a high-explosive filling), PT, and APHC-T (armor-piercing high-capacity tracer) ammunition. The APHC-T shell is unusual in carrying a heavy armor-piercing slug within an aluminum shell body; Bofors claims that APHC-T penetrates 30% deeper than earlier armor-piercing capped tracer (APC-T) rounds. As a side benefit, the aluminum body should have an incendiary effect on the target.

A new gun-mounted "U-sight" system is added, incorporating a laser range-finder.

As modernized, the land version of the gun trains at 85 deg/sec and elevates at 50 deg/sec; dispersion is less than 4 mrad.

For other versions of the 40-mm/60, see the U.K. and U.S. guns below.

SWITZERLAND

◆ Oerlikon 35-mm (Type GDM-A)

Caliber: 35-mm/90 **Rate of Fire:** 1100 rnds/min
Muzzle Velocity: 1175 m/sec [3850 ft/sec]
Effective Range: (air/surface) Radar Control: 5000/8000 m [5500/8700 yd] Optical Control: 2500/5000 m [2700/5500 yd] Local Sight: 3000/5000 m [3300/5500 yd]
Training Rate: 120 deg/sec (elevation 130 deg/sec)
Elevation/Depression: +85/–15
Ammunition Capacity: 336 rnds
Weight: 10,500 lb without ammunition
Working Circle: 4716 mm [185.7 in]

Unlike the British BMARC/Oerlikon GCM, this weapon is clip-fed, with 112 rnds of ready-use ammunition and another 224 rnds carried within the mount. The guns can be reloaded while they fire. GDM-A is electrically controlled and biaxially stabilized, and the gun has a stabilized sight and joystick for local control. The gun can also be manually controlled in an emergency.

The GDM-C version was developed jointly with OTO-Melara, using the same Type-KDC gun. A U.S. Navy Foreign Ordnance Review Team concluded about 1971 that the OTO-Melara version, described as an updated GDM-A, was better suited to U.S. requirements. The users are Iran (1 mount aft on the single Mk-7 frigate) and Greece (2 each on 4 missile boats).

The Japanese Maritime Self-Defense Agency uses a single version of this gun, with a sidecar for the operator.



The Oerlikon twin 35-mm gun (GDM-A). (Oerlikon)



The Oerlikon twin 35-mm gun (GDM-C), developed in collaboration with OTO-Melara. (Oerlikon)

◆ Oerlikon 30-mm

See United Kingdom BMARC-Oerlikon 30-mm below.

◆ Sea Zenith (Type GBM-B1Z)

Caliber: 25-mm/92 **Rate of Fire:** 850 rnds/sec
Muzzle Velocity: 1335 m/sec [4380 ft/sec]
Training Rate: 2.5 rad/sec (elevation of 2.5 rad/sec) [143.2 deg/sec]
Elevation/Depression: +127/–14 deg
Ammunition Capacity: 415 rnds/gun
Weight: 4600 kg plus 2150-kg ammunition feed system [10,140/4740 lb]

Sea Zenith is the 4-gun weapon associated with the Swiss Contraves Seaguard system (see above under shipboard radars and FCSSs). The guns are designated KBB-R03/L03. The ammunition supply is sufficient for 18 engagements, and the guns can be reloaded while they fire.

The unusual elevation arc makes it easier for the gun to engage very high targets; that arc is achieved by having the gun train in a plane canted at a 35-deg angle.



The Oerlikon 30-mm twin manned antiaircraft gun (GCM-A03-1). The A03-2 version has provision for local control (the sidecar lacks a wind-shield) but can also be remotely controlled. A03-3 is entirely remotely controlled. (Oerlikon)

◆ Oerlikon 25-mm (Type GBM Diane Navale and GBM-A01)

Caliber: 25-mm/80 **Rate of Fire:** 600 rnds/min/gun
Muzzle Velocity: 1100–1360 m/sec [3600–4460 ft/sec]
Training Rate: 1.4 rad/sec (elevation of 0.85 rad/sec) (80.2 and 48.7 deg/sec)
Elevation/Depression: +80/–20 deg
Ammunition Capacity: 500 rnds
Weight: 2300 kg (1900 kg without ammunition) [5070/4190 lb]

This naval version of the towed twin 25-mm gun was announced at Mostra Navale 1984. The mount can carry either the KBA gun (data given) or the more powerful KBB of the Sea Zenith. In a low-recoil version, KBA can also be used as a helicopter gun.

The KBA gun can also be carried in a GBM-A01 single manual mount; Oerlikon describes GBM-A01 as the most powerful available manually operated gun mount. Ammunition capacity is 140 rnds (two 70-rnd boxes), and elevation limits are +55/–10 deg. Cyclic rate is reduced to 570 rnds/min. Total weight, including ammunition, is 600 kg [1320 lb]. The boxes can be enlarged to carry 100 rnds each. This mount is no longer in production.

◆ Oerlikon 20-mm (Type GAD-A0A)

Caliber: 20-mm/85 **Rate of Fire:** 1000 rnds/min
Muzzle Velocity: 1100–1200 m/sec [3600–3940 ft/sec]
Elevation/Depression: +70/–12 deg
Ammunition Capacity: 100 rnds
Weight: 1055 kg including ammunition [2325 lb]
Working Circle: radius 2755 mm [108.5 in]

This turreted belt-fed 20-mm single-operator cannon (Type KAA, formerly known as 204GK) was designed for patrol craft, e.g., the Austrian Danube gunboat. GAD-A0A was manufactured under license by BMARC, reportedly for a Commonwealth customer. The mount probably dates from the late 1960s, BMARC announcing its version in 1977.

◆ Oerlikon 20-mm (Type GAM-B01)

Caliber: 20-mm/85 **Rate of Fire:** 1000 rnds/min
Muzzle Velocity: 1050 m/sec [3440 ft/sec]
Maximum Range: 2000 m [2200 yd]

Elevation/Depression: +55/–10 deg
Ammunition Capacity: 200 rnds
Weight: 92 kg without ammunition (90 kg of ammunition) [203/198 lb]

This manual mount carries a KAA cannon. Arming many fast attack craft, the 20-mm cannon is mounted on board most British warships as a result of the Falklands emergency. This cannon is manufactured in Britain by BMARC under the designation A41/820. The Royal Navy uses the GAM-B01 designation.

This cannon is essentially equivalent to the World War II Oerlikon 20-mm gun, with a higher muzzle velocity.



Oerlikon 20-mm single mount as selected by the Royal Navy (GAM-B01). (Oerlikon)

◆ Oerlikon 20-mm (Type GAM-C01)

Caliber: 20-mm/95 **Rate of Fire:** 900 rnds/min
Muzzle Velocity: 1050–1150 m/sec [3440–3770 ft/sec]
Elevation/Depression: +55/–10 deg
Ammunition Capacity: 200 rnds

This weapon is very similar to GAM-B01 but is a Hispano-Suiza 820 (now designated KAD-B13-3 by Oerlikon). Like the other mount, GAM-C01 was manufactured by BMARC as well as by Oerlikon itself. BMARC developed the new pedestal mount in 1968–70 as a private venture; production began in 1970.

◆ Oerlikon 20-mm (Type A41A)

Caliber: 20-mm **Rate of Fire:** 800 rnds/min
Muzzle Velocity: 835 m/sec [2740 ft/sec]
Elevation/Depression: +50/–10 deg
Ammunition Capacity: 58 rnds
Weight: 225 kg [496 lb]
Working Circle: 1.7 m [66.9 in]

Type A41A, with its ammunition drum, is the closest current equivalent to the World War II Oerlikon. The other current Oerlikons are belt-fed from a rectangular box on the front of the mount.

The gun is the Hispano-Suiza HS804, originally designed for aircraft use and having, therefore, a very low recoil force. A41A was dropped from the Oerlikon line but revived about 1980 because some customers liked its simplicity, ease of handling, and reliability.

This weapon has been manufactured both by Oerlikon and by BMARC.

◆ Oerlikon (Old Type)

See the U.S. entries below for details of typical World War II Oerlikon 20-mm cannon, which are still used by many navies.

USSR

The Soviets either have discarded or are discarding their *Sverdlov*-class cruisers and "Kotlin"- (and "Kotlin" derivative) and *Skoryy*-class destroyers. The following weapons have, therefore, been eliminated from this edition (details can be found in the previous edition of this book): the 6-in/57 B-38, the 130-mm/50, and the 45-mm. Descriptions of the 85-mm and 45-mm guns have been retained because they remain in PRC service.

◆ 130-mm/70

Muzzle Velocity: 1000 m/sec
Maximum Rate of Fire: 65 rds/min/mount
Maximum Range: about 28,000 m
Elevation/Depression: +85/-15 deg

This fully automatic dual-purpose weapon was introduced in the *Sovremennyy* class and is also mounted on board *Slava*-class cruisers and the *Frunze*. 130/70 may be triaxially stabilized. The barrels are liquid-cooled.

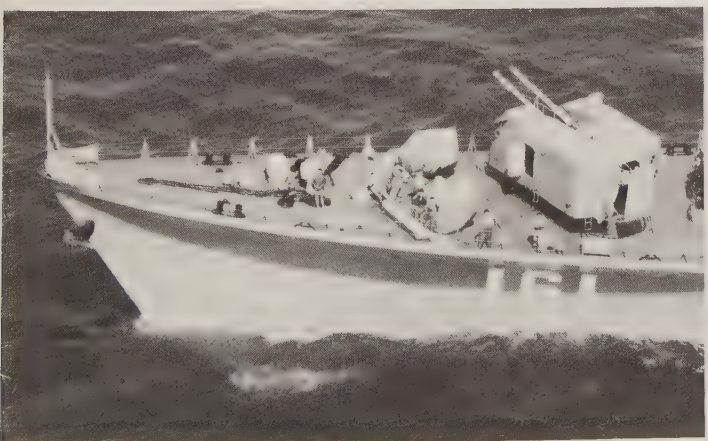
The associated fire-control radar is Kite Screech. The mount also has local controls.



A twin 130-mm gun on board the cruiser *Marshal Ustinov* at Norfolk, 1989. (S. Zaloga)

◆ 130-mm/58

Caliber: 5.1-in/58 (33.5-kg shell with 20-kg cartridge)
Rate of Fire: 15 rds/min/barrel (max)
Muzzle Velocity: 945 m/sec [3100 ft/sec]
Maximum Range: 28,000 m [surface]; 16-18 thousand (effective) [30,600/17,500-19,700 yd]
Elevation/Depression: +85/-5 deg **Weight:** approx 60 tons



Twin 130/58 mount on board a Chinese Luda-class destroyer. (U.S. Naval Institute)

This standard postwar, triaxially stabilized, dual-purpose, semiautomatic gun is installed on Kotlin-class destroyers. The gun is designated 56-SM, and the mount may have been derived from the wartime German 128-mm fully stabilized antiaircraft weapon. This gun and mount are currently manufactured in China (PRC), the Chinese version differing from the Soviet by lacking mechanical cross-level stabilization; the edges of the Chinese gunhouse are rounded, and the gun lacks the range-only radar of Soviet mounts.

The associated fire-control radars are Sun Visor and Post Lamp or Half Bow (Wasp Head director). All mounts originally incorporated Egg Cup range-only radars, but they have gradually been discarded.

◆ 115-mm

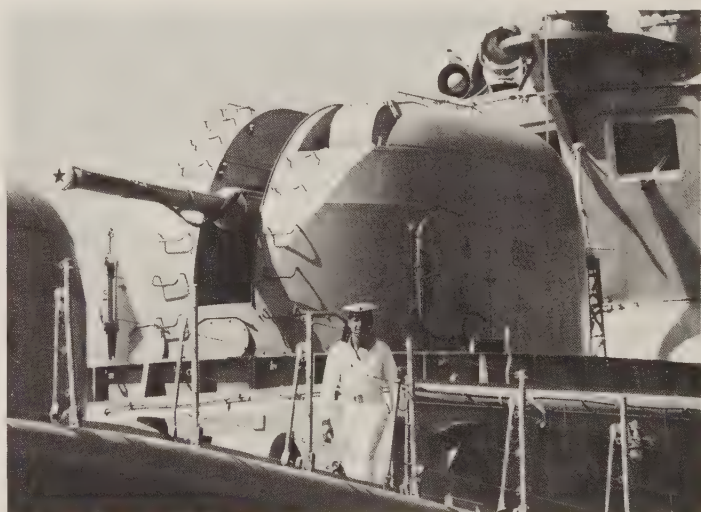
Caliber: 115-mm/55
Muzzle Velocity: 780 m/sec (HE-frag shells) [2560 ft/sec]
Maximum Rate of Fire: 4 rds/min
Elevation/Depression: +17/-4 deg
Maximum Range: 4800 m [5250 yd]

This tank gun is installed in Yaz-class river monitors. Figures above are for the U-5 TS gun as carried by the T-62 tank.

◆ 100-mm

Caliber: 100 mm/70 **Rate of Fire:** 80 rds/min
Maximum Range: 15,000 m (effective range 8000 m) [16,400/8700 yd]

This is the automatic single-barreled water-cooled mount on *Kirov*, *Udaloy* class, and *Krivak-II* and *-III*. It has optronic analog controls.

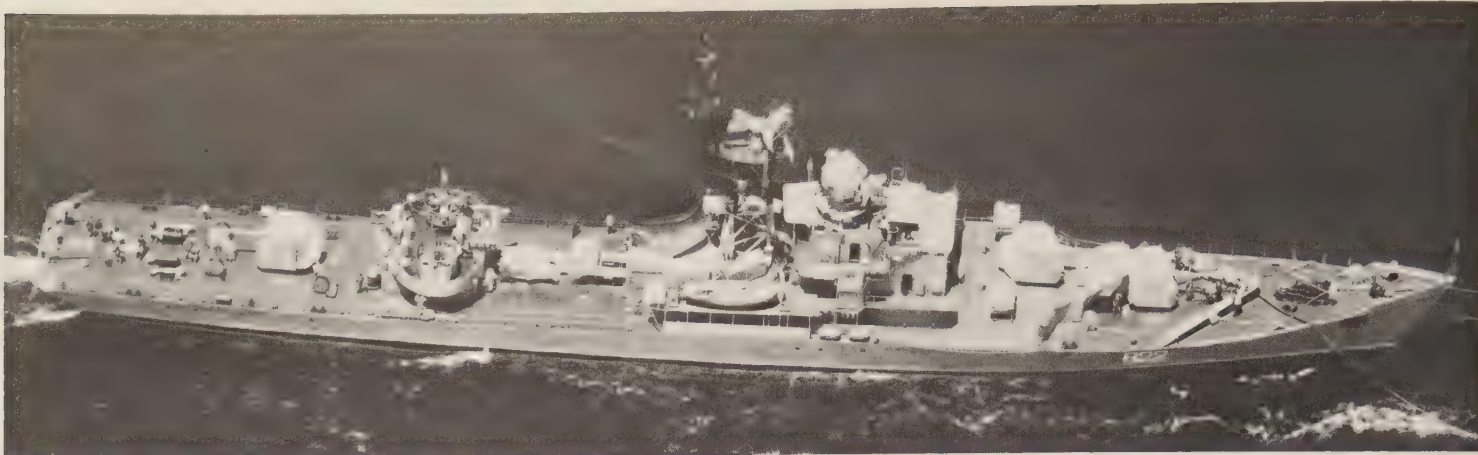


A single 100-mm gun on board the *Udaloy*-class destroyer *Admiral Vinogradov*, 1990, with its Kite Screech control radar in the background. (S. Zaloga)

◆ 100-mm/56

Caliber: 3.9 in/56 (15.6-kg shell, 28-kg fixed rnd) [34.4/62 lb]
Rate of Fire: 15 rds/min
Muzzle Velocity: 900 m/sec [2950 ft/sec]
Maximum Range: 16,000 m (effective range 10,000 m) [17,500/10,900 yd]
Elevation/Depression: +85/-5 deg
Weight: 13.5 tons (single mount)

This obsolescent single shielded mount is found on Riga-class frigates and Don-class submarine tenders. 100/56 was later manufactured in China. The original maximum elevation was 40 deg. This mount was formerly used as a secondary battery for cruisers and was modernized in 1947. Electrically driven, the gun can fire in automatic, local, or manual modes. The breech is a horizontal sliding block. A twin version was designed about 1940 for the abortive Soviet battleship program. China now manufactures an autoloading twin version (see above).



(Above) The Soviet 100-mm/56 mounted on board a Riga-class frigate, May 1984. The director is a Wasp Head, carrying a Sun Visor radar; and the main air-search radar is Slim Net. The guns aft are twin 37-mm, comparable to the old U.S. twin 40-mm Bofors. There are 4 torpedo decoys (of 2 types) on the fantail. The rocket launchers are RBU 2500s. (U.S. Navy)

The Soviet designation for the single mount is Bu-34. The associated director is Wasp Head with (in a few PRC ships) a Rice Lamp radar. Older Soviet ships used Cylinder Head to control this gun.

◆ 85-mm

Caliber: 85-mm/52 (9.6-kg shell, 13-kg fixed round) [20.9/28.7 lb]

Rate of Fire: 10 rds/min/barrel

Muzzle Velocity: 850 m/sec [2785 ft/sec]



(Below) Twin 76.2/60 guns arm this Mirka-class ASW corvette. There are torpedo decoys stowed on deck aft, 4 RBU-6000 rocket launchers, and 40-cm torpedo tubes. (U.S. Naval Institute)

Maximum Range: 15,000 m (effective range 8–9 thousand surface, 6000 m air) [16,400/8700–9800 yd]

Elevation/Depression: +75/–5 deg (maximum 85 deg in single version)

Weight: 5.5 tons (single)

This obsolescent twin mount survives on unmodified *Skoryy*-class destroyers. A single mount (maximum elevation 85 deg, elevation rate 8 deg/sec) is used by the PRC and other communist navies, arming smaller craft such as *Kronstadt*-type subchasers. The reported Soviet designation is 90K (twin mount HAM 39-3).

The modernized single mount (in use since 1948) is manually driven under local control. The twin mount is electrically driven; ammunition supply through the mount limits elevation to 75 deg.

◆ 76.2-mm/60

Caliber: 3-in (6.8-kg shell, 16-kg fixed round) [15/35 lb]

Rate of Fire: 45 rnds/min/barrel

Muzzle Velocity: 900 m/sec [2950 ft/sec]

Maximum Range: 15,000 m (effective at 11,000 m; effective for anti-aircraft at 6–7 thousand m)

Elevation/Depression: +85 deg

Ammunition Capacity: 43 (per barrel)

Weight: approx 25 tons (rotating mass)

The caliber is 3-in, not 76-mm. This weapon is installed on board *Kara*- and *Kynda*-class cruisers; *Kashin*-class destroyers; *Krivak*-I-, *Koni*-, *Petya*-, and *Mirka*-class frigates; *Smoln'nyy*-class training ships; and *Ivan Susanin*-class icebreakers. The 76.2/60 was introduced in 1961. The mount is semiautomatic, like the U.S. twin 3-in/50; rounds are hoisted 43 at a time (per barrel) into the gunhouse. The gun is not water-cooled, but standard practice is to use a fire hose to cool down the barrel after an engagement. The turret has an unusually deep cleft, so the guns can be mounted aft of the center of the trunnion, for



Two Shmel-class gunboats, probably on the Amur, show their tank-type 76.2-mm guns. The guns aft are machine guns; later ships of this type have the standard twin 25-mm (over and under) mount. (TASS via SOVFOTO)



A Tarantul-class missile boat of the Soviet Baltic Fleet fires her single 76.2-mm gun. The radome atop her mast is Light Bulb, probably a missile data link. Below it is a Bass Tilt fire-control radar, and the big radome is Band Stand. The missiles are SS-N-2Cs. (TASS via SOVFOTO)

a high angle of elevation. The associated fire-control radars are Hawk Screech and Owl Screech.

◆ 76.2-mm/60 Single Mount

Caliber: 3-in/60 **Rate of Fire:** 120 rnds/min

Maximum Range: 14,000 m surface; 6–7 thousand m (air target) [15,300/6600–7700 yd] **Elevation/Depression:** +85 deg

This automatic single mount, with on-mount crew, is found on Grisha-V- and Parchim-II-class light frigates; Nanuchka-III-, Pauk-, and Tarantul-class corvettes; Matka-class missile hydrofoils; and the 1 Slepenskiy-class patrol boat.

The associated fire-control radar is Bass Tilt.

◆ 76.2-mm/55 Single Mount

Caliber: 3-in/55 (6.6-kg shell, 11.2-kg fixed round) [14.6/24.7 lb]

Rate of Fire: 17–20 rnds/min

Muzzle Velocity: 815 m/sec [2675 ft/sec]

Maximum Range: 13,500 m [14,600 yd]

Elevation/Depression: +85 deg **Weight:** approx 5 tons

This weapon was introduced in the Soviet Navy in 1936 but is now used only by North Korea. The shield is similar to that of the Soviet 85-mm gun (90K), and the 76.2 Single Mount uses a vertical sliding-block breech.

◆ 76.2-mm/48 Single Mount

Caliber: 76.2-mm/48

Muzzle Velocity: 680 m/sec [2230 ft/sec] (HE shell)

Maximum Rate of Fire: 4–6 rnds/min (claimed 15 rnds/min max)

Elevation/Depression: +30/–4 deg

Maximum Range: about 800 m effective range, point-blank [about 870 yd]

The PT-76 tank turret gun (D-56TM) is found in Shmel-class river monitors.

◆ 57-mm (twin automatic mount)

Caliber: 57-mm/80 (2.7-kg shell, 5-kg fixed round) [6/11 lb]

Rate of Fire: 120 rnds/min/barrel

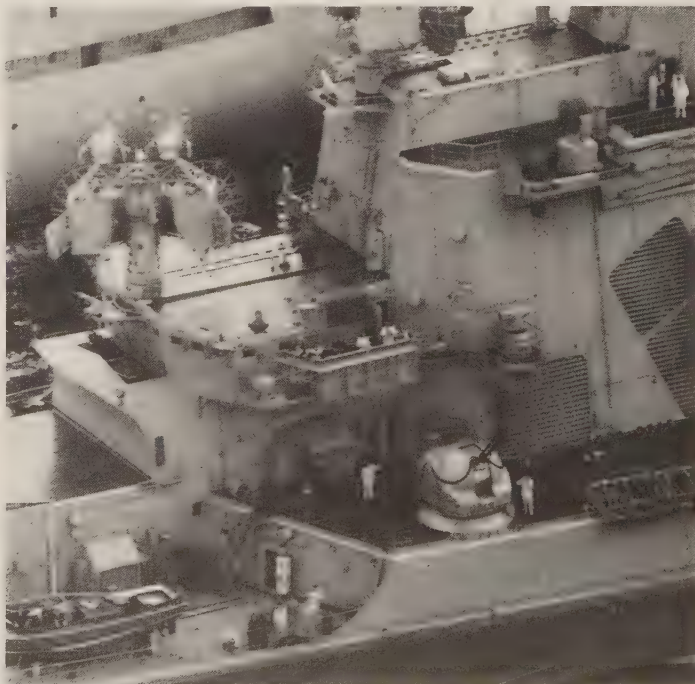
Muzzle Velocity: 1000 m/sec [3280 ft/sec]

Maximum Range: 12 km horizontal, 6.7 km vertical [13,100 yd/22,000 ft]; effective ranges about 9000 m horizontal, 5–6 thousand m vertical [9800 yd/16,400–19,700 ft]

Elevation/Depression: +90/–10 deg

Weight: 25 tons (without ammunition)

This fully automatic mount is found on *Moskva*, *Kresta*-I and -II, *Poti*, *Grisha*, *Nanuchka*-I, *Turya*, *Ropucha*, *Urga* classes, etc.



Twin automatic 57-mm guns on board a *Moskva*-class helicopter carrier, with a Head Lights SA-N-3 fire-control radar visible above the bridge. The small navigational radar below it is Don-2. [U.S. Navy]

The barrels are water-cooled. The 57-mm first entered service in 1963. Unlike the various forms of ZIF-31B, this mount is fully enclosed, with a metal shield; ammunition supply is presumably fully automatic. Control is generally by a Muff Cob radar director. In some classes, later units have the newer 76.2-mm/60 in place of this weapon.

The Soviet designation is ZIF-72 (the Indian navy reports an AK-257 designation for the mount on its frigate *Ganga*).



57-mm/80 Soviet-type twin mount on board the Indian frigate *Ganga*. The mount is designated AK-725 in Indian service. (*Ships of the World*)

◆ 57-mm Antiaircraft Gun

Caliber: 57-mm/70 (2.8-kg shell, 6.3–6.6-kg round) [6.2/13.9–14.5 lb] **Rate of Fire:** 120 rnds/min/gun
Muzzle Velocity: 1020 m/sec [3350 ft/sec]
Maximum Range: 4500 m vertical [14,700 ft]
Training Rate: 30 deg/sec (elevation 25 deg/sec)
Elevation/Depression: +90/0 deg
Weight: 28,000 kg quadruple mount; 6000 kg single mount; 14,500 kg twin mount [61,700/13,200/32,000 lb]

This weapon exists in single (e.g., modified *Skoryy* class), twin, and quadruple (Kanin, Kildin classes) forms. In the quadruple mount the guns are in superimposed pairs. This weapon entered service in 1958 and was a navalized version of the 57-mm/70 M-50 used by the Soviet army. That gun in turn was developed from a 55-mm antiaircraft gun under development in Germany late in the Second World War.

Like earlier Soviet naval antiaircraft guns, this one loads from clips. Heating and clip-feeding would probably limit its effective rate of fire to 90 rnds/min. The associated fire-control radar is Muff Cob.



Quadruple 57-mm guns on board a Krupny-class missile destroyer. The mast radomes are presumably a pair of Top Hat jammers with the associated Bell-series ESM above. (U.S. Navy)

The Soviet designation is ZIF-31B.

The PRC navy uses a water-cooled version of this weapon, designated Type 76. Muzzle velocity is 1000 m/sec [3280 ft/sec], and maximum horizontal and vertical ranges are 15,000 and 10,000 m. Rate of fire is 140–160 rnds/min, and elevation limits are +85/–5 deg. Maximum laying speeds are 25 deg/sec both in train and in elevation, but the mount can sweep (i.e., can move less precisely) at 40 deg/sec both in train and in elevation. Total mount weight is 10,500 kg [23,140 lb]. No working circle data are available, but the mount's length is 6.583 m and width is 3.36 m (height is 2.264 m).

◆ 37-mm

Caliber: 37-mm/63 (0.74-kg shell, 1.8-kg round) [1.6/4.0 lb]
Rate of Fire: 160 rnds/min/gun twin; 130 rnds/min/gun single
Muzzle Velocity: 880 m/sec [2890 ft/sec]
Maximum Range: 9500 m [10,400 yd]
Training Rate: 20 deg/sec (elevation 15 deg/sec); powered mounts
Elevation/Depression: +85/0 deg
Ammunition Capacity: 5-rnd clips
Weight: 6170 lb single mount, 8375 lb twin mount



Soviet single air-cooled 37-mm/63 gun. (TASS from SOVFOTO)

This obsolescent prewar weapon is found in twin mounts on board some *Sverdlov*-class cruisers, *Skoryy*-class destroyers, Riga-class frigates, and T-43-class minesweepers. There was also a single mount, now extinct in Soviet service. The single guns were air-cooled, with the usual Bofors-type recoil springs surrounding the bases, and barrels had to be changed after about 100 rnds. The twin mount, introduced in 1948, is similar in layout to the standard U.S. twin 40-mm of the time, with liquid-cooled guns. Loading is by 5-rnd clip. The Soviet designations are 70-K for the original single mount, V-11M for the initial-production twin naval mount, and V-47M for later twin mounts with water-cooled barrels. It appears that V-47M was the widely used postwar version. A quadruple version was begun in 1939–40 but appears not to have entered service.

This gun is derived from a Bofors 25-mm gun of 1933, sold to the Soviet Union some years later. Because the 25-mm gun was very similar in design to the Bofors 40-mm of 1934 (the ancestor of the standard World War II 40-mm gun), the 37-mm is very similar to the Bofors 40-mm/60, with different ancestry. The 37-mm fires ammunition derived from the Colt-Browning 37-mm, which was inferior to the contemporary Bofors 40-mm rnd. This weapon was developed in preference to a turreted twin 45-mm automatic gun, on which work began in 1937–38.

This mounting is standard in the PRC navy in both single and twin mounts. The mount was produced in China, but without the cross-stabilization standard in many Soviet mounts.



Soviet twin liquid-cooled 37-mm/63. (TASS from SOVFOTO)

◆ 30-mm Gatling

Caliber: 30-mm/65

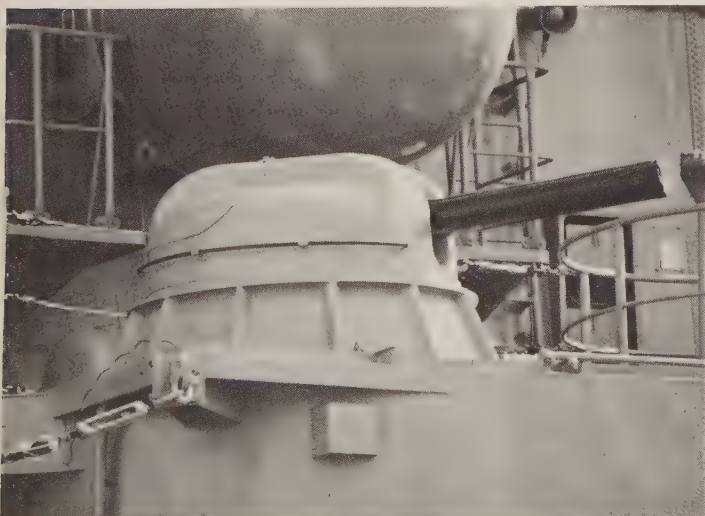
Rate of Fire: 3000 rnds/min/mount (probably 1000 rnds/min effective rate)

Muzzle Velocity: 1000 m/sec [3280 ft/sec]

Maximum Range: 2500 m (maximum altitude probably 500–600 m) [2700 yd; 1640–1970 ft]

Elevation/Depression: +90/–10 deg

This 6-barreled Gatling gun has a mount similar to that of the twin 30-mm weapon. The 30-mm Gatling, generally con-



A 30-mm Gatling gun on board the cruiser *Marshal Ustinov*, 1989. (S. Zaloga)

trolled by Bass Tilt or by a remote Kolonka-II visual director, is the standard current Soviet close-in defensive weapon.

The designation ADMG-630, which frequently appears, is a NATO rather than a Soviet name (Air-Defense Machine Gun 6 × 30). The Soviets probably call the gun AK 630. It first appeared in the summer of 1970.

◆ CADS-1

The cruiser *Kalinin*, the third unit of the *Kirov* class, completed in 1989, carries a new close-in weapon in place of the AK 630 of earlier units of this type. Each mounting carries a pair of guns under paired missile launchers. The missiles are paired vertically or horizontally, in different mountings; these alternatives are probably being compared to see which provides the least mutual interference.

A large radar antenna occupies the center of the mount, flanked on the right by a similar but smaller antenna. Each is much higher than it is wide, producing a beam narrower in the vertical than in the horizontal. That configuration might be extremely desirable for a system intended to detect and track low-flying missiles, postponing the onset of multipath problems. The combination of very similar large and small radar antennas in Soviet naval practice is generally associated with command guidance, and in this case there is a small dish (presumably to transmit the commands) between the 2 main radars. The left side of the mounting carries what appears to be an electro-optical device, possibly a television tracker or a laser, and there are small radomes on the lower part of the mounting. Other navies find a television or IR tracker very useful in avoiding multipath problems when engaging low-altitude targets (such as sea-skimmers).

The combination of guns with missiles on the same mount recalls the Soviet army 2S6 self-propelled antiaircraft weapon, which appeared in 1986 and is now replacing the earlier ZSU 23-4 quadruple mount. The 2S6 carries 2 twin 30-mm cannon and SA-19 missiles, 4 on either side. The cannon are part of a new family of weapons that includes the 2A42 cannon of the new BMP-2 armored personnel carrier; this weapon fires HE-T and AP-T ammunition at the rate of 200–300 or 500 rnds/min. In this case maximum vertical range is 5000 m, and effective antiaircraft range is 3000 m. Other members of the new gun family arm the Hind-E assault helicopter, the Su-25 Frogfoot ground-attack fighter, the MiG-29, and the Su-27 Flanker. In the case of the antiaircraft tank, the missiles are reloaded in clips of 2, and are probably launched in pairs. Estimated range is 7–10 km. The army version of the system probably carries a mixture of IR and command-guided missiles.

The new naval system differs substantially from the army's 2S6. Its guns seem shorter, and close-ups show that they are 30-mm Gatlings. They may use a new family of 30-mm ammunition now being introduced on Soviet army weapons.

The NATO designation, CADS, means Combined (i.e., gun/missile) Air-Defense System.

◆ 30-mm Twin Mount (AK 230)

Caliber: 30-mm/65 (0.54-kg shell, 1.0-kg round) [1.2/2.2 lb]

Rate of Fire: approx 1050 rnds/min/barrel (effective rate 200–240)

Muzzle Velocity: 1050 m/sec [3440 ft/sec]

Maximum Range: 4000 m [4400 yd]

Training Rate: 70 deg/sec (elevation 55 deg/sec)

Elevation/Depression: +100 deg

Ammunition Capacity: 100 ready use, 600 magazine

Weight: 3.5 tonnes without ammunition [7715 lbs]

This widely used light weapon is widely exported. The unmanned mount is fully enclosed, stabilized, and power-driven. The gun tubes are liquid-cooled, and the guns are gas-operated. This mount is normally controlled by a Drum Tilt radar or by a remote Kolonka-I optical director. The gun is a revolver, with a 4-rnd rotating breech.

AK 230 is the Soviet designation. This weapon appeared in 1959, as a successor to the earlier twin 25-mm. AK 230 is still in production, primarily for export.



The CADS-1 air-defense system is shown on board the Soviet cruiser *Kalinin*, 1988. It occupies the platform below, and to the left of, the Tin Man optronic sensor. Pairs of missiles and Gatling guns flank a nodding height-finder dish. (German MoD)

This weapon is produced in the PRC under the designation Type 69. Elevation limits of this version are $+87/-12$ deg, and the mount trains at 70 deg/sec and elevates at 50 deg/sec. Total weight is 1800 kg [3967 lb]; the weight figure above may include ammunition. Overall dimensions: $3.110 \times 2.100 \times 1.462$ m.



Soviet-type twin 30-mm gun mount on board the Indian frigate *Ganga*. (*Ships of the World*)

◆ 25-mm Twin Mount

Caliber: 25-mm/60 (0.25-kg shell, 0.7-kg rnd) [0.55/1.5 lb]
Rate of Fire: 450 rnds/min; effective rate 270–300 rnds/min (also given as 150–225 rnds/min/barrel)
Muzzle Velocity: 910 m/sec [2980 ft/sec]

Maximum Range: 3000 m; effective range 2300 m [3300/2500 yd]
Training Rate: 40 deg/sec (elevation 70 deg/sec) under hydraulic power (manual rates are 15 and 25 deg/sec, respectively)
Elevation/Depression: $+83/-10$ deg
Ammunition Capacity: 130 rnds **Weight:** 1.5 tons

Widely used for light craft, this weapon consists of 2 superimposed guns, with an on-mount optical sight. For ex-



Twin 25-mm anti-aircraft guns on board a P-6-type motor torpedo boat, about 1962. (TASS from SOVFOTO)

ample, this weapon arms Komar-class missile boats. It is still manufactured in China (PRC). The 2 machine guns are belt-fed from boxes on the left side of the mount, the gunner sitting on the right side. Guns are air-cooled, with prominent recoil springs around the bases. Normally, coupled 65-rnd belts are used, but the weapons can also be fed from 7-rnd clips.

This weapon is a Soviet version of the Bofors 25-mm, from which the 37-mm antiaircraft gun was developed. The Loginov design bureau, which was responsible for both weapons, actually concentrated on the 37-mm version (which entered production in 1939), and only in 1939 began to adapt the 25-mm version (Model 1940). Production began in September 1941. The twin-barreled naval version (2M-8) entered service in 1952; it was a heavily redesigned derivative of the army gun. The designation 2M-3 110PM has also been reported for this weapon.

The twin 30-mm mount (AK 230) was developed to replace this gun.

This weapon is produced in the PRC under the designation Type 61. The Chinese version has a maximum elevation of 85 deg. Total weight, including ammunition (65 rnds per gun), is 1735 kg [3824 lb]; overall length (at zero elevation) is 2.810 m, and maximum width is 1.974 m.

◆ 23-mm Machine Gun

Caliber: 23-mm/87 **Rate of Fire:** 1600 rnds/min/barrel
Muzzle Velocity: 970 m/sec [3180 ft/sec]
Maximum Elevation/Depression: +90 deg
Maximum Range: 3000 m (maximum altitude 2000 m) [3300 yd; 6600 ft]

This weapon appeared on board Pchela-class border patrol hydrofoils, all now retired, in a twin enclosed turret that resembles that of AK 230. This machine gun may survive on board river gunboats. It was introduced in 1965.

◆ ZU-23

Caliber: 23-mm/81
Rate of Fire: 1000 rnds/min/barrel (cyclic); effective rate 200 rnds/min/barrel
Ready-use Ammunition: 50 rnds/gun (box magazine)
Muzzle Velocity: 970 m/sec [3180 ft/sec]
Maximum Elevation/Depression: +90/-10 deg
Maximum Range: 7000 m; effective range 2800 m [7700/3000 yd]
Training Rate: manual **Weight:** 893 kg [1968 lb]

This twin-barreled army weapon is used by both the East German (e.g., on board *Libelle*-class light torpedo boats) and Polish (e.g., on board some *Krogulec*-class minesweepers) navies. It has replaced the Sea Cat launcher on board Iranian *Saam*-class frigates. The Indian government armed some of its merchant ships with this weapon during the Iran-Iraq War. The barrels are air-cooled.

◆ 14.5-mm Machine Gun

Caliber: 14.5-mm/93 **Rate of Fire:** 600 rnds/min/barrel
Ready-use Ammunition: 150 rnds/gun (linked belt)
Muzzle Velocity: 1000 m/sec [3280 ft/sec]
Maximum Elevation/Depression: +90/-5 deg
Maximum Range: 7000 m [7700 yd]

This light antiaircraft mount is no longer in widespread Soviet service but has been license-produced in China and serves on board Chinese Riga-class frigates, *Kronstadt*-type patrol vessels, *Huchuan*-class torpedo boats, and *T-43*-type minesweepers. This gun may no longer be in production. At one time it was described as a 12.7-mm machine gun; it replaced the earlier Degtyarev DHSK 38 12.7-mm gun on a 1-for-1 basis, beginning some time after 1945. The earlier gun used a 50-rnd metal belt and fired 300-500 rnds/min (0.043-kg bullets, muzzle velocity 814 m/sec [2671 ft/sec]).

The Soviet designation is 2M-7. In Soviet-made mounts the guns are superposed. The Chinese build a version in which the guns are side by side, e.g., in *Huchuan*-class hydrofoil torpedo boats. The Chinese version has been exported to Romania.

The PRC version is designated Type 82. It fires API (990 m/sec muzzle velocity) and API-T (tracer) (1000 m/sec) rounds.



Twin 14.5-mm machine guns forward, on board a Pchela-class patrol boat. Although this class has been discarded, the same mount is used on board the replacement Zhuk class. The radar is Pot Drum. (U.S. Naval Institute)

Effective range against air targets is 2000 m; against surface targets, 2200 m. Effective rate of fire is 150 rnds/min/gun. Elevation limits are +85/-10 degrees. Working circle radius is 1.757 m [69.2 in]. Total weight, without ammunition, is 600 kg [1320 lb]. Magazine capacity is 150 rnds.

There is also a modern twin enclosed 14.5-mm machine gun, in Zhuk-class patrol boats, which have been widely exported.

◆ DShK and DShKM

Caliber: 12.7-mm/76
Rate of Fire: 540-600 rnds/min (effective rate 80)
Muzzle Velocity: 860 m/sec
Maximum Range: 7000 m (1000-2000 m effective range)
Weight: 35.7 kg

This is a standard Soviet heavy machine gun, also used as a supplementary naval gun. It is gas-operated and has a flash suppressor. There are both single and twin mounts. DShKM differs from DShK only in having a simpler ammunition feed. Both guns are of prewar origin. In land service, they survive as standard tank antiaircraft guns, although newer tanks use the later NSVT. The basic gun has been very widely exported in Czech- and Chinese-built versions and may, therefore, be used by numerous Third World navies as a supplementary weapon. It is currently in production in China (PRC, as Type 54), North Korea, and Pakistan. It is definitely used by the Chinese and Iranian navies and is now being mounted on board some Soviet warships.

Typical performance includes penetration of 20 mm of armor at 500-m range, or 13.2 mm at 1000 m.

The NSVT is lighter, simpler, more reliable, and less expensive to manufacture. Its action is similar to that of the U.S. M73. It is also used in a tripod ground version (as the NSV). Presumably, then, it will ultimately displace DShKs and DShKMs used at sea. Cyclic rate is 680-800 rnds/min (effective rate 100 rnds/min), and maximum range is 8000 m (effective AA range is 1400 m in the AA role). Weight is 25 kg, including a tripod mount. In ground service, this gun normally uses a 50-rnd ammunition box. Development began in 1969, and the NSVT first appeared on T-72 tanks in the early 1970s.

UNITED KINGDOM

◆ 4.5-in Mk 5

Caliber: 4.5-in/45 (114 mm; 55-lb projectile)
Rate of Fire: 14 rnds/min (firing cycle 4.3 sec)
Muzzle Velocity: 2460 ft/sec **Maximum Range:** 20,750 yd
Training Rate: 20 deg/sec (elevation 20 deg/sec)
Elevation: +55 deg
Ammunition Capacity: none on mount
Weight: 33,562 lb **Working Circle:** 188-in radius



A Soviet under-and-over 12.7-mm machine gun on board the *Udaloy*-class destroyer *Admiral Vinogradov*, 1990. The ship carried 4 such mounts. (S. Zaloga)

This single open mount survives on board "Tribal"-class frigates in the Indonesian navy and on board the Malaysian *Rahmat*. No examples of the earlier British destroyers with single guns survive. The mounting itself was a converted 4.7-in CP XXII.

The rates of train and elevation listed above apply to the gun when it is under power control. The gun can also train and elevate under manual control, at slower rates.

◆ 4.5-in Mk 6

Caliber: 4.5-in/45 (55-lb projectile, 30–33-lb cartridge)

Rate of Fire: 10–12 rds/min/barrel (theoretical rate 24 rds/min/barrel)

Muzzle Velocity: 2460 ft/sec (derated to 2350 ft/sec in practice)

Maximum Range: 20,000 yd (maximum altitude 19,700 ft)

Training Rate: 25 deg/sec (elevation 25 deg/sec)

Elevation/Depression: +80/–15 deg

Ammunition Capacity: 80 shells, 45 cartridges in gun bay

Weight: 98,560 lb (revolving mass)

Working Circle: 218 in (radius)

(Below) A "Tribal"-class frigate displays her 4.5-in Mk 5 gun, forward. The director is MRS 3, carrying a Type 903 radar. This particular ship, HMS *Mohawk*, no longer exists, but 3 sisters survive in the Indonesian navy. (HMS Excellent)



This postwar, enclosed semiautomatic twin mount is found on many frigates and on ex-British "County"-class destroyers now transferred to other navies. At the end of 1988 only 2 of these mounts survived in Royal Navy service, on board the frigates *Achilles* and *Ariadne*. This weapon is roughly equivalent to abortive U.S. 5-in/54 semiautomatic twin mounts designed at the end of World War II, the rate of fire being somewhat slower. The very high rate of fire initially expected could not be realized in practice because the power rammer was unsuccessful; the guns had to be hand-loaded. A figure of 18 rds/min/gun was sometimes achieved.

Unlike previous types, this gun was designed from the outset for automatic aiming and for a high rate of fire. The weapon had many novel features, notably a loading tray, with which the gun recoils, and a rammer, which is pushed clear of the gun's axis by the vertically closing breechblock. Welding was





A twin 4.5-in mounting Mk 6, on display at Whale Island, 1985. (R. Cheung)

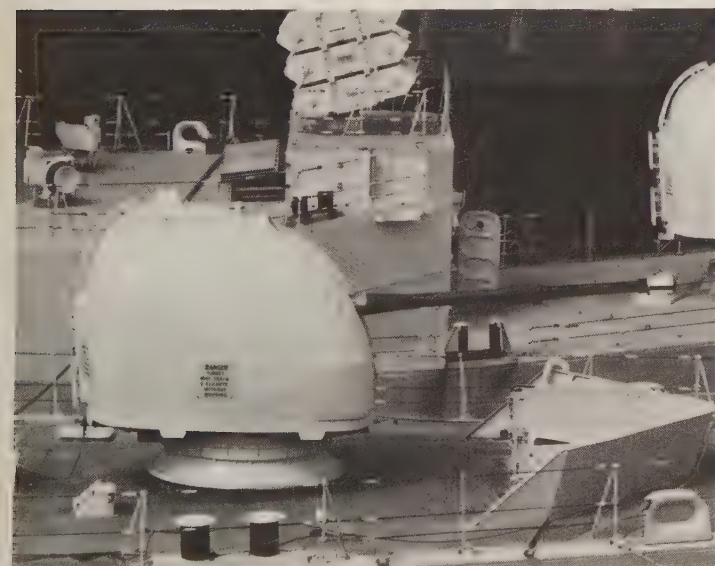
used extensively for the first time in British gun-mount construction. The training mass was entirely supported on a cantilevered structure that provided a circular gun bay clear of obstructions, for much easier transfer of ammunition to the revolving structure. This mounting was also unusual in using hydraulic rams for elevation. Ammunition was supplied by 2 magazines; the revolving structure had 1 cartridge hoist and 2 shell hoists per gun, so 2 types of ammunition could be used. The gunhouse plating is 0.375 in thick.

The only surviving examples of the earlier twin Mk 4 are 2 mounts on board the Iranian destroyer *Damavand* and 2 on board the Pakistani *Badr*, the sole surviving examples of the "Battle" class. This mounting weighed 46.3 tons, 11.2 tons of which were accounted for by a 0.5-in gunhouse. Elevation limits were +80/-5 deg.

Mk 7 would have been similar to Mk 6, for the *Malta*-class carriers and the *Lion*-class battleships, all of which were canceled at the end of World War II.

◆ 4.5-in Mk 8

Caliber: 4.5-in/55 (46-lb HE shell, complete round 80.5 lb)
Rate of Fire: 25 rnds/min **Muzzle Velocity:** 2850 ft/sec
Maximum Range: 24,000 yd
Training Rate: 40 deg/sec (elevation 40 deg/sec)
Elevation/Depression: +55/-10 deg
Ammunition Capacity: 16 rnds
Weight: 25.75 tons total (rotating mass 15.1 tons)
Working Circle: radius 19 ft 11 in



A 4.5-in Mk 8 on board HMS Glasgow, 1990. (Author)

This modern British unmanned single 4.5-in mount is installed on many current British frigates and destroyers. It is approximately equivalent to the U.S. 5-in/54 Mk 45, firing relatively slowly. The shield is fiberglass. Ready-service rounds are carried vertically, in an indexing feed ring, 2 spaces 180 deg apart normally being kept free for special types of ammunition, such as star shell. Mk 8 can open fire in 10 sec from the shut-down state. The developers considered rapid response more important than rapid rate of fire in self-defense against missiles, since each proximity-fuzed shell should be quite lethal, and since there would not, in any case, be much time for many rounds to hit. For the same reason, the gun is provided with a single multipurpose shell suitable for both air and surface action. Fuze mode is selected electronically just before the shell is rammed.

The gun itself was designed by the Royal Armament Research and Development Establishment (RARDE); modeled on the army's Abbot 105-mm howitzer, the gun has a muzzle brake and a fume extractor. The Royal Navy required that Mk 8 be able to sustain fire for 7.5 min (90 rnds). Water-cooling was rejected because it would have added too much weight, and the barrel had to be specially designed for sustained firing without cooling by water. Vickers designed the mounting.

The prototype Mk 8 was built in 1966, and the first installation was on board the Iranian frigate *Zaal* (now *Alborz*) in March 1971. HMS *Bristol* was the first British warship so fitted.

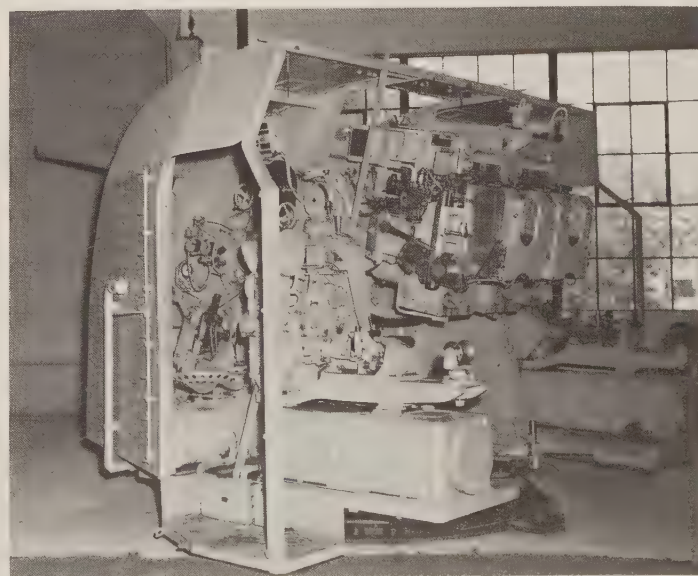
Vickers has developed a new HE/ER (high-effect/extended-range) ammunition, which employs base bleed and an improved shape to achieve 22% more range; in 1989 Vickers hoped ultimately to achieve over 30% more range, i.e., over 31,200 yd. In addition, standard muzzle momentum is achieved at a lower operating pressure, for reduced gun wear.

Shell types are high effect (HE), illuminating, radar echo (chaff for I- or J-band, either as a decoy or for wind-finding), AA practice (with a small flash filling to show that the fuze has functioned), and surface practice (completely inert). The 2 fuze types are N7 (mechanical time) and N97 (multirole: direct action, proximity low- or high-altitude, and post-impact delay). Rated barrel life is 3300 rnds.

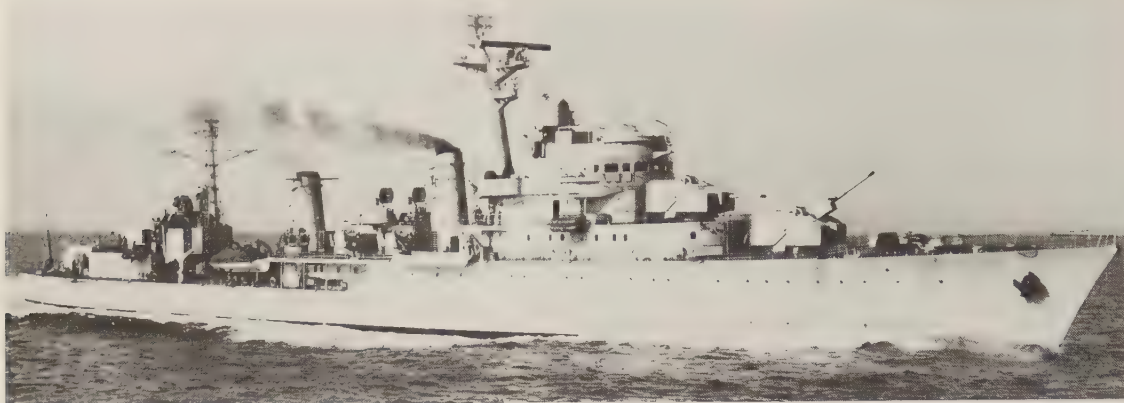
◆ 4-in Mk 19

Caliber: 4-in/45 **Rate of Fire:** 12 rnds/min/gun (firing cycle 5 sec)
Muzzle Velocity: 2660 ft/sec **Maximum Range:** 19,850 yd
Training Rate: 20 deg/sec (elevation 20 deg/sec)
Elevation/Depression: +80/-10 deg
Ammunition Capacity: none on mount
Weight: 17.8 tons **Working Circle:** 141-in radius

One twin mount survives on board the Malaysian frigate *Hang Tuah*, and 2 similar guns arm the Egyptian sloop *Tariq*.



Twin 4-inch gun. (Public Archives of Canada)



(Above) The Chilean destroyer *Almirante Riveros* shows the special Vickers 4-in guns manufactured for her. The radar at her masthead is SNW-12, with an SNW-20 slotted waveguide below it. She was later fitted with a Plessey AWS-1 aft but still retains the 2 SNW-20 antenna forward. (Vickers)

Mk 19 was once an extremely common weapon. The 2 guns share a common cradle, but each fires separately, with a separate recoil system.

◆ Vickers 4-in

Caliber: 4-in/62 (32-lb projectile)
Rate of Fire: 50 rnds/min (service rate probably about 40)
Muzzle Velocity: 2953 ft/sec
Maximum Range: 18.5 km (maximum altitude about 12,000 m)
Elevation/Depression: +85/-7 deg
Ammunition Capacity: 56 rnds (two 28-rnd hoppers)
Weight: 47,040 lb

As originally conceived, this mount would have carried the same gun as the standard Mk 19, in a mounting similar to that of an abortive 5-in automatic gun designed by Vickers. The original weapon, developed from the army's new mobile 4-in high-velocity antiaircraft gun, was proposed about 1953 for the projected (abortive) rearmament of the Argentine training cruiser *La Argentina*, and also for Peruvian and Chilean ships. Other potential buyers at this time were Israel and Venezuela, to use the gun either as the main battery of a 1200-ton escort or 2000-ton fast escort, or as the secondary battery of a 2600-ton destroyer also armed with 4.7-in antiship guns.

The unusual feature of the mounting is that it loads through the trunnions, the shells being carried in two 28-rnd hoppers between the trunnions. The hoppers could be topped up to maintain a rate of about 30-40 rnds/min (Vickers claimed 50 rnds/min, but the DNO [Director of Naval Ordnance] of the day was skeptical). Weight, with the standard 45-caliber 4-in barrel, was 19 tons empty (plus 1.6 tons of ammunition), and elevating limits were +85/-7 deg.

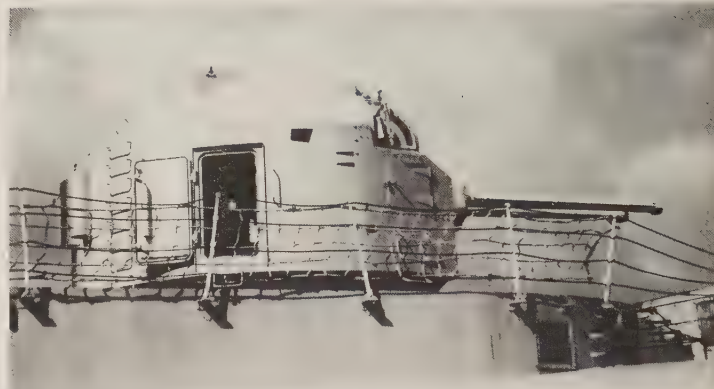
These guns arm the 2 *Almirante Rivero*-class Chilean destroyers and were being rehabilitated in Chile in 1987-88.

There was also a proposed 105-mm version, for the Argentine navy; that version would have weighed 53,760 lb and was rated at 40-46 rnds/min.

◆ 3-in Mk 6

Caliber: 3-in/70
Rate of Fire: 95-113 rnds/min/gun (designed for 120 rnds/min/gun) (15-lb shell) **Muzzle Velocity:** 3400 ft/sec
Maximum Range: 19,500 yd
Training Rate: 60 deg/sec (elevation 30 deg/sec)
Elevation/Depression: +90/-15 deg
Ammunition Capacity: 161 rnds/gun (2 hoppers per gun, 100 and 38 rnds, with others in the system); total 2000 rnds in the magazine
Weight: 83,150 lb (revolving mass, including 34 rnds/gun)
Working Circle: radius 234 in

This mount was designed in Britain but survives only on board 7 active Canadian frigates. Mk 6 used the same ammu-



A twin 3-in/70 Mk 6 on board the Canadian destroyer *Gatineau*, 1988. (S. Terzibaschitsch)

nition and the same gun tube as the U.S. twin 3-in/70 but was less ambitious in concept and, perhaps as a result, was much more successful. In the Royal Navy, Mk 6 was the intended main battery of the postwar frigates, but it was not ready in time, and the twin 4.5-in Mk 6 was substituted.

The guns are water-cooled. There are 2 hoists on the nonrotating structure (25 rnds/min), and the hoists top up the hoppers that rotate with the guns.

◆ 40-mm Mounts

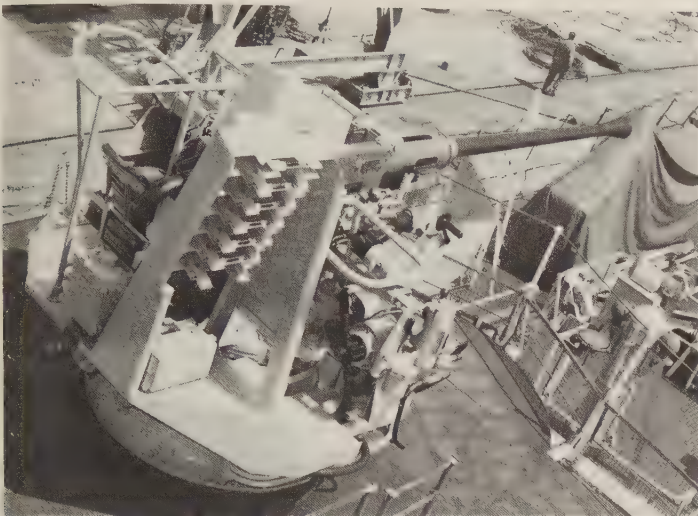
Caliber: 40-mm/56.3 (1.97-lb shell)
Rate of Fire: 120 rnds/min (140-150 with gun horizontal)
Muzzle Velocity: 2890 ft/sec
Maximum Range: 10,750 yd (but shells generally self-destruct at 3000-3500 yd)
Training Rate: 35 deg/sec (elevation 28 deg/sec; 35 deg/sec in Canadian-built mountings)
Elevation/Depression: +90/-15 deg (Mk 5)
Ammunition Capacity: 12 clips on mount (48 rnds); Mk 9 has 6 clips on the mount (plus the clips in the gun).
Weight: 6.397 tons

Data above apply to the Mk 5 twin power mount.

The Royal Navy still uses a few 40-mm Mk 7 and Mk 9 mounts, carrying the standard World War II 40-mm L60 gun (see the Swedish Bofors 40-mm/60 above for details). The Royal Navy expected to adopt the postwar 40-mm/70 but bought Sea Cat missiles instead; the British army did buy the L70 gun.

Mk 5 was the standard twin mount (water-cooled guns) with remote power control. There was also a Mk 6 sextuple mount, now extinct, the only British naval Bofors that did not use the standard gravity-feed clip. Instead, each gun had a 36-rnd ammunition tray operated by gun recoil.

Mk 7 is an adapted army single air-cooled mounting, with a light alloy structure and a splinter shield. Using 1-operator laying and a gyro sight, with a separate loader, Mk 7 is hydraulically driven, with the motor and pump on the revolving structure. Elevation rate is reported as 45 deg/sec, and total weight is about 3 tons. Mk 8 was an unsuccessful interim design with



Standard British single 40-mm gun, probably Mk 7. The rack is for spare clips. (National Maritime Museum)



Single 40-mm mount Mk 9, on board a British minesweeper. (A. Raven)

battery power. Mk 9 is a refurbished Mk 7 with electric rather than hydraulic drive. Mk 9 was used in the Falklands.

The Australian Maribymong Ordnance Factory remanufactures existing Mk 3 and Mk 7 mounts, designated 40/60 AN. The 40/60 AN first went to sea on a *Freemantle*-class patrol boat in 1980; as of early 1989, 30 were in service. This mounting has also been adopted by the Thai navy. Time between refits is 6 yr, compared to 9–11 months for Mk 7. Total weight without ammunition is 1500 kg [3350 lb]. Elevation limits are +90/–5 deg. Training rate is 40 deg/sec; elevation rate is 20 deg/sec; creep rates in both dimensions are greater than 20 deg/min. The system can be stabilized as a customer option, but none has yet been stabilized. Existing mountings are converted by discarding old components, which are difficult to maintain, and by replacing them with modern power, hydraulic, and control systems. The hand-drive train is replaced by a low-pressure oil-hydraulic system with an integrated power pack, controlled by a T-handle for rapid target acquisition coupled with slow and smooth tracking. The hydraulic power pack is fully enclosed for greater protection. The electrical box is relocated below decks.

The British version of the Bofors gun could accommodate two 4-rnd clips (or 10 rnds, with 2 loose between the clips), and it was claimed that a single loader could work fast enough for the gun to fire a burst of 24 rnds.

Another wartime British 40-mm mount, the Boffin, is to arm the new Canadian mine-countermeasures craft. The weapons

had been mounted on board the Canadian aircraft carrier *Bonaventure*, and then to protect Canadian airfields in Germany when the carrier was discarded. Boffin, a twin 20-mm Mk V or VC power mounting adapted to take a single air-cooled 40-mm gun, was very widely used late in World War II. The Canadian Boffins used for airfield defense were powered by on-mount gasoline engines. In August 1990 Mk 5C (Boffin) mounts earmarked for the mine-defense ships were diverted to the 3 Canadian ships going to the Persian Gulf: 2 each for the destroyers *Athabaskan* and *Terra Nova* and the replenishment ship *Protecteur*. They were supplemented by six 0.50-cal machine guns on board each ship.

◆ 30-mm A32

Caliber: 30-mm/75 (Type 831L cannon) (0.36-kg shell; 1.0-kg complete round) [0.8/2.2 lb]

Rate of Fire: 600 rnds/min/gun **Muzzle Velocity:** 3540 ft/sec

Effective Range: 3300 yd (maximum 11,100 yd)

Training Rate: 90 deg/sec (elevation 60 deg/sec)

Elevation/Depression: +80/–15 deg

Ammunition Capacity: A version: 160; B version 320

Weight: 3740 lb without ammo or gunner; ammo weight is 352 lb (A) or 704 lb (B) **Working Circle:** 8.25 ft [2.57 m]

This BMARC mount, for twin Hispano-Suiza guns, predated the twin Oerlikon that the company later marketed (BMARC was a Hispano-Suiza subsidiary, and Oerlikon later took over Hispano-Suiza). A32 is similar in overall configuration and was presumably adapted to the Oerlikon gun. The mount was designed in 1967, and 2 prototypes were produced for Finland (delivered 1968: one Series A, one Series B).

In the A version, the ready-service ammunition boxes elevate with the mount. In the B version they do not.

◆ 30-mm (Type GCM-A01)

Caliber: 30-mm/75 **Rate of Fire:** 1300 rnds/min

Muzzle Velocity: 1080 m/sec [3540 ft/sec]

Maximum Range: 10,000 m [33,000 yd]

Training Rate: 75 deg/sec (elevation 50 deg/sec)

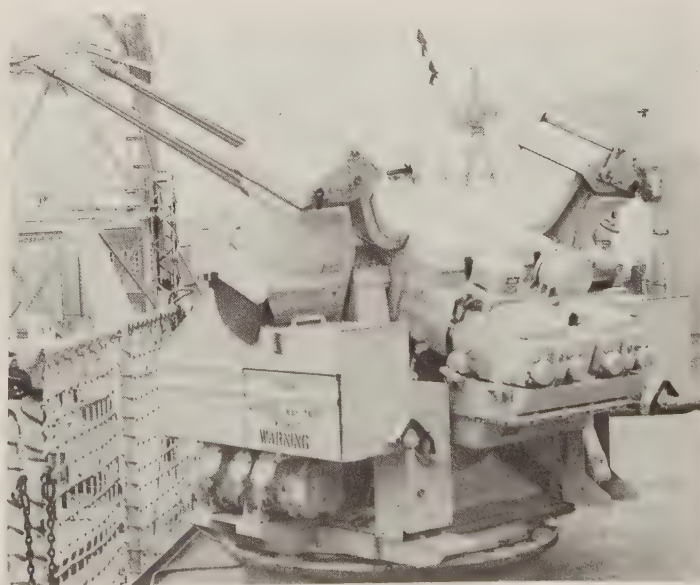
Elevation/Depression: +80/–15 deg

Ammunition Capacity: 160 rnds/gun (A03-1: 160 or 250 rnds/gun; A03-2: 250 rnds/gun; A03-3: 320 rnds/gun)

Weight: 2000 kg (A02); A03-1: 2150 kg; A03-2: 2050 kg; A03-3: 1900 kg [4410/4740/4520/4190 lb]

Working Circle: 2520 mm [99.2 in]

For this BMARC/Oerlikon project, Oerlikon provided the twin 30-mm guns and their new APDS ammunition, announced in 1975. The mount is gyro-stabilized and power-driven, with either local or remote control. The guns are twin 30-mm Type KCB cannon. BMARC (British Manufacture and Research Co.)



30-mm GCM-A01 twin mount. (A. Raven)

was part of the Oerlikon-Bührle Group, hence the use of Oerlikon guns as part of the weapon.

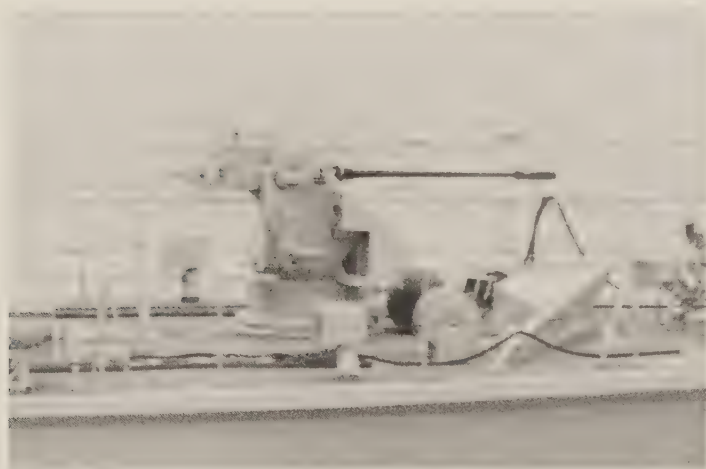
The original A01 version was introduced in 1968. A02 entered British naval service as an emergency close-in defense gun during the Falklands War, the Royal Navy buying 8 of the GCM-A02 version. The current version is A03. The version in the Brunei fast patrol craft built by Vosper Singapore in 1978 is GCM-B01, controlled by a Sperry Sea Archer 1.

BMARC also marketed the twin 35-mm Oerlikon gun (Type GDM-A; see the Swiss guns above).

◆ Laurence Scott LS-30B (DS 30)

Caliber: 30-mm **Rate of Fire:** 650 rnds/min
Muzzle Velocity: 1080 m/sec [3540 ft/sec]
Training Rate: 55 deg/sec (elevation 55 deg/sec)
Elevation/Depression: +65/-20 deg
Ammunition Capacity: 160 rnds
Weight: 1.2 tons (with ammunition)

LS-30B is a stabilized single mounting that carries the Oerlikon 30-mm KCB cannon. Twenty-five were ordered in September 1984 to arm "Duke"-class frigates and to replace some existing Bofors 40-mm/60 guns in Mk 7 and Mk 9 mounts, and the gun entered service in 1987. The mount was conceived as a gun adaptation of an existing optical director. Power-operated and gyro-stabilized, the gun is controlled by joystick. The original version, LS-30R, carried a 30-mm Rarden gun (as used on land) with a 21-rnd magazine. An alternative version, carrying a Mauser cannon, was designated LS-30F.



DS-30B, shown on board HMS *Brecon* (July 1989) and at the RNEE in 1989. (U.S. Naval Institute and Author)

There were 3 versions of the basic mounting: Mk I, controlled locally by an operator with a joystick; Mk II, controlled remotely by the director; and Mk III, with an added digital predictor. The Rarden Mk I version was tested on board HMS *Londonderry* in 1981. Overall system dispersion was less than 3 mrad in sea-state 5, and in one trial a towed 2-m² target was hit 80% of the time at 1000-1300 m in poor visibility. This mount weighed 800 kg including gun, with a 2.2-m working circle (radius), and training/elevation velocities of 30/35 deg/sec; elevation limits were +70/-20 deg. The gun could fire a 6-rnd burst, or 21 rnds if an extra magazine was fitted.

This mount was redesignated DS 30 in 1986, the manufacturer having been renamed Defense Equipment and Systems, Ltd. The company offers versions of the basic mount armed with a variety of guns: DS 30B (30-mm Oerlikon KCB cannon), DS 30E (30-mm EBO-Mauser cannon), DS 30F (Mauser 173 Model F), and DS 30R (30-mm Rarden cannon). There is also a DS 25M carrying the U.S. M242 Bushmaster 25-mm cannon, a weapon also used by the U.S. Navy. As of 1987, DS 30E was being evaluated by the Greek navy, and a NATO coast guard was evaluating the DS 25M. The Royal Navy uses DS 30B. Sea trials, on board the minesweeper *Cottesmore*, were completed at the end of October 1986.

This weapon is designated Single 30-mm Gun Mounting Mk 1 in British service; the first ship fitted with it is HMS *Cornwall*.

◆ L7A2

Caliber: 7.62-mm **Muzzle Velocity:** 838 m/sec
Maximum Rate of Fire: 625-750 rnds/min
Maximum Elevation/Depression: +45/-10 deg
Ammunition Load: 200 rnds **Maximum Range:** 1800 m
Weight: 10.9 kg (gun alone, empty)

L7A2 is the standard British light machine gun, and its role in the Royal Navy is broadly analogous to that of the U.S. 0.50. L7A2 serves as a policing weapon on board "Ton"-class minecraft, and the "Isles"- and "Castle"-class offshore-patrol vessels. It was also pintle-mounted on board larger ships, e.g., for close-in defense. The gun, which is a standard air-cooled infantry machine gun, can be mounted on a pedestal, a buffered tripod, or a bulwark pintle.

This gun is based on the Belgian FN MAG.

◆ GBN 155

Caliber: 155-mm/52 **Maximum Rate of Fire:** 12 rnds/min
Maximum Range: 24,000 m [26,200 yd]
Weight: 13,550 kg [29,860 lb]

This modified 155-mm/52 gun-howitzer (GBT) was exhibited by VSEL (and later by the Royal Ordnance Factories [ROF] at the RNEE 1983 and later shows, as a future naval gunfire support weapon that would use ammunition widely available for ground forces. This project lost much of its rationale when the Mk 8 4.5-in gun was incorporated in the Type 23 frigate. However, in 1988 ROF was considering a joint venture with the U.S. company FMC to market 155-mm naval guns, perhaps using FMC's vertical loader.

◆ VSEL 155-mm Naval Gun

Caliber: 155-mm/52 **Rate of Fire:** 10 rnds/min
Maximum Range: 40 km (with base-bleed projectiles)
Elevation/Depression: +80/-15 deg
Weight: about 20 tons plus 3.5-ton hoist

VSEL announced its new private-venture medium-caliber gun, a collaborative effort with Royal Ordnance, at RNEE 1989. Like several other lightweight gun designs, this one avoids allowance for antiaircraft fire to avoid complexity; the very high maximum elevation is valued for shore bombardment. VSEL claimed some Royal Navy interest, presumably generated by Falklands experience. The caliber was chosen because the gun was already used by the British and other NATO armies, with a wide range of specialized shells (VSEL did not, however, study the HERO consequences of using army shells, a problem that

helped kill the U.S. 155-mm naval gun). VSEL proposals include the use of the same projectile with the same charge, but with alternatives for greater lethality, accuracy, and range. The 2 main options are to place the charge in a metal case (which is removed after firing) for automated ramming, the charge and projectile being rammed together, or alternatively to use a stub case (standard round—fixed round). VSEL would prefer to use the version already in service on land, in which the charge burns completely, leaving a metal case to eject. The case encloses the bagged charge to simplify ramming; it is not a cartridge case in the usual sense. It, therefore, need not be solid.

The crew would be 2 in the gun bay, and 3 or 4 in the magazine, with a capacity of 200–250 rnds. The rounds and their charges are too massive for convenient automatic drum loading. This is not the GBN 155 described above.

◆ 105-mm Autonomous Patrol Gun

Caliber: 105-mm/51 **Muzzle Velocity:** 2400 ft/sec (HE)
Rate of Fire: 12–14 rnds/min (hand-loaded)
Training Rate: 30 deg/sec (elevation 10 deg/sec)
Maximum Range: 6000 m [6600 yd]
Elevation/Depression: +45/–12.5 deg
Ammunition Load: 30 rnds
Working Circle: swept radius 14 ft 9 in **Weight:** 6 tons

This adapted L7 tank gun, developed by the Royal Ordnance Factories, was first displayed in 1980. The 105-mm could be fitted in patrol boats from 35-m length up. Cost was estimated at £600,000 in 1981. The muzzle velocity given above is for high-explosive (full-caliber) shells; with discarding sabot shells the tank gun attains about 4800 ft/sec. Presumably, naval operators would not use such shells. Although sales were not forthcoming, the weapon is interesting as a Western equivalent of the standard Soviet practice for river patrol boats. No current Western river-gunboat weapon of this type is in service, although the U.S. Navy did use tank-type howitzers in Vietnam, on board monitors.

◆ Sea Venom



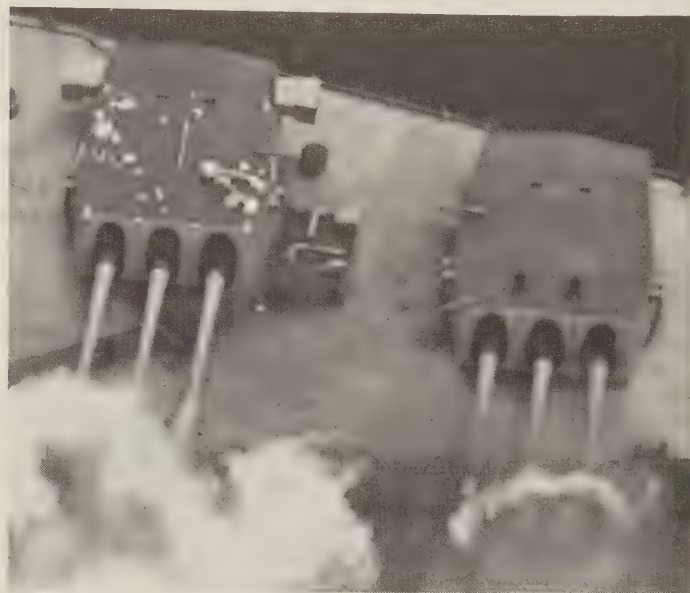
Radamec Sea Venom, a pair of remote-controlled 0.50-cal machine guns on the company's stabilized 429 servo platform. (Radamec)

This Radamec remote-controlled machine-gun mount was announced at RNEE 1989. It is a Type 429 servo-controlled platform carrying two 0.50-caliber machine guns, with 200 rnds each; the platform can carry heavier weapons if necessary, or 57-mm parachute flare launchers. It can be controlled by a Series 1000 stabilized director. Nominal height is 1 m (carrying the two 0.50-caliber guns), swept radius is 1.2 m, and weight is about 300 kg, including 400 rnds. Elevation limits: +50/–30 deg. Sea Venom can train and elevate fast enough to engage surface craft and helicopters from a small, lively, fast attack boat, but not quickly enough to engage fast aircraft.

UNITED STATES

◆ 16-in/50

Caliber: 16-in/50 (2700-lb AP shell, 1900-lb HC shell)
Muzzle Velocity: 2425 ft/sec AP; 2690 ft/sec HC
Rate of Fire: 2 rnds/min/gun
Training Rate: 4 deg/sec (elevation 12 deg/sec)
Maximum Range: 40,185 yd AP; 41,622 yd HC
Elevation/Depression: +45/0 deg (depression 2 deg in turrets I, III)
Working Circle: 36 ft 4.5 in
Weight: 1701–1708 tons (per turret) without ammunition



16-in/50 salvo. (Edward J. Bonner)

The 16-in/50s are now the most powerful naval guns in the world, the sole active survivors of the battleship era. The guns are mounted separately and elevate separately. Each gun loads at a fixed 5-deg elevation. After firing, each gun depresses to its loading elevation and then elevates again to fire. Each turret has a crew of 77, plus 30–36 total in the 6 magazines. The AP round will penetrate 30 ft of concrete. In Vietnam single HC rounds were used to clear 200-yd-diameter landing zones in triple-canopy jungle; the rounds made craters 50 ft wide and over 20 ft deep. The most important technical innovation of the Vietnam period was "Swedish additive," which was wrapped around the charge and which, when burned, reduced barrel wear. During Vietnam, too, some work was done on extending the gun's range. In the spring or summer of 1967 there was a proposal that sabot 280-mm shells (left over from the army's "atomic cannon" program, but nonnuclear) be fired, to ranges as great as 100,000 yd. The Naval Ordnance Station, Indian Head, proposed a \$4-million, 18-month program to modify 23,000 such projectiles. There was, however, concern that stable flight could not be assured, and that fuzes could not survive the heat of very high velocity flight. However, exploratory shots were fired at Yuma (up to 60,000 yd) and in Barbados (in the latter case, from 2 surplus 16-in/45 tubes welded end to end). In February 1969 the Barbados gun fired an 835-lb shell at 40 deg of elevation (4230 ft/sec) to 74,650 yd; in November 1968 the gun fired a 745-lb shell (4550 ft/sec) to 83,850 yd. It was estimated that at 45 deg of elevation the light shell would reach 102,000 yd (93,000 yd at 40 deg). The program died, presumably when the *New Jersey* was deactivated. However, these ranges are about what would be needed by a ship well offshore (i.e., over the horizon) to reach a V-22 landing zone inland.

As of 1981, when the battleships were being reactivated, the reported stock of ammunition was: 15,500 HC (high-capacity) shells, 3200 AP shells, and 2300 BL&P (blind-loaded training) shells. A total of 12,500 full-service and 12,600 reduced charges

were on hand. As a measure of consumption, USS *New Jersey* fired 771 rounds during World War II, 6671 during the Korean War and her midshipman cruises, and 5688 during the Vietnam War. As of 1986, it was expected that new 16-in shells would have to be manufactured for delivery in 1990; the last new 16-in shells had been made during the Korean War.

There are now 4 special-purpose shells using the 16-in HC (1900-lb) body but containing submunitions. Mk 143 HE uses an army proximity fuze. Mk 144 carries 400 M43A1 wedge (anti-personnel) grenades and is time-fuzed. Mk 145 is a time-fuzed high explosive. Mk 146 uses the time fuze and carries 666 shaped charge (SADARM) bomblets (M42/M46/M77 dual-purpose anti-personnel/antimatériel).

An operational requirement for improving the 16-in guns was approved in May 1986. It includes the development of a new 13-in subcaliber cargo shell carrying about 600 dual-purpose anti-personnel/antimatériel submunitions (SADARM) to a considerably greater range than the 16-in shell can achieve. Although the 13-in shell is much lighter and is of smaller diameter, it has a cavity about as large as that of the full-caliber shell. Other army submunitions are being evaluated. The design of the 16-in sabot and the 13-in body were begun in FY86; tests were expected in FY90, and the lead ship was to have received the first shells that year, with approval for full production expected in FY92. The shell acts as a bus and can carry other loads: possibilities include chaff, smoke, and land mines (which are already carried by shells on shore).

The sabot shell was chosen for extended range because it was simpler than a proposed rocket-boosted projectile. There have been recurring proposals for a ramjet shell, a gun-launched missile, but they have been put aside because of their inherent complexity.

The other major element of the program is the integration of a digital gun computer, a Mk 160 similar to that of the *Arleigh Burke*, into the Mk 38 FCS. The digital computer can make allowances for the different ballistics of the new shells, and in future it may be connected to a shell-tracking radar that will measure the actual muzzle velocity of the guns on a round-by-round basis, so that ballistic corrections can be applied. Neither improvement would have been possible with the old analog computer, in which ballistic formulas are represented by the complex shapes of cams.

When the guns were brought back into service, there were initial problems with powder, i.e., with the consistency of fire on a round-to-round basis. The problem is reflected in variations in muzzle velocity. Powder of the World War II era was expected to produce a variation of no more than ± 10 ft/sec; service figures were ± 5 ft/sec. During the Korean War typical figures were ± 14 ft/sec, and during operations off Lebanon this deteriorated to ± 32 ft/sec. The reworking program restores the powder to the original standard of ± 10 ft/sec.

Existing powder supplies were rebled during 1986, to improve the gun's accuracy. At that time the navy held large stocks of bulk 16-in/45 powder, plus prebagged 16-in/50 bags. The choices were either to remix and reload the 16-in/50 bags (but matching lots was difficult because the bags had differing histories) or to bag the bulk-stored 16-in/45 powder. Since the bulk-stored powder had more uniform characteristics, it was used. There is a small difference in composition between 16-in/45 and 16-in/50 powder, but it was possible to bag the former to 16-in/50 specifications and to impose sufficient quality control to come within the original specification for muzzle velocity noted above. New powder production will not be needed for some time: as of 1985 the navy had about 12 million pounds of 16-in/45 powder on hand. This material does not deteriorate, but it does age, partly because its volatile components vanish in the first few years. Afterward, change is more gradual.

As modernized, each turret carries a DR-810 radar that measures the muzzle velocity of each gun. These data make it easier to predict the velocity of the next shot (since it reflects the state of wear of the gun tube on the last shot). The radar elevates to follow gun elevation, and gun velocity is displayed

in the turret and printed out in each plotting room. The radar occupies a small radome directly on the roof of each turret, over the center gun; the radar aft is on a short tripod. There are also 2 HP-85 digital computers. Computer IBC 1 calculates expected initial velocity based on measured gun erosion, powder temperature, and history of initial velocities; the output is compared with radar velocity data. Computer IBC 2 corrects for trunnion height, target height, earth curvature and rotation, ballistic density, and air temperature, calculating fuze time setting for projectiles (Mks 144, 145, and 146) that require it.

The combination of better powder and this degree of detailed calculation makes for considerable accuracy at very long range. For example, firing off Crete on 23 November 1987, the *Iowa* fired fifteen 2700-lb AP rounds (5 from the right gun of each turret) at a range of 34,000 yd. The pattern size was 219 yd (0.64% of total range), and 14 of the 15 shells were within 250 yd of the center of the pattern; 8 of the 15 were within 150 yd. Shell-to-shell dispersion was 123 yd (0.36% of range).

Considerable effort has been expended to reduce wear on the barrels. The 16-in/50 gun was designed to fire 290 full-charge AP rnds before tube replacement (the lighter HE shell is equivalent to only a fraction of the full AP rnd). During the Vietnam War the battleship *New Jersey* used a titanium-dioxide jacket that reduced the wear per full-service round to the equivalent of 0.26 such rounds. A newer wax and polyurethane jacket does significantly better. One jacket is used around each bag of the propelling charge; the jacket forms a gaseous layer that protects the gun's bore. These jackets have been so successful that mechanical fatigue, rather than erosion, is now considered the limiting factor in liner lifetime; the 16-in/50 Mk 7 gun is now rated at 1500 FER (fatigue equivalent rounds). Even so, there was some concern at the beginning of the program that insufficient barrel liners remained. However, as of 1986 there were 35 new barrels on hand (one with a used liner), and also at least 10 new liners.

A 16-in Gun Improvement Conference was held in mid-June 1987. It called for several improvements:

- NSWC Dahlgren was tasked to produce super-charge powder to increase velocity and range of 1900-lb shell (full capacity of barrel not yet utilized).
- an increase in angle of fall of shot; an incremented charge would give more flexibility in angle of attack. Dahlgren was to develop a special powder load to enable reverse slope firing at shorter ranges.
- powder used in tests is often at 90°F; ships store it at 70°F and, thus, get longer ranges than predicted. Dahlgren was to evaluate powder charges at 70°F to measure range variation.
- a floating target was needed for surface target practice.
- the Mk 48 computer (WW II technology) had to be replaced by a modern digital plotting table.

Longer-term proposals were:

- full-charge flashless powder for 16-in/50 for night action.
- a new fire-control radar, to replace the existing Mk 13, a unique emitter that identified its platform as a battleship. Proposals included the use of a laser range-finder/illuminator. This proposal probably explains the installation of an SPQ-9A radar on board the battleship *Iowa*, which functioned as test ship for new installations.
- the Mk 37 GFCS should be replaced because it is obsolete.

In April 1989 the *Iowa* suffered an explosion in the center gun of her No. 2 turret before firing. Her turret was not immediately repaired, and she operated for a time with only 6 guns. In January 1990 it was announced that she and the *New Jersey*, which had been in commission the longest, would be returned to reserve; later it was decided not to repair the *Iowa*'s No. 2 turret. The other 2 ships are to remain in active service, and presumably the 16-in improvement program is to continue. As of mid-1990, the marines were pressing for the longer-range

saboted projectiles, which they considered essential to support their new doctrine of deeper-penetration landing.

◆ 8-in/55 Rapid-Fire

Caliber: 8-in/55 **Muzzle Velocity:** 2700 ft/sec HC; 2500 ft/sec AP
Rate of Fire: 10 rnds/min/gun
Training Rate: 5 deg/sec (elevation 8.2 deg/sec)
Maximum Range: 31,350 yd HC; 30,100 yd AP
Elevation/Depression: +41/-5 deg
Working Circle: 23 ft 3.0 in **Weight:** 451 tons



Triple 8-in/55 automatic turrets on board 1 of the 2 surviving *Des Moines*-class cruisers. The ship on the right is the *Newport News*, which has been stricken. Although these ships have been out of service for over a quarter-century, they are in excellent condition. The smaller guns are twin 5-in/38s and twin 3-in/50s; the latter would presumably be landed if the ships were recommissioned.

These guns, the sole survivors of a type that once armed many U.S. cruisers, remain in reserve on board the *Des Moines* and *Salem*. The guns are mounted in triple turrets. Work began in May 1943, after the development of a twin automatic 6-in/47 had shown that a large gun could be made to fire rapidly, i.e., about 10 rnds/min. This high rate of fire was achieved by all-angle loading with semifixed (i.e., cased) ammunition, all ammunition being power-handled. The mount was considered quite successful in service, suffering only 1 bad accident (which, however, knocked out the No. 2 turret of the cruiser *Newport News*).

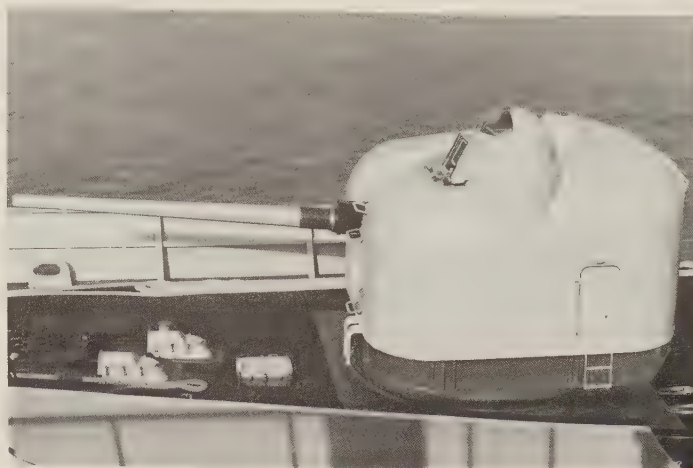
◆ 6-in/47

Caliber: 6-in/47 (105-lb HC shell, 130-lb AP)
Muzzle Velocity: 2800 ft/sec HC; 2500 ft/sec AP
Rate of Fire: 10 rnds/min/gun (rating: 3 rnds/min/gun)
Training Rate: 10 deg/sec (elevation 11 deg/sec)
Maximum Range: 24,010 yd
Elevation/Depression: +60/-5 deg (load at angles up to 20 deg)
Working Circle: 21 ft 7.5 in
Weight: 154-167 tons (for different turrets in the ship)

Only 1 ship still carries these triple mounts, the Chilean cruiser *O'Higgins* (ex-USS *Brooklyn*). The guns are semiautomatic, and they elevate together. The ammunition is semifixed. The gun's lifetime is about 750-1050 rnds at full charge. The associated director is Mk 34, similar to the battleship Mk 38. The crew per turret is 3 officers and 52 enlisted, compared with 17 enlisted for the semiautomatic Mk 39 5-in/54, and with 6 enlisted for the abortive automatic 8-in/55.

◆ 5-in/54 Mk 42 and Mk 39

Caliber: 5-in/54 (70-lb shell) **Rate of Fire:** 40 (derated to 28)
Muzzle Velocity: 2650 ft/sec
Maximum Range: 25,900 yd (Time of flight to 10,000 yd at 6-deg elevation is 15.8 sec.)
Training Rate: 40 deg/sec (elevation 25 deg/sec)
Elevation/Depression: +85/-7.5 deg
Ammunition Capacity: 40 (automatically loaded)
Weight: 145,930 lb (Mod 0) **Working Circle:** radius 269 in



5-in/54 Mk 42 mount, USS *William S. Sims*, 1986. (L. van Ginderen)

Data are for Mk 42.

Mk 42 was the standard U.S. single 5-in gun mount of the postwar era, conceived as an automatic equivalent of the twin 5-in/38 with the same rate of fire (but firing a more powerful round). Later versions required fewer crew: 13 in Mod 9, compared with about 20 in earlier types. For example, remaining mounts use a single joystick control, whereas the original mount had separate pointer and trainer.

In all variants, the gun is fed by 2 parallel 2-stage hoists, each extracting ammunition from a loader drum. Shells and cartridge cases are loaded separately into the drums, each of which holds 20 complete rnds. Shell and cartridge case are transferred together from drum to lower hoist, then to an upper hoist, and then to a transfer tray (on a cradle) that swings up parallel to the breech; the left and right hoists operate alternately, so that 1 places a round in the right cradle while the other descends to pick up another. Each transfer tray contains a fuze setter; it drops into position between rammer and breech to load the round. Having loaded, the tray pops up to avoid the gun's recoil, and an empty case tray moves into position to receive the ejected case. The entire process is complex mechanically, and the Mk 42 acquired a reputation for jamming during protracted firing, e.g., on the gun line off Vietnam: hence the current derating to about half the originally projected rate of fire. Mk 42 Mod 10 has a special trouble-shooting status board.

A laser-guided 5-in shell, Deadeye, was developed by Martin Marietta, primarily for shore bombardment. Initially Deadeye was to have been guided by a shipboard laser designator incorporated in the Seafire (EX-121) director; but when Seafire was canceled, shell development continued, the designator being a marine mobile unit, MULE. Deadeye could also respond to a helicopter-borne designator. The shell was rocket-boosted for additional range. Deadeye was tested at sea on board the *Briscoe* in 1981, and the first 300 rnds were scheduled for delivery in FY89, with another 15,100 planned. Delays between 1981 and 1989 were largely caused by disagreements about the cost per round, and the program died in the FY89 round of budget cuts.

The guided shell was 60.97 in long, with pop-out fins at its nose (for guidance) and at its base (for stability), and Deadeye weighed 104.7 lb. The standard 5-in/54 rnd, including its cartridge case, is 60.93 in long; the shell itself weighs 57.3 lb (carrying 7.9 lb of high explosive). The shell could be either a shaped charge or fragmentation warhead. Given the great length, the guided shell had to be double-rammed: once for the shell and once for the separate cartridge case. That requirement roughly halved the rate of fire, and the need to accommodate markedly longer shells accounts for the FMC proposals for vertically loaded guns, described below. The estimated range of the rocket shells is 40,000 yd, compared with 20,000 yd for a conventional shell. With the demise of Deadeye, vertical loading is a much less urgent issue.

There was also an IR-guided shell, developed nearly concur-

rently with Deadeye, which would have been used as a secondary antiaircraft round. This shell did not enter production, although there is an IR fuze. The rationale was that there were numerous existing antiaircraft weapons, and that, with a warhead much smaller than that of Sea Sparrow, the shell would not have been worthwhile.

Finally, there is a rocket-boosted 5-in/54 shell, Mk 58 (the standard shell is Mk 65), weighing 58 lb and carrying 3.8 lb of explosive. With cartridge case, the full round is 61.25 in long. The solid-fuel motor burns for 34 sec, and the maximum range against a surface target is 31,090 yd, compared with 23,690 yd for the conventional shell.

In 1988 a 5-in cargo projectile was under development, to carry chaff and other loads (presumably submunitions).

The current program for ammunition development includes a super charge that increases range for the high-fragmentation 5-in shell and that also gives 2–4 times the barrel life of the existing charge (the super charge is also under development for the 3-in gun). This new LOVA (low-vulnerability ammunition) charge will also reduce a ship's vulnerability to fire and blast because rounds in a magazine will be less likely to cook off. A multifunction fuze (remotely set point-detonation, time, or multiproximity) is being developed, so that a single fuze can serve for all air and surface targets. The existing IR fuze is being improved to deal with cooler targets and to reject background clutter more effectively.

Mk 39 is a semiautomatic single 5-in/54 mount that survives on board 3 former Japanese destroyers, now reclassified as auxiliaries (*Akizuki* class). These weapons were removed from the U.S. aircraft carriers *Midway* and *Franklin D. Roosevelt*. The gun is the same as that in the Mk 42 mount, but the rate of fire is about 15 rnds/min because of manual loading. The mount weighs 87,500 lb. The shield is 0.75 in thick. Elevation limits are +85/–10 deg, and the mount trains at 30 deg/sec (elevation rate 15 deg/sec). The working circle's radius is 276 in.

The 5-in/54 Mk 42 has been manufactured under license in Japan (by the Japan Steel Works) since 1965.

◆ 5-in/54 Mk 45

Caliber: 5-in/54 (70-lb shell)

Rate of Fire: approx 20 rnds/min (17 measured in test)

Muzzle Velocity: 2650 ft/sec **Maximum Range:** 25,900 yd

Training Rate: 30 deg/sec (elevation 20 deg/sec)

Elevation/Depression: +65/–15 deg

Ammunition Capacity (on-mount): 20 (10 guided rnds)

Weight: 47,820 lb (no lower hoist)

Working Circle: radius 261 in

Mk 45 is the slower-firing, low-manning replacement for Mk 42. Mk 45 was intended as the simplest of a family of such

weapons, some of which would have fired as rapidly as Mk 42, and some of which might have had twin barrels, but only Mk 45 ever entered service. Mk 45 is remotely controlled; personnel requirements are 1 gun captain, 1 panel operator, and 4 ammunition loaders, all below decks.

Compared with Mk 42, Mk 45 has a greatly simplified mechanism. There is only a single loader drum, and it includes the fuze setter. Some guns have no separate lower hoist; when a lower hoist is present, it feeds the drum. Rounds are loaded into a single cradle, which swings from the vertical up into position behind the vertical breechblock, which rises to open. The round is rammed, and the block drops to close. The empty case is ejected when the gun counterrecoils, the empty case tray being mounted atop the slide. Misfired rounds are removed automatically, compared to manual procedures for Mk 42 and for the earlier 5-in/38.

The barrel's lifetime is 7000 rnds, compared with 3070 for the earlier gun tube of the Mk 42. About 1974 Mk 42's barrel life was rated at 2000 rnds.

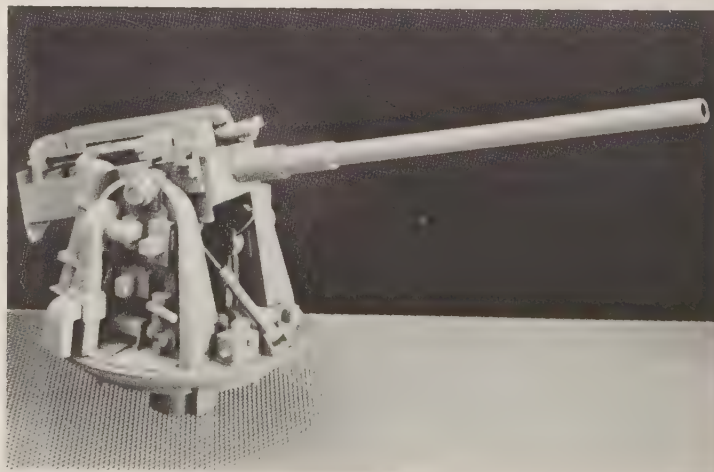
Mod 1 allows the operator to change the type of ammunition remotely, whereas in Mod 0 such a change requires special procedures. Mod 1 also incorporates an electronic fuze-setter in addition to the earlier mechanical unit. The loading station is lowered to make room for the longer guided shells. In 1982, when Mod 1 was first tested, 6 different projectiles were planned: high capacity (HC), white phosphorus (WP), star shell (SS), illumination 2 (SS2), semiactive laser (SALGP, Deadeye), and IR guided (IRGP). The last 2 were later canceled. There were also 7 fuzes: mechanical time (MT), controlled variable time (CVT), point detonating (PD), point detonating delay (PDD), infrared (IR), proximity (VT), and electronically set fuze (ESF).

Mod 1 development began in 1977, and the gun was first tested aboard the destroyer *Briscoe* in February 1980. Production began in 1982 for Aegis cruisers from CG 51 on, for *Arleigh Burke*-class destroyers, and also for the Greek and Turkish MEKO frigates. Selected *Spruance*-class destroyers will have their Mod 0 guns altered to Mod 1 standards.

The manufacturer, FMC, is developing an Advanced Mk 45 mount. It would have a credible future antiaircraft potential, achieved by increasing rate of fire (via modified projectile handling), higher gun elevation and training rates, and better ballistic performance (increased muzzle velocity and tube length). As of 1990, FMC expected to achieve a burst rate of 40 rnds/min (23 rnds/min sustained) and a maximum elevation of 70 deg. It is working on a new lighter-weight gun shield whose profile will minimize radar cross section. FMC also hopes to improve reliability and maintainability, e.g., by simplifying the hydraulics and the electric drives.



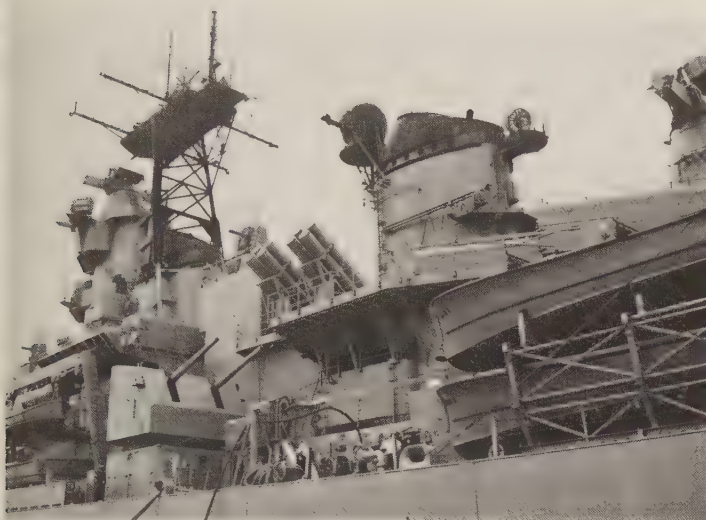
5-in/54 Mk 45 mount, USS *Vincennes*, 1987. (W. Donko)



Design model of a Mk 45 Advanced Naval Gun, as envisaged by FMC. (FMC)

◆ 5-in/38 (Twin Mount)

Caliber: 5-in/38 (54-lb shell) **Rate of Fire:** 10–15 rnds/min/gun
Muzzle Velocity: 2600 ft/sec
Maximum Range: 16,500 yd surface; 11,900 slant (time of flight to 10,000 yd at 11-deg elevation: 22 sec)
Training Rate: 25 deg/sec (elevation 15 deg/sec)
Elevation/Depression: +85/–10 deg
Ammunition Capacity: none on mount **Weight:** 95,700 lb
Working Circle: 11 ft 11 in



Twin 5-in/38 mount on board the USS *Iowa*, 1989. Two Phalanxes and 2 quadruple Harpoon missile launchers are also visible. The radome forward of the ship's after funnel houses her RPV control antenna; another is just visible forward of the tower foremast. (J. Kuersener)

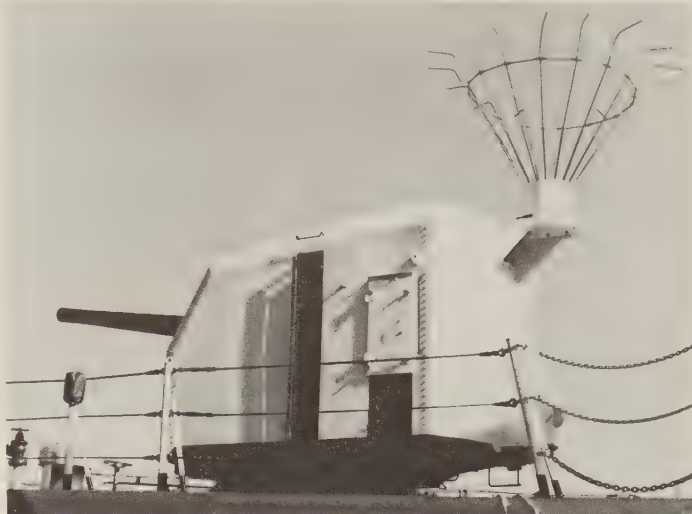
The 5-in/38 was the standard U.S. Navy dual-purpose gun of World War II. In very limited service in the U.S. Navy now (twin mounts on board the battleships), 5-in/38 remains on board many ex-U.S. destroyers in other navies. Data above are for the twin destroyer mount, probably the most common surviving type (*Gearing*- and *Sumner*-class destroyers). The weight given is for a 0.125-in shield; with an 0.5-in shield, the gun weighs 105,600 lb. The corresponding battleship mount, with a 2.5-in shield, weighs 169,000 lb. The usual crew for a twin mount, including loaders below decks, was 26 (13 on the mount itself).

A 5-in/38 rocket-assisted projectile (Mk 57) was developed during the Vietnam War. Including cartridge case, the projectile is 51.5 in long and has a maximum surface range of 23,770 yd. The rocket burns for 40 sec, and the shell carries 3.5 lb of explosives. Corresponding figures for the standard 5-in rnd (Mk 66) are 50.14 in, 41.6 lb (shell only), range 14,000 yd, and explosive content 7.9 lb.

The barrel's service life is 4600 rnds. Regunning time is 8 hr/gun, compared to about 1 hr for the 5-in/54 Mk 42 or Mk 45. There are no ready-service rounds on the mount.

◆ 5-in/38 Mk 30

Caliber: 5-in/38 (54-lb shell) **Rate of Fire:** 15 rnds/min/gun
Muzzle Velocity: 2600 ft/sec
Maximum Range: 16,500 yd surface; 11,900 slant (time of flight to 10,000 yd at 11-deg elevation: 22 sec)
Training Rate: 38.74 or 34 deg/sec (elevation 15 or 18 deg/sec) (GE or Ford controls, respectively)
Elevation/Depression: +85/–10 deg
Ammunition Capacity: none on mount
Weight: 40,900–41,400 lb (33,500 lb for the open mount)
Working Circle: 11 ft 11 in



Single enclosed Mk 30 5-in/38 mount aboard the U.S. Coast Guard cutter *Midgett*, 1987. (W. Donko)

This shielded single base-ring mount corresponds to the twin mount described above. In the U.S. Navy, this mount remains on board only FFG 1- and FF 1040-class frigates, which are being transferred abroad. Mk 30 also survives on board many ex-U.S. destroyers and destroyer escorts. Some auxiliaries have open base-ring mounts (Mk 37): 34,700 lb, 30/15 deg/sec training/elevation rates.

◆ 5-in/25

Caliber: 5-in
Shell Weight: 53.85 lb
Muzzle Velocity: 2200 ft/sec
Maximum Range: 14,500 yd; maximum altitude 27,400 ft (dual-purpose version only)
Elevation Limits: +85/–15 deg (+40/–10 deg)
Rate of Fire: 20 rnds/min (max)
Training Rate: 20 deg/sec; 30 deg/sec in elevation (manual: 1.5 and 2.5 deg per handwheel turn, respectively)
Weight: 23,270 lb (14,000 lb)
Working Circle: 121.5 in (99 in) (radius in both cases)

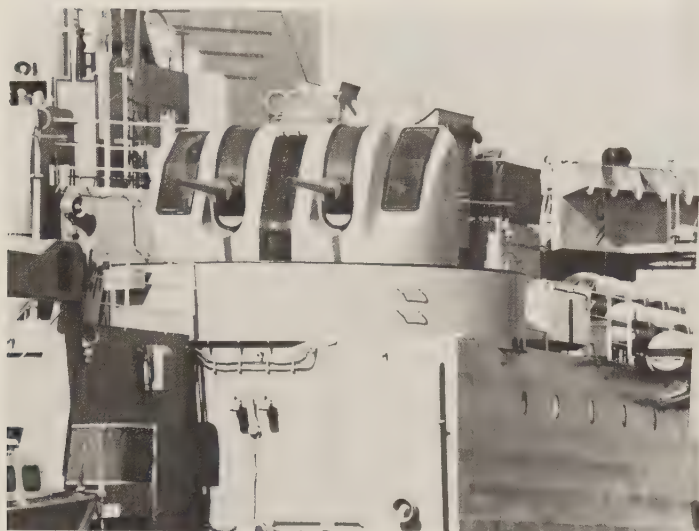
Data apply to the Mk 10 antiaircraft gun in a Mk 27 mount; data in parentheses refer to the wet submarine gun in the Mk 40 mount. Rated life of the gun bore was 3000 rnds (as reported in 1944).

These guns are survivors of a once-numerous group of weapons. Unlike the 5-in/38, the 5-in/25 fires a fixed round, just at the limit of quick handling by a single person. The 5-in/38 was developed from the 5-in/25 by increasing cartridge weight (hence muzzle velocity) for better surface performance. Both versions of the 5-in/25 are semiautomatic guns with vertical sliding-block breechblocks.

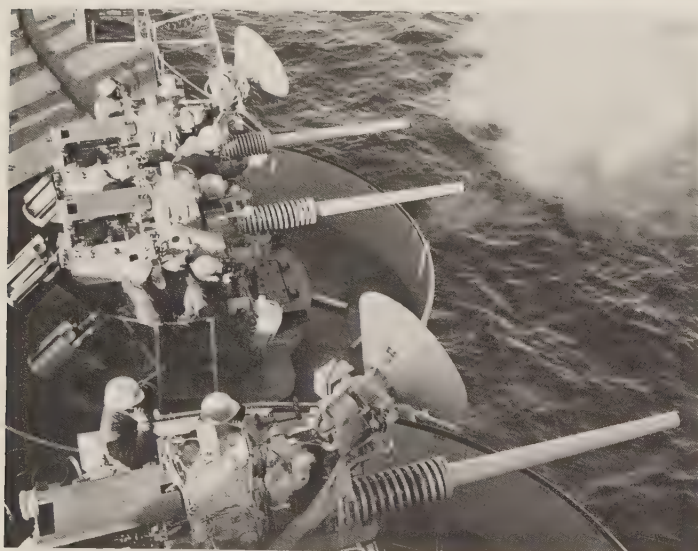
There are 2 types, an antiaircraft gun that survives on board the Chilean cruiser *O'Higgins*, and a wet submarine gun that survives on board several Peruvian submarines built in the United States. In addition, U.S. World War II-built fleet submarines, including those subject to "fleet snorkel" conversion, retained provision to mount one or two 5-in/25 wet guns. Guppy conversion presumably entailed streamlining to the extent that external gun foundations were eliminated, but the supporting structures below decks survived. Although no ex-U.S. submarines currently mount 5-in/25 guns, it seems likely that navies possessing such submarines retain these weapons and can mount them for special purposes, as the Royal Navy mounted 4-in guns on board its own streamlined submarines during the confrontation with Indonesia.

◆ 3-in/50

Caliber: 3-in/50 (15-lb shell) **Rate of Fire:** 45 rnds/min/barrel
Muzzle Velocity: 2700 ft/sec
Maximum Range: 14,600 yd (time of flight to 6000 yd at 5-deg elevation: 12 sec) Maximum altitude is 30,400 ft.
Training Rate: 24 deg/sec (elevation 30 deg/sec)
Elevation/Depression: +85/-15 deg
Ammunition Capacity: No ready-use ammunition on mount (but each barrel can have 5 rnds in its loader). Typically 200 or 300 rnds in ready-service locker, another 1200 in magazine.
Weight: 31,435-32,400 lb, depending on version
Working Circle: radius 120 in



Enclosed 3-in/50 mount Mk 33 on board the USS *Tuscaloosa*, 1987. (W. Donko)



Twin 3-in/50 mounts, with the dishes of SPG-34 radars atop them. The associated Mk 63 directors were mounted separately. (U.S. Navy)

Data are for the twin automatic 3-in/50 Mk 33, once very widely used in the U.S. Navy and in several other navies. This weapon was developed specifically to deal with kamikazes; in 1945 it was the smallest gun that could fire a proximity-fuzed shell. Although there is no magazine as such on the mount, the loaders continually refill the 5-rnd revolving loading drums that actually feed the guns. There is no rammer as such; instead the loader, which is an independent electrically driven device, catapults each round into the chamber, the breech-closing mechanism being triggered by the edge of the cartridge case as it trips one of the ejectors. Once a round is in the breech, the loader cycle is stopped until the gun fires and ejects that cartridge case.

This unusual arrangement was adopted because the gun itself is the earlier semiautomatic weapon adapted as simply as possible to automatic fire; in effect the loading and triggering cycle has been automated, without any basic redesign. That simple automation in turn limits the ultimate rate of fire. Because firing is automatic once a round has been catapulted into the chamber, the gun is unloaded whenever it is not firing: the loader has 6 slots, but only 5 can be occupied.

The original version of the twin automatic mount was Mk 27; Mk 33 is more common. Many mounts are enclosed in fiberglass gunhouses. There is also a single version (Mk 34), weighing, typically, 17,000 lb.

The barrel's life is 2050 rnds.

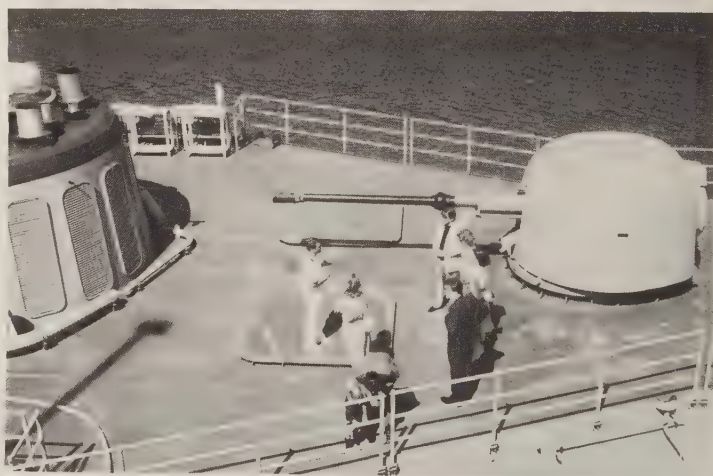
This gun is usually controlled by a Mk 56 director; others, with a Mk 34 (SPG-34) radar dish on the mount, are controlled by the Mk 63 system. Except for 2 escorts (the FF 1037 class), the U.S. Navy has removed all remote FCSs for these weapons from its ships, leaving the guns entirely locally controlled.

The 3-in/50 automatic gun was initially provided to Japan under the Military Assistance Program (MAP). From 1957 on the gun was manufactured under license by the Japan Steel Works.

Some surviving World War II ships (2 in the U.S. Navy) and many coast guard ships are armed with the earlier single semi-automatic 3-in/50 mount (Mk 26) from which this weapon was derived; Mk 26 has the same ballistics. Its rate of fire is 15-20 rnds/min, and because of the slower rate of fire, the barrel's life is rated as 4300 rnds. The working circle's radius is 96 in.

◆ 3-in/62 Mk 75

Caliber: 76-mm/62 **Rate of Fire:** 80 rnds/min
Muzzle Velocity: 3000 ft/sec
Training Rate: 65 deg/sec (elevation 35 deg/sec)
Elevation/Depression: +85/-15 deg
Ammunition Capacity: 80 (ready-service)
Weight: 16,500 lb above decks; 763 lb below decks
Working Circle: radius 208 in



Mk 75 3-in/62 gun on board the USS *Fahrion*, 1984. (A. Raven)

This U.S. version of the Italian OTO-Melara 76/62 is manufactured by FMC (and by OTO-Melara itself since FY86) and mounted on board U.S. frigates and missile hydrofoils and Saudi patrol craft. This gun, generally controlled by a Mk 92 FCS, is manned by 3 enlisted. Compared to the 3-in/50, the 3-in/62 carries a much larger supply of ready-service ammunition, allowing the gun to fire long bursts without reloading. Because it is very nearly unmanned, it can fire at very short notice. The muzzle brake reduces recoil by about 35%. There is also a tank-type bore evacuator. Compared with a 5-in gun, this weapon's one great defect is that it cannot fire any of the more sophisticated munitions.

The gun can be arranged to use 1, 2, or 3 loading drums (40, 80, or 115 rnds). Rounds pass up a hoist, from which they are

stripped by a pair of rocker arms. The arms in turn feed a revolving 4-rnd feeding drum above the loading tray. The tray pivots back and up to strip a round from the loading tray, then moves into alignment with the breech so that the round can be rammed. As in the Mk 42 mount, 2 rocker arms are needed to maintain a high rate of fire, 1 swinging up while the other swings down.

The 3-in/62 is manufactured under license in Japan (by the Japan Steel Works).

◆ 81-mm Mortar Mk 2

Caliber: 81-mm (53 lb for package of 3 rnds)

Muzzle Velocity: 787 ft/sec

Rate of Fire: 10 rnds/min trigger; 18 rnds/min drop-fire, 45-deg elevation

Maximum Range: 3987 yd

Elevation/Depression: +71.5/-30 deg **Working Circle:** 108 in



Over-and-under 81-mm mortar and 0.50-cal machine gun on board a patrol boat in Panama, 1983. (U.S. Navy)

This weapon can be mounted alone or in combination with a 0.50-caliber M2 machine gun, in a piggyback mount. In contrast to mortars for land service, this mortar is either trigger- or drop-fired, and it can, therefore, be fired at 0 elevation. Mk 2's recoil mechanism reduces deck loads when the gun is fired. Mk 2 uses army ammunition.

Mod 1 is the piggyback version carrying the 0.50-caliber machine gun; total weight is 722 lb.

◆ 60-mm Mortar

Caliber: 60-mm (49 lb for package of 10 rnds)

Muzzle Velocity: 500 ft/sec

Rate of Fire: 10 rnds/min trigger; 18 rnds/min drop mode, 45-deg elevation **Maximum Range:** 1850-2000 yd

Elevation/Depression: +80/-20 deg **Working Circle:** 114 in **Weight:** 177 lb

This mortar is a smaller version of Mk 2. Although rarer than Mk 2, it remains in U.S. service; some have seen service in the Persian Gulf on board patrol boats (PBs). During the Vietnam

War it was used on board PBRs, which could not accommodate the 81. In many cases it is combined with an M60 machine gun in a piggyback combination. The 60-mm mortar is descended from Mortar Mk 1, the Garrett (Kodak) trigger-fired mortar of 1945.

◆ 40-mm Guns

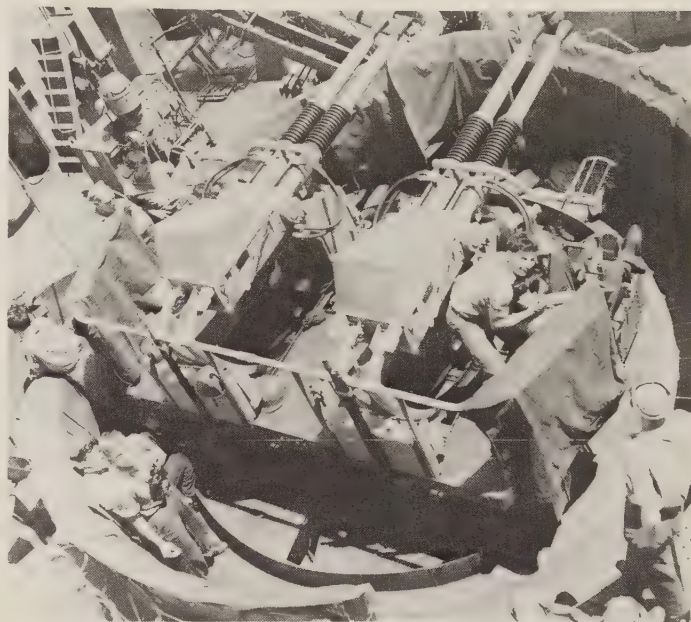
Caliber: 40-mm/56.3 (1,985-lb shell) **Rate of Fire:** 160 rnds/min

Muzzle Velocity: 2890 ft/sec

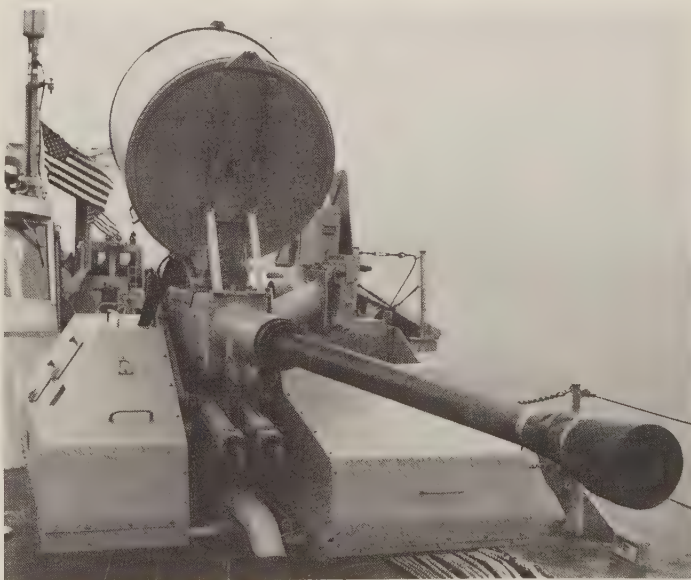
Training Rate: 24 deg/sec (elevation 30 deg/sec)

Elevation/Depression: +90/-15 deg

Weight: 24,900 lb (13,000-14,000 lb)



A quadruple 40-mm mount on board the cruiser *Portland*, 1944. Although the ship is long gone, some of these mounts survive. The boxes cover the paired feeds of the 2 guns. (U.S. Navy)



The new single 40-mm mount Mk 3 Mod 9, on board a 65-ft Patrol Boat Mk 3. The object above the gun is the autoloading magazine. (U.S. Navy)

The U.S. Navy developed 3 principal Bofors mountings: a water-cooled twin mount (Mk 1), a quadruple (dual-twin) mount (Mk 2), and an air-cooled single mount based on the army's version of the gun (Mk 3). Mk 4 was a lightweight quadruple mount produced in small numbers in 1945. Very few of these weapons remain in U.S. service, but they were widely exported. Data above apply to the quadruple mount (twin mount data in

parentheses). The only Mk 2s remaining in U.S. service are 2 on board the *Sphinx* (ARL 24), controlled by 2 Mk 51 Mod 2 FCSs.

Mk 3 was originally a hand-operated gun for submarines and PT boats, but many of these guns were converted to power drive (4200 lb rather than the original 2440 lb, with performance comparable to Mk 1 and 2, above).

Mk 3 Mod 9 is a rebuilt single army-type gun for 1-crew operation on board patrol craft. This version is power-operated and stabilized and autoloading (48-rnd magazine). The first 2 were converted, by an ordnance depot, under the FY82 program. These guns were installed on board 17 PB Mk III Sea Spectre patrol boats. Their loading drums were usually removed because they interfered with vision from the pilot house. This weapon is being replaced by the 25-mm Mk 88 Bushmaster described below.

◆ 40-mm Grenade Launcher Mk 19

This short-range machine gun is used on board riverine and coastal craft and on larger ships to defend against saboteurs and boarders. Operation is by blow back, and the gun fires 400–450 rnds/min at a muzzle velocity of 800 ft/sec. Maximum range is 2400 yd (35-deg elevation), and effective range is 1780 yd (15-deg elevation). A 24-rnd box of ammunition weighs 21.5 lb.

Mk 19 was developed during the Vietnam War and remains in production.

There was also a family of shorter-range grenade launchers, with a muzzle velocity of 215–230 ft/sec (maximum range 385–440 yd, effective range 350 yd): Mk 18 and Mk 20, rate of fire continuously variable from single shot to 250 rnds/min. These launchers were effectively rapid-fire versions of the army's M79 grenade launcher. Like Mk 19, they were externally powered.

◆ EX-74/Emerlec-30

Caliber: 30-mm **Rate of Fire:** 1100 rnds/min (selectable rate)
Muzzle Velocity: 3543 ft/sec **Maximum Range:** 3500 yd
Training Rate: 90 deg/sec (elevation 80–85 deg/sec)
Elevation/Depression: +80/–15 deg
Ammunition Capacity: 985 rnds/gun
Weight: 3469 lb (full system 4156 lb without ammunition)
Working Circle: 88 in



Emerlec-30 gun mount. (Emerson Electric)

This Emerson Electric mount carries one 30-mm Oerlikon gun on each side of a cab in which the operator sits. EX-74 was originally developed for the U.S. CPIC coastal-patrol boat (of which only a prototype was ever built), but a developed version of the mount was later very successfully exported, as the Emerlec-30, to Ecuador, Greece, Malaysia, Nigeria, the Philippines, and South Korea. As of January 1988, over 150 Emerlec-30s had been delivered. The principal difference between the U.S. Navy's version and the exported version is that the navy's gun did not penetrate the deck, whereas export guns have below-decks magazines.

Emerlec-30's characteristics generally follow those above, but the claimed rate of fire is 1200 rnds/min and weight without ammunition is 4200 lb. Working circle is 94 in. Training rate is 80 deg/sec (elevation 80 deg/sec). The gun is an Oerlikon (Hispano-Suiza) 30-mm cannon, with a barrel life of about 5000 rnds.

In the U.S. CPIC, the Emerlec-30 was controlled by GFCS Mk 93, which incorporated the Kollmorgen Mk 35 periscope director.

◆ EX-83

This powered mount carries a 30-mm GAU-8/A Gatling gun. EX-83 forms the basis of the Dutch Goalkeeper close-in weapons system and was proposed as the basis of the French Satan system. The Dutch selection of the EX-83 mount was apparently based on successful trials at Den Helder early in 1980, using an EX-83 controlled by a Signaal Flycatcher radar tracker (which is similar to STIR and thus to the VM40 proposed for Sea Wolf missile control). Success in these tests demonstrated both the pointing accuracy of Flycatcher and the tight dispersion of the 30-mm gun.

These tests were for land-based air defense, but they were clearly applicable to the naval close-in defense problem.

EX-83 is also the basis of the French SAGEM and SAMOS. There was also a proposed VSEL (Vickers) Sea Dragon carrying a Marconi tracker radar above the gun mount proper (1983), and there was a projected Israeli version. The U.S. Navy tested the EX-83, controlled by the Mk 86 FCS, on board the destroyer *Merrill* (DD 976) in 1981. For details of the EX-83 gun and mount, see the Goalkeeper entry above.

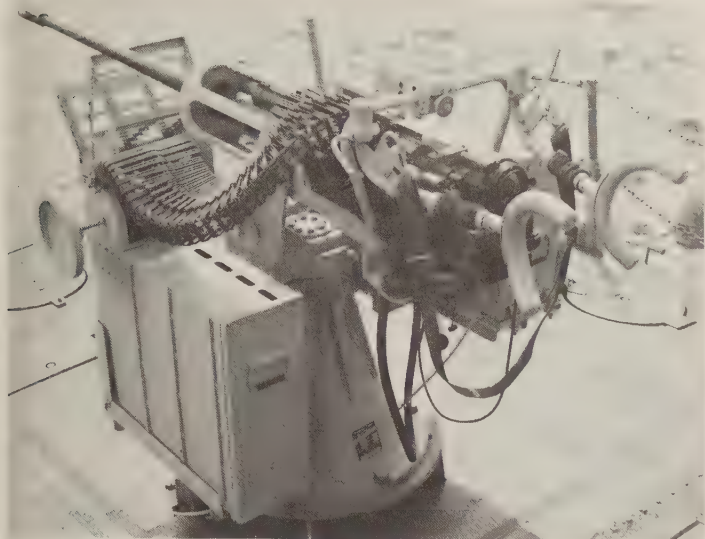
◆ 25-mm Automatic Cannon Mk 38 (Bushmaster)

Caliber: 25-mm/87 (1.1-lb round) **Muzzle Velocity:** 1100 m/sec
Rate of Fire: single shot, 100, or 200 rnds/min
Training Rate: manual mount **Maximum Range:** 6800 m
Elevation/Depression: +55/–20 deg
Ammunition Capacity: 150 linked cartridges
Weight: total gun weight (no mounting) 240 lb; total mounting weight 1250 lb

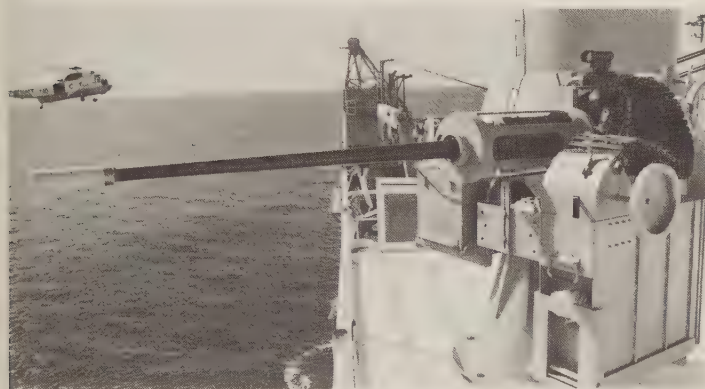
Bushmaster is the naval version of the "Chain Gun," an externally powered weapon developed by Hughes for the U.S. Army. The Chain Gun was originally a 20-mm, then a 30-mm (Aden ammunition) gun firing linkless ammunition at up to 900 rnds/min. Procured by the army as M242, the gun is designated Mk 38 for naval service; the pedestal mounting, Mk 88. The 25-mm gun is credited with a barrel life of 25,000 rnds; dispersion is 0.5 mil.

The name derives from the use of a loop of standard industrial double-row roller chain, carried horizontally, to drive the bolt back and forth. The length and width of the chain are determined by the length of the round and by the desired rate of fire. The chain runs at constant speed, carrying a shoe that drives the bolt. When in line with the bolt, the shoe pulls back and forth, locking and opening the bolt. When the shoe travels to one side (along the belt, perpendicular to the gun's axis), the gun has time to fire or to eject a fired cartridge (depending on where in the cycle this travel occurs). The feed to the gun is powered by the same motor that drives the chain.

Development and procurement of the Chain Gun were originally approved in December 1971. In 1977 the chief of naval operations approved procurement to replace existing obsolete



25-mm Bushmaster (Mk 38 gun on Mk 88 mount). (McDonnell Douglas Helicopter Co.)



A Bushmaster on board the *Mount Vernon* in the Persian Gulf, October 1987. (U.S. Navy)

Mk 16 20-mm guns, which were difficult to support (they required overhaul every 6500 rnds) and did not use standard NATO ammunition; many existing rounds were considered unsafe.

This weapon, already in large-scale production for the army, was operationally evaluated for naval use in the summer of 1987, and by mid-1988 over 5000 had been delivered to the U.S. Army. Bushmaster replaces existing U.S. Navy 20-mm cannon. The Mk 88 mount is not stabilized and is hand-aimed; it cannot, therefore, make very many hits when mounted on a lively small combatant. As of mid-1988, many Mk 88s were in service in the Persian Gulf, and they also equipped the Mark 4 patrol boats in the Panama Canal Zone. As of August 1988, the Naval Sea Systems Command planned to buy 460 Mk 88s.

Production of Mk 38 25-mm cannon was drastically accelerated in 1987-88 to meet the needs of ships in the Persian Gulf, much of the work being done at NWSC (Naval Weapons Support Center) Crane (which was responsible for the design of the gun's Mk 88 mount).

In 1989 the Chain Gun manufacturer, McDonnell Douglas Helicopters (the former Hughes helicopter division), announced a new series of weapons using the same principle:

- 20-mm Pit Viper (an entry into LHX armament competition, to be fired for the first time in December 1989, with a maximum rate of fire of 800 rnds/min, and with 25,000 MRBF.
- 30-mm Bushmaster II (which had already fired 500 rnds as of late 1989, and which was due for Austrian (AFV) and U.S. Navy (2000 rnds) tests during 1989. It fires

standard GAU-8 ammunition or, modified, RARDEN or KCB ammunition. 70% of the parts of this gun are the same as those used in the Bushmaster. Rates of fire are single shot, 200, or 400 rnds/min. Possible applications include the Minor Caliber Weapons Station being developed by AAI (see entry below).

- Bushmaster III, which can fire 35-mm or 50-mm rnds with minor changes (including a barrel change). As of late 1989, first firing was due in July 1990 in 35-mm configuration.

◆ L-CAT 25

Caliber: 25-mm **Training Rate:** 80 deg/sec (elevation 60 deg/sec)
Maximum Range: 3000 m (effective range)
Elevation/Depression: +60/-20 deg
Ammunition Capacity: 400 rnds **Weight:** 1500 lb empty
Working Circle: diameter 130 in

Emerson's single stabilized 25-mm gun mount, suitable for small patrol boats, was announced in 1984. It was developed as a result of a U.S. Navy project to define the characteristics of a standard minor-caliber mount. Empty weight is less than 680 kg, and the mount bolts to the deck. Control may be either manual or remote. Drive is electric rather than hydraulic, for simpler maintenance.

Data above refer to the remotely controlled 25-mm mount carrying the M242 Bushmaster. In the manned version, the gunner replaces one of the two 200-rnd ammunition boxes. This mount can also carry the Oerlikon KBA (570 rnds/min), which has about 3 times the recoil force of the M242.

Only a prototype was built, but L-CAT is interesting as an approach to the problem of installing guns on small combatants. At the 1986 Italian naval exhibition (Mostra Navale), Oerlikon Italiana showed a scale model of the mount, carrying a 25-mm KBA. The company was trying to interest the Italian navy in license production, on the theory that 25-mm guns would be attractive to many navies, to arm small combatants, but that most of the combatant operators would find a stabilized mount much more attractive than the standard unstabilized Mk 88.

The U.S. Navy tentatively assigned a Mk 89 designation to this mounting.

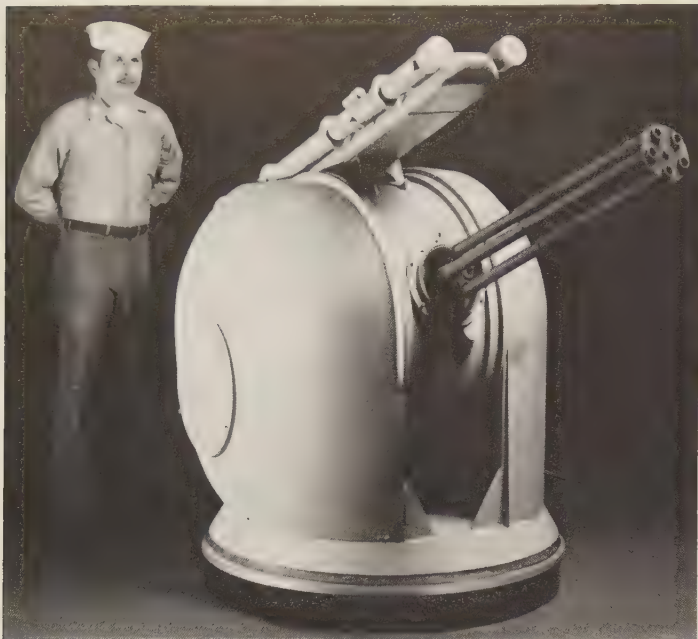
◆ Sea Vulcan 25

Caliber: 25-mm **Muzzle Velocity:** 3400 ft/sec
Rate of Fire: selectable, 750 or 2000 rnds/min
Training Rate: 1.6 rad/sec (train and elevation)
Ammunition Capacity: 500 rnds
Elevation/Depression: +85/-25 deg
Working Circle: radius 64.0 in **Weight:** 2800 lb fully loaded

General Electric's private-venture gun mount carries the lightweight 5-barrel 25-mm aircraft Gatling gun (GAU-12/U). Sea Vulcan was proposed for the abortive SWCM (surface-effect SEAL delivery craft), rejected, then restored to the program before the SWCM program itself died. The mount may appear on future U.S. small combatants, e.g., on whatever SWCM replacement emerges. Compared to the present 25-mm Bushmaster, Sea Vulcan 25 offers a much higher rate of fire and, more importantly, a stabilized line of fire suited to lively small craft. The mount was very successfully tested in 1987 on board the SES-200 surface-effect boat. The power-driven mount can incorporate an IR camera for accurate target tracking or can be controlled by a lightweight off-mount director. Although the version tested in 1987 carried only the 25-mm gun, full-size models displayed in the past have carried 2 Stinger missile tubes.

General Electric claims that Sea Vulcan 25 can kill targets, presumably corresponding to a small missile, at 2000 m (it has published a photograph of the destruction of a Lynx drone at 500 m). In tests, Sea Vulcan was controlled by a Mk 24 optical director and an electro-optical director. Dispersion is 2.23 mrad. Claimed reliability is 7000 MRBF or 200 hr MTBF (nonfiring).

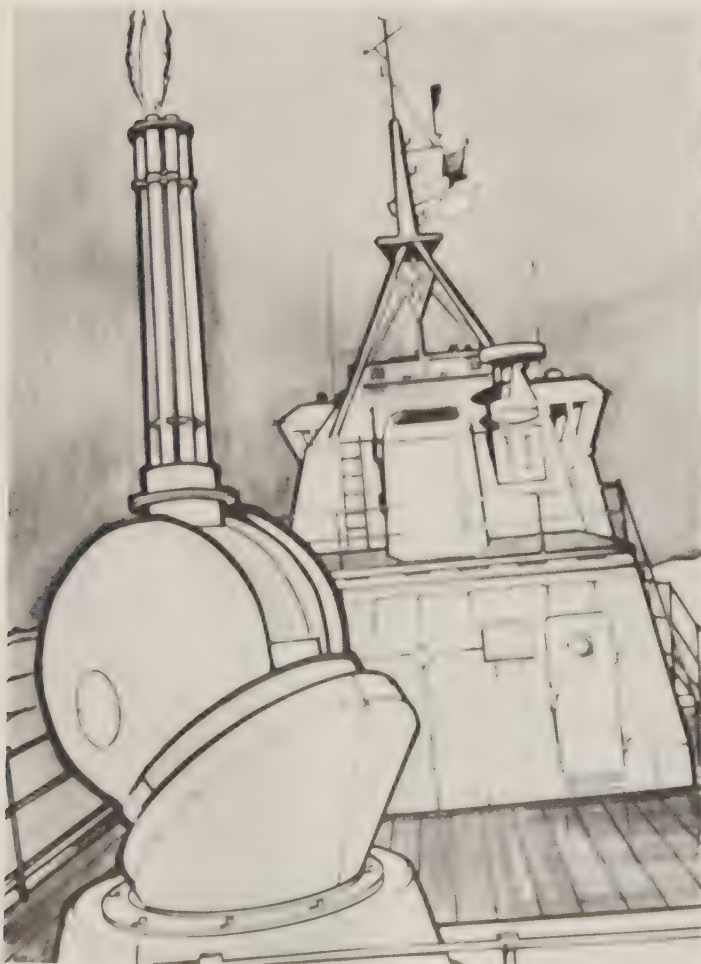
In the form planned for the SWCM, this mount was tentatively designated EX-90.



Sea Vulcan 25. (General Electric)

◆ Zenith 25/30

This projected General Electric turret on a canted mount is similar in concept to the Sea Zenith employed in the Swiss Seaguard system but carries a 25-mm GAU-12/U (as in the AV-8B) or a 30-mm GAU-8 gun. Zenith was announced in 1982. Sea Zenith was proposed either as main armament for a small combatant, or as the gun element of a ship's close-in defensive weapons system.



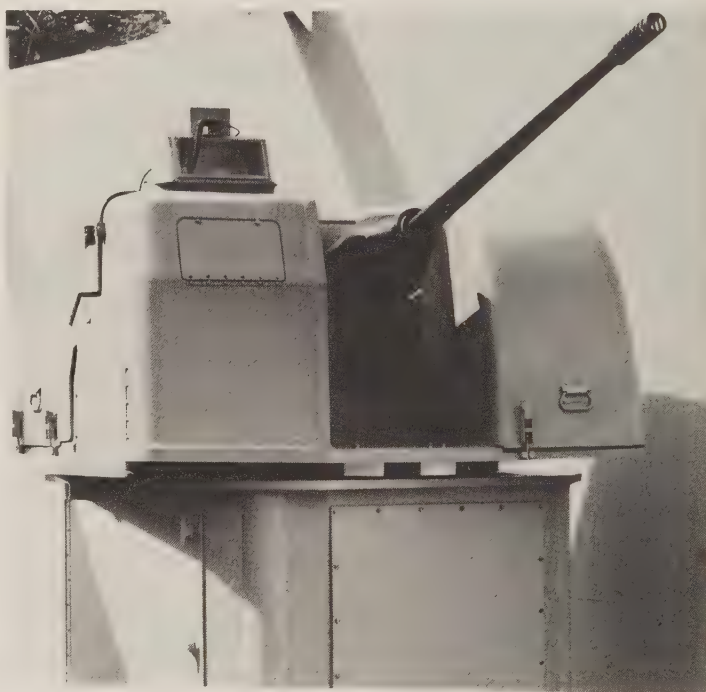
Sea Zenith. (General Electric)

In Zenith 25, the ammunition feed has been modified so that it can operate (at 2000 rds/min) at any angle of gun elevation. The manufacturer hopes to increase this rate to at least 3000 rds/min, or to 4000 by scaling down the linkless feed of the GAU-8. Total weight is 4000 lb, and the training/elevation rate is 1.6 rad/sec. Working circle radius is 68 in (base radius 36 in).

◆ AAI Naval Gun Mount

AAI Corporation is developing a naval version of the Minor Caliber Weapons Station (MCWS) under development for U.S. Marine Corps vehicles. This version will be electrically driven, with 2- or 3-axis stabilization, and will carry a 25-mm or 30-mm gun, plus perhaps a Stinger-missile launcher. Elevation limits will be -8 to $+60$ deg (slew rates up to 60 deg/sec), and the mount will carry 400 rds of 25-mm ammunition, or 150 to 200 rds of 30-mm, plus up to 2 twin-rail missile launchers. AAI proposes 2 configurations: through-deck (2200 lb) and above-deck (2500 lb), each with 100–500 lb of remote-control equipment and displays. Possible applications include future small combatants and landing craft.

As of early 1989, the AAI gun mount was being tested aboard a navy SWATH (presumably the *Kaimalino*) off Hawaii. The Military Sealift Command was showing interest in a modular version that could be stored ashore and then installed aboard ships in an emergency. MCWS was originally designed specifically for the Marine Corps and was tested on an AA-7 in late 1988.



AAI naval gun mount. (AAI)

◆ ASP 30

Caliber: 30-mm/49
Rate of Fire: single shot/400–450 rds/min
Muzzle Velocity: 2750 ft/sec
Maximum Range: effective range 2 km [2200 yd]
Weight: 105 lb

This McDonnell Douglas Helicopters (formerly Hughes Helicopters) automatic cannon, announced in 1989, is only slightly larger than the standard Browning M2HB 0.50-caliber machine gun and has little more recoil, thanks to a muzzle brake and 2 hydraulic dampers. It can, therefore, fire ADEN 30-mm ammunition from the same type of simple pedestal mount typically associated with the 0.50. In comparison to the figures above, the M2HB weighs 84 lb and is 65 in (rather than 79.8 in)

long; it fires at about the same rate and has a muzzle velocity of 2930 ft/sec. The barrel length quoted above for the ASP 30 includes the blast suppressor.

In 1989 Royal Ordnance bought the rights to market ASP 30 throughout the world, apart from the United States. At RNEE 1989 it quoted a unit price of £ 25,000. Likely applications include fast patrol boats and light vehicles ashore. Ammunition is HE, AP, or multipurpose (presumably Raufoss-type).

◆ Phalanx (Close-In Weapons System Mk 15)

Caliber: 20-mm/76 (0.22-lb round)

Rate of Fire: 1000–3000 rnds/min **Muzzle Velocity:** 3650 ft/sec

Maximum Range: 6000 yd (effective range 1625 yd)

Training Rate: 100 deg/sec (elevation 86 deg/sec)

Elevation/Depression: +80/–20 deg **Ammunition Capacity:** 989

Weight: 12,000 lb above deck, 466 lb below deck

Working Circle: diameter 216 in

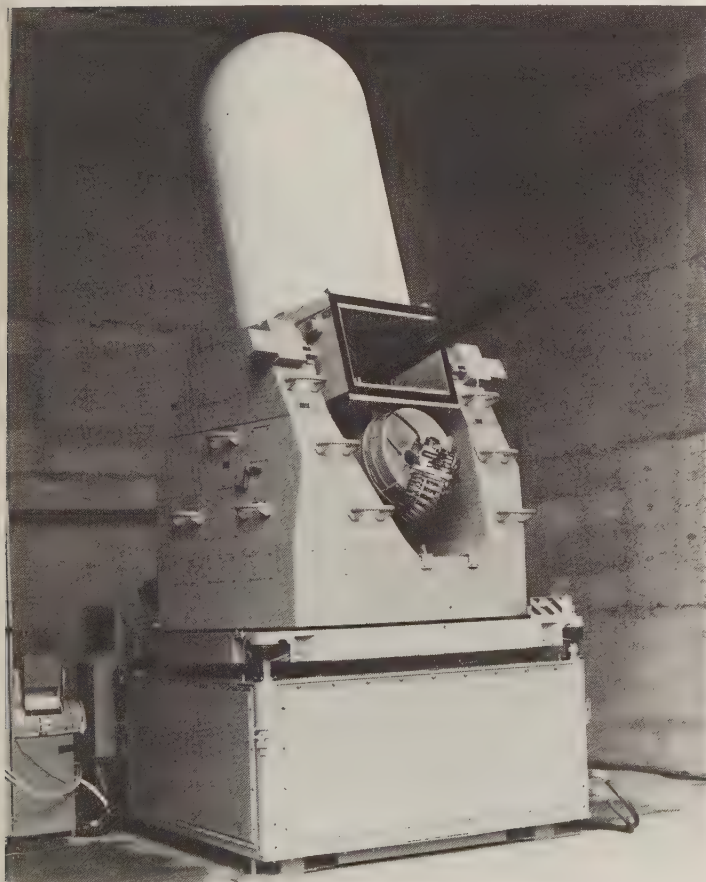
Phalanx is the standard U.S. Navy close-in weapons system, using bursts of depleted-uranium penetrators to destroy or fuze incoming antiship missiles. The weapons system's designation covers the mount plus integrated radar; the mount proper is Mk 72.

Phalanx combines a 20-mm Vulcan automatic cannon with a (search and track) Ku-band radar that has 2 antennas but 1 transmitter. The radar automatically detects and tracks incoming missiles. In the search mode, the radar uses unambiguous doppler/ambiguous range, switching PRF to achieve range resolution in 3 range-coverage zones. During target acquisition, the system again uses unambiguous doppler/ambiguous range and a derived search range, bearing, and speed to search a "basket" provided by the search radar. Normally there is no operator intervention: the system decides automatically to engage, and the operator has a veto.

When the gun begins to fire, the radar also tracks outgoing



Phalanx. (General Dynamics)



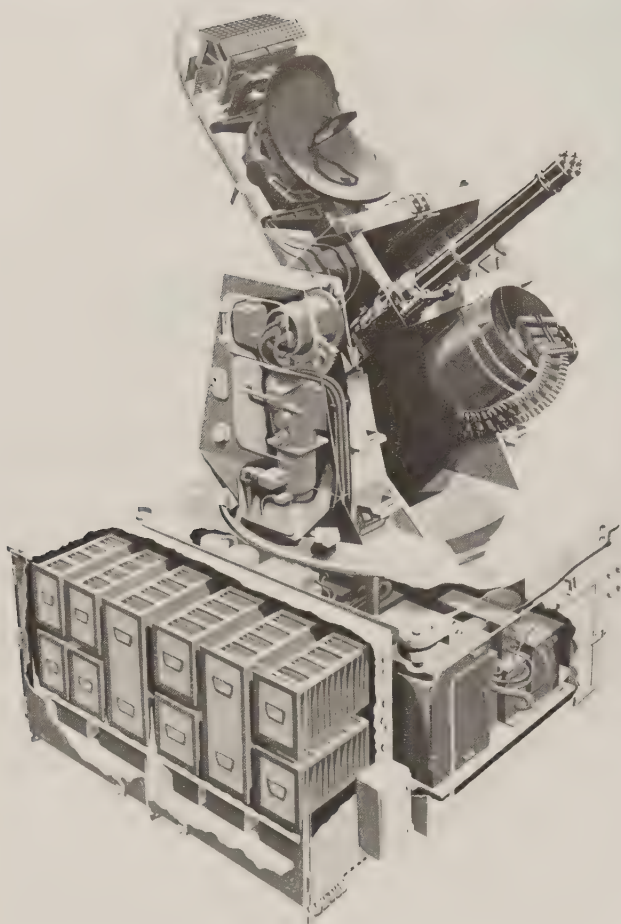
Phalanx (Close-in Weapons System Mk 15). The drum magazine is under the gun. (U.S. Navy)

bursts of fire, predicts their point of closest approach to the incoming target, and corrects the aim of the following burst(s). This electronic spotting uses variable PRF with selected spectral (frequency) line tracking to measure the projectile stream's angular error. The manufacturer, General Dynamics, claims that this closed-loop spotting system improves lethality by as much as an order of magnitude. This self-contained FCS was originally designated Mk 90, although that designation has been dropped in favor of the Mk 15 designation embracing the entire system.

Phalanx was designed so that it can be rigged to engage surface targets designated by conventional optical target designators. However, that configuration is officially discouraged; ships are expected to use dedicated light guns, such as single 20s or Bushmasters, for self-defense against small surface craft.

This system was first proposed in 1968 as part of the early antiship-missile defense program prompted by the *Eilat's* sinking; a feasibility contract was awarded to General Dynamics in 1969. The first closed-loop spotting system was demonstrated at White Sands in 1970, and a prototype was demonstrated on board the missile destroyer *King* in 1973. There were, however, doubts as to whether Phalanx could destroy incoming cruise missiles. They were resolved, and full-scale production was authorized in 1977, the first installation (on board the carrier *America*) following in 1980. The 400th system was delivered in 1985.

Some indication of Phalanx's performance is given by characteristics as projected in 1971. At that time Phalanx evaluated targets it detected in terms of range, range rate, and sector. It scanned between 0 and 5 deg in elevation (external designation



CIWS Block 1, showing the new upper [search] antenna and the enlarged magazine. (General Dynamics)

was needed for any target at a higher elevation). It was expected to detect a target at 5600 yd, acquire it at 4300, and open fire at 2500 (1st potential intercept at 2000). The inner boundary (keep-out zone) was defined as 100–230 yd. The closed-loop spotter tracked the centroid of 6 projectiles at a time. The slewing rate was 1.75 rad/sec [100.3 deg/sec] with an acceleration rate of 10.5 rad/sec/sec [601.7 deg/sec/sec].

Some difficulties were encountered in service. Block 0 guns suffered from sea corrosion, a problem corrected by construction of special "maintenance shelters" around parts of the mount. In addition, it takes 10–30 min to reload the ammunition drum.

Phalanx Block 1 (authorized for limited production in 1986) provides 50% more on-mount ammunition. This version is also designed to engage diving targets at steeper angles. The 2D scanning antenna of Block 0 is replaced by a 4-plate back-to-back antenna that continuously searches up through the zenith. In addition, a positive cease-fire function matches burst length to target characteristics, to conserve ammunition so that more targets can be engaged before reloading. Current developmental work is intended to counter faster, lower-altitude maneuvering targets with reduced radar cross sections. Block 1 was operationally tested at China Lake 3 December 1981–21 May 1982.

Block 1 deliveries began in January 1988; the first 4 were installed on board the *Wisconsin*. A new upgrade (a pneumatic gun drive) now in production increases rate of fire from 3000 to 4500 rnds/min, and further improvements are being investigated.

At the 1989 U.S. Navy League Show, GE displayed a new Phalanx Magazine Loading System, by means of which 2 gunners can reload a mount in less than 5 min, compared to 30 min at present. It uses a second ammunition drum, mounted on top

of the electronics enclosure, feeding rounds into the main drum when the latter is empty.

As of early 1990, the navy is shifting from depleted-uranium to tungsten penetrators. In nearly 700 test shots, the latter turned out to penetrate missiles and hit their guidance systems with greater mass intact. There was also concern about depleted-uranium handling problems; the material is mildly radioactive and must, therefore, be handled with gloves. When it is stowed adjacent to berths, the latter must be protected with lead. Until recently the higher cost of tungsten precluded any change, but now tungsten costs less than uranium. Tungsten accounted for 20% of the rounds bought in 1989 and will be 100% in 1990, although the navy's interest in depleted uranium persists.

Phalanx Block 1 (CIWS Mk 15 Mods 11–14) is now being improved. Baseline 0 was approved for limited production in FY85 and entered service in October 1988. It provides increased performance in search-elevation coverage, increased velocity coverage, a larger magazine, augmented reliability, BITE, and better system-operability test (SOT) and fault-isolation test (FIT) programs. Block 1 Baseline 1 adds a pneumatic gun drive (4500 rnds/min) and increased search sensitivity. It was approved for limited production as part of the FY88 and FY89 production lots; it is to be approved for full production in FY90. Work is currently underway on Block 1 Baseline 3, which is to undergo initial operational test and evaluation in FY91. Block 2, to enter service about the year 2000, will probably use a new gun, either GE's twin 25-mm or the Tround 25-mm. This weapon has also been referred to as CIWS-2000.

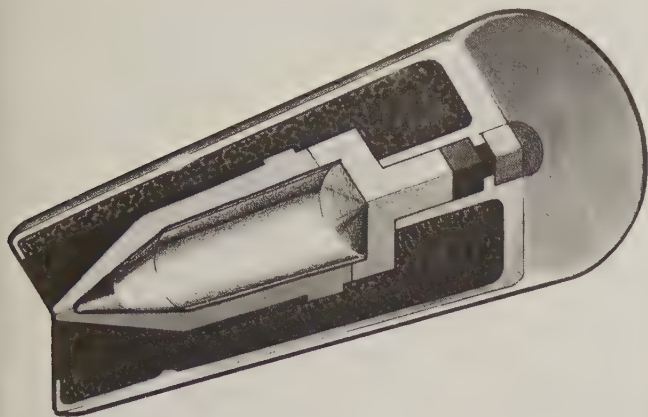
In August 1990 NSWC circulated a request for information on 3–5-micron sensor/trackers suitable to acquire antiship missiles at useful ranges. Reportedly, GE is already working on a Phalanx upgrade incorporating an IR sensor or an electro-optical adjunct. There is also speculation that the navy is considering a Phalanx upgrade in which the radar would be moved away from the gun proper; the radars apparently suffer from gun heat, smoke, and flash.

In 1983 a modified Phalanx, carrying a 4-barrel 30-mm GAU-13 gun, was proposed for the Royal Navy. The Signal Goalkeeper was chosen instead, but the proposal shows to what extent the existing Phalanx could be up-gunned (re-equipped with a more powerful gun) with minimum modification. In 1988 it was reported that General Dynamics was considering 2 up-gunned versions of Phalanx, 1 with a 4-barrel 30-mm gun and 1 with twin 25-mm guns.

In 1987–88 the follow-on system was nominally designated CIWS-2000. In January 1988 a congressional conference committee refused further funding for CIWS-2000 until the U.S. Navy had evaluated Goalkeeper. Admiral Metcalf, the outgoing chief of surface warfare, had already tried to cancel CIWS-2000 in the fall of 1987, arguing that the system represented an insufficient advance over the existing Phalanx, and that more revolutionary, rather than evolutionary, counters to attacking missiles were needed. That argument may reflect interest in such exotica as chemical lasers and directed-energy weapons.

GE has proposed a new cased telescoped (CT) 25-mm gun as a next-generation Phalanx weapon. Two such guns would fire up to 12,000 rnds/min, and a mount might accommodate up to 2600 rnds. The CT round, developed under an air force contract, is shorter than a conventional round and, therefore, allows for a more compact gun. A 20-mm prototype has fired over 6000 rnds successfully (and is more reliable than a conventional 20-mm Gatling), and GE expects the basic CT mechanism to have 67% fewer parts than an existing weapon. Estimated reliability is 50,000 rnds between failure, and system life should be 250,000 rnds. Estimated system dispersion is 1.1 mrad, and muzzle velocity should be 3700+ ft/sec. The gun would use a new linear linkless feed system.

Should tests prove successful, the Rockwell dual-band radar being developed for TASD (see the separate entry) may replace the current Phalanx radar. Its main advantage is that it promises to solve the multipath and glint problems.



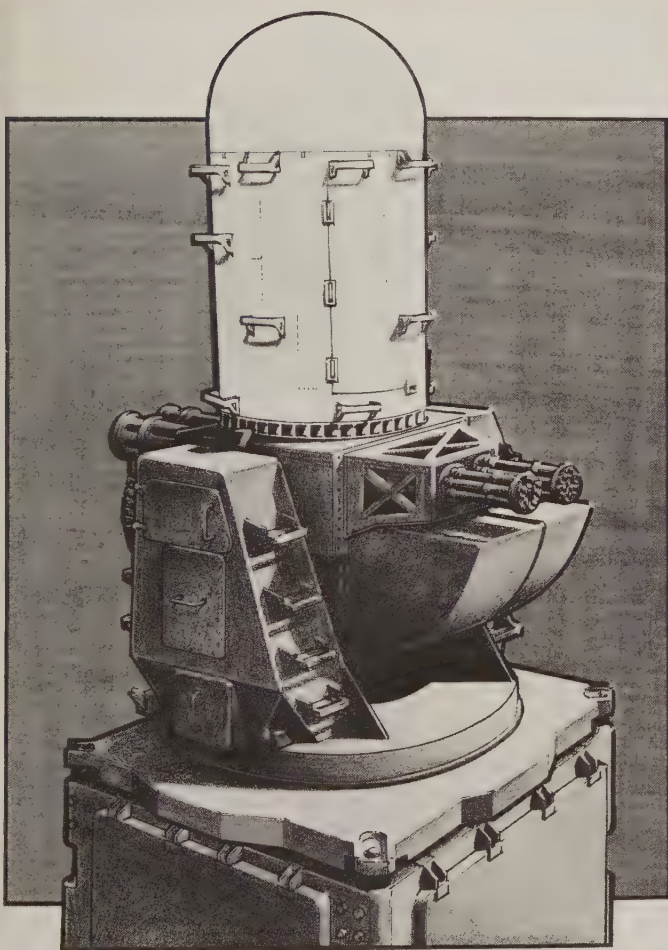
♦ Sea Vulcan 20 (EX-84)/20P

Caliber: 20-mm **Rate of Fire:** 750/1500 rnds/min
Muzzle Velocity: 3380 ft/sec
Training Rate: 80 deg/sec (elevation 60 deg/sec)
Elevation/Depression: +55/-10 deg
Ammunition Capacity: 500 rnds **Maximum Range:** 6000 yd
Working Circle: 130 in **Weight:** 318 kg empty, 465 kg loaded

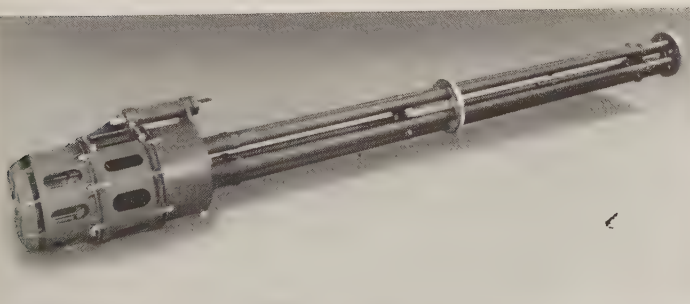
Data apply to Sea Vulcan 20.

Sea Vulcan 20 is a powered turret mount for a 3-barrel M197 Vulcan machine gun, for use on small craft. The turret itself is also designed to carry the 7.62-mm mini- (Gatling) gun and the M19 40-mm grenade-launching machine gun. Many components are identical to those used in the UTS turret of the AH-1 attack helicopter. The system is remotely controlled with its own on-board ballistic computer (to process target-designation data from another source). One EX-84 mount was built and tested in June 1981 on board a U.S. PB Mk III, but the weapon did not enter U.S. service.

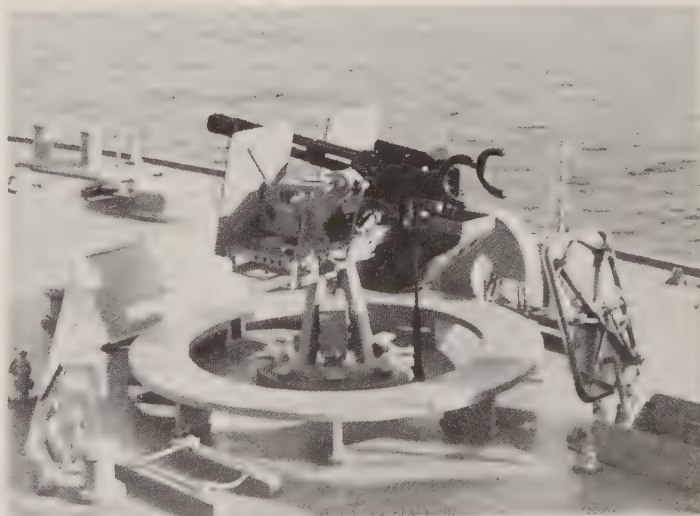
A Sea Vulcan 20 was mounted on board the Thai Hyuscat-18



Sea Vulcan 20 on board the Thai Hyuscat-18 fast patrol boat. (Tecnautic)



General Electric has proposed a 25-mm cased telescoped (CT) gun as the next-generation upgrade to Phalanx.



A JM61-M Vulcan mounting on board a Japanese minesweeper. (Sea Power)

patrol vessel, controlled by a Kollmorgen Mk 35 periscope director. Total weight was 800 lb empty or 1167 lb with ammunition, and training and elevating rates were 60 and 50 deg/sec, respectively. As installed on board the Thai patrol boat, the mount also carried a mock-up of a 2-missile SAM launcher on an extension of the elevation gimbal shaft. The mount could carry Stinger, Mistral, Blowpipe, Javelin, or RBS 70. This mount (less the missiles) was retrofitted into existing Honduran navy patrol craft (85-, 105-, and 106-footers) in 1986-87. In addition, 2 Sea Vulcans were installed on board the Boeing commercial Jetfoil operating as tender to the larger Saudi royal yachts. The hydrofoil is also armed with Stingers.

Sea Vulcan 20P is a much simpler pintle mount (originally designed to carry a twin 20-mm cannon) carrying the same 3-barrel gun and a 300-rnd ammunition box. Total weight is about 500 kg without ammunition, and elevation limits are +75/-10 deg. Although this mount is not in U.S. service, it has been bought by the Japanese Maritime Self-Defense Force. The South Korean navy uses this gun in its own specially weatherproofed mounting.

Both the gun and the Sea Vulcan mount are manufactured by General Electric.

◆ Tround

Tround is a new rapid-firing breechless gun that may ultimately replace the current Gatling. Each bullet is encased with its propellant in a triangular plastic or composite shell; shells are fed into triangular notches in a rotating cylinder. When the notch reaches the firing position in front of the single barrel, a strap comes down to hold it in place. The cartridge case replaces the breech enclosure of a conventional gun, and it is dropped into its notch rather than being rammed forward into a cylindrical breech. As a consequence, gun operation is quite simple and can be quite rapid. Because the gun uses a single fixed barrel, it does not suffer from the vibration (and consequent inaccuracy) of Gatling guns. Because the cylinder represents a smaller fraction of overall gun mass, it has less inertia than the rotating structure of a Gatling and, thus, can accelerate more quickly to maximum firing rate. The lighter cylinder and very simple firing cycle should also make for a higher rate of fire.

Tround might be considered a further application of the revolver principle used in several airborne cannon, with the important advantage of needing no reciprocating case extractor (see the discussion of the Mauser BK 27 in the Strike/Surface Warfare section).

In June 1989 the U.S. Navy awarded Tround International of Phillipsburg, New Jersey, a 3-yr, \$5.8 million contract to develop a 25-mm breechless gun and triangular round ammunition for it. The contract requires a minimum demonstrated rate of fire of 5000 rnds/min. The company demonstrated the Tround principle in a 0.50-caliber single-barrel version at China Lake in 1986; it achieved 2000 rnds/min. The next stage is a twin-barrel, 4000-rnd/min version. A British firm, Lucas Aerospace, has mounted the single-barrel version in a helicopter gun turret. The U.S. Naval Air Systems Command is currently considering 0.50-caliber and 20-mm Trounds.

A critical design review was scheduled for July 1990; it was to determine whether the Phase Two option, for a 4-barrel Tround gun, would be exercised. Phase Three would be integration into an operational naval system, such as Phalanx.

Tround International was formed in 1981. Initially, it applied what it calls open-chamber technology to mineral drilling (drill guns); the same technology is used in the machine gun. Other applications include nail drivers, fasteners, and engine starters. It obtained its first U.S. Navy contract in 1984, and in 1987 began work on 3 advanced versions: a gun for the Advanced Aircraft Program (which was later canceled), the Lucas Aerospace project for a 20-mm V-22 gun, and an agreement with Kollsman Instrument on a 30-mm Navy Advanced Minor Caliber Gun Program weapon.

◆ AMCGS

Advanced minor-caliber gun system is a projected replacement for the current 25-mm Bushmaster. Tentative specifications were circulated in mid-1990, calling for a 30-40-mm gun system to detect and kill small boats. The Bofors Trinity is a contender. This program is parallel to SWP (see below); draft RFPs were issued for both on the same day. In theory, the gun chosen under AMCGS will be carried in an SWP mounting, although the Bofors Trinity would seem to combine both requirements.

◆ Crossbow

See the detailed description under Strike/Surface Warfare. Crossbow was derived from LTV's unsuccessful entrant for the Stinger missile mounting in the U.S. Army's ADATS competition (see the Swiss section for Oerlikon's successful ADATS). As of September 1990, it had attracted interest both from the U.S. Navy and from 2 foreign navies. It was tested on board a U.S. surface-effect craft in the fall of 1989 and also on board a Swedish *Hugin*-class attack boat carrying RBS-70.



Crossbow at Farnborough, 1990, carrying a pair of 2.75-in rocket pods and 4 RBS-70 missiles. [Author]

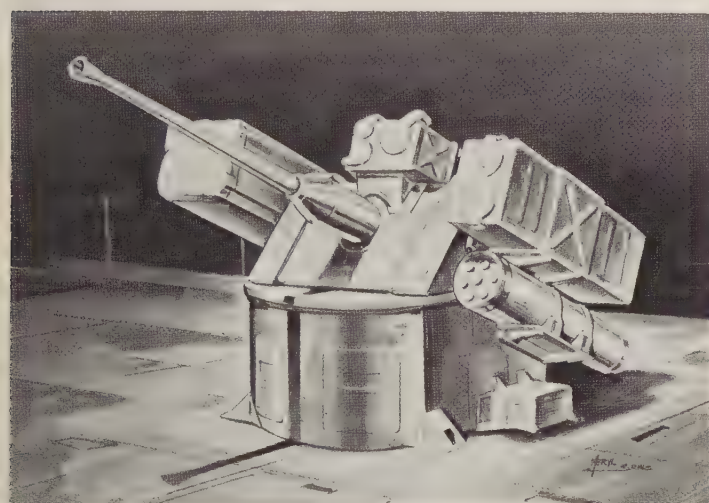
◆ SWPS

Stabilized weapons platform is a U.S. Navy program for a short-range weapon to attack small fast attack boats. The weapon is to be carried either by a future patrol boat or on board a larger ship. SWPS was conceived for a future large patrol boat and was originally tied to the projected large SEAL boat (the successor to the abortive Sea Viking). A new SEAL/patrol boat, just ordered from Bollinger, is to be the prototype for a new series, 17 of which were initially planned. The RFP was originally scheduled for release in February 1989; as of September 1990, it was expected by 1 October. One possibility is the LTV Crossbow carrying a 25-mm cannon, missiles, and 2.75-in rockets to deal with area targets on the water. The other main competitors are the AAI gun mount and the Boeing SWPS. As of September 1990 the expected number of mounts had just been increased from 33 to 54, although there was some question as to whether the extra 21 could be funded. The patrol boats now on order will initially be armed with 25-mm Bushmasters, then rearmed later with the SWP carrying the new minor-caliber gun (see AMCGS, above). The requirements figures suggest that each boat will be

armed with 3 of the new weapons. This program is being run by PMS-300, with technical assistance from the Naval Weapons Station at Crane, Indiana.

◆ SWPS (Boeing)

Boeing's stabilized weapons platform system, announced in 1990, is roughly equivalent to the LTV Crossbow and is presumably intended for much the same mission. It consists of a gyro-stabilized deck mount carrying up to 1500 lb of weapons, with a maximum weight of 3300 lb, controlled from a remote system operator's console (SOC). SWPS would probably carry a FLIR, an LLLTV, and a laser range-finder. The SOC's automatic video tracker (AVT) would lock onto a FLIR or LLLTV image (the SOC has a single 8-in screen, with 3 FOVs: narrow, wide, and rain mode to enhance the target area in high seas or bad weather) and would control the SWPS servos. Laser ranges would be displayed directly on the SOC and would be used to determine which weapon is appropriate to a given target, and then to determine when to open fire. The laser can also be used to guide Hellfire missiles. Each of 2 side-mounted launchers can accommodate 2 Hellfires or 4 Stingers or a 2.75-in rocket pod (7 or 14 rockets) and 4 Stingers. The mount also carries a 25-mm gun, and a 0.50-cal machine gun can be carried on the right launch beam.

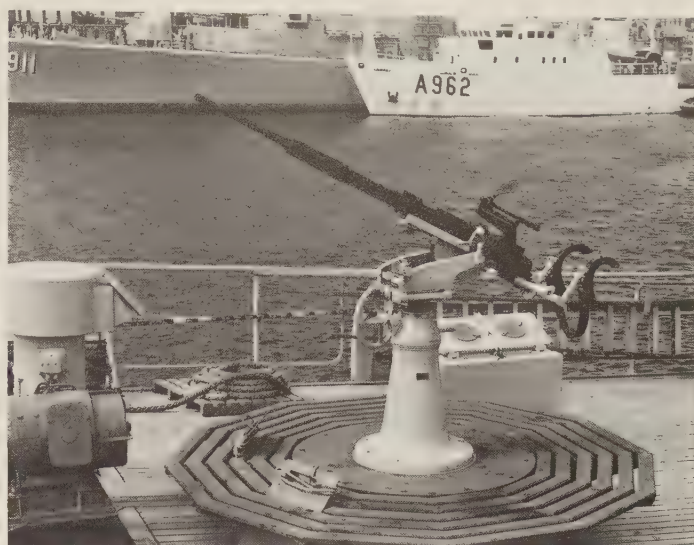


Boeing's SWPS (Stabilized Weapon Platform System) concept. (Boeing)

◆ Other U.S. 20-mm Mounts

Although early U.S. 20-mm guns are capable of anti-aircraft fire, they are primarily surface weapons. These guns are now being replaced in that ASUW role by the 25-mm Bushmaster or Chain Gun (see the Strike/Surface Warfare section), which clearly is a surface weapon. Some single 20-mm guns of U.S. design also survive in foreign navies.

World War II mounts carried a Mk 4 (Oerlikon) gun, using an 80-rnd drum magazine. This gun had a cyclic rate of 450 rnds/min and a muzzle velocity of 2730 ft/sec. Effective range was 2000 yd (maximum range 4500 yd at 35-deg elevation). This gun was blow-back operated.



A single World War II-type 20-mm Oerlikon gun on board the Belgian minesweeper *Breydel*, 1985. (M. Loagie)

The newer 20-mm guns are Mk 16s, modified aircraft guns (Hispano-Suiza HS404, designated M3) that are slightly lighter (116 vs. 150 lb) and shorter (78 vs. 84 in), and that are fed by box magazines carrying disintegrating link belts. The ammunition and muzzle velocity are the same, but cyclic rate is 600–650 rnds/min (reduced from the 800 rnds/min of the aircraft gun). These guns are operated by a combination of gas and blow back. Mk 16 also has a special oiler to lubricate its ammunition. Mod 5 adds a hand-pulled stepped mechanical trigger. Mod 4 has an electrical trigger mechanism.

About 5000 Mk 16s were delivered during the Vietnam War, and Mk 16 is a standard coast guard weapon. In recent years many M24 (air force version of M3) aircraft cannon have been cannibalized for Mk 16 conversion.

The then Naval Ordnance Systems Command developed a series of alternative 20-mm guns in the late 1960s and early 1970s, but ultimately adopted the 25-mm Chain Gun instead.

In the list below, Mk 10 and Mk 24 were the World War II single and twin mounts. Mk 67 was the standard mount for the Mk 16 gun, introduced in 1971 on board the *Tarawa* (LHA 1). Mk 68 was a stop-gap until Mk 67 could enter production; Mk 68 was tested in 1970 on board a radar-picket ship.

Only Mk 67 and Mk 68 are in current U.S. service; earlier mounts survive abroad.

◆ 0.50-Caliber Machine Gun (M2)

This standard U.S. heavy machine gun is used on board many coastal craft. Total weight is about 87 lb, and total length is 65 in. The gun is recoil-operated, and it fires 450–550 rnds/min. Muzzle velocity is 2900 ft/sec (nominal), and effective range is 1500 yd. Maximum horizontal range is 7400 yd (35-deg elevation). A 100-rnd disintegrating-link belt weighs 30 lb. This gun is often combined with an 81-mm mortar in an over-and-under mount.

Many surface combatants and auxiliaries have pedestal

MOUNT CHARACTERISTICS

	Mk 10	Mk 24	Mk 67	Mk 68
Gun	Mk 4	2 × Mk 4	Mk 16	Mk 16
Weight	970 lb	1216 lb	475 lb ^a	775 lb ^a
Working Circle	106 in	120 in	114 in	119 in
Elevation/Depression Limits	+90/−15 deg	+85/−15 deg	+75/−30 deg	+70/−45 deg
Ammunition	60 rnds	2 × 60 rnds	385 rnds	400 rnds

^aWeight without ammunition.

mounts on which shielded 0.50-caliber machine guns can be placed, for defense against small boats and swimmers. Sometimes these weapons are mistaken for larger 20-mm cannon. Typically small ships carry 2, destroyers and cruisers carry 4, and larger ships carry 8 of these machine guns.

A new mounting, Mk 26 Mod 15 (soft recoil), was developed by NSWC Crane. It entered service during the Gulf crisis. Mod 15 was originally developed after the 0.50 began to appear aboard large ships in 1978. It was soon apparent that the hard recoil of the existing version of the Mk 26 mount drastically limited accuracy. Mod 15 was developed in the early 1980s, and limited production was approved about 1985. However, it did not become important until ships in the Gulf began to encounter small attack boats in numbers.

The 0.50 itself gained importance with the introduction of a new explosive round, developed by Raufoss in Norway. Previous attempts to develop such a round for so small a caliber had failed because the 0.50-caliber bullet was too small to admit a mechanical safing-and-arming device (which was required to ensure safety, e.g., if rounds were accidentally dropped). Raufoss developed, in effect, a chemical safing-and-arming mechanism. The hard body inside the bullet is surrounded by explosive, and a detonating charge is packed into a cavity in the nose of the bullet. When the bullet hits, the charge bursts and ignites the main explosive charge, while the solid penetrator passes through thin armor. However, if the bullet is merely dropped, the impact is insufficient to set off the detonating charge.

Raufoss describes the round as multipurpose (MP) because it combines armor penetration with explosive effect. This type of construction was originally applied to 20-mm rnds, and then to larger calibers up through 40-mm. The first 20-mm MP rnd was fired in 1968, and the first production batch was delivered to the Royal Norwegian Air Force in 1971. The 0.50-caliber rnd was a later development; as of the end of 1989, about 12 million will have been delivered. This round is in service with Norwegian, Danish, French, and British forces. It is produced under license by Olin, Pykal (British), and FN (Belgian). The round can penetrate 11 mm of armor at 950 m at a 30-deg angle. There are now 3 types: MP, MP/T (tracer, production of which began in 1988), and APS (which was first marketed early in 1989). The APS round can penetrate 20 mm of armor at up to 30 deg from the normal, at 400-m range. The MP round is credited with penetration of 25 mm of steel at a 45-deg angle.

Rounds originally bought by the U.S. Navy for evaluation were sent to the Persian Gulf in 1987 on an emergency basis. As of 1989, Raufoss is supplying these rounds to the U.S. Navy. The Olin Matheson Company in the United States obtained manufacturing rights to the basic technology in 1981. Rounds were ordered only in 1987, and as of 1989 the company was still experiencing difficulties in production. As of 1989, however, production of both 0.50-caliber and 20-mm rnds was underway in the United States, and 25-mm rnds were undergoing qualification tests.

Compared to conventional 0.50-caliber rnds, the Raufoss round is much more accurate because of its weight and the different location of its center of gravity.

The effect of the Raufoss development is to extend some of the advantages of the 20-mm cannon, until now the smallest that could fire an explosive shell, to the much lighter and more portable 0.50. Presumably, that in turn makes the 0.50 much more attractive as an anti-small boat weapon, to be carried aboard both small boats and helicopters. Large numbers of these rounds have been sold (more than 3 million in France, the best customer).

As of 1989, Raufoss was developing a new tracer round based on its technology. Olin has developed the Raufoss projectile into a new round, WALAP (Winchester Anti-Light Armor Projectile), due to enter production after 1989. It is optimized for air defense, sacrificing armor penetration for incendiary effect; even so it penetrates twice as well as 20-mm HEI and can even defeat some reactive armors. It uses a tubular tungsten penetrator. Olin also makes a sabot light-armored penetrator (SLAP),

containing a 7.62-mm tungsten penetrator in a plastic (Lexan) sabot. SLAP was developed for the U.S. Government Joint Service Small Arms Program (JSSAP) project, for better penetration against Soviet armored personnel carriers. Its trajectory is reportedly so flat that a special companion SLAP tracer is required. Its velocity is reportedly 1200 m/sec. Singapore Technologies also makes a SLAP round.

Reportedly, the current (1989) trend is to improve armor penetration. In the past, 0.50-caliber AP rnds were merely hardened steel bullets, with limited performance (20-mm RHA plate at 325 m). The most common current option is to use a tungsten core in an AP/Incendiary round (APHCI or APIHC). Here HC means hard core; tungsten alloy HC more than doubles penetration range.

◆ Gecal 50 Naval Gun

A British firm, Astra Holdings, displayed a naval version of the Gecal 50 0.50-caliber Gatling gun at RNEE 1989. This mounting could be operated by 1 person, and carried 750 rnds. Weight without ammunition is 268 kg, and working circle (radius) is 712 mm. Elevation limits are +70/-20 deg.



The GECAL 50 naval gun. (Astra Holdings)



A 0.50-caliber machine gun on board the *Mount Vernon* in the Persian Gulf, October 1987. There are supports for a splinter shield, which has not been fitted in this case. U.S. ships in the Gulf were also provided with M60 light (7.62-mm) machine guns. (U.S. Navy)

◆ 7.62-mm Mini-Gun

This miniature Vulcan weighs 60 lb, including the drive motor and de-linking feeder. Total length is 30 in. Muzzle velocity is 2800 ft/sec, and effective range is 1200 yd (maximum 4000 yd). Cyclic rate is 2000 or 4000 rnds/min, and a 1000-rnd belt weighs 64 lb.

The gun is designated Mk 25 in U.S. naval service and is the GAU-2B/A aircraft weapon adapted for surface use, mainly by Special Forces (SEALs).

◆ M60

Caliber: 7.62-mm/85 **Rate of Fire:** 500–650 rnds/min
Muzzle Velocity: 2800 ft/sec
Maximum Range: 4000 yd (effective 1200 yd)
Ammunition Capacity: 1000 rnds (belt) **Weight:** 24 lb empty

M60 has been the standard U.S. light machine gun since 1957. It is often mounted on board ships as a convenient defense against boarders and small craft, and it is used with the 60-mm mortar in an over-and-under mount. It was also a major riverine weapon during the Vietnam War and as such may survive in Southeast Asia. The standard (basic) infantry model weighs 23 lb. There are also helicopter/aircraft models (M60C and M60D). The basic version has the gas cylinder and bipod attached to the barrel, which has no handle, so the barrel is both expensive and difficult to change. In the M60E1 version the gas cylinder and bipod are attached directly to the gun, separate from the barrel, and there is a handle for barrel changing. M60E2 is a version for Marine Corps M60A1 tanks, adopted in 1977. As of 1985, all Marine Corps M60s (except those on board tanks) had been converted to the product-improved (M60E3) configuration, which had been standardized in 1983 (as of that year the Corps bought 4630 new guns plus 1650 conversion kits and 977 rebuilt guns). Recent purchases (navy funds, mainly for the marines): 1384 in FY86, 1807 in FY87, 257 in FY88. M60E3 is 25% lighter than the original basic M60.

The U.S. Navy also used a Mk 21 machine gun, an earlier 0.30-cal weapon (M1919A4) adapted to 7.62-mm ammunition, in Southeast Asia, but those retained in its inventory are for war reserve use only. A newer weapon, M240E1, a U.S. version of the Belgian FN light machine gun, has been adopted for Marine Corps light armored vehicles (LAVs), but thus far has not been used aboard ships. The British version of the same weapon (L7A2) is used on board British warships (see the U.K. section).

which had been canceled in 1978. However, the 155-mm was rejected. Although the army's existing special-purpose rounds had been proven on shore, many of them could not be used in the naval electromagnetic environment without extensive and costly modifications. The marines, therefore, had to be satisfied with a combination of the existing 5-in guns and the revived 16-in/50s of the battleships.

The FMC project remains interesting for its unique loading system. All other naval guns load either at a fixed angle near the horizontal or at a variable elevation angle. For the 155-mm, FMC proposed loading vertically, the gun forming, in effect, a continuation of the loading hoist. Projectile and charge were loaded onto separate horizontal trays in the magazine, and then each tray rotated to the vertical, so that shell and powder rose in the proper sequence toward the breech. Shell and powder were there rammed together. After firing, the gun elevated so that its breech was in line with the empty-case door, ejected the case, and then continued to elevate to the vertical. The main advantage was that the gun could fire projectiles of differing lengths; inserting long guided projectiles greatly slowed the rate of fire of the existing 5-in/54. The usual loading tray was eliminated completely from FMC's design.

In 1981 FMC estimated that the mount could be ready in 6 yr (3 for development, 3 for production), that it would weigh less than 50,000 lb (revolving weight 43,000 lb), and that it would be cheaper and more reliable than the 5-in/54 (MRBF about 1320 rnds). The gun would have been a 155-mm/50, and elevation limits would have been $+75/-10$ deg (training rate 30 deg/sec, elevation rate 50 deg/sec). The conventional 155-mm shell would have weighed 103 lb, the guided shell 225 lb, and FMC claimed that the sustained firing rate would have been 10 rnds/min.

FMC has also proposed vertical-loading 5-in/54 and 8-in/36 guns. The 5-in/54 would have achieved a sustained rate of fire of 10 rnds/min, either conventional or long round. Weight dry without ammunition was given as 29,990 lb including barrel, of which 5700 lb were below deck; this compared with 47,820 lb for the lightweight conventional Mk 45. Elevation limits were $+75/-10$ deg, and the train rate was 40 deg/sec (elevation rate 50 deg/sec).

The 8-in/36 would have sustained the same rate of fire. Total mount weight (dry without ammunition) would have been 60,200 lb, of which 8700 lb was off-mount. Elevation limits were $+75/-10$, and train rate was 30 deg/sec (elevation rate was 50 deg/sec). The shell weighed 200 lb (250 lb for a guided shell). Presumably, the 8-in gun would have fired army 8-in shells.

◆ Combustion-Augmented Plasma (CAP) Technology

This high-energy gun technology was announced by FMC in 1987. This type of gun is a hybrid between an electrothermal (ET) and a liquid-propellant (LP) cannon; about 20% of muzzle energy is derived from an electrically generated plasma, and 80% from a conventional chemical reaction, as in other liquid-propellant guns. Compared to a pure electromagnetic gun, the CAP gun requires about a third as much electrical generating power. Compared to other new-technology guns (such as rail guns), the main disadvantage of the system is its complexity. On the other hand, the CAP gun has the shortest barrel (for a given performance) of a series of weapons, including pure liquid propellant guns and advanced conventional guns.

In this type of weapon, a sudden discharge of electricity heats the propellant in the breech to 5000 deg C and causes an ion plasma to form. The oxidant is then added. The resulting combustion is more rapid than usual and adds about 25% to the muzzle velocity of the weapon. That increase in velocity approximately doubles the range of the gun and, at short ranges, greatly increases the energy of the shell. In addition, because time of flight is reduced, fire control may be simplified, e.g., in antimissile defense. In the 1987 announcement, FMC showed its version of CIWS 2000, which carried 2 rather than 6 barrels.

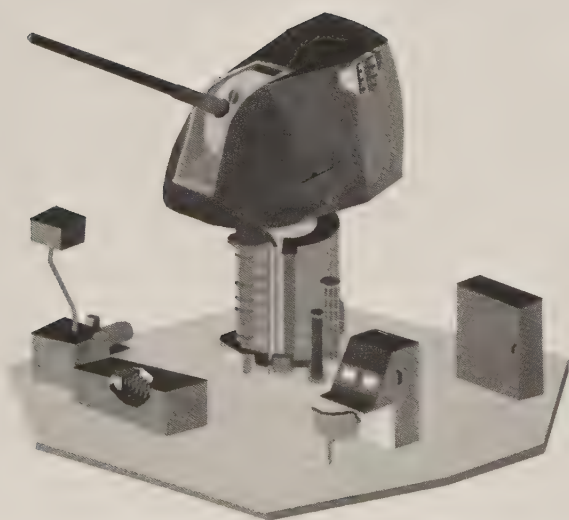
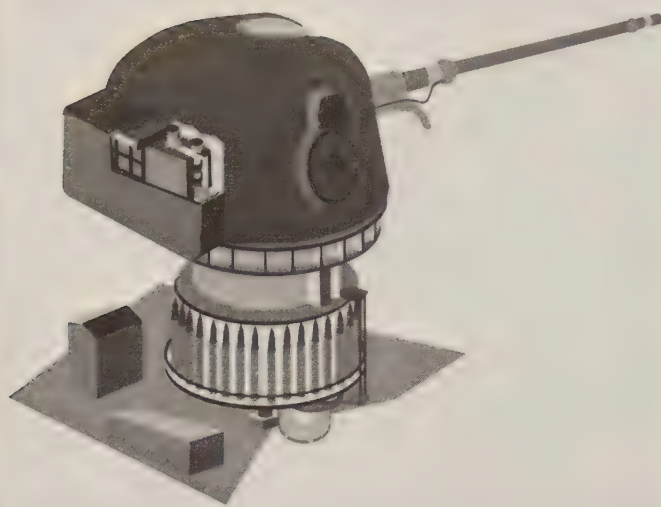
The first experiments used 10-mm projectiles, but later



An M60 machine gun on board the USS *O'Brien*, 1980. (U.S. Navy)

◆ 155-mm (6.1-in) Vertical-Loading Gun

This weapon was proposed by the FMC Corporation, the manufacturer of the U.S. 5-in/54 and 3-in/62, in 1981, to fire the army's existing standard rounds. The marines saw this weapon as a replacement for the 8-in/55 lightweight fire-support gun,



FMC's concepts for CAP (trademark) naval gun systems. (FMC)

30-mm were fired, and FMC expects to fire 90-mm projectiles. All of these experiments used liquid propellants, although a conventional solid propellant might also be used.

As of 1987, FMC was applying its CAP technology to an air force-funded hypervelocity ammunition technology (HAT) pro-

gram, in which a sideways-pointing antitank gun is to be mounted on board a C-130 or successor gunship that would fly just behind the battle line. CAP was also proposed as part of a hybrid rail gun for antimissile defense, to be used to inject a projectile into the electric gun.

FMC patented its CAP concept in 1985, and in 1990 it began a CAP naval gun project under the U.S. Navy's Balanced Technology Initiative. This weapon is also described as an electrothermal gun (ETG), and it is considered a much nearer-term proposition (e.g., for point defense) than a full electric gun. Compared to alternative exotic guns, CAP can use a conventional barrel and projectiles. FMC claims that CAP offers better reliability and internal ballistics control than a liquid-propellant gun.

FMC won a U.S. Army contract for a 120-mm electrochemical-gun demonstrator. The company has already demonstrated a 105-mm CAP gun with a muzzle velocity greater than 2500 m/sec. The army's 120-mm gun should be tested for the first time late in 1991.

For the army, the issue is kinetic energy since it is kinetic energy that penetrates tank armor. FMC offers 9 megajoules (MJ) at a muzzle velocity of 2500 m/sec, or 18 MJ at 1700 m/sec, or 4.5 MJ at 3000 m/sec. A conventional 120-mm tank gun produces 9 MJ at 1650 m/sec. FMC expects its CAP gun to be able to fire 3 rnds/min for 3 min, and to fire 100 rnds between major component changes. Firing rate and duration are presumably limited in part by the electric power stored at the gun, although they are not nearly so severely limited as in a pure electromagnetic weapon.

In contrast, a naval ETG would probably be optimized for high muzzle velocity, to simplify fire control against fast maneuvering targets. Reduced muzzle energy could be accepted as long as the projectile was heavy enough to be lethal against a fairly flimsy target. Moreover, the gun would benefit from the substantial electric energy output of the ship carrying it.

◆ Liquid-Propellant Gun Technology

For some time General Electric has been developing the technology for liquid-propellant guns for the U.S. DoD, both for ground and for naval missions. By 1983 GE had demonstrated its new regeneratively pumped direct-injection-combustion technique in a 105-mm test gun. Although not yet applied to a naval weapon, this technology is potentially important enough to be included here.

Interior ballistics are controlled by metering the propellant into the combustion chamber. Thus, to a considerable extent, a gun's muzzle velocity, hence range, can be varied without varying the elevation angle. Bulk stowage of propellant greatly reduces the weight and bulk of ammunition, and quicker loading of propellant can greatly increase the rate of fire. In the GE system, once the first round has been fired, the pressure in the combustion chamber is used to pump in the next load of propellant (hence the regenerative name).

YUGOSLAVIA

◆ 20/4 M75

Caliber: 20-mm **Rate of Fire:** 650–750 rnds/min
Muzzle Velocity: 850 m/sec [2790 ft/sec]
Training Rate: 80 deg/sec (elevation 50 deg/sec)
Elevation/Depression: +85/–10 deg
Ammunition Capacity: 4 × 60-rnd drums
Effective Range: 1500 m [1650 yd]
Working Circle: 1.895 m [radius] [74.6 in]
Weight: 1900 kg [loaded] [4190 lb]

Yugoslavia manufactures and uses this quadruple 20-mm gun. The guns themselves are locally made Oerlikons of World War II configuration, mounted 2 to a side, 1 above the other, with their ammunition drums protruding on each side. The rate of fire given is for the mount as a whole, not for the individual guns. Each gun can fire 180 rnds at a time but must then stop for 5–10 min to cool down.

The individual 20-mm gun is designated 20/1 M71. It is not

clear whether it is a World War II Oerikon or a locally made version of the current A41, which is somewhat different (photographs in the official Yugoslav arms catalog seem to show 2 versions). The single mount can elevate and train at 80 deg/sec (limits +90/-10 deg), and it weighs 460 kg [1014 lb] loaded.

The single mount is fitted with a reflex sight (RNS-M71T) with an FOV of $\pm 20 \times \pm 10.5$ deg; the objective lens is 110 $\times$ 120 mm, and total weight is 3.5 kg [7.7 lb].

SHIPBOARD ELECTRONIC WARFARE

This section includes 2 very different classes of systems: chaff or decoy launchers and electronic intercept/jamming devices. There are also a few towed or floating decoys and some electronic intelligence devices.

A chaff launcher can have 1 or more of 3 distinct functions. Firing at long range, the launcher can provide a targeting radar or an incoming missile with multiple targets. If all targets must be engaged, the attack is diluted, and close-in weapons have a better chance of dealing with those weapons that do lock onto the ship herself. The usual counter-countermeasure is MTI (moving-target indication). A radar easily distinguishes an airplane from chaff because the real target is moving so much faster. Such a distinction is much more difficult to make if the target is a ship. The second, intermediate-range function is to seduce the missile seeker away from the ship target onto a decoy cloud. The missile seeker is designed to avoid such seduction by using a range-gate, i.e., by reacting only to signals within a narrow band of ranges around the expected target's position. An active ECM transmitter (range-gate stealer or range-gate pull-off) is used to move the missile's seeker into the chaff cloud some distance from the ship. Finally, there is a last-ditch tactic, centroid seduction. The missile's seeker generally homes on the centroid of the target's return, seeing the ship target as a complex array of point and corner reflectors. If a large chaff cloud is added, it moves the centroid up and away from the ship target, and the missile may pass overhead or to the side. Success in this mode depends upon the reflective cross section of the chaff cloud compared to that of the ship proper. If the cloud is designed merely to move the centroid up, that countermeasure may be countered by a radio altimeter that keeps the incoming missile at low altitude.

Chaff (and IR decoys) may be launched by rocket or mortar. Rockets provide longer range (for the dilution role) and do not impose any load on the surrounding deck. However, they are relatively large, and a designer must protect against their back blast. Mortars are more compact, as is their ammunition. Both types exist in considerable variety.

ECM devices fall into 2 broad categories, intercept receivers (often termed ESM, electronic support measures) and active countermeasures (jammers and more sophisticated deception devices). ESM includes not only attack warning but also passive detection of air and surface forces beyond the sensor's horizon. Although such detectors may be considered more as antiship targeting devices than as self-protection, they are most conveniently included here. Attack warning requires, at most, coverage of the standard air-to-surface radar (X-) and missile-seeker (X- and K-) bands. OTH detectors of surface ships may exploit both the sea-wave emissions of P-band air-search radars and HF communications.

These devices can also be divided into wide-open and narrow-beam scanning types. A wide-open detector will pick up very short signals, but it may lack sensitivity in any 1 direction, and it will also generally lack directional precision. A narrow-band scanner will provide good directional data and may achieve great sensitivity; but with a finite scanning rate, a narrow-band scanner may miss a very short transmission. In the past, British practice has generally favored wide-open detectors using fixed antennas (and measuring signal direction by phase comparison); U.S. practice has favored rapidly scanning directional antennas (as in SLR-12). Current U.S. practice employs electronic scanning, in which a wide-open antenna can form numerous narrow beams continuously and simultaneously (e.g., SLQ-32).

Active countermeasures employ a variety of tactics, from simple noise (barrage) jamming up through false-target transmitters sequenced to confuse scanning radars. There are also multi-antenna antimonopulse techniques. For many years U.S. escorts were fitted with blip enhancers intended to make it difficult for an approaching antiship bomber to distinguish them from the accompanying carrier. Reportedly the implicit missile-absorber role was less than popular, but this measure suggests the subtlety of electronic warfare. Currently the U.S. and Royal Navies use floating decoys, which are called "rubber ducks" in analogy to hunters' decoys.

AUSTRALIA

◆ Winnin/Nulka

Winnin is a hovering rocket that carries an active jammer; the complete system is called Nulka. By hovering, the decoy prolongs its life. It can also be powered to move slowly away from the launching ship, thus simulating the movement of a real ship. The key technology is a variable-thrust solid-propellant rocket, whose thrust automatically decreases as the weight of the vehicle decreases (through fuel burning). Servo tabs in the rocket's exhaust control the rocket's direction. Winnin is fired in a precomputed direction but can also receive control data while in flight. This degree of control simplifies launching arrangements since the decoy can fly in the required direction whatever its initial launch path.

The hope is that the attacking missile will fly below the hovering decoy, on a heading away from its intended target. In that case it is, in theory, precluded from acquiring another target. The decoy, therefore, has its own sensors, which detect the character of the incoming missile and which also gather weather information. These data are passed back to the launching ship by data link, and a processor on the ship can feed back commands. The entire decoy system can be integrated with an automated CIC.

The decoy can be fired from a Mk 137 (SRBOC) launcher or from a 10-rnd module. The U.S. Navy calls the rocket "Hoveroc," and its tubes will be added to existing U.S. SRBOC tubes. In this form the rocket can carry an IR payload in addition to its active-radar decoy.

Winnin was conceived in 1974 and first flew in 1981. The concept was developed by the Weapons Systems Research Laboratory at Salisbury, South Australia, and by the Government Aircraft Factories in Melbourne. It has been tested by the Italian navy.

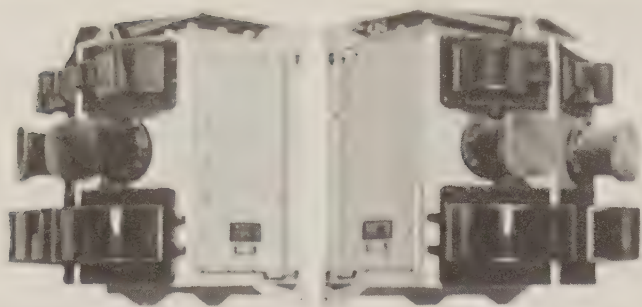
CANADA

◆ CANEWS (SLQ-501)

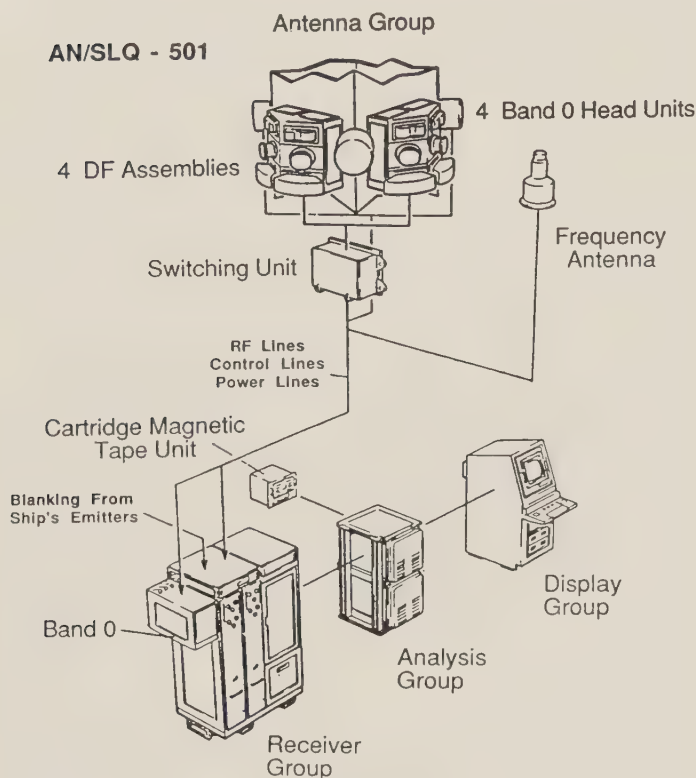
MEL's system for the Canadian "City" class was first tested in the fall of 1981. CANEWS embodies the MEL instantaneous-frequency-measurement (IFM) device also used in the British Abbey Hill system (see below) and claimed, in 1983, to be the only one of its type manufactured in Europe. Some accounts suggest that CANEWS is a derivative of the British UAA-1.

Radar intercepts are compared with a library, providing automatic classification within 2 sec of an intercept. The system covers 1-18 GHz in 5 bands, each with its own receiver (8 horns, wide open in frequency, for full 360-deg coverage, a bearing accuracy of better than 4 deg, and a frequency accuracy of 5 MHz). The system can be expanded below 1 GHz if desired. Two UYK-20 computers are used, to process up to 500,000 pps; the library stores up to 2000 emitter modes, tied to geographical area. The operator can add up to 128 emitters (a "regional" file, of radars most likely to be encountered). There is also a smaller preprogrammed threat library. CANEWS was described as fully automatic, unlike the British Abbey Hill.

The antenna weighs less than 200 kg. It consists of 8 boxes, each covering 45 deg and each carrying 4 radomes, for 4 frequency bands. The 2 highest-frequency radomes are side by side, with intermediate- and lower-frequency radomes below. Four



CANEWS antenna array. (MEL)



CANEWS, SLQ-501. (MEL Defense Systems)

Band-0 (low frequency) units are located between the pairs of 45-deg boxes. Each antenna feeds a wide-open receiver; in addition, there is an omnidirectional antenna feeding an IFM.

Work began in 1973, the MEL proposal being accepted in 1976; the first set was delivered in July 1980. It was tested on board the Canadian frigate *Terra Nova* that October. CANEWS was selected for the Destroyer Life Extension Program and then for the "City" class. Successful sea trials of a production set were reported in mid-1983. The first operational installation was on board the frigate HMCS *Huron*, in 1986; and by early 1987 CANEWS was also on board HMCS *Gatineau* and *Huron*, with 4 more installations planned. The new "City"-class frigates will carry communications intercept-and-DF equipment in addition to CANEWS, and also the MEL RAMSES (SLQ-503) noise/deception jammer.

MEL Defense Systems (of Canada) was set up specifically for this program.

◆ SLQ-503 (RAMSES)

This MEL system is combined with CANEWS (SLQ-501) in new and modernized Canadian destroyers. RAMSES is an acronym for Reprogrammable Advanced Multimode Shipboard Electronic-Countermeasures Systems. RAMSES can operate either under SLQ-501's control or independently. Software-controlled, RAMSES can jam several threats simultaneously. MEL claims

that RAMSES is effective against monopulse radars, even though it uses only 2 antenna assemblies, 1 to port and 1 to starboard. Each incorporates a pair of radomes, presumably for 2 different frequency ranges.

◆ Low-Cost MM-Wave ESM

In August 1990 MEL announced a new low-cost mm-wave ESM receiver, for which it had conducted systems engineering as well as proof-of-concept development. Because MEL is the EW systems house for the Canadian navy, its new ESM device will probably appear on board Canadian surface ships. The Ka-band receiver can be built in 4-, 6-, or 8-port versions, and it has digital output. It can handle pulse widths from 50 nanosec to CW, and the throughput rate of the associated ESM device, presumably with 8 ports like SLQ-501, is better than 500,000 pps. Bearing accuracy is 5–7 deg, and elevation coverage is 40 deg. Sensitivity is –60 dBm, and dynamic range is 60 dB.

◆ Model 100

This naval direction-finder, manufactured by General Precision Industries, covers 10 kHz to 180 MHz. For LF/HF Model 100 uses a pair of multiturn switched loops (sense from balanced dipoles); for VHF the system uses 16 monopole elements that can be arranged as crossed-Adcock and parallel-dipole arrays for both horizontal and vertical polarization. There is also a ground mobile version, Model 109. This system dates from the early 1970s.

Signals are displayed as bearing lines on a CRT. Bearing and frequency can be displayed together by using color modulation to indicate the latter.

◆ CCP/TECMUS

Canadian ULQ-6 ECM systems are currently being upgraded by addition of Telemus Electronic Systems' Coherent Countermeasures Processor (CCP). The initial improvement to the ULQ-6 was replacement of the original Frequency Memory Loop (FML) for better reliability; later Telemus replaced all major ECM components except the antennas and the high-power transmitter tubes.

ULQ-6 is a reactive (deception) jammer, and it uses the FML to shape the jamming pulses into delayed replicas of the original pulse, e.g., for range-gate stealing. The old analog FML is replaced by a digital RF memory (DRFM) unit. An FML is not coherent, is limited in storage time, and cannot be filtered to reject the signal emitted by the jammer itself. Without such filters, the jammer signal leaks in through sidelobes, and the system as a whole tends to lock into a feedback loop. A target radar escapes jamming by shifting frequency or PRF. A DRFM can be filtered by software, so it can continue to return signals reflecting the character of the original.

The DRFM samples incoming signals at a rate of 120 million per sec, representing their amplitude by 4 bits, with an instantaneous bandwidth of 10–550 MHz within an operating bandwidth of 2–18 GHz. Memory capacity is at least 340 microsec of signals. TECMUS offers 4- or 8-channel receivers, or a combination. The 4-channel receiver uses a frequency divider to double the bandwidth of the DRFM, to keep a frequency-agile threat radar within a single channel. In either case a frequency selector detects and selects the proper channel within 25 nanosec of signal detection. Throughput delay from the receiver flange input to the transmitter flange is 10 nanosec, to capture leading (pulse)-edge trackers and narrow pulses. The DRFM contains 11 parallel processing channels (per signal channel).

Channelization makes for sensitivity; Telemus claims –70 dBm, sufficient to detect the sidelobes and backlobes of most search and target-acquisition radars. Frequency coverage is typically 7–11 or 6–18 GHz (customer specified), and each channel is 1 GHz or 500 MHz wide. The system can deal with pulse widths between 20 nanosec and 340 microsec, and range-gate delay resolution is only 8.5 nanosec. The associated library contains 100 spot entries.

Given the flexibility and sensitivity of the DRFM, the system

could do much more than merely return a slightly delayed replica of the incoming signal. The memory cycle is much faster than in the earlier analog processor. The full upgrade, therefore, includes a programmable countermeasures generator. It is called TECMUS (Tactical Electronic Countermeasure Upgrade System).

CCP/TECMUS includes an integrated, programmable, deception-techniques generator. ECM techniques include scan-rate modulation (SRM) (angle deception against conically scanned or scanned radars), swept SRM, false targets, and range-gate pull-off (RGPO) and pull-in (RGPI). Swept SRM is used against radars that scan on receive only, in the expectation that as the SRM modulation rate is swept, it will pass through their modulation rate. Other techniques, including noise, are available as options. Up to 4 RGPO programs can be run simultaneously and independently; SRM and swept SRM can also be run simultaneously with RGPO or RGPI, to maximize the chance of capturing the threat range gate.

False targets are injected into the sidelobes or backlobes of radars, as well as into the main lobes. The memory cycle is so short (8 nanosec, comparable with minimum-range bin size) that it should be possible to attack synthetic-aperture and other imaging radars. Similarly, because the memory cycle is very short, TECMUS can attack the elements of a chirped signal and, thus, can deal with pulse-compression radars (both phase- and frequency-coded).

Telemus argues that by running 4 RGPO programs simultaneously, it has an excellent chance of defeating a generic threat (i.e., a threat whose parameters are unknown). All of the RGPO programs include velocity profiles (each is a 3-segment velocity profile). The profile is user-defined, and it can terminate in zero velocity. The threat radar will quite possibly derive a velocity from target position, projecting ahead target position. If the RGPO ends with zero apparent velocity, the threat radar will be easier to shift onto a chaff decoy, as the threat system tracker will not be accelerating through the desired dump position. Telemus argues that this is the only way to defeat a monopulse angle tracker, which will then angle-follow the decoy away from the ship.

The operator inserts the desired offset angle in degrees into the system, and the system tells whether jamming on that bearing is possible. TECMUS does not emit until it has received a trigger signal from the threat radar; the jamming signal bears a constant relationship to that trigger, so that the apparent target is stable in range, even if the threat radar jitters or staggers its PRF. This technique in turn is possible only because the receiver reacts quickly enough to the trigger, rather than to a memory loop based on some earlier received signal.

TECMUS is run by two 68000-series microprocessors on a VME bus. One manages the system and the technique generators and is also responsible for power management of the TWT, within its available duty cycle (the operator is told if he or she is trying to execute too many programs in parallel). The other is the scan processor, reporting a lock-on or a conical scan or search-and-acquisition radar.

Telemus offers optional narrow-band receiver extension to deal with phase-coded as well as frequency-coherent (pulse-compressed) threats, and new antennas and high-power amplifiers.

The Telemus company also offers a system to improve the signal de-interleaving capacity of current broad-band ESM systems, and the company has received a study contract for a low-cost off-board active decoy.

CHINA (PRC)

At the ASIANDEx exhibition in Beijing in the fall of 1988, the China Shipbuilding Trading Co. displayed a radar noise jammer (EAJ-7), a decoy launcher (ERC-1), and a tactical data system (ECIC-1). No details of these devices are available.

The China National Electronics Import and Export Corp. offers a submarine radar ESM device, Type 921-A. It provides bearing accuracy within about 30 deg for signals at 2–18 GHz in 4

bands. There is no IFM. The antenna unit is a dome, 560 mm [22 in] in diameter and 515 mm [20 in] high, weighing 80 kg. The 4-band operation and lack of Western-style displays suggests that this system may be derived from Soviet ESM technology (as in Watch Dog) obtained prior to the Sino-Soviet split of the late 1950s.

The same company offers a surface-ship radar-warning receiver, RW-23-1, operating over the same 4 bands, and storing parameters of up to 15 radars. The system employs 2 antennas, 1 on either side of the ship.

BM/HZ 8610 is an ESM system advertised by the Southwest China Research Institute of Electronic Equipment. It covers the 2–8- and 7.5–18-GHz bands, with elevation coverage between +30/–10 deg. Frequency is measured to within 5 MHz, and direction to within 2.5 deg; sensitivity is better than –70 dBm (dynamic range 40 dB). Pulse width is 0.1–99.9 microsec, and the system can store 500–1000 radar modes. Data are presented both graphically and in tabular form.

FRANCE

ELECTRONIC SYSTEMS

◆ ARBB 32

Électronique Serge Dassault conducted the first design studies for this shipboard jammer in 1967, and ARBB 32B entered production in 1974. Two prototypes (ARBB 32A) and 10 ARBB 32B were manufactured in 1974–79, and they were installed on board the major French warships: the cruiser *Colbert*, the *Suffren*, the *Aconit*, the *Tourville*, and the first 3 ASW C70-class corvettes. ARBB 32 was limited to range-gate pull-off, and in 1979 the French navy asked ESD to develop a more sophisticated jammer, which became ARBB 33.

A few ships have the older ARBB 31.

◆ ARBB 33

Électronique Serge Dassault began design studies for this electronically steered multiple-threat shipborne jammer in 1979; the prototype was completed in 1983, and series production began in 1986. In current form, the system employs a pair of semicylindrical radomes (height 2.2 m, diameter 1.2 m, weight less than 500 kg), port and starboard, each of which contains upper and lower dielectric windows, containing the transmitting and receiving antennas, respectively. The antennas are electronically scanned, and there are thirty-six 10-deg lobes on each side (so that the direction of jamming can be controlled to within 5 deg). Jamming power is 100+ kW.

A major advantage claimed for ARBB 33 is its ability to counter target-designation radars as well as fire-control and missile-seeker radars. System functions are threat detection/classification; data transmission to a combat system; and jamming, either automatically after detection, or controlled by the EW system. Typically, jamming is coordinated with decoy firing.

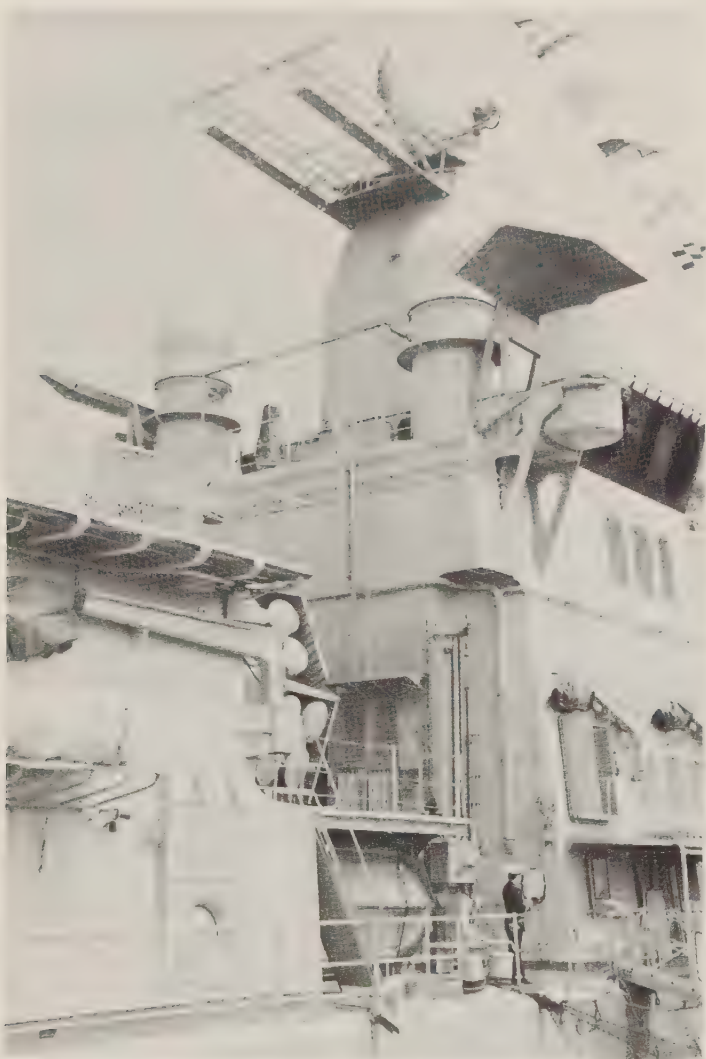
The detector operates over H-, I-, and J-bands, measuring frequency, pulse width, PRF, and direction (accuracy within 5 deg); reaction time is less than 500 msec. The jammer operates over the same bands and can deal simultaneously with 2 (optionally 4) threats. Its primary operating modes are continuous noise, pulsed noise, synchronous false echoes, asynchronous false echoes, and range-gate pull-off (e.g., onto chaff). The jammer uses dish antennas for higher gain compared to the planar antennas of ARBB 32 and other systems. The bands are chosen to cover missile seekers, fire-control radars, and target-designation radars.

◆ ARBR 10

This ESM set has been replaced on board most French warships by ARBR 16 or ARBR 17. ARBR 10C survives on board the destroyers *La Galissonnière* and *Du Chayla*. ARBR 10F survives on board the cruiser *Colbert*. The antenna array, carried on a platform just below the masthead, consists of an omni antenna



ARBB 31 occupies the squat cylindrical radome on board the destroyer *Suffren* (ARBB 32 is on the foremast). The radome above is for ARBR 10F. (Sea Power)



ARBB 33 on board the French destroyer *Cassard*. Note the shield to prevent interference with the nearby satellite antenna above. (Sea Power)

and 4 directional antennas, with preamplifiers. Typically, ARBR 10 was combined with other equipment. For example, the *Tourville*-class frigates also carried a trio of U.S.-type spinning DF antennas and a German Telefunken Telegon TV masthead HF/DF.

◆ ARBR 15

V/UHF receiver.

◆ ARBR 16/DR 2000

The current standard surface-ship ESM system is made by Thomson-CSF. ARBR 16 works either with an ARBB 31 or 32 jammer (*Jeanne d'Arc*, *Colbert*, *Suffren* class, the F67-class frigates, the *Aconit*, and the first 3 C70 ASW class) and Syllex medium-range chaff; or with DAGAIE chaff launchers (8 *Commandant Rivière* class and the A69 class).

ARBR 16 is a modified DR 2000.

DR 2000 is an F-band analysis receiver for warning, for surface ships (2000S, with 27-kg antenna), and for submarines (2000U, with 34-kg antenna and, as an option, a 14-kg periscope antenna). DR 2000 is designed to detect pulse and CW signals, including those of frequency-agile radars, and it has a 500- or 1000-signal library against which the video signal (or an optional printout) can be compared. An automatic alarm is provided, either to begin jamming or to dive the submarine. Data output: band, PRF, pulse width, power level, antenna rotation period, jitter, and bearing. PRF accuracy is 1 Hz in 1000 Hz. Larger ships (ARBR 16) have a superhet receiver for greater accuracy in frequency.

There are 6 D/F antennas plus an omnidirectional antenna, and a frequency-determining unit (indicating whether a signal is in S-, C-, X-, or Ku-band). In DR 2000, these antennas are enclosed in a radome. This is the radome atop the masts of German S143B- and S148-class fast patrol boats (S143A has the newer FL1800 system).

DR 2000 is typically combined with Dalia 500 (500 threat modes) or Dalia 1000 (1000 threat modes). DR 2000 is to be replaced by DR 4000.

DR 2000 was introduced in 1977, and by 1978 a total of 136 sets were on order, including both the DR 2000S surface-ship version and the DR 2000U submarine system. Later sales included sets for small and medium maritime-patrol aircraft. By May 1980 orders totaled 165, and by 1988 the number in service or on order had increased to more than 400. The DR 2000U

submarine version is reported operational in 25 navies (presumably, it replaces the earlier DR 875, which was on board older Type 209 submarines, such as those in the Turkish navy). DR 2000U was the standard ESM set of German-built submarines, and it is the French navy's ARUR/ARUD.

Users of the DR 2000 surface-ship version are Argentina (A69-type corvettes), Belgium (*Wielingen*-class frigates), Ecuador (3 *Quito* and 3 *Manta* class), Greece (10 *Combattante-III* class plus 4 *Combattante-II*s), Germany (20 Type 148, 10 Type 343 minesweepers, 12 Type 331 minehunters), Indonesia (4 PB57 class), Iran (12 *Combattante-II* class, 2 now lost), Libya (10 *Combattante-II*, 1 now lost), Malaysia (4 *Combattante-IIAL* class), Peru (6 PR72-560 class), Qatar (3 *Combattante-III*), Turkey (probably 8 *Kartal*-class missile/torpedo boats), Tunisia (3 *Combattante-IIIs*), and Venezuela (6 *Constitucion* class, removed when Harpoon replaced Otomat).

The French navy's ARBR 16 installations are 2 *Clemenceau*-class carriers, the *Jeanne d'Arc*, 7 *Georges Leygues* class, 3 *Tourville* class, the *Aconit*, 2 *Suffren* class, 3 older destroyers (of 12 in existence in 1977), 17 A69 class, and 9 *Cdt. Rivière* class (now being transferred to Uruguay).

Probable submarine installations are Argentina (5 TR 1700s and 2 Type 209s), Australia (6 *Oberons*, replaced by the Timnex system), Canada (3 *Oberons*, now replaced by *Manta*), Brazil (3 *Oberons*), Chile (4 IKL Type 1300s and probably 2 *Oberons*), China (some purchased mid-1980s, possibly for SSBNs), Colombia (2 Type 209s), Denmark (2 *Narhvalens* [modified Type 206s] and 4 *Delfinens*), Ecuador (2 Type 209s), France (6 SSBNs, 4 *Rubis*, 4 *Agostas*, 8 *Daphnes*), Germany (18 Type 206s, 6 Type 205s), Greece (8 Type 209s), India (4 Type 1500s), Indonesia (2 Type 209s), Netherlands (4 *Dolfijn* class), Norway (10 Type 207s), Pakistan (2 *Agostas*, 4 *Daphnes*), Peru (6 Type 209s), Portugal (3 *Daphnes*), South Africa (3 *Daphnes*), Spain (4 *Agostas*, 4 *Daphnes*), Sweden (5 *Sjoormen* class, possibly 4 *Drakens*), Turkey (6 Type 209s), Venezuela (2 Type 209s), and Yugoslavia (possibly 2 *Sava* class).

The aircraft version is in the Atlantic (in French and Pakistani service, 40 aircraft), Gardien (5 French naval aircraft), Super Frelon helicopters (24 built for the French navy for patrol out of Brest in support of SSBNs), and Super Puma naval helicopters (8 for Abu Dhabi, 6 for Brazil, 26 for Indonesia, 6 for Kuwait, 2 for Oman, 6 for Saudi Arabia, and 6 for Singapore). It is not certain how many of the helicopters were fitted with DR 2000H. Although DR 2000H was adapted for the EMB 111 and the Fokker Maritime Defender, aircraft of those types generally carry Elettronica's ESM equipment.

A new DR 2000U Mk 2 reduces size and increases performance. It covers the D-J-bands, and DF accuracy is about 6 deg. Total weight is about 90 kg.

Thomson-CSF is currently updating DR 2000 with a higher-sensitivity antenna and with an improved processor.

◆ ARBR 17/DR 4000

Thomson-CSF's ESM system (covering D-J-bands) for surface ships was announced in 1984 for the new generation of French warships, including the nuclear aircraft carrier *Charles de Gaulle* and the *Cassard*-class air-defense frigate. In these ships ARBR 17 cues the ARBB 33 jammer and the chaff launchers. In the new FL25 frigate, announced in 1984, ARBR 17 was intended to cue the 2 Dagaie chaff launchers. There are 2 antennas, an omnidirectional unit (initial detection, IFM, and threat analysis), and two 8-port directional arrays slightly below on the same mast (for D/F and more accurate frequency analysis).

The first ARBR 17 was installed on board the missile frigate *Cassard* in 1986.

DR 4000 is the export version. Compared with DR 2000, DR 4000 gives wider frequency coverage (C- through J-bands). There are 3 basic versions: 4000S for ships, 4000U for submarines, and 4000A for aircraft. The antenna array consists of 1 omnidirectional antenna and 2 groups of 6 directional antennas (1 each for the high and low bands, respectively H-J and C-G). Analysis involves 10 radar parameters, to reduce the chance of

mistaken identity. The system triggers an alarm if it detects a preset threat radar, such as a missile seeker, requiring instant attention. DR 4000 can process 15 tracks automatically and can track 40 emitters under operator control.

The display shows both raw video and a generated picture, using the usual NTDS symbols supplemented by 3-color coding to indicate particularly urgent threats (red is most urgent), on the theory that color should be used only to trigger an immediate response from an operator. Also showing jammer and decoy use, the display can be used for overall EW management.

DR 4000U has been adopted for the new Brazilian Type 209 submarines. Claimed DF accuracy is 5–6 deg, the antenna array consisting of an omnidirectional antenna (for IFM) and two 6-port assemblies, 1 for C–G-bands and 1 for H–J-bands.

The DR 4000 antenna consists of an omni and 2 stacked DF channels, each with 6 antennas. The omni antenna is 260 mm in diameter and 415 mm high (including a short knob at its top); it weighs 9 kg. The DF antenna fits within a 480-mm circle, is 425 mm high (including both frequency components), and weighs 44 kg (two 22-kg components). All components can be mounted together, or the DF antenna can be split into port and starboard segments. The below-decks console carries a display, a keyboard, and a trackball; the console also carries controls for chaff launching and for a jammer. It carries a de-interleaving module and a video processor. The screen shows 3 different displays: an "activity display" showing the tactical situation (with SENIT/NTDS symbols), a track display, and maintenance displays.

In the submarine version, DR 4000U, the 12 DF antennas surround the omni antenna (which is limited to a knob on top of the cylindrical radome).

Thomson-CSF designates DR 4000 as TMV 201.

Current users are Brazil (DR 4000U in Type 1400 submarines) and Saudi Arabia (*Al Madinah*-class frigates).

◆ Alligator

Alligator is Thomson-CSF's dual-mode (noise/deception) X-band jammer. Its antenna weighs 120 kg; its transceiver, 320 kg. Alligator was designed to work with the DR 2000 crystal-video ESM set. It incorporates an IFM to measure the frequency of the radar to be jammed; Thomson claimed that it could begin to jam upon receiving a single pulse. Alligator is a noise rather than a repeater jammer, the intent being to blind the targeting or surveillance radar rather than to confuse an antiship missile. However, its signal can be modulated in a preset (not reactive) pattern to confuse a missile (hence the reference to deception). Alligator 5A, the jammer for surface craft, was introduced early in 1978, and by later that year 15 were on order. That included 12 for Iranian *Combattante-II*-class missile boats (2 subsequently lost).

◆ ALTESSE

Thomson's shipboard communications alert and situation monitoring system was first displayed at Bourget Naval 1990 (October 1990), where it was described as the shipboard sensor providing the earliest warning. French naval trials were underway in the fall of 1990. ALTESSE is a potential successor to the German-supplied Telegon series of HF/DF systems. ALTESSE is built around the company's TRC 610 radio direction finder designed to overcome modern HF counterdetection techniques (frequency hopping, free-channel search, and burst transmission). ALTESSE integrates interception, DF, and analysis functions with short processing time; it also applies broad-base interferometry techniques for greater DF accuracy.

Operating modes are automatic scan (display is a frequency-bearing plot), recurrent surveillance mode (frequency-bearing plot of preset targets, with technical analysis data), and fixed-frequency (directional data displayed in polar or PPI format, with essential technical data). For example, the frequency-scanning (automatic-scanning) display shows minimum and maximum frequency of signals at an indicated bearing, frequency step (for a frequency-hopping system), measurement resolution

and duration, signal azimuth, center frequency, frequency range, signal level and duration, number of signals received (and measured), and a measure of signal quality. The display is a standard rectangular color CRT.

The base system operates over 20–500 MHz, using 2 nested arrays, each of 5 vertical dipoles, plus a sense antenna in the middle. The struts supporting the dipoles lie in the same plane. To extend coverage up to 1350 MHz, a third set of 5 shorter dipoles is added above the other 2. To extend coverage down to 1 MHz (1–30 MHz), the system adds a conventional pair of crossed loops. Bearing accuracy is better than 0.5 deg. There are separate HF (TRC 6113) and V/UHF (TRC 6123) antenna switches, both feeding a bank of 5 receive channels and a TRC 6105 signal processor. The signal processor in turn can supply data directly to a ship's combat system or to the TRC 6108 operator terminal.

◆ Dalia

Thomson-CSF's radar analyzer works with the DR 2000 receiver, operates over the E-J-bands, and uses IFM. Signals are compared to those in a 500–1000 signal library (the suffix, 500 or 1000, indicates the size of the library; Dalia 1000 was an-

nounced in 1976). Identification is based on the characteristics of 3 consecutive pulses, and as of 1976 Thomson-CSF claimed that any pulse train could be identified within 1.5 sec. When a signal matches several in the library, all are displayed, each with a "confidence level." Thomson-CSF designates the Dalia/DR 2000 system THV 433 or TMV 434.

◆ DBI 3000

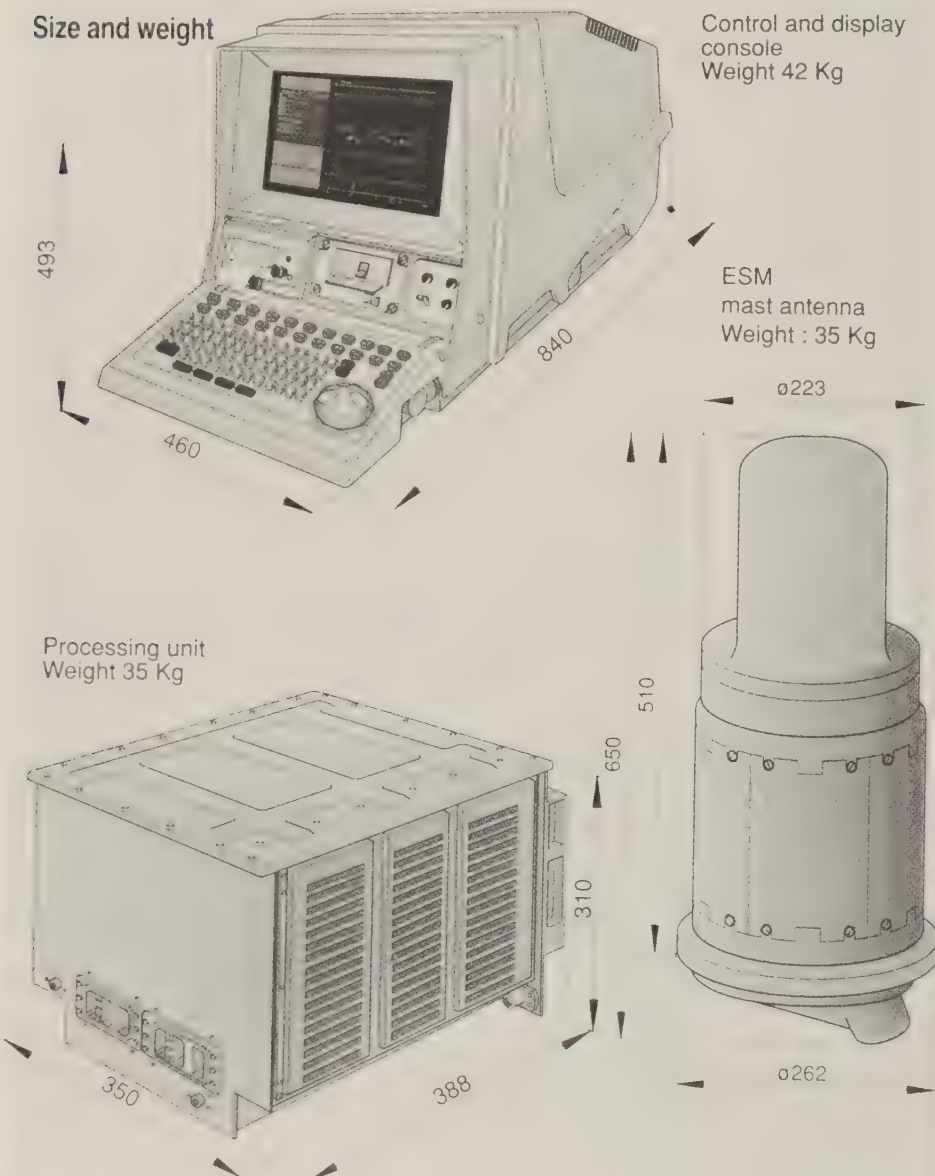
Thomson-CSF's project for a new jammer integrates DR 3000 with the Janet jammer; BI presumably stands for *Brouilleur Integrale*. There may also be a phased-array jammer element to deal with shorter-range threats with high angular rates. DBI 3000 competes with Salamandre for future export orders.

◆ DR 3000

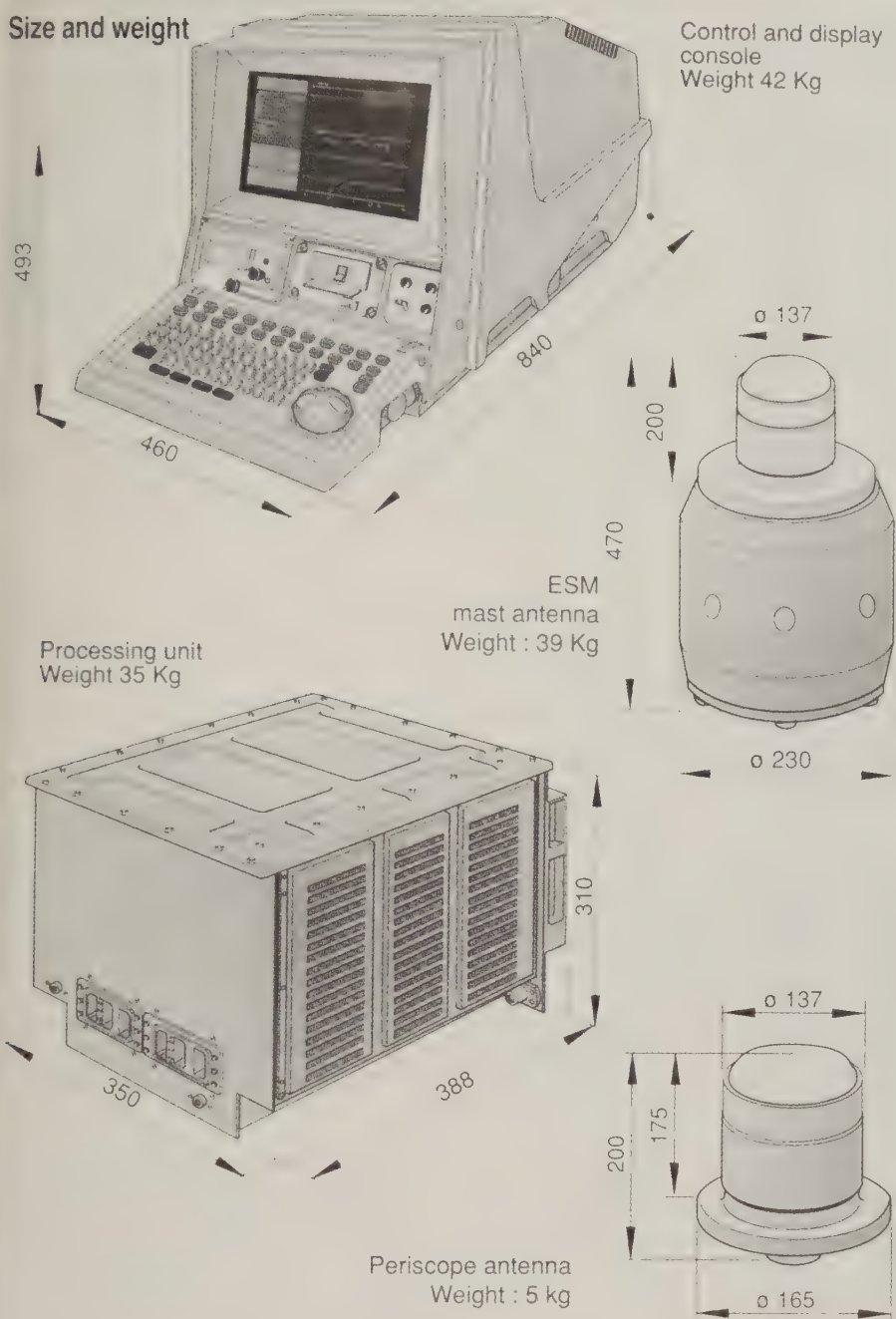
This system is under development (1988) and should be available in 1990–91. About half the weight of DR 2000U, DR 3000 covers the D–K-bands, with an accuracy much better than 6 deg. The antenna is the new lightweight type introduced in DR 2000U Mk 2.

There are 3 variants: DR 3000A (maritime aircraft), DR 3000S (surface ships), and DR 3000U (submarines). This system has been sold to the French navy, but the application has not yet been revealed and, therefore, the designation has not yet been released. It has also been exported. The surface-ship and submarine versions use masthead antennas with omnidirectional

DR 3000S components. (Thomson-CSF)



Size and weight



DR 3000U components. (Thomson-CSF)

elements above a series of monopulse directional antennas. The submarine version also has a separate periscope warning antenna. The maritime-patrol version uses 6 DF antennas plus an IFM antenna. All share a common processing unit (35 kg) and a common desktop console (42 kg) using a keyboard and a trackball. No specific data have appeared.

Compared to DR 4000, DR 3000 uses new technology to achieve higher sensitivity (with a low-noise amplifier in its antenna) and better instantaneous DF accuracy (better than 1 deg monopulse accuracy for targeting, with better accuracy available as an option). The proprietary IFM is fast enough to measure frequency within a pulse or on a subpulse basis, accurate to within a few MHz. An ASIC-based window processor is used to compare received pulses with those already identified and tracked; up to 256 series of pulses can be handled in this way. The use of the comparator reduces system identification workload and, thus, makes it easier for the system to acquire new signals rapidly while operating in a very dense pulse en-

vironment (over a million pulses/sec). An expert system approach is used for pulse identification.

◆ DR 3012 (Arial)

This broad-band omnidirectional radar receiver for surface ships and submarines is made by Thomson-CSF. DR 3012 normally operates with an Arial 15 analyzer, intended for small ships operating briefly in low-threat environments. The system's memory is manually programmed with about 15 radar modes.

◆ ELISA

The latest Thomson-CSF ESM/ELINT system can also work with DR 4000. ELISA is an acronym for ELINT, Search and Analysis. ELISA covers the C-J-bands (500-MHz instantaneous bandwidth) and is considered sensitive enough to detect a radar's sidelobes or diffused lobes. Signals may be designated to this system by a DR 4000 operator; ELISA carries out detailed analysis using superheterodyne techniques. Search parameters, including those of friendly radars (which are to be locked out), can be programmed in. The plasma display shows a series of histograms (DF, amplitude for scan rate, pulse width, and PRI); the operator positions markers in each histogram to read out

the measured radar parameters, which are displayed below the 4 histograms.

♦ Janet

Thomson-CSF's shipboard I/J-band jammer is usually associated with DR 4000. Janet provides both noise and deception jamming, either in sequence or simultaneously. Each jammer is computer-controlled for automatic response and for choice of tactics; the computer can store received signals to recreate them for deception jamming. A full Janet is built up of up to 4 modules, each incorporating an IFM receiver and a 2-horn antenna for signal acquisition and for monopulse signal tracking (azimuth and frequency, not elevation).

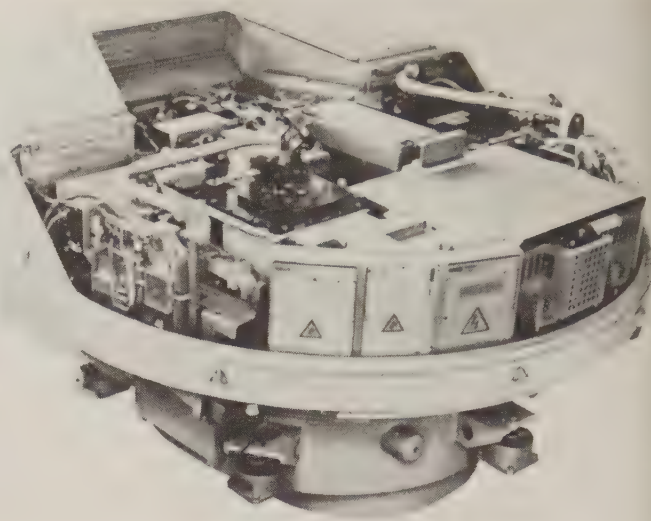
Each module contains 2 TWTs, 1 for noise and 1 for deception jamming. Thus it can jam 2 threats (from different directions) simultaneously. The associated receiver provides accurate bearing and frequency measurement after the system has been alerted by an RWR. Reception is sufficiently insulated from jamming transmissions so that the system can receive the signals it is attacking while jamming; there is no look-through pause in the jamming. Thus, Janet can deal with frequency-agile radars, which can defeat the usual jam/see-through systems.

Jamming modes include noise, pulsed noise, self-masking, various forms of deception, and blip-enhancement.

Each module is 1000 mm (diameter) × 270 mm and weighs 250 kg.

Janet is part of the electronics suite of the Saudi *Al Madinah*-class frigates. The first Janet was delivered in 1985.

Thomson-CSF is working on an upgraded Janet, on the theory that it would be more affordable than ARBB 32 or SLQ-32; the



Janet. (Thomson-CSF)

company feels that it may yet be adopted for the new frigates. Its argument is a combination of relatively low cost and high ERP (compared to any phased array). The company also argues that because the basic Janet already exists an upgrade will be relatively quick and inexpensive.

♦ NEWSY/NADS

NEWSY, the Naval Electronic Warfare System, is intended for the C70AA class and the carrier *Charles de Gaulle*. NEWSY uses a dedicated computer that monitors an ARBB 17 ESM system (D-J-bands) and operates an ARBB 33 jammer and chaff/IR decoy launchers (DAGAIE and SAGAIE).

NADS is the export version of NEWSY.

♦ Salamandre

Dassault Electronique's series of modular integrated EW systems is based on its experience with systems such as ARBB 33. Salamandre consists of a receiver (a pair of half-pie-shaped radomes clamped around the ship's masthead), up to 3 phased-array transmitters in cylindrical radomes (generally arranged around a ship's mast), and separate processors and control/display consoles. There are 4 versions: (V)1 is ESM only, (V)2 provides 1 jammer canister (providing 360-deg coverage by a combination of electronic and mechanical steering), (V)3 provides 3 canisters (instantaneous 360-deg coverage), and (V)B is a jammer only. (V)1 and (V)2 are suitable for ships of under 1500 tons; (V)2 is considered insufficient for a ship displacing 3000 tons or more. Total weight of the (V)3 version is 800 kg.

The ESM subsystem uses wide-band phase interferometry for precise (within 1-deg RMS) direction finding and threat tracking in the E- through J-bands (C- and D-bands are available as options). Sensitivity is better than 55 dBm. The manufacturer claims that its form of interferometry is inherently much more precise than the more usual reliance on amplitude comparison. It argues that azimuth is the only stable parameter of a modern threat (particularly a missile homing on a ship); radar parameters are easy to vary from pulse to pulse. The company also argues that, the better the direction-finding accuracy, the easier it is to deinterleave pulse trains and thus to identify an incoming signal. Signal frequency, pulse width, and pulse repetition interval are measured and compared with a library of more than 2000 radar modes. Salamandre uses an array of TWTs for jamming. Because it has multiple jamming transmitters, it can achieve high radiated power against 1 target (by combining several transmitters), but it can also switch rapidly in azimuth and in frequency, and it can overcome the failure of any single TWT.

Salamandre can handle up to 8 threats (depending on scenario) in the H-J-band, reacting in less than 5 sec. The main jamming modes are continuous and pulsed noise, cover-pulse jamming



Janet jammer on the foremast of a Saudi *Al Madinah*-class frigate (the 2 round radomes on the left, one above the other). The wire arrays near the masthead are for a Telegon VI HF/DF. The collars below them are a pair of standard French navy mast UFH antennas (AN 192). The big rounded radomes conceal Otomat control antennas. The radar visible is Sea Tiger. The DAGAIE decoy launcher (without its "suitcases") is on the platform below the top of the superstructure. (Thomson-CSF)

(masking), synchronous and asynchronous false echoes, range-gate pull-off, and dual mode.

Salamandre is to be installed on board the new *La Fayette*-class frigates.

◆ SAPIENS

SAPIENS is Thomson-CSF/CSEE's surveillance alarm and protection, intelligence EW naval system. There are 3 versions. SAPIENS 1, for small craft, uses Dalia and a 1000-emitter library, DR 2000 receiver, and DAGAIE launcher. SAPIENS 2 uses DR 4000S with IFM and can detect low-frequency radars. SAPIENS 3 has a noise and deception jammer.

◆ Shiploc

Shiploc is a small-ship version of the Thomson-CSF Sherlock (TMV 011) airborne radar detector. Reported resolution: 22 deg, 130 dB. Typical displays are LED (to show up to 4 threats) and a small-diameter synthetic-video CRT (marked out in 30-deg sectors). The LED display shows threat bearing, approximate course, and priority; it assigns a letter or number to indicate the type of threat. Shiploc competes with the British Matilda. No sales have been reported to date, but the system is still being marketed.

◆ TMV 026

TMV 026 is for fast patrol boats, to interface with the Vega FCS as well as with Signaal's FCS. Connected with the DR 2000 and Dalia 500, TMV 026 provides coverage of the E-G-bands.

◆ TMV 430

This ESM suite was designed for fast patrol boats but is adaptable to submarines and to larger surface ships. It comprises a DR 2000 broad-band receiver, an analysis/identification/warning receiver such as the Thomson-CSF's Dalia 500 or DR 3012, a noise/deception jammer (such as Alligator 5), and a printer.

◆ TRC 243/298

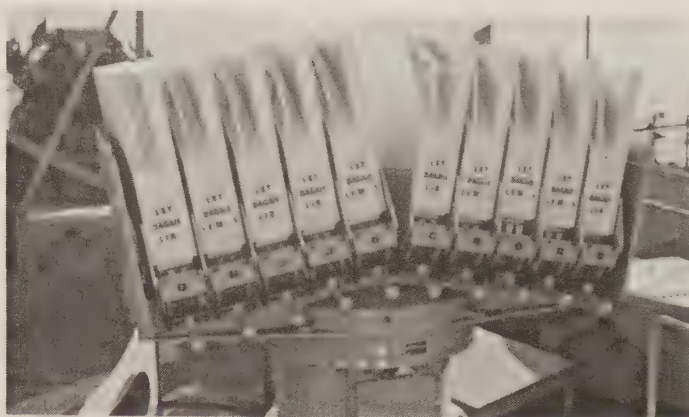
Thomson-CSF offers naval COMINT workstations using the company's standard land-based modules (TRC 243 for HF, TRC 298 for VHF/UHF). TRC 298 uses an ultra-fast frequency synthesizer, controlled by 2 processors. It can handle 1-100 frequencies and scans 1-10 sub-bands, masking known frequencies to contain its workload.

EXPENDABLES

◆ DAGAIE

This short-range decoy system stands alone on small warships and complements SAGAIE on board French destroyers and larger ships. DAGAIE is sometimes marketed as Squid. The trainable launcher carries 10 suitcase-type charges, each 24 × 31 × 5 in (up to 110 lb). In small ships, 1 launcher is mounted on the centerline; larger ships have 2 launchers. Each suitcase in turn contains either IR or radar decoys fired by mortar, the IR decoys reaching various altitudes and then descending in sequence by parachute to prolong their individual and net effect. Given a warning signal, calculation time is less than 0.2 sec, and each launcher slews at 1.2 rad/sec.

The manufacturer, CSEE, credits the system with the capability to deal with up to 5 incoming missiles in less than 10 sec (i.e., 1 IR and 1 radar suitcase per missile). A suitcase contains 33 predirected mortars (34 for IR). For IR, there are 10 initial-action and 24 continued-action charges. The initial-action charges operate very close to the ship and break up IR tracking. The delayed-action charges extend the net operating life of the decoy and ensure that the chaff cloud is colocated with an IR source. Alternative suitcases "A" and "B" can be used to deploy clouds at different altitudes, maximum altitudes being 150 and 300 ft, respectively. Combining both types gives a very large cloud, with a radar cross section of up to 24,000 yd². A special suitcase (Type D) provides a smaller cloud (3600 yd²) for small vessels.



DAGAIE launcher. (Compagnie de Signaux et d'Entreprises Électriques)

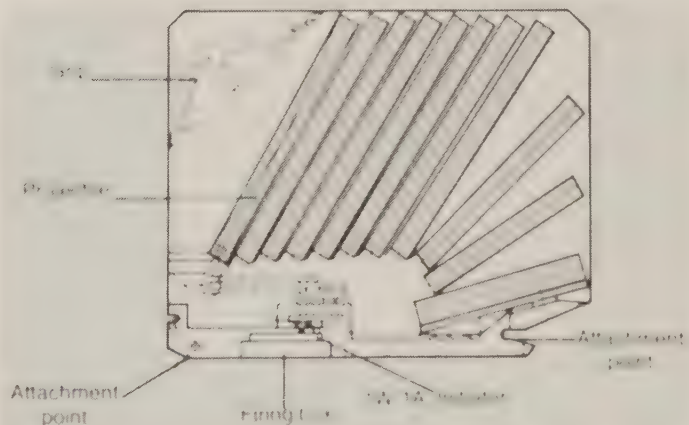
The radar decoy's bloom time is less than 2 sec, 132 blooming points being distributed per suitcase, to form a radar reflector over 5500 yd² in area, covering H- through J-bands and lasting longer than 10 min. The IR decoy's duration is 30 sec, the emitting surface having an area of 360 yd² at an altitude of 45 ft. Individual decoys hit the water at 1-sec intervals, after having drifted with the wind.

There is also a 6-suitcase version (990 lb rather than 1100 lb for the 10-suitcase launcher).

The system provides recommended helm orders for evasion based on the expected decoy disposition.

In large warships (frigates and above), DAGAIE is generally used in conjunction with SAGAIE, providing close-range back-up. DAGAIE was developed to meet a 1974 French navy requirement for antimissile self-defense for ships; DAGAIE had to be able to cope with attacks distributed around the horizon and had to be quick acting (reaction time about 5 sec).

The large-ship DAGAIE launcher is designated AMBL-1B.



The DAGAIE "suitcase."

A new version, DAGAIE Mk 2, was announced in 1986. It has a more powerful computer and digital/analog, rather than pure analog, interfaces. Mk 2 can, therefore, be integrated with a computer-based combat information system such as SENIT or NTDS. Mk 2 is also designed to fire new chaff and IR rounds requiring more complicated software, such as dilution decoys. A new medium-range REM rocket can be carried in a standard-sized suitcase (4 per suitcase), fired individually. Each round has a radar cross section of about 1000 m² and deploys 800 m from the launcher. The basic DAGAIE launcher can still carry the earlier types of suitcase; the new rounds replace 1, 2, or 3 modules in the middle of the mount.

◆ LAD

Leurre Actif Decale, or launched active decoy, was the subject of a 1986 competition between Thomson-CSF and ESD. LAD is to be fired from both DAGAIE and SAGAIE launchers, and maximum dimensions are 127 mm × 1.76 m (weight 27 kg). LAD will be launched and deployed in 8 sec and should operate for 60 sec. The dimensions make it compatible with the U.S. Mk 36 SRBOC launcher. In 1988 LAD was described as a centroid decoy, carrying a mini-TWT wide-band transmitter (10 kW, 40-sec operation). ESD reportedly prefers deception (presumably by means of a repeater); Thomson-CSF, a noise jammer (which is simpler to implement and may overcome pulse coding). As of 1988, there was no official program, and LAD was being referred to as RAD (Remote Active Decoy). Each round was likely to be both complex and expensive, and there was some interest in an RPV-carried (reusable) solution.

◆ MAGAIE

A lighter version of SAGAIE, MAGAIE carries only 3 suitcases. There is only 1 type of ammunition (chaff/IR combined); as in DAGAIE, the mortars are trainable but are fixed in elevation. Operation is fully automatic, based on an attack alarm from an ESM detector, a search radar, or an optical director. The threat sensor provides bearing, and the ship also provides relative wind direction and velocity and ship's heading and speed. Once the decoys have been fired, the system provides recommended helm orders for evasion (favorable course, emergency maneuver, recommended course). Average reaction time is 5 sec.

The 400-kg launcher slews at 1.2 rad/sec, with a working circle of 400 mm. Each ammunition suitcase weighs 65 kg (630 × 785 × 135 mm).

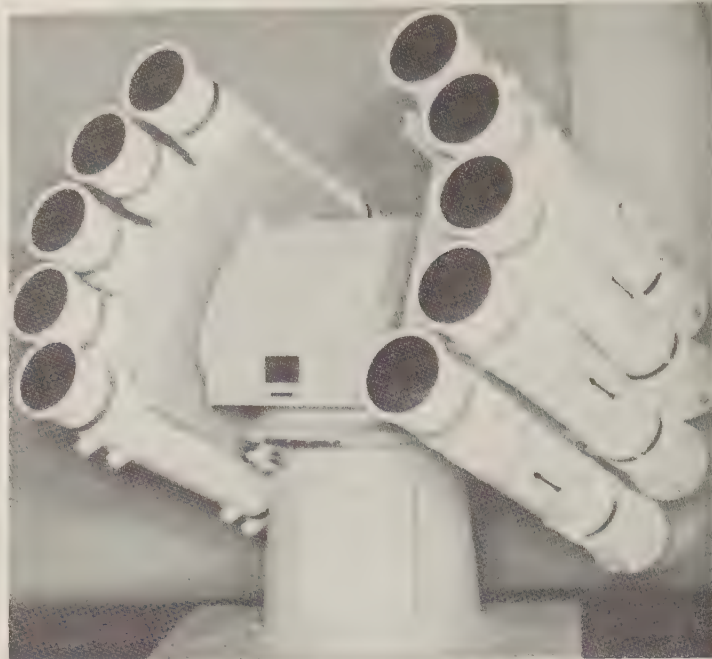
The name means antimissile self-defense decoy mini-system (*Mini-dispositif d'Autodéfense pour la Guerre Antimissile Infra-rouge et Électromagnétique*).

◆ REM

This new medium-range chaff round was introduced in 1988; as of early 1988, the French navy had not yet decided whether to adopt this chaff. REM can be launched to 250, 500, or 750 m (altitude 50 m) in less than 5 sec, providing a radar cross section of 1200 m² (H-J-bands) for about 2 min.

◆ SAGAIE

SAGAIE is a long-range radar and IR decoy system (*Système d'Autodéfense pour la Guerre Infra-rouge et Électromagnétique*). It is intended to deal with missiles approaching around the entire horizon, confusing the enemy's targeting radars at long range and, in combination with DAGAIE, confusing missile seekers. A typical installation consists of two 10-tube trainable and elevatable launchers (1 on each side), fired from CIC. Each 40-kg rocket carries a 24-kg payload and flies at 250 m/sec (average). The chaff (EM) version fires projectiles radially, to create a large chaff cloud. The subprojectiles of the IR version contain parachutes that lower them in sequence, to prolong the effective life of the IR decoy. Each rocket is fired from its shipping container (330 × 1800 mm, 30 kg containing a 170 × 1740 mm, 40-kg rocket); the entire launcher weighs 1900 kg (empty) and has a working radius of 1.6 m. Range is 8 km for chaff or 3 km for chaff/IR decoys.



SAGAIE. (Compagnie de Signaux et d'Entreprises Électriques)

Used alone, the decoys provide confusion and distraction. With a jammer, they can dilute an attack and cause missiles to home on a false target after the real target has been concealed or after the missile has been distracted by gate-stealing.

SAGAIE will be mounted on board French frigates, destroyers, and aircraft carriers. It will also be installed on board the new Italian *Animoso*-class missile destroyers. In French service, this system is replacing the modified British 8-barrel Knebworth-Corvus system (Syllex). The prototype was tested on board the trials ship *Île d'Oléron* early in 1986, and the first production installation was on board the destroyer *Cassard* (the second was the carrier *Foch*).

Work is proceeding on a future single system to replace both DAGAIE Mk 2 and SAGAIE. Late in 1989 the Italian navy became the first SAGAIE export customer (for the *Animoso* class).

GERMANY (WEST)

ELECTRONICS

◆ DFS 800 SM

This AEG periscope direction-finder was begun in 1987 and announced in the fall of 1989. It is currently (1989) in prototype form. Frequency coverage is 2–18 GHz, extendable to 40 GHz. It consists of an omnidirectional IFM aerial surmounting a monopulse direction-finder, which consists of 4 antennas; it also has an integrated GPS channel. Dimensions: 150 mm diameter × 220 mm.

◆ ES400

Telefunken's automatic signal collection-and-analysis suite covers 0.5–18 GHz (with optional extension to 40 GHz). Radar signals are acquired and analyzed, and their parameters are stored. ES400A is an electronic-intelligence version using a high-gain directional antenna feeding a superheterodyne receiver and an IFM receiver (with its own omni antenna). The tactical version uses an interferometer (monopulse) antenna, compressive receiver, and pulse analyzer. It employs a signal mode library for signal identification. Threats are automatically listed in priority order. The system is software controlled.

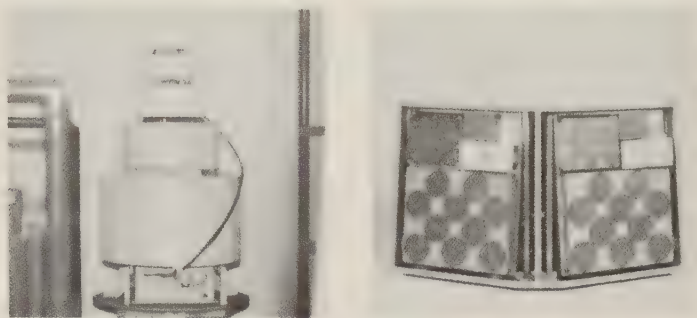
◆ FL1800S/FL400/FL1800B/FL1800U/FL1800H

FL1800 is the AEG system in German Type 122 frigates and the replacement for the U.S. WLR-6 in the German missile destroyer upgrade of 1986. FL1800 is also fitted in Type 143A missile patrol boats.

FL1800S covers 7.5–17 GHz. This system is designed to engage a large number of close-in emitters automatically, e.g., a short-range missile attack in the North Sea or in the Baltic. A very high processing rate is achieved by preprocessing before signals are entered into the main computer.

In a Type 122 frigate, the D/F array is mounted at the head of the lattice mast amidships, the omnidirectional antenna (for frequency and other signal characteristics) on a pole atop the bridge. The omnidirectional antenna consists of 5 antennas (for 5 bands) stacked vertically. Each DF array consists of a series of planar antennas mounted on a common base, again to cover 5 bands. The associated quartet of jammers is mounted on a frame at the base of the housing under the Signaal WM25 radome, on the foremast.

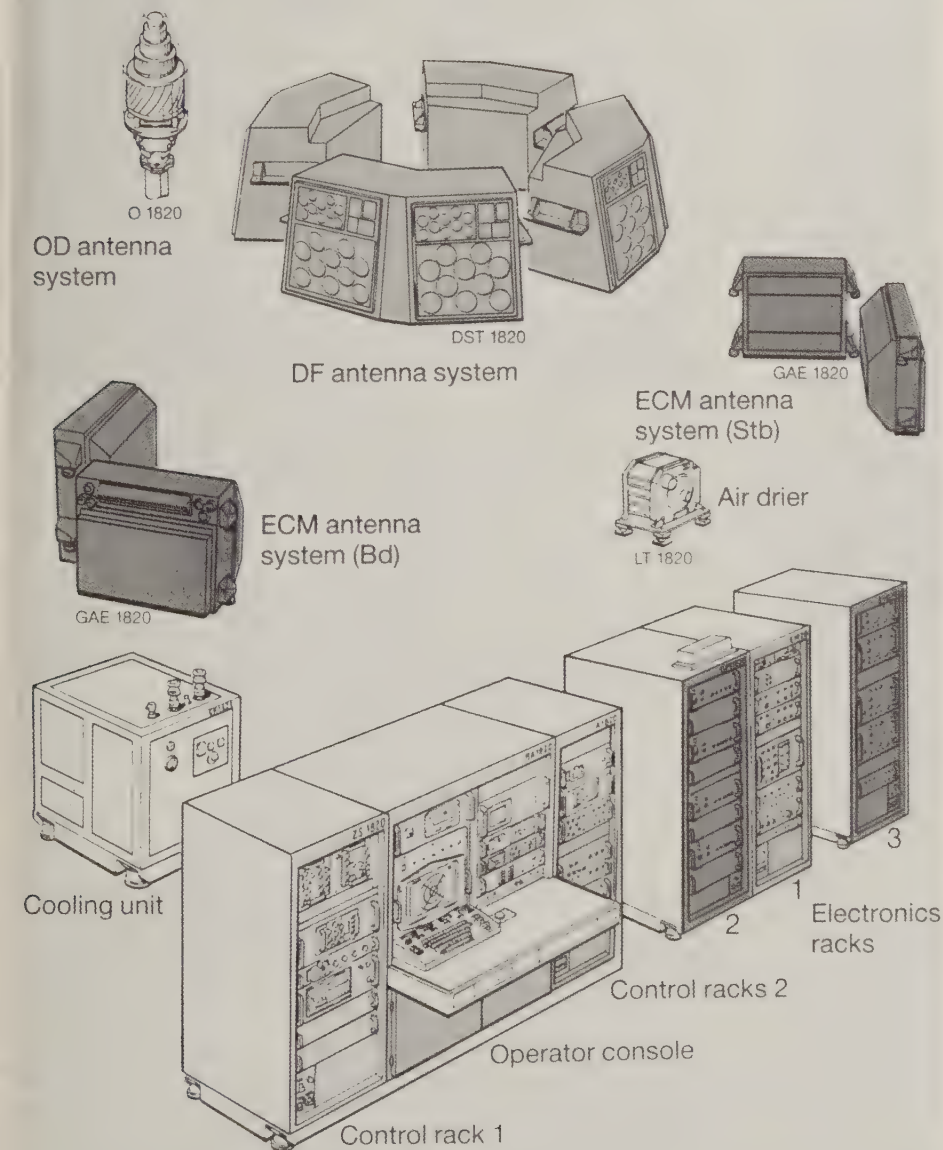
The FL1800S system now standard in the German navy is to be upgraded to FL1800S Step II standard. The existing omnidirectional and DF antennas are modified, and a Racal SADIE parallel processor is introduced to handle the expected very high data rates. For ECM, there are a new tracking processor (to achieve almost pulse-synchronous jamming) and a new switching matrix (to deal with multiple threats). Step II employs 8



The omnidirectional (left) and directional (right) ESM antennas of the German FL1800S system. The omni antenna shows a separate cylindrical element for each of its 5 bands. (AEG)

TWTs facing in different directions, rather than the more common technique of time-sharing a single signal generator. TWTs not needed to jam in their directions can be switched to the threat directions. Displays are also being modified to provide a

Elements of the German FL1800S system. The OD (omnidirectional) antenna feeds an IFM. (AEG)





FL1800S on board a German fast patrol boat. The DF antennas are below the Signaal "egg" radome, and the jamming antennas are above the sides of the bridge. (AEG)

clearer color picture. Finally, the German navy requires some indication of threat range, the ESM system being used to trigger RAM defensive missiles. Step II estimates range using the amplitude of the received signal.

Step II is the basis of a modular family of systems for small patrol craft, submarines, and maritime-patrol aircraft. FL1800S (*Schiffe*) is the frigate or large-ship version. FL1800B (*Boote*) is the fast-patrol-boat version; FL1800U is the submarine version; FL1800H is the maritime-patrol-aircraft or helicopter version.

For compactness, AEG combined omnidirectional and DF antennas into a single biconical antenna. FL1800 is a modular system, so different elements can be updated separately. Alternative antennas include a directional dish as well as the IFMs and monopulse DF arrays. There are also special submarine masthead antennas (dome plus 4 small domes pointed horizon-



FL1800S on board the German frigate *Karlsruhe*, 1990. The omni antenna (for IFM) is carried between the STIR antenna and the Signaal "egg," and the usual pair of jammers is visible just above the bridge windows. The DF array is in the masthead radome. (G. Arra via *Ships of the World*)

tally) and an airborne version (pairs of cavity-backed spirals for 2 frequency ranges). Modifiable function blocks (such as classification, emitter-data bank, display and symbolism, and interface control between the ECM component and the central computer) are implemented in flexible software modules run on standard microprocessors. The microprocessors can be fitted into standard VME-bus computers.

FL1800B uses a combination omni and DF sensor stack (4 nested omni antennas, with monopulse DF antennas around the base, or 2 spiral omni sensors with monopulse DF antennas between and below them). The lighter-weight DF sensor is designated DFS 800B. The simplest associated jammer is a rotating high-gain antenna fed by a TWT. A heavier installation uses a stabilized high-gain directional ECM antenna that occupies a small radome forward of the WM20-series radome. It is fed by 6 or 8 TWTs. This system is designated GAS 800B. The system as a whole can be equipped with 1 or 2 color displays. The submarine version, FL1800U, can use 1 of 2 antennas, a masthead array of an omni and 4 DF sensors (DFS 800 SM), and a periscope head (USK 218) carrying radar, ESM, SatNav, and other communications antennas. FL1800U uses a special "snapshot" technique, scanning the spectrum within a few seconds to generate visual and aural warnings and, thus, avoiding undue exposure.

FL1800H can operate as a cockpit warning system, or it can support a 2-display, color, analysis console. A highly directional DF sensor (presumably a trainable high-gain dish) can be added for ASW and maritime surveillance. The system is built around a data bus, and it can, therefore, accommodate other sensors such as laser, IR, and missile-approach warners. The typical array consists of 6 pairs of cavity-backed spirals, each consisting of 1 large spiral and 1 small (half the diameter of the large 1).

◆ Octopus

For details of Octopus, a new patrol boat system, see the United Kingdom section below (Racal is the main contractor).

FL400 is a smaller derivative of FL1800, for export. There are 3 modules: FL400A, for ELINT; FL400U, for ESM; and the FL400G jammer. Normally FL400U drives FL400G. These systems were all designed for small patrol boats, but they have also been offered for ground use.

FL400A uses an enclosed masthead radome containing 3 omnidirectional antennas over a rotating high-gain reflector for direction finding. The fixed antennas feed an IFM. The frequency range is 0.5–18 GHz, with an optional extension to 40 GHz (higher frequencies are down-converted into the standard range for analysis). FL400U covers the same frequency range, and it is not clear to what extent the FL400U antenna differs from that of FL400A; FL400G is a 20–60 kW noise and deception jammer (7.5–17.5 GHz).

◆ ASDF

AEG's Advanced Shipborne Direction-Finder was introduced in 1985 to achieve high bearing accuracy (particularly in HF) by suppressing reradiating fields to eliminate ambiguities almost completely. Special wide-band antennas, with nulls at various bearings, can help eliminate receding targets. The A1288 antenna consists of a crossed-loop unit plus a parallel-loop unit to create nulls directed at the presumed locations of fields reradiated by the ship. The processor is designated PST1288.



ASDF antenna. (AEG)

◆ PST 1720

AEG's communications intercept and direction-finding system was adopted for the ANZAC frigate. It covers the 10–500-MHz band. The associated PSI 1720 is an interferometric direction finder.

◆ Telegon/ASDF

Telefunken's HF/DF systems (TELEfunken GONiometers) break down into 2 series: odd numbers denote single-channel receivers, even numbers Watson-Watt 3-channel receivers. Most or all naval versions are Watson-Watt HF/DFs. The single-channel receivers are classical goniometers sampling different directions in sequence. Because they must tune only a single channel to a new frequency, they can rapidly scan through a

wide frequency range (330 MHz/sec in the current Telegon 11) to deal with frequency hoppers. On the other hand, because the Watson-Watt continuously monitors all directions (its channels are north-south, east-west, and omni for sensing), it can detect very short signals.

The advantage of the single-channel system is that it can scan over frequency much faster than a Watson-Watt, all of whose channels must be tuned in parallel, and all of whose channels must have their gains (in amplitude and phase) set together to match signal amplitude. The classical calibration technique is sequential sampling of the 2 DF channels, but it is too slow to deal with very short signals, as in burst or pulsed communication. Telefunken developed its own parallel calibration method for this purpose. The system generates a calibration signal so that it can automatically recognize that channel calibration is needed, in which case a microprocessor compensates for amplitude and phase differences between the channels and adjusts the gain control.

It seems likely that the Watson-Watt technique was well suited to short transmissions but that the single-channel technique was required to deal with very fast frequency hoppers. Its antenna can be electronically scanned quickly enough to detect most short signals. Typically each antenna of the Telegon 11 has its own electronic goniometer.

Telegon 11 reduces the performance difference between the 2 types by scanning electronically in direction.

Of the Watson-Watt series, Telegon 4 was adopted by the French and Italian navies as well as by some lesser navies. It is carried at the mastheads of the cruiser *Colbert* and the frigates of the *Georges Leygues* and *Tourville* classes. The basic antenna is a flattened egg-shaped radome with whips radiating at angles to it. In Italian ships (the cruisers, the *Audace*-class missile destroyers, the *Lupo*-class frigates, and the *Pietro de Cristofaro*-class corvettes) the egg-shaped radome was often later enclosed in a circular cage, which in turn supports 4 vertical UHF dipoles (an Adcock) and a central sensing dipole. See the illustration of the Egyptian *Ramadan*-class missile patrol boat under the British Cutlass system. The British CXA is a Telegon adapted to submarines.

Telegon 4 dates from about the mid-1960s. It used only the egg-shaped ferrite antenna, which is limited to intercepting ground waves. Telegon 6 was a modular version specifically for the German armed forces and is probably carried on board the current German frigates. It was exported to Saudi Arabia for the *Al Madinah* class. Subsequent Telegons have also been modular in design, and at least some share their receivers with ship communications.

Telegon 8 (PGS 1521) is a current digital system that uses the ferrite egg (antenna AK 1200) to cover 10 kHz–30 MHz. It is tuned either by hand or by keypad and achieves a resolution of 10 Hz (frequency accuracy better than 0.3 parts in 1 million). Output is typically on a CRT display driven by the 3 channels. Typically, a bearing will be accurate to within 1 deg. Telegon 8 can adjust to a 60-dB jump in signal level in less than 10 msec. To compensate for quadrantal errors (frequency-dependent errors caused by reradiation from the metal parts of a ship), Telegon 8 divides its signals into 56 subranges, for each of which it makes the necessary corrections. The system can accommodate 2 different arrays, switching between them. Bandwidths are 0.1, 0.3, 0.6, 1.5, 3, 6, and 10 kHz. Memory capacity is 30 frequencies. Telegon 8 introduced the automatic channel-calibration technique. Development began in 1979, and series production began in 1981–82.

Telegon 10 (PGS 1720) uses additional antennas to cover the range 10 kHz–1000 MHz. There are 3 sections: 0.01–30 MHz, 20–500 MHz, and 480–1000 MHz. Not all are always present, e.g., there is a shipboard system for 20–500 MHz. The full system uses the AK 1200 egg plus 2 sets each of 4 vertical dipoles: A 1269U (UHF) and A 1265V (VHF). Typical large-ship installations are probably limited to VHF. Telegon 10 incorporates 100 memory channels for DF frequency settings. Frequency can be reset, accurate to within 10 Hz, in 1 msec.

Of the single-channel series, Telegon 3 and 5 date from the 1950s, and none is likely to have survived. Telegon 7 covers 20–1000 MHz HF/DF. The associated receiver is E1900, which is also used for communications. Telegon 9 covers 20–500 MHz (extendable to 1000 MHz). Telegon 9 could operate with Telegon 8 to cover the full range 10 kHz–1000 MHz. Telegon 11 (PGS 1655) is the most recent member of the family. The display is either synthetic video of a histogram of signal strength vs. bearing or a conventional directional display with adjacent digital readout. The tuner can scan in wide band at as much as 330 MHz/sec. DF time can be 50, 100, 200, or 800 msec.

Telegon 11 uses characteristic square loop antennas instead of the dipoles and egg of earlier versions. It can also use the standard antennas of the earlier Watson-Watt systems.

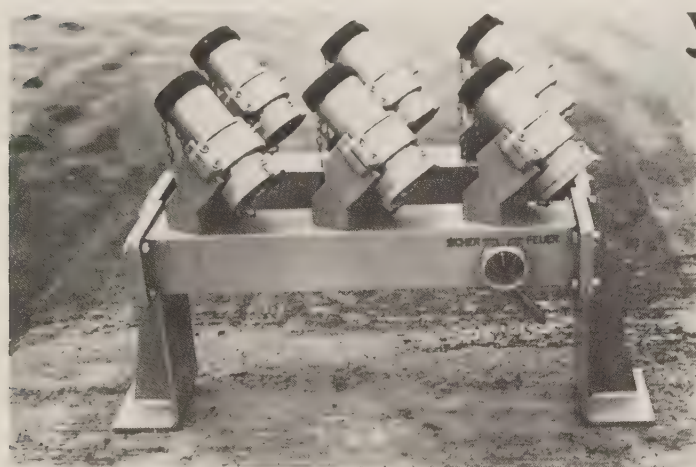
The associated V/UHF receiver is E1900/3.

ASDF (PST 1288), the Advanced Shipborne Direction Finder, is a related system introduced in 1985, achieving high bearing accuracy by suppressing reradiating fields to eliminate ambiguities almost completely. This approach is an alternative to the table look-up compensation used by Telegon 8, which cannot deal with very ambiguous signals. Reradiation from a ship's hull and superstructure can be extremely distorting over the HF band (1.5–5 MHz; masts and other antennas dominate the range 4–20 MHz). ASDF adopts a special antenna, A1288, consisting of a crossed-loop unit plus a parallel-loop unit to create nulls directed at the presumed locations of fields reradiated by the ship. Telefunken claims that this approach improves accuracy by at least half an order of magnitude. ASDF was designed so that it could be added to the Telegon 8 receiver, producing on-line correction data that can be fed into the conventional HF/DF system.

EXPENDABLES

◆ Hot Dog/Silver Dog

The 76-mm IR (Hot Dog) and chaff (Silver Dog) grenade decoys are made by Buck-Wegmann. Payloads: 0.9 lb for Hot Dog, 1 lb for Silver Dog. Silver Dog blooms in about 2 sec. The 12 launchers (in 4 groups of 3) are set at 45-deg elevation and 30-deg train.



Hot Dog/Silver Dog decoy launchers. (Wegmann)

◆ Schalmey

AEG-Telefunken's radar (G–K-band)/IR (medium-range) decoys are fired by a trainable launcher, typically 1 each port and starboard, each holding two 10-tube GRP magazines of chaff or IR rockets. Each magazine can be elevated independently between +13 and +63 deg, and the entire mounting is trainable (in 5-deg steps from 0 to 110 deg relative to the ship's centerline). The 70 × 560-mm (2.5-kg) rockets are launched either singly or in salvos of 2 or 3 at 60-msec intervals. There is also an 800-

mm decoy rocket with twice the chaff payload. Reloading is by replacement of a magazine (570 × 587 × 230 mm, 40 kg).

This system has a low magnetic signature and is, therefore, suitable for MCM craft.

HUNGARY

The Hungarian defense electronics industry provided ESM equipment to the Polish navy (Soviet prices were reportedly too high). This equipment is now being marketed. The descriptions below are from brochures distributed at the Bangkok Asian Defence Services Exhibition and Conference in December 1990. This equipment is exported by the Technika Foreign Trading Co. of Budapest; the manufacturers include the Mechanical Laboratory for Telecommunication Engineering and the Electronic Directorate (for DAMA, below). The latter specializes in the design of EW systems; the Mechanical Laboratory makes ELINT and DF equipment.

◆ IU-60

This VHF DF uses 4 vertical, rectangular-loop antennas arranged around a central mast, as in some versions of Telegon. It is an 8-antenna, electronically rotated Adcock, covering the 20–100-MHz range (receiving bandwidth is 15, 30, or 200 kHz; frequency resolution is 1 kHz). The goniometer frequency is 54.25 Hz, and average accuracy is better than 1.5 deg. Measurement time is at least 0.4 sec, and angular resolution is 0.5 deg. The antenna weighs about 19 kg. Antenna dipole height is 1.8 m (base 1 m).

◆ VREV-T/VREV-P

VREV-T is a general-purpose VHF receiver for ESM/COMINT. It can search the spectrum in 100-Hz steps (knob-controlled), or it can search automatically between 2 preset limits with variable frequency steps, or it can scan (continuously check stations in its scan memory; setting and dwell time per channel is about 30 msec). In scan mode the search can be stopped for a set period so that the operator can listen to the emissions of that station and determine its main characteristics. VREV-T incorporates a nonvolatile memory storing 100 prohibited frequencies and 100 sets of station data (frequency, operator mode, bandwidth). Minimum channel spacing is 12.5 kHz. Frequency resolution is 100 Hz, and typically it takes 25 msec to change frequency.

VREV-P is a panoramic receiver showing 10 MHz of the full 20–100-MHz band nearly instantaneously on a 9-in CRT, using 3 microprocessors to control the receiver and synthesizer, to sample and digitally prefilter the received signals, and to control the display. The full scanned band is displayed in 5 lines, each signal being represented by a bar graph (12 steps). Alternatively, the CRT can display 21 lines (80 characters/line) of alphanumeric data. Horizontal resolution is 12.5 kHz/mm; bandwidth is 15 kHz. The readout of data on any signal is by cursor.

◆ DAMA

DAMA is a signal analyzer (signal rates of up to 9600 bits/sec) based on an IBM AT-compatible computer with a 720-kbyte floppy disk and a 27-Mbyte hard disk. Its buffer can accept up to 8 kbytes of data, sampling at 5 kbits/sec.

INDIA

In 1986 India announced that its Armament R&D Establishment at Pune had developed a multibarrel medium-range chaff launcher, which either is, or will be, used on board Indian ships.

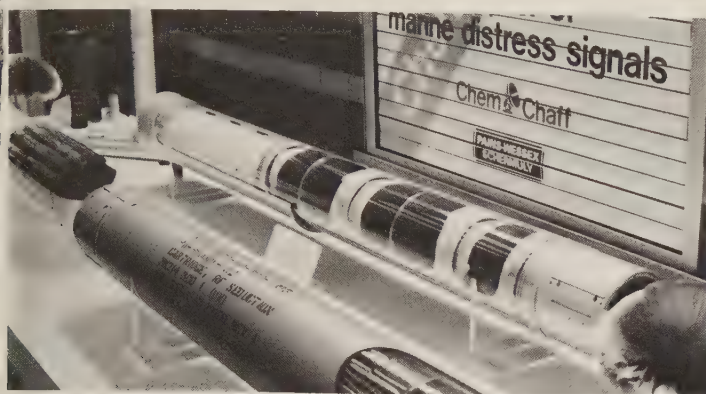
◆ Ajanta

This new Bharat Electronics ESM unit is installed on board the new corvette *Khukri*. It has a 1500-emitter library and is used to trigger two 16-barrel chaff launchers, presumably of the standard Soviet small-ship type. The only photograph of the ship published to date shows an installation similar to that of the Selenia INS-3 of the frigate *Godavari*, but the claimed library size is much larger than that of the older Italian system.

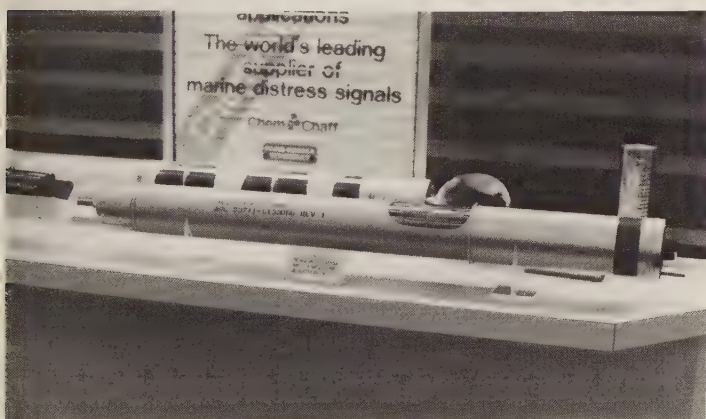
INTERNATIONAL

♦ Sea Gnat

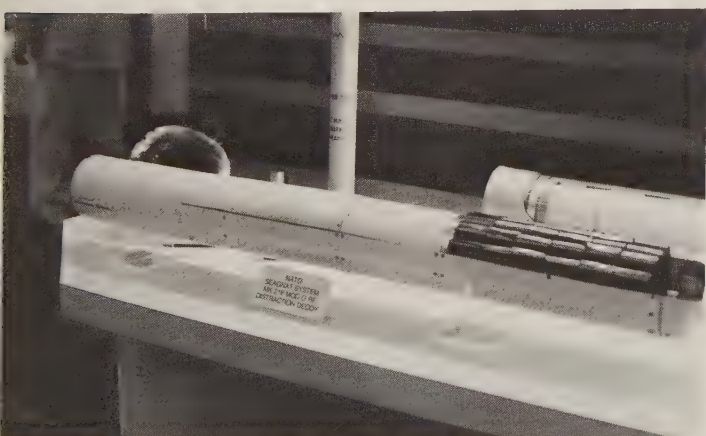
NATO's program for a chaff/IR decoy, Sea Gnat is compatible with the U.S. SRBOC (Mk 36) launcher. The decoy deploys chaff and also a hot gas bag (for IR), the 2 drifting together in the wind. In Britain, the contractors are Hunting Engineering (fire control by Thom-EMI), and the launcher is DLB (to be replaced by DLJ). As fitted to a British Type 22 frigate, Sea Gnat employs either the U.S. Mk 36 or a pair of 8-barreled launchers on each side, all 8 barrels apparently sharing the same elevation, the 2 launchers at 2 different (fixed) bearings.



NATO Sea Gnat cartridges: the IR-seduction cartridge is at the top, and the Mk 214 Mod 1 (UK) chaff cartridge below it. (Author)



The NATO Sea Gnat Mk 214 Mod 1 (UK) chaff-seduction cartridge, cut away to show its load. There are 6 sections of chaff payload, and total decoy cross section is comparable to that of a ship. Mk 214 is mortar-launched. It is 1.2 m long. (Author)



The NATO Sea Gnat Mk 216 Mod 0 chaff-distraction decoy, cut away to show its load. Mk 216 is rocket-propelled and has 3 sections of chaff payload. A drogue chute slows cartridge flight. Mk 216 is 1.4 m long. (Author)

Decoys associated with Sea Gnat include the U.S. Mk 214 seduction cartridge and Mk 216 distraction cartridge. Hycor developed an IR cartridge under this program, M-BIRD (Balloon Infrared Decoy), a balloon that floated on the water. M-BIRD did not enter production. The new Sea Gnat cartridges were scheduled to enter U.S. service during 1989.

This program began in 1973, the NATO MoU being written in October 1976 and signed in January 1977. The NATO program was begun in April 1977, the major cost-plus-fixed-fee contract being awarded in September 1977. Integrated system firing tests followed in August 1978, with at-sea development tests in April 1979. For the Royal Navy, Sea Gnat was approved for production December 1985, with limited production in 1986. Reportedly, the delay between tests and deployment reflects problems with the associated IR decoy. A remotely settable fuze is currently (1989) under development by the U.S. Army Harry Diamond Laboratories.

As of 1989, Sea Gnat was being produced for the Royal Navy, and it was a U.S. Navy program. Germany planned to use it on board Type 123 and Type 124 frigates. No Norwegian or Danish application had been announced.

ISRAEL

ELECTRONIC SYSTEMS

♦ EL-1040

Elta's system is found in Taiwanese (GRC) FRAM-II destroyers.

♦ EL/L-8303

Elta's computerized ESM system is for ship, air, and ground applications. EL/L-8303 intercepts, digitizes, identifies, and records signals in the 2–18-GHz range, with an optional extension to cover 0.5–2 GHz; this system can interface with ECM and chaff systems for manual or automatic operation. Features include direction finding, a combined alphanumeric and graphic (bearing/threat level) display, and a comparison with a built-in emitter library. Accuracy: 5 deg in bearing, 1 MHz in frequency; nominal reaction time is 1 sec. Sensitivity (narrow-band) is -80 dBm, and dynamic range is 60 dB.

♦ EL/L-8310

Elta's ESM receiver is for 0.5–18 GHz (with optional extension to cover 0.06–40 GHz).

♦ EL/L-8312

Elta's computerized ELINT/ESM microwave reception and classification system (computer-controlled autoscans, signal acquisition, and display) covers 0.5–18 GHz (optional extension to 60 MHz–40 GHz range). EL/L-8312 is a monopulse DF system. It has 1 operator. EL/L-8312A is an airborne ELINT/ESM system. This system employs the EL/L-8310 receiver, the EL/L-8320 pulse analyzer, the EL/L-8610 computer, and the EL/L-8570 display.

♦ MN-53

Elbit's passive intercept is used in Israeli navy and South African *Reshevs* and Israeli *Romat*, *Aliyah*, and *Sa'ar-II* and *-III* -class missile patrol boats. Reportedly, the ESM/ECM system was designed by the Italian firm Elettronica and manufactured by Elbit. Radar parameters measured are band, PRF, pulse width, and PRF wobble. Modes: manual/automatic direction finding, manual/automatic analysis (based on PRF, pulse width, PRF jitter), automatic printing and recording of radar parameters (frequency, pulse width, PRF, PRF jitter, time of arrival, direction of arrival). In 1 version, there are 3 separate functional receivers. Elbit claims that MN-53 reflects Israeli experience during the 1973 Yom Kippur War. The NS-9000 is an alternative.

♦ NATACS

The Tadiran (Elisra) naval tactical COMINT and DF system was announced in August 1989; it is a version of a land-based system

that has been in service for some time. The DF antenna is a pair of stacked Adcocks for different frequency bands, each consisting of figure 8-shaped loops instead of single vertical elements. They are supplemented by an omnidirectional COMINT antenna. Both feed into a single main computer (DF data are presumably used to help sort omnidirectional signals).

The typical below-decks installation is a pair of equipment racks, one of them carrying a CRT.

NATACS covers a frequency range of 20–500 MHz, optionally extendable to 2 MHz. DF accuracy is within 2 deg. Frequency resolution is 1 kHz. AM, FM, and CW signals can be analyzed. NATACS scans up to 1000 channels/sec. A minimum of 16 frequency search ranges can be preset, with 200 protected channels and a minimum of 150 preset frequencies. IF bandwidths, which determine the degree of information extractable, are 10, 20, 50, and 100 kHz. The system can accommodate up to 32 receivers and tape recorders.

NATACS is installed on board the Singaporean fast attack boat *Victory*.

◆ NS-9000 Series

These AEL Israel (Elisra) EW systems were announced in 1982. NS-9001 is an automatic ELINT gathering system to map emissions (0.5–18 GHz). The display shows frequency vs. bearing. Direction-finding accuracy: 10 deg in X/Ku-bands, 3 deg in S/C-bands. Frequency measurement: 2-MHz resolution. Sensitivity: 70 dBm (omni), 80 dBm (sector). Modes: instantaneous direction finding (IDF), monopulse direction finding (MDF), and search (SDF).

NS-9002 is a simulation van, which can generate up to 256 emitters (frequency resolution 1 MHz, PRF 125 pps up to 250,000 pps, scan rate 100 Hz TWS to 20-sec search).

NS-9003 is an automatic computer-controlled ESM system. Direction finding is monopulse, and the system incorporates an IFM. NS-9003 can be used to trigger chaff, flare, or ECM responses (typically by NS-9005). Direction-finding accuracy is 1 deg in X/Ku-bands and 3 deg in S/C-bands. This version was originally developed for the hydrofoil *Shimrit*.

NS-9004 is an ESM system for submarines.

NS-9005 is a noise and deception jammer (2–18 GHz) that uses steerable antennas to engage multiple threats simultaneously, using spot, barrage, or swept noise, or RGPO, RGPI, AGPO deception. NS-9005 can also produce false targets.

NS-9007 upgrades existing EW equipment.

NS-9008 is an automatic repair facility.

NS-9009 is a compact version for small patrol boats of up to 200 tons. It uses a wide-open receiver for dense (over 200,000 pps) electronic environments (2–18 GHz). DF accuracy is 8 deg, and sensitivity is 35 dBm. The operator has both a tabular readout and a polar display. Visual and audio alarms are activated when specific threat signals are recognized. This system can control chaff launchers, and it can be upgraded to provide IFM. Measured parameters include direction of arrival, band, signal amplitude, time of arrival. NS-9009 computes launch parameters for chaff launchers. The antenna weighs 15 kg, and the display 30 kg.

A faster version of -9003, NS-9010 uses distributed microprocessors for dense environments (over 250,000 pps). It is used against radars in the 2–18-GHz range. It employs monopulse switching direction finding (instantaneous direction finding is optional). NS-9010 uses a multibeam static-antenna array. Accuracy is 3 deg in X/Ku-bands and 5 deg in S/C-bands.

NS-9003 and -9010 both use the Elbit EA-917 lightweight circular receiving array. A typical integrated ECM suite consists of NS-9010 controlling an NS-9005 jamming-and-deception system.

NS-9025 is an airborne standoff jammer for naval and ground applications.

All of these systems were announced in 1981 as the Elisra Compact Naval Electronic Warfare Suite; they were renamed in the NS-9000 series in 1982 (NS-9001 was introduced late in

1982). As of 1985, they had been exported to at least 3 countries and were in Israeli navy service.

Elisra exhibited advanced versions of its existing NS-9000-series naval EW systems at the Paris Air Show in June 1989: the NS-9003 ESM system and the NS-9005 jammer. Elisra claims that the new version of NS-9003 (suffixed PR) can deal with pulse compression, frequency agility, frequency hopping, and wobbled (jittered) PRF signals. NS-9005 PR can produce both noise and deception jamming, and it can be integrated with a multibeam array transmitter (MBAT). Typically, NS-9005/MBAT employs 4 MBATs and 1 exciter, each array covering 90 deg. It incorporates 4 trackers and, thus, can simultaneously deceive 4 threats, and it can be expanded to cover more, with up to 16 trackers available as an option.

NS-9003 PR covers the 1–18-GHz range. Direction of arrival is measured with an accuracy of 1–3 deg for signals of 2–18 GHz. The system employs a total of 60 directional antennas.

Elisra claims that its new proprietary lens technology provides NS-9005/MBAT with high effective power in the 7.5–18-GHz band.

The new systems are the third generation to be produced by Elisra. The company produced its first naval systems about 1978/79, for service in the early 1980s. They were initially ESM devices, integrated with existing ECM. The second generation (NS-9010) entered service in the mid-1980s. It employed new technology in the form of an RKR lens, which was more compact than the earlier spiral antennas. This system was an RWR as well as an ESM system. Its related ECM system was a conventional, mechanically steered antenna but with a very sophisticated exciter employing deception techniques. The new third generation features are concentrated mainly in the ECM portion of the system: an MBAT antenna, high ERP, and very fast switching for transmission and deception.

NS-9001, an ELINT version of the original NS-9003, falls between the first and second generations.

The associated submarine ESM system, NS-9034, is not yet a real product, but rather a design for using existing NS-9000-series components in repackaged form. It is intended to achieve 1-deg bearing accuracy, for targeting. NS-9034 will operate in a moderate pulse environment (about 100k pps). It will use 6 spiral antennas (2–18 GHz), an optional coarse DF array (Elbit-supplied RKR lenses, 7.5–18 GHz), and an omnidirectional array (2–18 GHz) on the periscope mast. Coarse DF accuracy is 6 deg, fine accuracy 1 deg, and elevation coverage +30/–10 deg.

◆ SEWS/Rattler

Rafael's Shipboard Electronic-Warfare System is in current Israeli service. There are 3 elements: GET/RAN-1001, the ESM system; the Rattler jammer; and the MBAT/RAN-1010 microwave lens, which directs jamming power. SEWS itself is RAN-1100. It is possible that the RAN designations refer to larger-ship versions of the basic system since the manufacturer's brochures show *Perry*-class frigates rather than Israeli-size fast attack craft.

GET/RAN-1001 uses a broad-band IFM receiver and a broad-band instantaneous direction finder (IDF), the latter employing RKR lens technology. There are separate omnidirectional (IFM) and directional (IDF) antennas, typically 2 of the latter. Processing is conducted partly in parallel, and Rafael claims that GET can identify such complex signals as chirps, frequency-agile pulses, and staggered or jittered PRFs. Frequency coverage is 1–18 GHz, and accuracy is 2 deg in bearing and 1.5 MHz in frequency. Dynamic range is 60 dB, and sensitivity is better than –60 dBm. Signals are automatically compared to an emitter library, on the basis of frequency, bearing, amplitude, time of arrival, pulse width, scan rate, and pulse coding. The display shows the true and relative bearings of detected emitters. The ECM response is either automatic or operator controlled. In automatic mode, reaction time is less than 1 sec. This device was developed by Rafael in collaboration with a German firm, Litef.

Rattler is a Rafael jammer for air, ground, and naval applications. It can engage up to 3 radars simultaneously, over 2–18 GHz. One high-powered, broad-band amplifier is time-shared among the 3 channels, excited by a lower-powered microwave source. Output power is reportedly greater than 400 W. Development probably began in 1979–80.

MBAT/RAN-1010 is a multibeam array transmitter for ECM. It employs electronically steered lens antennas and can generate several jamming signals simultaneously. MBAT operates over the 7.5–18-GHz range. Each of 32 beams is 6×25 deg, and time to switch between beams is 150 nanosec.

SEWS/RAN-1100 is a shipborne EW suite combining a receiver (RAN-1001 technology), 2 high-ERP MBATs, and a distributed data processor that decides which signals to generate. In July 1990 Rafael announced the supply of several of these systems, using MBAT jammers, to an unnamed foreign navy following harbor and sea trials. That navy was almost certainly Singapore's; the timing of the delivery voyage of the new fast attack boat *Victory* (which was also fitted with NATACS, see above) fits the Israeli announcement.

The Malaysian fast attack boats (Spica-M class) are fitted with a Rafael system but with antennas similar to those of the Italian Newton system.

◆ TIMNEX 4 CH

Elbit's ESM/ELINT system for the 2–18-GHz range has channelized IFM and automatic classification. Mk 1 has been in service on board *Gal*-class submarines since 1982, and Mk 2 will be fitted in the Taiwanese submarines built in the Netherlands. A related ESM system is probably being fitted to Australian *Oberons*, and Elbit and Kollmorgen are responsible for the ESM suite planned for the next-generation Israeli submarine.

The TIMNEX 4 CH is optimized for ELINT rather than for threat warning. In the Mk 2 version, the system has 4-channel IFM associated with an enlarged DF array covering its frequency range (expandable to 0.5–40 GHz). There is also a miniature DF mast atop the periscope, for threat warning (8–18 GHz, accuracy 3–5 deg).

Elbit claims PRF and time-of-arrival measurement accuracy of better than 0.25%; frequency accuracy and resolution (for the associated IFM) are 1.5 and 0.5 MHz. Outputs are frequency, pulse width, PRF, modulation, amplitude, direction of arrival, and time of arrival. The system is designed to deal with up to 100,000 pps. Its emitter library lists 64 radars, including 32 preset threats. The associated computer is a ROLM 1602B (16 bits, 64 keywords). Control is either manual or automatic; the displays are alphanumeric, polar, and rectangular-coordinate.

Elbit uses much the same elements in 3 other naval systems: Timnex-6CH, MN-21, and ST-31. Timnex-6CH is a wide-band receiver (-4CH is narrow band). MN-21 is an IFM, and ST-31 is a direction-finder. Presumably, the MN-53, often listed as an Israeli navy ESM set, is another IFM belonging to the same family. Timnex 4CHV2 (2–18 GHz) equips Australian *Oberon*-class and Israeli Type 206-class submarines.

These systems can be adapted for airborne use.

EXPENDABLES

The current Israeli navy's chaff launcher is a 48-tube unit (sometimes reported as 45-tube) that elevates and trains to form a 3D chaff cloud under computer control (chaff rockets are fuzed to "walk" the cloud away from a ship). This device, which resembles the Italian SCLAR in appearance, was introduced about 1983. It is the launcher on top of the hangar of an *Aliyah* or on the quarterdeck (just forward of the gun) of a *Romat* or *Reshev*. The new *Sa'ar V* has four 72-rnd chaff launchers.

◆ ACDS

Elbit's private-venture decoy rocket system (Automatic C/M-Dispensing System) launches both chaff and flares. It selects

and launches countermeasures on the basis of the threat's character, range, and bearing, and also on the basis of weather and ship's speed. There is a manual backup. The system can control 24 rockets. The typical installation is one 45-barrel or four to six 24-barrel launchers. ACDS was introduced about 1982.

This system is used by the Israeli navy as well as by Chile and South Africa.

◆ Chaff Rockets

Israel's chaff rockets were developed as a complement to the Gabriel missile. The designed range of the missile was much shorter than that of the Styx missiles of the Arab navies, so the Israeli strategy was to induce the Arabs to fire first—and to miss—primarily by using long-range chaff rockets to produce false targets. The superstructures of the Israeli boats were covered with radar-absorbing material that minimized their own radar signatures when the chaff was fired. Styx's effectiveness was further reduced because the effect of the sudden appearance of targets was to force snap firings. The missile used gyros that had to be run up for about 2 min before it could follow its preset course before turning on its seeker.

Wartime experience showed that, despite the deception tactics, some missiles would lock onto (or at least closely approach) the missile boats. Hence the postwar development of short-range chaff rockets and the associated jammers.

The long-range chaff rocket used in the 1973 war was AV-2, carried in 4 tubes per ship, preferably on the superstructure's sides, with a firing box on the bridge. It is a boost-sustain rocket with an altitude fuze, energized from the launcher (so no batteries are needed). The decoy targets appear 1–2 min after firing and persist for up to 15 min.

The postwar short-range chaff dispenser was originally designated SRCR (ship's perimeter-defense radar-decoy system); it used a 6-rnd launcher on a pedestal (described below), carrying a launcher pod. The rocket has a single-pulse motor, and it follows a preselected optimum-operation trajectory. The chaff deploys to form a full decoy within 15 sec, and the decoy persists for 10–15 min depending on the weather.

The 3 current Rafael chaff rockets (as of mid-1989) are:

	Short-Range	Beamtrap	Long-Range
Weight	3.2 kg	6.6 kg	9.4 kg
Chaff	1.75 kg	—	1.3 kg
Diameter	90 mm	115 mm	89 mm
Length	640 mm	804 mm	922 mm
Fin Span	125 mm	115 mm	179 mm

The short-range rocket is typically fired from a 6-rocket launcher on a standard 0.50-caliber machine-gun mount, 3 rockets being carried together in a loading unit. Elevation is fixed at 45 deg. A single firing box controls 2 launchers. Total weight of the loading unit is 22 kg. The 6-barrel launcher is now being marketed in the United States under the designation LADS. These launchers are used by Israel, Chile, South Africa, and Taiwan.

Beamtrap, a newer system that will replace the current short-range rocket, is mounted in a 6-tube launcher on the side of the ship's superstructure; the firing unit on the bridge or in the CIC controls 24 rockets. The typical firing interval is 0.5 sec.

ITALY

◆ BETA

Elettronica's ESM system is found in the Spanish *Descubierta* class. BETA is not integrated into the combat systems. Unlike the later generation of Elettronica systems (such as Gamma and Farad), this one uses a pair of large stabilized cylindrical antennas, which are probably DF spinners. Above each is a spherical radome housing, presumably, a jammer (ELT 828 or its predecessor). The later Elettronica systems all employ monopulse DF.



Beta radomes (a sphere above a cylinder on the side of the tower mast) are visible on board the Spanish frigate *Descubierta*, 1981. (Nick J. Waters III)

◆ CO-NEWS

Elettronica's communications ECM system (VHF/UHF) is installed in the *Maestrale* class. This system, designed for continuous surveillance and intercept, measures bearings and classifies emitters. CO-NEWS uses a high-scan-rate receiver and a fast automatic direction-finder. The antenna consists of 3 stacked arrays, each consisting of 4 vertical dipoles (to cover the full VHF/UHF range) and a switching matrix; intercepted signals are demodulated for surveillance.

◆ ELT 116

Elettronica's radar interceptor is used as part of an ESM or ECM system. Typically such a system covers 2–18 GHz and uses a 4-channel IFM receiver, whose outputs are displayed on 2 CRTs. The system can discriminate between pulsed and CW signals, and an automatic-warning module with a lamp alert can be added. The module can be set to respond to up to 32 emitters. Frequency measurement is accurate to within 0.2%, and sensitivity is -70 dBm.

◆ ELT 123

Elettronica's basic ESM module is similar in principle to ELT 116 above. ELT 123 provides direction finding for both pulse and CW signals and can be programmed to provide automatic warning of particular threats. In the FARAD system, ELT 123 passes its data automatically to an ELT 261 for analysis.

◆ ELT 124

ELT 124 is used for threat warning and D/F; see THETIS.

◆ ELT 128

This communications direction-finder is for air, ground, and naval service on the HF, VHF, and UHF bands. ELT 128 automatically finds the direction of an emitter and provides technical analysis of modulation. The HF antenna consists of half-dipoles or ferrite crossed loops (mobile applications); for VHF/UHF, the device uses an array of active dipoles.

◆ ELT 211

This ESM receiving system is for Newton (see below). This device provides warning of preprogrammed emitters; continuous wide-open angle and frequency surveillance; autotracking of selected emitters; and tactical evaluation (with appropriate symbology on its display). It can interface directly with a command/control system, or it can be part of a larger EW system. Digital processing makes a single-operator design practical. Typically ELT 211 uses a 60-kg masthead unit. ELT 211 employs 5 antennas: 4 omnis (2 cones and 2 cylinders; typically, the cones are mounted over the cylinders) and a monopulse DF receiver in the form of a collar surrounding a mast. The omnis feed an IFM; the collar feeds the main processor separately. ELT 211 can be connected with up to 4 ECM processors.

◆ ELT 224

See THETIS below.

◆ ELT 261

Elettronica's radar analysis module (see FARAD below) provides automatic tracking and automatic analysis of intercepted signals, with continuous surveillance on a panoramic display.

◆ ELT 311

ELT 311 is Elettronica's manually operated jammer. Jamming techniques include noise, deception, automatic, and semiautomatic. For example, the jammer can use spot noise or modulated spot noise against search and tracking radars (conscan types). There are look-through and time-gated circuits for control.

◆ ELT 318

Elettronica's dual-band CW noise jammer operates with either medium- or high-gain antennas. Using variable modulation techniques, it jams search radars and can adapt to new threats. It normally uses 1 or 2 ELT 828 stabilized-antenna assemblies or an ELT 814 omni antenna. This device was announced in 1981.

◆ ELT 361

Elettronica's dual-band CW noise jammer is capable of spot and barrage jamming; see FARAD below.

◆ ELT 511

Elettronica's manually operated jammer is used as part of an ECM system.

◆ ELT 521

This Elettronica high-powered deception jammer uses either directional (in conjunction with a D/F system) or omnidirectional antennas. It has wide frequency coverage, to engage fire-control radars and active and semiactive missiles. ELT 521 can engage multiple targets simultaneously.

◆ ELT 711

Elettronica's radar-identification module is used as part of an ESM or ECM system.

◆ ELT 712

Elettronica's programming unit is used as part of an ESM/ECM system.

◆ ELT 715

This intercept/jamming system is found on board the Moroccan *Descubierta*-class frigate *Lt. Col. Errhamani*. This system lacks the prominent cylindrical and spherical radomes of the Beta system on board other ships of this type.

◆ ELT 716

Elettronica's data-transmission module is used as part of an ESM or ECM system.

◆ ELT 724

This submarine omnidirectional, preamplified warning antenna, for installation atop an attack or search periscope, is available to supplement THETIS. Equivalent Italian ships use Newton.

◆ ELT 814

Elettronica's omnidirectional jamming antenna (receiver/transmitter) is cylindrical; it is normally connected to an ELT 521 deception (e.g., range-gate or speed-gate pull-off) jammer but can also be fed by an ELT 318 noise jammer.

Farad system components. (Elettronica)

◆ ELT 828

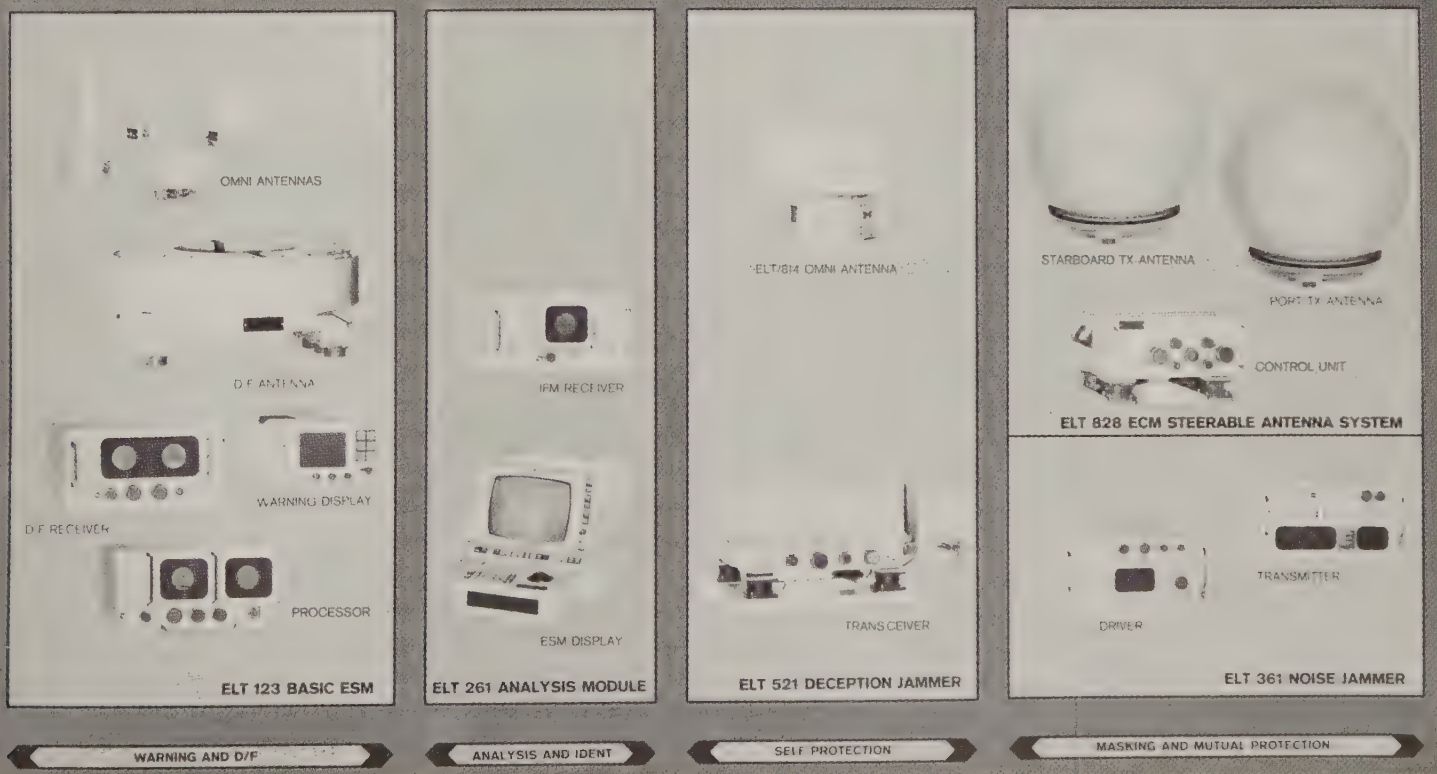
Elettronica's directional jamming antenna is generally connected to an ELT 318 noise jammer or to an ELT 521 deception jammer. There are 2 sizes, to cover 2 bands. This antenna is included in the Gamma and Newton suites, and it was reported in 1987 that the PRC's Jianghu-V frigates were being fitted with Elettronica suites including this antenna.

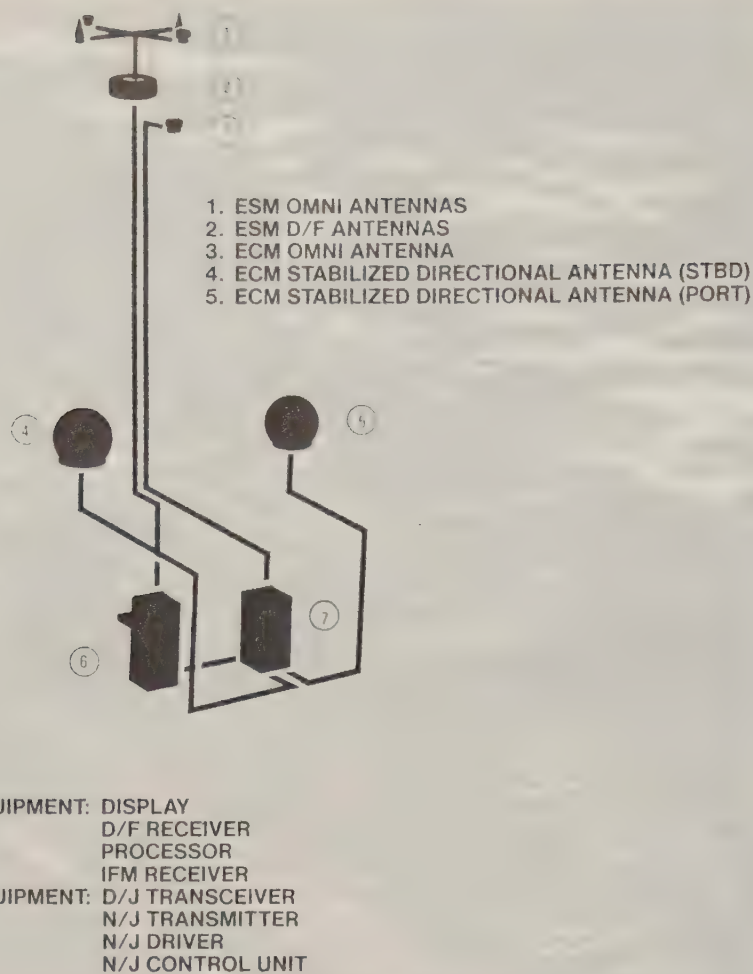
◆ FARAD

FARAD is Elettronica's small-ship system. The core unit is ELT 123 (basic ESM), supplemented by ELT 261 (analysis), ELT 521 (deception jammer), and ELT 361 (noise jammer). Both omni and directional jamming antennas may be used. ELT 123 consists of a warning display, a DF processor, and a pulse-recognition processor. It performs instantaneous direction finding (IDF) of pulse and CW emissions and automatically warns of preprogrammed threat emissions, displaying a symbol indicating the threat family type with the strobe indicating threat direction. The warning display incorporates a small operator keypad. Elettronica describes ELT 123 as a warning and DF system. ELT 123 does not require a dedicated operator. ELT 261 consists of the IFM receiver and the large-screen ESM display, with its keypad, soft keys, and trackball. It recognizes complex mode emissions, identifies emitters, and automatically tracks selected emissions. Elettronica describes ELT 261 as an analysis and identification system. The separate warning display can be deleted when ELT 261 is installed, or it can be retained as a bridge display. ELT 521 and the ELT 814 omni antenna constitute the self-protection portion of the system, and the ELT 361 noise jammer and ELT 828 direction antennas are the masking and mutual-protection elements. ELT 521 is a stand-alone transmitter, with programmable deception routines, different deception techniques, and a capability for multiple-threat engagement (hence the use of the omni antennas). The noise jammer is automatically driven by the FARAD ESM system (ELT 123 and ELT 261).

Elettronica stresses the reprogrammability of the system, and also its ability to transfer data directly into a CDS. The company describes 3 typical configurations:

Patrol: ESM only, ELT 123 with or without ELT 261. The current FARAD brochure seems to associate this system with





Farad installed on board a typical fast attack boat. (Elettronica)

a large coast guard patrol boat. This is probably the system on board Italian *Lerici*-class minehunters and *Cassiopeia*-class patrol boats.

Attack: ESM plus self-protection (deception jammer). An enhanced configuration includes ELT 261 for target identification. The current FARAD brochure shows a *Sparviero*-class hydrofoil in this role. This system, designated FARAD A1, is installed on board the private-venture demonstration attack boat *Saettia*.

Coastal and High-Value Target Defense: The main role is to deny information to the enemy's search and acquisition radars. ELT 261 is necessary, and at the least the craft must carry a noise jammer. In the enhanced version it also carries a deception jammer with an omni antenna. The current FARAD brochures seem to associate this system with the Thai *Praburapak* class, and it is also carried by the *Chonburi* class.

The masthead antenna array weighs less than 25 kg, and each ET 828 weighs less than 50 kg, including stabilization.

◆ G-100

This Eltcom (Elettronica subsidiary) interferometric direction-finder was displayed at Mostra Navale in 1989. Although developed initially for the army, it is intended for triservice use. G-100 covers the 20 MHz–1 GHz band but can be extended up to 2.2 GHz and down to 1.5 MHz. Interferometry, i.e., wide-open direction finding, was chosen for its speed; G-100 is intended to locate medium-speed frequency-hopping radios, burst transmissions, and radar pulses. Minimum acceptable signal duration is 2 msec in VHF and UHF, 50 msec in HF. This performance is appropriate for frequency hoppers at about 400 hops/sec in the VHF and UHF bands. G-100 is controlled by

multimicroprocessor; it can scan 1000–4000 free channels/sec, using a subchannel search technique, or it can search a preset list of 100 channels. The resolution of the display is 0.1 deg, and RMS accuracy is 1 deg at a clear site, after calibration, in VHF and UHF. For HF signals, accuracy is 2 deg with the full antenna array, or 4–8 deg with reduced arrays.

◆ GAMMA

Elettronica's ECM suite covers the 2–18-GHz range in 4 bands. The 4 outputs are displayed on 2 CRTs that can discriminate between pulse and CW signals. Two other CRTs display signal-analysis data, and a fifth gives D-band data. Several jammers are provided, including radar-angle jamming to confuse TWS radars. This system was intended for corvettes and large fast attack boats. It incorporates the same spherical jamming antenna and the same sensing antennas as Newton but uses a simpler processor. Gamma may be the version of Newton intended for ships of 1000–3000 tons, consisting of 1 ELT/211, 1 ELT/318 noise jammer, 2 ELT/828 directional ECM antennas, and 2 or 3 ELT/814 omnidirectional ECM antennas. Newton proper is presumably the version for ships of 2500 tons or more, and FARAD is the version for ships of 250–1500 tons.

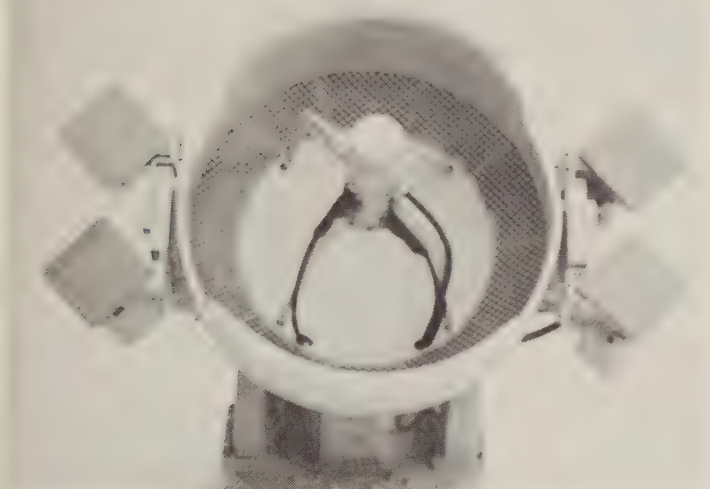
◆ INS Series/RQN Series

Selenia's Integrated Naval Systems, INS-1, is for small ships such as fast patrol boats. INS-3 is for large ships. INS-1 consists of an RQN-1 radar detector, a PAW-1 pulse analyzer (with warning), and an optional TQN-1 jammer and an RIN-1 identification unit.

RQN-1 employs an omnidirectional cone antenna (for wide frequency range) plus an array of directional antennas, measuring signal source bearing, pulse width, PRF, and band (L, S, C, and X: a lamp indicates the band). There is no IFM. Coverage



The intercept and direction-finding antenna of an Italian INS-3 installed on the Indian frigate *Godavari*, 1986.



INS-5 is the latest of a series of Selenia jammers. They are generally mounted on masts, without radomes. (Selenia)

is 1–12 GHz (but the system works up to 18 GHz), and nominal sensitivity is 48 dBm. Directional accuracy is 5 deg for the 2–12 GHz range, PRF is measured to within 10% for 50–10,000 pps (displayed on a 3-in CRT), and pulse width is measured to within 10% between 0.3 and 5 microsec. Bearing is indicated by a CRT strobe.

The designation INS-3 indicates Integrated (ESM-ECM) Naval System, third generation. Selenia characterizes the first generation as having separate analog video displays for D/F and frequency measurement and as using a digital analyzer. In dense environments, it could be difficult to correlate a strobe with the associated pulse characteristics. Second-generation systems introduced a frequency-bearing (situation) display, for quick analysis and unique D/F-frequency correlation. A system of this type was successfully tested on board an Italian corvette but

did not enter production. However, the second generation led directly to INS-3, whose main feature is automatic data extraction, done by a processor that carries out automatic analysis in real time and that controls active countermeasures. Compared with the second-generation display, INS-3s associate an identification symbol with each intercept. The processor maintains an active radar file of up to 64 emitters and can provide warning of up to 32 preprogrammed threats. There are 2 intercept channels, to cover the full 1–18 GHz range. For DF, there are 8 fixed antennas surrounding the omnidirectional antenna feeding the IFM processor. Directional accuracy is 5 deg.

INS-3 is built around a digital interceptor (RQN-3), with instantaneous frequency measurement for 1–18 GHz and with automatic control of chaff launchers. It is usually associated with the RIN-1 digitally augmented display system, which includes an RQN-3B for automatic detection, analysis, and tracking. Threat library capacity is 3000.

The ECM section is designated TQN-2; it receives data for automatic reaction (noise and pulse jamming, as well as chaff and flare control). The stabilized jamming antenna automatically tracks its target by 2-channel monopulse (the DF array provides coarse data) and emits noise over a range of 6–18 GHz. Beamwidth is 3 deg. There is a second 6-deg beam used to avoid the nodding effects due to multipath reflection at low elevation angles. A separate ULQ-2 deception unit can be added, to modulate the jamming signal for range and angle deception. The system can also provide passive tracking data to other self-defense weapons.

INS-3 is based on a helicopter system, IHS-6, which uses an RQH-5 receiver and a TQN-2 jammer.

The latest system in the series is INS-5, employing the RQN-5 receiver and the TQN-2 active jammer of the INS-3 system. The system can track up to 50 emitters, and its threat library contains 3000 emitters. Emitters are tracked both in bearing and in elevation (as in the case of aircraft and missiles).

INS-3 employs an ND-160 computer and a specialized hardware processor to sort the received pulses, as well as a hardware-based pulse analyzer and a signal identifier. The 16-in circular CRT can be arranged to show 2 alternative displays, a B-scan (frequency vs. bearing, with signals identified by track number and by standard NTDS symbol), and a PPI display similar to that of SLQ-32, in which the range rings correspond to degrees of threat. In each case the screen also shows 2 alphanumeric displays: a list of track numbers with category symbols, and a list of signal characteristics (track number, band letter, minimum and maximum frequency in MHz, PRF, pulse width, and identification).

These Selenia systems can be recognized by the characteristic single omni/DF antenna. RQN-1A/B uses a cone atop a cylindrical section (the 2 are not separated, and they are more massive than the corresponding Elettronica components); this antenna is mounted at the masthead. The cone houses a spiral antenna, which will detect circularly polarized radiation. The frequency characteristics of this type of antenna are determined by its apex angle, and bandwidth by the rate of spiral around the cone. The cylinder below it houses a series of directional horns operating at various frequencies. Dimensions: 38 cm in diameter, 76 cm high (30 kg weight). INS-1 used the same antenna. RQN-3 uses a different IFM/DF antenna (illustrated) with a blunter cone, but it is still a single unit, unlike the multiple antennas associated with the Elettronica systems. The blunt cone is 76 cm high, including the base containing the directional antennas, and it is 44.2 cm in diameter; the maximum width across the directional antennas is 86 cm. The entire assembly weighs 18 kg. The standard directional jammer, illustrated here, is never enclosed in a radome. The 4 square antennas (horns) alongside the main dish are used for monopulse target tracking.

Because it did not adopt this system for its newer frigates and destroyers, the Italian navy allowed it to be exported to Iraq and Libya for their *Wadi M'ragh*-class corvettes. INS-3 was later adopted for the Italian *Minerva*-class corvettes.

◆ Newton

Elettronica's larger-ship alternative to FARAD has been exported to Spain (*Lazaga* class) and to Thailand (PFMM Mk 16, or *Ratanakosin*, class). The related but more sophisticated Lambda (or SLQ-D/SLR-4) is used on board *Maestrale*- and *Lupo*-class frigates. The system is built around the ELT 211, which employs parallel omni and DF channels feeding its operator console/processor. There are 4 omni antennas: 2 cones ("witch hats") and 2 cylinders. Elettronica uses omnidirectional cone ("witch hat") antennas for HFs. The cylindrical radomes cover half cones. They feed an RF unit. The DF antenna is a monopulse collar mounted around a mast, feeding through a mast-mounted service module box. The mast elements weigh about 60 kg, and ELT 211 weighs about 450 kg altogether. ELT 211 automatically analyzes and displays emitter parameters, matching them with its library; it displays threat identification symbols; it automatically tracks selected emitters; and it warns automatically of preprogrammed threats. ELT 211 automatically indicates a preferred ECM reaction, and it can drive up to 4 jammers. Like FARAD, it drives its associated noise jammer (ELT 318). Unlike FARAD, it is connected directly to the ELT 521 deception set. In a ship carrying both types of jammers, either can be switched to either the directional or omnidirectional antenna. The single operator at the console controls all ECM and ESM functions. Because it can transfer information into a ship's CDS, Newton can easily be coordinated with other active countermeasures, such as chaff launching and missile firing.

Elettronica offers 3 basic versions:

100–500 tons: ELT 211 with either noise or deception jamming for self-protection. In the deception version, only the omni antenna is used; for noise, only the directional one. The brochure shows the silhouette of a fast attack boat. The brochure also shows the system antennas on board what appears to be a

Newton system components. (Elettronica)

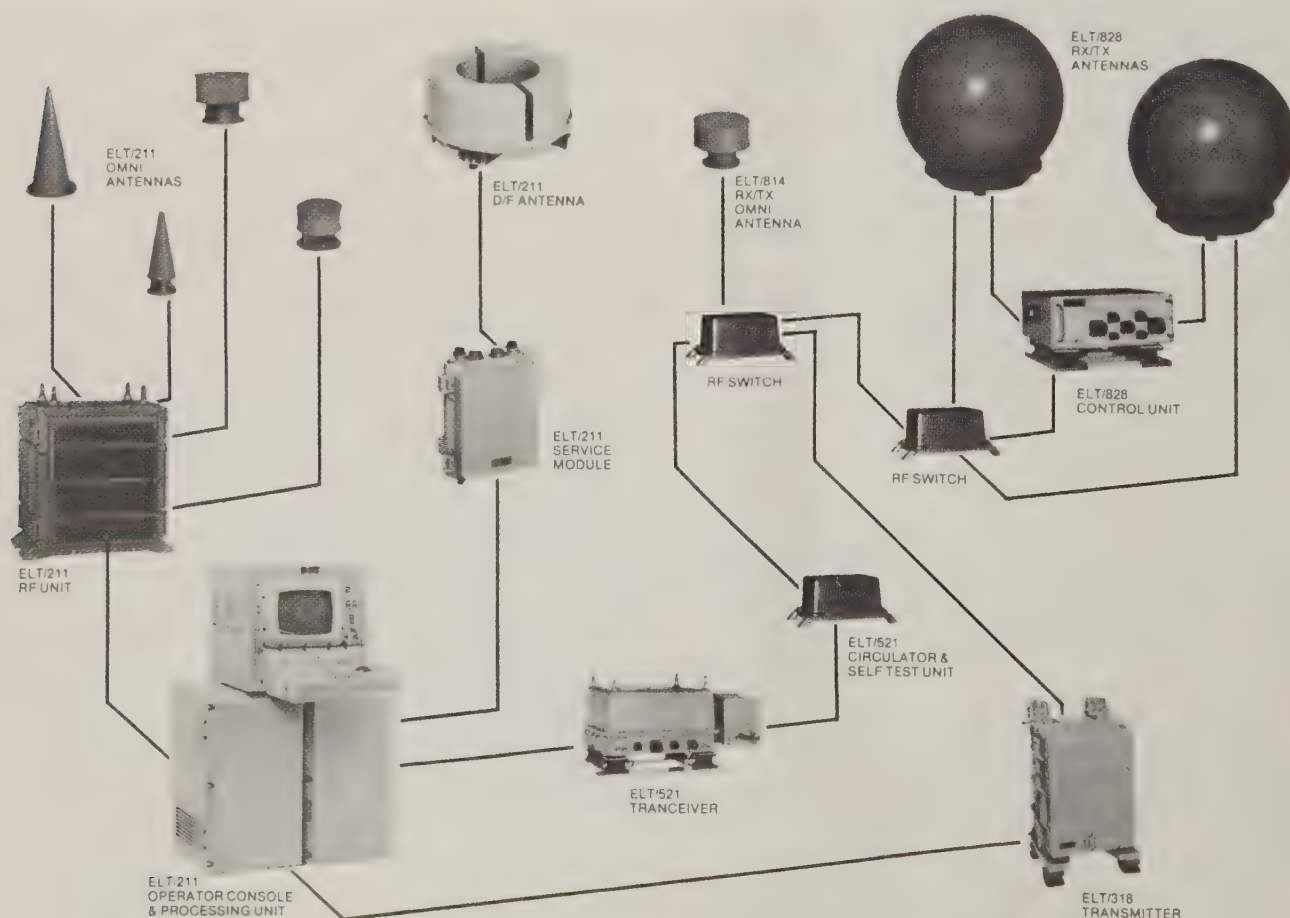


Newton on board a Spanish *Lazaga*-class fast attack boat. (Elettronica)

Spanish *Lazaga*-class fast patrol boat, with a pair of the directional antennas.

250–1500 tons: ELT 211 with both noise and deception jamming, and with both types of antenna. The silhouette in the Elettronica brochure is that of a *Descubierta*-class frigate, and that suggests that Newton may have replaced Beta on board some of the Spanish ships.

1000–3000 tons: ELT 211 with 2 deception jammers and 2 directional antennas, or with that suite plus 1 noise jammer and a third directional antenna. The brochure shows the silhouette of a *Lupo*-class frigate. The Italian *Lupos* show radomes or en-





The Italian frigate *Maestrale* is equipped with the Lambda (SLQ-D/SLR-4) system. The cylinder above her bridge is an ELT 814 omnidirectional jammer. A similar centerline radome is mounted atop her helicopter hangar. (Coll. S. Cioglia)

closures (presumably for jammers) at the after ends of their forward superstructures. The similar *Maestrale*s show a pair of omni radomes at the ends of their superstructures.

Over 2500 tons: ELT 211 with 4 jammers and 4 directional antennas (either 1 noise and 3 deception, or 2 noise and 2 deception). The brochure shows the silhouette of a "Standard" frigate, but no such installation has been announced.

The objects at the ends of the yardarm high up the mast of the frigate *Aliseo* are the IFM antennas of her SLR-4 system. In some *Lupo*-class frigates, the mast is surmounted by a Telegraf HF/DF. (L. Grazioli)

◆ MM/SLQ-D and MM/SLR-4 (Lambda)

This combination, rather than Newton, is the ECM/ESM system of the Italian navy's *Lupo*- and *Maestrale*-class frigates. The antennas resemble, but are not necessarily identical to, those of Newton, but the processing system is quite different. Newton uses a wide-open ESM system. SLR-4, the ESM component of the Italian naval system, incorporates a superheterodyne receiver for better frequency discrimination. Earlier Italian naval systems (for the cruisers and for the *Audace*-class destroyers) also incorporate superheterodyne receivers.

Lambda is the commercial designation for this system. It was exported to Peru and Venezuela (which has now replaced it with Guardian Star) but not, despite reports, to Iraq. Iraq received the Selenia INS-3, which the Italian navy had not, as of then, adopted; later the Italian navy did adopt it for *Minerva*-class corvettes. Ecuador received the similar but less sophisticated Gamma.



◆ Nettuno/Nettunel

Elettronica's ECM system was ordered for the carrier *Garibaldi* in 1983; it is also on the hydrofoil *Sparviero*. It is either closely related to, or identical to, the Nettunel of the Spanish carrier and *Santa Maria*-class frigates. The ESM subsystem employs 4 omnidirectional antennas (a cone and 3 pot-shaped radomes) feeding an IFM and pulse measurement receiver, plus a pair of roll-stabilized, multibeam, high-band, directional antennas (fore and aft) and a circular, low-band, DF antenna (an array of spirals). Pulse data are automatically extracted for emitter analysis and identification (the size of the emitter library is not given). Direction and frequency are measured on a pulse-by-pulse basis, presumably for de-interleaving.



Elettronica Nettuno (Nettunel) jammer on board the Spanish frigate *Numancia*, 1989. (S. Terzibaschitsch)

The Nettuno system. (Elettronica)

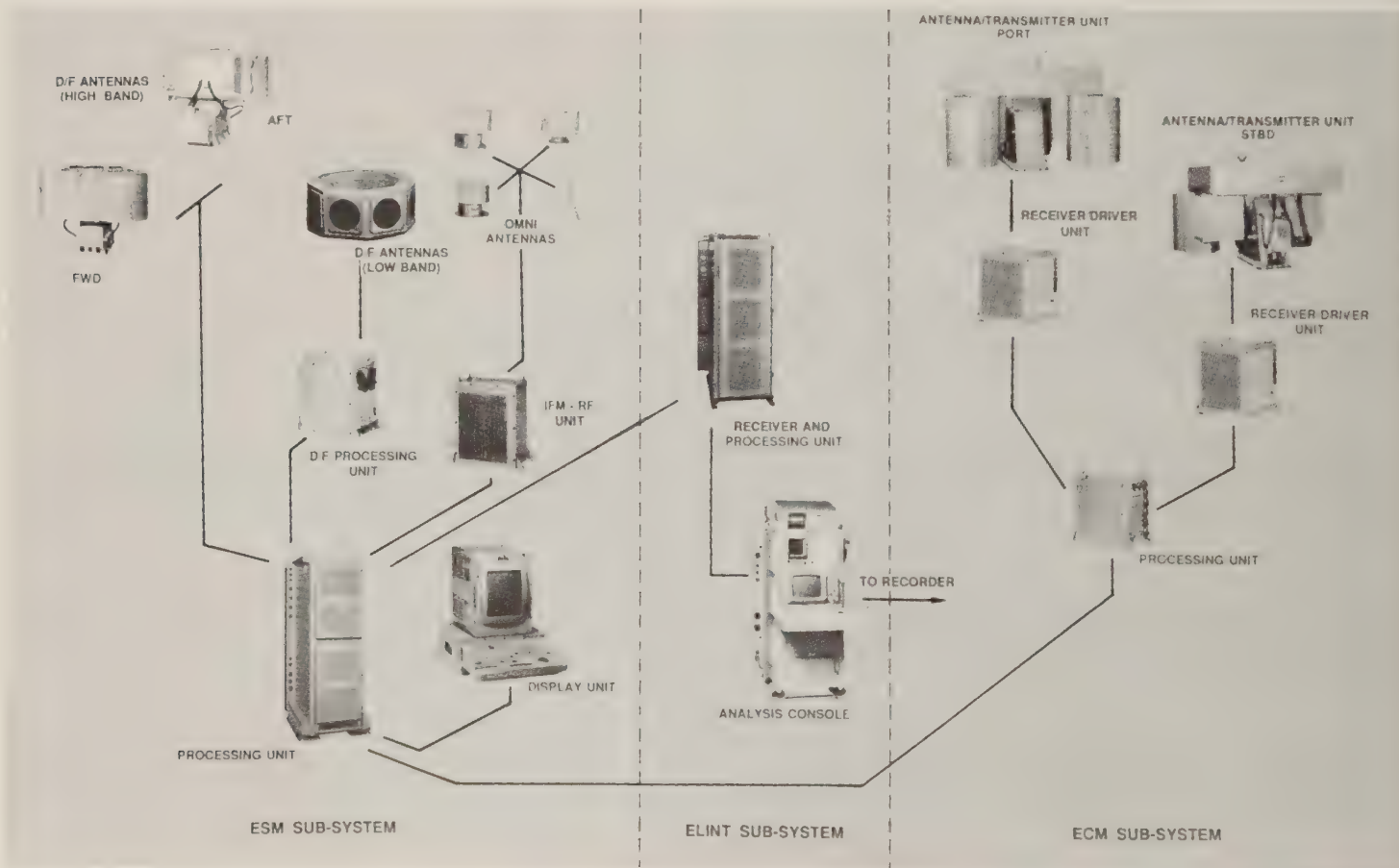


Passive elements of the Elettronica Nettuno (Nettunel) system are shown on the mast of the Spanish frigate *Santa Maria*, 1989. The object at the masthead is a TACAN. Below it the mast is encircled by the low-band DF antennas, a series of 8 cavity-backed spirals. The short yardarm below carries 4 omni antennas, for IFM in various bands: a cone over a short cylinder on the left, and 2 short cylinders (above and below the yard) on the right. The double-cylinder on the main yardarm below that is the high-band DF antenna. The 2 high-band DF antennas can also be carried fore and aft, rather than port and starboard. The radar on this level is SPS-64(V). Both the high-band DF antennas and the jamming antennas are roll-stabilized, and both are electronically steered. (S. Terzibaschitsch)

The ESM subsystem has its own display, and it also feeds both the ELINT and the ECM subsystems. The former has an analysis console and an associated recorder. The PRF and antenna patterns of selected emitters can be displayed, together with the effectiveness of countermeasures.

The ECM subsystem employs a pair of antenna/transmitter units, port and starboard.

In the Nettunel on board the Spanish frigates, the low-band



array is mounted at the mast head, just below the TACAN antenna, in the form of 8 D/F panels. The 4 omnidirectional antennas are mounted on the cross trees and are similar to those of Newton (ELT 211), except that Nettunel uses 3 pots and 1 cone whereas Newton uses 2 pots and 2 cones. The 2 high-band D/F boxes are at the yardarm ends; they are about half the size of the bigger jammer boxes on the superstructure. Both the high-band D/Fs and the jammers use dielectric lenses to achieve high angular resolution.

• Nettuno/Nettunel is descended directly from Newton (below).

◆ MM/SPR-A

Elettronica's ESM system for the Italian navy is presumably a version of 1 of the commercial systems listed. Coverage is 1.0–10.5 GHz, using 4 fixed omnidirectional antennas to achieve wide-open performance in bearing. The system employs crystal video receivers; it has no associated IFM. Emitter bearing is indicated by a strobe on the CRT display.

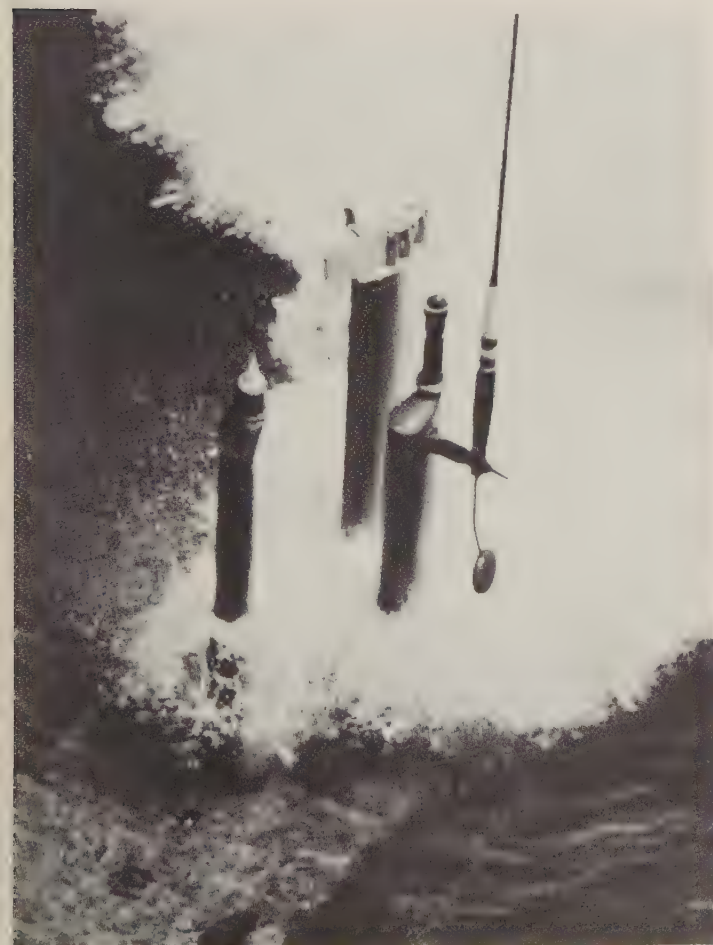
This system appeared in the late 1970s.

◆ RQN Series

Selenia's signal receivers are associated with digital data-analysis threat libraries. RQN-1 operates over 1–12 GHz; -1A over 1–18 GHz. Outputs are bearing, frequency band, pulse width, and PRF. Directional accuracy is 5 deg. With the addition of a special module, RQN-1 can provide automatic warning of up to 8 selected threats. Sensitivity is 48 dBm. RQN-3 uses an IFM, and its sensitivity is 65 dBm.

◆ THETIS

Elettronica's submarine ESM system provides threat warning (via frequency measurement) and direction finding. The name



The Italian submarine *Sauro* displays the antennas of her Elettronica Thetis ESM system (left and right), as well as her BPS-704 radar antenna. (*Ships of the World*)

means Threat Evaluation Tactical Information System. THETIS is available in 2 configurations, ELT/124-S and ELT/224-S. The basic system gives threat warning and direction finding only; the more sophisticated version also gives full ESM (it adds an IFM receiver and full ESM display). Both versions use the same D/F antenna (1 conical spiral omnidirectional antenna plus 8 plane-spiral D/Fs assembled in a single casing to withstand pressure), and both can be fitted with a separate omnidirectional antenna (ELT/724-S) with preamplifier, which can be mounted on the attack or search periscope for primary warning before surfacing.

◆ Breda 105-mm Rocket Launchers (SCLAR)

There are 2 types, a 20-rocket trainable and elevatable launcher and a light-chaff launcher.

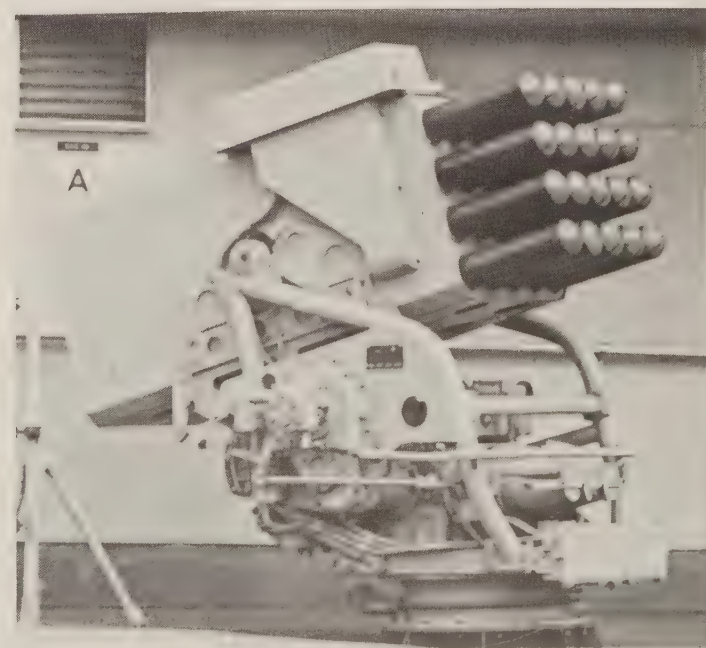
The 20-tube heavy launcher is part of the SCLAR system, which has been successfully exported. The launcher consists of 4 horizontal rows of tubes; weight is about 1150 kg empty or 1750 kg loaded. The launcher trains at 60 deg/sec and elevates at 30 deg/sec (limits +55/–3 deg). Firing rate is approximately 1 rocket/sec. Working circle is 1.38 m.

This launcher can also fire illumination and bombardment rockets. Rocket types are chaff distraction (range 12,000 m), chaff seduction (5000 m), IR seduction (5000 m), illumination (4000 m), bombardment to support a landing force (11,000 m), and coastal bombardment (11,000 m). Rockets are carried in waterproof containers with frangible heads. The launcher itself can be modified to accommodate 81-mm or 127-mm rockets (e.g., 24 × 81 mm or 12 × 127 mm).

The original 20-rnd launcher system was designated UCLAR. SCLAR, which was funded as part of the *Maestrale* program, introduced a digital microprocessor based on the Elsasg ESA-24. It stores a large number of alternative decoy patterns, any of which can be chosen based on such circumstances as the nature of the threat and weather conditions. One processor drives 2 launchers, setting train and elevation and programming decoy firing patterns.

As of early 1989, a total of 128 SCLARs were in service, with another 28 on order. The first units were ordered in 1978.

At the 1989 Genoa show, Breda exhibited a new version of its SCLAR chaff launcher, carrying 2 sets of tubes for a total of 6 French Mistral short-range missiles atop it. A television cam-



Breda's 105-mm rocket launcher, for both decoys and shore bombardment. (Breda)

era is mounted between the Mistral tubes. Control is exercised from a 1-operator below-decks console incorporating a television monitor and a joystick. The daylight television can be replaced by a low-light or IR unit for night operation. Typically, the mounting receives target designation from a 2D or navigational radar, the operator slewing it onto the designated bearing and then searching in elevation. It begins to auto-track optically when it is within 0.5 deg of the target.

Long-range chaff can be launched, followed by missiles when the target comes within range, and then followed by short-range chaff in the event the defensive missiles fail. The entire launcher is stabilized and remotely controlled.

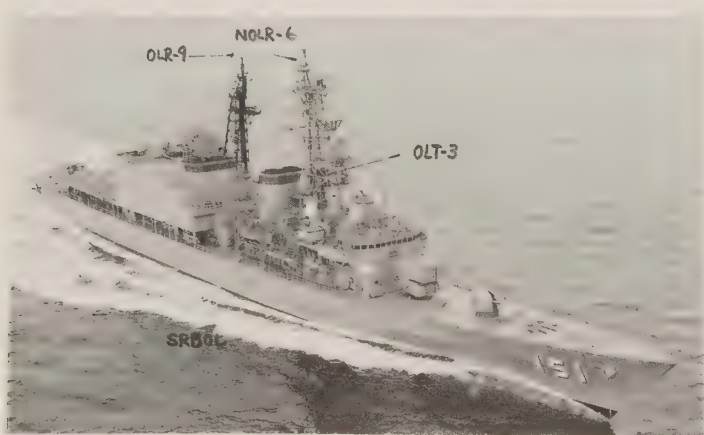
Total swept radius of the launcher is 1.380 m; elevation limits are $+57/-4$ deg. Total weight, including 20 rockets and 6 Mistrals, is 2150 kg (1430 kg empty). Training velocity is 60 deg/sec (elevation rate 30 deg/sec). The manufacturer estimates that the 6 Mistrals can be reloaded manually in less than 5 min.

The light-chaff dispensing system uses only short-range rockets, for distraction or seduction; this system is intended for craft too small for the 20-tube launcher. Rockets are carried packed in their fiberglass shipping containers, and the 6 tubes of each launcher (port and starboard) are fixed in elevation (35 deg) and in train (45 deg from the centerline), in a chassis fixed on the deck. Typically 4 tubes face onto each bow, and 2 onto each quarter. The system can fire 1 rocket onto each bearing, or 4 onto all 4 bearings (045, 135, 225, and 315 deg), or 2 onto the 2 bow bearings.

Each 6-round launcher weighs 105 kg empty or 145 kg loaded. Each short-range rocket weighs 5.2 kg; and when fired at a 35-deg elevation, the rocket reaches a maximum altitude of 100 m (300-m range) in 4.426 sec, and falls into the water in 9 sec (range about 560 m). The rocket is designed to burst at 80 m (to ensure a cloud duration of about 2 min, with a reflecting area of 800–1200 m² on I/J-bands).

JAPAN

The earliest modern Japanese naval EW systems were NOLR-1A and -1B, which were comparable to U.S. mechanically scanned units (WLR-1 series). They were succeeded by NOLR-5, a radome-enclosed antenna on board some frigates. These devices could not scan the frequency bands quickly enough to detect antiship missiles. The electronically scanned NOLR-6 appeared in the early 1970s; it covered the spectrum up to 18 GHz. It had 2 rotating direction-finding antennas to cover the main radar bands, plus a circular dipole array on the foretop for direction finding in the VHF/UHF band. NOLQ-1 was introduced in 1980; it is an electronically scanned array, comparable to the U.S. SLQ-32, typically integrated with 2 OLT-3 deception jammers (1 on each side) and with MK 36 decoy launchers.



EW systems on board the Japanese destroyer *Asagiri*. The masthead radar is OPS-28, the cruise-missile detector analogous to the U.S. TAS Mk 23; OPS-28 is used in conjunction with the radome-enclosed FCS 2-12E aft, which controls the Sea Sparrow (launcher on the stern). The fire-control radar forward is FCS 2-21A, and the air-search radar is OPS-14C. NOLR-6 combines equipment on both masts. (JMSDF)



EW systems of the missile destroyer *Hatakaze*. NOLQ-1 combines the masthead array, the antenna just forward of the main air-search radar (SPS-52C), and the flat array at the base of the big lattice mast. The 2D radar aft is OPS-11C, and the slotted array at the masthead is the OPS-28B anti-sea-skimmer set. (JMSDF)

◆ Fleet ECM Policy (1988)

The main current systems, with their U.S. equivalents, are:

NOLR-6 very similar to WLR-8

NOLQ-1 very similar to the U.S. SLQ-32(V)3

NOLQ-2 currently under development

OLR-9 very similar to WLR-11

OLT-3 very similar to SLQ-17



OLR-9 mainmast array (at maintop) and NOLR-6 mainmast array (radomes on platform) on board the destroyer *Amagiri*. The position of the cylindrical radomes varies among units of the class. The big radome is for Sea Sparrow fire control (FCS 2-12E). (Sea Power)

ZLR-3/5 warning receivers, very similar to WLR-8

ZLR-4/6 ESM systems, very similar to WLR-1G

Surface units will have the following systems:

DDH, DDG—NOLQ-1 (ESM/ECM), Mk 36-2 SRBOC

DD—NOLR-6 (ESM), OLR-9 (WR), OLT-3 (ECM), Mk 36-1 SRBOC

DE—NOLR-6 (ESM), OLR-9 (WR), Mk 36-1 SRBOC

After JFY88, NOLR-8 will replace NOLR-6 and OLR-9. New ships after JFY90 will have NOLR-8 and Mk 36 SRBOC.

Submarines have ZLR-4/6 (ESM) and ZLR-3/5 (WR); new submarines after JFY88 will have NZLR-1.

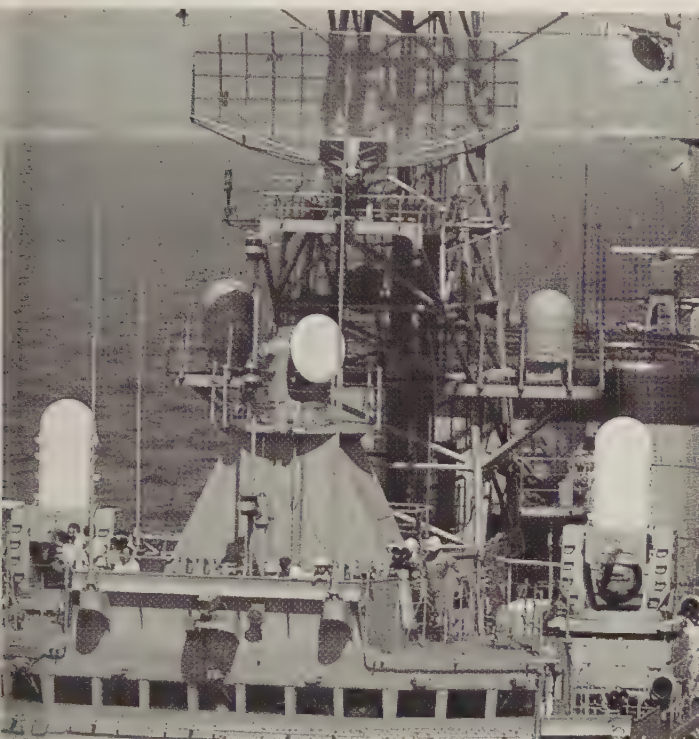
Aircraft:

—P-3s have ALQ-78 or ALR-66(V3)

—P-2Js have HLQ-101 (domestically developed)

—SH-3Hs have ALR-66(V1)

—SH-60Js have HLR-108 (domestically developed)



The big radome just above the Phalanx on board the *Amagiri* is an OLT-3 jammer (another is just visible on the other side of the ship). Somewhat similar radomes, aft on board older ships, are U.S.-type DF spinners. (Sea Power)

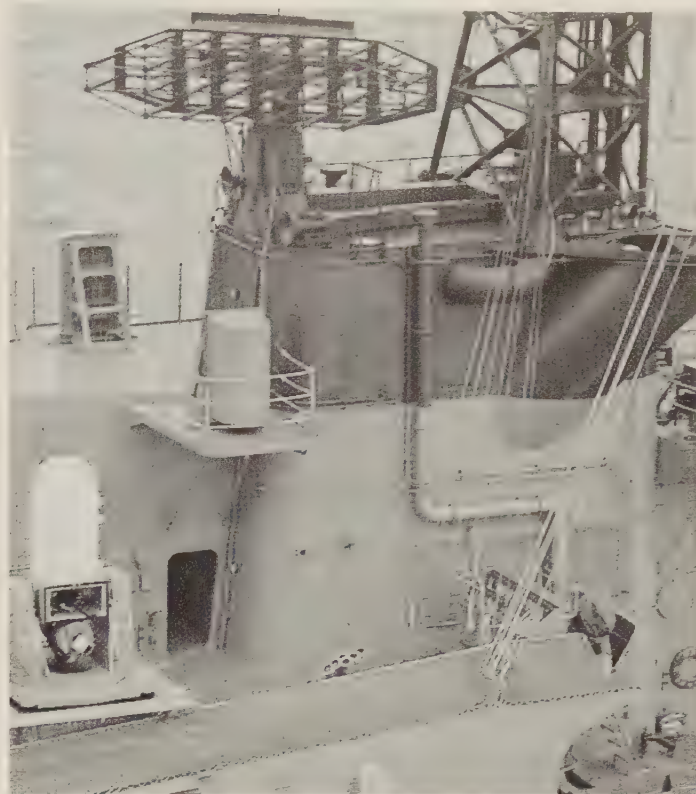
NETHERLANDS

Signaal and the British MEL company were both members of the Philips group, and Signaal transferred its countermeasures systems to the British company in 1985. In 1989 Philips announced that it would sell off its defense companies, and control of Signaal went to the French company, Thomson-CSF. Signaal/MEL products are listed here under the original parent company.

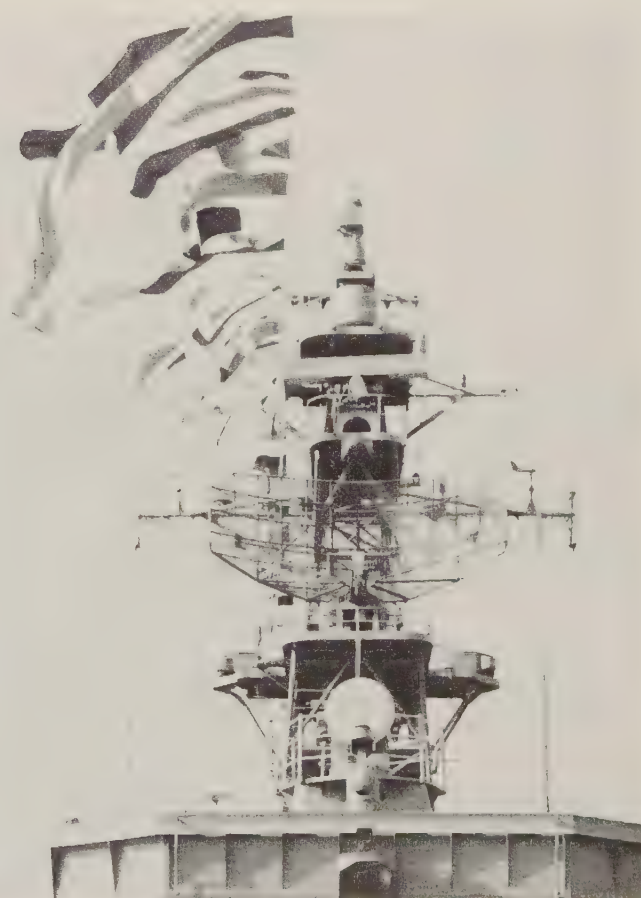
◆ RAMSES/Scimitar

Signaal's Reprogrammable Multimode Shipborne ECM system is a noise and deception jammer (I/J-band) that uses a pair of egg-shaped masthead or yardarm radomes (350-mm diameter × 1100 mm, 25 kg each). The antennas inside rotate and are stabilized.

The jammer is automatically controlled by a processing cabinet although there is also an emergency local-control panel. Typically, jamming is triggered either by the ship's tactical data system or by an ESM system, such as Rapids. The jammer is fed with target characteristics (based on ESM data) and bearing;



NOLQ-1 arrays on board the destroyer *Haruna*, with an OPS-11C radar above them. They presumably correspond to the lens antennas of SLQ-32. (Sea Power)



Commissioned in 1990, the escort *Abukuma* shows a new ECM suite that includes a pair of lens antennas on a platform above her forward fire-control radar. This combination is presumably NOLR-8. (Ships of the World)



Ramses jammer (2 radomes, separated vertically, with radiation-reflecting plates between them) on board the former Dutch cruiser *de Ruyter*, now in Peruvian service. The radar above is DA-08. (Signaal)

1 of the 2 antennas is assigned to the threat and slewed onto it. Meanwhile, the jammer looks up target characteristics in its own look-up library. Its upper (receiver) antenna goes into a search mode around the designated bearing, seeking a target that matches library information. Once it has locked on, it tracks and then triggers a preprogrammed response (via the lower, transmitting, antenna) as determined by Function Generators in the processing cabinet. The RF cabinet contains 2 TWTs, 1 for CW (noise) and 1 for pulsed (deception) jamming. Typically, the jammer uses noise against target-acquisition radars and pulse jamming against the seekers of antiship missiles. Signaal claims that noise jamming can be effective at ranges as great as 180 or 200 km.

The separate tracker antenna, identical to the jammer antenna, makes it possible for the jammer to operate continu-

ously, without pausing to look-through and check the status of the target. Identical antenna characteristics make for more precise jamming, which is particularly valuable against distant targets. Given 2 antenna systems, 1 on either side of the ship, the jammer can deal with 2 targets simultaneously. Also, because the processor cabinet contains 2 function generators, the jammer can set up a jamming sequence for a second target while the first is being jammed, and switch over as soon as needed.

The fundamental deception mode is false-target generation (the jammer sends back an exactly similar pulse). The responses can be modulated in strength to deceive sequential tracking radars such as conscans; this mode is, however, ineffective against monopulse seekers. Other standard jammer tactics include range-gate pull-off and swept scan rate modulation (SSRM), the latter a form of angle-gate pull-off useful against search radars.

A NATO version of RAMSES, Scimitar is a reprogrammable noise and deception jammer for the 8–16-GHz band, intended primarily to deal with missile seekers and target-indication radars. Jamming modes include noise (either spot or wide band), range-gate seduction, inverse scan gain, and false-target generation. Power output is 1.0 kW in pulse mode and 100 W in CW mode (later increased to 1.5 kW and 150 W). Scimitar can jam several radars (with different characteristics) simultaneously, as long as they are all in its beam. The 2 antennas can track 2 separate radars simultaneously. Beamwidth is 7×7 deg (gain 23 dB), and frequency sensitivity is 60 dBm.

Scimitar, with its own receiver, can be used as a stand-alone system if the associated ESM system fails.

See also the Canadian SLQ-503 above.

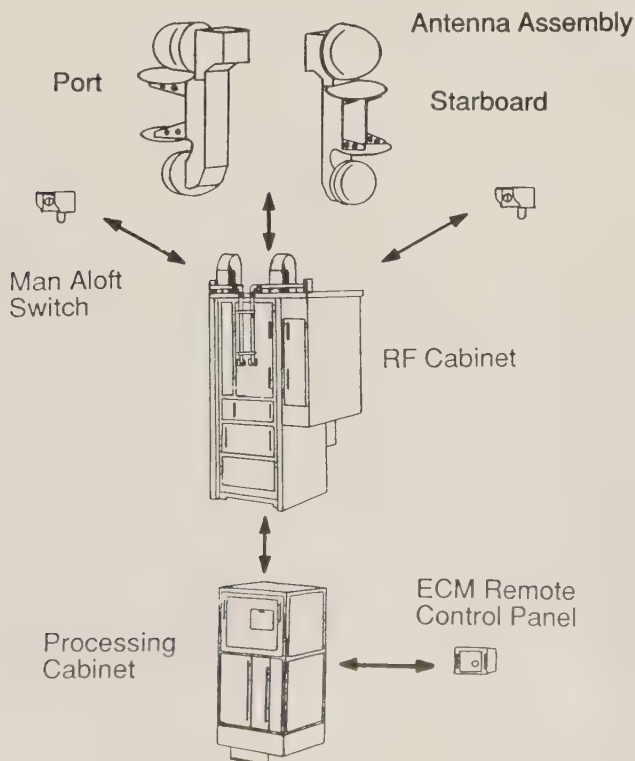
German-built FS-1500 frigates carry RAMSES. An order for units to equip the Argentine MEKO frigates was canceled because of the Falklands War. There is some question as to whether the full installation planned for the Peruvian cruisers was ever completed, as some equipment had to be postponed for financial reasons.

◆ Sphinx/Rapids



The ESM arrays around the mast (under the DA-08 radar) of this Dutch *van Heemskerck*-class missile frigate serve Rapids. The antennas on the mast are omnis for the system's IFM. (Signaal)

Sphinx (System for Passive Handling of INtercepted Xmissions), the Signaal ESM system, was later taken over by Signaal's partner, MEL. It incorporates a wide-open DF array under the Signaal "egg"; its sensitive IFM, with digital output, uses 3 mast-head antennas. Sphinx automatically warns of radar lock-on and automatically analyzes and tracks selected signals. Selected sig-



RAMSES, SLQ-503. (MEL Defense Systems)

signals tracked in bearing, or selected sectors, can be blanked out. Sphinx exchanges data with associated ECM (e.g., Ramses) and CDSs. Frequency coverage (1–18 GHz) can be extended to 33–40 GHz. Other optional features: threat warner with 12 preprogrammed channels, and a CW detection package.

The DF antenna has 8 sectors, each of which contains 5 antennas, including a horizontal cone. Vertical coverage is 40 deg. Sensitivity: –65 dBm for the IFM, –40 dBm (37 dBm in J-band) for the bearing antenna (–65 dBm for the high-sensitivity bearing antenna). Dynamic range is 65 dB. Frequency is measured within 0.125%, and bearing to within 4.5 deg (5.5 deg for the high-sensitivity mode). Resolution: 5–10 MHz and 1.4 deg. Measurable pulse width is 0.1–100 microsec, PRF 100 Hz–56 kHz, and scan period 0.1–80 sec. Sphinx can track 14 signals and can lock onto and trigger a warning of 3 signals. Signals are presented at 3 strength levels. Processing time is about 2.5 microsec/signal. There are 3 displays: a circular CRT (situation display) shows bearing vs. frequency, and 2 alphanumeric displays show pulse analyzer output and emitter identification.

The bearing array's diameter is 2.156 m (height 1.189 m, weight 560 kg). Frequency aerial diameters $\times$ heights: 250 $\times$ 268 mm, 185 $\times$ 251 mm, 357 $\times$ 335 mm, 610 $\times$ 415 mm, and 280 $\times$ 470 mm (1 large cylinder and 2 pairs of smaller ones, all with axes vertical).

The associated computer is SMR-4.

The Sphinx antenna is probably identical to the A2 version of the contemporary MEL Susie, which uses a less capable processor. Signaal almost certainly originated the idea of wrapping the antenna around the base of its "egg," and MEL and Signaal were both associated Philips companies when Sphinx and Susie appeared. MEL was ultimately given responsibility for producing and marketing Sphinx.

Sphinx first appeared on board the Dutch Standard frigates, the first of which entered service in 1978, and it is probably also the ESM system of the Argentine MEKO 360-class frigates (which carry Scimitar jammers).

Rapids (Radar Passive Identification System) was intended as a less complex successor, using next-generation technology (an SR-MU computer with additional bearing-and-frequency analysis racks, and a cursive, rather than analog, display). MEL, which now markets the system, claims that it is descended from CANEWS. Initially, about 1981, Rapids was described as a less

capable system, covering 8–18 GHz but expandable down to 2 GHz, with a sensitivity of 60 dBm, a bearing accuracy of 3.5 deg, and a frequency accuracy of 5 MHz. The *van Heemskerck*-class missile frigates use a DF antenna similar to that of Sphinx. Another version, in Turkish MEKO frigates and in Malaysian FS-1500-type frigates, uses the Anaren DESM antenna also used in Cutlass B1. The last 2 Turkish frigates use Cutlass B1.

Rapids operates on 4 bands (2–4, 4–8, 8–12, 12–18 GHz). Pulse parameters are digitized and fed to a processor that sorts the pulses into identifiable radar signals (de-interleaves). Its output is then further processed to give radar parameters. The display is synthetic rather than raw video; it shows frequency against bearing, with alphanumeric information alongside (radar number, name, threat, CF, purpose, category, platform, geographical position, scan type, minimum and maximum frequency, minimum and maximum PRF, mean pulse width, mean bearing, scan period, amplitude level, frequency agility indication, pulse jitter indication). Rapids is controlled by soft keys (on the display) and by a light pen.

In 1984 Signaal credited the version using the DESM antenna with a sensitivity of 60 dBm at 2–7.5 GHz, and 55 dBm at 7.5–18 GHz, and with a bearing accuracy (in free space) of 3 deg. It could track 10 signals, lock onto 3 of them, and had a threat-warning capacity of 6 signals. Library capacity was 256 complex radars and 64 platforms. These capacities could be extended.

Like Sphinx, Rapids was transferred to MEL.

NORWAY

◆ SR-1A

This shipboard radar-intercept receiver (2.5–18 GHz) was made by Nera A/S. The antenna consists of a rotating antenna in a radome and a fixed octagonal horn array. The spinning antenna gives a bearing accuracy of 3.5 deg, compared with 22.5 deg for the omnidirectional horns at the base. The system as a whole can measure PRF between 200 Hz and 10 kHz, and pulse widths between 0.2 and 10 microsec. The spinner can rotate at up to 500 rpm, the speed varying automatically to avoid synchronizing rotation with that of the transmitting antenna (and thus losing all signals). The display is a CRT, showing a deflection pattern of multiple radial lines corresponding to the rotation of the spinner; the longest lines give the direction of the emitter, and these data can be read off as either relative or true bearing.

This system dates at least from the mid-1970s. This is the system originally on board German Type 143/143A/143B-class fast attack boats; it is being replaced by FL1800 (antennas grouped under the WM27 "egg" replace a masthead radome). The earlier Type 148s had the French DR 2000 at their mastheads. This system equipped Norwegian *Oslo*-class frigates, but it has presumably been removed upon their modernization. Nera A/S abandoned production of EW equipment in 1979.

◆ NE-10A

The Nera A/S broad-band submarine warning receiver operates between 2.5 and 11 GHz (usable up to 18 GHz). It covers the entire hemisphere over the antenna, and PRFs of 0.1–10 kHz. The system does not discriminate among signals: it emits its audible warning when it receives any pulsed radar signal over its bandwidth.

This system dates at least from the mid-1970s.

◆ VR-1B/C

Nera's submarine (VR-1B) and small-craft (VR-1C) RWR uses 2 tiers, each of 8 horns (with separate horns for vertical and horizontal polarization), to cover 2.5–18 GHz in 2 bands (E-lower J and upper J). Measurable PRFs are 200 Hz–10 kHz, and measurable pulse widths are 0.15–10 microsec. Bearing accuracy is 22.5 deg. Each horn has its own crystal video detector. The dual-beam CRT uses a logarithmic time scale to display the entire range of PRF and pulse width without changing scales.



The Dutch frigate *Van Kinsbergen* shows a Sphinx DF array around her foremast, under the egg-shaped radome of her Signaal WM25. The mast above carries the characteristic triplet of omni antennas for the system's IFM: 1 large cylinder (foreground), 1 small cylinder with a cone above (on the yard facing away from the viewer), and (on the yard facing forward) 1 small cylinder with a smaller 1 below it. The surface-search radar is ZW-08. (L. van Ginderen)

◆ VS-30

Nera's radar search receiver, ca. 1976, uses fixed wide-open ports to cover the 2.5–18 GHz range, with instantaneous measurement of PRF, pulse width, and bearing. There are 5 versions, with 3 types of antennas and 4 display and output arrangements. A typical unit consists of 3 tiers of horns, 8 per tier, alternating horizontal and vertical polarization.

SPAIN

There is now a national naval EW program. The navy's research center (CIDA) is developing the first entirely indigenous integrated ESM/ECM system, Aldebaran. It is less sophisticated than the Italian Nettuno of the frigates and the carrier and is intended for smaller ships such as the new EEZ-patrol vessels. The first trials units were delivered in 1989, and first production deliveries are expected in 1992. Aldebaran is associated with the Altair IR warning system being developed to control point-defense weapons, such as Meroka.

Four other systems are under development:

Canopus, under development by Inisel, is to replace the ELT/311 and /511 noise and deception jammers of the *Descubierta* class.

Deneb, under development by ENSA, part of the Ceselsa group, is to replace the passive parts (ELT/114 and /116) of the Gamma system of the *Descubierta* class. *Deneb* is also to be installed on board the *Baleares*-class frigates now being modernized.

Elnath is a communications countermeasures system.

Kochab is a decoy-launcher controller, developed by Inisel, to be installed on board the older frigates under the Tritan modernization program.

Inisel and Ceselsa initially agreed to split EW work, with Inisel responsible for the active elements and Ceselsa for the passive ones. This agreement lapsed in 1989, and Inisel is currently developing passive systems for submarines and small surface craft.

A special center for EW simulation has been set up at Rota.

About 1976 the Spanish navy installed a strategic ELINT system on board the fast attack vessel *Alsedo*, which typically patrols southern Mediterranean waters near the Straits of Gibraltar and off the North African coast.

◆ ENSA COMINT System

This system, suitable for naval, air, or ground use, is being marketed by ENSA, a division of the Ceselsa group. It has 7 elements:

- A fast interception receiver (EN/TSR-600) scanning at 640 MHz/sec over the 20–500 MHz range (expandable to 1200 MHz), with a resolution of 5 kHz, a sensitivity of –107 dBm, and a 120-dB dynamic range.
- An interferometric direction-finder (EN/TSD-530) accurate to within 2 deg.
- A classifier (EN/TRX-800).
- A monitor receiver (EN/TRR-400) that measures signal parameters (AM, FM, SSB, and CW signals).
- An exciter/jammer (EN/TLQ-700) operating over the 100–500-MHz range (expandable to 20–500 or 100–1200 MHz) and producing 1.1 kW of ERP. Jamming techniques are: single channel, barrier, multiple multiplexed channels, and responsive.
- An operator's console (EN/SRY-1000) with a high-resolution (1280 × 1024 pixel), 20-in color monitor, a keyboard, and a trackball.
- A processor (EN/TYK-610) using a 68020 chip, with 5 Mbytes of memory.

ENSA claims 100% probability of detection for emissions lasting 0.75 sec; its system can track up to 200 signals. They are correlated by time-frequency-direction, and post-processing analysis uses artificial-intelligence techniques.

SWEDEN

◆ EWS 905

Saab-Scania's dual-mode ESM/warning system identifies targets detected by search radar; this system is found on board Swedish fast attack craft (*Stockholm* and *Hugin* classes). EWS 905 automatically commands shipboard chaff launchers and other self-defense measures. The display shows bearing, frequency band, pulse interval, pulse width, and scan time, as well as the major evaluated threats. Up to 50 emitters evaluated as less threatening are stored and can be called up. There are 3 operating modes: alert (all bands covered, with the system concentrating on a single threat sector; the sector and frequency are displayed); decision (the antenna rapidly scanning a selected sector; bearing, band, pulse interval, and pulse width are displayed); and surveillance (the antenna slowly scanning the selected sector; the above parameters plus the target antenna's rotation rate are displayed).



EWS 905 masthead array. (Saab)

◆ 9CM and 9EW Series

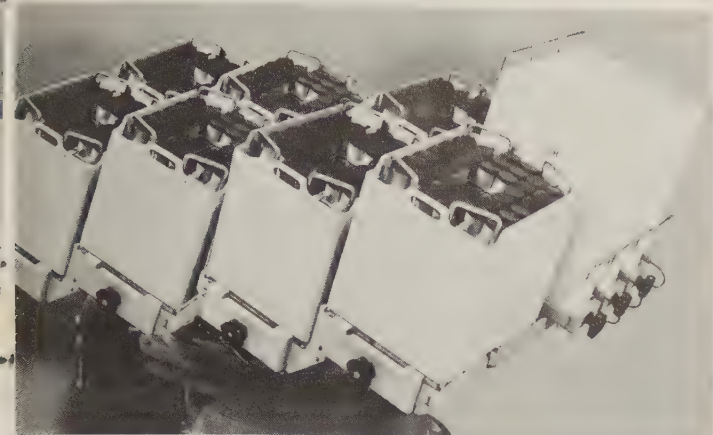
PEAB's EW systems are intended for integration with the 9LV-series of FCSs. The chaff launcher is Philax, either in fixed (4-magazine) or trainable (8-magazine) form. Each 9CM system consists of a radar warner, a computer processor, and the associated chaff launcher: Matilda for 9CM100 (in the *Spica* class); Rapids, Phoenix II, or Cutlass in 9CM200. Computer inputs are warning data plus ship's heading, speed, and roll angle; ship's radar cross section and IR signature; and wind direction.

9CM100 (2 sets) and 9M200 (4 sets) use the fixed 4-magazine launcher.

The new 9CM300 will equip the *Goteborg* class. It employs a new 8-magazine trainable chaff launcher and a new ESM system (ARGOS Carol) using new lens and omnidirectional antennas and laser warning receivers. In the *Goteborg* class, the Luneberg lens antennas are mounted on the fore and after surfaces of the mast, just below the search radar. The lens antennas are used for both ESM and jamming.

There is also a new medium-range chaff rocket in fixed launchers for distraction. Systems incorporating this rocket are denoted 9CM150, 9CM250, and 9CM350.

The system was initially announced in 1987 as 9EW300, the



The trainable launcher of the 9CM300 system; this one carries 7 chaff magazines and 1 IR-flare launcher; it can fire 36 chaff salvos and 3 IR salvos (Saab)

corresponding 9EW400 being intended for small frigates. These systems do not include the active ECM system of the corresponding 9CM systems, and they may also use different ESM devices. Finland uses 9EW300 in her *Helsinki II*-class fast attack boats.

Philax, the PEAB chaff system, is rather larger than that associated with the Saab EWS 900CA. There are 2 versions, Philax 105 and 106, the latter carrying IR decoys. Small ships carry 2 launchers, larger ones 4. Each launcher carries a series of magazines, each magazine carrying groups of 40-mm chaff grenades that are fired together by a single ejection charge. In the seduction mode, the 9 grenades of 1 group form a 1000-m² chaff decoy about 2 sec after firing (about 20 m from the launch point, at a height of 50 m) and remain effective for about 20 sec. In the distraction (-50) mode, grenade flight time is 4 sec, and cloud cross section is typically greater than 300 m².

Each magazine holds 4 groups of grenades, a total of 36 grenades; it weighs 40 kg. Each grenade weighs 0.37 kg and carries 0.175 kg of chaff.

A magazine can be replaced by 3 IR-flare containers (Philax 106 version), each holding 21 decoys. Deployment is much like that of the French DAGAIE system, but the decoys are not the same. The first 5 IR grenades form an initial decoy near the ship (about 10 m away), then 2 remaining groups of 8 each are fired on varying trajectories, with parachute descent, to merge with the chaff cloud about 10–15 m above the sea surface. Reaction time is 2 sec, and the IR target is 150 m long. The decoy lasts about 25 sec. The IR payload is 4.5 kg, and the decoy works in both the 3–5- and 8–14-micron bands.

There are 82 Philax installations in Swedish service, and another 24 (the first of which was ordered in 1978) on board Egyptian fast attack craft. During the Gulf War this system was reported on board merchant ships operating in the Gulf. See also the British MEL Protean, which is essentially the same device.

◆ Bofors Rockets

Chaff rockets (57 mm) can be fired from rails rigged to existing Bofors gun mounts, using the existing gun-control system. Rocket dimensions are 57 × 1385 mm (16.5 lb carrying 2–2.2 lb of chaff), with maximum velocity of 420 m/sec; range at 30-deg elevation is 1400–6000 m. Time to bloom is 30 sec, and the chaff cloud lasts at least 6 min, forming a radar target similar to that of a 2000–3000-ton ship.

There is also a long-range 103-mm rocket (payload 2.4 kg, range 10,000 m).

TAIWAN (ROC)

The current EW systems are designated in a new Chang Feng (Long Wind) series:

Chang Feng I Probably WD-2A. It is a threat-warning receiver for small or secondary units, such as fast attack craft, developed

during the 1980s by CSIST, and covering the E–J-bands. Six were made for the PF800-series frigates (former U.S. destroyer escorts), and at least 30 more for *Hai Ou*-type missile fast attack boats. The frigates mount WD-2A on a short mast just forward of the Sea Chapparral launcher. WD-2A may also equip the 2 PSMM Mk 5 fast gunboats. This warning receiver is used to trigger the AV 2 and SMOC-3 chaff-rocket systems. This designation may include the rockets controlled by WD-2A.

Chang Feng II CS/SLQ-2, the ESM/ECM system for Wu-Jinn I (modernized *Fletcher*)-class destroyers; 4 were made. This system is probably integrated with the CR-201 chaff launcher. This designation may include the CR-201 rocket controlled by SLQ-2.

Chang Feng III Current-generation destroyer EW system, designed by Hughes and produced by CSIST; at least 10 were manufactured, for modernized *Gearing*-class destroyers. This system was based on the Hughes MEWS (SLQ-31) and SLQ-17. It incorporates a separate radome, probably containing a spinner antenna, for precise location of emitters. Reportedly, *Chang Feng III* has not been entirely satisfactory, and the new frigates will carry a new system, *Chang Feng IV*.

Chang Feng IV This is probably the Raytheon Shield system. Raytheon claims that its Sidekick jammer (see the U.S. Navy SLQ-32 entry) was originally evolved to meet a Taiwanese navy requirement, and a photograph of its new Shield system looks very much like an SLQ-32 with a Sidekick. *Chang Feng IV* will equip the new *Perry*-class frigates.

Other systems are:

AV-2 Israeli-type chaff rockets, carried as a pair of twin launchers with a common control panel. The rockets are electrically fired and manually reloaded; they produce an 80-m² chaff cloud. About 1500 chaff/flare rockets were made. For details, see the Israeli section.

CS/CR-201 Decoy-rocket system, using four 16-tube 126-mm launchers, carried by all GOCN destroyers. This system was based on the abortive army Kung Feng IV bombardment launcher (40 barrels in two 4 × 5 packs) and was installed in the early through mid 1980s; at least 19 sets (4 launchers each) were made. A new launcher (12 × 2 barrels) similar in appearance to the U.S. RBOC was displayed in October 1989. CR-201 resembles the Italian 105-mm SCLAR system; as in that system, there are both long-range distraction rounds and short-range break-lock rapid-bloom rounds.

SMOC-3 Decoy (chaff and flare) launcher for frigates and large fast attack craft (PSMM Mk 5 type), a slightly modified AV-2,



A Taiwanese (ROC) destroyer, firing her Hsiung Feng I missile, shows a CR-201 trainable chaff rocket launcher in the foreground. (Fu S. Mei)

probably with quadruple tubes and a different display/control unit. It was developed by CSIST in the 1980s, and at least 8 were made.

Until recently the chief warning systems were the U.S. Navy WLR-1 and the ARGO 680/681, the latter equipping Wu-jin Mk 1 ships (and thus perhaps forming the basis for SLQ-2). Surviving WLR-1s have been modernized to cover the J-band, to deal with new PRC missiles with J-band seekers (such as C801 and FL-1).

USSR

◆ Amber Light

This ESM for Akula- (and presumably Sierra-) class submarines is carried with Stop Light.

◆ Bald Head

Bald Head is the ESM in Alfa-class submarines, integrated with the Snoop Head search radar.

◆ Bell Series (Bell Bash, Bell Clout, Bell Crown, Bell Nip, Bell Push, Bell Shroud, Bell Slam, Bell Squat, Bell Tap, Bell Thump)

These surface-ship ESM antennas, located in small radomes, are often associated with jammers. Visual identification is complicated by the Soviet practice of mounting several radomes as a single unit, e.g., with a small radome pointing down below a larger 1 to save space. When the 2 units are separated, they are

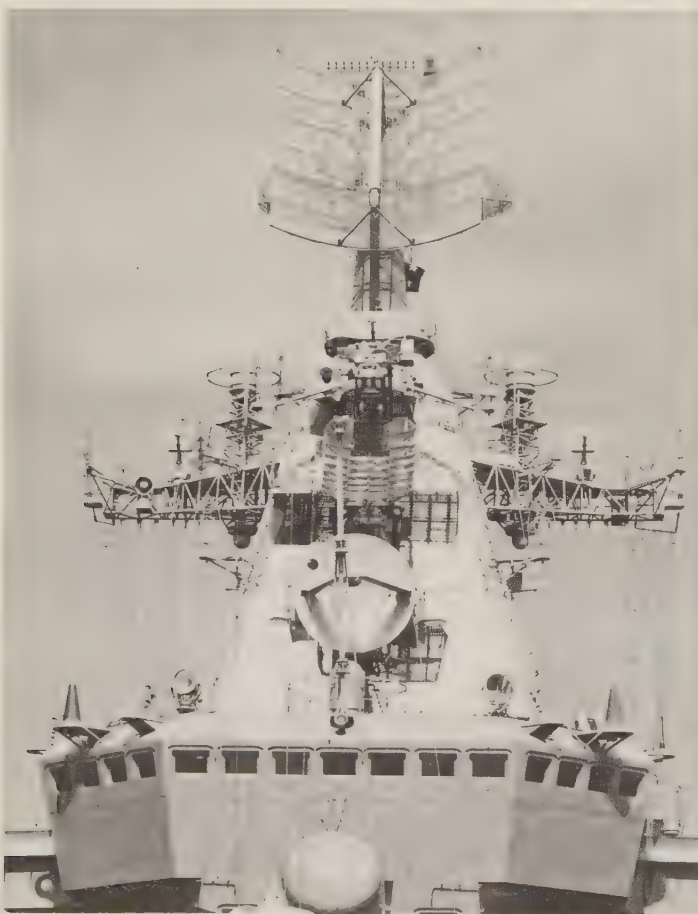
still given a single nickname. Similarly, the elements of Bell Shroud are now often mounted separately.

Presumably, the Bell-series antenna associated with each jammer provides coarse (intermediate-grade) target data; it may also be a look-through receiver. For example, each pair of Side Globes or quadrant of Rum Tub or Wine Flask has an associated Bell-series antenna nearby. Each group of jammers also has a somewhat larger associated Bell-series antenna, which is probably the initial signal receiver for the ship's ECM system.

Typically, the 2 pairs of Side Globes on each side of a ship are associated with 2 different Bell-series radomes, Bell Slam and Bell Tap. These antennas antedate the Side Globe series; they were associated with the earlier Top Hat jammers in the Kynda and Kanin classes (1 for each pair of 2 Top Hats).

Bell Bash is associated with Bell Thump, in analogy to the combination of Bell Slam and Bell Tap. The associated jammers are Wine Flask and Wine Glass. The main external difference seems to be that Wine Flask is always mounted in a group of 4, whereas Wine Glass is to be found in pairs (e.g., in the *Udaloy* class).

Bell Clout is apparently the current initial large-ship signal receiver, replacing the earlier Watch Dog. It provides very coarse



The combination of a large radome (visible on each side of the tower foremast of the cruiser *Marshal Ustinov*) and the small radome under the yardarm is probably Bell Push. The conical antennas on the top of the bridge are sometimes identified as Pert Spring (for satellite navigation, as in submarines), and the small radome just visible on the right-hand side of the picture is Shot Dome (communications). In this ship, Bell Nip apparently replaces the earlier Bell Slam/Bell Tap combination. (S. Zaloga)



The *Sovremennyy*-class destroyer *Boevoy* shows a Wine Glass jammer with, below it, the 2 components of Bell Shroud. In most ships the small radome, with its bulb, is mounted above the large shroud. (S. Zaloga)



Bell Shroud on board the *Udaloy*-class destroyer *Admiral Vinogradov*, 1990. (S. Zaloga)



The cruiser *Kirov* displays her Side Globe jammers and a variety of Bell-series radomes in this 1981 photograph. The large radomes near the Side Globes and Rum Tubs are probably Bell Slam and Bell Tap; the small radome between the 2 Rum Tubs is probably Bell Push. Above it is Bell Crown, a communications antenna. The radar is Top Pair, and the 2 large flat radomes are Round Houses for tactical air navigation, analogous to the U.S. TACAN. The small radar above Bell Crown is Palm Frond. (U.S. Navy)



Bell Squat on the yard of the *Udaloy*-class missile destroyer *Admiral Vinogradov*, 1990. (S. Zaloga)



A heavily shrouded radome, apparently an auxiliary Bell Squat, on an outrigger on the foremast of the destroyer *Admiral Vinogradov*, 1990. The shielding testifies to considerable electromagnetic interference from shipboard radars and communications gear, such as the Round House tactical-air-navigation antenna in the upper right-hand corner of the photograph. (S. Zaloga)

data, and an intermediate receiver/tracker is interposed between it and the fine tracker associated directly with the jammer. This is an EW equivalent of what was once standard radar practice in many navies, i.e., the use of a broad-beam air-search radar to cue a target-indication radar, which in turn cued a target tracker. The target indicator (equivalent to Bell Clout, in this case) was a TWS device, whereas the target tracker was dedicated to a single target and provided much more precise data.

Bell Push appears to be the successor to Bell Clout, in the *Kirov* and *Slava* classes. Presumably, it has a wider frequency range since it is associated with the combination of Side Globes and Rum Tub.

Bell Nip is associated with the Rum Tub jammer. A pair of these conical radomes (of 2 different sizes) is associated with each pair of Rum Tubs on board a *Slava*-class cruiser.

Bell Shroud is the large radome just forward of the bridge in Krivak-class frigates. Its size suggests that it is the replacement for the earlier Watch Dog. Destroyers and frigates carry 2 Bell Shroud and 2 of the much flatter Bell Squat (on yardarms), a suite introduced about 1970 (for Krivaks, modernized Kashins, and *Udaloy*s). These ships lack any associated jammer; the receivers may be used to trigger chaff firing. Bell Shroud is recognizable by its tapered shape and by the knob (presumably a secondary radome) on its top. The shape of Bell Squat suggests that it is a monopulse DF array.

Bell Crown is a communications antenna.

◆ Brick Group (Brick Spit and Brick Pulp)

These passive threat-intercept and -warning systems for submarines were delivered from the late 1960s on, beginning with Victor and Charlie. Many submarines have only Brick Pulp. In Delta-I/II, Brick Pulp is supplemented by Squid Head. In contrast to Stop Lights, this group have radome-enclosed antennas. They are, therefore, probably U.S.-style rapidly spinning antennas rather than British-style wide-open DF systems. The advantage of the rapid spinner is that it has very high gain, so it can detect an airplane at a great distance, though it may well miss an intermittent transmission. The long-range detection would seem the more likely option for a submarine because an approaching airplane will use its search radar almost continuously.



Brick Pulp (2) on board a Victor-class submarine. The other visible masts are: (1) the Snoop Tray radar, (3) the VHF antenna, (4) the VHF antenna, and (5) the search periscope. This type of submarine has a total of 9 masts, the others carrying Pert Spring (navigation) and Park Lamp (VLF/LF reception), an attack periscope, and a snorkel. (*Sea Power*)

◆ Rim Hat

This ESM system is integrated with the Snoop Pair submarine search radar.

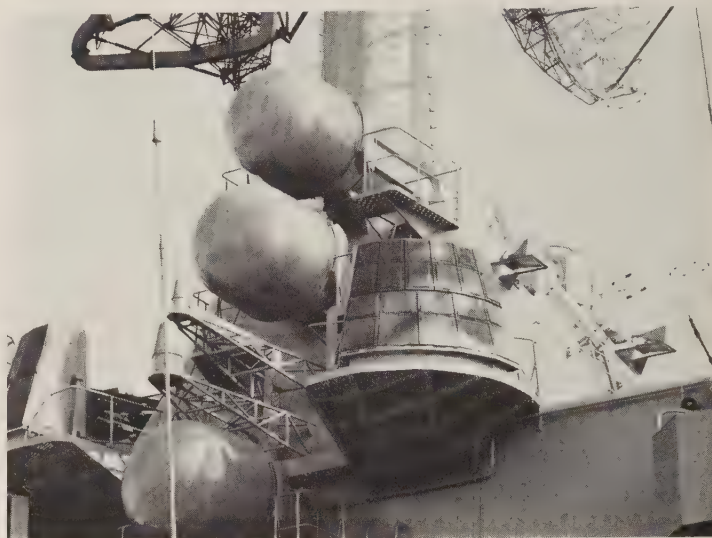
◆ Rum Tub

Rum Tub is a set of 4 radomes, divided into quadrants; each is split horizontally into a wider base and a narrower top, and each segment is further split into segments (5 at the base, 6 at the top), each segment showing 2 square plates, 1 atop the other. The appearance is quite unlike that of earlier Soviet radomes and may indicate some form of electronic scanning, like the lens operation of the U.S. SLQ-32. Each quadrant of Rum Tub is associated with a Bell-series radome. This association strongly suggests that Rum Tub is a jammer, covering a higher frequency band than Side Globe. If that is the case, then it may use some form of electronic scanning to track rapidly maneuvering antiship missiles such as Harpoon. However, Wine Flask, which replaced both Side Globes and Rum Tub, shows no signs of electronic scanning.

Rum Tub supplements the Side Globe series in large ships; it was initially installed on board the *Kiev*-class carriers and the cruiser *Kirov*, the *Slava* class, and then on board the modernized cruiser *Kerch*. Thus it first appeared about 1974 and was presumably developed sometime in the mid-1960s. Its origins, then, would coincide with the appearance in service of Ku-band aircraft radars (e.g., on the A-6 Intruder). It probably also covers at least some missile-seeker frequencies.

◆ Side Globe

Side Globe is reportedly a broad-band jammer. It consists of vertical pairs of radomes, invariably 2 pairs on each side of a ship, on the side of a tower mast or mack. Each vertical pair is accompanied by a Bell-series radome. Side Globe was a standard Soviet heavy-ship system of the late 1960s and later, in the *Moskva*, *Kresta-I* and *-II*, *Kara*, and *Slava* classes, and in the large cruiser *Kirov*. This system replaced the earlier Top Hat.



Side Globes and Rum Tub radomes on board the missile cruiser *Marshal Ustinov* at Norfolk, 1989. The 2 conical radomes between the Rum Tub quadrants are Bell Nips; presumably, they are analogous to the Bell-series radomes associated with Side Globes (which in this ship are carried on the yardarm). The 2 waveguides entering the Rum Tub quadrant suggest 2 bands, which would correspond to the 2 Bell Nips. (S. Zaloga)

As in the Western RAMSES system, each pair probably consists of a target-tracker and a jammer. Two identical directional antennas are used, so the tracker can achieve sufficient precision in measuring target parameters. The identification of 2 distinct Bell-series radomes with the 2 pairs of Side Globes on each side of a ship suggests that the 2 pairs cover different frequency ranges. The sheer size of the Side Globe radome suggests a very high gain antenna, and reportedly Soviet jammers produce very high effective radiated power.

Side Globe appeared in 1967; it was, therefore, probably designed in the early 1960s, when the sole important threat to Soviet ships was Western aircraft; the system is, therefore, presumably designed to jam aircraft search radars. To do that it would have to operate at relatively long range (hence the need for very high power), in the S- and X-bands. In the early 1960s the U.S. Navy was just beginning to move toward Ku-band in attack-aircraft radars (such as APQ-126 and the A-6 sets). Comparison with Western jammers such as RAMSES, which have much smaller antennas, suggests that the system uses high effective radiated noise power instead of some more subtle deception mode, such as false-target generation.

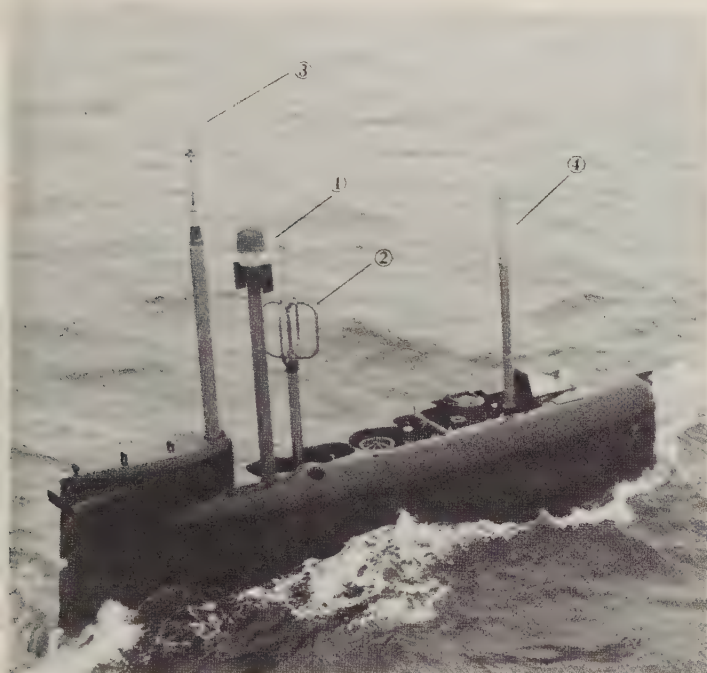
In the *Kiev* and *Slava* classes and in the cruiser *Kirov* the usual Side Globe installation is supplemented by Rum Tub. Rum Tub was also installed when the cruiser *Kerch* was refitted in 1988 with her new main air-search radar.

In the *Slava*-class cruiser *Marshal Ustinov*, new conical radomes were mounted near the pairs of Side Globes. In Western ships such radomes usually protect broad-band omnidirectional antennas.

The Soviet name for Side Globes is Gorzuf (after a town in Asia); the associated Bell series (D/F and emitter identification) is Zaliv (Bay).

◆ Squid Head

This standard submarine ESM antenna replaces Stop Light in many units. It can be distinguished from Brick Pulp by its smaller overall size and by the array of spiral antennas at its lower edge.



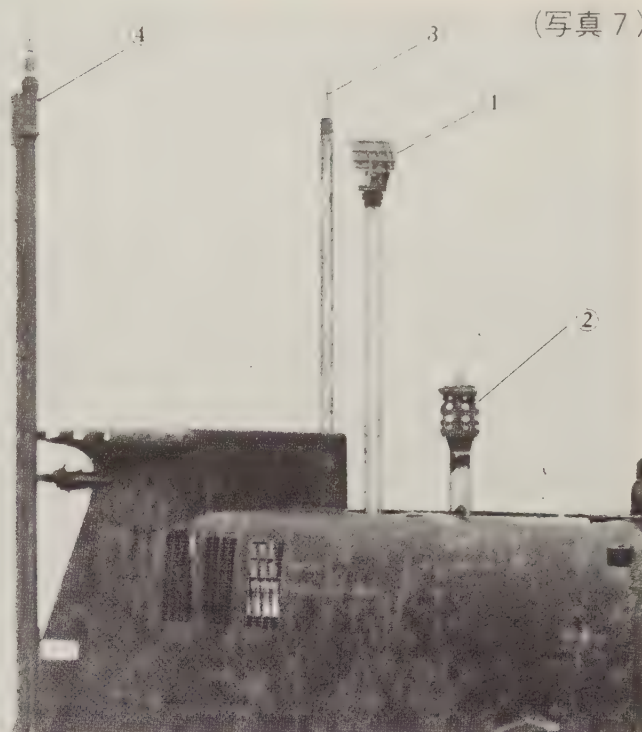
Squid Head (1) ESM antenna on board a Tango-class submarine. Antenna (2) is Quad Loop, a radio DF (the very similar Park Lamp, which has more loops, is a VLF/LF receiver). (4) is a periscope, and (3) is an HF whip. (Sea Power)

◆ Stop Light

This submarine ESM array was introduced about 1957. It is installed in submarines of that vintage (Foxtrot, Golf, Hotel, Echo, November). The Soviet name is Machta. This system is roughly analogous to Watch Dog, but there is only a single (octagonal) radome with the 4 tiers of horns (8 horns per tier, or band). A radome on top presumably houses an S-band dipole; the horns cover the X-, C-, and S-bands (probably 2.5–10 GHz). DF accuracy is probably about 10 deg. This system was replaced by Brick Group in submarines completed from the late 1960s on (Tango, Charlie, Victor, Yankee).

◆ Top Hat A, B

The first Soviet naval jammers, Top Hat operated in a 500-MHz band around 9370 MHz, with an output (in the original version) of 150 W CW using noise-modulated AM. There was a directional antenna (4-deg beam, 24–28 dB gain). In a few cruisers



Stop Light B (the A version lacks the pimple, presumably for an IFM, at the top of the array) (2) on board a Foxtrot-class submarine. The other antennas are (1) the Snoop Tray search radar, (3) the VHF whip, and (4) the HF whip. (Sea Power)

and destroyers Top Hat replaced a radar. Top Hat first appeared about 1962. It was replaced by Side Globe.

In Modified *Skoryys*, the jammer was mounted on the centerline, and 2 shallow cylindrical radomes (which presumably contained the directional ESM antennas supporting the system) were mounted on the sides of the ship.

Presumably, the ideal arrangement was paired jammers and receivers, as in the later Side Globe. A *Skoryy* probably lacked the reserve of top weight that would have been required and had to make do with a single jammer, on the centerline. However, *Kynda*-class cruisers and *Kashins* had paired jammers and receivers, an arrangement equivalent to, and presumably leading to, that in the later Side Globe. Unlike the Side Globes, Top Hat used widely separated ECM receiver and transmitter radomes, and they were not always identical. Presumably, the Side Globe's configuration was chosen to avoid the parallax and antenna mismatch problems inherent in the earlier arrangement.

Top Hat can be recognized by its squared-off appearance, as contrasted with the rounded shape of a Bell-series radome.

Kiev-class carriers are sometimes credited with 4 Top Hat A and 4 Top Hat B radomes.

◆ Watch Dog

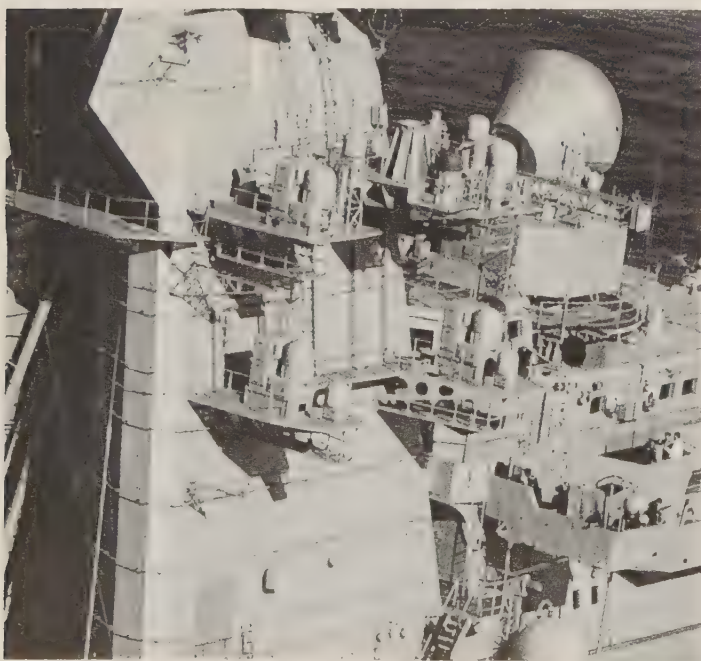
The first Soviet ESM system, Watch Dog was introduced about 1957 and is still in service. Watch Dog is apparently a wide-open system, its array consisting of a cylinder carrying 4 tiers of microwave horns (8 per tier). Typically a ship carries 1 array on each side, each backed by a reflector. Presumably, each horn is tuned to a fairly narrow band, for a combination of threat warning, direction finding, and identification, over a 1–12 MHz band. In a *Kotlin*, for example, Watch Dog is mounted on the radar platform on the foremast. This system was apparently enclosed in radomes in later ships.



Watch Dog ESM (inboard of yardarm) and the Top Hat jammer it controls (lower left), on board the Kashin-class missile destroyer *Strogii* at Massawa, 1972. (Royal Navy)

◆ Wine Flask

This is a new jammer replacing both Side Globes and Rum Tub. It first appeared in the cruiser *Frunze*, completed in 1984, and



The battlecruiser *Frunze* displays the generation of jammers and ESM antennas that replaces the Side Globe/Rum Tub series. The 4 large vertical radomes are Wine Flasks, originally called Footballs. The small adjacent radomes, painted light gray, are Bell Thumps and Bell Bashes. The single dark-colored radome is probably Bell Crown. The small white antenna on the yardarm is probably Shot Dome. (*Sea Power*)

also in the carrier *Novorossisk*. The 4 antennas on each side are paired horizontally and vertically, with 1 vertical pair at each corner of a tower mast. Each big vertical Wine Flask radome has a smaller Bell Thump associated with it. This device has also been called "Modified Football" in the past.

The radome is substantially smaller than Side Globe, so the enclosed antenna presumably has reduced gain. That would be acceptable if the jammer depended more on deception than on pure noise, and such a change would be a logical consequence of improving Soviet electronic sophistication. Because none of the radomes is very close together, it seems unlikely that the pairing represents tracker/jammer combinations. Rather, each radome probably is vertical to accommodate stacked trackers and jammers. The vertical pairing probably represents a division by frequency band (presumably, Wine Flask is a broader-band device than Side Globes/Rum Tub), and the horizontal pairing provides the ability to deal with multiple targets.

◆ Wine Glass

This device is carried on board *Sovremennyy*-class destroyers. *Sovremennyy* was completed with 4 Wine Glass jammers, but the more usual complement is 2, 1 on each side of the forward



Wine Glass is the large radome visible just atop the bridge wing of the *Sovremennyy*-class missile destroyer *Otlichnyy*. The squat radome below it appears to be the upper portion of Bell Shroud; the radome on the yardarm above is Bell Squat. Other ships of this class have only Bell Shroud and Bell Squat. (S. Zaloga)



Wine Glass (inboard) and (probably) Bell Crown (outboard) on the mainmast of the missile destroyer *Admiral Vinogradov*, 1990. (S. Zaloga)

superstructure. Wine Glass resembles Rum Tub in shape but is smaller and covers 180 rather than 90 deg. It is probably the successor to Bell Shroud and, therefore, most likely an ESM device (ultimately the successor to Watch Dog).

Later units of the *Udaloy* class (from *Simferopol* onward) have 2 new radomes, presumably ECM-related, at the base of their mainmasts.

◆ Communications Intercept Systems

Cage Pot Kiev, Moskva, Slava, Kara, Kresta II, Kresta I, Kynda, and Mod Kashin classes

Grid Crane VHF-UHF intercept: *Slava* class

Site Crane VHF intercept: *Kynda, Sovremennyy, Kashin, Nanuchka, Petya, Ivan Rogov, and Alligator* classes

Sprat Star VHF intercept antenna, consisting of 2 bent dipoles of different lengths, apparently in the same plane. It is standard on combatants down to patrol boat size.

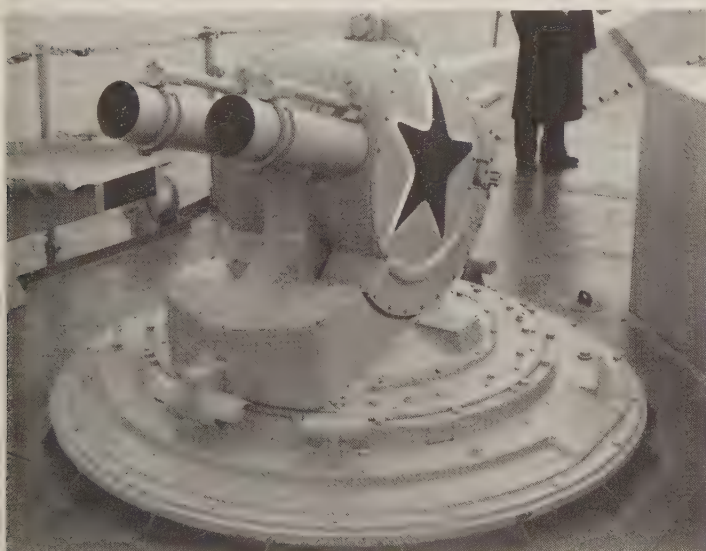
Cage Pot (in pairs) and *Sprat Star* (in pairs) are also carried on board intelligence-gathering ships (AGIs). The AGIs also have numerous specialized ESM antennas: Fir Tree, Log Maze, Trawl Net, Twin Wheel, Wing Fold. Specialized DF antennas: Cross Loop A, High Ring C, Park Plinth.

EXPENDABLES

Twin-tube trainable or 16-tube fixed chaff launchers are mounted on board many ships. There is also a spherical floating radar decoy containing a corner reflector.

One *Krivak, Bodryy*, has ten 10-tube chaff launchers in place of the usual four 16-tube units. The new 10-tube chaff launcher has also appeared on *Udaloy*-class destroyers. Unlike the standard 2-tube unit, it does not reload automatically from below decks.

The Pacific Fleet's *Udaloy*-class destroyer that visited San Diego in 1990 had small drums (distraction decoys) located along her deck edges; they are probably Soviet equivalents to



Chaff launcher on board the cruiser *Kerch*, 1989. This is the standard Soviet unit for ships of large destroyer size and above, generally mounted aft. Many older ships, including cruisers, still lack chaff launchers. Smaller ships use non-reloading units with more barrels, e.g., 16-barrel launchers in *Parchim*- and *Grisha-V*-class light frigates, in *Pauk*-class corvettes, and in *Tarantul*-, *Nanuchka*-, and *Sarancha*-class attack boats. The chute visible to the left is used to drop duds over the side. (Eric Grove)

Rubber Duck (DLF/SLQ-49), i.e., inflatable floating radar reflectors. In contrast, the short-range chaff mortars are seduction decoys. The *Sovremennyy*-class destroyer that accompanied the *Udaloy* had no deck-edge drums, but that probably means only that the drums are new and have not yet reached all ships (they



Not all the radomes on board Soviet warships are related to EW. The white radome visible above the electro-optical device and the chaff launcher is Shot Dome, for communications. This photograph was taken on board the *Udaloy*-class destroyer *Admiral Vinogradov*, 1990. (S. Zaloga)



A new countermeasures device on board the *Udaloy*-class destroyer *Admiral Vinogradov*, July 1990. Its appearance, particularly the buttons, suggests that it is a laser-warning device, developed in response to U.S. deployment of laser-guided bombs and missiles. Examples were scattered over the upperworks of the ship. (S. Zaloga)



Two of the new 10-tube chaff launchers, 1 horizontal and the other nearly vertical, on board the *Udaloy*-class destroyer *Admiral Vinogradov*, July 1990. (S. Zaloga)

certainly are not on board all *Udaloy*s). These drums are not the standard inflatable rafts common to modern Soviet warships.

UNITED KINGDOM

◆ Royal Navy Decoy Outfits

Current systems are:

DLA 6-tube Sea Gnat decoy rocket launcher, each barrel elevated 30 deg; mounted in 2 sets on each side of a ship, 1 at 30- and 1 at 120-deg angle to the centerline. Initial fit for Type 22 frigates, replaced by *DLB*. This is essentially the U.S. Mk 36; the rocket is RE Mk 4.

DLB 8-tube Sea Gnat decoy rocket launcher, to be replaced by a new *DLJ*.

DLC Knebworth/Corvus 8-tube 3-in launcher, often with 50-mm flare launcher atop.

DLD U.S. Hycor Mk 137 6-tube launcher for U.S. SRBOC Mk 36; several configurations.

DLE Plessey Shield for RFA auxiliaries.

DLF Irvin "Rubber Duck" floating corner reflector; also in U.S. service (*DLF*-2 launches the successor "Replica" decoy).

ELECTRONIC SYSTEMS

◆ Type 668/669

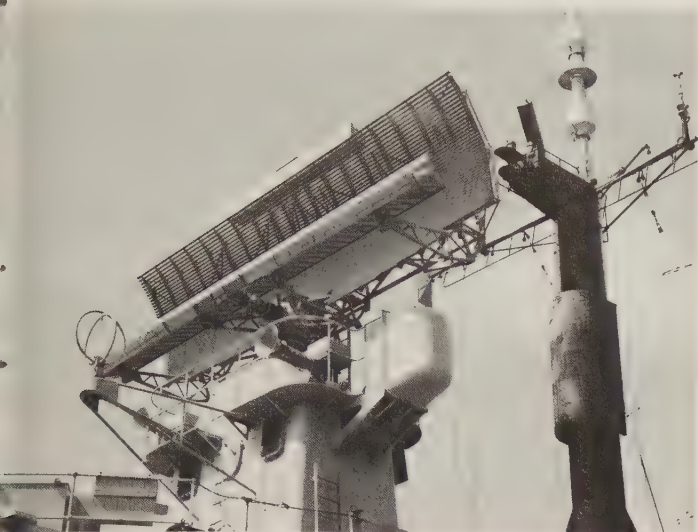
These jammers, associated with the UA-8/9 ESM system, were introduced in the early 1960s. The third member of the family was Type 667 (Cooky), a high-powered spot noise jammer (covering a 20-MHz band in S-band, and a 40-MHz band in X-band, in each case with a trainable 30-deg beam). By 1958 trials of Type 667 had shown that it could screen a carrier to a range of about 30 nm in S-band, or 10 nm in X-band, or screen a destroyer to 5 nm in S-band (and completely in X-band). The hope was that Cooky would screen a task force within an area roughly comparable to surface-to-air missile range, forcing enemy missile bombers (the AS-1 was the principal threat at the time) to approach so closely that the defending missiles could shoot them down. Types 668 and 669 were probably more sophisticated versions of Cooky, to include C-band jamming and pulse repetition (which was not yet available to the Royal Navy in 1958). The figures for Type 667's performance probably approximate those to be expected of the later 668/669.



A Type 669 jammer on board a "County"-class missile destroyer (second series). Type 668 has 1 jamming unit (rather than 2) on each side, presumably sufficient to deal with 1 rather than 2 threats at a time. (R. Cheung)

◆ Type 670

Racal's jammer, code-named Heather, is intermediate between early systems such as 668/669 and the UAF-1 jammer. Racal has supplied 27 sets for Type 42 destroyers and *Leander* Batch 3 and Type 22 frigates.

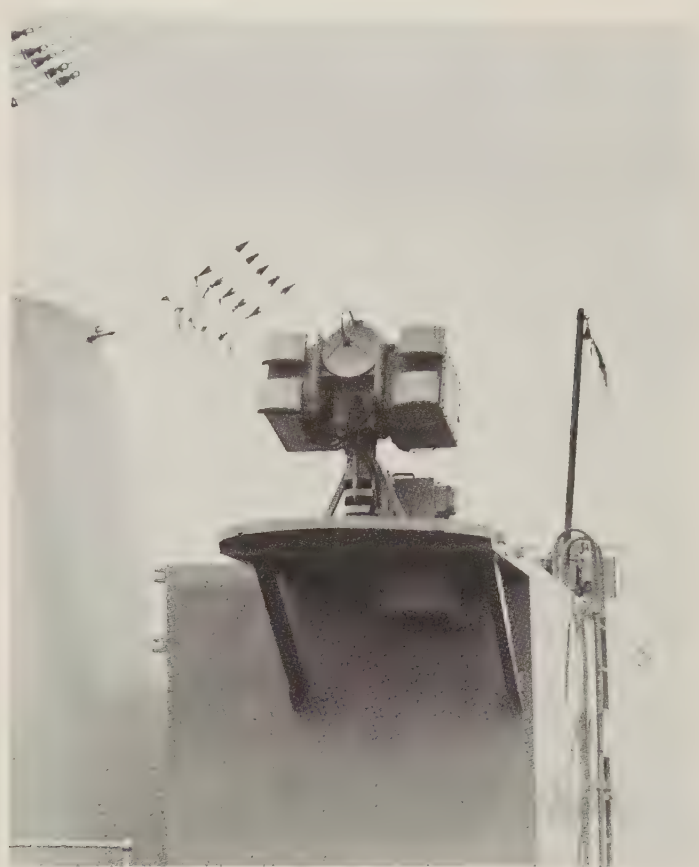


Type 670 (in the radome) is visible just below the Type 1022 radar, HMS *Manchester*, Antwerp, May 1990. The material wrapped around the mainmast, at the same height as the big air-search radar, is intended to absorb its signals so as not to create misleading echoes. (L. van Gin-deren)

◆ Type 675 (Guardian)/ETW

Thorn EMI's low-cost intercept system replaces Type 670. The first contract was announced in 1983. Guardian is an intercept system and associated jammer for both area (i.e., anti-surveillance) and point defense. Area defense is by pulse or barrage noise jamming; point defense (against missiles that have already locked on) is by RGPO and amplitude pull-off. Guardian can deal with several simultaneous threats. It employs 2 stabilized antennas (port and starboard or fore and aft), each including a DF receiver and transmitting antennas. The jamming antennas are mechanically steered for full azimuth cover and for elevation cover up to 50 deg. Each antenna consists of a pair of boxes around a pedestal, each box bearing 2 oblong antennas, 1 over the other. Bearing and threat data are fed by the associated ESM system, searching its own library for appropriate jamming techniques. Guardian can also use its own DF receivers to operate autonomously, classifying incoming signals. Because it incorporates a separate receiver, Guardian can remain open to new threats while jamming existing hostile signals.

Guardian incorporates a Thorn-EMI channelized ESM receiver, Wavefinder, which that company also offers on a stand-alone basis. Wavefinder is a hybrid receiver: signals are initially



Containerized Type 675(2) on board a Type 42 destroyer; a similar jammer is mounted on the other side of the container. The right-hand antennas are the receivers, the left-hand antennas the jammers. Type 675 and the commercial Guardian lack the dish antenna in the center of the mounting. (Thorn-EMI)

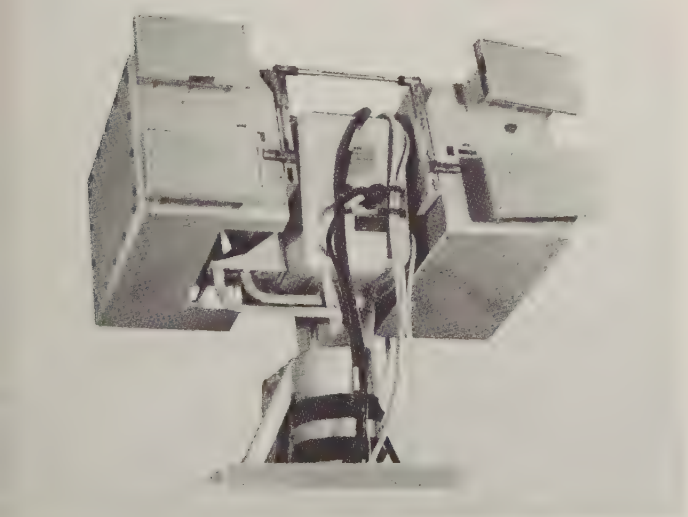


HMS *Nottingham* shows 1 of her 2 Type 675(2) jammers atop the container abaft her uptakes, 1990. (E. J. Grove)

channelized to reduce the loads on the superheterodyne and IFM stages.

Type 42 destroyers are normally equipped with Type 670 jammers, but in the Gulf at least some (such as HMS *Nottingham*) were equipped with Type 675 instead, on a pair of raised platforms, port and starboard, between funnel and mainmast. They may not always have been radome-enclosed.

Type 675 has been ordered to equip Type 22 frigates, Type 42 destroyers, and the *Invincible*-class aircraft carriers. It became operational in 1987. Thorn-EMI developed Type 675 as a less expensive alternative to an ESM/jamming system, Millpost (ordered 1975). Millpost, which was enclosed in an inflatable radome, ran trials in 1981-82, but a requirement had already been issued for what became Type 675(2). Guardian is the commer-



Basic Type 675 (Guardian). (Thorn-EMI)

cial derivative. Compared to Type 675(2), Guardian lacks the dish between the pairs of oblong antennas.

A new Early Threat Warning (ETW) program is intended to provide the existing Type 675(2) jammer with its own threat warner so that it can respond to changes in target-radar mode. As of June 1989, a contract was expected sometime in the summer of that year. Bidders included MEL and Thorn-EMI (the manufacturer of Type 675).

◆ Type 695

This is to be the jammer for Type 23 Batch 2 frigates. As of early 1990, the staff requirement had not yet been completed. The contract will be let on a competitive basis, one bidding team being Elettronica/Plessey.

◆ CXA

CXA is a communications-band (LF to A-band) direction-finding and threat-warning receiver found on board British nuclear attack submarines; it is an AEG-Telefunken Telegon. In British service CXA is arranged so that it can be augmented as required for signals or communications intelligence.

◆ FH 4/5

The standard HF/DF was developed during World War II; the characteristic "bird cage" antenna is still very widely used.



A standard FH-series (in this case serving FH 12) HF/DF array at the foretop of a *Leander*-class frigate, 1988. Below the "bird cage" array are omnidirectional antennas and 4 antennas for DF, with omnidirectional antennas (for IFMs) on the crosstree below them. They serve UA-8/9. (A. Raven)

◆ UA-1/UA-4

UA-1 was the first postwar British S-band DF set, for surface ships, ca. 1956. The antenna consisted of 4 horns mounted

around a mast, other sets of 4 each being added later to cover the C- and X-bands. The receivers were crystal videos without RF amplification, and the display showed intercepted signals as radial lines showing direction. Direction finding was by amplitude comparison, and a loudspeaker gave the PRF as an audible note. Operators tried to recognize radars by the combination of FRF and timed scan rate (antenna rotation rate).

These systems were later upgraded by adding a pulse analyzer (outfit YAF), 68 of which were bought after tests aboard HMS *Ocelot* and HMS *Ulster* in April and May 1971. This improvement was also bought for Brazil, Chile, and the Netherlands (for the *van Speijk* class); in all, Thorn-EMI had manufactured 80 by the end of 1973.

UA-2 and UA-3 were related systems for radar-picket destroyers, and UA-4 was a submarine-mounted equivalent, used primarily for warning.

◆ UA-8/9/10 (Porker)

These older passive intercept systems were derived from the original MEL IFM system, Pendant, which appeared in the late 1950s. Coverage: UA-8, 2.5–4.1 GHz; UA-9, 7–11.5 GHz; UA-10, C-band (also reported that each covers a 500-MHz band, so it may be coarse-tuned over the whole band, with IFM over 500 MHz). UA-8/9/10 are analog systems, and the display is a polar plot of frequency against bearing. The digital successor to these systems is the MEL Susie (see below). Compared to UA-1/4, these sets use broader-band superheterodyne receivers of greater sensitivity. UA-8/9/10 also introduced facilities for isolating and analyzing specific signals, using a library of known signal characteristics to identify them. Finally, these sets introduced pulse blanking, so that they would not pick up pulses from the ship's own radars (which would have swamped the much weaker pulses from distant radars). UA-8/9/10 have 4-channel amplitude-comparison DF systems similar to those of UA-1/4.

UA-8/9 are typically mounted together on a masthead, with their arrays superimposed.

Like the roughly contemporary U.S. WLR-1, UA-8/9 required the operator to search through the spectrum, find signals, and classify them. Operating experience demonstrated the need for an automatic mode (Project Tonga), a requirement eventually met in UAA-1. Feasibility and definition studies were conducted in 1963–66, project definition was completed in March 1966, a design and development contract was let late in 1967, and the prototype appeared on board HMS *Grenville* (delivered September 1969, in service January 1970).

◆ UA-11/12

UA-11/12 are Racal ESM sets for British SSBNs and SSNs, respectively. The associated array normally surmounts the dedicated ESM mast. UA-11/12 is used for precision bearing- and frequency-measurement, but reportedly its operation is slower and requires much greater operator concentration than does a more recent set. UA-11/12 dates from the 1970s. These sets are being replaced by Outfits UAB and UAC.

◆ UA-13

This passive array (25–1400 MHz) on *Ariadne*, *Cleopatra*, and *Phoebe* consists of a conical D/F antenna at the masthead, with projecting dipole arrays.

◆ UA-15

Racal's add-on to existing Royal Navy ESM systems extends coverage to the 12–18-GHz band.

◆ UAA

See Abbey Hill below.



UA-13 array on board a British frigate at Portsmouth, 1988, with UA-8/9 arrays below it. (A. Raven)

◆ UAB/UAC

UAB/UAC are Racal ESM sets for British SSBNs and SSNs, respectively. UAC has been installed on board *Trafalgar* and *Swiftsure* classes since 1985 and will be on board the new *Upholders*. UAC-3 will be on board the new Trident missile submarines. In existing submarines, outfit UAB is being replaced by the Racal outfit UAP.

◆ UAF-1

The Type 23 ("Duke"-class) ESM suite by Racal is the first Royal Navy ESM system to employ color displays. The antenna is an 8-port array atop the foremast. The system looks up intercepted signals in its library, displaying signal identity, bearing, and threat significance in tabular form, plus raw data on a frequency-bearing display that can be overlaid with symbology. There is also a manual pulse analyzer for further analysis of specific intercepts. The first production sets were delivered in the fall of 1989, for installation on board Type 23 frigates. In collaboration with AEG, Racal proposed a modified UAF(1) for the abortive NATO frigate.

Although UAF(1) is being fitted to the new Type 23 frigates, it is no longer considered adequate in view of the large number of high-PRF emitters, such as point-defense systems. The Royal Navy has, therefore, requested a new higher-capability UAF(X) for Type 23 Batch 2 frigates; Racal, Marconi, Thorn-EMI, and Plessey submitted bids in February 1989. UAF(X) was to use an identical ship interface (antenna system and front-end receiver),



HMS *Trafalgar* shows her ESM search outfit (UAB) atop a telescopic mast. The other two masts are, fore to aft, the snorkel induction (air intake) and the diesel exhaust for her emergency diesel. Forward are a radar mast and two side-by-side periscopes, all retracted. This photograph probably dates from 1985; more recent ones show a much more elaborate ESM array, with at least four monopulse DF antennas (probably spirals) around the broad-band cone visible here, and a short dipole surmounting the cone. These two antenna systems may be part of UA-11/12, the simpler cone being the UAB antenna. (G. Arra via *Ships of the World*)

but would have better man-machine interface and better processing.

Racal is offering a UAF(1) modified to use its SADIE VLSI processor; the latter has already been chosen for Royal Navy EH-101 helicopters. The receiver would use filter banks to channelize incoming signals, scanning each channel separately.

Marconi is offering a developed version of its UAG (developed for auxiliaries). In this case signals are channelized by Bragg cells. An experimental Marconi 500-MHz Bragg cell broke incoming signals into 500 parallel frequency channels (each presumably 1 MHz wide, and each having its own detector).

Thorn-EMI is also offering a channelized receiver; it claims that it can achieve ELINT precision in such a device and that its channelized receiver can detect signals at least as well as a conventional wide-open device. Moreover, the company claims that channelization makes the signal-to-noise ratio in each channel so high that its system can detect the sidelobes of a radar and, thus, can detect a sector-scanning set even if the latter is not pointing at the receiver. Thorn-EMI also proposes signal analysis by parallel computer (transputer). The faster the analysis, the larger the library that the system can consult. The company's generic Wavefinder ESM system can accommodate a threat library 10-15 times as large as that employed by a conventional ESM system.

No details of the Plessey system have been made public.



UAF-1 array at the masthead of HMS Norfolk, with Type 996 radar above, May 1990. (A. Preston)

◆ UAG-1

UAG-1 is an ESM/chaff-triggering system for patrol craft up to fleet auxiliaries. The requirement for this system was issued about 1983. Marconi was chosen, and the first application will be the new *Fort*-class AOR; UAG may also be installed on board the new LPD, the aviation training ship, and the proposed aviation support ship. This system is based on Mentor (see below); Mentor A was tested on board an RFA in 1987.

The first UAG system was delivered for trials in February 1989. It employs an omnidirectional antenna and 6 DF antennas, covering the 2–18-GHz range. As installed on board the new underway replenishment ships (AOR), the DF antennas are mounted on the sides of the radar platform. Marconi, which developed UAG, claims that it is the only ESM system that can overlay a synthetic picture on raw video. The 2500 radar-mode library can be searched in 1 sec, compared to 26 sec for standard Royal Navy systems that list only 200 radar modes. The export versions of UAG are Mentor 1 and 2.

◆ UAH

UAH is *Oberon*'s ESM suite; see Manta below.

◆ UAJ

Racal's ESM suite for *Oberons* is a modified Porpoise. UAJ uses the same display and processor as the Cutlass surface-ship set.

◆ UAL

Churchill-class SSNs' suite is similar to UAH (and, therefore, to Manta). UAL will also probably be retrofitted in other British nuclear attack submarines.

◆ UAP

UAP is an ESM suite by Racal; see Sabre below. UAP was selected by the Royal Navy in 1987; it employs the SADIE processor. UAP has much in common with the UAF of Type 23 frigates and will equip British submarines; it underwent sea trials late in 1989. The UAP(1) version will equip most British submarines; UAP(2) is the existing UAC, updated and with new antennas added. UAP(3) is for Trident submarines. UAP will form the basis of the Racal bid for the integrated ESM of the new SSN 20 class. Racal offers an export version of UAP(1) as ISIDORA III.

UAP shares the SADIE processor and the high-definition VU1400C color display with UAF(1). It is unique among British submarine ESM systems in providing an on board training facility. A typical system has a 2-bay console with 2 CRTs, 1 typically showing bearing vs. frequency (in a B-scope format); a typical display shows a box indicating accuracy limits around a detected signal. The second screen is an alphanumeric tote. The operator communicates with the system via a main keyboard plus 4 smaller ones splayed out to its right.

◆ UAR

UAR is the ESM suite for royal fleet auxiliaries, such as the new *Fort*-class AOR.

◆ UAS-1

Continental Defence Electronics's microwave surveillance receiver (RX-740 series) operates at 1–18 GHz (extendable down to 100 MHz and up to 40 GHz). Frequency resolution is 10 kHz (100 Hz is available as an option). Dynamic range is 60 dB. The receiver can sweep continuously over a frequency range, or it can step between any 2 preselected frequencies and search over a preselected range (minimum 50 MHz up and down) around any set frequency. Up to 99 channel steps can be preselected, stored, viewed, and recalled. Scan time is selectable between 100 msec and 100 sec. The spectrum display width is variable from 1 MHz to 50 MHz in 8 steps.

Continental also manufactures an Adcock DF array, a double stack of 8 vertical dipoles (4 for 2–500 MHz and 4 for 500–1000 MHz).

◆ UAT

The choice of MEL's EW suite for Type 23 Batch 2 frigates was announced in April 1990. It is derived from Manta and incorporates transputers for parallel processing. The choice of MEL reportedly reflects dissatisfaction with the Cygnus/Cutlass combination (UAF) in Type 23 Batch 1 frigates, and the UAT contract may include some improvements to the existing Cutlass/Cygnus.

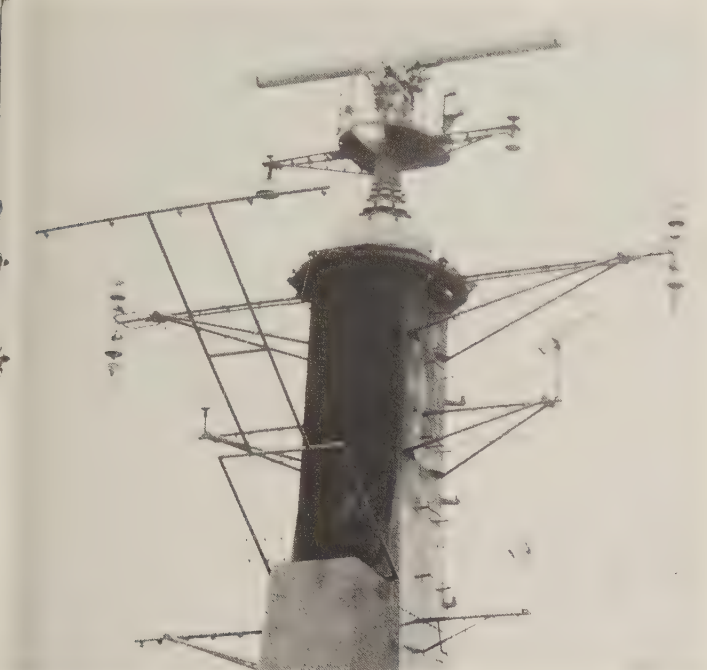
◆ Abbey Hill (UAA-1)

Abbey Hill is the ESM system developed by MEL for the Type 42 destroyer, then for Type 22 (and, later, Type 21) frigates. Abbey Hill is also being fitted to most earlier types. Frequency range is 1–18 GHz. UAA-1 is the passive reception and pulse-measuring portion of the system, using the MEL IFM. UAA-1 in turn was designed to work with a constant-beamwidth antenna with a direction-finding accuracy of better than 3½ deg, compared to 15 deg for other systems.

MEL IFMs operate between 0.7 and 18 GHz in a variety of ranges and can exploit pulses with durations as short as 0.05 microsec. There are 2 ranges: binary, for high integrity in dense signal environments, and quaternary, for less demanding situations.

The intercept and D/F antenna is a series of ports (radome-covered horns) typically mounted under the masthead radar antennas, and covering 4 bands (probably 8 per band). Frequency-measurement accuracy is reportedly 1.5 MHz, and bearing accuracy better than 3 deg.

In Abbey Hill, UAA-1 is combined with an EMI threat-identification system and, reportedly, with an EMI jammer code-



Abbey Hill (UAA-1) DF antennas under the platform of a Type 992Q radar antenna. The round objects on the small yardarm are presumably the associated omnidirectional antennas feeding the system's IFM. There are 4 tiers of DF antennas, corresponding to 4 bands. (A. Raven)

named Millpost. At least in the original form, Abbey Hill made a tentative identification of a received signal, but the system also provided raw data so that the operator could decide. In 1981 it was reported that the Royal Navy considered the signal environment in the North Atlantic too dense for anything but fully automatic operation and so was seeking an updated version of the threat-identification system.

As of 1989, existing UAA-1 systems were being upgraded to UAA-2 configuration to deal with denser pulse environments.

◆ Masthead Repeater (Bexley)

This countermeasure was introduced in the 1960s to provide protection against Styx and similar missiles, which steer in both altitude and bearing. The repeater pointed back toward the sea surface to provide a false target some distance from the ship, toward the incoming missile. This type of countermeasure is not effective against a sea-skimmer, which approaches at fixed altitude and has a radar that does not look down; but the repeater should be effective against diving missiles, such as AS-4/6.

◆ Cutlass

Cutlass is Decca's combined ESM/ECM suite for a very dense signal environment (up to 500,000 pps, as in the Middle East or Europe); Cutlass operates in the 2-18 GHz range, using 2 digital bearing and frequency discriminators (2-7.5 and 7.5-18 GHz). Signals are automatically compared with a 2000-radar library, and the results displayed in tabular form, with threats automatically ranked. The display can show up to 150 threats on 5 pages, and the 30 most important threats are displayed automatically. The display also shows the level of confidence to be applied to the identifications. Selected digital data can be sent to other systems (e.g., antiship-missile fire control). Signal analysis is by IFM, the ESM receiver operating on 2 channels (frequency and bearing). The bearing channel can be used for weapons direction. A typical installation, providing all-around coverage from the masthead, consists of an omnidirectional antenna (to provide an input to the IFM) and 6 ports for direction finding by amplitude comparison. Cutlass B1, which achieves much greater precision in direction, uses a 32-element array for phase-analysis direction finding (2-deg rather than 7-deg accu-



An Egyptian *Ramadan*-class missile patrol boat equipped with Cutlass ESM gear, visible clamped to her mast above the big radome of her Marconi S1810 radar. The masthead array is probably the AEG Telegon HF/DF. The Cygnus jammer has not yet been mounted aft. (Giorgio Arra)

racy). The more accurate direction-finder suffices to target antiship missiles such as Harpoon.

The small-ship version of Cutlass (currently Cutlass E) uses the same antenna as the earlier Racal RDL series. Cutlass B1 uses the Anaren DESM antenna, described below in the U.S. section. It is installed, for example, on board Danish *Willemoes*-class fast attack craft, Danish *Nils Juel*-class frigates, and later Turkish MEKO frigates. A modified version is going on board German S143-class fast attack boats.

Cutlass generally provides (a) bearings over the entire 2-18-GHz range, with preamplification over 4-18 GHz; (b) IFM over the whole range; (c) signal processing/library look-up; and (d) CW bearing and frequency measurement over 2-18 GHz. As of 1988, frequency and bearing accuracies of 5 MHz and 5 deg were being claimed, over the 0.6-18-GHz range.

Cutlass can incorporate its own responsive noise jammer, which can track the target and can provide either spot or barrage noise. Cutlass can also be integrated with chaff launchers and with self-defense weapons such as Sea Wolf. In a typical installation, Cutlass operates with a Cygnus directional jammer.

The system is modular so that it can fit ships ranging in size from fast attack craft to frigates. Cutlass entered production in 1979. As of 1985, over 40 Cutlass systems had been exported, and this figure had risen to nearly 100 as of early 1988.

Cutlass was adopted in modified form for the Type 23 frigates (as UAF-1). Porpoise is a modified version, as are Octopus and Type 242.

Users include Bahrain (Cutlass E in FPB 62-class fast attack boats), Denmark (*Nils Juel* and *Willemoes* classes), Egypt (*Ramadan* class), Germany (Octopus for S143 boats), Kenya ("Province" class), Kuwait (FPB 57 and TNC 45 classes), Nigeria (*Erin'mi* class), Oman (Type 242 in "Province" class), Qatar (Combattante-III class supplementing DR 2000), Turkey (later

MEKO frigates), UAE (FPB 62 and modified FPB 38 classes), and the United Kingdom (UAF-1 for the first 4 Type 23 frigates).

◆ Cygnus

Racal's ECM system uses a narrow-beam tracking jammer (1–18 GHz). Cygnus was designed specifically to operate with the Cutlass ESM system, operating over a variable bandwidth for spot or barrage jamming. Cygnus has 2 separate antennas but 1 transmitter, so the system can jam 2 targets on a time-shared basis at maximum power. The associated IFM tunes the jammer within microsec of the receipt of a pulse. Radiated power is reportedly over 300 kW, which suffices to counter aircraft-surveillance and missile-guidance radars.

In 1988 it was reported that the latest version operates over the 8–18-GHz band (300 kW minimum power, 480 kW in mid-band), with 1/deg tracking accuracy.

Available jamming techniques include RGPO and false-target generation. A next-generation derivative now in production (Cygnus 2) uses a customer-defined ECM response code to respond to threats in its library. It will cover the range from 7.5–18 GHz. Maximum ERP is 480 kW in the middle of its frequency range, and 300 kW on average.

The Cygnus jamming dish antenna is flanked on its top and left side by interferometers (made by Anaren, a U.S. company), which it uses for target tracking. Each interferometer is accurate to within 0.2 deg. However, each can also function in a coarser mode. Thus the jammer can accept data from an ESM set with 20-deg accuracy, then refine those data to sufficient accuracy for jamming. By using the 2 interferometers, the system avoids the need for a separate directional receiver. Moreover, by using a special mechanism to differentiate target main lobes from target sidelobes, it can avoid the need for a separate omnidirectional antenna. An associated IFM can measure the target frequency to within 2 MHz. Once a target has been acquired, the pair of interferometers can point the dish to within an accuracy of 1 deg (elevation and bearing).

Each interferometer consists of 3 arrays—coarse, medium, and fine. The coarse beam is 40 deg wide. Once a signal has

been acquired, error signals from the coarse array place the signal within 10 deg, which is the width of the medium "zoom" beam. This array in turn positions the platform until the target is within the FOV of the narrow beam (2.5 deg wide). Each array is split in half and lobe-switched to track the target. Anaren claims that its approach overcomes multipath effects over water, an effect proportional to antenna beamwidth.

Interferometer frequency coverage is 8–16 GHz, and minimum pulse width is 150 nanosec.

Cygnus production began in 1977. Egypt ordered it for the *Ramadan* class in 1978, Bahrain ordered it in 1984, and it was ordered for the British Type 23 in December 1985. Users are Bahrain (FPB 62- and TNC 45-class fast attack boats), Denmark (Stanflex 300 class), Egypt (*Ramadan* class), Kenya ("Province" class), Kuwait (FPB 57- and TNC 45-class fast attack boats), and U.A.E. (FPB 62 and modified FPB 38 classes).

◆ Guardian

See Type 675 above.

◆ Hermes

Hermes is Marconi's airborne, shipboard, or ground ESM system.

◆ Manta/Sceptre/UAH

Manta, an ESM system for submarines, was derived from MEL's Rapids and was announced in 1983. Manta covers the 2–18 GHz range, providing automatic detection, analysis, and identification, and can feed into a tactical data system. The operator can override the threat library if the system picks up an unassigned signal. The capacity of the threat library is 2000 modes, and the operator can add another 100. The system intercepts signals at elevations between –10 and +30 deg, with horizontal, vertical, and circular polarization; 50 nanosec–100 microsec pulse width, and 0.02–40.0 sec scan period. Bearing accuracy is about 2 deg, sufficient for torpedo fire.

In 1987 MEL announced that it was working with Philips to extend coverage into the Ka-band (27–39 GHz).

UAH, for the modernized *Oberons*, is a version of Manta.

Sceptre is a version for surface ships, announced in 1985. It employs a boom-mounted omnidirectional antenna and a pair of mast-mounted DF half-arrays, each carrying 3 sets of 3 antennas (for 3 bands). The typical display consists of 2 side-by-side CRTs, 1 showing frequency against bearing, the other a series of best fits to library data.

MEL is currently delivering its Sceptre XL system to the Royal Swedish Navy for the *Göteborg*-class corvettes. The system operates in 3 bands, the DF antennas for the bands being mounted in 2 mast boxes. Frequency range is 2–18 GHz. Elevation coverage is +30/–10 deg, and bearing accuracy is 4.5 deg (with 2 deg available as an option). Sensitivity is –64 dBm, and dynamic range is 60 dB. The system can handle PRFs between 100 Hz and 300 kHz, pulse widths between 50 nanosec and 100 microsec, and scan periods of 0.02–40 sec. It is intended to detect radars with simple or modulated pulses, using frequency and PRF agility. Maximum pulse density is 1 million pps. The associated threat library covers 2000 emitter modes, with 144 emitter modes selected for threat warning and an operator library of 100 emitter modes.

Sceptre XL is the most complex of a series of Sceptre ESM systems. Sceptre X covers the same frequency range but uses a simpler antenna (single arrays of horns and spiral in each direction), is limited to 6 deg bearing accuracy, cannot deal with complex pulses, and has a threat library containing 1000 emitter modes. Dynamic range is reduced to 40 dB, and sensitivity is –50 dBm. Sceptre O is a much simpler system employing a single masthead antenna array (for both omnidirectional reception and DF), achieving a DF accuracy of 10 deg. The threat library is limited to 144 emitters; dynamic range is 35 dB, and sensitivity is –40 dBm.

Sceptre O is for fast patrol craft.

In September 1990 it was announced that Sceptre XL had been



Cygnus jammer, with the 2 boxes of its Anaren tracking receiver above the dish and to the right. (Anaren)

chosen for the ANZAC frigate program (10 systems were ordered, with an option for 2 more). This system is being developed into the new Royal Navy UAT (see separate entry).

◆ Matilda

MEL's Microwave-Analysis Threat-Indication and Launch-Direction Equipment is a lightweight low-cost intercept system for patrol craft and was announced in 1981. The design targets were £70–75 thousand and a masthead weight of 5 kg (to be reduced to 3–3.5 kg). The antenna is designed to provide a broad vertical beam, to detect both sea-skimmers and steeply diving (but not vertical) missiles. Typical coverage is 7.5–18 GHz. Frequency resolution: 1.5 GHz. Pulse-width range: 0.1–6.4 microsec (resolution 0.2 microsec). Bearing resolution: 45 deg. Sensitivity is –30 dBm, and dynamic range is 40 dB. Antenna gain (7.5–18 GHz range) is 6–8 dB.

Besides automatic threat recognition, Matilda provides a synthesized-voice warning of the impending attack, as well as advice of correct evasive action, within 1 sec of detection. A lamp indicates the sector from which the threat is coming, and Matilda can be connected to trigger an ECM system.

The system is optimized against locked-on or tracking radars. It avoids false alarms by scanning the rate at which incoming signals arrive, initiating action only when (i) more than 250 pulses of similar bearing, pulse width, and amplitude arrive in less than 500 msec, or (ii) continuous CW has been received for more than 100 msec. These conditions do not apply to secondary threats such as TWS radars.

The antenna consists of 4 spiral antennas (to intercept signals of any polarization), arranged in 2 matching halves that are clamped around a mast, each a tube about 115 mm in diameter.

MEL conceived Matilda as the simplest possible small combatant ESM system; it concentrated on the main threat, the locked-on missile or fire-control radar. Instead of using a library, the system looks for the generic characteristics of such emitters: low rate of change of bearing, constant pulse width, relatively constant signal strength, frequency 7.5–16.5 GHz. An MEL study of a wide range of missile radars showed that these characteristics were indeed common to virtually all and, therefore, that a valid generic warner could be built. Given such simplicity, Matilda can provide an alert within 1 sec of signal detection, and against a subsonic threat it provides at least 30 sec of warning, sufficient for some evasion. MEL argued further that chaff was the best instant countermeasure, particularly when the threat could not be identified in detail. It developed the Protean chaff system specifically to work with Matilda.

The parent PEAB company marketed this ESM system as Matilde, but in a more elaborate form, allowing the operator to do some signal analysis. As in Matilda, 4 horns clamped to the masthead feed 4 RF channels. However, information is displayed on a 12-in CRT that can show either signal direction or alphanumeric signal data. Threat evaluation is automatic, probably on the same basis as in Matilda, and hostile threats are listed as Threat 1; all others are listed as Threat 2, and further classified by the operator. Matilde is used to trigger Philax grenades identical to Protean grenades. Matilde uses the ship's FCS computer.

As of 1985, 12 Matildas had been ordered by the Royal Navy, to be integrated with Wallop's Barricade-series chaff launchers. Matilda E, an uprated version, was installed on board British "Hunt"-class minesweepers before they were sent to the Persian Gulf in 1987. Matilda E had been tested on board HMS *Dumbarton Castle* in 1986. This version will also be part of the PEAB EW system of the Finnish *Helsinki 2*-class fast attack craft. Other announced Matilda users are Egypt (October-class attack boats), Finland (Matilda E in *Helsinki-II* class; total of 9 sets bought), and Kuwait (8 on order as backups for Cutlass, given Cutlass's unreliability). The British Matildas are cross-decked among minesweepers going to particularly hazardous areas. The Korean navy may also use Matilda since this RWR is associated with the Protean chaff system that Korea has bought in some quantity.

Matilda was conceived as a very low cost RWR for merchant ships operating in the Persian Gulf, on the theory that it would reduce loss rates sufficiently to cut insurance costs, paying for itself. It is not clear whether any units were sold to private ship owners. For insurance and other legal purposes, a merchant ship carrying chaff rockets (Protean) would be a warship, so any merchant-ship captain would be reluctant to admit the presence of such a system. There were, however, occasional reports of rockets launched by merchant ships in the Gulf. Matilda reportedly suffers from a high false-alarm rate. The preferred method of operation would be to use a more reliable ESM system to trigger Matilda; once Matilda had been turned on (to launch chaff), the ESM system could focus on other threats.

◆ Mentor

This family of shipboard ESM systems, by Marconi, was announced in 1985 and was designed for small craft such as hydrofoils and minesweepers. The installation consists of an omnidirectional antenna and 4, 6, or 8 DF antennas. The system can be extended to mm wavelengths. Its library contains 3000 emitter modes, and it can have up to 100 programmable threat-warning channels. The display shows emitters in tabular form (typically track number, identification, bearing, frequency, PRI, and pulse width) as well as automatic warning information.

Mentor is built around a special-purpose digital signal processor that transforms incoming video for library comparison.

Mentor 1 is a simple missile warner (7.5–18 GHz, 9-deg bearing accuracy, –45-dBm sensitivity). Mentor 2 is a surveillance system (1–18 GHz, 6-deg bearing accuracy with 1-deg accuracy optional, –65-dBm sensitivity). Coverage can be extended into the MMW range. The masthead unit consists of 3 omnidirectional antennas and 6 DF antennas, presumably to cover 3 bands. Mentor 3 is the target-acquisition version, with bearing accuracy improved to 1 deg. The 6 usual channels are supplemented by a special dish (fine DF) channel. Elevation coverage is +50/–10 deg. The system can handle up to 1 million pps, with PRFs of 100–330,000 pps and pulse widths of 50 nano-sec–100 microsec; it can detect scan periods between 0.1 and 99 sec, and it can track 200 emitters simultaneously. Radar types recognized are: pulse, frequency-agile, PRF agile, frequency and PRF hopping, CW and high duty cycle, and FM-chirped pulse compressed.

The standard omni antenna is either 170 × 450 mm (5 kg) or 610 × 1240 mm (16 kg); the DF antennas are 445 × 457 mm (50 kg) or 1800 × 710 mm (100 kg). The masthead unit weighs 89 kg, and the ESM office set and console add 220–245 kg and 312 kg, respectively.

Extended versions are available for surveillance and for target acquisition (for the use of OTH missiles). Comparative characteristics, which are presumably typical of ESM devices, follow:

	Warning	Surveillance	Acquisition
Range	6–8 GHz	1–2 GHz	0.5–40 GHz
Accuracy	9 deg	6 deg	1 deg
Channels	4	6	6 plus dish antenna
Sensitivity	–45 dBm	–65 dBm	–65 dBm
Dynamic Range	45 dB	55 dB	65 dB
Amplitude Resolution	1 dB	1 dB	1 dB
Parameters in Library	1000	3000	3000
Processing Time	1 sec	1 sec	1 sec

Three versions, Mentor A, B, and C, were announced about 1987; they are export variants of UAG (see above). Mentor A and B are described as inexpensive variants of Marconi aircraft systems, something between an RWR and a full ESM suite. Mentor A identifies threat radars by their PRFs. Bearing accuracy is 10 deg, and typical processing time is 1 sec; coverage is

E- to J-band, with C/D-band optional. The library contains 2500 radar modes and provides audio warning with visual highlights. Marconi claims an MTBF of over 2000 hr. The display is similar to that of an aircraft RWR, showing emitters as alphanumeric symbols at their approximate bearings, the color of the symbol indicating its character (friendly, neutral, hostile, or unknown). The same display includes a table of emitters, giving their tags (as used in the bearing display), bearings, PRFs, relative amplitudes, and estimated identities. An adjacent display shows which automated warnings have been set.

◆ MIR-2

MIR-2 is the MEL ESM system for aircraft and small ships, for the 600 MHz–18 GHz range. MIR-2 uses 6 antennas, flush or externally mounted. The display shows frequency band, bearing, and amplitude activity; the operator can strobe to obtain true bearing and PRF.

See also Orange Crop in the Strike/Surface Warfare section.

MIR-2 equips British "Isles"-class OPVs. Reportedly, although Orange Crop was effective on board helicopters, it was unsuccessful aboard the OPVs; late in 1990 the Royal Navy was reportedly seeking an alternative. This situation was probably analogous to the problem the United States had with ALR-66(V)6; perhaps a shipboard system, unlike an airborne type, suffers from confusing reflections off the sea surface.

◆ Octopus

Octopus is a new Racal system recently selected by the German navy to replace the Thomson-CSF DR-2000s on board its Type 148 fast attack boats. It consists of a Cutlass B1 ESM system, a Scorpion jammer, and an AEG threat library. The German navy has specified 2 antennas: a wide-beam (40 × 40 deg) horn for area defense and a steerable carbon-fiber dish for point defense. Scorpion provides 150-kW mid-band ERP (50-kW minimum) and can jam up to 16 threats.

◆ Porpoise (UAI)

Racal's automatic ESM equipment for submarines (2–18 GHz in 2 bands: 2–8 and 8–18 GHz) is based on Cutlass. Parameters measured are bearing, frequency, signal strength, pulse width, and time of reception. Porpoise has a 2000-signature library, corresponding to about 400 radars (operating in different modes); and the operator can feed in another 100. The display shows emitters in order of threat priority, either in graphic (track) or tabular form. The highest priority emitters trigger both audio and visual alarms. The tabular display can show 25 tracks at a time, 150 in all being stored. Priority is based not only on the character of the emitter, but also on a calculation of the submarine's probability of detection, given the level of radar reflection from the masts, including the snorkel, and the sea-state.

Racal designed the Porpoise's mast specifically for the German Type 209 submarine, the most widely exported type. That boat required a nonretracting telescoping design. The antenna head is made of titanium, with an omnidirectional antenna (for IFM) surmounting 2 rows of directional ports for the 2 bands (6 in each row, spirals for the low band and horns for the high band). Signals are amplified in the head proper before being transmitted into the hull of the submarine for analysis.

Porpoise 2 is an improved version (DF accuracy 3 rather than 5 or 6 deg).

◆ RCM

Racal's (originally Decca's) RCM-series jammers were introduced in 1975 to work with other Decca equipment, such as the RDL series. RCM-1, which operates with the RDL-2 series, covers the 8–10-GHz range (using a high power CW TWT). RCM-2 series has its own IFM receiver and can handle several targets; 2 bands (5–9 GHz and 9–16 GHz) are available. The installation consists of transmitting and receiving antennas covered by a radome (2 radomes on larger ships). If a particular ESM signal is chosen, the system sets a 100-MHz slot around

it, the receiver searching within the slot to find the target frequency very accurately. The antenna trains and elevates.

The RCM-3B jammer is an improved RCM-2 with a processor and an IFM. RCM-4B has additional modes, such as noise covered pulse, combination jamming, and much higher effective radiated power. The original jamming modes were RGPO in RCM-1, with conical-scan deception added in RCM-2. RCM-3B and -4B have a memory loop to cope with frequency-agile radars. They have a responsive noise mode, in which the IFM is used to fast-tune a local oscillator to the frequency of the incoming pulse.

The RCM-3 gate-stealing jammer is now being added to large British surface combatants. The Nigerian MEKO frigate is fitted with the RCM-2 jammer (and the RDL-2 intercept receiver).

◆ RDL

Decca's RDL-series ESM system is used primarily to detect the enemy's radar-controlled weapons systems. Work began in 1968, the system being intended for Third World navies needing something less expensive and less sophisticated than existing Western ECM systems. By 1980 over 100 were operational in over 30 navies.

RDL covers a fraction of the 1–18-GHz band, the particular range depending on the version selected. The typical output is bearing, frequency, automatic pulse analysis, and alarm. The antenna consists of 2 semicircular units that wrap around a mast (so that it need not be positioned at the masthead); more can be added to expand frequency coverage to match specific threats.

Versions:

RDL-1 is the basic system, covering 2–11.25 GHz and including the APA-1C automatic pulse analyzer.



RDL-2/3 intercept and DF arrays around the foremast of a Brazilian frigate, 1986. Each array is split to fit around the mast.

RDL-1BC, for fast patrol boats, provides frequency band, bearing, automatic pulse analysis, and warning.

RDL-1BCS is a submarine version of -1BC, with an antenna consisting of 16 separate encapsulated elements (rather than a single encapsulated array).

RDL-2 adds the frequency of a particular threat. **RDL-257** extends coverage to 1–18-GHz; **RDL-268** adds frequency measurement.

RDL-2ABC, for larger warships, adds frequency measurement, visual pulse analysis, and RF amplification of the signal in the analysis channel for greater range and more effective analysis. The antenna consists of that for **RDL-1BC** plus additional units.

RDL-2ABC 6AC 8AC covers the entire 1–18-GHz range, with FM and automatic pulse analysis.

RDL-4BCS is a semiautomatic threat-warning system for submarines, covering 2.5–20 GHz. It provides instantaneous bearing and frequency measurement.

RDL-5 and -6 add D-band capability.

RDL-7 and -8 extend coverage to band J8.

The basic display is an A-scope (signals appear as spikes along frequency coordinate, presumeably corresponding to a mechanically or electronically scanned superheterodyne receiver). The operator selects the sector to be scanned in frequency and can select either auto-stop (the receiver stops scanning when it finds a signal) or auto-pause; in either case, the signal's frequency is read off digitally. Optional additions include fine tuning for better frequency accuracy, and the suppression of up to 3 known frequencies to avoid concentrating on known or friendly signals. Pulse-analyzing versions add a dual-trace pulse display, showing either pulse width or PRF in 2 ranges.

RDL-1C is an automatic pulse analyzer that can be added to any member of the series. It provides automatic digital readout of pulse parameters, either of all received signals or of those selected from the directional antenna array. Parameters for up to 5 emitter modes can be entered by plug-in circuit cards; the reception of a corresponding signal triggers an alarm, such as a warning light.

RDL-1C is a signal-recognition unit (with a 500-emitter library) that can be added to the basic **RDL** system.

RDL series users are Argentina (MEKO 140 frigates and TNC 5 class), Brazil (*Niteroi* class), Brunei (Vosper-Thornycroft missile boats), Iran (*Damavand* and Mk 5 frigates), Nigeria (MEKO 60 frigate, *Combattante-III*B- and FPB 57-class fast attack boats), and U.A.E. (TNC 45 class). The basic **RDL** wraparound antenna is also used in the later *Cutlass*, so it is difficult to distinguish between the 2 systems. **RDL** may also equip the Peruvian ex-*Daring*-class destroyers. It is not clear how these relatively limited sales can be reconciled with the manufacturer's claims given above.

◆ RACAL COMINT System

Racal introduced a new shipboard COMINT system in 1989, based on the company's land-based equipment. Two alternative antennas are used: a single compact stack for 90–400 MHz and a stack of 2 separate antennas for 20–500 MHz. The simpler antenna covers civilian and military marine bands; the more complex includes land combat net radio frequencies as well as paramilitary bands. These systems now incorporate a computer-controlled Fast Acquisition Receiver System (FARS). Changes of variable operating parameters, such as changes in signal level and target-activity level, are preset, and FARS filters incoming signals, e.g., to provide a display of the most recent active signals or of newly acquired signals.

In land applications, FARS has 2 alternative modes, scan and stop. It can scan at 40 MHz/sec or it can address up to 250 selected (listed) frequency channels, at the rate of 160 channels/sec.

◆ Sabre/Sea Lion

Racal's ESM system (Sabre for surface ships, Sea Lion for submarines) employs the company's SADIE signal processor and 14-in color raster display, both of which are also used in UAP and in the airborne Orange Reaper. Sabre is a development of the earlier *Cutlass*, covering the 0.6–40-GHz band with selectable bearing accuracy of 2 or 8 deg.

Sabre has been selected for the Danish Stan Flex 300, and Sea Lion for Danish and Norwegian submarines. These systems reportedly appealed to the Danes because of very fine DF accuracy, allowing them to distinguish individual targets on a crowded coast. The Royal Danish Navy requires 2-deg bearing accuracy since it hopes to use the system to target Harpoon missiles. The processor is SADIE, and this version of the system covers the 0.5 to 18 GHz band.

◆ SADIE

Racal's Segregation, Association, De-interleaving and Identification Equipment processor, for ESM, has separate elements for pulse segregation; for known emitter monitoring; for new emitter analysis; and for ESM processor control. The segregator recognizes pulses from emitters already characterized and segregates those pulses from new ones. That segregation allows the system to concentrate on new signals so that the system can function in very dense environments. The segregator uses the maximum number of monopulse parameters, e.g., frequency, pulse width, bearing, modulation flags, expected time of arrival, and expected amplitude. The monitor receives these data, including emitter number and whole pulse record, accumulating pulse parameters for each emitter and deriving exponential averages for the key parameters. The analyzer de-interleaves and characterizes emitters.

A typical SADIE consists of a segregator, monitor, 3 analyzers, 2 processors, and an operator/machine interface, all connected by a VME bus.

The SADIE processor receives parameters from the segregator and derives exponential averages for the key variables. Peaks that do not come from main transmitter lobes are rejected. The rest are passed to the ECM control processor (ECP), which performs a full scan analysis on all monitored emitters, if required. The analyzer is implemented on cards based on 68020 chips.

As of 1989, Racal had developed a new VLSI circuit (EWAM, extended window-addressed memory) for segregation in denser pulse environments. EWAM stores a window of values for each parameter in a set of emitters and rapidly matches input data against them. It can handle missed pulses and new scan bursts, automatically processing pulse data with invalid parameter measurements. EWAM uses 2.5-micron CMOS technology, incorporates 27,000 gates, and can process 25 emitters at a rate of 500,000 pps; 8 chips are mounted on a board to handle 200 radars simultaneously.

◆ SARIE

EMI's Selective Automatic Radar Identification Equipment, manufactured for the Royal Navy and for NATO navies, complements existing ESM systems. SARIE is an automatic ESM library look-up device (operating time about 0.1 sec) that accepts video from a receiver and displays the results of analysis (PRF, pulse width, and scan period) in alphanumeric form together with an assessment of the confidence of the identification. The system can also accept data on frequency, frequency agility, modulation, and scan type as aids to identification and will indicate PRF jitter. SARIE II contains data on up to 1000 radars, presenting data in tabular form.

SARIE II measures PRF between 31 Hz and 19.5 kHz (accuracy 1 Hz up to 1 kHz, 100 Hz at 10 kHz); PRF jitter; pulse width between 0.1 and 99.9 microsec (in increments of 0.05 microsec); and scan period between 0.1 and 59 sec (in increments of 0.1 sec). The system can compare a set of parameters with up to 1000 radars in less than 350 msec. Radar parameters are entered into the library by magnetic tape.

SARIE I, in production 1973–79, was sold to the Royal Navy and to other NATO navies; about 75 copies were made. Production of SARIE II began in 1979, and many were exported. SARIE was developed as a private venture, beginning in April 1972; it ran trials (with UA-8/9) on board HMS *Achilles* in November 1972.

◆ Scorpion

Racal's wide-beam jammer is capable of dealing with 5 targets simultaneously (to be expanded to 8 in later versions) in the 7.5–18-GHz range, with up to 50 kW of radiated power. The dual beam (wide/narrow) antenna weighs less than 100 kg, and the jammer operates in continuous, burst, cover, conscan, and RGPO modes.

Scorpion B is a wide-beam jammer version for the 7.5–18-GHz range, being supplied to the German navy; it can be integrated with Cutlass. Scorpion also equips Omani "Province"-class FPBs (others of this type are equipped with Cygnus).

◆ Sea Saviour

Racal's RWR (8–18 GHz) is designed for small combatants such as minesweepers. It uses a 4-port antenna, measuring bearing by comparing signal amplitude at the different ports to achieve 45-deg accuracy. Elevation limits are +40/–5 deg. Reaction time is less than 1 sec. Warning is by both digital readout and audio alarm. This system can also be programmed to fire decoys from systems such as Barricade.

◆ SPRAT

Racal's threat-warning system (8–18 GHz), designed for submarines, is mounted on the periscope. Detected pulses pass via the periscope cabling to an indicator in the control room; that indicator in turn uses LEDs to show the signal level, and a loudspeaker gives a corresponding audio alarm.

◆ Susie

MEL's solid-state ESM system has a frequency range of 2–18 GHz. Data are displayed in alphanumeric form. Susie automatically correlates frequency band, pulse width, and bearing, and displays these data together with PRF and signal strength. The operator can arrange for automatic tracking of selected targets and for an automatic lock-on alarm (i.e., missile alarm). Bearing antennas have 8 ports, for high accuracy. There are 3 versions, for fast patrol craft, frigates, and large warships. Antenna weight is 154–300 kg, depending on the version.

Susie-1 is intended for small warships. It equips the Dutch-built Indonesian frigates and is connected to chaff launchers. Susie-1 also equips Turkish *Dogan*-class fast attack boats and the Colombian FS 1500-type frigates (with Scimitar jammer and ARGO Phoenix II). Reportedly, it was bought for Malaysian Spica-M-class boats, but it appears to have been replaced by Israeli equipment. Susie-1F (for medium-sized ships) is a redesigned Susie-1, providing accurate frequency measurement.

Susie-2 is intended for medium-sized ships. The main improvement is to display precise frequency rather than frequency band; coverage extends down to 1 GHz. A threat library can be added.

Susie-3 is more sensitive and more accurate. It is probably the system on board the Indonesian frigate *Hajar Dewantara*, built in Yugoslavia. The Korean navy may also have bought Susie.

Susie was designed so that it could be used to control a Scimitar jammer.

Susie-1's performance: sensitivity, 30 dBm in fine range, 40 dBm in coarse range. Dynamic range, 50 dB. Antenna gain, 5.5–7.5 dB. Accuracy, 3.5 deg in fine mode. Pulse width, 0.1–100 microsec. Pulse repetition interval, 10 microsec (PRF 100 kHz) to 10 msec (PRF 100 Hz). Display write time, 18 microsec. The system displays frequency band and pulse width/bearing. It can auto-track 7 signals; it can store 5 signals, on receipt of which it triggers a warning signal, and it can store 2 signals that it blanks out automatically (i.e., own-ship or friendly signals).

These figures typify the very limited capacity of contemporary systems. Bands: 2–4, 4–7.5, 7.5–12, and 12–18 GHz. Susie 1F adds accurate frequency measurement (5 MHz) and is more sensitive (frequency receiver 40–47 dBm, optionally 65 dBm, gain 1–3 dB; the bearing receiver is the same as that of Susie 1). MEL offered 4 alternative antennas for these systems: A1, with a total of 24 antenna modules (to cover the 4 bands); A2, designed to support a Signaal search/fire-control "egg" (as in the case of the Indonesian ships); B1, which could share a masthead with a large air-search radar antenna; and B2, which differed from B1 in that access to the ESM antenna modules was from outside. A1/A2 weighed about 170 kg, and B1/B2 weighed about 315 kg. These arrays differ visually from the Signaal antenna in that there are only 8 radomes, each containing the antennas for each frequency range (presumably the 2 higher frequency bands share a single antenna). Each radome has a curved upper edge and straight sides.

MEL describes Susie as descended from UAA-1, but the antenna design, which is similar to that used in Sphinx, more likely derives from Signaal. CANEWS was a parallel development of UAA-1.

◆ TOAD

Marconi's Towed Offboard Active Decoy was conceived during the tanker war in the Gulf, and several sales were reportedly canceled when the war ended in 1989. TOAD is interesting mainly as a *civilian* ECM device, an attempt to protect merchant ships against attack. Early in the Gulf War there were reports that ships were towing corner reflectors to attract radar-homing missiles, but apparently these devices either did not exist or else were ineffective. After all, even the best corner reflector is unlikely to have anything like the radar cross section of a 100,000-ton tanker. Nor is it clear whether reports of chaff launchers on ships were accurate.



The Marconi towed decoy (TOAD), on display at RNEE 1989: the jammer in the radome is powered by the 2 propellers, which turn as the small boat carrying the decoy is towed through the water. The boat hull carries the Vosper-Thornycroft logo. (Author)

TOAD should have done better because it used active ECM techniques. It is an unmanned boat, towed by a ship, carrying wind generators and a solar panel, with a radome on top. Marconi also offered it in a catamaran version. TOAD was designed to operate in X-band, searching over a 100-MHz range for a seeker signal. It could handle 1 threat at a time, using noise and some deceptive jamming techniques. Frequency accuracy was within 5 MHz.

• Type 242

Racal's integrated ESM/ECM system was announced in 1987 (the number is Racal's, not the Royal Navy's); 242 has already been ordered by the Sultan of Oman's navy. This system combines modified Cutlass and Scorpion in a single console, and Racal describes 242 as one-fifth the weight of its predecessors (as well as cheaper and more reliable). The jammer is driven by the frequency-measurement unit of the ESM system, and the ESM data processor feeds the jammer directly. The processor is the new SADIE (see also the entry for Sabre/Sea Lion), which can handle pulse densities greater than 1 million/sec. The Type 242 ESM suite is based on that of the Royal Navy's EH-101 helicopter, covering the 0.5–40-GHz range.

EXPENDABLES

► Barricade/Super Barricade/Stockade

Barricade, a lightweight chaff launcher made by Wallop Industries, fires spin-stabilized 57-mm rockets from a stacked series of 6 open frames (3 rockets/frame), which point in various directions at different elevation angles, to form a large chaff cloud. The lower 3 sets of tubes are angled at 60 deg to each other for full azimuth coverage by long-range Stockade rockets (range 100–2000 m). The upper 3 sets fire short-range Pallisade rockets to 60 m from the ship to form a large overhead decoy for centroid seduction. Typically 1 set of 110-kg launchers is fitted to each side of a ship. Decoys are both chaff and IR. The original rocket had a range of 2000 m and carried a pound of chaff; that rocket dispersed its load centrifugally, spinning at 9000 spins/sec. Control is by a microprocessor that chooses the appropriate mode (distraction, dump/RGPO, confusion, seduction/centroid) and that also provides a recommended course to steer.

In 1981 Wallop announced a new 500-m rocket.

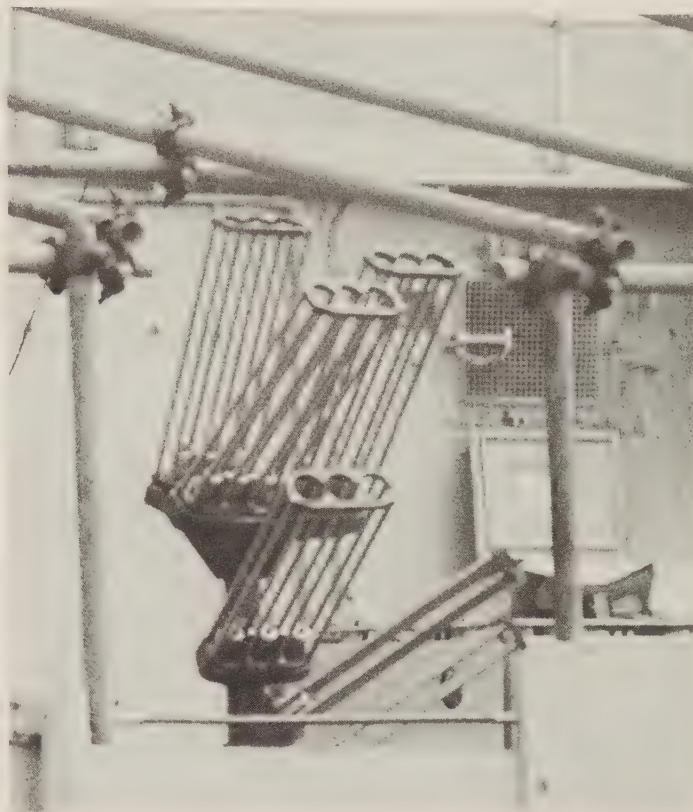
Barricade Mk II is controlled by a microprocessor, which stores decoy-firing sequences corresponding to various tactics.

Super Barricade fires a larger rocket (a new spin-stabilized fin round) than Barricade, to cover a larger ship. It uses 4 sets of triple barrels, the lower 2 trained 90 deg away from the rest so that a pair of launchers covers all 4 quadrants. The upper 2 sets are preset to point along the same bearing, but at different elevation angles. The upper 2 sets fire short-range Super Pallisade rockets in centroid deception mode; the lower 2 fire medium- and long-range Super Stockade in dump, distraction, and confusion modes. An associated tactical computer stores firing sequences for alternative tactics.

Super Barricade development began in 1987, and in 1989 Finland ordered it for a new minelayer; Chile has also expressed interest.

Wallop displayed a new long-wavelength IR decoy rocket at NEE 1989, to counter thermal imaging systems, which are more difficult to deceive than the earlier scanning-seeker heads because they look for extended targets rather than particular hot spots. It ran Royal Navy and NATO trials in the fall of 1989. Wallop sees the new decoy as an alternative to Sea Gnat, which uses a floating flare and reportedly has had problems in rough water.

As of 1989, Wallop hoped to sell Super Barricade to the U.S. Navy, initially for the PHMs and then probably for mine-countermeasures ships. Compared to SRBOC, Super Barricade can achieve long range without any deck reaction (SRBOC is a mortar, so the deck reaction worsens as the required range increases). The system is also lighter than SRBOC.



Barricade chaff launcher. (A. Raven)

Stockade is a related lightweight chaff launcher for fast patrol boats. Unlike most chaff launchers, Stockade consists of frames, inside which are launch tubes containing 57-mm fin-stabilized rockets. The launcher itself weighs only 10 kg unloaded. Each assembly consists of 3 frames holding 9 rockets, pointed in 3 directions and elevated; together the rockets form a chaff cloud with a radar signature approximating that of a corvette. Typically, 1 launcher is mounted on either side of a ship.

The rockets burst at an altitude of 70 m, at ranges of 400–1500 m. The associated IR decoys ignite at 1000 or 1500 m and burn for 30 sec. As of 1980, longer-range (5000 m) and hotter IR decoys were under development.

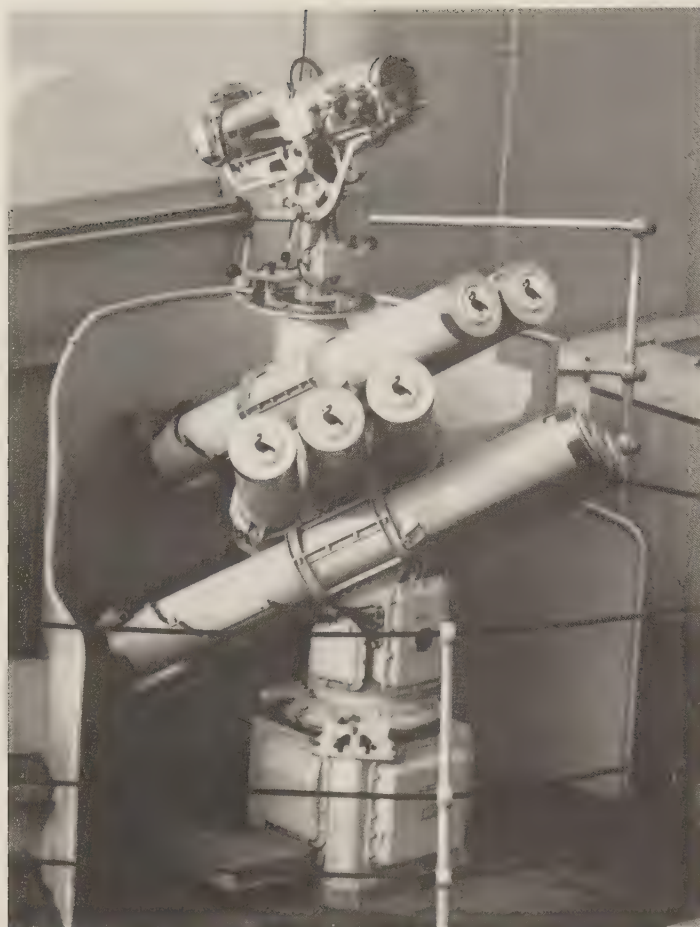
Wallop also offers Stockade-Seafish: a remotely controlled boat launches the Stockade chaff rockets, usable at ranges as great as 20 km. The boat carries 2 decoy launchers (18 barrels).

As of 1988, 42 Barricade installations were on order, and 56 had been delivered (including 40 on order and 28 delivered to the Royal Navy). Unit price was then about \$625,000. Export users include Chile (*Prat* class), Denmark, Kenya (*Nyayo*), and Oman.

◆ Corvus

Plessey-Vickers's chaff-decoy rocket launcher consists of 8 tubes: 2 sets of 3 at right angles, and 1 set of 2, above, bisecting that angle; all tubes are at a fixed elevation of 30 deg. The usual pair of port and starboard launchers is considered sufficient to deal with 3 attacks. In 1979 a new Plessey BBC (broad-band chaff) round (101.6 × 1580 mm, 21.8 kg including a 6.8-kg payload) replaced the earlier Knebworth. At the time the BBC round carried the heaviest payload available in a rocket of its dimensions. Chaff is dispensed in 1 of 3 modes to cover the G–K bands; dispensing range is set by a fuze adjusted manually before launching. At a threat wavelength of 2.6 cm, 2.5 sec after bursting, the BBC rocket produces a 1200-m² radar target that, given the enhancement effect of echoes off the sea surface, is equivalent to a 12,000-m² ship's radar target.

There is also an associated IR decoy. One version, by Plessey, uses the chaff rocket as a buoy, with the IR flare on top.



A Corvus launcher, with its rocket flare (illumination) launcher on top.

The prototype 6-barrel launcher went to sea on board HMS *Arethusa* in 1968. This system was exported to the Dutch, Brazilian, French, and other navies.

Many standard Corvus 8-barreled launchers carry a single Attwell 2-in rocket-flare launcher atop them. This launcher is manually fired. There is also a single stand-alone rocket-flare launcher, manually trainable on its own pedestal.

◆ Offboard Active Decoy (Outfit DLH)

Bids for a Royal Navy offboard active decoy were submitted in February 1989 by Marconi, Thorn-EMI, and Racal. Thorn-EMI and GEC-Marconi were selected in June 1990 for project-definition studies, and deliveries should begin in 1992 (the decoy is expected to enter service in 1993). A feasibility study was completed in 1988. The device is to be fired from the standard 130-mm Sea Gnat (U.S. Mk 136) launcher. Reportedly, its role has not yet been defined. A long-range decoy might make do with a 100-W TWT and a frequency-memory loop, whereas a short-range decoy would need much more power to deny an incoming missile burn-through vision of the ship. Marconi has proposed a rocket, burning for about 1 sec to project itself well clear of the ship. After burn-out the decoy, based on Marconi's Siren, would descend by parachute. Marconi claims that Siren can acquire a threat signal in less than 1 sec. Racal uses a BAe glider (reportedly resembling an ultra-light aircraft) with flip-out wings; it claims that its novel and highly accurate receiver system, based on its shipboard equipment, will be effective against multiple simultaneous threats, and that inherent accuracy of positioning will ensure that the decoy does not seduce incoming missiles into other ships. In each case, ongoing efforts to reduce a ship's radar cross section are expected to reduce the load on the decoy.

DLH was the third element of the ARE's future air-defense program, with SDMS and VSRAD (described above).

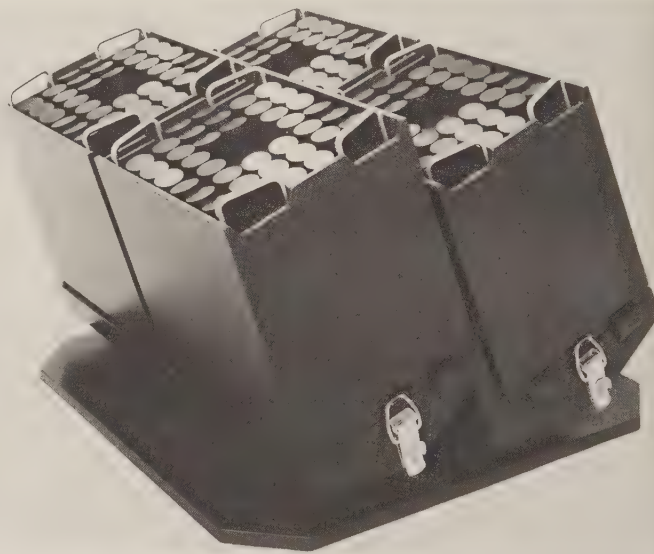
See also Siren, below.

◆ Protean

Protean is a chaff system developed by MEL to work with the Matilda ESM warning system. The parent Swedish PEAB company markets it as Philax (see above). MEL considered a rapid-blooming chaff the best instant countermeasure to a missile attacking a small combatant such as a minesweeper; chaff can bloom in less than 5 sec to give an effective cross section of over 1000 m². In the case of Protean, a salvo of 9 grenades gives the desired 1000-m² cloud; each launcher can develop 16 such clouds before reloading. Each launcher contains 4 cells (36 grenades each); cells reload as units. Total reload time is less than 1 min. The grenades can be fired directly by Matilda or manually on receipt of a Matilda alert. They operate in seduction mode, fired into missile's bearing and range gate, while the target vessel maneuvers to keep the cloud between herself and the missile while she moves out of range.

The typical installation is 2 or 4 launchers, and 1 or more chaff magazines can be replaced with IR grenades. Time to deploy a grenade cloud is 5 sec; height is 40–60 m (flight time 1 sec). Grenades weigh 0.35 kg, and they can be made in several wavelengths.

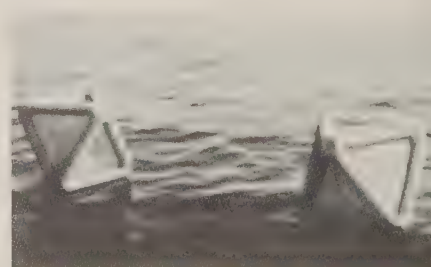
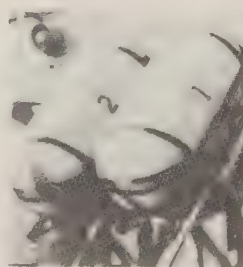
Protean appeared in the late 1970s, and by 1980 it equipped several fast attack boats as well as the Nigerian Mk 9 corvettes.



Protean chaff launcher. (MEL)

◆ Replica (DLF-1/Rubber Duck/SLQ-49)

Replica is an inflatable buoyant structure that supports a fabric-backed octahedral corner reflector; Replica operates as a distraction/seduction decoy. To a radar, the result looks very much like a ship. Replica, a substantial physical structure, is inherently broad-band, unlike chaff, and is considered effective for up to 3 hr in sea-state 4. The standard decoy is carried in two 1.14-m-long containers, similar to those used for life rafts, on inclined ramps. When the containers are released (either man-



Irwin Replica radar decoy, stowed (left) and deployed (right). (Ships of the World)

ally or automatically), they begin to inflate before hitting the water. The 2 decoys remain connected by a 4–5-m line, and the end of 1 of the 2 containers remains connected as a drag anchor, to keep the line taut (and thus to prevent the 2 decoys from collapsing together). Each decoy is about 2.5 m from apex to apex. Inside, the decoy has silver-coated nylon mesh suspended from aluminum-alloy tubes. Replica can be set to self-destruct or can be activated by remote control.

Rubber Duck was developed as a consequence of Falklands War experience. Reportedly, it was inspired by a Soviet decoy, which is similar but spherical (about 2.5 m in diameter). DLF-2 is an improved version (with a larger radar cross section). Reported export customers are Saudi Arabia and Thailand. Proposed fitting to British warships has been reduced because of budget cuts. The Royal Navy calls DLF Rubber Duck.

This decoy has been adopted by the U.S. Navy as SLQ-49. In April 1987 the U.S. Navy reportedly tested an air-launched version of Replica, comparable in size and shape to a Mk 46 torpedo. At that time the navy was also testing an improved version of the basic SLQ-49.

♦ Seafan

Vickers-Plessey's 105-mm decoy rocket launcher, for small craft such as fast attack boats, was originally conceived as a smaller equivalent to Corvus, for rapid installation on board merchant ships that might have to operate unescorted (albeit in convoy) during a period of rapidly escalating prewar tension. Seafan employs a 200-kg (vs. 762-kg for Corvus) 6-rnd fixed launcher. As originally proposed, Seafan was to have been fired from a lightweight triple launcher, and it was claimed that an existing Corvus launcher could fire 15 Seafans.

In 1977 Plessey announced a new Seafan rocket to dispense broad-band chaff (105 mm $\times$ 979 mm, 17.26 kg, carrying 4.1 kg of chaff). Elevation was fixed at 25 deg so that the rocket would begin to seed the chaff cloud while still rising. The resulting triangular chaff cloud was expected to last longer than most. A 0.33-sec fuze setting would produce a cloud between 24 and 155 m from the ship, and between 10 and 61 m high. After 2.5 sec this cloud (from a triple launcher) would have a reflecting area of 2500 m², reaching 4100 m² in 10 sec and lasting about 3 min.

The key to reduced rocket size was a multinozzle motor using wraparound fins; Vickers claimed that Seafan would be considerably smaller than the existing Knebworth rocket. The advent of this rocket in turn led Plessey to develop the Shield broad-band decoy system, using the original Corvus tubes instead of smaller-diameter ones.

There is also an associated IR decoy, the Vickers Honeydew hot-spot round, which is a spar decoy. A hot spot is held above the water by the bulk of the rocket, which acts as a spar buoy. As long as the hot spot lasts, it has a considerably stronger IR signature than a ship and will, therefore, decoy an approaching missile.

♦ Shield

Plessey's broad-band chaff decoy system employs port/starboard sets of parallel- or crossed-barrel 6-tube launchers and variable-range rockets to distract or seduce incoming weapons (seduction is by moving the target's centroid). Chaff can be deployed at ranges from 35 to 2000 m, each 4-in (102-mm) broad-band chaff (BBC) rocket carrying about 6.5 kg. Variable chaff range is obtained by setting a time fuze (0.5–12 sec) that ignites a secondary gas generator in the nose, unlocking the nose and spraying out the chaff packs. There is also an IR decoy, the rocket having a range of 40–160 m. Each carries 7 IR submunitions, to cover a large physical area in the 3–5- and 8–14-micron bands.

Each launcher carries two 3-rocket modules, either parallel or crossed at an 80-deg angle, and fixed in elevation at 30 deg. The launcher is strong enough to carry 3 modules so that in the crossed-launcher case the number of forward-aligned barrels can be doubled. Plessey recommends the crossed-barrel launcher for

corvettes or smaller vessels, and a pair of parallel-barrel launchers for larger ships.

Three different tactics can be used. In the distraction mode, up to 4 separate chaff clouds are deployed in a pattern around the ship, up to 2 km away, in hopes of attracting incoming missiles and diluting the incoming attack. The manufacturer states that only a rocket system can execute this tactic since no mortar can provide the necessary range. A second mode, dump decoy, is used in conjunction with an active ECM system such as Decca's Cutlass. The missile's range gate is distracted onto a chaff cloud about 400 m from the ship. Actual range depends upon ECM characteristics. For example, if the fuze is set at 2.5 sec, the burst will occur at 400 m at an altitude of 145 m; by 2.5 sec after burst, the chaff cloud will be ship-sized. Typically, such a chaff decoy is placed abaft and to 1 side of the real target. Finally, there is centroid seduction, a last-ditch defense. The chaff cloud is superimposed on the missile's image of the ship. Because the missile tends to home on the centroid of this image, and because the chaff cloud is more reflective than the ship itself, it may lock onto the cloud. The radar cross



Shield launcher. (U.S. Naval Institute)



Shield launcher being loaded. (Plessey)

section of the cloud is further increased by reflections off the sea surface because of multipath propagation. If the fuze is set at 1.5 sec or less, the cloud can extend between 90 m and 395 m in range, and between 25 and 138 m in height. The reflecting area 2.5 sec after burst is 3000 ft², expanding to 5500 m² 10 sec after burst; the cloud remains in place for up to 5 min.

Shield is designated DLB (DLE when adapted to royal fleet auxiliaries). The basic launcher is sometimes used to fire IR decoys as well as chaff rockets. Plessey offers a containerized version, incorporating two 6-barrel launchers, to protect merchant ships. This version includes a 24-rnd ready-use locker but apparently not the associated ESM warning device.

Shield 2 is an automatic version for export; it has been adopted by Brazil, Canada, and 1 unidentified Southeast Asian customer. The Royal Navy's version is manual. The Canadian ships will fire P6 IR rounds (using the same pyrotechnic material as in the German Hot Dog), and P8 chaff rounds (adapted BBC, with a larger payload and a programmable electronic fuze). P5 is the broad-band chaff rocket, using a manually set fuze, in Royal Navy service. P5 was used in the Falklands War (20,000 rockets were deployed to the South Atlantic).

P6 is a mortar because long range is not needed; missiles will generally use their IR sensors for terminal homing. Each tube fires 7 submunitions to walk the IR sensor away from the target, the first at 50 and the last at 250 m. The recoil of each shot indicates that firing to the launcher, and dampers in back of the launcher cushion recoil to eliminate deck reaction. The entire decoy tube is removed and thrown away after firing. Decoys are available in both the 3–5- and 8–14-micron bands. P6 dimensions are 102 × 1630 mm (17 kg).

Each P8 round contains 7.5 kg of chaff and can be set to burst at any range between 50 m and 2.5 km. It is essentially P5 but with an electronically set fuze for remote automated operation. Decoy modes are seduction and distraction. Shield is, then, intermediate in range between Corvus and decoys (such as Sea Gnat) currently entering service. The Royal Navy places it aboard larger ships, with Barricade aboard smaller ones. Both will be reduced to a supporting role when Sea Gnat enters service. P8 dimensions are 102 × 1700 mm (19 kg).

Shield was developed as a private venture after the Falklands War. As of early 1989, at least 106 Shield installations were in service, and 74 more were on order. Unit price was about \$250,000, plus \$120,000 for radar-absorbent cladding, without which Plessey will not sell Shield. The system was first sold in 1983 for the Brazilian *Inhauma*. Shield 2 is an automatic version for export; it has been adopted by Brazil, Canada, and Singapore. The Royal Navy version is manually fired.

In conjunction with Shield, Plessey offers a system for computer simulation of chaff-firing scenarios. A massive series of computations, typically as many as 5 million, is used to determine a short list of optimum tactics. These in turn can be fed into the decoy system's memory, which is connected to the ship's tactical data system. When threat data are fed to the decoy controller, the appropriate tactics are looked up in the preset table (which can hold up to 8 threat types, and which is also fed with such variables as wind speed and direction, sea-state, and ship's course and speed). The table is carried in an EPROM computer card.

◆ SIBYL

British Aerospace/Thomson Brandt's joint venture was announced in 1982. It uses a combination of rocket chaff/IR decoys and off-board ship-controlled jamming. The launcher has 12 tubes (4 tubes for smaller craft), is trainable and elevatable (limits +80/–20 deg, with automatic loading at 90 deg), and is stabilized in 2 axes. There are 7 types of ammunition—floating active decoy (simulating a ship's radar, to seduce ARMs); remotely controlled off-board jammer; long-lifetime chaff decoy; combined IR/chaff decoy; "hot balloon" decoy carrying chaff; a radiation-absorbing decoy covering the spectrum from the visual to 14 microns; and a practice round—in 2 sizes, 170 mm and 263 mm. Effective range is 0 to 8.5 km.



Sibyl decoy rockets, with the combined chaff/IR round on the right. (British Aerospace)

◆ Siren

Marconi's expendable 130-mm (1.8 m long, 28 kg) active-decoy round was announced in 1985 as the world's first intelligent off-board ECM jammer. Siren is parachute-retarded and is intended to seduce incoming missiles. Typically it is fired in company with chaff and IR rounds, selected by a central processor. At a preset distance from the ship, Siren switches on its own receiver, transmitter, and control electronics, using the RGPO seduction technique. The decoy is fired to a position 400–500 m from the ship, and Siren takes more than 1 min to descend by parachute.

Siren development began in 1982. This is 1 alternative for the Royal Navy DLH active decoy (see above). In 1989 it was evaluated by the U.S. Navy under the Foreign Weapons Evaluation Program. Compared to the long-life Nulka, Siren is conceived as a last-ditch decoy.

Siren will be fired from triple or sextuple launchers, 2 for a small ship and 4 for a larger one.

◆ Warrant

Widney-Aish announced this new chaff and IR decoy system in July 1989. It is similar in concept to the Barricade and Stockade launchers, which Widney designed in 1978–79 and still manufactures, but with a new 76-mm spin-stabilized rocket made by Astra Holdings. Warrant incorporates the same course-to-steer technology as Barricade. It is intended for small surface combatants, up to 100 m long, and lies between the 57-mm Barricade and the larger Super Barricade.

There are 2 different rockets, 1 for confusion (range 2500 m, weight 4.6 kg) and 1 for distraction/dilution and short-range



Warrant. (Widney-Aish)

duction (range up to 800 m, weight 6 kg). Each launcher consists of 6 triple subunits, 3 upper ones, very close in bearing, for short-range rockets, and 3 lower ones (splayed out at different bearings) for medium/long-range rockets. There are also IR rockets.

A single control unit normally connects to 2 launchers, but it can accommodate up to 6 more.

UNITED STATES

ELECTRONIC SYSTEMS

◆ ALR-66(V)6

These General Instruments's ESM systems are on board the *Pegasus* and *Taurus*. (See the photo of *Taurus* in the Strike/Surface Warfare section, under the APS-137 radar. See that section for details of this equipment, originally designed for airborne use.) The antenna array is similar to that of Locator 1000, which is not the same system. Reportedly, ALR-66(V)6 has not proven satisfactory in service, and only the 2 ships currently fitted have it. Its replacement is the new SLEWS (see below).

◆ BRD-7

This radio direction-finder for submarines uses an antenna on the General-Purpose Periscope ECM antenna group; BRD-7 also contains an internal DF antenna. The DF antenna is typically mounted atop the snorkel air induction mast. BRD-7 may be connected to the periscope ECM antenna group.

◆ SLA-12

SLA-12 is the EW antenna group used with ULQ-6 and SLQ-22, -23, and -24. SLA-12 uses the AS-1751A/SLA-12 trainable-antenna group and the complementary AS-1750A fixed-antenna

group, 1 each of the latter being mounted above and below the trainable AS-1751A. A complete installation consists of sets of all 3 antennas located port and starboard. Although this system is no longer widely used in the U.S. Navy, SLA-12 was transferred to many friendly navies on board former U.S. destroyers and frigates. It is recognizable by the latticework support holding all 3 antennas away from the structure of the ship; in FRAM destroyers SLA-12 is the antenna set on the after deckhouse.

The trainable AS-1751 carries 3 radomes on top, and a fourth horn below, separated by a mid-section pedestal. The upper set consists of a conical ECM receiver with skewed DF horns on either side; the lower radome covers the transmitting horn. Each set weighs 193 lb. Power rating is 25 kW peak, 1 kW average. The ECM horns may be either wide (low gain) or narrow (high gain) with, respectively, 17-deg and 8-deg beams.

Of the 2 AS-1750 antennas, the lower is used to transmit and the upper to receive. Each consists of a microwave horn covered by a radome, and each covers 180 deg in azimuth. Power rating is 25 kW peak, 1000 W average. The trainable AS-1751 consists of 2 trainable antennas. The upper consists of a conical receiving horn flanked by skewed direction-finding horns. The lower antenna is a transmitting horn. The transmitter may use either a narrow high-gain (8-deg beam) or a wide low-gain (17-deg beam) horn antenna.

◆ SLA-15

Analogous to SLA-12, SLA-15 has a different frequency range. SLA-15 is used as part of ULQ-6. SLA-15 consists of a trainable AS-2431 antenna flanked above and below by 2 AS-2430 fixed auxiliary antennas; 1 unit is mounted on each side of a ship. As in SLA-12, 1 fixed antenna is a receiver, the other a transmitter. Beam size is 17×155 deg.

The trainable AS-2431 is recognizable by its set of 3 horns, in radomes on a common base, above a fourth horn. All 4 train together, as a unit. Of the 3 upper horns, the outer ones are DF horns and the middle one is the ECM receiver; the lower horn is the ECM transmitter. The ECM horns may be either wide (18-deg) or narrow (9-deg) beam types. Peak power is 25 kW in both subunits.

SLA-18 is a supplemental antenna system consisting of 2 AS-2430s, but without the rotatable element of SLA-15.

◆ SLQ-17

Hughes's jammer/deception system for carriers replaces the earlier ULQ-6. SLQ-17 is automated, tracking threats and providing a combat system with identification information. Originally unreliable, SLQ-17 was unpopular. However, in 1985 Hughes claimed that the system had been cured, that its MTBF had improved from 20–30 hr to 250 hr (availability increased from 25 to 97%). Nevertheless, to increase standardization, SLQ-17 is being replaced by SLQ-32(V)3.

Like other jammers, SLQ-17 incorporates a receiver matched to its transmitter. Unlike its predecessors, SLQ-17 uses electronically steered reception and jamming beams and, thus, can scan very rapidly. However, because it lacks a multiple-receiver lens (like that of SLQ-32), it has only a single beam in each frequency range or for each set of transmitters.

The roll-stabilized aluminum box contains paired antennas, to cover its frequency ranges. The outward-facing side carries a pair of flared horns at its top and another at its bottom, 1 pair (representing 2 frequency ranges) presumably for reception and the other for transmission. Between the 2 is a pair of semicircular slotted waveguides (of 2 sizes) called parabolic toruses, each enclosed in a semicircular reflector. Each port in the waveguide is used to generate a different beam. As a transmitter or receiver is switched from port to port, the beam, in effect, sweeps across a broad angle, up to 180 deg. The more numerous the switches, the finer the beam. A Hughes drawing suggests that the big horns scan mechanically, albeit over a limited angle. Unlike the semicircular antennas, the horns are duplicated top and bottom on the beam face of the SLQ-17 box, a practice that suggests that 1 set transmits while the other receives.



SLQ-17 on board a carrier. (Hughes)

Each of the 2 angled faces of the radome carries a pair of semicircular slotted waveguides (1 atop the other) at its top and a pair of horns at its bottom. Presumably, each of the broadside semicircular antennas covers 180 deg; each of the antennas in the angled faces covers 90. Since beam shapes match, either set could receive for the other; if the broadside antennas receive, then the antennas in the angled sides could be used to transmit,

(Below) The *Enterprise* shows an SLQ-17 antenna outboard of her angled deck, on a trellis mast, February 1986. (Hughes)

and the system could jam 2 targets on each side at the same time. If that is correct, then the 2 pairs of horns on the broadside are both jammers (again, to deal with 2 targets at once, which was presumably the specification for the system), and the single pair of horns in each angled face is a receiver/tracker.

The entire assembly is 68 (high) $\times$ 71 $\frac{3}{4}$ $\times$ 50 in and weighs 1200 lb (for each side).

Carriers are equipped with SLQ-17A(V)2. The associated computer is UYK-20. The first production contract was let early in 1978, with options for 2 or 3 more. The first was installed on board the *Enterprise*. The fourth was delivered early in 1983; 8 had been delivered by late 1985. The FY80 program included funds for integration with NTDS. An upgrade program began in 1985. SLQ-17A(V)2 installations: FY80, CVN 65 and CV 66; FY82, CVN 70; FY83, CV 64; FY84, CV 41, 43, 63; FY85, CV 62, CVN 71; FY86, CVN 72, 73. As of FY87, unit cost was about \$2.8 million, compared to an estimated \$7.2 million for SLQ-32(V)4, its replacement.

SLQ-51, a projected advanced version of SLQ-17, was canceled in favor of further SLQ-32 development.

SLQ-29 is a combined WLR-8/SLQ-17 package installed on board 20 U.S. warships about 1976.

◆ SLQ-32/Sidekick

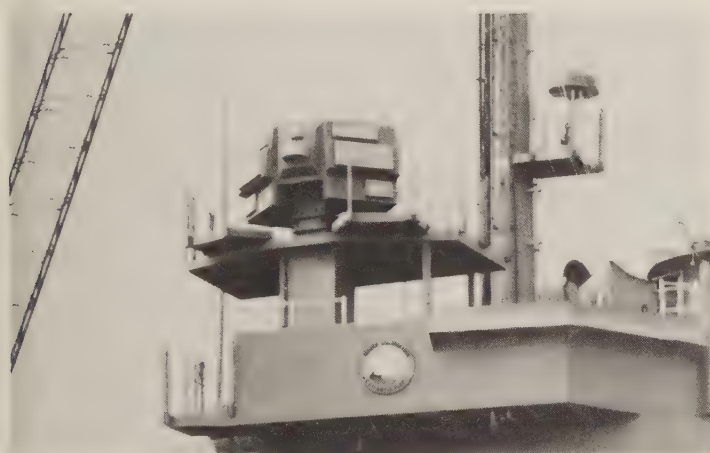
SLQ-32, manufactured by Raytheon, is the current standard U.S. Navy ECM system. It was the successful competitor in the Design-to-Price EW System (DPEWS), beating the Hughes SLQ-31 (which in turn became the basis for the current Taiwanese navy ECM system). The DPEWS RFP was issued in October 1973, and Phase I contracts for studies were let in January 1973. Phase II (hardware) contracts followed that October. A total of 6 design studies narrowed down to SLQ-31 and -32, which were evaluated in 1975-77. SLQ-32 was operationally evaluated February-September 1976, and its selection was announced in February 1977. As of March 1989, 360 SLQ-32s had been bought.

This system uses an internal library to automatically detect and categorize threats. The (V)3 version can also jam. Other versions are used to trigger such defensive reactions as chaff and weapons firing. Reportedly SLQ-32 does not automatically steer a ship away from its own chaff cloud, as some foreign systems





SLQ-32(V)2, USS *William S. Sims*, 1986. The upper antennas cover Band 3, the lower (larger) ones Band 2. The flat plates cover the DF lenses; the semicircular radomes cover semi-omni antennas. The system also includes Band 1 quadrant antennas at the yardarms. The simpler (V)1 version is limited to the Band 3 antennas but uses the same box as (V)2. (L. van Ginderen)



SLQ-32(V)3 on board the replenishment ship *Kalamazoo*, 1988. The lowest set of plates cover Band 3 transmitter antennas (for jamming). In contrast to the (V)1 and (V)2 versions, the box is roll-stabilized. (W. Donko)



SLQ-32(V)3 on board the battleship *Wisconsin*, 1988. The small box under the main SLQ-32 box carries Band 1 antennas; it is usually mounted at the end of the yardarm, but this ship has no suitable location other than that at the head of the fire-control tower. (S. Terzibaschitsch)



SLQ-32(V)3 on board the missile destroyer *Dahlgren*, 1986. The 2 flanking radomes contain lens antennas that improve Band 1 DF accuracy, for antiship missile targeting. (Author)

may. Versions are: (V)1, radar warning on H- through J-bands, for auxiliaries and amphibious ships (most will be upgraded to (V)2); (V)2, radar warning on B-J-bands, for newer destroyers and frigates (replaces WLR-1 where fitted); (V)3, radar warning on B-J-bands and jamming/deception on H-J-bands, for battleships, cruisers, DDG 37 class, and major amphibious ships; and (V)4, for carriers (to replace SLQ-17). Modular design allows for upgrading from one variant to the next.

The system is designed to handle 3 frequency bands: (V)1 is limited to band 3 (missile seekers), and (V)2 and (V)3 are extended to bands 1 and 2. The band 3 receiver is wide-open in direction and in frequency, using 2 stabilized-lens direction-finders (each covering 90 deg) and a semi-omnidirectional antenna that senses the dominant pulse in the incoming energy for instantaneous frequency analysis. For band 2, (V)2 adds 2 more lens arrays and another semi-omnidirectional receiver. For band 1, (V)2 uses 4 masthead spiral antennas, typically 2 each port and starboard. The (V)3 transmitters are located in the bottom of each box. The band 1 antenna is AS-3316, and is unique to the SLQ-32.

The (V)1 antenna assembly weighs 1560 lb, (V)2 2400 lb, and (V)3 5000 lb. Band 1's lens antennas are $25 \times 13 \times 18$ in (30 lb).

The key to SLQ-32 performance is the use of an internal beam-forming lens. Each position on the inboard side of the lens corresponds to a beam direction, as represented by signals on the outboard side of the lens. Thus a signal fed into the appropriate position on the inboard side produces signals all along the outboard side, with appropriate phase differences, which can be transmitted by a series of wide-angle antennas. The phases applied to these antennas produce a net beam in the appropriate direction. Because the system is linear, the same lens can serve a series of inboard elements, each representing a different beam



SLQ-32 integrated polar display, showing own-ship and friendly emitters in the center circle, hostile missiles in the broad middle ring, and hostile nonmissiles (such as ships) in the outer ring. That arrangement corresponds roughly to frequency, since missiles (with the smallest available space for antennas) generally operate at the highest frequencies, and the least urgent threats, ships, operate at the lowest. Engagement data and further emitter data for analysis and identification are displayed around the edges of the 8 × 10-in CRT. (Raytheon)

direction, simultaneously. Similarly, the lens converts an incoming beam in a particular direction into an output, inboard, at the element representing the appropriate direction. Each element enjoys the same gain, given by the total aperture.

This is very different from a nonlens system like the Hughes SLQ-17 or SLQ-31, in which a series of phase shifters generate a single beam. The single beam can scan rapidly, but it cannot be everywhere at once.

Each band covers more than an octave in frequency. The scheme of installation suggests that band 3 covers missile seekers (J-band), band 2 covers aircraft radars (E-I-bands), and band 1 is lower frequencies, probably C/D-bands.

Band 1, the lowest frequency range, uses planar-spiral antennas similar in concept to those in aircraft RWRs, which have relatively little resolution. This frequency range probably includes such major Soviet air-search radars as Top Sail and Sky Watch and so can be useful for antiship-missile targeting. There is a current effort to improve DF accuracy by changing to a different antenna in this band. Presumably, the original SLQ-32 used a very simple band 1 antenna because it was intended primarily as warning that a major Soviet unit, which might be able to fire missiles, was present. ARGOSystems began producing band 1 improvement kits under a January 1985 contract. Operational test and evaluation of the SLQ-32 improvements for OTH Detection (OTH-D low-band improvement) was completed during FY88.

The band 2 DF antenna uses a linear array of 38 vertical horns to cover 90 deg. The horns feed 9 receivers through a microwave lens. Effective beamwidth is therefore 10 deg. The lenses are built up of parallel plates built in stripline form using printed circuits.

The band 3 DF antenna uses a linear array of 66 horns to cover 90 deg, feeding 17 receivers through a microwave lens; each beam is therefore 5.3 deg wide.

The band 2 and 3 antennas are mounted in a stabilized box, with the flat lens-fed arrays radiating at 45 deg to the centerline of the ship, and a stack of semi-omnidirectional antennas (with semicircular radomes) directed out on each beam. These latter antennas are used to pick up the dominant pulse in each train, for IFM.

Raytheon backs the array of receivers with a series of crystal video receivers plus an IFM. The alternative Hughes proposal, for SLQ-31, was a scanning superheterodyne. Coarse frequency data (from the IFM) and amplitude data (from the DF array) are combined in a direction/frequency correlator; time-of-arrival data are added to form a pulse word, stored by frequency and angle in an emitter-file memory. If 3 or more identical pulses are received within a programmable interval (up to 32 msec), the digital tracker decides that a new emitter is present, and additional data are collected for analysis. PRF, scan type, scan period, and frequency are all extracted.

The corresponding jammer also uses a lens, interposing a TWT between each point on the lens and the corresponding horn radiator, for a total of 140 moderate-power TWTs. They amplify the jamming signals generated on the other side of the lens, with appropriate phases imposed by the lens. There is no beam-switcher passing high microwave power, and total jamming power is the sum of the power of the TWTs. The jammer is fed by a 35-element linear horn array, and it forms 64 beams on either side of a ship. Total radiated power is reportedly 1 MW. Jamming modes include RGPO and AGPO, the latter jamming CW missile-guidance radars. It is claimed that the system can jam 75 hostile threats simultaneously, each with a separately tailored countermeasure.

Current SLQ-32 and other U.S. ECM improvement programs include SADI/DDI (shipboard automatic decoy integration/DECM decoy integration), a tactical emitter feature (TEFE) for SLQ-32, improved antiship-missile/deception ECM (ASM/DECM), countertargeting countermeasures, and the EW Control System (EWCS)/Rapid ASMD Integrated Defense System (RAIDS). The FY90 program includes exploratory work on a new real-time adaptive monopulse countermeasure, which is to be tested at sea in FY91, and to begin formal development in FY92.

The initial SLQ-32 development contract was awarded in May 1977, with first production deliveries in June 1978 (final sea trials were on board the cruiser *Leahy*). It covered the first 3 versions.

(V)1, (V)2, and (V)3 all use UYK-19 computers. Originally, all had 64-kword memories. There have been 3 upgrades. First the (V)3 version was increased to 96 kwords. Then all versions were increased to 128 kwords, primarily to accommodate CDS integration (although this was not done in all ships, the new configuration was made standard). The latest digital processing unit (DPU) upgrade is to 512 kwords, and in the (V)4 version there is an adjunct processor (256 kwords) as well as the main unit. The 512-kword version includes an embedded 20-Mbyte hard disk. The display console memory has been upgraded as well, from 4 kwords (16-bit words) to 16 kwords. The 512-kword upgrade is part of a larger Phase B upgrade that increases band 3 sensitivity and suppresses interference. Other major improvements under the FY85-88 programs were higher-angle coverage (HAT) for band 3 and the much increased DF accuracy (by about an order of magnitude) for band 1.

The new (V)4 version, for carriers, employs fiber optics. The first was on board the *Saratoga*. It is also to be installed on board the *Kitty Hawk*, *Enterprise*, and *Forrestal*. The major improvements are a digital memory for faster threat evaluation and improved interference suppression (presumably between the jamming and sensing elements). Some components are as much as 300 ft apart. The system uses 2 computers, each near 1 set of transmitter/receivers, which are connected by fiber-optic cables for fast data exchange. The wide separation between components results entirely from the broad beam of the carrier, which complicates coordination between elements of the system.

The V(5) designation (possibly unofficial) is for V(2) plus Sidekick. Current plans call for *Spruance*-class destroyers to be upgraded from (V)2 to (V)3. There has been some question as to whether the *Arleigh Burke*-class can be upgraded similarly. *Knox*-class frigates are being upgraded from (V)1 to (V)2. Other frigates and coast guard cutters have the (V)2 version. (V)3 is installed on board (or planned for) the fast combat support ships (AOE and AOR), the battleships, the cruisers, the *Kidd*-class

destroyers, the *Mahan*-class destroyers (the *Adams* class have the (V)2 version), the amphibious flagships (LCC), and the amphibious carriers (LHA, LHD, and LPH). *Perry*-class frigates have the (V)2 version but are scheduled for installation of the Sidekick independent jammer. Sidekick is similar in concept to (V)3, but with lower radiated power.

Unit prices, as of early 1989, were \$335,000 for (V)1; \$600,000 for (V)2; about \$5.4 million for (V)3; and about \$7.2 million for (V)4.

As a result of the attack on the frigate *Stark*, existing SLQ-32(V)2s on board selected *Perry*-class frigates are being modified with a separate jammer, designated Sidekick. Raytheon had already developed such a system for the Taiwanese navy some years ago; the company took about 3 months from initial request (7 weeks from contract award) to first installation. The U.S. Navy bought 13 Sidekick sets through late September 1990, and on 29 September ordered 8 more. The original orders were prompted by Persian Gulf operations during the Iran-Iraq War.

◆ SLQ-33

See the ASW section.

◆ SLQ-34

This new-generation (1986) cover and deception system uses 2 small antennas, 1 for reception and 1 for transmission (about 30 lb each, approximately 20 × 15 × 15 in). They will probably be masthead-mounted.

◆ SLQ-35

See the Mine Warfare section (countermeasures).

◆ SLQ-36

See the ASW section (torpedo countermeasures).

◆ SLQ-37

See the Mine Warfare section (countermeasures).

◆ SLQ-39

Chaff buoy.

◆ SLQ-41 through -47

Active expendable EW buoys.

◆ SLQ-48

See the Mine Warfare section (countermeasures).

◆ SLQ-49

SLQ-49 is an inflatable decoy or "Rubber Duck"; it is the U.S. version of the British DLF. See above for details.

◆ SLQ-50

SLQ-50 is E-Systems's surface-ship terminal for the Battle-Group Passive Horizon-Extension System (BGPHEs), the airborne passive electronic-intelligence collector. The original contract was awarded in 1984, and the first SLQ-50 was shipped for installation in 1987. SLQ-50 consists of 4 UYK-44 computers and 3 UYQ-23 terminals connected by a Militarized LAN (MLAN).

Plans for the shipboard BGPHEs terminal were revised about 1989, the UYK-44 computers being replaced by DTC IIs. The change was expected to reduce cost and risk, and also to help bring BGPHEs into a new common architecture using standard computers and LANs. It then becomes much simpler to connect BGPHEs to systems such as JOTS, and the intelligence personnel handling and maintaining the major systems need become familiar with only 1 set of terminals (although the different systems do remain distinct).

◆ SLR-12A

This wide-band shipboard EW direction-finder uses a rotating directional microwave antenna in a radome. The antenna itself (AS-2209, formerly AS-1789) is a small paraboloid feeding a horn in the upper part of the radome. The antenna is mast-mounted.

◆ SLR-16

This HF SIGINT receiver uses SRD-19 arrays. SLR-16 automatically seeks and acquires signals, then selects those of interest for further analysis while avoiding set frequencies of no interest, e.g., those used for friendly communications. SLR-16 and SRD-19 are used together in the Classic Outboard (SSQ-72) system.

◆ SLR-21

This ESM system for small ships, made by EM Systems, was announced in 1978. The broad-band DF antenna consists of 4 cavity-backed spiral antennas, with 4 crystal video receivers, apparently with associated IFMs. Frequency range is 2–18 GHz, and the claimed direction-finding accuracy is better than 10 deg. SLR-21 is an automatic table look-up system, and in 1978 the manufacturer claimed that SLR-21 could cope with up to 200,000 pps. The display is a table of parameters of the detected emitters.

SLR-21 was developed specifically for the *Pegasus* class, with a projected unit cost of \$30,000.

SLR-21 was chosen in favor of an alternative Amecon SLR-20, a fully automatic system developed from the ALR-59 used on board the E-2C.

◆ SLR-22

A cover and deception device for carriers, SLR-22 was developed about 1985.

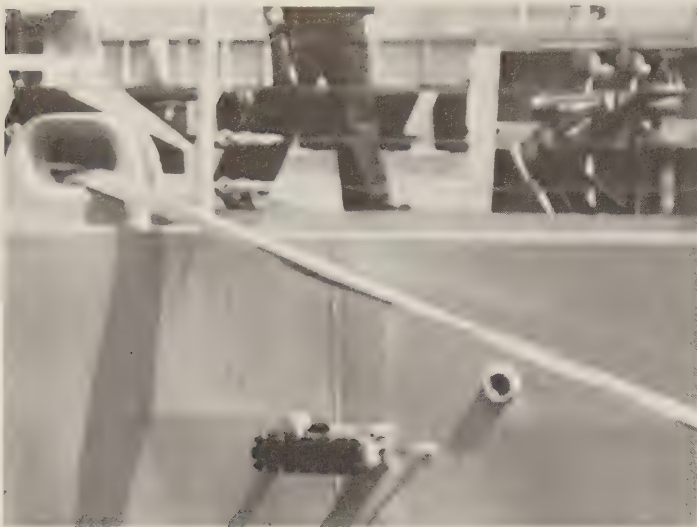
◆ SLR-23

An intercept direction-finder in the J-band, SLR-23 works with WLR-1 and SLQ-32.

◆ SRD-19



AS-3112/SRD-19 antennas, part of the Classic Outboard suite, are shown at the masthead of a British Type 22 frigate: the DF array covers the VHF range in 3 bands. The upper 2 are covered by Adcock arrays, the lower by closed loops. The entire array is 85 in high. The 2 cylindrical objects below the array are UHF receive and transmit antennas. (A. Raven)



SRD-17 (AS-3202) deck-edge antenna, USS *Mississippi*, June 1988. (Stefan Terzibaschitsch)

SRD-19 is a system for exploiting SIGINT (LF/MF/VHF) and is part of the shipboard Classic Outboard (SSQ-72) system. SRD-19 uses 24 small deck-edge antennas in 3 groups of 8 (LF/MF-HF). These antennas include standard communications antennas (for target acquisition and reference: 1 combination would be a 10–30 MHz inverted cone, a 35-ft 2–35-MHz whip, and 2 broad-band discages), and an Adcock-type VHF D/F array (dipoles and crossed loops) mounted in 3 tiers on the masthead. SRD-19 is often used with SLR-16. In that application SLR-16 has priority over the DF functions.

The deck-edge antennas are electronically switched in sequence to form receiving beams. The masthead array (AS-3112/SRD-19) includes both a wide-open directional system and a wide-band target-acquisition/reference system.

◆ SRS-1 (Combat DF)

Combat DF is a less elaborate (own-ship) version of Outboard (SSQ-72/108) for missile targeting. Compared to Outboard, Combat DF lacks any intelligence function; Outboard is more an intelligence than a targeting system. It is concerned mainly with HF communications signals and can exploit their internal details to at least some degree. Combat DF operates over a broader band and was conceived primarily to support the Tomahawk antiship missile. Block 0 is basic step-search signal acquisition and DF against communications signals. Block 1 adds a modular subsystem, the foundation for future automated signal acquisition. The first 8 Block 0 systems are in production; delivery was to be completed in the 1st quarter of FY91 (October–December 1990). More may be ordered under the FY91 program. Plans originally called for SRS-1s on board the battle-ships, the *Wasp*-class amphibious carriers, and 14 *Spruance*-class destroyers. It is currently planned for selected destroyers and missile destroyers, as well as selected amphibious ships. To at least some extent SRS-1 superseded SSQ-72. SRS-1 in turn has largely been superseded by SSQ-108, more of which were bought than SSQ-72 and SRS-1 combined. Presumably, that development reflects the greater interest in connectivity (as symbolized by the emergence of JOTS) and the growing importance of OTH data not only for targeting but also for other operations.

Combat DF encountered severe cost, scheduling, and technical problems, and for a time was close to cancellation. About 1988 it was very nearly combined with BGPHEs to save it.

Sanders is the major contractor.

◆ SSQ-70

SSQ-70 is a system for collecting operational intelligence.

◆ SSQ-72

See SRD-19 and SLR-16 above. SSQ-72 consists of SLR-16, SRD-19, and a local monitoring station; a phase 2 program added SLR-23 and SYQ-8 for target identification. It was conceived in the late 1970s, as part of the same OTH-T program that gave rise to Outlaw Hawk and then to TFCC. Plans originally called for 2 Outboards per carrier battle group; 24 were ordered for missile cruisers and destroyers (to match 12 deployable carriers), plus 6 more to make up for ships that might be unavailable. Ships carrying SSQ-72 are intended to provide data for their entire battle groups and are linked with each other and with shore stations by satellite. See also Combat DF (SRS-1) and the various OTH systems described in the Surveillance and Control section.

◆ SSQ-74

A van-mounted radar and communications simulator, SSQ-74 is called ICADS (Integrated Cover and Deception System). SSQ-74 may be temporarily installed on a destroyer's weather decks; ICADS has a gross weight of 18,000 lb (1974). This system is now being modernized. The current prototype is on board the *Comte de Grasse*.

◆ SSQ-80A(V)

SSQ-80A is a portable (carry-on) 2-operator, 3-rack, automated communications-signals collection, analysis, and exploitation unit, for signals between lower MF/HF and V/UHF. An automated radio-frequency management system (RFMS) distributes collected signals, protecting the system from local interference and also conditioning the received signals for analysis. Audio distribution, recording, and storage are also automated, and the system incorporates a computer data base (e.g., of technical data references, threat profiles, and activity summaries). Output may be by printer, paper tape punch, or cryptographic device. Major contractors include Engineering Research Associates (ERA), Electronic Support Systems Inc. (ESSI), and Cubic Communications.

◆ SSQ-82

SSQ-82 controls a ship's electronic emissions (MUTE: Multiple Unit for Transmission Elimination). By centralizing control of all electronic emissions on board a ship, MUTE makes full electronic silence possible.

◆ SSQ-91

SSQ-91 is the communications simulator in the *Kidd* class.

◆ SSQ-108

Outboard, superseding SSQ-72 and parallel to SRS-1, is for real-time OTH passive detection, localization, and targeting of hostile emitters. There are 2 phases:

Outboard I (SSQ-108(V)1) consists of SRD-19A, the SLR-16A countermeasures receiver, the OK-324/SYQ system-supervisor station (SSS), the local monitoring station (LMS), and tactical intelligence (TACINTEL) communications.

For Outboard II (SSQ-108(V)2), the SLR-23 automated narrow-band acquisition system and an OK-324/SYQ modification kit have been added.

SLR-16A, SLR-23, and LMS detect and recognize signals; SRD-19A provides sufficiently accurate DF for targeting. The SSS provides the interface to the ship's CIC and to off-board systems (other Outboards, the shore HF/DF Bullseye net, and the future Combat DF system). Outboard has been installed on board 36 selected DDs, CGs, and CGNs. The major contractors are UNISYS, Sanders (which is responsible for the DF portion of the system), and Southwest Research Institute.

◆ URD-9

URD-9 is a radar D/F (225–400 MHz).

URD-27

URD-27 is a broadcast-frequency D/F for SIGINT (250 MHz–8 GHz).

ULQ-6 and SLQ-22/23/24/30

ULQ-6 is a deception repeater/jammer for cruisers and destroyers, often found on board ships transferred abroad. ULQ-6 has been almost completely superseded in U.S. service by SLQ-32. For details of the antenna system, see SLA-12 and SLA-15 above.

ULQ-6 is a deceptive repeater, conceived primarily to defeat the conical-scan seekers of early Soviet antiship missiles such as AS-1 and then SS-N-2. It produced a false target and, thus, could function as a track-breaker. Later, in the late 1960s, ULQ-6 was improved by the addition of an RGPO capability (swept audio). The original amplifier (1 kW) was replaced by a higher-powered unit (20–25 kW). About 1968 many ships were fitted to react automatically to the 3 main threats either present or expected in Vietnam, Styx, SS-C-1, and SS-C-2.

ULQ-6 was developed alongside the ULQ-5 S-band blip-enhancer. In theory, the effect of ULQ-5 was to prevent a Soviet bomber from deciding which in a formation of ships was the carrier. If it failed, ULQ-6 provided self-defense. In practice, ULQ-5 was unpopular since each ship carrying it was a likely target, and it never appeared in any numbers. ULQ-6 became the standard U.S. deception jammer, 2 (port and starboard) being placed aboard each ship from destroyers up. The original ULQ-6 concentrated on I-band, but ultimately the system covered the range G-I.

ULQ-6 was derived from the ALQ-32 airborne deception repeater, and it was first tested in 1959. At that time the AS-1 threat was quite urgent, and initial installations (1959) were of ALQ-32s in huts, which could be placed aboard selected carriers by helicopters. Initial tests of ULQ-6 showed that it could handle up to 3 pulse chains simultaneously, but against more it tended to provide the same signal to all incoming pulses.

The original ULQ-6A was the 1-kW anti-conical scanning device for destroyers. The operator slewed the horn antenna

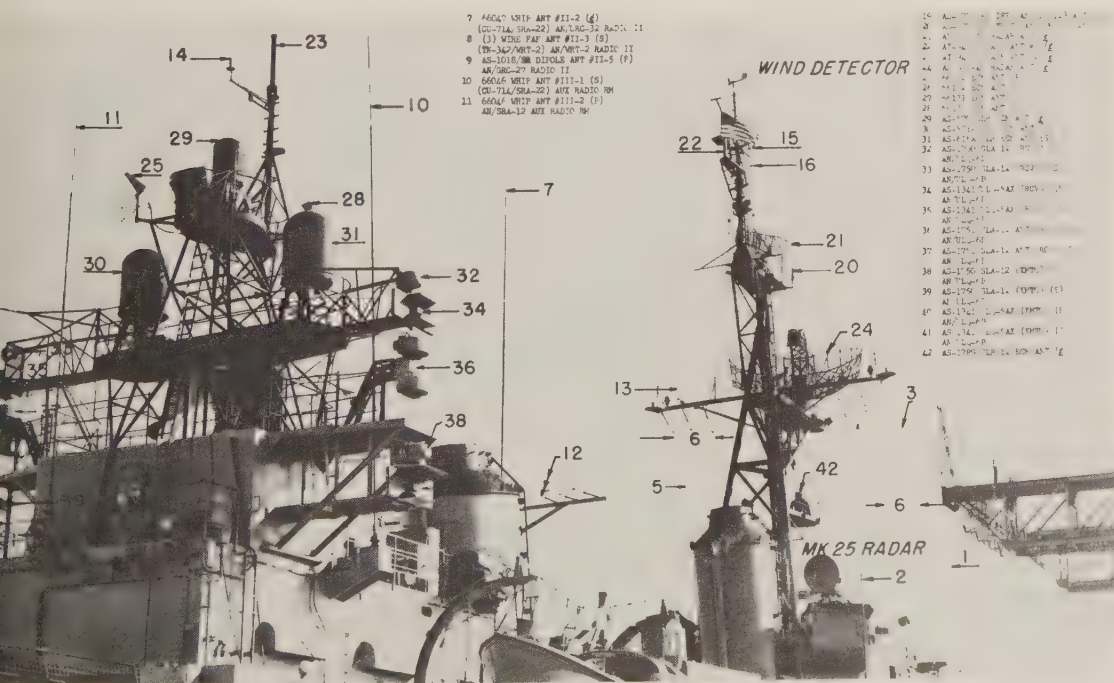
ECM arrays associated with ULQ-6B, on board the destroyer *Hamner*, 1965: [32] AS-1750/SLA-12; [34] AS-1341/ULQ-5AX (receiving); [36] AS-1751/SLA-12; [38] AS-1750/SLA-12 (transmitter). The big radomes are direction-finders containing spinning antennas: [29] AS-570/SLR; [30] AS-571A/SLR; [31] AS-616A/SLR. Number 25 is a "sword" [66132], and number 28 is a "derby" [66131]. Antenna 42, on the foremast, is AS-1789/SLR-12. (U.S. Navy)

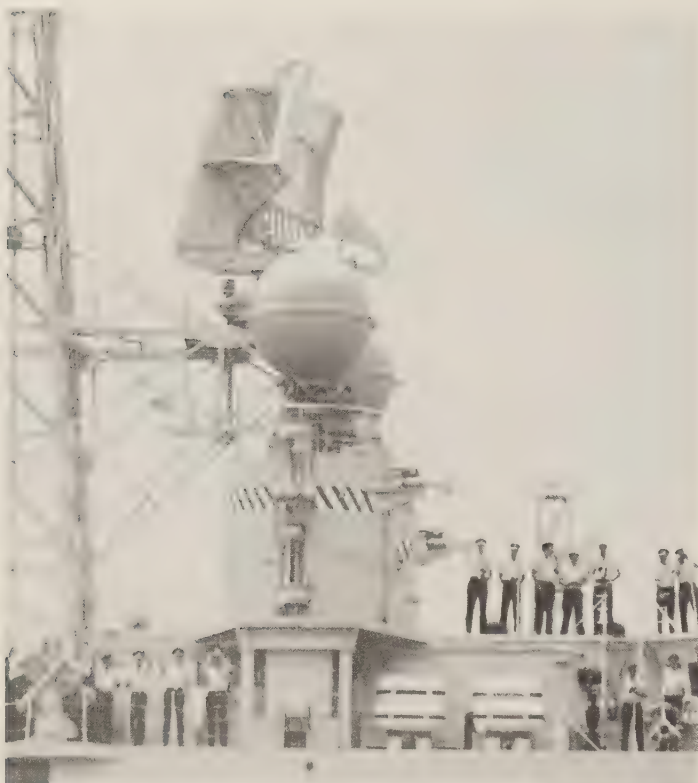


ULQ-6 on board the carrier *Coral Sea* at Norfolk, 1986, with the array trained. The middle portion of the antenna is SLA-12 or -15. (S. Terzi-baschitsch)

toward the threat, which was generally indicated by separate ESM equipment. ULQ-6B added the RGPO mode. Carriers had a similar system, probably ULQ-6C, with a narrower beam.

At least from 1968 on, all versions have employed a pair of fixed radomes with a trainable array between them; surviving examples have AS-1750/1751 and AS-2430/2431 antennas. The fixed antennas provide unfocused countermeasures against other targets. The modern trainable antennas, but not the earlier ones, include DF antennas. These probably feed an automatic target tracker. In the original system, the operator probably used a single ECM receiver antenna, colocated with the transmitting horn, both as a receiver of target pulses and as an indicator that the transmitter was pointed appropriately.





ULQ-6 on board the Canadian Tribal-class frigate *Iroquois*, 1986. The arrays differ from those in U.S. ships, but the system is the same. The arrays are visible along the barquette under the Signaal "egg" on the near side of the ship. (Author)

ULQ-6 was used in combination with chaff launchers: the jammer would break a missile's track, which would then transfer to the chaff cloud (see the account of U.S. chaff rounds below). ULQ-6 was the basis of the ECM/chaff systems added to U.S. warships on an emergency basis during the Vietnam War, both in the Western Pacific and in the Mediterranean.

This system currently equips Canadian frigates. In 1987 an additional coherent countermeasures processor (CCP), to be added to ULQ-6 on board all 17 Canadian frigates, was announced. CCP contains its own 500-radar threat library and can deal with such ECCM techniques as pulse coding and pulse compression. Instantaneous bandwidth is up to 550 MHz. CCP is manufactured by Telemus Electronic Systems.

SLQ-22/23/24 are high gain versions of ULQ-6, using the same SLA-12 or -15 antennas. SLQ-30 is an updated ULQ-6 by Kuras-Alterman (TRUMP, or Threat-Reactive Update and Modernization Program).

During the mid-1970s the U.S. Navy encouraged buyers of former U.S. destroyers (which were equipped with ULQ-6) to adopt the SLQ-30 upgrade. SLQ-30 added a channelized receiver to ULQ-6B and -6C, at a cost (in 1975) of \$250,000. It used the SLR-12 receiver, the spinning DF antenna of which was carried in a small separate radome (19 in in diameter, 31.9 in high). Presumably, the extra antenna was needed to extend system coverage to higher frequencies.

◆ WLQ-4

The *Sturgeon*-class submarines' ESM system (Sea Nymph) was developed by GTE-Sylvania. WLQ-4 searches automatically for unknown signals. Presumably, it was developed for electronic reconnaissance: in 1975 it was revealed that for some time *Sturgeon*-class submarines had been employed in that role. The U.S. FY84 budget included upgrades of existing systems to WLQ-4E configuration. The FY85/86 budget included concept definition of a next-generation version, WLQ-4(), looking toward a competition for full-scale engineering development to begin in FY87, to meet new operational requirements. However, it ap-

pears that instead a repackaged version, WLQ-4(V)1, will be installed on board new *Sea Wolf*-class submarines.

◆ WLR-1/WLR-11

WLR-1 was the standard U.S. radar-warning system of the 1960s, for both surface ships and submarines. As such it has been transferred to many friendly navies, and it continues in U.S. service. WLR-1's chief disadvantage was that the operator had to search manually through the frequency range(s) and so could easily miss transient signals. That limitation was acceptable for electronic intelligence gathering but not for quick reaction to an incoming missile. On the other hand, WLR-1 was liked for its resolution and for its very wide bandwidth covering VHF through SHF (50 MHz–10.75 GHz). WLR-1 simultaneously finds the direction of a selected signal and displays information.

WLR-1 uses a combination of wide-open fixed antennas (NT-66131 for UHF [300–3000 MHz] and NT-66132 for VHF [40–300 MHz], the "derby" and "sword," respectively; and the AS-1174 [or AS-3200] for UHF/SHF, a tape-wound cone) and rotating DF antennas in radomes (AS-571, AS-616, and AS-899; in some cases the roles of AS-571 and -616 are combined in a single AS-1023 antenna). In FRAM destroyers the radomes are typically located atop the after deckhouse, near the ULQ-6 arrays. The sword/derby combination has been in service since World War II and is used in the Royal Navy as well. Scan rates for AS-571 and -616 are 0–250 rpm; for AS-899, 300 rpm maximum. Beamwidths: AS-571 (300–600 MHz), 50 × 90 deg at lowest frequency to 30 × 70 deg at highest, combining vertical and horizontal dipoles; AS-616 (550–2600 MHz), 35 × 85 deg to 20 × 70 deg on low band and 35 × 70 deg to 20 × 50 deg on high band (vertical horns 20 × 95 deg to 10 × 65 deg on high band); AS-899F (1 GHz–20 GHz, i.e., bands 6 through 10), 40 deg in horizontal width at lowest frequency, 4 deg at highest.

AS-571 uses a double-sided high-gain dipole array, 1 side of the array acting as a reflector and the other as a planar surface. Three dipoles are mounted vertically on the planar surface, and 2 are mounted horizontally on the corner reflector, so that the antenna can receive both vertically and horizontally polarized signals, although only 1 polarization is selected at any 1 time. AS-616 uses similar dipoles, 6 arranged horizontally on 1 side and 3, vertically, on the other, to intercept signals in the lower UHF band. Below the dipoles it carries waveguide horns, 4 mounted vertically on 1 side and 4 horizontally on the other, to receive signals from the higher UHF band. The radome is identical to that of AS-571 (diameter 45¹¹/₃₂ in, height 62 in), but the antenna inside is much heavier (total weights are 250 lb for AS-571 and 425 lb for AS-616).



A "sword" antenna typical of those feeding the WLR-1 pulse analyzer. This is on board a British ship, but U.S. "swords" (i.e., monopoles emerging from ground planes consisting of a few wires) are identical. WLR-1 also employs higher-frequency "derby" antennas, which are analogous in design. (A. Raven)

The current AS-899F is a more complex antenna, consisting of a stationary spiral feed, a multiplexer, and a reflector tilted at about 45 deg so that it always focuses signals on the stationary feed. This type of construction is quite common in the spinning ESM antennas developed during the 1950s and 1960s. Earlier versions were more complex, with 4 feed horns, 2 at the top and 2 at the bottom of the antenna, and a spinning reflector, angled at 45 deg. These antennas were more limited in frequency response (to bands 7, 8, and 9, because the horns were not broad-band antennas). AS-899F is 34 in in diameter and 82 in tall and weighs 268 lb. AS-1174 is an omnidirectional broad-band antenna, for UHF through low SHF in 3 bands (designated 7, 8, and 9: 300–2450 MHz, 2450–4375 MHz, and 4375–7350 MHz). It employs 2 strips of aluminum tape spiraling up a fiberglass cone; a triplexing filter separates signals from the 3 bands. The basic frequency of the antenna is determined by its apex angle; bandwidth is determined by the tightness of the spiral. The antenna itself is 16.5 in in diameter and 41.5 in high (weight 11.25 lb). Existing AS-1174s are being replaced by AS-3200s, which are very similar in shape but are larger, with 4 spiral copper bands (diameter 30.3 in, height 45 in, total weight 45 lb.)

WLR-11 is an IFM system. It also adds capacity through J-band to the basic WLR-1 system. WLR-11 uses the same antennas, for the 7–18-GHz frequency range. WLR-11 is being added to existing WLR-1 systems, the designation of the new configuration being WLR-1G. It incorporates an automatic look-up feature. For its IFM function, WLR-11 adds a further omnidirectional antenna, AS-2918/S, a fiberglass cylinder housing a biconical horn, a polarizer, and a diplexer. The horn consists of 2 cones, apex to apex, with a small gap between, this region forming the antenna aperture. The pattern is omnidirectional and is at least 25 deg wide in elevation. The diplexer breaks received signals into 2 bands: 7–11 GHz (low pass) and 11–18 GHz (high pass). The entire antenna is only 6.3 in in diameter and 24 in high (the attached preamplifier is considerably larger than the antenna proper), and it is typically mounted on a yard-arm or other high horizontal position. The manufacturer is ARGOSystems.

The current version is WLR-1H, which scans automatically and covers a wider bandwidth (0.55–20 GHz). It was adopted instead of the more expensive WLR-8(V)4, the latter being canceled in September 1983. This was partly a demonstration of the effect of the procurement process. Since -1H was, in theory, no more than a minor improvement over earlier versions of the same device, it could be developed very quickly and at relatively low cost. It was, therefore, actually a generation or more *ahead* of WLR-8(V), which had been developed from the beginning as a new system. The most important new feature of -1H is fast electronic scanning of its frequency bands, for much greater probability of intercepting short signals. Each tuner is micro-processor-controlled, and a central processor manages the system as a whole. WLR-1H retains the individual-signal manual-analysis capability (for which WLR-1 was valued) and adds a threat library and an automatic search-and-signal-identification mode. The kit that upgrades a WLR-1 to -1H standard costs about \$900,000, and the system is used by the Australian and German navies as well as by the U.S. Navy. Low cost (compared to the alternative WLR-8 system) reflects the rapid fall in electronics prices. In addition, a WLR-1 could be upgraded relatively easily, whereas WLR-8(V)4 installation required a shipyard availability.

In 1983 it was reported that a WLR-1H cost less than half as much as the WLR-8(V)4 it was replacing.

Work on WLR-1H can be traced back to 1979 contracts let to ST and to ARGOSystems for upgrades including improved signal-processing equipment. In 1981 ST began work on upgrading the WLR-1G signal-acquisition interface, and ARGOSystems began work on improvements to -1G signal-processing units. Improvements in -1H are officially listed as a new Signal-Acquisition System (SAS) and/or Upgraded SAS (depending on which model of WLR-1 is replaced), a Signal-Processing Unit

(SPU), an Emitter-Classification Unit (ECU), BITE, and Enhancement Modules (DFEMs).

Existing WLR-1, -1B, -1D, -1F, and -1G are being replaced by -1H. Existing WLR-1C are being upgraded to -1H standard. The first 10 *Spruances* were fitted with -1G as an interim measure.

◆ WLR-3

WLR-3 is a radar-warning and signal collection system for surface ships and some submarines.

◆ WLR-4

WLR-4 is an ESM receiver, part of Shortstop.

◆ WLR-5

WLR-5 is an acoustic intercept receiver.

◆ WLR-6

WLR-6 is a reconnaissance signal-collection system. In submarines, this device is called Waterboy.

◆ WLR-8

WLR-8 is a radar-warning system for sequential or simultaneous scan over the 50 MHz–18 GHz spectrum. Signals are automatically classified and recognized on the basis of PRF, frequency, modulation, pulse width, amplitude, and scan rate. The system can trigger threat warnings for particular signals. It can also be directed to search particular frequency segments on a priority basis. This is currently more a signals-intelligence than a tactical system although it is compatible with NTDS; it is not used for automatic direction of jammers or weapons.

WLR-8 employs 7 electronically swept, octave-band, super-heterodyne receivers, to achieve high sensitivity and accuracy. All but the lowest-frequency band (which is varactor-tuned) are YiG-tuned. Three more tuners are available as reserves or for expanded frequency coverage. The system can operate with any of the U.S. Navy's standard rotating DF antennas, either manually or by computer control. The display is a 5-trace CRT; the upper 2 traces, which can be switched to any tuner, show amplitude vs. frequency. The next 2 are A-scans for manual PRF (actually PRI) measurement. The last is used for signal analysis. A PS-300 computer is used for system control, signal acquisition/analysis, and file processing.

WLR-8 was originally to have been purchased for both submarines and surface ships, but after protracted development the surface-ship version was canceled in September 1983 in favor of WLR-1H.

WLR-8 was conceived in 1968, and in 1971 GTE-Sylvania won a design competition, beating Watkins-Johnson, ITT, and Loral. The requirement was urgent because the Shortstop antimissile ECM program had just been canceled because of its high cost. Ironically, the surface-ship version of WLR-8 later died for the same reason.

Originally, 3 versions were planned: WLR-8(V)1, which was not built, was the basic computer-aided surveillance system. (V)2 added automatic signal acquisition, parameter measurement, and a threat-alarm function (Scan Lock). It was intended primarily for submarines. (V)3, for destroyers and larger surface ships, was (V)1 plus an interface to NTDS. (V)3 in turn was superseded before production by (V)4 Mod 1, which benefited from submariners' experience. Improvements included a Threat Early-Warning (TEW) operating mode and more automatic signal-parameter measurement. (V)2 was updated to include many of the features of (V)4 Mod 1. Later a new submarine version was introduced, designated (V)1; the (V)2 version is installed on board *Los Angeles*-class submarines (550 MHz–20 GHz). (V)5 is for Trident submarines.

After the cancellation of the surface-ship versions, the submarine versions remained in production. A typical current unit price is \$541,000 in FY90. The first submarine version was approved for service use in 1973. Of the surface types, 3 (V)4 were made before cancellation: only 1 for shipboard, for the carrier

Enterprise. GTE is prime contractor, with an ARGOSystems receiver and IBM improvements.

◆ WLR-9

WLR-9 is an acoustic intercept system; see the ASW section.

◆ WLR-10

WLR-10 is a radar-warning system. In its (V)1 version, it consists of a tuner assembly (4 tuners) and a receiver-processor. Each transmission received is converted to audio intelligence data, primarily monitored and recorded on magnetic tape. WLR-10 shares a periscope antenna with WLR-8.

◆ WLR-13

WLR-13 is an IR/EO-warning receiver.

◆ WLR-14/WJ 1140

This Watkins-Johnson automatic signal-acquisition and processing system for submarine electronic-intelligence collection is a version of the company's WJ 1140. WJ 1140 uses a series of parallel tuners to cover the frequency bands 0.5–1, 1–2, 2–4, 4–8, 8–12, and 12–18 GHz, and coverage can be extended down to 40–550 MHz and up to 18–40 GHz. The associated antenna systems are L-4/A/RS-160 (40–550 MHz), L-6/A, and L-5/A (18–40 GHz). L5/A consists of fixed horns looking up into a spinning reflector. L-6/A is a spinning-horn antenna in a radome, scanning at 0–2000 rpm; the antennas can also be manually steered from the control console. They have a relatively broad pattern and are circularly polarized. The system also employs conical omnidirectional antennas. WJ 1140 can employ a C-204 analysis control unit (ACU), which measures signal parameters and identifies signals automatically, based on time of arrival (TOA), amplitude, pulse width, and angle of arrival (AOA). ACU tuner modes include fixed, band scan, limit scan, and sector scan. The ACU can automatically scan through the tuners at either an automatic scan rate or under operator control. Displays include pulse-by-pulse and average PRI formats, which can be used to determine the detailed characteristics of a signal consisting of a multiple pulse train, such as a phase-coded pulse-compression signal.

WJ 1140 is reported to have been installed on board the Ko-



The Korean destroyer *Jeong Buk* is reportedly equipped with the WJ 1140 signal-collection system (the commercial version of WLR-14), presumably using the directional HF antennas visible here above the usual U.S.-type ESM radomes. (*Sea Power*)

rean destroyer *Jeong Buk*, presumably replacing the earlier U.S.-supplied WLR-1, and using much the same antennas (a pair of lower-frequency antennas has been added). This system is presumably used for radar ELINT. Compared to later versions of WLR-1, WJ 1140 lacks automated signal analysis, but some additional processors may have been added. The later Watkins-Johnson receivers all are automated for signal analysis, as is WLR-1H.

Watkins-Johnson produced a series of later multituner receivers to replace WJ 1140; WJ 1240, 1440, and 1740. WJ 1440 in particular has had naval application. WJ 1240, which covers 0.03–40 GHz, has independent digital control and parallel displays for its bank of tuners, for simultaneous surveillance of several channels. WJ 1440 was derived from WJ 1740; it has microprocessor-controlled memory scan, allowing the operator to store up to 16 scan-control matrixes, the controlling computer automatically scanning through any preselected series of them. A tuner-integrated local-oscillator synchronizer (TILOS) improves overall stability and frequency accuracy.

The current successor to WJ 1140 is WJ 36500 (which is currently under naval contract for testing although it has been built to commercial specification). WJ 36500 (SIRS, signals intelligence receiving system) is a 15-channel superhet receiver covering 30 MHz–40 GHz (although it can be extended to higher frequencies). It can be provided with a DF antenna and can be used for ELINT with a monitor or tape recorder or processor. It has multiple interactive operator stations, using a 1553B bus (LAN) to distribute signals to a variety of tuners, chosen according to application. Such an architecture makes tuner replacement relatively simple, compared to the redesign required in the unbussed systems of the past.

◆ WSQ-5

The Watkins-Johnson carry-on ELINT system for *Los Angeles*-class submarines covers the range from UHF up to mm-wave. This automated system reduces the workload, and presumably the volume, of those it replaces. That is important, since a *Los Angeles* probably has less free internal volume than a long-hulled *Sturgeon*, a type that had been enlarged specifically to make room for a new electronic reconnaissance system, and that is likely to be retired in the near future. WSQ-5, a multioperator system, includes a signals-acquisition system, automated interaction with a series of superhet tuners, signal processors, a means of automatic emitter identification, and automatic data logging and storage (with capability to monitor an advanced tape recorder). WSQ-5 uses distributed 80386-based processors on an LAN. Work on the advanced development model began about 1986, and several have been delivered. WSQ-5 *does not* replace WLR-8/WLR-1H, which are basically threat warners with little or no ELINT capability.

◆ Mk 105 (Target Acquisition Console)/ALR-76

In the mid-1970s selected destroyers and missile frigates were modified to fire Standard ARM antiship missiles. A target-acquisition console Mk 105 made by IBM was added to their WDS Mk 4. The console, which was connected to a version of the ALR-47 airborne ESM set, provided automatic detection, classification, and processing of targets detected passively. Under operator control, ALR-47 passed data to the ship's FCS to preset the Standard ARM antiship missile. Predecessor of the current ALR-76 of the S-3 Viking, the modified ALR-47 had a 4-channel, digitally tuned, superhet receiver. It was fed by an array of 8 cavity-backed spirals. The associated signal-processing computer was an IBM System 4/Pi type SP-0A with 2 memories (total capacity up to 24 kwords). Mk 105 was used primarily against pulse radars. It was selected early in 1972, and 2 were delivered that November for installation on board the 2 prototype Standard ARM ships, the fast gunboats *Grand Rapids* and *Douglas*. In November 1973 IBM received a further contract for 12 production Mk 105s for DDGs and FFGs. Mk 105 may also have been supplied to the Korean navy, which operates Standard ARM on board 3 *Paek Ku*-class missile boats.

The Canadian navy added ALR-76, the successor to ALR-47, to the 3 ships it sent to the Persian Gulf in 1990. It may be the standard means of targeting planned for Harpoon aboard the new "City"-class frigates. The ALR-76 installation is presumably equivalent to the earlier U.S. Mk 105 (but with a more powerful computer).

◆ AEWS

The Advanced Electronic Warfare System was conceived as an add-on to the existing SLQ-32. Work at NRL began about 1978, with Norden as hardware contractor. AEWS is now at the full-scale-development stage; the competitors are Hughes, Norden, and Raytheon.

AEWS is presumably largely or entirely the anti-monopulse-radar concept mentioned in declassified descriptions of the current naval R&D program.

◆ AIEWS

The advanced integrated EW system is a projected successor to SLQ-32.

◆ LAIR

Lamp-augmented IR is a shipboard IR jammer developed by Loral under NRL contract. LAIR is an enlarged and repackaged equivalent of the company's airborne IR jammers. It is now (September 1990) in the advanced development stage. A system of this sort is needed when threat missiles improve in sophistication to the point at which they can distinguish flares. That occurred relatively early for aircraft since missiles could distinguish flares by their motion relative to the real target. For ships, the key development is probably an inexpensive 2-color or 2-tone IR seeker, which can in effect measure the temperature of the flare. NRL interest in an IR jammer would seem to imply that such seekers are now close to entering service. Several Soviet antiship missiles have IR variants or use IR-radar seekers, and there is also the Norwegian Penguin. LAIR was demonstrated during the summer of 1990.

About 1984 Loral supplied an aircraft-type IR countermeasure to protect the yacht of a foreign head of state, perhaps Brunei, from weapons such as SA-7s.

◆ SLEWS

The Shipboard Lightweight Electronic Warfare System is for small combatants and auxiliaries. It is envisaged as a simple modular and expandable system, a nondevelopmental item (i.e., essentially an existing system). An RFI (request for information) was issued in July 1990, and the formal RFP was expected in December 1990 or January 1991. As of the fall of 1990, 80 are to enter service between 1992 and 1997, in 2 versions, 50 for smaller ships and 30 for larger ones. SLEWS originated in the navy's dissatisfaction with the ALR-66(V)6 on board 2 PHMs, and it will equip the PHMs as well as many auxiliaries. Like ALR-66(V)6, SLEWS still retains some requirement for precision DF for missile targeting (probably an accuracy of about 2 deg). Because SLEWS is to be nondevelopmental, foreign companies were invited to bid. Presumably, the RFP will be issued to a reduced list of those answering the RFI. Each company will be asked to provide 1 system to the navy for a 3-month test, at its own expense (a similar procedure was recently followed in the case of electro-optical sensors), using navy-supplied test data. As of September 1990, foreign bidders included Elisra (probably teamed with Loral), MEL (teamed with Westinghouse, offering Sceptre 0), Racal, and the Taiwan Development Corporation. Raytheon probably intends to offer a version of ALQ-142. General Instruments is also bidding. The bids will probably include a firm price commitment so that the ultimate choice can be made on the basis of both cost and performance.

◆ EWCM

Electronic-Warfare Coordination Module is part of the new carrier and large combatant command/control system. It supports the OTC and the EW coordinator. EWCM requires a Twin Data

Bus (TDB) supporting a controlled LAN to segregate compartmented data (SCI, i.e., sensitive electronic intelligence) from normal classified data (GENSER data). EWCM is to use off-the-shelf equipment as much as possible. The core portion includes the TDB. Phase I develops the EW/C3CM software, and Phase II is to incorporate state-of-the-art technical advances. EWCM is intended to work with the TFCC, which is to be fully operational by FY92. As of 1988, 28 operational EWCM were planned, for the carriers, the LHDs, the LCCs, and shore sites.

◆ APECS

Advanced Programmable Electronic Countermeasures System is a multibeam integrated ESM/ECM system that gives elevation and azimuth data on each pulse by monopulse techniques. The phased-array transmitter antennas (2 modules per system, port and starboard) can engage multiple targets simultaneously. This system, manufactured by ARGOSystems, is light enough for installation on fast patrol boats.

◆ APECS-II

APECS-II is a surface-ship EW (ESM and ECM) system for ships displacing up to 8000 tons. In 1988 APECS-II was in production for 4 navies. It employs a phased-array multibeam (16-target) antenna covering 360 deg in azimuth and up to 30 deg in elevation, with high radiated power both in pulse and in CW modes. Compared to older phased-array designs, APECS has polarization diversity (to counter monopulse threats), is easier to install (because it requires neither external waveguide nor water cooling), and can handle complex signals. For example, it can deal with frequency/PRF-agile seekers by tracking the leading edges of their pulses, not waiting until the full pulse has been received before sending the countering signals. Frequency coverage is 0.5–18 GHz.

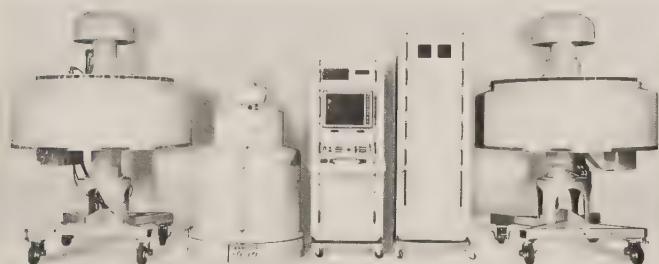
The ESM portion of the system is the AR-700 receiver, including an upgraded version of the ASP-32 signal processor. The



An ARGOSystems ESM antenna (probably Phoenix II) on board a Korean *Ulsan*-class frigate, with a Radamec HWK 409-029 electro-optical director visible behind it, and an Emerlec-30 mount below. Similar radomes can be seen on board Colombian FS 1500-type frigates, Finnish *Helsinki*-class fast attack boats, New Zealand *Leander*-class frigates, and Swedish *Stockholm* and *Spica-II* classes. (*Sea Power*)



APECS II on board the Pakistani destroyer *Tughril*. (Sea Power)



Passive elements of the ARGOSystems APECS-II EW system for surface ships: 2 low-band ESM arrays (with their omni antennas for IFM) and a radome enclosing the higher-frequency monopulse array, with its IFMs at the top. (ARGOSystems)

ECM portion is controlled by a multiprocessor-driven power-management unit and radiates from 2 stabilized transmitters. Because control is software-based, ECM tactics can be tailored to specific threats. The 2 basic operating modes are transponder (in which the appropriate response signal is preset) and deception (in which the response signal is constructed in response to the details of the received signal). The 2 techniques can be run in sequence, and the entire system can operate fully automatically, semiautomatically (the command to radiate is under operator control, but everything else is automated), or manually.

This system is manufactured by ARGOSystems.

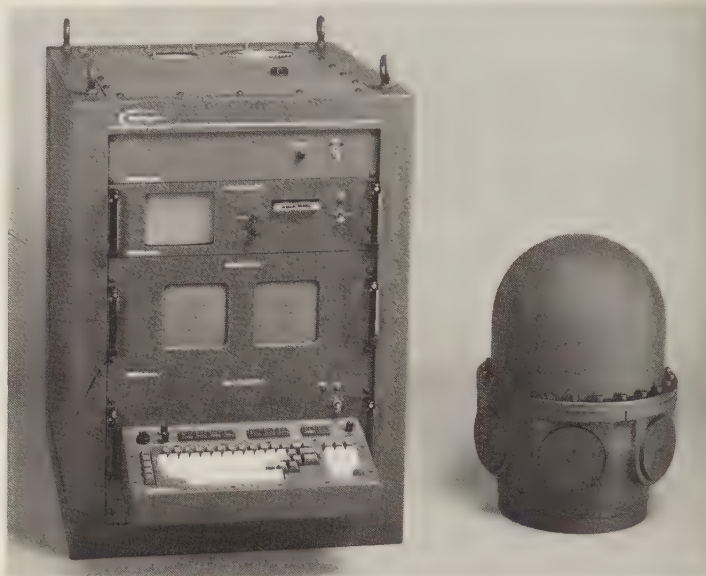
The first APECS II was delivered in 1986. The II/AR-700 suite will be carried on board the new Portuguese MEKO frigates, and APECS II was selected in 1987 for the Dutch *Karel Doorman* class, in place of a more expensive Signaal system.

◆ ARGO 680/681

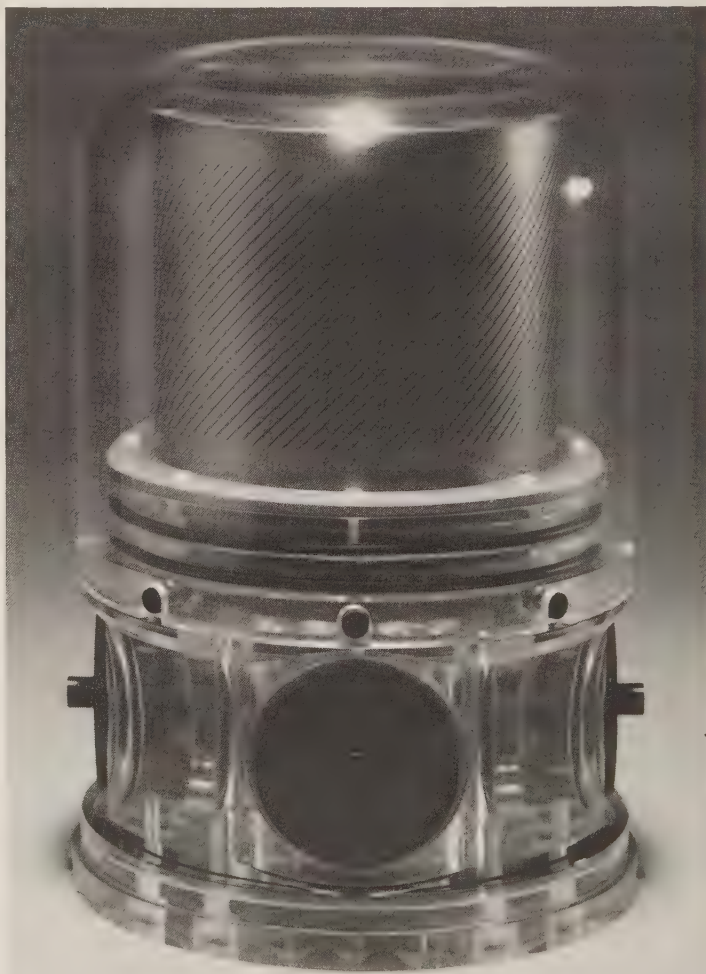
This system is found on board some Taiwanese (GOC) destroyers. This system employs a single mechanically scanned D/F antenna to cover the E-J-bands. ARGO 680/681 uses electronically scanned antennas for frequency fixing, which is much faster than with WLR-1.

◆ AR-700-S5

AR-700-S5 is an ESM system for submarines that provides threat warning, surveillance, and targeting information using signals in the 2–18-GHz band. DF is by monopulse rather than by a rotating antenna, and the system is also wide open in frequency, using paralleled digital IFM receivers. Bearing accuracy is 5 deg (rms). The embedded signal processor, an ARGOSys-



ARGOSystems's AR-700 ESM system for submarines, with the indicator on the left and the antenna on the right. Three D/F ports are visible on the antenna. (ARGOSystems)



ARGOSystems miniaturized ESM antenna for submarines. (ARGOSystems)

tems ASP-32, can track up to 200 signals simultaneously, identifying them by reference to a library. The system's frequency range can be extended to 40 GHz.

A miniaturized version of the mast assembly, 6.5 in in diameter and 11.8 in high, has been developed.

This system is manufactured by ARGOSystems.

◆ CAROL

ARGOSystems's intercept receiver and deception transmitter is designed for the new Swedish *Göteborg*-class missile corvettes.

◆ DCJSS

Tracor's Direct-Coupled Jamming/Surveillance System covers the communications bands (100–500 MHz). It couples 2 monitor receivers directly to two 400-W jammers (each containing a receiver, exciter, and transmitter). The system is intended for ship, air, and ground use and can be expanded to 14 monitors (to cover 2–1100 MHz), up to 10 receiver/exciter combinations, up to 10 high-power amplifiers, and direction-finders. DCJSS was derived from a training system; as of 1989 it was under U.S. Navy evaluation and was reportedly the subject of a NATO order.

◆ Digital ESM Receiver (DESM)

This is an Anaren DF receiver, a component of the Rascal Cutlass B1 and reportedly also of a version of the Signaal Rapids. The receiver occupies a radome; a complete 7.5–18-GHz array has a diameter of less than 10 cm. Anaren claims that these small dimensions reduce vulnerability to multipath.

DESM covers the 2–18-GHz range in 2 bands, 2–7.5 GHz and 7.5–18 GHz. It employs a 32-element circular array feeding a Butler Matrix, followed by a phase-comparison receiver. The Butler Matrix produces phase shifts at its outputs proportional to integer multiples of the angle of arrival. Five channels are used: one (1×) with a phase shift equal to the angle of arrival, one with a phase shift equal to twice (2×), one to 4×, and one to 8× the angle of arrival; they are compared to a reference channel. The 8× channel provides the most precise information, but it is ambiguous because every 45-deg shift in angle of arrival produces the same result. The other channels resolve this ambiguity. Thus the masthead unit requires only 5 amplifier channels in each band. From top to bottom, the masthead unit consists of a band 2 antenna, a band 2 matrix, a band 1 antenna, and a band 1 matrix, with the amplifiers and other electronics below in the flared bottom of the radome.

Each pulse is represented as a 55-bit word giving frequency, bearing, amplitude, pulse width, and time of arrival. Bearing accuracy is less than 2 deg, and elevation coverage is +40/–10 deg. Good directional accuracy makes it possible to use angle of arrival as a parameter in de-interleaving trains of pulses, and 2 deg is the level of precision needed for missile launching.

Minimum acceptable pulse width is 200 nanosec in the 2–7.5-GHz band and 100 nanosec in the 7.5–18-GHz band; bearing resolution is 1.4 deg (8 bits), pulse width resolution is 25 nanosec (12 bits), and time of arrival resolution is 1 microsec (16 bits).

The masthead unit is 60 cm in diameter × 101 cm and weighs 60 kg.

The device was publicly described in 1982, by which time it was already in production. The Butler Matrix technique was publicly described in 1980.

As of September 1990, Anaren was considering downsizing the DESM antenna for submarine installation and was also considering a frequency extension down to 0.5 GHz.

◆ EW-100/200/300

These threat-warning suites are designed for fast patrol boats. EW-100 is the basic system; EW-200 is improved; EW-300 is an integrated suite. All provide 360-deg cover in azimuth and 60 deg in elevation, are based on a 16-bit programmable computer with 1-sec reaction time, and have a library of 75–100 emitters. EW-300 weighs 300 lb and covers the D–J-bands.

These systems are manufactured by Loral.

◆ FERRET

An austere submarine ESM set by GTE, FERRET uses an Israeli front end and covers the entire 1–40-GHz band. The narrow-band subsystem (1–18 GHz) uses up to 4 superheterodyne receivers for precise analysis. Claimed DF accuracy is 5–10 deg. Frequency resolution is 125 kHz (narrow-band) and 5 MHz (broad-band).

◆ GUARDIAN STAR

Sperry Marine's automatic ESM direction-finder (ADF/ESM) is for small patrol combatants. The Mk 3(V) version, announced in 1987, combines omnidirectional and monopulse DF antennas (6 spirals) with an RF digital frequency-discrimination (DFD) unit. Guardian Star is interesting as an example of the capabilities that are possible using modern high-density electronics with distributed (rather than concentrated) microprocessors.

The antenna, with its radome, is 36 cm high and 15 cm in diameter (14 × 5.9 in) and weighs 5 kg. The associated digital interface unit weighs 33.5 kg. The display is a 48-cm-diagonal raster-scan color unit. The system as a whole illustrates the high density of modern electronics. The digital unit converts each received pulse or CW signal into digital form. The display sits atop a processor that sorts pulses and compares them with library entries. Output can include platform identification and threat-level determination based on library matching. Sperry describes the library (containing 1000 emitter modes) as uniquely structured for ease of automatic identification; the operator can load the library with specific emitter characteristics, or the load can be from some separate electronic data base. The operator has a scratch library with a capacity of 50 emitters.

The display is normally a polar plot (emitter frequency vs. bearing), but because the display is digital it can also show emitter frequency vs. amplitude. Typically the display also provides tabular data on particular emitters (e.g., name if identified, bearing/confidence level of bearing determination, frequency/amplitude, PRF/pulse modulation, scan rate/threat level, and platform/use if library matched). The operator interacts with the display by means of a touch screen and a keyboard.

The system covers frequencies 2–18 GHz (frequencies are determined within 7.5 MHz), PRFs 100–300 kHz (determined to within 0.002%), pulse widths 0.1–100 microsec (measured to within 0.05 microsec), and scan rates 16 msec–40 sec (deter-



Guardian Star Mk 3(V). (Sperry)

mined within 10%). Elevation coverage is within a 30-deg cone. Sensitivity is -60 dBm across the entire bandwidth. Claimed false-alarm rate is less than 1 per hr, and the manufacturer claims a probability of detection greater than 99% (Sperry claims a probability of intercept of unity if 6 successive pulses are received). The system can track 250 emitters simultaneously. Emitter throughput is less than 1 sec, and the display is updated 50 times/sec. Sperry claims a bearing accuracy of 10 deg for 2–8 GHz, and 5 deg for 8–18 GHz.

Sperry offers several optional extensions. The frequency range can be extended down to 0.5 GHz and up to 40 GHz. Frequency precision can be improved. The system can be extended to receive communications (VLF through UHF). Guardian Star can be connected to control chaff and flare launchers and to correlate with a radar; Guardian Star can also be modified to estimate target range by target-motion analysis (analogous to submarine ranging by TMA).

Guardian Star is based on the electronically scanned ESM antenna of the U.S. Type 18 periscope, on *Sturgeon*- and the new *Seawolf*-class submarines. In this application it has no specific designation, and it uses standard military processors, etc. The display is the one Sperry developed for its anticollision shipboard radar.

Guardian Star has been ordered for retrofitting to Venezuelan *Lupos*.

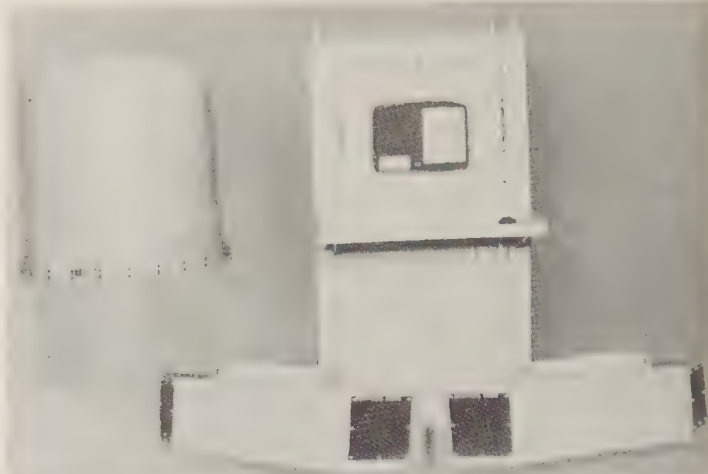
◆ Locator 1000/2000

Locator is General Instruments's modification of ALR-66(V)3 for shipboard self-protection. Because it includes a user-generated threat library, Locator can be used to trigger defensive measures such as chaff launching. Like ALR-66(V)3, Locator incorporates a precision direction-finder and covers the C–J-bands. There is an automatic mode for minimum manning; in a large ship, an operator can change the priority assignment of different signals, display emitter data, and analyze selected intercepted signals.

Locator 1000 is a new-generation export system that uses much the same antennas (at least the same radomes) as ALR-66(V)6. Locator 1000 employs a directional antenna (87 lb, 26.1-in diameter $\times$ 16 in), a pair of fixed antenna receiver enclosures (FARE, 40 lb each), a frequency measurement unit (FMU), and an ESM console. Frequency coverage is E–J-bands, with C/D optional; DF accuracy is better than 3 deg. MTBF is 1000 hr, and MTTR is about 30 min. Locator 1000 is designed to support OTH-T but also provides threat warning for a separate ECM system. The console incorporates a plasma touch display showing both polar and tabular emitter data. General Instruments describes the system as a unique combination of wide-band receivers, parallel DF channels, and multiple processors. Presumably, the reference to parallel channels means a combination of relatively imprecise monopulse DF (for contin-



Locator 1000 array, with the DF antenna in the dome at the center, probably on board a *Pegasus*-class hydrofoil. (General Instruments)



Locator 2000 DF antenna and jammer antennas, with the console. (General Instruments)

uous signal tracking) and a directional antenna (e.g., for targeting). Locator includes pulse-analysis capability.

Locator 2000, for larger ships, can incorporate a jammer using a multibeam array transmitter, which uses repeater and transponder techniques (e.g., range-gate stealing). The high-resolution color display is controlled by keyboard and trackball; it shows emitter data in both polar and tabular form. The ESM portion of the system matches that in Locator 1000, except that the console is larger (presumably with greater computer capacity). The ECM portion consists of 2 semi-omni antennas (6 lb, 7.5-in diameter), 2 multibeam array transmitters (MBAT, 490 lb each, 30.7 in wide $\times$ 34.5 in high $\times$ 32.4 in), an ECM rack (570 lb), and a repeater/switch (82 lb). ESM performance matches that of Locator 1000. The optional ECM system can deal with up to 16 simultaneous threats, at frequencies of 7.5–18 GHz, with ERP up to 86 dBm.

Unlike their competitors, these systems do not incorporate separate IFM channels. In a conventional digital ESM system, the IFM and monopulse DF channels operate separately, each producing output words. The processor must then match IFM pulse data to directional words to characterize each pulse. General Instruments uses a proprietary fast IFM, matching frequency and direction on a pulse-by-pulse basis, thereby avoiding the correlation problem.

◆ MEWS

Hughes's Modular EW System was based on SLQ-31, the unsuccessful alternative to Raytheon's SLQ-32; MEWS was the basis of the current Taiwanese navy Chang Feng III. All of these systems use the antennas of the larger SLQ-17, such as the slotted waveguide inside a nearly semihemispherical reflector (a multiple-feed parabolic torus). Hughes liked this particular design because it provided stronger beams on the broadside, where the ship's cross section is greater and, therefore, where more jamming power is needed to overcome reflections from that cross section.

For Hughes, the key to cost control was provision for capability growth without excessive additional system expansion. Hughes placed particular emphasis on anticipating possible threat growth and change since some elements of the system (such as antennas) could not be expected to change inexpensively. For example, a system initially designed to deal with sea-skimmers might later face steep divers. The beam generated by a linear array, which might be quite effective at low angles, might spread out at higher angles of elevation, and a more complex antenna with better beam control at higher elevation might, therefore, be preferable.

Within the signal processor, Hughes sought growth potential by using microprocessors in parallel. Increased system capability would be achieved by adding more of these parallel channels, each on a circuit board, and each fitting into a slot provided

when the original less-capable system was manufactured. For example, signals would be de-interleaved by microprocessor PRI trackers, each responsible for 1 train of pulses. Given this architecture, the system would add the ability to track more targets by adding more trackers. In a typical system, incoming signals would be split up in a power divider, which would direct them into signal-processing channels. Each channel consisted of a frequency filter and 4 PRI trackers, and the total system might be able to accommodate up to 6 channels and thus up to 24 trackers, i.e., 24 simultaneous target signals.

A published description of MEWS logic (1982) showed the application of these ideas to a typical antenna, a multiple-feed parabolic torus like the ones used in SLQ-17. This type of antenna uses a series of ports to form beams; the beam is moved by switching the signal generator among the ports. Such an antenna might be designed with 10 feeds to produce 10 high-gain beams. On the other hand, the feeds might initially be paired to produce 5 lower-gain beams, at a lower cost in electronics. In the example given (which probably does not precisely correspond to MEWS), two 4-port electronic switches were used, 1 feeding 3 ports and also the second switch. The second switch fed the other 2 ports, 2 of its outlets being unused. In an expanded version of the array, each of the 2 original switches would feed 4 ports, and a third switch would be added to feed 2 more. The 10 original beams would have been 20 deg wide (10 deg for the 2 pointing abeam), compared to 40 deg (20 deg for the 1 beam pointing abeam) for the simpler version.

The full 10-beam version could be further expanded by adding a fourth 4-port switch and using 3 of its outlets and the 2 previously unused outlets of the third switch to drive a second series of beams elevated above those of the 10-beam array, doubling elevation coverage by forming four 40-deg beams and one 20-deg beam. This growth would be possible by allowing for additional torus antennas in the system radome, additional cable runs, and additional switches and their driver cards. Because the improvements are preplanned, and because they use hardware identical to that already in the system, this growth should be relatively inexpensive.

A Hughes diagram of a typical EW system shows masthead arrays for reception in 2 bands. One array consists of 2 receivers, each at a 45-deg angle to the centerline, at each end of a yard. The array below it appears to use 4 receiving antennas, 2 side by side pointed broadside and 2 more angled out from the central pair. In this version, the typical Hughes box antenna, with its 2 angled sides and its flat side pointed broadside, is used for transmission (presumably it does include ECM receiving antennas for beam direction). On the other hand, Hughes's description of MEWS offers antenna options ranging from rotating high-gain horns to fixed switched arrays.

In 1984, with MEWS presumably in production for Taiwan, Hughes claimed ESM coverage of 2–18 GHz with a sensitivity of –60 dBm and dynamic range of 60 dB. DF accuracy was 5 deg (monopulse), with 1 deg available using a precision dish. Elevation coverage was 0–15 deg (using the stabilized boxes), and the library carried 1024 emitter modes (with 256 emitters in an active environment file). Reaction time was 1 sec or less. The ECM portion of the system could operate over 7.5–18 GHz, with a sensitivity of –70 dBm, and it could handle 40 simultaneous threats. Deception modes were listed as sequences and combinations of RGPO, countdown, swept audio, noise cover, and false targets; the system could also produce spot, swept, and barrage noise. Reaction time was listed as 1 sec or less.

The version illustrated in the 1984 brochure employed masthead receiving antennas (with both monopulse and dish elements) and stabilized boxes for transmission. Photographs of a Taiwanese navy Wu-Jinn III destroyer, fitted with Chang Feng III, show a single radome near the 2 transmitter boxes. There is also a small foremast radome, probably a TACAN.

◆ PHOENIX II

ARGOSystems's ESM/DF system (1–18 GHz in 5 bands) is for ships of fast-patrol-boat size and larger. Announced in 1984,

PHOENIX II was ordered for the Colombian HDW corvettes and the Indian Type 1500 submarines, among others. PHOENIX II uses a combination of omnidirectional, monopulse, and directional antennas and IFM receivers. All signal processing and identification is automatic.

Phoenix IV is a fully automatic version.

◆ PMTS

Passive Multitarget Tracking System is Anaren's new precision direction-finder, proposed for the NAAWS system. Angle accuracy is to within 0.2 deg, and the system can track in azimuth and elevation to within 0.5 deg. Tracks can be reported within 2 sec of detection, and 10 targets can be tracked simultaneously, the system operating in TWS mode. A land-mobile version has 2–5-MHz frequency accuracy, and DF accuracy is within 0.8–0.2 deg, depending on frequency. Total antenna beamwidth in this version is 2–13 deg, and the system covers 2–18 GHz in azimuth and 3.8–18 GHz in elevation.

The standard version uses a pair of interferometers in 1 reflector, which forms the overall 2.5×60 -deg beam. The azimuth array extends horizontally across the top of the reflector. It breaks the 2.5-deg horizontal beamwidth into 32 beams, each 0.09 deg wide. The elevation array forms 2 beams, the 2.5×60 -deg beam and a 2.5×2.5 -deg "deck" beam used to overcome multipath effects because its beams tend not to intersect the horizon. The main 60-deg high beam is broken into 512 elements, each 0.09 deg wide. The deck beam is broken into 32 elements, each also 0.09 deg wide.

PMTS also incorporates a new technique that uses relative phase to determine whether an intercepted signal comes from the side- or main lobe of the target.

PMTS was tested by the U.S. Navy in 1989; it demonstrated its ability to track low-lying targets over water. Anaren has proposed PMTS for other applications, such as the U.S. Air Force TR-1 battlefield-surveillance airplane. As of September 1990, sea trials were scheduled for the fall of 1991.

In mid-1990 Anaren began to develop its PMTS technology for application to an active radar, providing limited 3D capability by adding an interferometer array to the top of the conventional 2D antenna. An operator would obtain altitude data on a target designated by azimuth or by a range bin. The additional electronics would be installed on the antenna pedestal, with minimal synchronization with the receiver. Elevation data would be provided for a subset of the target tracks.

◆ S3000

S3000 is EM Systems's surveillance system for submarines. S3000 is installed in British *Oberon*-class and nuclear submarines. S3000 uses a high-gain scanning antenna plus an omnidirectional antenna and IFM receiver; the operator selects scanning, sector-scan, or pointing modes for the directional antenna. There is an associated threat library and an automatic threat-alarm feature. Coverage is 0.5–18 GHz.

◆ Sea Sentry

Kollmorgen's ESM system for submarines and surface ships was announced in 1980. Versions I and II are for surface ships, with version III for submarines. The basic system covers the 1–18-GHz range, with automatic detection and DF (accuracy better than 10 deg). A 150 MHz–1 GHz receiver is available as an option so that all communications bands can be covered. Sea Sentry I is a simple ESM system to support fire control in fast attack craft. Sea Sentry II is more sensitive and can incorporate an IFM or superheterodyne receiver. Sea Sentry III is designed for full integration with a submarine's combat system, using both the periscope and its own antenna (multiple arrays and microwave receivers on a mast). The General Instruments DF/threat processor has a 128-emitter threat library, and it can be supplemented by additional ELINT information collected by the Sea Sentry III system. Up to 35 emitters can be processed simultaneously, and 15 displayed. The user assigns a priority to each threat radar, CW (fire-control) radars having the highest.

Threat surveillance is automatic, and there are 2 modes: (i) surveillance, as a wide-open receiver providing all-around cover; and (ii) search, in which frequency is measured and direction is more accurately measured. The system measures both CW and pulse signals, displaying threat identity, bearing range, and other signal data on its CRT. DF accuracy is about 10 deg.

Kollmorgen claims that Sea Sentry III (Model 962U) is the first completely automatic broad-band radar-threat detection-and-analysis system integrated into a submarine's surveillance periscope. Sea Sentry III detects and identifies signals in the 100 kHz–1 GHz range and detects, determines the bearing of, and identifies signals in the 1–18-GHz range. The antenna consists of 3 omni and 4 DF spirals that collectively receive 100 kHz–18 GHz signals. The LF omni units are a voltage probe antenna; a top-loaded electric-field probe connected to an impedance-matching transistor amplifier, housed within a dielectric radome on top of the array; a sleeve/stub, a thick quarter-wave monopole above a ground plane around the spiral antennas and receiver components; and a biconical omni housed within the dielectric radome below the VPA. The 4 DF spirals are identical and mounted spatially around the cylinder to provide 360-deg coverage in 90-deg segments. Four identical microwave receiver channels are housed within the antenna array, each receiver fed by 1 of the DF antennas. A 4-digit LED readout displays the threat's center frequency, within 15 MHz; threat characteristics are presented on a radar-parameter digital display.

Although only 1 version is for submarines, Sea Sentry is intended primarily for a submarine's use; Kollmorgen is a periscope maker. Argentina bought Sea Sentry III for its TR 1700 submarines, and India bought both the system and the company's periscope.

◆ Series 800

This is a mobile and shipborne communications-surveillance and DF system, operating over 3 alternative frequency ranges (1.6–30 MHz, 1.6–180 MHz, and 1.6 MHz–1 GHz) and incorporating an automatic single-station location (SSL) system. In the sky-wave region of the HF spectrum (2–30 MHz), SSL is achieved by vertical triangulation using information about the height of the ionosphere. For higher-frequency signals, the emitter is located by comparing bearings from adjacent directional receivers. The shipboard installation consists of a number of wide-band HF receivers spread around a ship, sampling the currents excited on the ship's structure by an incoming signal, and comparing phases to obtain accurate bearing and elevation angles.

The related Series 810 automatically acquires, analyzes, and catalogs HF signals; it can be set to sort signals and generate alerts for important ones.

The land-based equivalent (Series 400) employs a large circular Wullenweber array antenna, which can be as much as 300 m in diameter, or a series of crossed loops. A land-mobile version employs 9 foldable crossed loops, each 2 m on a side.

Series 800 is manufactured by Technology for Communications International (TCI).

◆ Shields

Raytheon has developed an integrated EW suite, Shields (Ships Highpower Electronic Defense System), for export, using the unique lens-fed MBAT developed for SLQ-32. There are 2 versions, (V)1 for small ships and (V)2 for mid-size ones such as frigates and destroyers. Like SLQ-32, Shields uses its lenses to generate multiple beams simultaneously, each beam having the full gain of the aperture. Using its multiple receiving beams, Shields can detect and track multiple threats simultaneously.

Shields has a separate lens jammer. As in the receiver, the lens is used to form beams by adjusting the relative phases of different signals passed through it. In Shields, the jamming modulation is applied before the low-energy signals are passed through the lens. Each position on the lens surface corresponds to a beam. The lens applies the necessary phases to form beams, and the resulting signals are picked up on the far side of the



Shields (essentially SLQ-32(V)2) and the Sidekick jammer (marked "Shields ECM"). (Raytheon)

lens. Then they are amplified by moderate-power TWTs before transmission. The usual problem of such an electronic beam-forming jammer is high-speed switching of a single high-powered jammer; Shields avoids the problem by providing a moderate-powered jamming transmitter (TWT) for each array element. The separate jammer is probably the Sidekick, which has been adopted by the U.S. Navy as an adjunct to SLQ-32.

Shields was designed, developed, and tested for an unspecified export customer, probably Taiwan. Shields was announced in 1989.

◆ SLR-600 Series

These private-venture ECM systems are made by General Instruments Corporation specifically for fast patrol craft. SLR-600 is an ESM system for fast patrol craft; it is highly automated for ships with small crews. It uses IFM techniques and combines a broad-band (E–J-band: 2–20 GHz) receiver with a fast processor for rapid response. Automation requires the system itself to decide which radars it is detecting: the display shows radar identifications, based on data in the threat library, as well as the details of pulse width, PRF, and scan rate for radars that do not fit the library's information. The operator can select data on any specific radar for readout, and the system provides an alarm if a specific threat radar is detected. SLR-600 responds to tracking radars within 1 sec and to scanning radars within 2.

SLR-600, a navalized version of the ALR-66 RWR, uses a 4-antenna array to measure direction with an accuracy of 15 deg.

SLR-610 is much the same system with expanded frequency coverage (C–J-bands, 6.5–22 GHz) and with a different display (presumably making greater use of the operator).

SLR-640 is an improved SLR-610, adding accurate directional information. The dual CRT display shows both a polar plot of detected signals and a detailed parameter readout on a selected list of detected emitters. ALR-646 is a similar airborne system.

SLQ-630 is a jammer.

SLQ-650 (INEWS, Integrated Naval EW System) is a fully integrated system consisting of an SLR-640 receiver and an SLQ-630 jammer. The monitor shows both the threats being jammed (monitored by the ESM system) and the type and level of jamming. The system can track up to 100 targets continuously, presenting their parameters in tabular form (20 to a page) and also displaying them in polar form. The system automatically selects the highest-priority threats and passes their data to the jammer, which uses a high-gain steerable antenna. Several emitters can be jammed simultaneously: modes include range and angle deception.

PERFORMANCE OF SR-200

	Band 1 (0.5–2.0 GHz)	Band 2 (2.0–4.0 GHz)	Band 3 (4.0–8.0 GHz)	Band 4 (8–18 GHz)
Direction of Arrival accuracy	7.5 deg	5 deg	4 deg	2 deg
Frequency accuracy	9 MHz	9 MHz	17 MHz	21 MHz
PRF range	75–100 Hz	125 Hz–100 kHz	250 Hz–100 kHz	500 Hz–100 kHz
PW range	0.2–100 microsec	0.2–100 microsec	0.1–100 microsec	0.1–100 microsec

Some SLR-600 series systems were exported to an unnamed customer. These systems are no longer in production. The Thai *Ratcharit* class, completed in 1979–80, shows a radome similar to that of the later ALR-66(V)6 on board some of the U.S. *Pegasus* class, so Thailand may be the customer. For a time, SLQ-650 was planned for the *Pegasus* class, but it appears that instead SLR-21 was selected and then ALR-66(V)1.

◆ SR-200

SR-200 is a shipboard ESM receiver with automatic frequency measurement (0.5–18 GHz, with optional extension to 40 GHz). The frequency range is broken down into 4 bands (C/D, E/F, G/H, I/J, with an optional extension into K). This receiver is intended for fast patrol boats and is designed to provide sufficiently accurate DF to support the targeting of antiship missiles. SR-200 is designed to operate in a dense pulse environment. The antenna array consists of an omnidirectional antenna and a rotating multihorn (for multiband) DF antenna. The omnidirectional antenna hands over the signals it intercepts to the DF antenna, which in turn provides signals for analysis. SR-200 provides an alarm based on the identity of an emitter. The display is either a PPI (strokes) or tabular. SR-200 can also be adapted to provide ESM data to a conventional radar display.

To measure direction of arrival, SR-200 uses a rotating antenna with sidelobe blanking. The receivers use wide-open IFM, for rapid intercept and acquisition. Automatic signal processing is employed to achieve rapid identification in a dense environment. The signal processing technique is azimuth-oriented spatial sampling. There are 3 receivers: IFM, TRF (tuned RF), and logarithmic video. Outputs are digitized pulse by pulse. The IFM is fed only by the narrow-beam directional antennas; the other receivers are fed by the omnidirectional antenna (TRF can be either).

The design emphasizes angular accuracy, which is required to estimate the range to a potential target. Range can be obtained by observing the change of bearing angle as the ESM platform moves along a baseline. The system can get within 10% of the range by measuring the bearing angle within 1 deg. For shorter ranges (within radar range), the ESM system can be used to point a ranging radar; accurate pointing permits very short radar transmission and so minimizes the risk of counter-detection.

Parameters: RF, PW, PRI, scan, DF, amplitude
Capacity: 500,000 pps, can display 58 active tracks

As measured in 1980, the system's performance was typically better than 2 deg on a single pass, and better than 1 deg on multiple passes. The accuracy above is measured at 1000 PRF. In a test in August 1980, SR-200 outperformed the requirements listed above. At 1 GHz, the requirement was 10 deg, but the system achieved an accuracy of about 3 deg; at 3 GHz the requirement was 5 deg, but the system was actually accurate to about 1 deg. At 6 GHz the measured accuracy was about 2 deg (the same at about 2 GHz); at 13 GHz it was about 1 deg (requirement was 2 deg).

SR-200 is manufactured by Sanders Associates. Sales: 8 to Peru (for FBPs) and 11 to another unnamed customer. SR-200B (baseband) was sold for land use.

◆ WJ 8957 (SCANS)

The Watkins-Johnson signal collection-and-analysis system is applicable to ships and submarines.

◆ WJ 8958 (DFS)

The Watkins-Johnson shipboard DF systems (0.5–2 GHz) for ships and submarines are currently in service both in the United States and abroad but are not as yet assigned any official U.S. nomenclature.

◆ WJ 32500

WJ 32500 is a ship or submarine ELINT signal-collection system (0.5–12 GHz, covering the COMINT and ELINT bands). Typically, it has 5 operator positions: 3 for COMINT (Morse or HF, voice/VHF/UHF, and special signals in HF-SHF), 1 for telemetry, and 1 for ELINT. It requires 9 racks of electronic equipment.

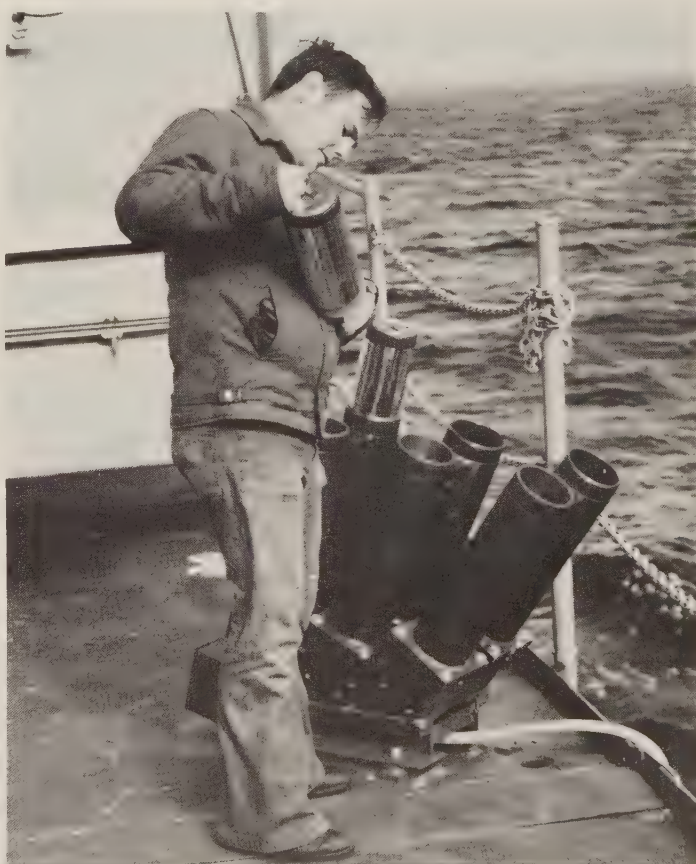
◆ WJ 34901

The Watkins-Johnson DF antenna, covering 2 MHz–2 GHz, uses loops and monopoles to achieve an accuracy of better than 3 deg within a radome 16 in wide and less than 31 in high. It can be used by both surface ships and submarines. This antenna is under navy contract, but it has not yet been delivered.

EXPENDABLES

◆ Mk 33/34 Launcher (RBOC)

RBOC was the Hycor Rapid-Blooming-Chaff launching system. Mk 33 was for frigates or destroyers (4 launchers); Mk 34, for corvettes, fast patrol boats, or hydrofoils (2 launchers). The launcher itself is Mk 135. This system has now been replaced in U.S. service by Mk 36, but it was exported. These launchers



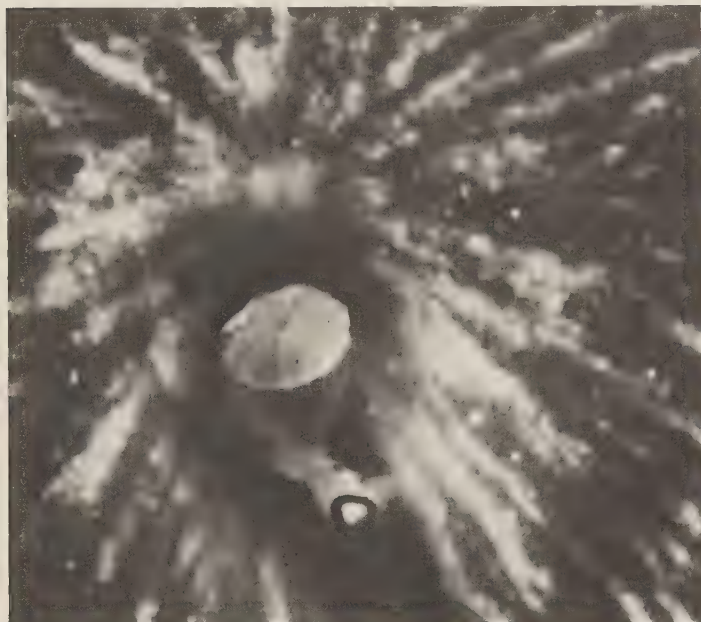
Loading a Mk 33 RBOC. (U.S. Navy)

were either automatically or semiautomatically controlled by the ship's ESM system. Each launcher was a 6-barreled mortar fixed in position: the barrel elevation angles were 55, 65, and 75 deg (by pairs). The standard Mk 171 chaff cartridge provided short-range protection, to about 150 yd (slant range). For longer ranges (about 1000–1500 yd), a rocket motor could be added to the cartridge.

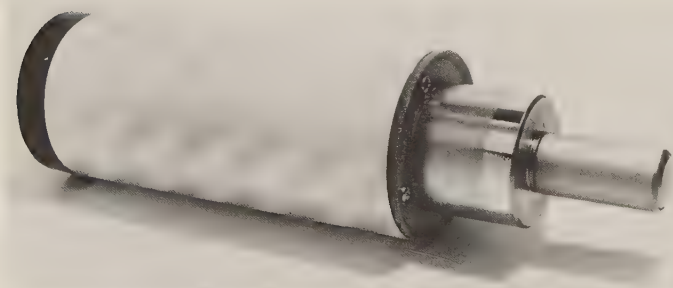
Decoys included chaff (2–20-GHz range), an IR decoy (HIRAM), and a combined decoy (Gemini, a parachute-suspended flare).

In 1977 a typical cartridge outfit for two 6-barrel launchers was 32 Mk 171 and 16 HIRAM (IR) decoys, plus 2 Mk 173 test cartridges.

Loral (Hycor) continued to market RBOC and to produce improved rounds, such as LOROC, for the 4.4-in RBOC after the U.S. Navy shifted to the 5.1-in SRBOC launcher. Its RBOC II launcher has been sold to foreign navies for small warships.



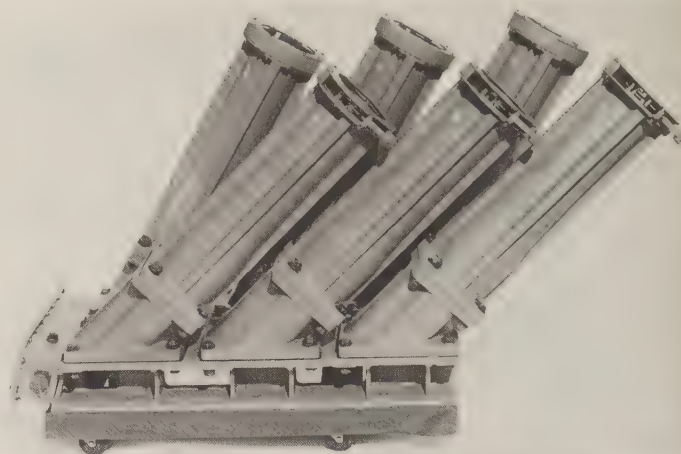
The burst of a Gemini combined IR/chaff decoy. The chaff streamers blow apart, while the IR flare descends slowly on a parachute. (Hycor)



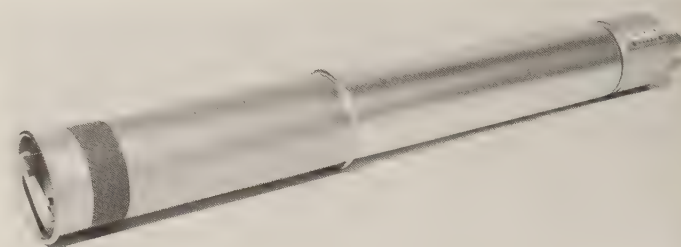
A Gemini decoy. (Hycor)

◆ Mk 36 SRBOC

The Super Rapid-Blooming-Chaff launcher fires 130-mm cartridges. Mod 1 with two 6-tube launchers is for ships under 140 m; Mod 2 with 4 launchers, for ships over 140 m. All use Mk 182 chaff-dispensing cartridges, which climb to 244 m. A "Torch" IR decoy is being developed for use with Mk 36 SRBOC, and the NATO Sea Gnat rocket chaff dispenser may be adopted. Cartridge types are Super Chaffstar, Super Hiram III/Super Hiram IV (IR), and Super Gemini RF/IR.



Mk 36 SRBOC launcher. Versions exist with the tubes either splayed, as here, or in rows of 2. (Hycor)



A Super Chaffstar decoy for SRBOC. (Hycor)

◆ AEB

The U.S. Navy's Active Expendable Buoy is similar in size to an A-size sonobuoy and contains a receiver, power supply, TWT, programmable signal processor, and deployable antenna. In June 1984 Dalmo Victor received a contract for 45 test buoys. Operational evaluation was completed in FY87, and a cost-reduction program began in FY88. AEB is deployed from aircraft or ships. This buoy counters enemy command/control; an advanced multipurpose buoy, now under development, will counter surveillance and targeting radars and missile seekers into the 1990s.

◆ AED

AED is the U.S. Navy's Active Expendable Decoy.

◆ ARM Decoys

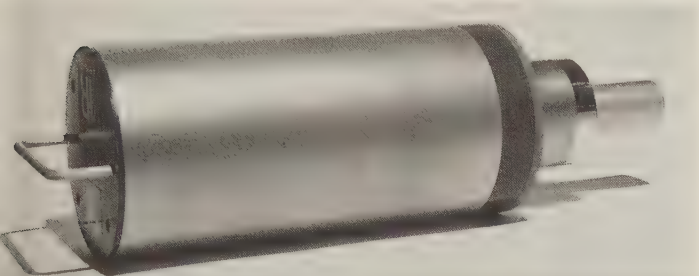
In September 1989 it was reported that projected ARM decoy systems for several radars had been canceled: those planned for SPS-39A, -48, and -52, and for SPN-6, -35, and -43A. No decoy had been planned for SPY-1. Presumably, these decoys would have been projected from standard chaff launchers. These reports were made in the context of an OSD report on new Soviet antiradar missiles. It is not clear why the cancellation of ARM decoys for obsolete or obsolescent radars (such as SPS-39A and SPN-6 and -35) radars excited much comment. It would seem, too, that the ship-simulating active decoys would have an anti-ARM effect since they presumably emit signals similar to those of standard combatant radars.

◆ CAD

CAD is a ship-fired radar simulator, made by Brunswick Defense. CAD hangs from a parachute and mimics the emissions from search radars. The program was jointly funded by the air force (for land application) and the navy, but funding was suspended just as the program was about to enter full-scale engineering development, about 1987.

◆ HIRAM

Hycor's IR Anti-Missile decoy for RBOC launching (112 × 117 mm, 4.1 kg) is a floating (spar buoy) IR decoy, sufficiently bright to duplicate the radiant intensity of even a large ship. HIRAM-2 (8 × 35 in, 29.4 lb; the decoy extends beyond the mortar's muzzle, and the portion in the mortar is of 112-mm diameter) uses liquid (similar to JP-5) rather than solid fuel, to burn longer (1 min rather than 0.5 min) with a brighter and higher flame (3 m high), to protect against IR missiles seeking their targets in either of the 2 typically used wavelength ranges (windows). HIRAM-2 will strike the water about 150 m from a ship in 5–7 sec. HIRAM was announced in 1980, for deployment in 1981.



HIRAM IV decoy (with "IR" marking). (Hycor)

◆ LODED

NRL's project for a Long-Duration Expendable Decoy was announced in the early 1980s. LODED was a slow-flying aircraft, planned for an endurance of 12 hr and a payload of 40 lb. Only a scale model, slightly over half scale, was built. It had tandem wings and a pusher propeller. It had no tail as such: the forward wings pivoted together for pitch control, and the after wings pivoted separately for roll control and together for pitch trim. The power plant was a 1-HP 2-stroke engine driving a 2-blade propeller. Dimensions: span 5 ft 8 in × length 4 ft 1 in, maximum body width 6.75 in, propeller diameter 11 in. Weight: 25 lb loaded (8-lb fuel, 10-lb payload). Launch speed was 33 kt. This project is interesting as an example of the way an RPV can be used for a ship's protection.

◆ TORCH

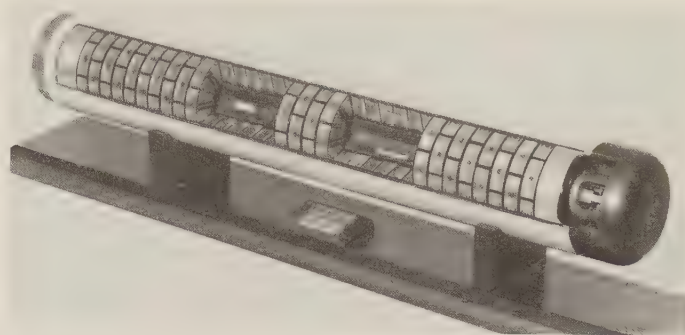
TORCH is a replacement for the earlier SOID. A quick-reaction off-board IR decoy launched by SRBOC, TORCH burns while floating on the water.

◆ Standard U.S. Chaff Cartridges

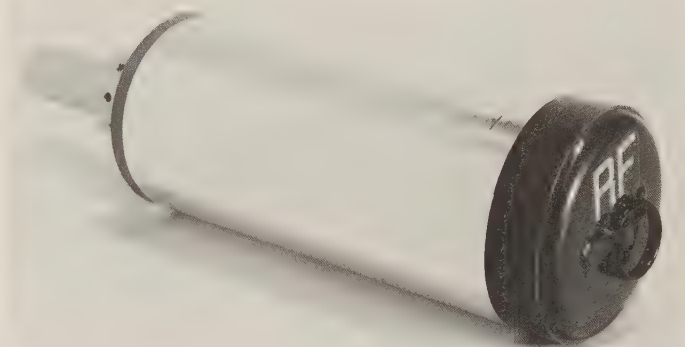
The first U.S. chaff cartridge, the Mk 76 Chaffroc, was fired by Zuni (5-in) rocket, using a modified aircraft launching pod. Its 10-kg payload was burst open by a time fuze, at up to 15-km range. The theoretical cross section was 60,000 m², but because all the chaff was released at one point, the effective cross section was 1000–2000 m². Mk 76 was in service in 1965–69.

Mk 76 was succeeded by the Hycor Mk 84 (1969–71); it used new packaging and deployment technique. About a third more chaff was carried, and it was in hundreds of packages (cassettes), that rapidly bloomed in patterns 100 m in diameter. Total radar cross section was about 3 times that of Mk 76. However, Mk 84 was expensive; only about a third of its weight went into chaff; it was too large for a small ship; a separate jammer (ULQ-1) was needed to shift the missile tracker from ship to chaff cloud; and chaff deployment/track transfer took too long.

The next step was a mortar with a seduction round, RBOC (Rapid-Blooming Off-board Chaff) Mk 171 (1972–74). Hycor delivered the first 11 sets of Mk 33 mortars early in 1972. Mk 171 carried much more chaff, using a new plastic-film wrap to sub-



Chaff packaged in an early decoy: Mk 84. (Hycor)



Chaffstar I decoy (with "RF" marking). (Hycor)

divide the load. The initial mortars were delivered to the fleet off Vietnam and were, therefore, called Westpac. The developed version, Mk 171, entered service in 1974. Radar cross section was about 7 times that of Mk 76. Mk 171 could be made for any frequency from 2–20 GHz. Mk 173 is a reusable inert test cartridge. Hycor markets Mk 171 as Chaffstar.

Mk 171 was intended to protect destroyers; and a new round, Mk 182 (Super RBOC, 130 mm rather than 112 mm), entered service in 1977. SRBOC carries about 4 times the payload of Mk 171, in 2 stages (macrocassettes for first-stage deployment, and plastic wraps within each macrocassette for second-stage deployment). Radar cross section is about 13 times that of Mk 76. Mk 182 is currently the standard U.S. chaff round.

The next stage is Mk 214, development of which was completed in 1986. Mk 214 provides about 26 times the radar cross section of the original Mk 76.

At present the U.S. Navy uses only chaff mortars; there are no chaff rockets. In the past, and probably still, there were also 5-in chaff rounds. The major chaff rocket program, Chafroc, was canceled in 1974 because of technical difficulties. However, as decoys become heavier and more elaborate, deck reaction in the existing mortars grows and becomes less acceptable; it seems likely that rockets will return in the near future.

◆ ALEX

A shipboard decoy (chaff or IR) system made by Hycor, ALEX is available in 2 calibers (130.2- and 112.8-mm) and with 2–20 launchers that have automatic round selection and sequencing. ALEX can use all current U.S. Navy cartridges, as well as the Chaffstar, Gemini, HIRAM, and LOROC series.

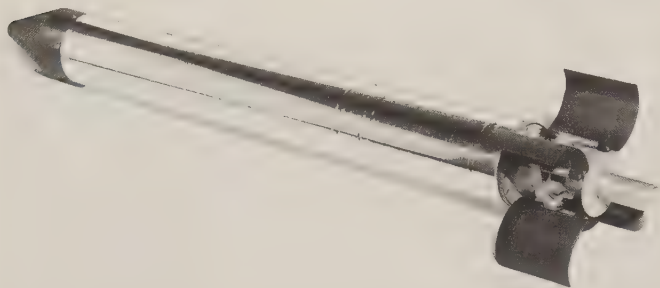
◆ Chaffstar II

Announced in 1986, Hycor's chaff cartridge produces a much larger chaff cloud than Chaffstar (Mk 171). Chaffstar II is much longer than Chaffstar (112.3 × 1067 mm, 18.2 kg vs. 112.3 × 412.1 mm, 4.15 kg) and, therefore, must be launched from an RBOC II launcher with barrel extenders. Muzzle velocity is 200 ft/sec, and the typical cloud is 328 ft [100 m] in diameter, with an area of 7850 m². Payload weight is 8.2 kg [18 lb].

◆ LOROC

Hycor's long-range off-board countermeasures chaff decoy can be launched from a lengthened RBOC II launcher and has an additional booster rocket. LOROC is launched to burst 1.0–4.5 km away from the ship for distraction. Dimensions: 112 × 1200 mm, weight 14.75 kg, payload weight 2.3 kg.

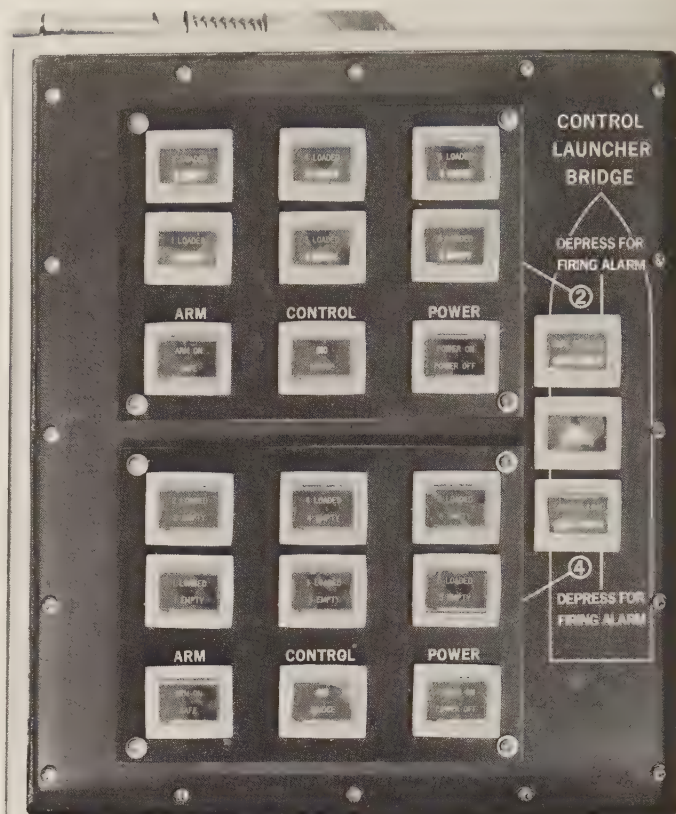
This round outranges the only current U.S. Navy chaff rocket, Sea Gnat Mk 216 (maximum range is reportedly 1.5–2.0 km). The U.S. Navy abandoned its long-range chaff-rocket program in 1974 because of technical problems, and by the late 1970s all surviving chaff rockets (adapted Zuni aircraft rockets) had been landed. LOROC has been exported to several foreign navies. It cannot be adopted by the U.S. Navy because the United States no longer uses the 4.4-in-caliber mortar.



LOROC chaff decoy. (Hycor)



A typical CIC control panel for chaff launchers. This system is CAMLAC, by Hycor, controlling two 6-barrel launchers that are loaded, in this case, with a mix of RBOCs and LOROCs. (Hycor)



A typical bridge control panel for chaff launchers, in this case the Hycor CAMLAC. There are 2 launchers, and the lower set of buttons indicates that control is being exercised from CIC rather than from the bridge. (Hycor)

ANTISUBMARINE WARFARE

Antisubmarine warfare is carried out by 3 almost distinct forces: long-range maritime-patrol aircraft, which are cued by underwater surveillance systems or other very long range intelligence; surface ships, which may themselves launch helicopters (or cue aircraft); and submarines on patrol in likely areas of enemy submarine concentration, which rely largely on passive sonars and on long-range heavy torpedoes.

At this writing, the only ASW sensors effective beyond a few hundred yards are acoustic. Numerous (and expensive) attempts to develop nonacoustic sensors have not succeeded, except under very specialized conditions; and there is every evidence that the world's navies must continue to rely on acoustics. Non-acoustics is attractive because, at least in theory, a nonacoustic sensor can be operated continuously by an airplane or even a satellite. Acoustic sensing demands that the sensing platform put something in the water, either an expendable sonobuoy or a hull or towed sonar. Because sonobuoy fields must be of limited size and density, an airplane's search rate is inherently limited. In addition, the finite supply of sonobuoys always limits possible searches.

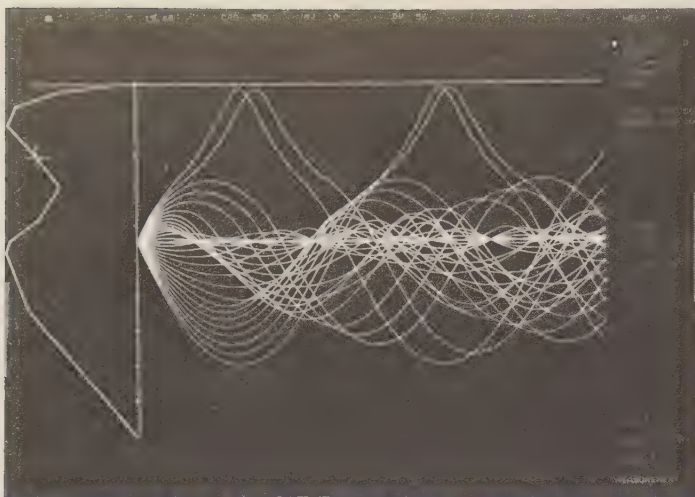
Generally there is a surface layer in the sea, kept at constant temperature (hence constant sound velocity) by mixing due to weather; this surface layer acts as a waveguide. The surface layer is about 300–600 ft deep in the North Atlantic, for example, depending on weather conditions. Within this layer, sonar acts much like radar, with signals propagating in nearly straight lines.

Below the layer, the velocity of sound varies with the depth, so rays of sound tend to bend, just as light passing through a complex medium will be refracted. One effect of this bending is to limit drastically the detection range of a surface ship against a submarine below the surface layer. For a hull-mounted sonar, the maximum (direct-path) range in the surface layer is about 20,000 yd, and ranges are often considerably shorter. Whether a given sonar can realize such maximum performance depends upon the sonar's power and frequency.

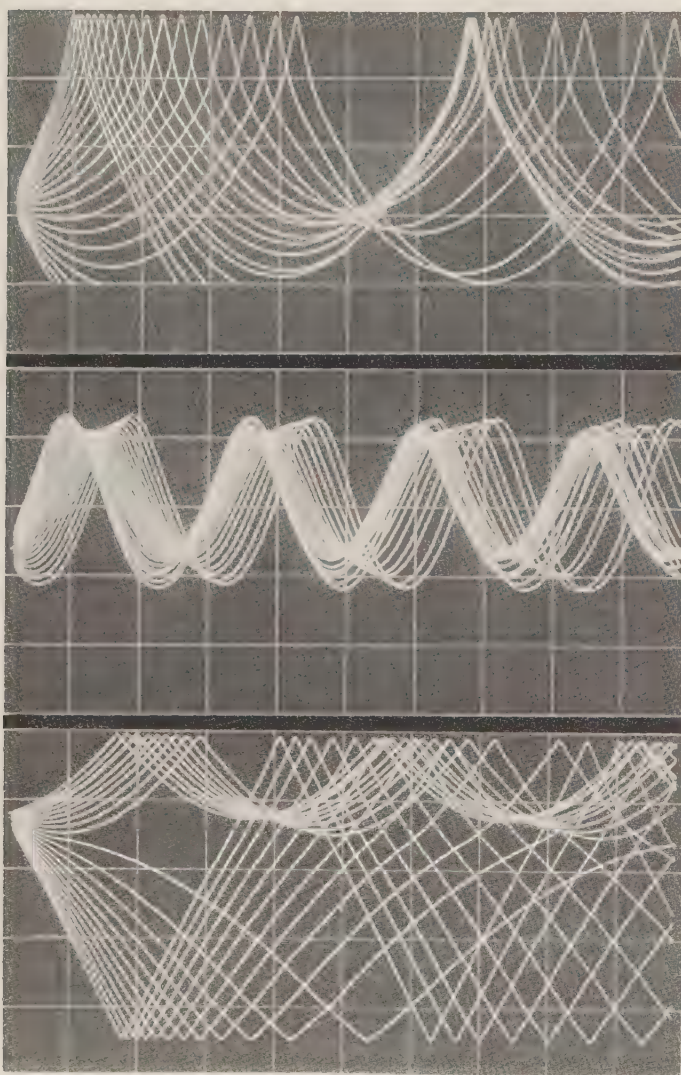
If the sonar's signals can propagate far enough, and if the water is deep enough, they bend down to a region of minimum sound velocity and then refract back up. The signals focus in a convergence zone around the ship, at a range set by water conditions. The convergence zone forms an annular ring around the ship, and additional convergence zones form at multiples of this first range. The typical range to the first convergence zone in the North Atlantic, for example, is 35 nm, and additional zones are found at 70, 105, 140, etc. Each zone may be 5 nm wide, and the sonar detecting a submarine in a convergence zone cannot distinguish positions within that zone. As a result, weapons cannot be fired on the basis of very long range detection. Instead, some platform must search the area in the zone within which the submarine may be located, to reacquire the target before attacking.

Two other acoustic paths deserve mention here. One is bottom (or surface) bounce: both the bottom and the surface can function as acoustic mirrors. In the late 1950s it appeared that bottom-bounce propagation could help fill the gap between relatively short direct-path ranges and long convergence-zone ranges; maximum bottom-bounce range was about 40,000 yd. Bottom bounce later lost much of its popularity because the sea bottom in much of the world turned out to be much more absorptive than had been expected.

A submerged submarine (or, in theory, a submerged variable-depth sonar) can use surface-bounce propagation. Presumably, U.S. submarine sonars are spherical (i.e., can both depress and elevate their beams) specifically to exploit surface- as well as bottom-bounce propagation. Soviet submarines, such as Victors, have bow torpedo tubes and are presumably, therefore, limited to chin sonars, which are unlikely to make much effective use of surface-bounce propagation. That limitation in turn may be related to an emphasis on operation at shallow depths. Surface-bounce propagation is somewhat limited by weather, since reflection will be much less efficient if the surface is rough on the scale of sonar wavelengths, i.e., several feet.



Undersea warfare is complicated because sound does not travel in straight lines. It is, therefore, important to be able to predict that path. This display is a sonar ray-path predictor; the sound velocity profile is at left, and the corresponding prediction is at the right, for a sonar deep in the water. There is a combination of convergence zone refraction and reflection off the surface. (Thomson Sintra)



Typical sonar transmission patterns are shown on a ray-path predictor. All are from submerged sonars (variable-depth sonar or a submarine). At top, the rays bounce off the surface and curve around because of the convergence-zone phenomenon. The middle picture shows the effect of refraction in bending sonar rays up and down; this effect is the convergence-zone phenomenon. The bottom picture shows rays trapped in the surface duct at top, and bouncing off both the surface and the bottom. Whether a ray is trapped depends on the angle with which it is projected. (Signaal)

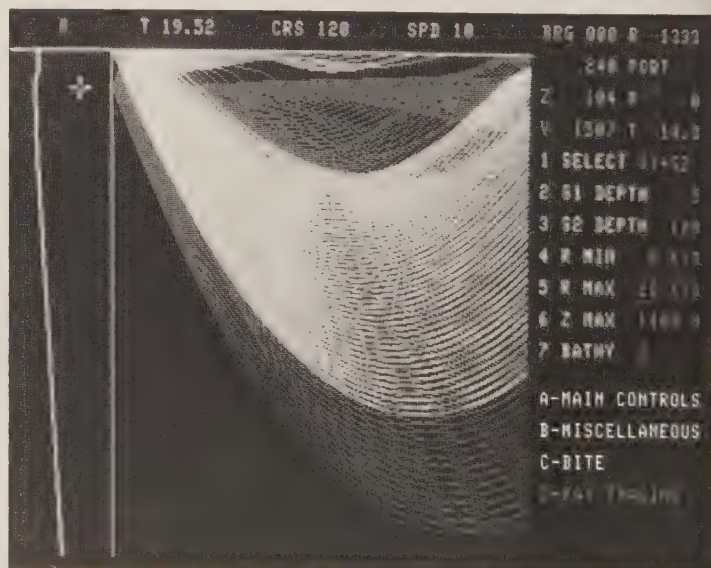
Both bounce paths are inherently limited in range because the sound ray must pass steeply enough through the various layers to avoid refraction and trapping, a phenomenon equivalent to that of the critical angle in optics. Actual range must depend on the bottom depth (or, in the case of surface-bounce, on the depth of the source), but for surface ships under average conditions the usual assumed maximum range is 40,000 yd. That figure may be based in part on an estimate of the loss to be expected in reflection off the bottom.

The other alternative is the reliable acoustic path (RAP), essentially the vertical path from bottom to surface or vice versa. No matter what the acoustic layering of the sea, a signal propagated perpendicular to the layers should pass through without distortion. There should also be a small angle around the vertical in which signals can pass with little loss or distortion. If the sound source or detector is deep enough, even that small angle can subtend a very considerable distance at the surface. RAP is hardly new, as it explains the successful operation of echo-sounders. However, the widespread application of RAP to sonar operation is relatively recent because an RAP sonar generally has to be quite deep.

In relatively shallow water, inside the 100-fathom (600-ft) curve, convergence-zone propagation is impossible. Hull sonars suffer from multiple bottom bounces, so detecting real targets is very difficult. However, a very high frequency upward-looking RAP sonar can function effectively. A sonar source well below the surface, moreover, can send out a horizontal beam that can avoid bouncing off either bottom or surface. Horizontal transmission is probably one mode of operation of the new low-frequency helicopter dipping sonars.

Sonar may be active or passive. Active operation has the advantage of imposing a signature on a submarine, and thus of overcoming silencing; but active operation reveals the presence of the searcher, and range is limited by the amount of energy that can be poured into the water. Passive operation depends upon picking up relatively faint sounds against the background of a relatively noisy ocean. When passive signals can be picked up, extraordinary ranges can be achieved because of multiple convergence zones. In most cases, success with passive sonar has been the key to NATO's ASW dominance, with active operation virtually limited to homing torpedoes. That situation may now be changing.

The major development of the past few years has been the Soviets' progress in countering Western sonars. Countermeasures consist of both silencing submarine noises to reduce pas-



Given knowledge of the possible sound paths, sonar performance can be predicted. This typical modern display has the sound-velocity profile at left. Maximum effective range, read out at right, is 20,000 yd, and maximum target depth is 1400 m (limited by refraction). (Thomson Sintra)

ive ranges and applying anechoic coatings to absorb active signals and, thus, to make active detection more difficult. The anechoic coatings cannot be very thick, so they are likely to be most effective against relatively high frequency sonars, i.e., against the sonars on board homing torpedoes.

The basis of passive operation, i.e., of all signal processing, is that the submarine's signals are regular, whereas the background noise is random. There are 2 fundamental approaches: the signal may be analyzed in spectral (frequency) terms, on the theory that over time the constant signature of the submarine will emerge; or the sonar can look instead at small volumes (cells) of ocean, choosing a particular cell that is consistently louder than its neighbors on the assumption that it contains a noise source. Mathematically, the 2 approaches are Fourier-transform alternatives. Spatial processing (i.e., concentration on a cell or on a volume defined in terms of bearing angle) is equivalent to adding up (integrating) signals over a broad band of frequencies from sources within that cell or angular range. Spatial processing is, therefore, often described as broad-band. The alternative (spectral processing) is, naturally, described as narrow-band.

Narrow-band noise is produced by rotating devices such as machinery and propellers or, for a diesel, the regular firing of the engine. In practice, each line of noise is accompanied by harmonics, weaker repetitions of the sound at progressively higher frequencies. A signal processor may concentrate on a harmonic, even though it is weaker, because it occurs in a quieter part of the background noise. Moreover, because listening arrays are limited in size, they will have better gain (i.e., better discrimination in direction) at higher frequencies. The better that discrimination, the less background noise is mixed with the signal of interest.

Broad-band noise is much less well defined. Examples might include the flow noise over the submarine's hull and the gurgling of piping inside the submarine.

The appropriate choice for analysis depends on several factors. The fainter the submarine's sounds (i.e., the better it is silenced), the longer the period of integration required to separate a regular acoustic signature from the surrounding noise. If the signature is not really constant, integration time is limited, perhaps below what would be required to overcome noise. In that case broad-band (spatial) processing may be a much better choice.

Many systems combine the 2 types of analysis, forming beams (i.e., processing spatially) and then breaking down the signal in each beam by narrow-band processing. The greater the computing power of the system as a whole, the more easily it can conduct this 2-step analysis. Given sufficient processing power, the user must cope with an enormous amount of data; typically, then, the user needs some semiautomated means to indicate the presence of a real signal in a narrow frequency band of 1 of many beams.

Conversely, a computer-based combat system can track an enormous number of targets simultaneously. There will generally be relatively few real ones, but analysis of the motion of the others will often allow them to be disregarded. This is also true of decoys, and it explains the need for a modern torpedo, such as Murene, to track numerous targets simultaneously.

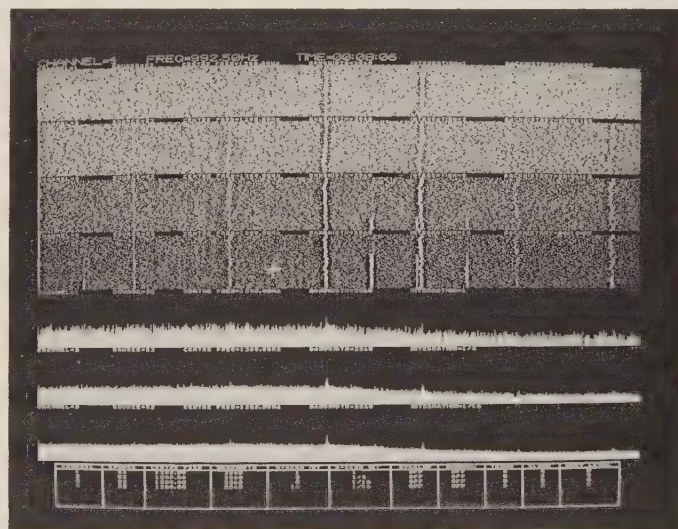
To deal with quieter and more distant targets, arrays have grown in complexity and in area; in one typical case, the number of separate hydrophones (in several arrays on board a submarine) quadrupled. Since all the array data is digital, it can all be processed together, a single system forming beams out of all the array data. This type of processing can be very powerful (for example, it can form nulls to cancel out self-noise and jamming), but it also entails a very high data rate, in this case more than an order of magnitude greater than in the past. This output in turn is needed to improve resolution, both in space and in frequency space, to detect quiet targets more effectively amid the surrounding noise. The associated system has over 200 channels of track information: 12 passive broad-band trackers, 2 DEMON trackers, 4 adjustable spectral window trackers, 8

passive-ranging trackers, 5 active track channels, and 164 high-quality automatic trackers. Such numbers would overwhelm an operator at a display; the system must make many of the decisions as to how the targets it detects are to be tracked, the operator monitoring the process and intervening when necessary.

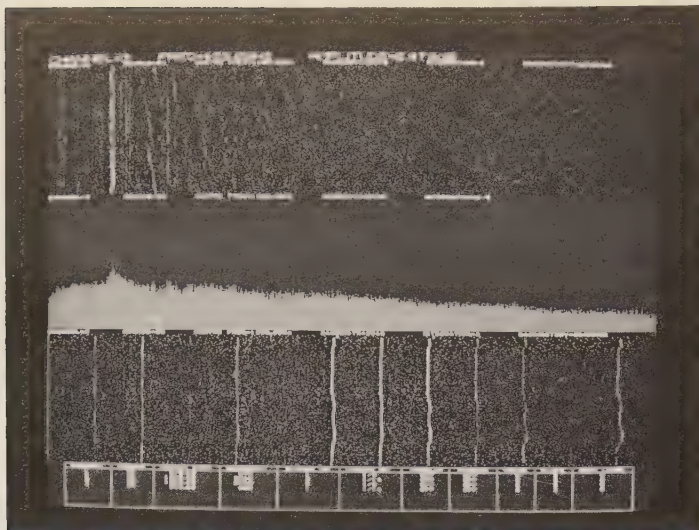
Both types of processing can be quite sophisticated, and both represent alternatives to active operation. After World War II, when submarines (particularly those snorkeling) were relatively loud, passive operation entailed essentially no integration: a sonobuoy (or, for that matter, a homing torpedo) had only to seek a noise noticeably louder than its surroundings. That operation was very simple broad-band processing. That era ended in the early 1950s, as submariners learned not to snorkel for protracted periods. The question then was whether passive ASW was still practical. The solution turned out to be low-frequency narrow-band processing and integration, which the U.S. Navy code-named LOFAR (Low-Frequency Analysis and Recording).

LOFAR was the basis for Western passive acoustics from the mid-1950s on, and for many years it was a closely guarded secret. The success of LOFAR depended in part upon knowledge of the detailed acoustic signatures of potential enemy submarines because signal processing could be much more effective if specific features of a target submarine's acoustics were known. During the 1970s Soviet recording devices began to turn up in areas where NATO submarines operated, such as Norway and Puget Sound. Such devices are useful only in a LOFAR-acoustics context. In 1988 the U.S. DoD provided confirmation by publishing a photograph of a Soviet equivalent of a U.S. LOFAR sonobuoy.

Many modern passive sonars use waterfall displays, in which the vertical ordinate is time. The horizontal scale is either frequency or bearing. In either case, the data flow down from the



LOFAR was the most important ASW discovery of the first postwar decade. Here the upper 4 bands are LOFARgrams, and the targets are visible as the brighter lines amid the noise. Below the LOFARgrams are A-scans in which the total strength of each frequency interval is shown. All of the displays show the same real data, but the different LOFARgrams represent different integration periods. The longer the integration time (i.e., the greater the time represented by the vertical scale), the brighter a steady line will be. On the other hand, a line that is steady for a time but then fades out (e.g., because the submarine alters her behavior) will vanish over a long integration period. Thus some lines that are fairly clear in some of the LOFARgrams vanish in others. The different A-scans use different exponential integration periods. All of the LOFARgrams look grainy because this is a CRT display rather than a copy of a paper printout. Parameters are shown at the bottom, and also at the top and bottom of the displays. A similar display could be used to show data from several sonobuoys simultaneously, or to show different frequency ranges (in an attempt to match up harmonics of the same line). The original of this photograph is in color, and different colors are used to distinguish the different processing times used. (GEC-MUSL)



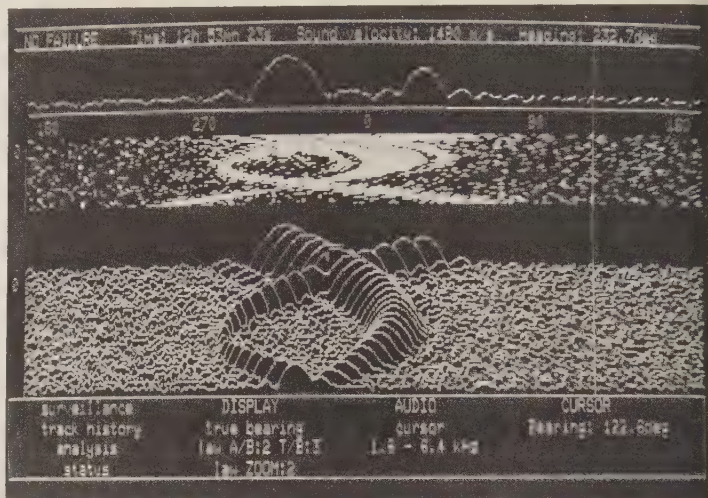
In many cases, an airplane will monitor several sonobuoys simultaneously. Here a LOFARgram and its corresponding A-scan are shown top and center, and another LOFARgram (with several prominent lines) is shown at bottom. The peak in the A-scan corresponds to the bright line in the LOFARgram at top, but the line is much more visible. The center display is automatic line integration (ALI); many modern passive systems automatically detect signals whose integrals pass through some preset threshold. An alert operator might well have seen the line in question long before ALI caught it. Moreover, ALI might well miss the bright lines at bottom, which change in frequency over time. In both LOFARgrams the latest time is at the top. The cross is a cursor used to read out the frequency of the line it is placed over; the corresponding data (465 Hz, 2.979 dB) read out at the top. (GEC-MUSL)

top of the display, which shows the short-term history of what the sensor receives. The beaming version, therefore, shows relative target motion. Signals that are constant in frequency stand out in a frequency waterfall (a LOFARgram, often shortened to "gram"). The observer integrates the data visually to separate the stable signals (which appear as more or less continuous vertical lines) from the surrounding noise. The LOFARgram is, in effect, a spectrogram. Some systems record relative intensities at different frequencies at time intervals and then integrate over time to form a true spectrogram that is usable, for example, for automatic or semiautomatic target recognition.

The original grams were paper records equivalent, in theory, to waterfalls. The new signal appeared across the top of the paper and moved down as the paper moved. Marks on the paper indicated the intensity of the signals picked up at various frequencies. The electronic form of a gram shows signals over only a short period; the associated system generally relies on its memory to pick up long-term but weak signals. A paper gram can be spread out and integrated, in effect, by eye, and sometimes that is superior to the mathematical analysis. For example, a line varying slightly (e.g., due to doppler) can be picked up by eye. Some current systems provide both CRT and paper readout specifically so that signals missed on the CRT will be picked up when the paper gram is spread out.

The hard-copy printer is inherently limited by the speed at which a record can be written, usually 1.25 sec/line. Hence the paper recorder must show signals as they are processed and, thus, cannot easily switch from channel to channel. A CRT can rapidly switch, so it can show all the historical data in the processor. The CRT can simultaneously display several portions of a frequency spectrum to emphasize harmonic relationships between lines. This technique is specially valuable in deciding whether particular lines are related to submarine speed or to machinery gear ratios. The CRT can also be used to designate a particular line to the system to begin, e.g., a tracking or bearing measurement algorithm. Hard copy, however, is more useful to regain a lost contact since the operator's eye can bridge a vertical gap in a line, whereas a gap may break the computer's track.

Waterfalls are not suitable for active sonar displays since a waterfall cannot show range and bearing simultaneously. Therefore, active scanning sonars generally use PPIs. In cases of ODT transmission, the display often uses an expanding ring to represent the outgoing minidirectional pulse; in contrast, in a radar PPI, a line representing the directional pulse and its echo revolves around the face of the scope. Many active sonars use B-scans, rectangular displays of range (vertical) vs. bearing. Compared with a PPI, a B-scan has the advantages of compressing distant targets into a limited space yet showing nearby targets clearly. Searchlight sonars use an A-scope and bearing indicator.



This view is a passive-detection display of a Thomson Sintra sonar; the original is in color. At any one time the spectrum can be integrated to provide a graph showing the directions from which the loudest noises come (as at the top of the display). These lines are not quite like the lines of the usual waterfall, showing more gradation. The bottom of the display shows these integrals as they have changed over time, to indicate target maneuvers. The result is like a waterfall but more finely graded. (Thomson Sintra)

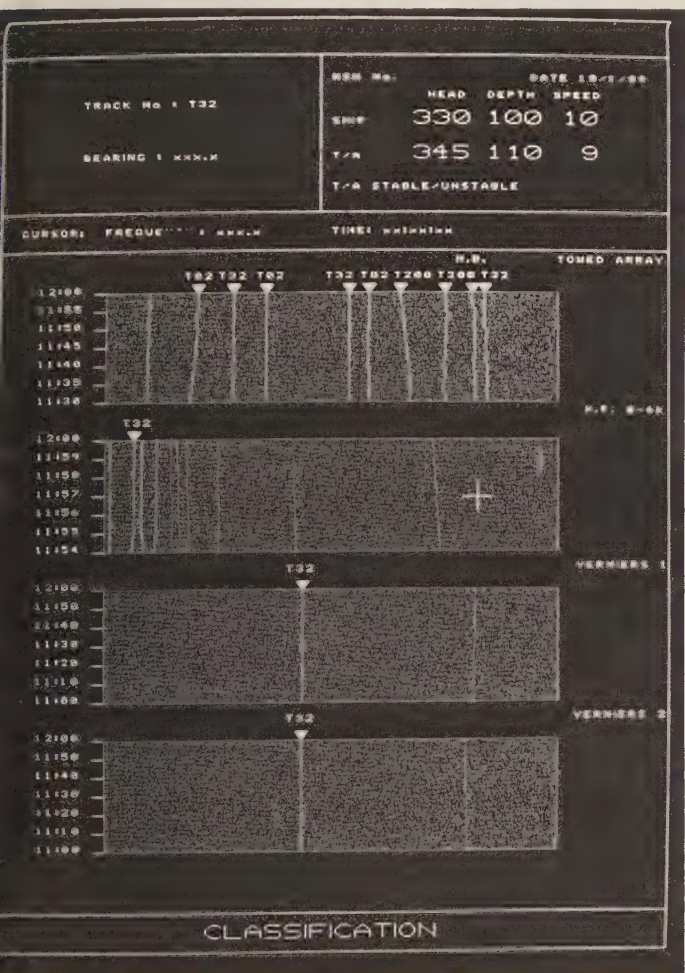


As a submarine maneuvers, a nearby target changes bearing. The change can be used to measure the target's range. Modern computer-assisted submarine combat systems do this target-motion analysis automatically, sensing changes in own-submarine course and speed. This Thomson Sintra passive-ranging display shows the assumed target path at top and the own-submarine maneuver at bottom; the graph at the bottom shows how target bearing has changed during the maneuver. The ranging algorithm assumes that the target is following a steady (but unknown) course. The upper right-hand corner indicates that the operator can choose instead passive ranging by triangulation or active ranging. Target-motion analysis requires time: the longer the analysis, the better the range accuracy. Modern computer-aided systems tend to be much faster than older manual plots, using essentially the same techniques. (Thomson Sintra)

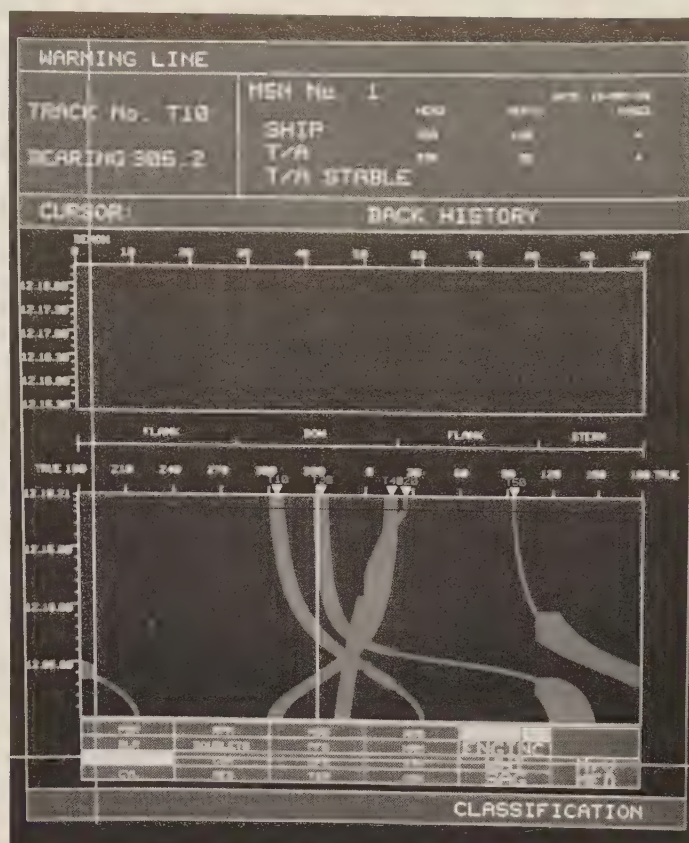
Armed with knowledge of the primary Western signal-processing technique, and probably driven by revelations of the effectiveness of NATO's detections of submarines, the Soviets have been able to achieve considerable silencing in their latest classes. The question, again, is whether passive signal processing has much of a future.

Three possibilities emerge, and as yet it is impossible to choose between them. One is that improvements in LOFAR technology—e.g., by adding more spatial discrimination, by tightening discrimination between nearby frequencies, or just by increasing integration time—can solve the problem. The United States' new LOFAR array sonobuoys and continued investment in towed passive arrays typify this approach. If this approach succeeds, the current situation, that Soviet submarines can be detected at long range without revealing the presence of NATO forces, will basically continue.

Another possibility is that low-frequency narrow-band passive sonar will lose its capability, so that passive operation will be reduced to medium-frequency flow noises. In that case, it will pay to abandon expensive signal processing in favor of mass producing relatively simple (broad-band) sensors of flow noise and strewing them about the estimated position of a submarine. This approach would seem to be the basis of the new low-cost sonobuoy. An intermediate possibility would be to distinguish regular features of broad-band noise and, thus, to retain longer-range operation at a cost in processing complexity.



LOFARgram concepts are also applied to towed and other passive arrays. This is a typical towed-array classification display. The upper gram is narrow-band. In the next, the frequency scale is expanded (wide-band) to show many more lines than those above. In the 2 Vernier displays below, the frequency of the line of interest (T32) can be measured more precisely because the entire scale is quite narrow. Each line is assigned a track number so that the associated computer tracker can perform MA on it. The heading of the array (which is not the heading of the ship towing it) is read out; that is the function of 1 of the modules in the array. (GEC-MUSL)



Two methods of broad-band classification are shown. At top, demodulated noise (DEMON) is represented in LOFARgram form (a single line is visible). At bottom, these data are shown in correlogram form. This is a type of waterfall display, the broad areas showing several targets maneuvering over time. The towed array floats above the submarine towing it so as not to foul her propeller. (GEC-MUSL)

The third alternative is to abandon passive operation in favor of very low frequency, i.e., very long range, active operation. In that case the existing low-frequency systems would be retained, but they would function as the receivers in bistatic sonars, receiving echoes from the pings of relatively simple noise sources. Several active towed arrays, described in these pages, typify this approach.

Driving the development of ASW weapons, sensors, and tactics are the basic facts of sonar operation: sound propagates farthest at low frequency, and sound tends not to propagate in straight lines. Lower frequency means longer wavelength, and a sonar operating at that lower frequency must be larger to maintain the same gain (directionality). World War II sonars operated at high frequency (20–30 kHz) to assure directionality even with relatively small transducers. Medium frequency might loosely be defined as the range 5–15 kHz, and low frequency as about 1–5 kHz. However, some navies regard 5–7 kHz as low frequency and so describe their sonars. Operation below about 1 kHz generally requires devices, such as towed arrays, different enough from conventional sonars for another differentiation to be made, e.g., very low frequency. Another way to draw this distinction would be to associate high frequency with short direct path ranges and with sonars essentially limited to the surface layer. Medium-frequency sonars can detect submarines below the (surface) layer at useful ranges, and, if properly designed, they can use the bottom-bounce path. Low frequency means convergence-zone propagation, at least potentially. On this basis 5 kHz is low frequency in the Mediterranean, but about 3 or 3.5 kHz is required for low-frequency operation in the Atlantic and the Norwegian Sea. The history of sonar since 1945–50 has been a series of jumps down in frequency and, therefore, up in range. The velocity of sound in water is about 4700 ft/sec, so 30 kHz equates to a wavelength of about 1.8 in. A typical World War II maximum operational

as a very broad range of frequency responses. A single unit of the array may be long enough to provide good directionality for signals at the highest frequency (i.e., shortest wavelength) with which the system deals. That unit becomes the middle subunit of a second, longer subarray used at a lower frequency. Typically, all the subarrays are built of identical basic units, so in this case the second subarray is 3 times the length of the first, operating at a third of the first's base frequency. The 2 are nested, the units of the first subarray working simultaneously at both frequency ranges. Forming the middle of the lower-frequency array, the first is said to nest in the second. Adding 2 more units to the ends of the 3-unit array gives a third array 5 times the length of the first, operating at a fifth its frequency.

If the first subarray was designed to work in the range around 500 kHz, the second would be centered on 200 kHz and the third on 120 kHz. The U.S. SQR-18A reportedly consists of 8 identical subunits, 2 of which form the highest-frequency subarray. The combination of those 2 with the 2 at their ends forms the next lower-frequency subarray (at half the highest frequency). If the next 2 are counted, then the next-lower subarray consists of 6 basic units, at one-third the highest frequency. All 8 basic units form the lowest-frequency receiver, working at a base frequency a quarter that of the highest-frequency subarray.

In each case, the subarray is imagined as built out fore and aft from the center of the array as a whole. That design greatly simplifies beam-forming. Beams are formed by adding the outputs of the subelements of the subarrays in proper phase, and that addition changes least from frequency to frequency when the array is handled symmetrically.

Current towed arrays are passive receivers of sounds made by submarines; but as the submarines become quieter, it becomes attractive to provide an active sound source, generally in the form of a flex-tensional transducer operating at about 150–600 Hz (wavelength about 7.5–30 ft). The array would then act as the receiver of a very low frequency sonar.

Systems vary from navy to navy partly because different navies operate under very different acoustic conditions, and partly because navies perceive their missions very differently. For example, the Royal Navy operates its frigate-towed arrays largely for surveillance. They must, therefore, be relatively long (to work at the low frequencies at which sound propagates most effectively); and the ships must be very carefully silenced. In contrast, the U.S. Navy operates separate surveillance arrays (the SURTASS program) and separate tactical arrays, the latter for defending battle groups or convoys. U.S. tactical arrays can, therefore, be shorter, and they can tolerate worse acoustic conditions.

Sea conditions modify sonar choices. In summer, the surface layer in the Mediterranean, for example, may be only about 50 ft deep, so hull-mounted sonars become nearly useless. That condition explains the long-standing interest of the French and Italian navies in variable-depth sonars, which can operate under the layer. In the Mediterranean, too, the deep sound-channel is much shallower than in the Atlantic, and the convergence zone is much closer. In consequence, there is little point in using very low frequency sonars, and neither the French nor the Italians have gone as far as the U.S. Navy in the development of lower-frequency sonars. Other warm areas, such as the Arabian Sea, also have shallow surface layers, heated by the sun and often not mixed with deeper, cooler water. The Baltic is notorious. Because so many rivers empty into that sea, its acoustics are dominated by alternating layers of different salinity, from which sonar pings reflect. That condition is 1 reason the Swedish navy effectively abandoned ASW in the 1960s, and also 1 reason why it has been so difficult to determine whether the Soviets really are operating midget submarines in shallow Swedish waters. On the other hand, the Arctic Ocean is at a nearly constant temperature, so that the surface layer extends down to the bottom, making for very much longer effective ranges. Presumably, the only problem is the reflection and refraction of sound in the presence of large masses of ice. Special sound conditions may also be caused by particular marine life

or particularly heavy shipping lanes or fishing areas. Other special conditions obtain in other areas, such as the South China Sea or the waters around Australia, and these conditions help explain why different navies have adopted such different approaches to essentially the same sonar technologies.

Some technological points require explanation. Virtually all modern sonars scan. They may send out directional pings, but they do not wait for the ping to return before looking in another direction. Reception is separated from transmission because the sonar can receive in all directions, either in quick sequence (with a scanning cycle much shorter than the ping's length, so that the sonar is in effect looking in all directions all the time) or actually simultaneously. Because the sonar need not continue to stare in 1 direction before looking elsewhere, the scanning rate is independent of the expected time between ping and echo (i.e., independent of range), and a sonar can search a large volume with a reasonable probability of detecting a target.

A scanning sonar consists of an array of more or less omnidirectional transducers, achieving directionality by combining the signals from several adjacent transducers in the appropriate phase relationship, much as a phased-array radar works. This idea is not new: as long ago as World War I, linear hydrophone arrays formed beams using delay lines (which were sometimes called "artificial" or "electrical" water because the lines corresponded to effective water paths to different elements of the array).

Scanning sonar was developed in parallel by the United States, Britain, and Germany during World War II. In older U.S. (and many other) scanning sonars, a commutator carrying the appropriate (beam-forming) phase relationship scans physically. Each transducer stave feeds a stator element, and the commutator (rotor) spins within this external stator to form a series of successive listening beams that, in effect, sample the returning echoes. The listening beam must scan quickly enough to pick up at least part of the echo from any target within range, so the emitted pulse should be about as long as the time for any single scan. The shorter the pulse, the faster the scan must be. For example, a pulse 33 msec long would be associated with a scanning rate of 1800 rpm.

The usual display for such a sonar is a radar-like PPI, in which the point of light indicating a possible target describes a spiral, sweeping simultaneously around and outward at a rate proportional to the local speed of sound. Sometimes a circle indicating the outward motion of the omnidirectional ping is superimposed.

Similarly, the transmitting beam can be rotated by a second stator within which another rotor spins. Each transducer stave is connected to 1 stator pole in an oscillator programmer (in U.S. terminology) in the sonar control room. The scanner rotor turns continuously and is energized only when the sonar transmits. It in turn energizes the stator poles and, thus, forms the rotating beam. The faster the rotor speed, the shorter the pulse, since each stator is energized for a shorter time. The rotor carries low-energy signals that are amplified between stator and transducer stave.

It might seem simpler to spin a commutator within the transducer itself, but the separate stator arrangement makes it possible to provide 1 or more additional beams that need not turn continuously. The main examples are a tracking beam using left-right comparison and a separate audio beam, which the sonar operator can place atop a target of interest. The audio beam picks up target sound for classification; at least until very recently audio was the chief means of target identification. The U.S. SQS-4 and SQS-23 series have separate video (continuously scanning) and audio beams. ASPECT (see below), a sonar echo technique, was 1 attempt to find an alternative means of target classification.

This scanning system was used in SQS-4, -23, and -26. The use of an external rotor later extended to the big spherical bow sonars used in submarines, such as BQS-6.

The commutator has several disadvantages. It inevitably adds to the noise of the system. Because it samples all the transducer

outputs, it cannot listen continuously; therefore, it misses some transient sounds. It also cannot fully exploit the strength of a long pulse since it will be listening in the appropriate direction for only part of the received pulse. Finally, the mechanically scanned system is really most appropriate to a cylindrical (or, in modified form, a spherical) sonar since the commutator must treat every group of adjacent staves alike. In a sonar transducer without such symmetry, the same transducers require different delays or phases to form beams pointing in different directions.

The parallel British approach was to provide appropriate networks of delay lines from groups of transducers to form separate beam patterns simultaneously (the prototype used 72 elements and formed 72 beams). Each beam was provided with a separate amplifier and rectifier, the charge on the rectifier representing the strength of the signal from the direction in which that particular beam was pointed. It, therefore, stored the whole of the returning ping. The array of 72 rectifiers could be scanned periodically. This arrangement was more complex than the U.S. commutator, but it could be applied relatively easily to shapes other than a simple cylinder. On the other hand, scanning rate was unrelated to ping length, and the sonar could get the full benefit of each ping. The wartime British set was scanned 1000 times/sec, equivalent to a range of 2500 yd.

This British system could be called beam preforming, and it was more closely analogous to radar technology than was the U.S. system. In theory, different groups of staves could be activated to produce the desired beams, and the beam could scan in some random pattern. The British verdict was that the faster scanning possible with preformed beams allowed for better contact-keeping. Moreover, because such a sonar could be other than cylindrical, it could concentrate sonar energy (and listening capability) on a narrower sector, for greater range. This view led to the development of the flat-plate Type 177. To the extent that the Soviet spy rings at Portsmouth were obtaining uniquely British sonar technology in the mid- to late-1950s, they were presumably obtaining the sector-scan/preformed-beam technology of Type 177.

The wartime German GHG passive submarine sonar (which led postwar to most of the major Western passive submarine sonars, and probably also to Soviet types) was broadly analogous to the British scanner, with a network of delay lines (compensators, also sometimes called "artificial water") to form its beams. Typically, a compensator switch was combined with a series of delay lines. Turned into a position corresponding to a given beam direction, the compensator switch sampled only certain hydrophone outputs and fed them through the appropriate delay lines.

Modern sonars use preformed beams, which make better use of the entire transducer array than any commutator system. Unlike the British wartime and postwar sets, however, they are not hard-wired, and they do not scan through the outputs of the beams. Instead, the beam-forming phase relationships are stored electronically. Individual transducer outputs are digitized, and beams are formed arithmetically, these outputs being added and subtracted with the appropriate multipliers. The sonar signal processor can then deal with all of the beams simultaneously. In effect, the sonar stares in all directions at once. This type of processing explains the very high computing power required in modern sonars.

Such digital operation is called DIMUS (digital multibeam steering) or beam preforming. Beam preforming is clearly easiest for a symmetrical sonar but can also work for a more complex shape, such as that of a conformal array. In any case it has the great advantage of making full use of the arriving signal, eliminating scanning loss. In addition, the relationships between outputs from the different transducers can be adjusted to meet changing operational or water conditions (adaptive beam-forming) since the relationships may be software-controlled rather than hard-wired. Thus, beam-forming is a prerequisite for building complex conformal sonar arrays.

Beam-forming can also be used to project or to receive multiple beams, just as a phased-array radar can produce several

beams simultaneously. A commutator sonar requires a separate commutator for each such beam. Physically, beam-forming generally involves the replacement of a mechanical commutator by a digitizer and the associated digital computer(s). The effect is greatly to increase the number of targets that can be handled simultaneously.

The first scanning sonars sent out omnidirectional pulses (ODT, omnidirectional transmission). These sonars had the advantage of effectively matching their transmissions with omnidirectional reception, but the power available in any 1 direction was limited. One modern alternative is RDT, rotationally directed transmission, the sonar sending out concentrated pulses along each bearing while scanning through all transmission directions, like a 360-deg radar. The drawback to simple RDT is that it does not scan through all directions quickly enough. Some sonars employ tribeam transmission, scanning 3 transmitting beams that are 120 deg apart.

Sonars are sometimes classified as search or attack, or a single sonar may operate in both modes. Attack always implies a narrower beam capable of tracking a target sufficiently well for weapons to be aimed. The required standard of aiming depends on the lethal envelope of the weapon. A mortar or rocket launcher, whose bomb has only a very limited lethal range, generally requires 3D ballistic information, including the underwater equivalent of height-finding. A homing torpedo, delivered either over the side or by rocket or missile, may need little more than an initial range and bearing, although the target's depth may still be important for predicting a target's position.

Most ASW surface ships armed with mortars or rocket launchers in the early postwar period were provided with separate search and attack sonars, and some ships still show this distinction. On these ships, the attack sonar has a narrow beam that can both train and elevate. In more recent sonars, the beam can be depressed electronically, since each vertical stave (an element that resembles and is named after a barrel stave) consists of several fairly nondirectional transducers that can be phased relative to each other. In large sonars the beam can be elevated fairly precisely. However, in a few cases there is only 1 fixed elevation or perhaps 2 alternative elevations. For example, a 24-stave sonar credited with 48 beams probably produces a fan of 24 beams at 1 elevation and 24 at another. It is impossible for any modern stave sonar to depress its beam continuously so as to match the motion of a target precisely.

A few sonars still employ searchlight operation, which was standard through the end of World War II: they concentrate their energy in a single directional pulse and have only a single receiver. They must ping in 1 direction, and listen for an echo, before they shift to another direction. That requirement severely limits the search rate. All specialized attack sonars are searchlights capable of depression.

There is also an intermediate case, a flat-plate sonar that scans a limited sector. Compared to an ODT scanner, the flat-plate sonar provides a stronger ping and may achieve a tighter beam over the scanned sector. Such sector scanning might be justified for a ship operating as 1 of several escorts in a screen.

Many of the sonar entries mention alternative range scales. They equate to alternative pinging rates. As in a radar, a sonar cannot easily distinguish a ping returning from a very distant target (after another has been sent out) from the echo of a nearby object: the problem of the second-time-around echo (STAE). Therefore, a sonar operator will set the ping rate beyond the maximum range he or she expects to achieve. On the other hand, the operator will try to get as many pings as possible, to increase the probability of detection, typically using some type of sonar-performance predictor to set the ping rate.

As in radar, the length of the sonar's pulse determines the precision with which nearby objects can be distinguished. The length of sonar pulses is typically measured in msec (thousandths of a sec), compared to microsec (millionths) for radar pulses.

Many current search sonars can generate very short pulses for a form of target imaging for classification; in the U.S. Navy this

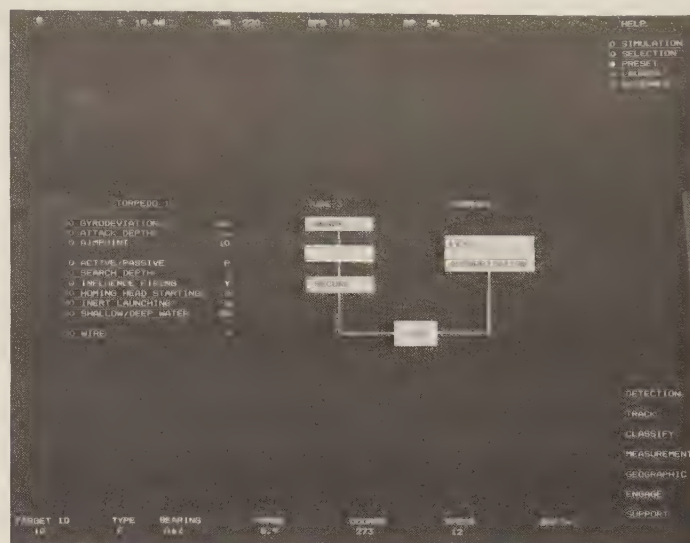
is called ASPECT (acoustic short pulse echo classification technique). ASPECT first appeared about 1960, and was applied to U.S. sonars through the following decade. Several short pulses are sent in rapid succession. Like longer pulses, they are reflected, not by the target as a whole, but mainly by a series of highlights. Because they are very short, the pulses produce separate echoes from the separate highlights (the echoes that longer pulses produce from the different highlights overlap). The combination of short echoes is a sort of target image, and it can indicate both the character of the target (for classification) and even its heading (target aspect, hence the name) relative to the sonar. ASPECT initially used a paper recorder similar to that of LOFARgram; the echoes printed as a series of horizontal lines.

Torpedoes, both antiship and antisubmarine, are listed in this section because so many weapons are dual-purpose. They deserve some comment. Three kinds of torpedo seekers are in current use: active pingers, passive, and wake-followers (or wake-homers). There are also straight-runners, pattern-runners, and command-guided (wire-guided) weapons.

Until World War II, all torpedoes were straight-runners, analogous to artillery shells. In many cases these torpedoes could be turned through an adjustable gyro angle after leaving the tube, but then they ran as straight as possible. Effective range was, therefore, limited by the accuracy of the torpedo and by the ratio of the torpedo's speed to the target's speed. Since the main method of torpedo warning was visual observation of the wake, it was often argued that a wakeless (electric or oxygen) torpedo could be fired at a faster or more distant target, in the expectation that evasive action would not be taken. The main countermeasure to such torpedoes was zig-zagging (whether or not the torpedo was detected), in the hope that the firing platform would be unable to anticipate the target's maneuver.

Straight-runners were generally fired at designated targets. Weapons fired beyond the effective single-target range were said to be fired "into the brown," i.e., into the mass of targets in hopes of hitting 1 (this was also called a "browning shot"). One way to increase the efficacy of such a shot was to program the torpedo to weave back and forth in the mass of target ships until exploding under 1 of them. The most common pattern-runners zig-zagged (the French even designated their pattern-runners in a Z series); but the Germans, Italians, and probably the Soviets produced aerial torpedoes that circled. Pattern-runners are still an economical way of attacking convoys from a safe distance. Wake-following (see below) was conceived as an improvement on simple pattern-running.

The alternative was to provide the torpedo with a homing system so that the weapon could convert a miss (due to firing at excessive range) into a hit. During World War II the Germans developed passive homing torpedoes as antiescort weapons, and



A typical torpedo fire-control display shows target data at the bottom (bearing, range, course, speed) and torpedo parameters at left (gyro angle, attack depth, aim point along the length of the target, the choice of active or passive homing, search depth, the choice of whether to use a proximity [influence] fuze, the enable range of the seeker, the type of launching, and whether the water is deep or shallow). In this case the torpedo is a wire-guided F17, fired against a slow (12-kt) surface target, so the choice is for passive homing and a search depth of 6 m and a proximity fuze. The torpedo is fired at a 140-deg gyro angle: the submarine is almost beam-on to the target. (Thomson Sintra)

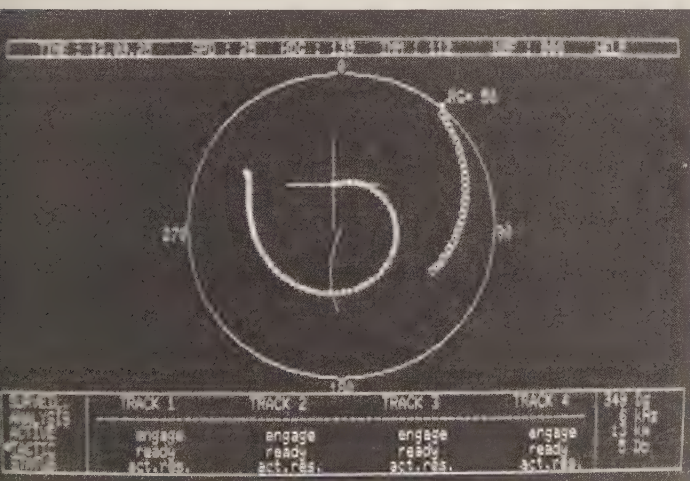
the Allies developed much the same technology for ASW. At that time, both submarines and surface ships were loud enough to attract such weapons. Later, however, the development of antiship and antisubmarine torpedoes diverged.

Antiship torpedoes almost have to be passive homers for 2 reasons. First, the water's surface acts as a mirror, and an active homer near the surface can easily be attracted into it. Second, a surface ship does not provide much of an echoing target (distinct from the surrounding surface, that is).

As long as submarines were relatively noisy, it was not too difficult to design a torpedo to home on their loud noise. It is much more difficult to design a torpedo to listen for subtle low-frequency (long-wavelength) sounds, to automatically decide that it is hearing a submarine, and then to steer for the source of that noise. As submarines became quieter, then, torpedo designers had to turn to active operation, incorporating powerful high-frequency sonars in the noses of the weapons. This development was accepted most readily in the United States. Active homing automatically alerts the submarine target, and U.S. designers have assumed that an alerted submarine will run off at maximum speed. They have, therefore, required torpedoes fast enough to catch up, the rule of thumb being that the torpedo must be 50% faster than its target.

Until recently, European torpedo designers preferred what they called a covert approach, homing passively at relatively low speed. They argued that, unless alerted, a submarine commander would generally operate at low speed, and that a relatively slow (and very quiet) torpedo might well catch the submarine unaware. Consequently, many European torpedoes employ inherently quiet electric motors, at the cost of high speed. It now appears that submarines, at least Soviet types, will increasingly be too quiet for the covert approach to work and, therefore, that all future ASW torpedoes will be fast active homers. In turn, torpedo design will be substantially more difficult. This evolution is exemplified by British practice. Tigerfish was a very quiet, relatively slow torpedo. Its successor, Spearfish, is being marketed as the fastest torpedo in the world.

On a more detailed level, the earliest homing torpedoes could be described as using 2- or 4-beam energy comparison (i.e., only left-right or a combination of left-right and up-down). Their signal processors were, in effect, hard-wired. During the 1960s it



Once targets can be tracked automatically, a combat system computer can help evaluate threats as a decision aid. It can also superimpose torpedo operating limits on the display, to show which targets can be engaged. (Thomson Sintra)

became possible to form multiple beams so that the torpedo's view of its surroundings was better defined. As in a shipborne sonar, the narrower the beam, the better the torpedo's ability to reject the noise around a target. In some passive systems (such as the French E14), phase comparison replaced energy comparison. During the 1970s new torpedoes were designed with software-controlled signal processors and seekers and with more sophisticated sonars, which could be doppler-enabled (i.e., which switched tactics depending on the target's velocity) and which could use coded sonar waveforms (to improve the signal-to-noise ratio, perhaps without increasing peak power, thus denying the target longer-range warning). The torpedo's acquisition range defines a cone within which the weapon can locate targets. The longer the range, the greater the band in depth equivalent to the angle of view of the torpedo's seeker. A torpedo with a narrow depth-band must describe a helical search path through the water, whereas 1 with a broader depth-band may be able to search at a single depth. The latter technique reduces the fraction of (limited) torpedo endurance that must be devoted to search, and also reduces the evasion time available to the target.

There is 1 other modern homing technique: wake-following. A surface ship's wake extends many ship's lengths aft, and the wake's boundaries can be detected relatively easily. A torpedo can be programmed to turn through a preset angle each time it crosses the wake, so that it takes a sinuous path toward the ship, around the wake (assuming that the torpedo enters the wake at an acute angle). If the torpedo can detect both wake boundaries, it can run up the wake itself, wasting less time in turning back and forth and, thus, giving itself a better chance of catching a fast target. Wake-following was invented in Germany during World War II (as a variation on pattern-running), and this program has been tried out by most of the major torpedo manufacturers since then (see the Soviet torpedoes and the U.S. Mk 45F). Wake-following has 2 great virtues. First, the wake is so massive a ship's signature that it is difficult or impossible to disguise or for a decoy to duplicate. Second, wake-homing is a specialized anti-surface ship technique; so it would be possible, in theory, for a wolf pack of submarines to fire wake-followers toward a targeted formation without fear of hitting one another. That safety would not be possible with conventional passive-homing torpedoes.

All homing techniques for torpedoes are effective only at relatively short ranges because limited torpedo dimensions cause frequencies to be high. However, shipboard or submarine sensors, which can operate at much lower frequencies, can reach out much farther. One way to combine the 2 capabilities is to provide the torpedo with mid-course guidance in the form of a wire. Wire guidance can also be used to correct the course of a nonhoming torpedo attacking a maneuvering target, a technique used by the heavy Swedish torpedoes. This type of remote control was used as early as World War I by the Germans and was tried both in Germany and in Italy during World War II. In its simplest form, wire guidance is 1-way, commands being issued by the submarine. However, in some recent applications, the wire is used both ways, the operator on board the submarine receiving the picture generated by the torpedo-borne sonar. The passive triangulation that results can be used to negate some countermeasures a target may take.

Torpedo homing naturally inspires the development of torpedo countermeasures. For a surface ship faced with passive homers, the natural countermeasure is a noise-maker whose output more or less duplicates that of a ship. There are 2 main technical problems. First, although the level of noise must be high enough to fool the approaching torpedo, the noise cannot be allowed to blank out sonar operation: generally, the signal output of the decoy must be controlled. Second, there is always some fear that, having attracted (but not destroyed) a torpedo, the noisemaker will merely lead the torpedo closer to the targeted ship. Most modern missiles (including torpedoes) have some form of re-attack logic, which causes them to try again

after having been fooled once. The decoy must be far enough from the targeted ship that the torpedo, trying again, hears the decoy rather than the ship.

Countering a wake-follower seems altogether a bleaker prospect because no noise-maker on earth can make anything that resembles a wake.

The point is that, to be effective, existing types of countermeasures must be closely matched to the weapons they counter. Against a torpedo, the alternative is a direct-kill countermeasure, an antitorpedo weapon. There have been several such programs since World War II, both in Britain and in the United States, but they have generally died because the problem of finding and killing a small torpedo is so very difficult technically, and is also very expensive.

From a submarine's point of view, acoustic countermeasures come in 3 varieties. First there are self-propelled submarine simulators, which may mislead the sonar operator and which may also attract passive-homing torpedoes. Then there are sonar transponders, either hull-mounted or ejected, which can confuse an active pinger. Finally, a submarine may eject bubble-makers, which will create a screen between the boat and an active pinger. Since the bubbles reflect pings, the torpedo will be unable to see into the screen and may home on the screen itself. What happens afterward depends on the torpedo's re-attack logic. The bubble screen may also be intended to obscure the submarine and its track from a longer-range sonar. In that case, a torpedo with a 2-way wire may be steered around the bubble, to look beyond.

For example, in a submarine vs. submarine engagement, the targeted submarine will want, first, to break track. It must accelerate, and it will, consequently, make more noise. To cover that acceleration, the submarine can launch decoys and create a bubble screen. The targeted boat can also fire back (without wire guidance) at the pursuing submarine in hopes of escaping while the latter evades. If track-breaking fails, the targeted submarine can still hope to counter torpedoes fired by the pursuing submarine, either by firing back (to force the pursuer to break the guidance wires while counter-evading), by using decoys, or, more likely, by using both methods. It is also possible to imagine using hull-mounted transmitters, in appropriate sequence, to break lock, just as a surface ship would use a radar lock-breaker and chaff launchers.

Mines, including ASW mines, are listed separately.

Minehunting sonars, which may be used to detect bottomed submarines, are listed in the Mine Warfare section.

Surface-search radars, which are often used by ships and aircraft to detect periscopes and snorkels, are listed in the Strike/Surface Warfare section.

SONARS AND UNDERWATER FIRE-CONTROL SYSTEMS

AUSTRALIA

◆ ASSTASS

ASSTASS is the Australian Surface-Ship Towed-Array Surveillance System. The Royal Australian Navy decided against using frigates for long-range submarine surveillance, and in favor of buying a specialized surveillance towed array to be deployed on board inexpensive specialized ships, similar in theory to the U.S. SURTASS. A formal Naval Staff Target for such a system was formulated. Unlike SURTASS, ASSTASS would reportedly process its data on board. It is not clear whether the Kariwara thin-line wet end would be suitable for ASSTASS. As of 1989, ASSTASS was expected to enter service in 1996. An RFP for a project-definition study was released in August 1989, at which time the Australian government hoped that the effort would be completely indigenous. The towing vessels are to be suitably modified commercial offshore-support craft with on-board signal-analysis and -display equipment.

◆ Kariwara

The Australian-developed thin-line towed array is for use by surface ships or submarines. The requirement was stated in 1984–85, and the array was developed by the Australian Defence Research Center; trials began in 1987–88. The array is reportedly 30 or 40 mm in diameter, consisting of hydrophones in long embedded in a fully reelable ropelike matrix. The array is unique in being manufactured in continuous lengths, using rope-making techniques. The core, a buoyant polypropylene rope in which the electronics are embedded, is surrounded by a gel-filled weave of electrical conductors and Kevlar fibers, the whole being covered with a polyurethane sleeve.

Kariwara grew out of a 5-year Australian-U.S. project, Boolee, of the 1970s. Boolee reportedly demonstrated the value of towed arrays in Australian waters; but the RAN found the existing 90-mm-diameter fluid-filled type unsuited to its diesel-electric submarines and asked the Defence Science and Technology Organization (DSTO) to devise a light reelable array that could be stowed in a submarine casing. Reelability was presumably important because an Australian submarine would have to operate in shallow water. Sections of Kariwara's wet end were tested on board the submarine *Oxley* in 1982. *Otama* began Kariwara trials in 1984, and *Otama* received the first clip-on operational version in April 1987.

Presumably, these were predevelopment arrays since the Kariwara development and production contracts are currently being competed. Plessey completed project-definition studies in 1988. The Invitation to Register Interest (ItR) for full-scale engineering development closed on 25 July 1989. Two preproduction arrays are to be manufactured, based on new technology, not that developed by Plessey. Kariwara is still envisaged as a low-cost array and as a candidate for installation on board the new Australian submarine. Plessey got a contract for 2 slim-line arrays for 2 submarines for delivery in November 1991, with a performance less than that envisaged for the final Kariwara. The likely bidders are Plessey, Ferranti, Marconi, BAe Australia, and AWA.

◆ Mulloka

This Australian-developed replacement for British hull sonars such as 177 and 184 was developed in the early 1970s. The prototype was completed in 1975 and tested on board HMAS *Yarra* through 1979. The initial production contract was let in 1980, for 5 sets for the "River"-class frigates (installed 1983/84). In contrast to other Western sonars, Mulloka operates at a relatively high frequency (transmission, 6–11 kHz; passive, 3.5–14 kHz), to produce a very narrow but powerful beam. The cylindrical transducer consists of 96 staves, each of 25 spot transducers, to produce very narrow beams. It forms beams digitally and uses random transmission to reduce warning to submarines, transmitting for 1–4 sec and then listening. The object of the design is to achieve very solid coverage out to about 10 kyd, accepting virtually 0 coverage at greater ranges. Mulloka resulted from a late 1960s requirement, and an R&D contract was let to EMI of Australia in the early 1970s. Honeywell produced the transducer.

Mulloka will be installed on board the 2 U.S.-designed *Oliver Hazard Perry*-class frigates that are building in Australia, in preference to the U.S. SQS-56.

◆ PIPRS

Ping Intercept Passive Ranging is a concept developed by the Australian DSTO (Defence Science and Technology Organization) Sonar and Surveillance Group. It uses existing arrays in Australian *Oberons* and is currently in production at Sonartech (Sydney).

CANADA

◆ BQG-501

See Micro-PUFFS under U.S. sonars below.

◆ SQR-501

The Canadian towed array (CANTASS) uses a U.S. SQR-19 "wet end" and a Canadian (Computing Devices) signal processor. The requirement was stated in 1981, and in mid-FY84 the U.S. Navy offered 6 SQR-19s. The Canadians opted to develop their own dry end. CANTASS was developed in 1983–87. A system was tested on board HMCS *Fraser* in 1986–88 under the designation ETASS. CANTASS is to go on board all 12 "City"-class frigates



A towed array, probably SQR-18, on board a Canadian destroyer at Halifax, 1989. The fish is the towed body used in the U.S. SQS-35/SQR-18 combination. (G. Till)



SQR-19 or SQR-501 port in the transom of HMCS *Annapolis*, 1989. (G. Till)

and also on board 2 modernized *Annapolis*-class frigates in 1990-95.

Canadian experiments using quarter-scale arrays began in 1980. The one-half scale ETASS was tested on board HMCS *Nipigon* in 1983 and on board HMCS *Iroquois* in 1984; in 1985 it was decided that ETASS would be fitted semipermanently on board HMCS *Fraser*, replacing her ASW mortar and several internal compartments. In this version the length of the tail was doubled, bringing ETASS up to full SQR-19 size. However, the handling system is much more primitive than that of the full CANTASS. The *Fraser* installation introduced a new third console, for a supervisor who analyzes the collated information, leaving the 2 primary operators free to watch incoming data and to do primary search. This configuration proved successful enough to cause a change in the CANTASS design to incorporate the third position. Installation began in October 1986 and was complete by early December.

The first full CANTASS will be an SQR-19 tail combined with a commercial Motorola 68020/UYS-501 Teamed Architecture Signal Processor (TASP). Later examples will use a fully militarized 68020/UYS-501 by Computing Devices of Canada.

◆ SQS-501

See Type 162 under U.K. sonars below.

◆ SQS-502

The Canadian derivative of the British Type 170B is for Limbo fire control. See U.K. sonars below.

◆ SQS-503

This hull-mounted medium-frequency (8-12 kHz) scanning sonar is found in Canadian frigates of the *Restigouche* and earlier classes and in the underway replenishment ships. SQS-503 equips the French *Foch*-class aircraft carriers. This sonar was developed by Canadian EDO of Cornwall, Ontario, from an abortive U.S. set.

◆ SQS-504

SQS-504 is a medium-frequency (8-15 kHz) variable-depth searchlight sonar. The British Type 199 is a derivative. See the U.K. entry below for details.

Canadian work on VDS dates from 1947, and a naval staff project, code-named Dunker, began in April 1949. The dipping sonar was particularly wanted to exploit a sound channel lying between the warm surface layer and the warm bottom layer on Scotian Shelf off the Canadian east coast. The first trials employed a dipping version of the British Type 144, on board the fleet minesweeper *New Liskeard*. It turned out that, with both the target and the sonar in the axis of the channel, ranges as great as 9400 yd could be achieved. Even when both were at the upper edge of the channel, the range was 4200 yd, far beyond the performance of a hull-mounted Type 144. The early trials employed a transducer dipped from a stopped ship, and through the early 1950s work proceeded on viable towed bodies. They, too, carried Type 144 transducers.

Through 1953 the project concentrated on submarine detection in the shallow Gulf of St. Lawrence and off Halifax, where conventional hull sonars were often useless. In 1953, however, the project was redirected toward achieving maximum possible sonar range (for early warning) by placing the transducer at the optimum position under a much wider variety of conditions. By this time much work had been done on suitable towing bodies. The first fully developed experimental system, CAST/1/X electronics in a body designated TRILBY Mk V, was turned over to the Royal Canadian Navy on board HMCS *Crusader*, a destroyer.

CAST/1/X was re-engineered as SQS-504. In tests in 1958, off Bermuda, off New London, on the Scotian Shelf, and in the Gulf of St. Lawrence, it outperformed the hull-mounted Type 144 by a factor of 5. This result led immediately to a decision to include SQS-504 (and the associated SQA-501 hoist) in the mid-life modernizations of the *St. Laurent*-class frigates. In addition,

CAST/1/X outperformed the contemporary British Type 192X experimental VDS (which was then mounted on board HMS *Brocklesby*). Hence the British decision to adopt SQS-504 as Type 199.

Further development was concerned largely with handling gear, which caused particular problems in heavy weather. By 1964 there were complaints from sea that the system was useless, and a get-well program had to be instituted. The lessons learned at this time were applied to the VDS version of SQS-505 (which uses a hoist designated SQA-502). SQA-502 permits operation at higher speeds and at greater depths, and it is officially claimed that overall search capability is 20 times that of SQS-504. In early trials, it achieved a range of 27,500 yd compared to 5000-7000 yd for SQS-504.

◆ SQS-505/509/510

SQS-505 is the hull sonar in the *Iroquois* and *Halifax* ("City") classes. The *Iroquois* class has the same transducer in a variable-depth fish (SQA-502 hoist). In the first 6 "City"-class frigates, SQS-505 will be integrated instead with the SQR-501 towed array. The sonar was designed to be fitted in either a fixed or a retractable dome (in the former case, the transducer can be either fixed or retractable).

SQS-505 uses a 36-stave (10 elements/stave) cylindrical transducer (4 ft diameter × 4 ft) producing a 10 × 10-deg beam. The hull dome is 14 ft long, and the towed body is 18 ft long and weighs 14,000 lb (10,000 lb submerged). Operating frequencies are 6.4, 7.2, and 8.0 kHz (bandwidth 400 Hz). There are 36 beams, with 16 channels/beam (25 Hz wide). Nominal range is 200-32,000 yd (range scales 2, 4, 8, 16, 32 kyd). Target doppler: ±40 kt. Modes: ODT, triple RDT (TRDT), directional transmission (DT), acoustic short-pulse echo classification (ASPECT), and swept FM pulse wide-band mode. Pulse lengths: 2.5, 10, 40, 480 msec. Source level: 126 dB (ODT), 135 dB (TRDT, DT). Passive operation: 10 kHz. Signal processing: matched filter with time, function automatic gain control (TFAGC) and frequency, function AGC (FFAGC) or incoherent (wide-band) processing. There are 2 CRTs, 1 showing range and doppler (range-doppler indicator, RDI), the other passive, plus alphanumeric readouts. In the RDI mode, the sonar uses a DVST tube (A-scan display of 7 successive range-only traces with doppler). SQS-505 can track 5 targets while searching for more.

The sonar can operate in both manual and computer modes, providing both digital and analog data. Targets are classified by doppler, by a separate steerable audio channel, or by ASPECT. This sonar can track multiple targets, and it can display a 12-ping history, a 5-ping history, or raw video.

SQS-505 has been criticized for lacking true LF capability, and for a time it appeared that the "City" class would be equipped instead with SQS-509; but they have SQS-505(V)6, with its LF



SQS-505 VDS on board HMCS *Gatineau*, August 1988. (S. Terzibaschitsch)

passive capability. SQS-505 TASP with digital acoustic processing and SHINPADS display was tested on board an *Iroquois*-class destroyer in 1984.

Versions:

- (V)1 Hull mounted version.
- (V)2 VDS version.
- (V)3 AOR hull-mounted version.
- (V)4 Number of ASPECT pulses limited to 20. Hull version.
- (V)5 Number of ASPECT pulses limited to 20. VDS version.
- (V)6 New version with new transmitter and receiver (OA-5168 transmitter and OA-5119 receiver in place of OA-5118 and OA-5116). Source level: 133 dB; pulse length 10 and 40 msec. Doppler: ± 40 kt at 7.2 kHz (operates at 6.4, 7.2, or 8.0 kHz active, but at 4.5 kHz passive). This version is designed specifically to work with the SHINPADS combat direction/data system. Although similar in form to the (V)4 version, it has no separate control indicator group since the SHINPADS consoles substitute. Passive modifications: operation at 4.5 kHz and a steered passive mode.

Users: Belgium (*Wielingen* class: SQS-505A), Canada (Tribal class, including VDS version; destroyers modernized under DELEX program; *Protecteur*-class underway replenishment ships), Greece (ex-Dutch "Standard" frigates), India (first 4 *Nilgiri* class, hull and VDS), and the Netherlands ("Standard" frigates). The last 4 Dutch "Standard" frigates use a lower-frequency (5-kHz) version, SQS-509, which is closely related to the Dutch PHS-36. The Canadian "City"-class frigates have SQS-505(V)6, which includes a computer-aided detection and tracking feature developed by Westinghouse Canada. This version feeds data directly into the ship's SHINPADS combat system bus. SQS-505 was originally chosen for the U.S. *Perry* class (in preference to the more expensive SQQ-23). The generally comparable SQS-56 was chosen very late in the design process to permit redesign of the frigates to take a second helicopter without increasing their total cost (1974). SQS-505 was developed in 1966-69 for the Tribal class.

SQS-508 was an abortive follow-on, using the same transducer (10-, 40-, or 80-msec pulses), but -508 was much more powerful (224 dB ODT, 233 dB TRDT or DT). It used a digital receiver. In CW mode its signal processor was a 16-replica correlator, and in FM mode it was a replica correlator. It could be mounted (as a VDS) on board ships of 400 tons and greater displacement.

SQS-509 operates at 4.8, 5.4, and 6.0 kHz, and power output is increased by about 2 dB; transducer size is increased by a ratio of 4:3. SQS-509 operates passively at 3.125 kHz. Nominal range matches that of SQS-505. Source level: 137 dB. Pulses: 10 and 40 msec. Doppler limits: ± 40 kt.

SQS-510 is essentially an SQS-505 combined with an SQR-501 towed array. Because the array processing is so important, the prime contractor is Computing Devices Co. rather than Westinghouse of Canada, which was responsible for the SQS-505 series. Like SQS-505(V)6, SQS-510 is designed to use SHINPADS or other standard multifunction displays rather than special sonar displays or indicators. The associated computer is UYK-502, and the signal processor is UYS-501. This sonar was adopted for the Portuguese MEKO frigates (the analogous Greek and Turkish units have SQS-56). As of the fall of 1990, it seemed likely that Portugal would buy SQS-510(V) for her 4 existing *Joao Belo*-class frigates.

◆ SQS-507/HS-1000 Series

"Helen," a lightweight towed sonar, was developed specifically for the ASW hydrofoil *Bras d'Or*. Development began in 1963, and the sonar was delivered in 1968. This work, in turn, led to the HS-1000 series. SQS-507 was a smaller, simplified version of SQS-505.

The HS-1000 series is a joint Canadian navy/Westinghouse of Canada development project for fast attack craft, based on experience with the SQS-507 towed sonar. HS-1001 is a light-

weight VDS; -1002 is a lightweight hull sonar; -1003 is a VDS for small ASW ships; -1007 is a medium hull or VDS; and HS-1001/2, -1002/3, and -1007/7 are combination installations, the hull and variable-depth sonars sharing a common transmitter and signal processor. The VDSs use a 330-ft cable and can be towed at 35 kt. HS-1007 uses the same receiver, display, transducer, and variable-depth fish but an SQS-505 power supply, for 4 times the power of HS-1001 and -1002 in ODT mode, and 20 times the power in tribeam mode. HS-1001/2 operates only in ODT mode.

R&D began early in 1970, and a prototype was completed in 1972. The HS-1001 version was tested on board the U.S. hydrofoil *High Point* in 1980. Details of sales have not been reported, but in 1972 sonars of this type were reported in production for the West German navy. That report may reflect projected installation in the abortive German hydrofoil (equivalent to the U.S. *Pegasus* class).

In 1985, 2 Westinghouse hull and 3 VDS sonars were reported sold to the Indian navy, and the HS-series would seem to have been the most likely candidate. The VDS arrays were carried in fish built by Fathom Oceanology, Ltd., of Canada. Both hull and VDS use the same array, which has 21 staves.

There is a new receiver (with new software) developed by CDC, and the sonar is designed to feed data directly into a SHINPADS or STACOS (Signaal) data bus.

◆ Towed Arrays

The Canadian Department of National Defence is supporting two new towed-array projects:

Focal Technology uses fiber-optic telemetry in a standard-diameter wet end (with 6 multipurpose fibers). The Focal wet end was tested at sea in June 1987.

Hermes Electronics has produced replacement multimodule arrays similar in performance to SQR-19 but 64 mm (a reduction of about one-third) in diameter.

◆ CTS-36 RDN

C-Tech has received a contract for this multibeam, scanning, hull sonar to equip the Danish IS-86-class fishery-protection frigates and expects to receive additional contracts for the hull sonars of the StanFlex 300-class (*Flyvefisken*-class) corvettes. CTS-36 is a more sophisticated version of the C-Tech family of light commercial (fish-finding) hull sonars already in widespread use (developed since about 1970). It operates in both CW and FM (chirp 1 kHz wide) at 36 kHz (33 kHz optional), both active (ODT and SDT) and passive modes. Active modes: omni (ODT or directional CW transmission, automatic target detection; audio beam continuously steerable through 360 deg; transmit sector width and position selectable); tracking (3 separate receiving beams, each 6×6 deg, are manually locked onto each of 3 separate targets; transmission is FM chirp or CW); surveillance (12-deg search beam stepped through operator-selected sector; selected transmit sector width); and search MCC (maintenance of close contact: a broad 30-deg receive beam is depressed to maintain contact with a close-in target). There is a separate audio receiving beam (800 Hz). The sonar beam is continuously adjustable electronically between $+8/-24$ deg, stabilized for roll and pitch. Receiving beam is 6×6 deg. Transmission: ODT or SDT. The transmitter uses 270 50-W channels. Source level is 220 dB (re 1 microPascal at 1 m). CTS-36 uses either the ship's own display or its own 1280×1024 -pixel display (7 colors). Display modes: PPI, B-scope, and bearing-time for tracking, all oriented true north or to the ship's bearing.

The first CTS-36 sonar was delivered to Denmark in February 1991. A somewhat simpler variant was installed in August 1990 on board the 3 Canadian ships sent to the Persian Gulf to help them evade mines.

◆ New Dipping Sonar

The Canadian navy is buying a variant of the EH-101 helicopter as its NSA (new shipboard aircraft). The NSA systems integrator, EHI Canada, issued RFPs for a dipping sonar in April 1988.

By September, 5 teams had submitted proposals: Lockheed Canada-Sanders, Thomson Sintra-GEC Avionics (AQS-934 processor), Bendix (HELRAS), Thomson Sintra (FLASH), Martin Marietta (HIPAS), and Plessey-CDC (AQS-503 system, consisting of Cormorant and UYS-503). As of mid-1989, the Canadian Department of National Defence (DND) was expected to select 2 bidders for a final selection in mid-1990, but the choice has been delayed.

DND already has a HAPS (Helicopter Acoustic Processing System)-development project, using an AQS-503 (UYS-503 plus Cormorant sonar) supplied by CDC (which leads the NSA Mission Systems Consortium) and Plessey. AQS-503 was evaluated on board a barge in Bedford Basin, Halifax, in 1988 and was formally delivered in April 1989 for flight trials on a Sea King. The UYS-503 processor may later be used with Bendix and Martin Marietta wet ends as part of the NSA dipping-sonar selection.

◆ ASROC Fire-Control System

Canadian *Restigouche*-class frigates rebuilt in 1968-73 have a Canadian-developed ASROC FCS, the first Canadian all-digital shipboard system (which was developed by CDC). Reportedly, it was developed because of bad experiences with the U.S.-developed Gunar anti-aircraft FCS; the Canadian navy saw the U.S. Mk 114 as an underwater application of Gunar concepts.

◆ ASWDS

ASW Data System is used on board the "Tribal"-class and west-coast *Restigouche*-class frigates. It employs a Signaal SMR computer to track up to 27 targets detected by an SQS-505 sonar, and (in the "Tribal" class) provides these data directly to the ship's CCS-280 combat system. In an Improved *Restigouche*, a second display is provided in the Operations Room, and data are transmitted in analog form to the plotting table, driving 2 contact lights, the plotters either using grease pencils or sitting at the ASW system console. In the latter case, 1 contact light is used for the contact, the other for the helicopter the ship is conning into position to reacquire and attack the contact. Signaal developed most of the system. Typically, ASWDS employs 2 primary and 1 remote sonar indicators with vertical CRTs, plus a sonar signal injector and a computer and sensor weapon converter assembly. The system also includes ASROC- and mortar-firing panels and radar-data panels. It uses digital displays for sonar (spiral-sweep) video and alphanumeric. The displays can be true-motion and off-center. The maximum sweep display range is 32 kyd, and the maximum symbology display range is 64 kyd; range scales are 2, 4, 8, 16, 32, and 64 kyd.

The system was originally to have used half of the L-304 computer power of the CCS-280 system. However, the Signaal computer was purchased as an offset to a Dutch purchase of Canadian-built F-5 fighters, so the L-304 was only half utilized.

The Canadian navy first became interested in a decentralized combat system (see CCS-280) during the development of the abortive ADACS system. The ASWDS requirement was started in 1967-68. ASWDS is UCS-280, the underwater-warfare portion of CCS-280. The prototype ASWDS was tested on board HMCS *Terra Nova*.

◆ SBF 256

This beam-former, made by Interactive Circuits & Systems Ltd. (ICS), was announced in 1987 as the world's most powerful. Whether or not that is true, it is presumably typical of current practice. Beams can be formed either by applying phase shifts to the outputs of individual hydrophones or by taking their outputs at differing (delayed) times, in either case adding them up. ICS argues that the time-delay technique it chose is superior because it is effective over a broader bandwidth. The time-delay technique requires that the output of each hydrophone be available at any arbitrary time. That would entail an impractically high sampling rate. Instead, SBF 256 interpolates between received hydrophone inputs to estimate the required values; that in turn reduces the sampling rate to the acceptable figure set

by the highest frequency to which the system need respond. Interpolation resolution is 1024:1 (interpolation is equivalent to a thousandfold increase in sampling rate).

ICS argues that the time-domain techniques it chose are superior to the alternative, to form beams in the frequency domain (i.e., to do an FFT before beam-forming) because they are simpler and because they produce an audio output in each beam. An SBF 256 accepts inputs from each hydrophone in sequence; each cycle of samples (from hydrophone N back to hydrophone N-1) is a frame, up to 512 words long. The output frame, a sequence of beam samples, is up to 256 words long. Since total throughput is fixed, there is a trade-off between the sampling rate applied to each hydrophone or beam and the total number of hydrophones or beams (see below). Each frame is, in effect, a sample at 1 point in time; each input or output channel is represented by a series of such samples, frequent enough to represent a continuous signal. For example, if each of 512 hydrophones is sampled at 1 kHz, the beam-former receives 512,000 data points each second. That is equivalent, in terms of arithmetic workload, to 128 hydrophones operating at a sampling rate of 4 kHz. An output of 256 beams at this sampling rate equals 256,000 output data points/sec. These figures explain the need for a very high throughput, in this case 2 GOPS, using 16-bit (4-bit exponent) floating-point data.

The beam-former weights (shades) some of the hydrophone outputs to reduce the sidelobes of the beams. It can handle up to 512 hydrophones, the delays and shadings compensating for an arbitrary configuration (e.g., linear, circular, nested, 3D) described by the system software. Generally, the required time delays will not correspond exactly to intervals between samples. To avoid an impractically high sampling rate, SBF 256 estimates (interpolates) the required values; the beam-former can then use the lower sampling rate consistent with the highest usable hydrophone frequency. Interpolation is equivalent to dividing the time interval between samples by 1024. The speed of the interpolator, 12.5 million taps/sec, determines overall throughput, using 8 taps/channel, i.e., using a total of 8 samples to estimate the signal through a channel so as to interpolate properly. For example, given 512 inputs (hydrophones), the interpolator can handle a sampling rate of 3.1 kHz. The interpolator can also work (more accurately) at 16 taps/channel.

SBF 256 uses time-domain beam-forming. Frequency-domain is the alternative (the FFT is carried out before the beams are formed). ICS argues that its choice is preferable because it provides a direct audio output in any given beam, because its hardware is simpler, because each beam can easily be separately shaded, and because very high bearing resolution can easily be achieved.

SBF 256 consists of a VME bus carrying 2 major elements: an I/O board and a series of 16 beam-former cards (plus 1 diagnostic card). Each beam-former card performs more than 125 MOPS, simultaneously forming 4 beams by shading, interpolation, and delay-summing and 16 by multiplexing (i.e., by accepting a lower data rate). The number of output beams depends on the number of inputs. With identical shading for each beam, 256 beams can be formed with up to 128 hydrophones, 128 beams for 129-256 hydrophones, and 64 beams for over 256 hydrophones. If each beam is to be shaded uniquely, the beam-former produces 256 beams for up to 64 hydrophones, 128 for 65-128, and 64 for 129-256; it cannot accommodate more than 256 hydrophones. Given constant computing power, the maximum available channel-sampling rate (which determines the maximum frequency at which the system can operate) depends on the number of hydrophones and beams:

Hydrophones	BEAMS		
	Up to 64	Up to 128	Up to 256
32	48 kHz	24 kHz	12 kHz
64	24 kHz	12 kHz	6 kHz
128	12 kHz	6 kHz	3 kHz
256	6 kHz	3 kHz	—
512	3 kHz	—	—

The VME bus also carries an on-board CPU, which enters parameters into the I/O board and the beam-formers; it holds the system software in PROM. SBF 256 also communicates with a host computer, which sends it commands and data and which receives the beam data via a 16-bit parallel link.

DENMARK

◆ Submarine Tactical Data System

Terma's tactical data system is adapted to submarines for the Danish *Kobben* and *Narhvalen* classes. It supports the Terma torpedo FCS, which has its own processor cabinet and which can control 4 wire-guided torpedoes simultaneously. The main components are the data processing unit (DCU), the graphic display (GD), the system terminal, and the torpedo-guidance unit (TGU). The graphic display is a 20-in-high color raster monitor, whose lower portion is used for alphanumeric data. The upper portion can show 3 alternative pictures: a general operational plot (GOP), which is a PPI-like picture including tracks, ESM data, and maps, and which can be ship- or geographically oriented; a contact evaluation plot (CEP), a waterfall display oriented to passive sensors; and an attack plot (AP), which extracts data from the GOP and the CEP to produce a picture of the local attack situation, including vector diagrams, predictions, and recommendations for torpedo attacks against selected targets. The system terminal is the means of communication with the system; it consists of an alphanumeric keyboard, 60 dedicated function keys, and a roller-ball.

FRANCE

SONARS

With the merger of Sintra-Alcatel into Thomson-CSF in 1987, Thomson Sintra is now the sole supplier of French naval sonars.

◆ SLASM

SLASM (*Système de Lutte Anti-Sous-Marin*) is the future (1990s) French ASW system, consisting of a very low frequency (well below 2 kHz) transmitter in a towed "fish," with a dual towed array receiving the resulting signals. The fish will also carry a medium-frequency transmitter (as in DUBV 43), and there will be a medium-frequency hull sonar. A dual towed array, as in the earlier frigates, will function both as a submarine detector and as a torpedo detector.

A French description of this system emphasizes the "deep integration" among elements since the arrays, processors, and displays will have to shift functions, the displays allowing the operators to choose an optimum configuration (depending upon both physical oceanographic circumstances and the tactical situation).

Other automatic inputs will be sonar intercepts and helicopter-laid sonobuoys, both active and passive.

The modernized *Tourville* class will be the first to be fitted with SLASM. The first tests of the very low frequency active sonar were conducted on board the trials ship *Commandant Rivière* early in November 1987.

◆ DSBV 1

DSBV 1 is a torpedo-detection sonar (passive) found in postwar French destroyers and escorts, at least up through the *Commandant Rivière* class (where this sonar shares a dome with DUBA 3). DSBV 1 operates over the 5–40-kHz range and presumably shares some of the components of Velox (DUUG-1).

◆ DSBV 61 (DSRX 61X) (FLUTE)

DSBV 61 is the French towed array for surface ships. DSRX was the experimental version tested on board *L'Agenais*. Reportedly, the array consists of 50 hydrophones at the end of a 1000-m cable. The requirement was stated in the mid-1970s, and Thomson Sintra received a research contract in 1977, delivering the prototype in mid-1980. Trials were completed late in 1984, and DSBV 61 was approved for production early in 1985.

It was announced in January 1988 that the Netherlands would

buy this array (rather than SQR-18) for M-class frigates. For the Dutch, the processor is derived from the Mangouste airborne processor and interfaces with a SEWACO-VII combat system.

◆ DSUV 2

This passive low-frequency (i.e., sonic) keel (bow) array of *Narval* (now extinct) and *Daphne* classes replaced the earlier G36. G36, in turn, was a 36-transducer array descended from France's standard prewar passive arrays, G12 and G16 (12 and 16 transducers, respectively). DSUV 2 is not a GHG-style array (like the U.S. BQR-2) but is much smaller, and the transducers are apparently spot hydrophones. DSUV 2 is associated with a correlator (GC 02) that automatically scans in bearing, registers all noise sources on a hard-copy printer, finds their direction, and tracks them automatically. This sonar system incorporates both a CRT display and an audio output.

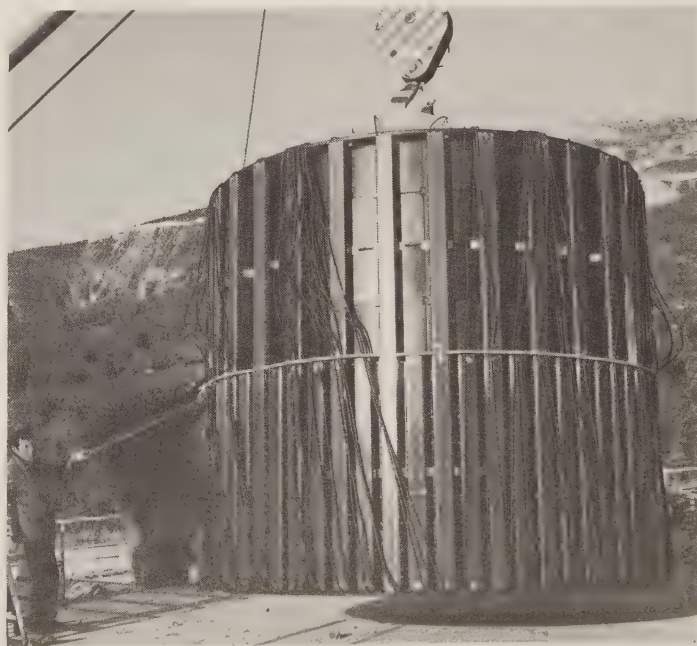
DSUV 2B was first tested in 1977, and the first unit was installed in 1979 on board the submarine *Rubis*. DSUV 2B is now the primary sonar for French nuclear attack submarines, in combination with DUUX 5 (FENELON).

◆ DSUV 22 (Eledone)/Scylla/Type 2040

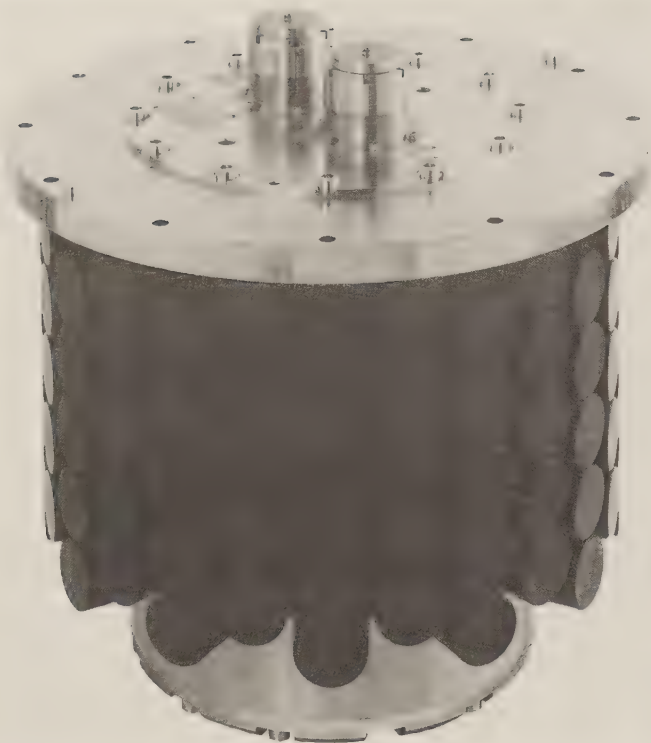
DSUV 22 is the passive hull array of the *Rubis* and *Agosta* classes.

Eledone is the commercial version of DSUV 22, adding other arrays to form an integrated modular sonar system for submarines. Eledone consists of some or all of: a passive bow array, an intercept array, flank arrays, a towed array, passive-ranging arrays, an active array, and a mine-avoidance sonar. The primary (search/attack) active sonar operates at 5 kHz (source level 215 dB for search) and incorporates an 8–11-kHz underwater telephone. Transmission is CW or FM, and the passive bow sonar is used for reception. The active transducer is a planar-array searchlight, active operation being used primarily for single-ping ranging at 5 kHz.

The bow transducer is 1.25 or 3.5 m (49.3 or 137.8 in) in diameter and 0.8 or 3 m high (32 or 64 staves; a larger 96-stave version was also developed, but it was not sold), operating at up to 12 kHz in 2 or 3 frequency bands (e.g., 1–5 and 5–12 kHz for the smaller version). There are 128 preformed beams, for 360-deg coverage. Eledone can automatically track 4–12 targets, providing very accurate azimuth data. It can also provide audio output or spectral analysis in 1 or 2 directions. An optional associated intercept receiver operates at 2–80 kHz, i.e., from LF search to torpedo seekers. The transducer is typically mounted on the submarine's sail. Target emissions are analyzed using



Eledone passive attack (bow) array. (Thomson Sintra)



Eledone active array, typically located in the submarine sail. (Thomson Sintra)

tunable low/high-pass filters. The associated PPI shows active transmissions in 3 bands (2–7.35 kHz, 7.35–27 kHz, 27–80 kHz) with an accuracy of 3–5 deg.

The associated single-ping active sonar operates at 5 kHz (4-kW peak power) with an unambiguous range of 100–1400 m. This sonar can also be used as a passive receiver (1–6 kHz) if the main hull array fails.

Eledone uses the same MIRTA 1500 series computers as do Beluga and Remora.

Scylla, the sonar system of the Australian Type 471 submarine, is an advanced version of Eledone, with the following arrays: cylindrical bow, flank, distributed passive-ranging, intercept, active (in the sail), mine-avoidance, and self-noise-monitoring (astern of the flank arrays, on each side). The towed array is the Australian Kariwara.

For Type 2040, see U.K. sonars below.

◆ DSUV 23

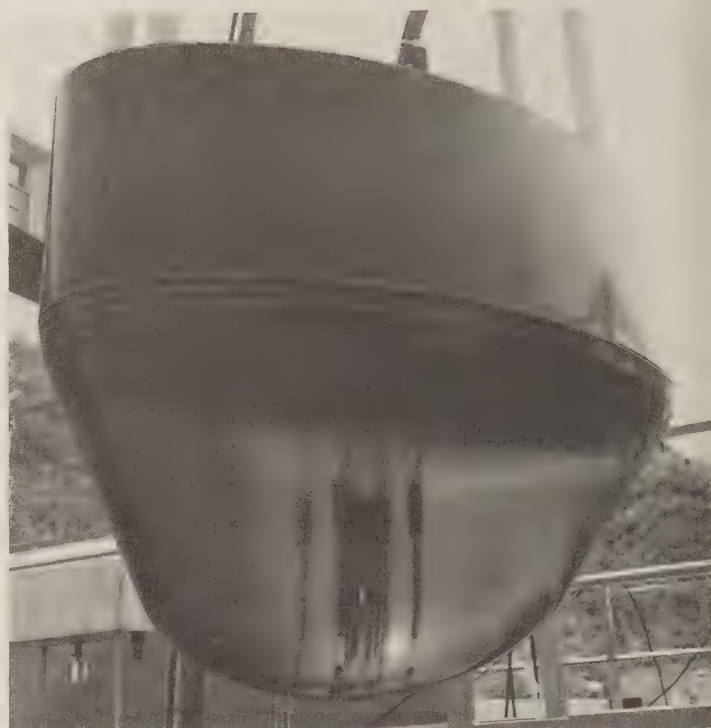
DSUV 23 is a passive low-frequency hull array found on strategic submarines.

◆ DSUV 61

A towed array for strategic submarines, used primarily for evasion, DSUV 61 is comparable to BQR-15 and Type 2023. Tests were conducted in 1974–77, the first installations following in 1977–78. *Le Tonnant* and *L'Inflexible* were completed with this array, and the 4 earlier units were retrofitted.

◆ DSUV 62

DSUV 62 is a towed array for attack submarines, used for passive fire control rather than evasion. Thomson-CSF received a research contract in 1975–76 after work was already proceeding on DSUV 61. The prototype was completed in 1979, tests following late in 1980, and approval for production in 1981. The first unit was installed on board the submarine *Rubis* early in 1983.



Typical modern French submarine sonar-intercept array. (Thomson Sintra)

◆ DSUX 20

DSUX 20 is a new active/passive multifunction sonar for the *Améthyste* class. As of 1989, it was being tested on board the trials submarine *Dauphin*.

◆ DSUX 21

A multipurpose system for *L'Inflexible* and earlier strategic submarines, DSUX 21 consists of bow or flank passive arrays. It replaces DSUV 23 in all strategic submarines.

An entirely new system for the new strategic submarines (*Le Triomphant* class) is being designed. It will be integrated with their command/control system, SET (*Système d'Exploitation Tactique*).

◆ DUAA-2A

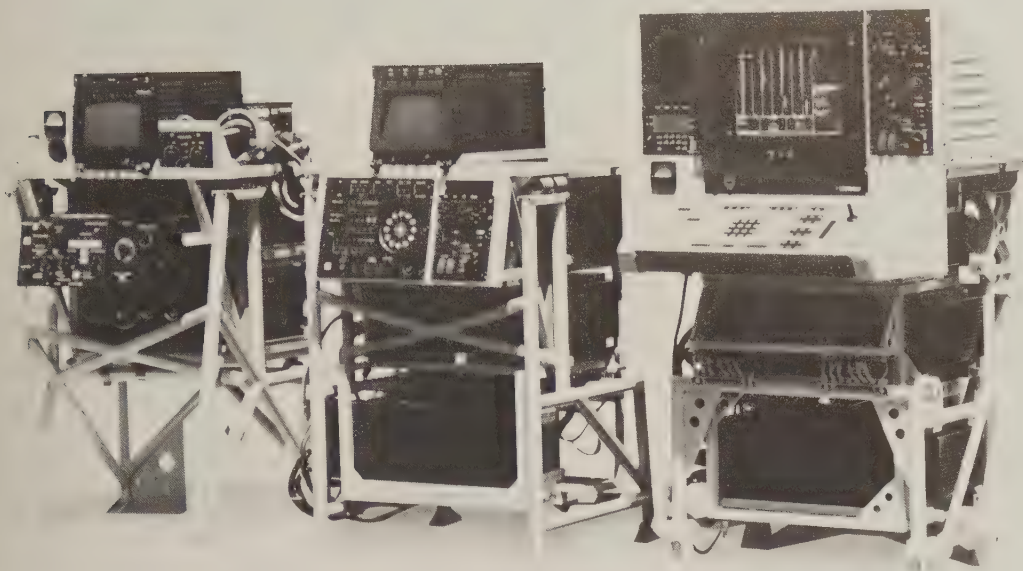
DUAA-2A is on board French-built *Daphne*-class submarines as well as many German-built Type 209s (including those of Colombia, Ecuador, Greece, Peru, and Venezuela). DUAA-2B is on board French *Agosta*- and *Rubis*-class submarines.

◆ DUAV 4 (HS 71)

DUAV 4 is Sintra-Alcatel's dipping sonar for the Lynx (WG-13) helicopter. Development began in 1968/69, and the sonar entered service in 1975. DUAV 4 is also used by the Dutch and Swedish navies. It operates at 21, 22.5, and 24 kHz (source level 119 dB), and the maximum depth is 495 ft. There are 3 operating modes: search (bearing and range), plot (bearing, range, and speed), and passive.

DUAV 4 is 1 of an HS-70 series of dipping sonars; HS 73 was announced in 1975 (for use on board French navy Lynx helicopters). HS 73 uses a coherent processor to reject reverberation echoes in shallow water.

Studies for DUAV 4 began in the late 1960s, with R&D work in 1968–69 and tests in 1972–74; the sonar entered service in 1975, with the first foreign sales were in 1978. Reported users, as of the end of 1987, were France (58), the Netherlands (12), and Sweden (10). DUAV 4 was small enough to fit a Lynx helicopter. Most Lynx operators do not use dipping sonars at all; these aircraft deliver torpedoes to targets detected by hull sonars, in some cases using MAD for final target location. The



The Thomson Sintra family of helicopter dipping sonars. Left to right they are DUAV 4, HS 12, and HS 312. (Thomson Sintra)

Royal Navy considered adding a dipper as part of its Lynx upgrade program but ultimately could not afford it. DUAV 4 is light enough so that a Lynx can also carry light antiship missiles, such as Sea Skua or AS 15TT. The French navy used this sonar on board its large shore-based Super Frelon helicopters. In their case the advantage of the light weight was that the helicopter could also carry Exocet antiship missiles (AM 39s) and a long-range surface-search radar for targeting. Reportedly, DUAV 4 has not been particularly successful, and it has been replaced in French service (initially on the Super Frelons, but now also on Lynxes) by HS 12 (see below). Production ended about 1987. The other 2 buyers, the Netherlands (Lynx Mk 27/81) and Sweden (KV-107) still use this sonar. Reportedly, the Dutch navy plans to replace its DUAV 4s with HS 12s, but funds are not yet available. The German navy uses AQS-18 on board its Lynxes, and Portugal will use AQS-13 on hers. Argentina has 2 Lynxes equipped with Type 195. At one time Westland apparently offered this sonar as an option; it proved too heavy, and a Dutch order was changed to DUAV 4. Libya has 6 Super Frelons equipped with the modified HS 73 sonar and with L5 torpedoes (and Exocets). Both India and Indonesia ordered DUAV 4 for large helicopters but ultimately received HS 12 instead (see below).

Other naval Lynx operators (and thus potential purchasers of sonars comparable with DUAV 4 or HS 12) are the Royal Navy (HAS Mk 2, 3, and 8), Brazil (Mk 21), Denmark (Mk 80), Korea (Mk 99), and Nigeria (Mk 89).

HS 70 (DUAV 1) was an earlier dipping sonar, now obsolete. It was probably carried only by the French navy's Super Frelon helicopters (replaced by DUAV 4 and then by HS 12). South Africa bought both the Super Frelon and the Puma, and some of her helicopters may carry dipping sonars. Israel bought the Super Frelon and may have bought some French dipping sonars. For details of HS 70, see the previous edition.

◆ DUBA 1

This searchlight attack sonar for postwar French destroyers (*Surcouf* class) and frigates is designed to control K-1 straight-running torpedoes (the French equivalent of Squid). DUBA 1B operated at 23–26 kHz, with a peak power of 2.5 kW, and 8- or 20-msec pulses; range scales were 0.75, 1.5, 3, 4.5, and 6 kyd. In a *Surcouf*-class destroyer, this sonar operated in conjunction with a DUBV 1 search set.

The only surviving examples are found on board the old missile destroyers *du Chayla* and *Dupetit Thouars*, controlling Bofors-type 275-mm rocket launchers.

◆ DUBA 2

This hull attack (searchlight) sonar was found in postwar French-built 174-ft subchasers; it survives only in the Tunisian and Yugoslav navies. This craft was a modified version of the World War II U.S. 173-ft patrol craft; the U.S.-built postwar version was equipped with SQS-17A. DUBA 2 operates at 8–30 kHz, with 8-, 20-, and 200-msec pulses (the last presumably for search, since this sonar is used for both search and attack). Range scales are 0.75, 1.5, and 3 kyd, reflecting the limitations of high-frequency operation.

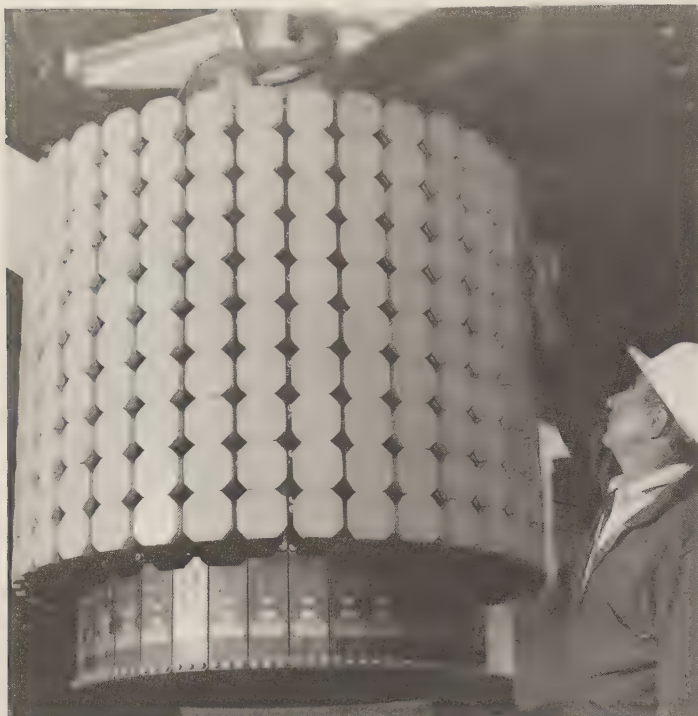
◆ DUBA 3

This high-frequency attack (searchlight) sonar for the *Commandant Rivière*-class frigates controls the 305-mm mortar; SQS-17 is the associated search sonar. Peak power is 4 kW (source level 126 dB), pulse lengths 10–30 (11–33 yd) or 100 msec (100 yd), and frequency 22.6–28.6 kHz (21.4 or 29.8 at reduced power). This sonar shares its dome with the SQS-17 search projector and with an underwater telephone. Sonar outputs are elevation (target depth), bearing, and radial speed (doppler analysis of a single ping).

◆ DUBA 25 (Thomson Sintra TSM 2400 Tarpon)/TSM 2080

This medium-frequency hull sonar was designed for the A-69-class Avisos and the C70AA destroyers (which cannot accommodate the big DUBV 23/43). DUBA 25 operates at 8, 9, or 10 kHz, with 30- or 90-msec pulses, and has a 10-deg beam-width (36-stave transducer, 9 elements per stave, with 36 preformed reception beams). Pulses can be CW or FM, and they can vary in length. This sonar was specially designed for use in coastal waters (on the continental shelf). Range scales are 3, 6, and 9 kyd, and the display is a PPI. The operator can place a filter over any 1 of the preformed beams to reject a narrow frequency band centered on the transmission frequency, to reduce clutter and reverberation (i.e., to limit returns to those that are doppler-shifted). For attack, special fine-bearing circuits are used, together with an auxiliary display (B-scan) showing an area 10 deg wide and covering one-eighth of the whole range scale. The transducer is 1.1 m in diameter and weighs 1500 kg.

Development began in the late 1960s, to a dual light frigate-export requirement. Thomson Sintra received the R&D



Tarpon low-frequency hull array. (Thomson Sintra)

contract in 1970, and development was complete by 1974, the first unit going to sea on board the *D'Estienne D'Orves*.

The Tarpon designation was also applied to TSM 2080. It was described as a sonar for ships displacing 2000–5000 tons. Its parameters are somewhat different from those initially published for the more austere Tarpon. In this sonar, source levels are over 220 dB in ODT mode or 227 dB in directional mode. The system produces 32 stabilized beams. All beams are subject to 2 forms of signal processing: spectral analysis (768 doppler cells formed by FFT) and pulse compression (maximum compression ratio of 300). The display console consists of 2 identical high-resolution (1000 × 1000) flicker-free color TV monitors. Total weight of the system is 6000 kg. Maximum instrumented range is 32 kyd.

Total weight of the hull-mounted sonar is less than 4.8 tons.

The associated VDS uses the same signal processor but has 24 staves and operates at medium frequency.

DUBA 26, presumably a successor to DUBA 25, has been reported.

◆ DUBM Series

See the Mine Warfare section under countermeasures.

◆ DUBV 23

France's standard hull-mounted sonar of the early 1970s is operated in conjunction with the DUBV 43 VDS. The sonar was developed in 1964–67, and the preproduction version was tested on board the *D'Estrées* destroyer in 1968. The upgraded DUBV 23 was tested in 1977.

The 23/43 combination was designed to counter quiet, deep-diving diesel submarines, i.e., relatively slow targets. The combination was chosen to achieve reliable direct-path ranges of 10–15 km, without seeking bottom-bounce or convergence-zone performance, and to support the Malafon stand-off missile and the Lynx torpedo-delivering helicopter (which reacquires the target using its own dipping sonar). Tactical-data processing was limited to a noninteractive display.

The current version is DUBV 23D. It has 6 modes: ODT, strip surveillance, sector surveillance, passive search at sonar frequency, panoramic attack, and directional (pseudo-searchlight) attack. The sonar operates at 4 frequencies between 4.9 and 5.4 kHz, producing pulses of 4, 30, 150, and 700 msec. Beams are

15 deg wide (48 vertical staves), and power output is 96 kW. Accuracy in range is 150 yd ± 1% of the range scale; accuracy in bearing is 1 deg; and accuracy in speed is less than 0.4 kt on the 0–10 kyd scale, or 1 kt on the 0–30 kyd scale.

Reported performance: 50% probability of detection against a target at 200-ft depth at 8000 yd, or against 1 at periscope depth at 14,000 yd. Reportedly, the French consider this sonar superior to the U.S. SQS-23.

In the *Georges Leygues* class, the associated VDS is modified, and it tows a DSBV 61 array, for improved performance. This improvement is described under the entry for DUBV 43.

◆ DUBV 24

DUBV 24 is a slightly less powerful version of DUBV 23. DUBV 24C, the current (1983) version, incorporates the transducer developed for the unsuccessful commercial SS24. DUBV 24 was 1 of the first French preformed-beam sonars. It uses 24 staves (8 transducers/stave); and modes are ODT, triple-beam search/receive (3 ping), stepped single-beam, searchlight transmit-receive for attack, ODT for attack (to deal with fast targets), and passive. In the ODT search mode, DUBV 24 has 6 audio beams. Tribesearch uses omnidirectional reception.

SS 24 (and presumably DUBV 24C) operates at 3 frequencies around 5 kHz, forming 24 beams (15 deg wide) using CW or FM pulses. Source level: 223 dB (ODT)/232 dB (RDT).

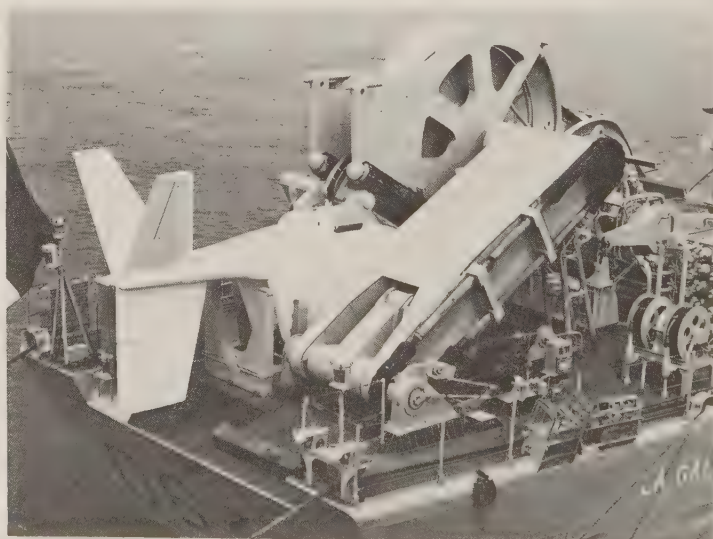
DUBV 24C is in the last 3 *Georges Leygues*-class frigates.

◆ DUBV 43

The towed VDS fish of the *Tourville* class generally operate in conjunction with a DUBV 23 hull sonar. Typical towing depth is about 300 m. Tow speed is 4–24 kt. The transducer in the stabilized fish has 24 staves (192 elements, 8 per staff). DUBV 43 can operate either independently or synchronized with DUBV 23, in scanning or in attack mode. The sonar operates on 4 frequencies around 5 kHz, with 15-deg beams (peak power 96 kW).

In the *Georges Leygues* class, the DUBV 43C is towed at more than 600-m depth. This increased depth adds 4 months to the period during the year when the sonar pair can cover the full depth of the Mediterranean. In addition, the "fish" tows a tactical array (TACTASS) 200 m aft. A second TACTASS is towed 3000 m astern of the ship, at a depth of 500 m. The TACTASS is fully digital, and it automatically tracks targets (presumably once they have been manually designated). The offensive element of this system is the Lynx helicopter; no Malafon is carried.

The DUBV 23/43 requirement was issued in 1963/64; Sintra-Alcatel used DUBV 24 as a building block. DUBV 43 was ap-



DUBV 43 fish, on board the experimental destroyer *La Galissonnière*. (U.S. Naval Institute)

proved for service in 1969, and an upgrade program was begun in the early 1970s. Tests followed in 1977, and the system was installed in 1978 on board the *Georges Leygues*. The last unit was completed in 1983, for the fourth C70-class corvette. In 1988 DUBV 43 was being modified for deeper operation, using a new transducer (developed by GERDSM), with a new signal processor (UTCS).

◆ DUUA 1A/B/C

This active searchlight sonar is found on the *Daphne* and *Agosta* classes. Beam is 8.5×8 deg. Frequency range is 13.5–30 kHz (6 bands); the high-power element operates at 17 kHz, with pulses of 8, 20, and 150 msec (power levels 100 or 400 W). There are 2-, 4-, and 6-km range scales. Passive operation is at 2–40 kHz. There are 3 versions of the transducer mount: MSS-1, -2, and -4. The transducer can scan manually or automatically. Automatic scan rate in azimuth is 15 deg/sec for MSS-1 and -2 and 30 deg/sec for MSS-4. Elevation limits are $-100/+30$ deg. There are 3 scan speeds (maximum 9 deg/sec) in MSS-1 and -2; MSS-4 does not scan. A is the basic version; B is a double sonar, and C is an intermediate sonar.

◆ DUUA 2

CIT-Alcatel's active submarine sonar is for the modernized *Daphne*, *Rubis*, and *Agosta* classes. DUUA 2 is a searchlight (beamwidth about 10 deg at 8 kHz) transmitting at 8 kHz (30 kW, 1.5 kW in reduced-power mode), with CW or FM pulses. Because DUUA 2 is a searchlight sonar, looking in only 1 direction at a time, each burst of pulses must be manually triggered. Pulse width is 30–500 msec, depending on mode. Range scales in active mode are 3, 6, 12, or 24 km. Displays are an A-scope (range vs. amplitude) and range-bearing. DUUA 2A scans at 4 or 8 deg/sec, between -175 and $+175$ deg, and its elevation angle can be set between $+15$ and -30 deg. The associated mount is MSS 5.

DUUA 2B is a passive adjunct, in a smaller sonar dome, operating narrow-band (500 Hz around frequencies between 2 and 15 kHz) and broad-band (2.5–15 kHz).

◆ DUUG-1/AUUD-1/Type 197 (Velox)/DUUG-2/DUUG-6

DUUG-1 is the first-generation Safare-Crouzet broad-band sonar intercept receiver; more than 500 were sold worldwide. The target's bearing is displayed on a CRT, and 1 loudspeaker provides audio warning. An associated system (AUUD-1B) measures the frequency of the intercepted signal. In a French *Daphne*-class submarine, the DUUG-1B hydrophones are located around the sail, on its fore and aft sides. This wide-band intercept receiver, without frequency analysis, gives only an approximate bearing.

DUUG-2 is in the *Agosta* and *Rubis* classes.

DUUG-6 (Velox M5) is a Safare-Crouzet stand-alone sonar-intercept system, intended to replace DUUG-1/AUUD-1/Type 197. Velox M6 is a similar unit intended for integration into a centralized combat system.

See also the private-venture Velox-M7 below.

◆ DUUX 2A/B/C

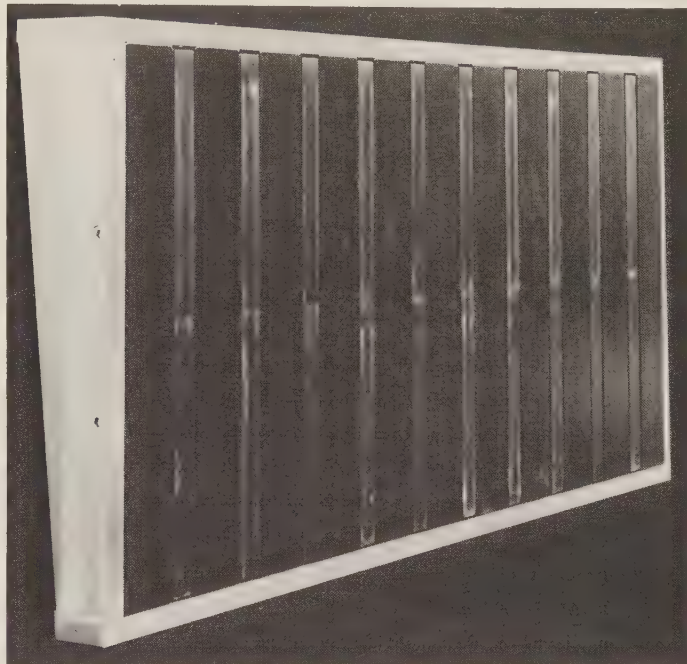
This passive range-finding system was developed in the late 1950s. A total of 120 were supplied to 14 navies for 8 different types of submarines. DUUX 5 is the successor.

The baseline (for 3 transducers on each side of the submarine) is 20–36 m, and the sonar operates on 5, 7, 12, and 18 kHz. Direction is determined by the delay (phase difference) in reception between the 3 transducers, as measured in a correlator/integrator, with the aid of variable delay lines. DUUX 2 covers a 90-deg arc on each side and achieves 1.5-deg accuracy in azimuth. Accuracy in range is 1% at 1–5 km, 2.5% at 5–10 km, 5% at 10–20 km, and 10% at 20–30 km. As of 1970, version A was in service, B was in preliminary production, and C was for the German navy.

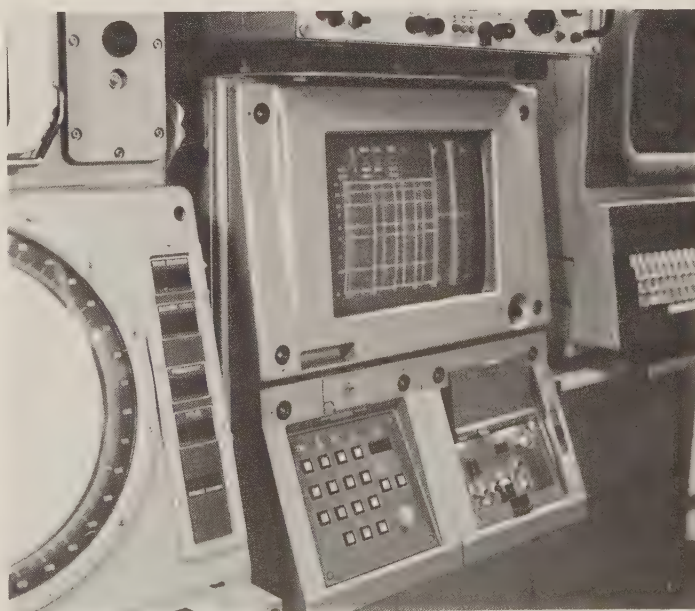
◆ DUUX 5 (FENELON)

This third-generation passive range-finder replaces the earlier DUUX 2. DUUX 5 can be used as a stand-alone passive-search sonar, tracking up to 3 targets simultaneously; as a passive range-finder (by triangulation); or as a sonar-intercept receiver. In each case DUUX 5 measures both the frequency and bearing of intercepted signals and noises within a 2–15 kHz range. Displays include a 20-min track history of any target, to assist in classification.

DUUX 5 uses 2 arrays, each consisting of 3 hydrophones on 1 side of the submarine's hull. Range is by triangulation, and the target's course and speed are estimated by TMA. DUUX 5 automatically and continuously measures the bearing of any loud noise source near the submarine and calculates the range of up to 3 contacts in a 120-deg sector on each side of the submarine. A fourth target can be tracked by means of an acoustic



DUUX 5 array, 1 of 3 on each side of the submarine. (Thomson Sintra)



DUUX 5 display. Each half covers a 120-deg sector, with bearing running along the horizontal axis and time along the vertical. Radiated noise spectra can be displayed vertically on the right-hand side. (Thomson Sintra)

intercept receiver. DUUX 5 can listen on several frequencies between 2 and 10 kHz, and bearing resolution is 2 deg abeam and 4 deg at 60 deg fore or aft of the beam. Data can be transferred automatically to the submarine's FCS.

There are 5 standard alternative hydrophone units, ranging from 730 × 380 × 184 mm (DUUX 5-H1) to 1350 × 840 × 212 mm (DUUX 5-27H2). The latter version uses a beam-preformer (for resistance to countermeasures) with its large high-gain arrays (about 1 m², with 10-stave hydrophones).

DUUX 5 was developed for the French nuclear attack submarines. The contract to Sintra-Alcatel was let in the mid-1970s, the prototype being tested on board the submarine *Doris* in 1977. The first operational unit is in *Saphir*. A version of DUUX 5 is incorporated in the Eledone system.

◆ Diodon (TSM 2630)/Sorel (TSM 2630)

Thomson Sintra's medium-frequency sonar is for medium-sized ships. Diodon is the bow sonar, Sorel the same sonar in VDS form. They share common information handling and signal processing but can transmit separately. They operate at 11, 12, or 13 kHz, with pulses of 20 or 80 msec (CW or hyperbolic FM). FM pulses are pulse-compressed for reception. CW pulses are used for doppler processing. The stabilized transducer has 24 staves and uses 48 preformed beams for reception. Operating modes are ODT, RDT, SRDT (directional transmission confined to a sector), and SDT. Transmission can be at reduced power. Maximum power source level is 123 dB. There are 2 signal-processing modes: linear integration filtering (which can accommodate doppler speeds of up to 30 kt) and coherent processing (FM transmission, to reject reverberation). The coherent mode can show the fine structure of the target (range definition 1.5 m).

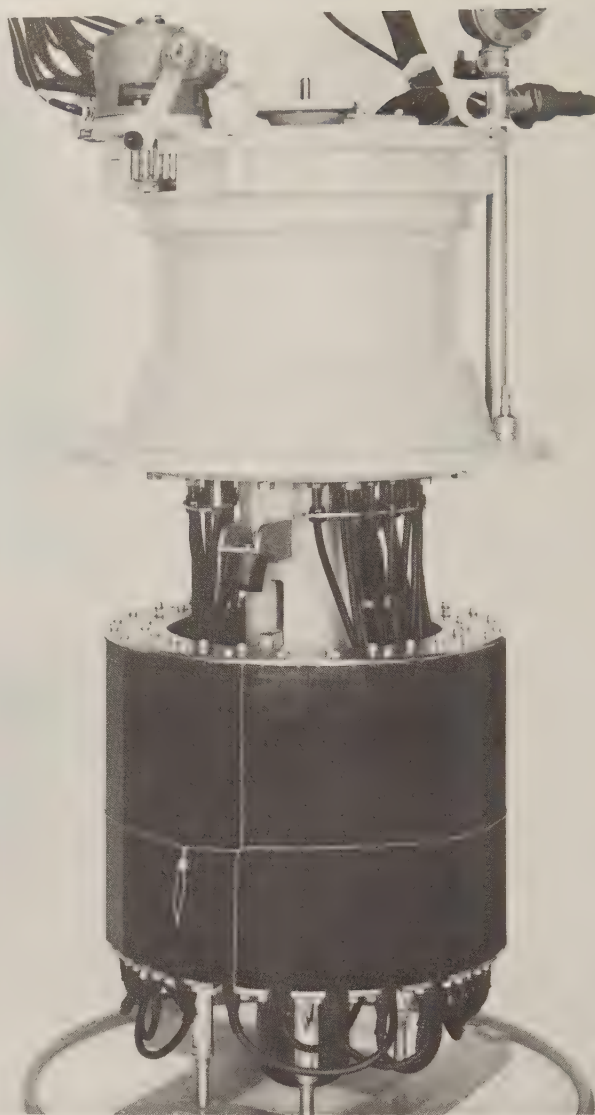
Generally all 24 staves are processed simultaneously (multiplexed). Range scales are 2–16 kyd. For attack, special precision circuits are used (range to within 1%, bearing to within 1 deg); data are displayed separately on a scope showing bearing within 10 deg to either side, and range within one-eighth of the chosen range scale, centered on the position of a surveillance marker on the main PPI. There is a separate doppler display (± 1 kt) for target following.

The signal processor can discriminate fast and slow targets (doppler). This sonar can be set for doppler enhancement (to eliminate reverberation) on 1 receiving beam, or on 2 adjacent beams for target following (beam comparison for accurate pointing). A target can be automatically tracked.

For the towed sonar, typical operating speed is 14 kt, and maximum towing speed is 20 kt. The fish is launched/recovered at 4–10 kt (10-min launch/recovery time).



Diodon medium-frequency VDS fish. (Thomson Sintra)



Diodon hull array. (Thomson Sintra)

Diodon employs the same display as DUBA 25 (Tarpon) and has the same function, but Diodon was intended to cost half as much: hence the choice of 24 rather than 36 staves, and the higher frequency for reduced size. Diodon was an early application of digital technology, for reduced overall volume, and has built-in fault-detection equipment that can isolate a fault to within 5 circuit boards. Estimated MTBF is 500 hr, and MTTR is 15 min.

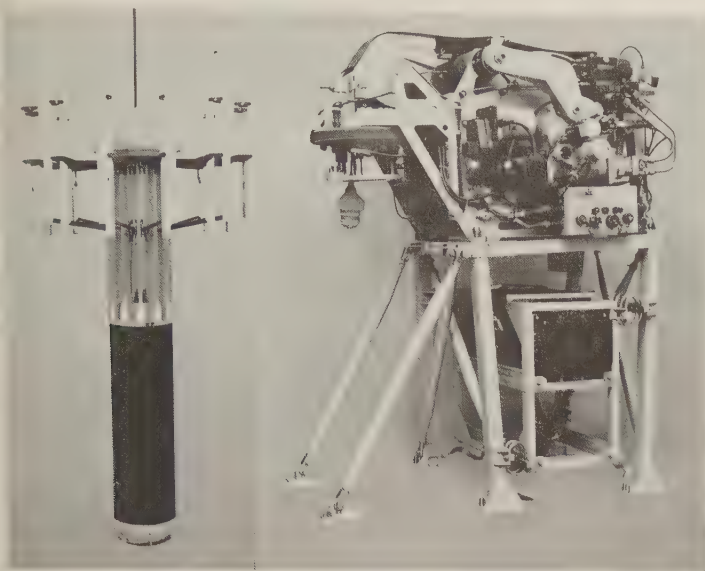
Work began in 1969, and Diodon ran sea trials in 1971. TSM 2630 is an improved version (to which data above may refer). Diodon users: Argentina (A69-class corvettes), Ecuador (*Wadi M'ragh* class), Iraq (*Wadi M'ragh* class: TSM 2630 version), Libya (Vosper Mk 7 frigate and *Wadi M'ragh* class), Portugal (*Baptiste de Andrade* class), Saudi Arabia (*Al Madinah*-class frigates: TSM 2630 version).

◆ FENELON

See DUUX 5 above.

◆ FLASH

The Folding Light Acoustic System for Helicopters is a low-frequency helicopter dipping sonar that Thomson Sintra has offered for the U.S. ALFS, the Canadian NSA (New Seaborne Aircraft), and the European EH-101 and NFH90 programs. The associated processor can handle 8 or 16 sonobuoys. FLASH has 24 preformed beams and 3 frequencies (all below 5 kHz).



FLASH, showing the extended array and the winch assembly. (Thomson Sintra)



FLASH being tested on board a U.S. Navy helicopter. (Thomson Sintra)

◆ HS 12/SS 12/DIP 12/HS 312

Thomson Sintra's helicopter dipping sonar is the fifth generation this company has produced. HS 12 was developed from the company's SS 12 VDS for small ships.

HS 12 operates either actively (about 13 kHz, short CW pulse or FM slide) or passively (7–20 kHz), at depths as great as 300 m, with a figure of merit of 175 dB. The sonar employs 12 preformed beams, for a base directivity of 30 deg. However, the display consists of 4 quadrants, north-stabilized, each obtained by processing the 3 adjacent beams. In this panoramic mode the operator can select a CW mode, in which each quadrant shows the target's range and the target's doppler (speed range ± 40 kt). Alternatively, the operator can select FM processing (target range displayed precisely enough for the target's motion to be seen from sweep to sweep). There is also a sector mode for simplified target tracking, in which the 3 adjacent beams of the

sector are displayed. The manufacturer claims a maximum range of 10+ km. In the dip cycle, the winch operates at 5 m/sec (average). HS 12 can track 2 targets simultaneously.

Construction is modular, for quick installation; HS 12 can be removed from any helicopter in less than 45 min. Total weight is 508 lb (121 lb for the dome; 42 lb for a 300-m cable; 158 lb for the hydraulic winch; and 187 lb for the display, control panels, and black boxes). The sonar dome itself is 10.3 in in maximum diameter and 33.7 in long and weighs 16 kg [33 lb]. The manufacturer, Thomson Sintra, claims that HS 12 is currently the lightest helicopter sonar in the world.

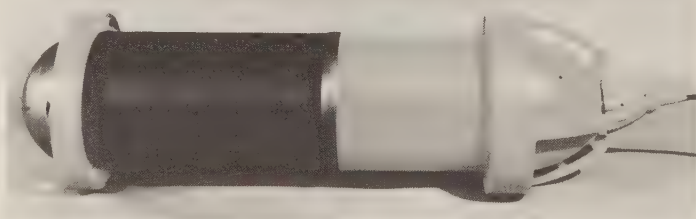
As in the case of DUAV 4, HS 12 is attractive to have on board a large helicopter (Sea King, Super Frelon, or Puma) because it leaves space and weight for a large antiship missile (Exocet or, for India, Sea Eagle). This sonar can also be installed on board the AS 365F/565 Dauphin 2 helicopter in ASW configuration (in the alternative attack configuration, this helicopter carries 4 AS 15TT missiles).

DIP 12 was an abortive dipping version for surface-effect craft.

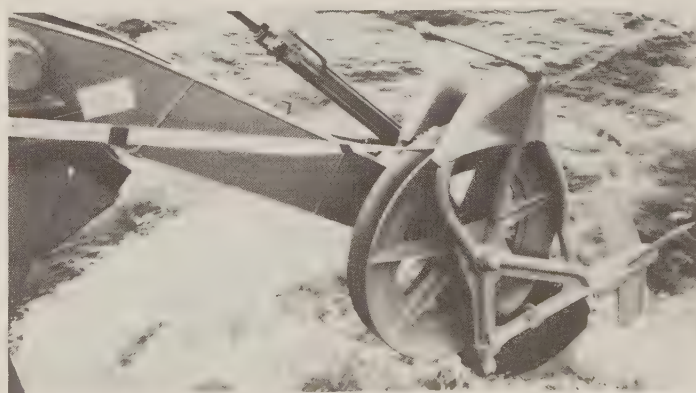
SS 12 is a hull and variable-depth searchlight sonar for fast attack craft and corvettes, operating in 3 frequency ranges around 13 kHz, using CW (rectangular or cosine-squared pulses) or FM pulses (source level 212 dB). SS 12 can automatically track 2 targets. The variable-depth fish can operate at 600 ft and at speeds of up to 16 kt; it can also be used with SS 24. Alternative range scales are 2, 4, 8, and 16 km or kyd. This sonar is comparable to the TSM 2640 Salmon, which has been more successful in its market niche.

HS 312 is essentially HS 12 integrated with a sonobuoy processor for 4 or 8 sonobuoys. Apparently, none has definitely been sold; probably all reported sales refer to HS 12. In some cases the original HS 12 may have been upgraded (FoM 177 dB). HS 312 was announced as the standard sonar of Super Puma naval helicopters, but they presumably carry HS 12 instead.

Reported HS 12 users are Chile (4 Dauphins, for which 20 Murène torpedoes were ordered in 1989), China (3, see below), Finland (2 on Super Pumas, others on Mi-8 and -14 helicopters), France (at least 30 on board Super Frelons and Lynxes, with more as DUAV 4 is replaced on board Lynxes), India (24 on Mk 42B Sea Kings), Indonesia (20 or 26 on board Pumas), Iraq (8 on



SS 12, the shipboard version of the HS 12 dipping sonar. (Thomson Sintra)



SS 12 fish (Thomson Sintra)



HS 12 on a Lynx helicopter. The dipping body and winch are on the left, the control panel on the right. (Thomson Sintra)

board Super Frelons, possibly others planned for 6 Super Pumas and 6 Dauphins on order in 1990), Portugal (5 Super Pumas), Saudi Arabia (12 on board Dauphins), and Singapore (on at least 5 of 22 planned Super Pumas). Other Super Puma naval operators are Brazil (6, plus 7 on order), Chile (3, plus 4 on order), Kuwait (6), Saudi Arabia (6), and UAE (8). Not all of these helicopters carry sonars. For example, the Chilean aircraft carry only Exocet missiles and VARAN radars (with TMV 026 ESM). The Finnish installation is interesting because other operators of Soviet naval helicopters may follow suit.

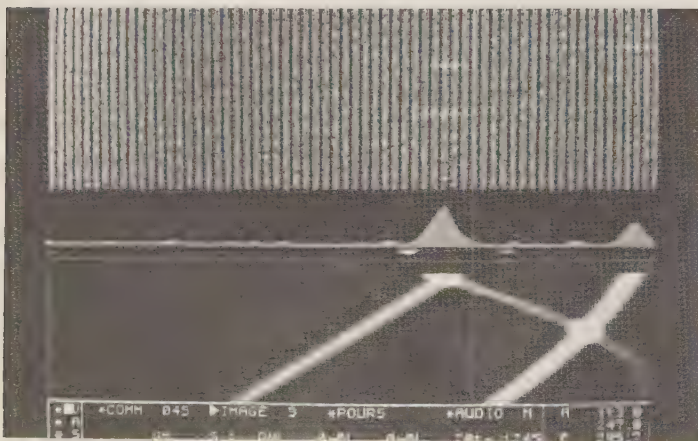
China bought 3 HS 312 (probably HS 12) sonars for Super Frelons. Reportedly, the 3 Super Frelons with HS 312s are prototypes for license production (under the designation Zhi-8) in China, so further sonars may be either on order or built locally. If the sonars really are HS 312s, that would seem to imply an additional sale of French sonobuoys.

HS 12 was first ordered in 1980.

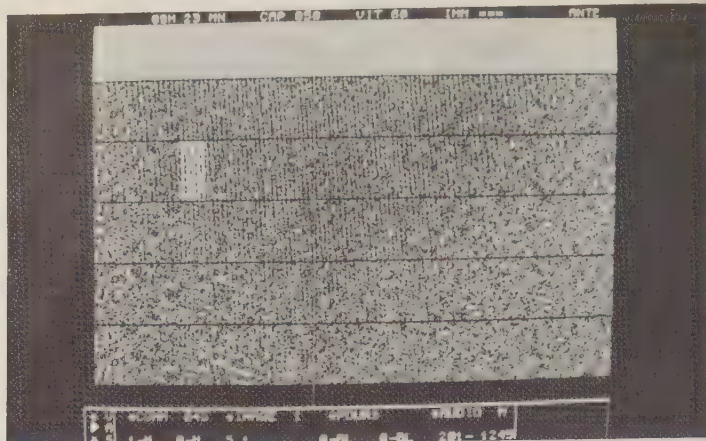
Only 2 prototype SS 12s were built, and both were sold to the PRC in 1987. One is on board the Haijui-class patrol boat hull 688.

◆ Lamproie

Thomson Sintra's commercial towed array incorporates both wide- and narrow-band processing and automatic torpedo warning. The array proper is 74 m long, including the usual vibration-



Lamproie combined narrow- (top) and broad- (bottom) band display for initial detection. The upper display is a LOFARgram, showing frequency (horizontal) plotted against time (vertical). The graph below is a series of time integrals of the highlighted areas of the LOFARgram. The lower (broad-band) display is a waterfall, showing potential target tracks, bearing (horizontal) being plotted against time (vertical). (Thomson Sintra)



The Lamproie classification (LOFARgram) display, showing a series of 6 different frequency bands (separate horizontal bands) simultaneously. (Thomson Sintra)



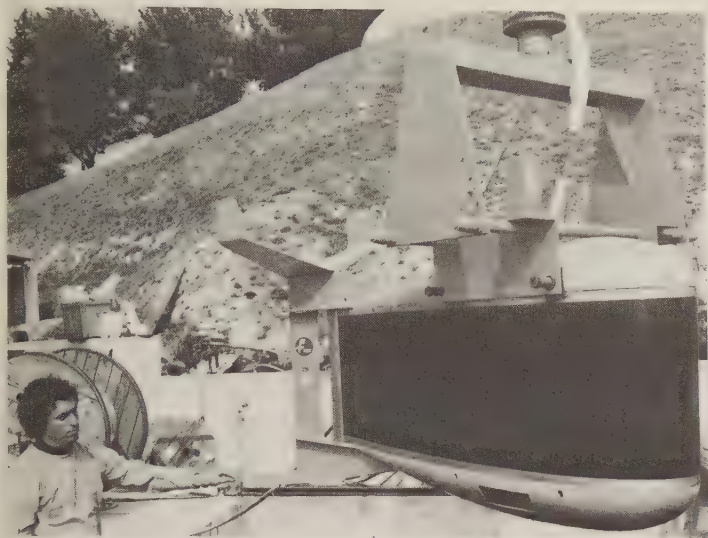
Towed-array handling gear on board the frigate *Lamotte-Picquet*. (Thomson Sintra)

isolation dampers at each end. Diameter is 80 mm, and the casing is Kevlar. The array can be towed at up to 32 kt and at depths as great as 1000 m [3280 ft]. It can be towed by submarines (either in reel-in or clip-on configuration) and by surface ships (either in critical-angle or depressor-tow configurations, the latter for shallow water). The processor can operate simultaneously in several frequency bands, permitting comparison among different harmonics of the same signal, and the processor provides automatic threat (i.e., torpedo) warning while in the detection mode. Lamproie can track targets in either broad- or narrow-band mode, either automatically or manually, and can automatically reject narrow-band jammers. Classification resources are LOFAR, DEMON, and a special high-fidelity audio channel. The display is the usual pair of high-resolution color CRTs. This array is based on DUBV 62.

The wet end can be a critical-angle tow or it can be towed from a VDS fish.

◆ Salmon (TSM 2640)

Thomson Sintra's lightweight high-frequency towed sonar for small patrol ships is dismountable. The 24-stave transducer (diameter 290 mm, weight 150 kg) operates at 3 frequencies around 12 kHz (217-dB source level). The operating mode is ODT with CW or FM pulses (which can be pulse-compressed). CW pulses are used for doppler (spectral) analysis. The transducer produces



Salmon high-frequency VDS fish. (Thomson Sintra)



Salmon array. (Thomson Sintra)

48 beams with FM pulses or 24 with CW. Maximum instrumented range is 12 kyd.

This sonar can track 3 targets simultaneously, and Thomson Sintra describes its signal processing as particularly suited to shallow water with substantial background noise and reverberation. The techniques in question are pulse compression with a high compression ratio (for sharp discrimination in range); high doppler resolution in the CW mode; normalization (adjustable gain, to reduce reverberation effects); and computer-aided detection. A flexible display also aids the operator.

The fish lowers to nearly 300 ft. It can be streamed at up to 20 kt (typical operating speed is 14 kt), and launch/recovery speed is 4–10 kt (time 10 min). The fish weighs 550 kg, and the

towing/handling mechanical assembly weighs a total of 5.2 tons.

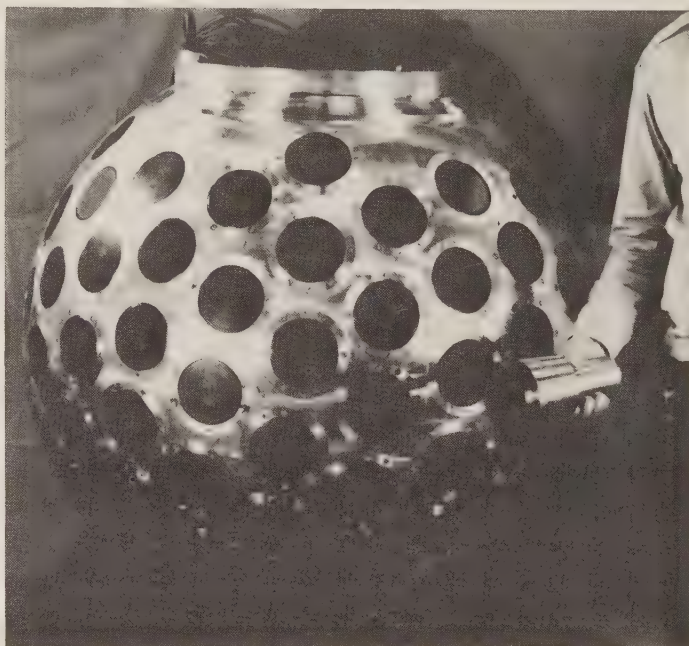
Development began in the late 1970s, the first unit being installed on board Swedish *Stockholm*-class fast patrol boats. Salmon was first tested in 1985. The *Göteborgs* are to have TSM 2643. Salmon has also been ordered for the Danish *Thetis* and *Flyve Fisker* classes.

◆ SPDT-1A

This passive broad-band preformed-beam sonar for surface-ship torpedo detection is made by Safare-Crouzet. Classification is by analysis of a torpedo's radiated noise. SPDT means *Sonar Passif pour la Détection des Torpilles*.

SPDT-1A is currently (1988) being installed on board the first of 11 major French warships. This sonar uses the array of an active hull-mounted or a towed sonar. SPDT-1A operates at medium frequency. The system reportedly detects a torpedo at 10 km or more under favorable conditions; it does not measure range.

◆ Spherion (TSM 2633)



Spherion array. (Thomson Sintra)

A Thomson Sintra VDS, Spherion is thus far in service only with the Norwegian and Indian navies. Spherion derives its name from its spherical shape. Like the much larger U.S. BQS-6, Spherion is covered with spot transducers, and presumably it can steer its beam both in azimuth and in elevation, for full 3D performance.

Derived from the TSM 2630, Spherion consists of 160 transducers on a 1.15-m sphere, weighing 1830 kg. This VDS operates at 10–13 kHz (on 3 or 4 frequencies), using 10- or 15-deg beams. Source levels are 217 dB ODT and 227 dB directional mode. There is also a sector directional mode. There are 36 preformed beams stabilized in azimuth and elevation; all CW beams are subject to spectral analysis (768 doppler channels), and FM pulses are pulse-compressed (TB of 300). The signal processor can extract and maintain 25 tracks simultaneously. Criteria provided by the system for target analysis include apparent length, inclination, and doppler. As in TSM 2630, the display incorporates 2 identical high-resolution monitors. Total system weight is 6000 kg.

Spherion was announced in 1985.

TSM 2633 is an ES/LF hull-mounted version, operating at 6–8 kHz, also producing 36 preformed beams, with instrumented ranges between 2 and 24 km. There is a VDS version of TSM 2633; it is not clear whether the higher-frequency Spherion de-

scribed above would be used as the complementary VDS. The Thomson Sintra brochure describing this sonar shows it installed on board what appears to be a Norwegian *Oslo*-class frigate, with a large spherical transducer in the bow sonar dome and a much smaller transducer in a towed fish. Reportedly, the new ANZAC frigate will be equipped with this Spherion B sonar. This sonar equips the last 2 Indian *Nilgiri*-class frigates.

◆ TSM 5421

Thomson Sintra's mine-avoidance sonar uses automatic mechanical scanning. It would typically be mounted in the upper bow of a submarine. Large obstacles are detected at 1000 m, and small ones (such as moored mines 1 m in diameter) at 600 m (12-dB reflection index). The sonar transmits a 30×15 -deg beam and receives using 10 preformed beams (each 3.2×15 deg). The entire transducer can scan mechanically (automatically) at 8 deg/sec to extend its search sector to a total of 60 deg (within about 4 sec) or 120 deg (within about 11 sec). The search sector can be moved over a 175-deg arc on either side, i.e., very nearly to dead astern. Range scales are 50, 150, 500, 1500 meters. There is also a passive mode (at 38 kHz) with audio presentation (beam 8×40 deg, directed on any manually selected bearing). This last mode is apparently intended for the reception of special pinger signals.

This is probably the mine-avoidance sonar of the standard current French integrated submarine-sonar suite.

◆ Velox-M7

This sonar-warning receiver for submarines is under development by Safare-Crouzet as a private venture, to replace Velox-M5/DUUG-6B. M7 automatically gives an alarm when sonar signals are detected, giving the bearing of the source and measuring the transmitter's frequency, relative level, pulse width, and PRF. M7 will also detect ultrasound communications and acoustic noise generated by surface ships.

◆ PVDF/PVF

In 1988 Thomson Sintra announced a new material, PVDF (polyvinyl fluoride), for passive sonar transducers. A continuous sheet of alternating piezo-electric film and metallic electrodes, to replace conventional ceramic hydrophones, PVDF is made in panels about 1.5×3 ft and about 2 in thick. It will initially replace conventional flank-array hydrophones; sea trials reportedly show a better signal-to-noise ratio (hence greater effective range) than conventional hydrophones, with useful response up to 5 kHz. Theoretically PVDF should be effective up to 10 kHz. This improvement is important because, given the baselines involved, ranging requires the kind of accurate bearing data available only above 5 kHz. Below that frequency the bearing of a target can be obtained, but individual flank hydrophones do not differ enough in their bearing data to provide range by triangulation. PVDF is already in service on board Norwegian submarines and is planned for French ballistic-missile submarines. Existing spot hydrophones have to be isolated from water flow over the hull to achieve sufficient signal-to-noise ratios. They are, therefore, mounted in fairings, and the fairings in turn cause drag as well as noise due to flow disturbance. The flat PVDF panels can presumably be mounted directly on the outside of a submarine's hull.

In May 1989 the nuclear submarine *Saphir* was fitted with Thomson-Sintra PVF flank arrays. These 5-cm-thick panels were developed specifically for the new *Le Triomphant*-class strategic submarines. A second version was to be fitted to a French nuclear submarine in the winter of 1990-91. See also the description of the test submarine *Le Dauphin*, below.

◆ New Submarine Sonars (Sonar Test Submarine)

The French diesel-electric submarine *Le Dauphin* was converted into a sonar test ship in 1983-85; all weapons were removed. She has tested a future spherical bow sonar, presumably a submarine version of Spherion. During 1989 she was fitted

with 2 types of hull side arrays and a long towed array. Both hull arrays are made of polyvinyl-fluoride (PVF2) extended-surface sensors. One consists of panels (several square meters each) with a complex acoustic structure. Its hydrophones are set against a rigid reflector elastically mounted on the pressure hull and flush-faired. The other is a pseudoconformal array distributed longitudinally over much of the hull to operate at VLF. As of October 1990, trials had been scheduled to begin in the fall of 1990.

UNDERWATER FIRE-CONTROL SYSTEMS

◆ DLA

Direction de Lancement d'Armes, a torpedo fire-control console for the Saudi *Al Madinah*-class frigates, controls 4 F17P wire-guided torpedoes fired from stern tubes. The console receives the essential data from the ship's combat system (target's bearing, range, heading, and speed); alternatively, DLA obtains these data directly from the ship's sonar. Two target tracks can be shown simultaneously, but only 1 torpedo can be controlled. If both targets must be attacked, 1 of the torpedoes must be fired on a preset track.

◆ DLT D3A

The standard French torpedo FCS is *Direction Lance Torpilles*. Versions in current service are the following:

D3A in *Agosta* class and modified *Daphne* class. All operations are controlled by an IRIS 35M computer. This version tracks 8 targets and guides 2 torpedoes while preparing a third for firing. The console has 3 displays, side by side: tactical situation, firing path, and an alphanumeric display of situation parameters (tote). There are 2 keyboards; typically, 2 operators sit at the console in the control room, with a third in the torpedo room. In recent installations the computer is a CIMS 15M125. This is the FCS installed in Spanish and Pakistani *Agosta*-class submarines.

L4C in surface ships.

S4E in *Daphne* class, controlling Z16, E14/15, and L3 torpedoes. S4D was in the modernized *Narval* class, now defunct.



Agosta CIC, showing the torpedo FCS display (DLT), DUUX 5, and the panoramic (integrated) sonar displays. (Thomson Sintra)

◆ SUBICS

This Thomson Sintra integrated submarine combat system is a follow-on to the earlier combination of separate sonars and the DLT D3A torpedo FCS; the latter already provided a tactical summary plot. SUBICS uses the new Colibri multifunction display consoles, with their 68000-series microprocessors; screens are up to 19 in in size. The associated sonars automatically detect and track targets, and TMA calculations are automatically conducted for all sonar tracking channels. Operators can interact with the TMA calculations to refine target data. Targets are identified by analysis of their radiated noise signatures, and also of their own sonar pulses (using a library look-up). The system can also use ESM and optronic-periscope data. Data from the different arrays are automatically correlated to form a single integrated picture, using data association and computer-aided data fusion. There is a large-screen command plot summarizing these data. Threat analysis includes torpedo alerts.

Details have not been published, but it would appear that SUBICS is a distributed system built along a data bus. In the past, 1 problem in such designs has been insufficient bus capacity to carry the very large amount of sonar data from the arrays (and preprocessors) to the consoles in the submarine CIC. A specialized cable can easily carry data from 1 array to 1 console, but true distribution demands that 1 bus carry all sonar data (as well as other data) simultaneously. This was 1 of the problems that killed the original version of the U.S. BSY-1. The published description of SUBICS suggests that Thomson Sintra plans to do much more of the processing at the array, without much human intervention, so as to reduce the load on the system bus (and also so as to make data fusion more practical). Such data reduction is probably also necessary if the central processing is to be done by a collection of 68000-series microprocessors. At least in the case of passive sonars, such automatic detection is still more an ideal than a reality.

SUBICS, then, represents a current universal ideal: to present the submarine commander, automatically, with a picture of the surroundings corresponding to the full set of sensors in the craft. The modular character of the system should make it amenable to changes in sonars and in weapons, the latter being particularly important given rapid developments in underwater-launched missiles.

GERMANY (WEST)

SONARS

Virtually all West German sonars are produced by Krupp-Atlas Elektronik GmbH (KAE).

◆ DBQS-21 (CSU 83)

Compared to the earlier CSU 3-4, this system adds a flank array and a towed array. CSU 83 is the primary sensor of the new German SLW-83 submarine's fire-control and command/control system now being developed, and also of the ISUS (integrated-sensor underwater system) for export. CSU 83 was evaluated on board a Type 206 submarine during 1985, the German navy ordering 13 sets for its SLW 83 integrated submarine combat system, 12 of them for Type 206A submarines being modernized and the other for a shore site. Others were ordered for the Norwegian *Ula* class, for the Swedish *Vastergotland* class, and for 2 Type 209s for Brazil.

The system consists of a passive bow array (0.3–12 kHz), a trainable active transducer (8 kHz, range 10 kyd, 30-deg beam), a passive flank array (10 Hz–2 kHz, range 50 kyd), a passive-ranging array (2–8 kHz, effective to 15 kyd), a towed array (100–800 Hz, maximum range 100 kyd), a sonar-intercept array (1–100 kHz, effective at up to 100 kyd), and 2 self-noise sensors (sail and machinery room, 0–12 kHz).

CSU is a commercial designation, meaning Compact Sonar for U-boats.

◆ DSQS-11

See the Mine Warfare section.

◆ DSQS-21/ASO80 Series

These are Krupp-Atlas's hull and variable-depth sonars for surface ships. DSQS-21A is for large destroyers. DSQS-21B for destroyers and frigates has 32 beams (variable-depth version has 64 beams). DSQS-21C for corvettes and DSQS-21D for small ASW patrol vessels have 32 beams in both hull and variable-depth versions. In each case a Z suffix, as in DSQS-21BZ, indicates that the transducer is electronically stabilized against roll and pitch. The transducer's diameter varies from 0.95 m (32 staves) in DSQS-21D, to 1.8 m (64 staves) in DSQS-21B, to 3.0 m (96 staves) in DSQS-21A for destroyers.



Console for a DSQS-21 sonar, showing a ray-trace indicator on the upper display and a PPI (plan position indicator) below it. (Krupp-Atlas Elektronik)

There are 5 selectable range brackets (2–32 kyd). Transmission modes are 5 and 50 msec CW; 50 msec FM; and 5/50, 50/50, and 300/300 msec CW/FM. The returning pulses are subject to processing optimized separately for each type (CW and FM) of pulse. On the PPI display, fixed navigational points (such as cliffs) are shown in yellow, approaching targets are in red, and retiring targets in green. In active mode, the sonar can automatically track 3 targets simultaneously, giving their range, bearing, and radial speed (i.e., doppler). In the passive mode, 3 targets can be tracked automatically in bearing. There is also a sonar-intercept facility. This sonar incorporates geometric processing, new plots being correlated with past tracks to reduce the false-alarm rate. The track list is constantly thinned by checking and by assigning each track a confidence level.

This sonar began with a German navy requirement for a sonar for the frigate (which became Type 122) that was planned for the 1980s; the export market was secondary. Krupp-Atlas began

feasibility studies in 1972. Bids were solicited in 1976, Krupp-Atlas carrying out R&D between 1976 and 1979, leading to tests of DSQS-21BZ in 1979. It is intended primarily to operate in shallow water, often with a cluttered bottom.

The export version of the DSQS-21 is the ASO80 (Type 80) series. ASO83 is a low-volume single-display system; ASO84 is DSQS-21; ASO85 has 64 preformed beams; and ASO86 has 96 preformed beams. There are variable-depth versions of each sonar.

ASO 84 to 86 are derived from DSQS-21; over 50 had been manufactured as of 1987, and all versions were compatible with a VDS. ASO83 is a smaller single-operator sonar intended for smaller surface craft up to corvette size. Dimensions are as follows:

	Hull Sonar/VDS Array Dimensions	Preformed Beams
ASO86	3.0/1.0 m	96/32 deg
ASO85	1.8/1.0 or 0.58 m	64/32 deg
ASO84	1.0/1.0 or 0.58 m	32/32 deg
ASO83	1.0/0.58 m	32/32 deg

Each has a stabilized beam option.

As of 1987, a total of about 50 DSQS-21s had been delivered to 15 navies. This sonar has replaced the U.S.-supplied SQS-23s of the *Lutjens*-class missile destroyers.

As of 1990, KAE claimed deliveries of about 60 DSQS-21s to at least 15 navies. That figure may include replacements for the SQS-23 sonars of the German *Lutjens*-class missile destroyers and the sonars of the *Bremen*-class frigates (11 ships in all). Reported export users:

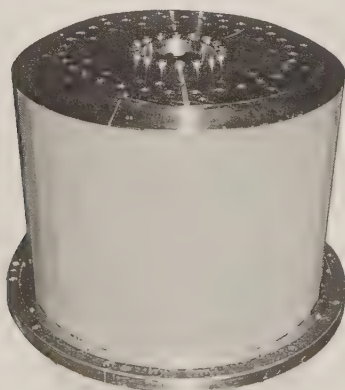
KAE ASO 80 series: Argentina (10 MEKO frigates), Brazil (4 *Inhauma* class, ASO 84-2), Colombia (4 FS 1500 class, ASO 84-2), Malaysia (2 FS 1500 class, ASO 84-5).

DSQS-21: Nigeria (replaced PHS-32 in *Aradu*), Taiwan (10–15 DSQS-21CZ sonars in refitted non-SQS-23 destroyers and DSQS-21CZ for the modified *Perry* class) and Thailand (DSQS-21B in PFMM Mk 16s [*Ratanakosin* class]; DSQS-21CZ in the frigate *Makut Rajakumarn* [replacing PMS 26], in the U.S.-supplied PF 103 class [replacing SQS-17], in the new *Kamronsin* class, and in the last 2 frigates to be built in the PRC).

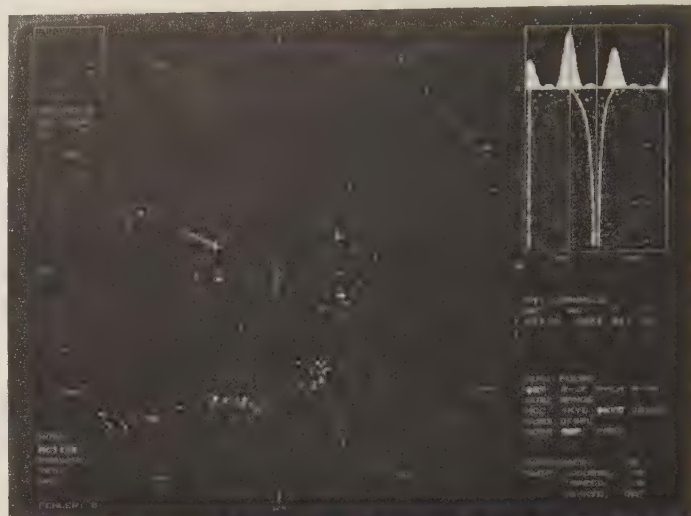
Most or all of the remaining exports are probably replacements for U.S.-supplied SQS-4-series sonars on board destroyers and frigates. Estimated unit cost is \$4 million.

◆ DSQS-23B/ASO 90

This is a new series of Krupp-Atlas active sonars to succeed the ASO 80 series. DSQS-23B is the sonar of the new F123-type frigates, and it probably corresponds to ASO 96.



ASO 90-series transducer. (KAE)



ASO 90-series active-sonar display, showing both a PPI and a B-scan centered about a bearing of interest. The circle at the very center of the PPI shows own-ship course and speed. (KAE)

	Hull Sonar/VDS Array Dimensions	Application
ASO 92	0.7 × 0.3 m (conformal)	patrol boats, corvettes
ASO 93	0.58/0.58 m	patrol boats, corvettes
ASO 94	1.0/1.0 or 0.58 m	corvettes, frigates
ASO 95	1.8/1.0 or 0.58 m	corvettes, frigates
ASO 96	2.5/1.0 m	destroyers, frigates

ASO 92 and 93 operate at high frequency; ASO 94 and 95 at medium frequency; and ASO 96 at low frequency.

The F123 sonar suite includes an intercept sonar and an active/passive towed array (with either a hull or a towed active transmitter).

◆ SLW 83/ISUS

This integrated sonar suite uses the CSU 83 (DBQS-21) sonar plus tactical data-handling and weapons control. ISUS (integrated-sensor underwater system) is the export version. Each sonar can initiate a target track, the data then being supplemented by data from the other sonars. Each track is subject to automatic classification and TMA (for up to 24 targets) before being combined with periscope and ESM data in the tactical data-handling system (TDHS). The TDHS in turn generates a combat-situation display. The system can handle up to 3 simultaneous engagements, either from a single console or from several consoles.

These systems are modular, built up from multifunction consoles: 2 for a small submarine or up to 6 for a submarine of over 1800 tons. German Type 206A submarines have 4 consoles, 2 devoted to the CSU 83 sonar suite, 1 to CIC duties, and the other to fire control. Each console carries two 15-in 3-color CRTs, the lower screen functioning as a PPI and the upper carrying alphanumeric tables.

The new Turkish Type 209/IKL 1400 submarines (the first of which was ordered in 1987) have CSU-83/1 sonar systems and KAE FCS, presumably of this type.

◆ CSU 2 and CSU 4

These searchlight sonars for submarines are tiltable and trainable. CSU 4 is an electronically scanned active sonar. These sonars are part of CSU 3-2 and 3-4.

◆ Krupp-Atlas CSU 3-2/CSU 3-4

An integrated sonar system for submarines, CSU 3-2 uses a fixed passive array and a searchlight active sonar that is mechanically tilted and rotated. Development began in 1963–64, and the first units (CSU 3-2 passive only) were installed in German Type 205

submarines in 1966–68, after which an improved version was exported. The AN526 passive array consists of a 96-stave horseshoe wrapped around the chin of the submarine, each stave consisting of 3 elements, and the entire array covering the sector back to 30 deg on each side of the bow. Beams are formed by delay lines. In service, it was soon found that individual staves could easily be knocked out of alignment and that they were difficult to replace.

Accuracy was about 1 deg. Hydrophone output was in 6 bands between 350 Hz and 3.2 kHz, all 6 being displayed above the main PPI as an aid to frequency analysis and classification.

CSU 3-4 is an improved version of CSU 3-2, with a circular passive array (3-m diameter, 900 mm deep). Because this array, which is designated AN5039, is more symmetrical than the chin array, its beam-forming network is easier to manufacture, and the array itself is easier to align. Type 205 and Type 206 submarines in Danish, German, and Norwegian service use the AN5039 chin array.

CSU 3-4 is specially intended for shallow water. Able to track 4 contacts automatically, this sonar system provides target elevation angle to estimate range and optimum sound ray path. An audio channel improves classification. The active mode is displayed in 30-deg sectors (waterfall) on the CRT, with continual memory update. The cylindrical array is electronically scanned. The intercept function can display up to 8 pulses in the center of the CRT, plus data on bearing, frequency, signal level, and signal duration on 1 pulse. These pulses can also be presented on the audio channel. Two passive-ranging sonars, PRS 3-4 and PRS 3-15, can be added as options. In 1987 German production shifted to the CSU 83, which combines active, passive, intercept, and 2 flank arrays, a doppler log, and an underwater telephone.

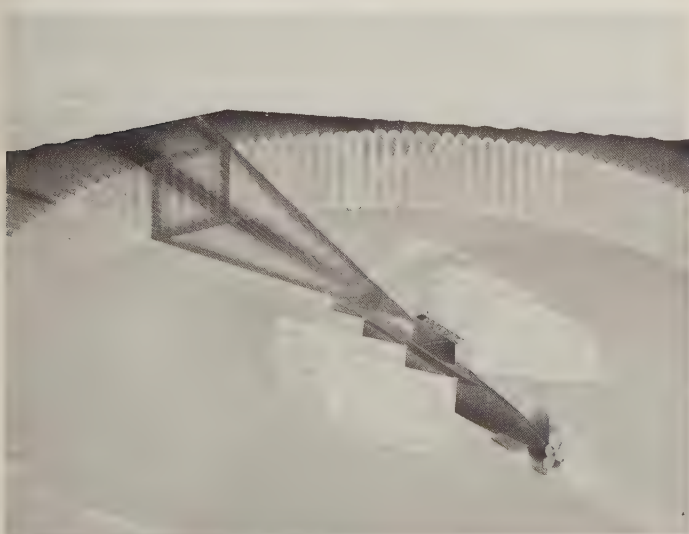
Reportedly, through mid-1988 KAE sold a total of 140 active, 144 passive, and 55 active/passive submarine sonars.

◆ CSU 3-41

CSU 3-41 is an active-passive sonar for submarines (in Canadian *Oberons*). The active transducer in the sail replaces the original Types 187, 197, and 719.

◆ CSU-83

This is the sonar suite of recent Brazilian, Norwegian, and Swedish submarines, as well as of modernized German Type 206s. It is intended for submarines displacing 500 tons or more; the smaller PSU-83 suite is for smaller units. CSU-83 incorporates the FAS 3-1 passive flank array as well as the cylindrical bow array and the trainable (over about a 30-deg sector) active transducer of earlier Krupp-Atlas sonar suites. There is also a sonar intercept receiver.



CSU-83 sonar coverage, including 3 passive-ranging arrays on each side. (KAE)

The associated sonar-information processor is generally the Atlas SIP 3.

◆ CSU-90

This is a new-generation submarine-sonar suite. The basic version consists of a passive scanning attack sonar (a 2.8-m cylindrical array with DEMON processing), a passive intercept sonar, and a low-frequency (i.e., long-range) flank array. The cylindrical array operates on both direct and bottom-bounce ray paths. Any target detection by 1 of the 3 elements initiates automatic data collection and compound track formation. There are 8 ATT channels for the attack sonar and 8 ATT channels for the DEMON analyzer (each with 8 ALTs [automatic line trackers]). An optional TMA controls 8 compound tracks and a sonar tactical-situation display, and it can control further manual tracks. Finally, the flank array has 8 ATT channels and 8 MLTs (multiline trackers), each with 8 ALTs. The system associates tracks from the different sensors to form up to 8 full compound tracks. All compound tracks can pass through the optional TMA analyzer; the analyzer can also evaluate other sensor data to form a more complete tactical picture, which is displayed on a tactical-underwater-situation display (TUD) associated with the TMA option.

The other optional add-ons are: passive-ranging sonar (PRS), own-noise analyzer (ONA), acoustic passive classification (APC), automatic warning channels (AWC), a disk mass memory unit (DMU), and plotters and simulation facilities. The disk holds data for comparison purposes (for the SIP) and the classification file for the intercept sonar, and it carries the interface to the plotter.

The system uses EPR 2300 32-bit processors (using 68030 chips) and the new standard 2-screen console described in the Surveillance and Control section of this book. Only 70 different computer boards are used for the total of 500 boards in the system.

◆ ELAC 1BV

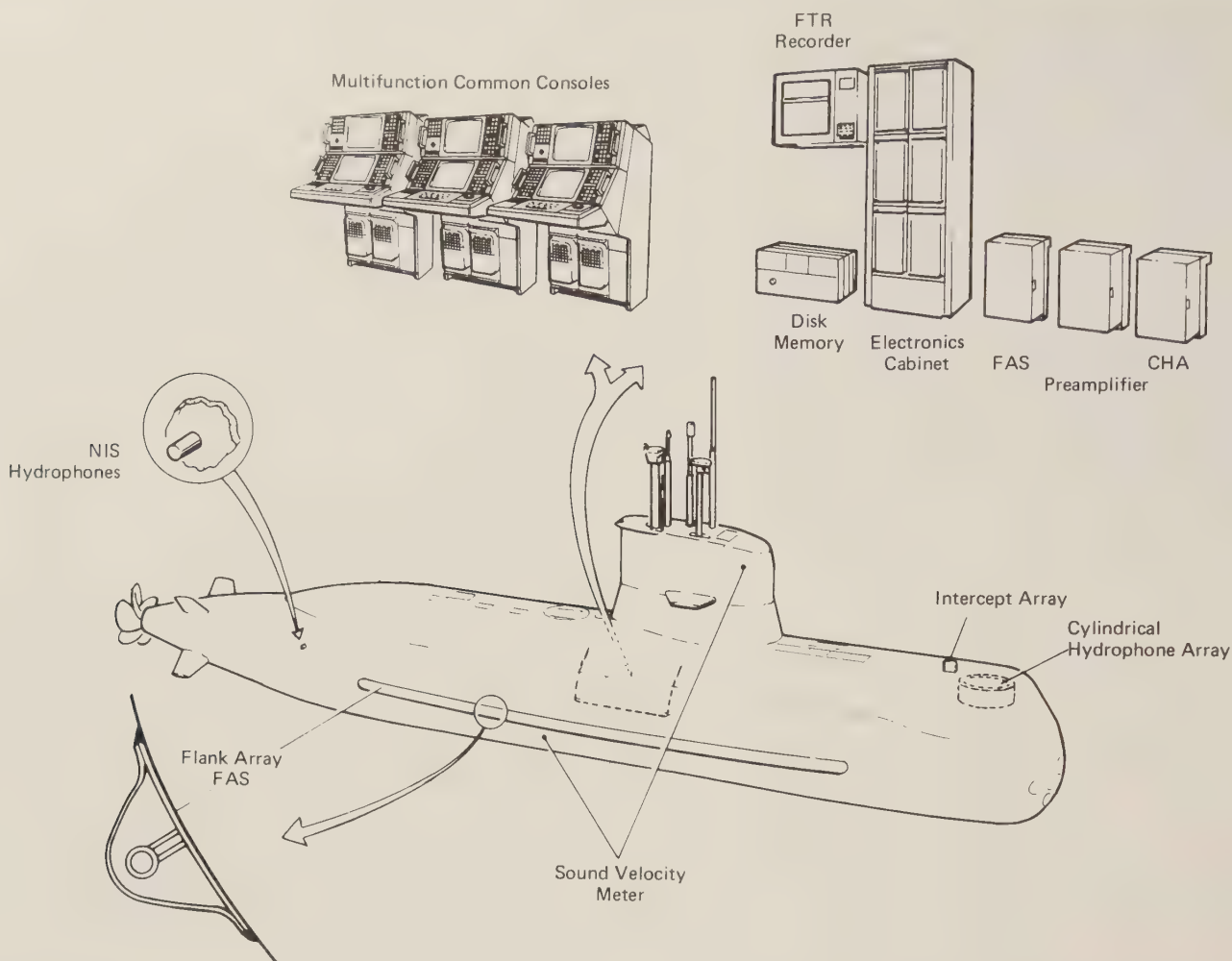
ELAC 1BV was the first modern German-produced surface-ship sonar; it is installed on board the *Hamburg*-class destroyers and the *Thetis*-class corvettes (the contemporary *Köln* class have the Dutch PAE/CWE combination). This sonar was reportedly also installed on board early Israeli *Saar*-class attack boats, and there has been speculation that it is the sonar for which the Spanish *Lazaga* class is fitted.

This is a biaxially stabilized searchlight sonar, trainable and elevatable. There are consoles for target direction, elevation angle, doppler/range, and coarse doppler/range. The target-elevation-angle measurement was necessary for the sonar to control the Bofors ASW mortar mounted in the 2 classes of German ships.

There were several versions. Some of the data below are from official data sheets prepared in 1973 and 1979 (the latter for 1BV/2). However, the official specification for ELAC 1BV2 is dated December 1965 (revised to February 1966). These are all magnetostrictive sonars.

The sonar originally operated primarily at 18 kHz (alternatively, at 12 or 15 kHz). When the transducer was enlarged (for the 1BV2 version), primary operating frequency was reduced to 10 kHz (it could also be set at 12 or 15 kHz) because otherwise the beam would have been too narrow to be tactically useful. ELAC also proposed an 8.2-kHz version. The other major improvements made at this time (1965) to both 1BV and 1BV2 were automatic sum-difference reception (for target following), transistorization, own-doppler compensation, sonar self-test, and a heater for use when the sonar was not operating. These sonars have a sector-scan mode (both vertical and horizontal), the scan rate being set by sector width and by range scale.

ELAC 1BV/1 operates at 14.9 kHz (5–50-msec pulses, 4 kW). Range scales: 1500, 3000, 6000, 9000 m. This sonar could operate with either of 2 FCSs, 9 AU 101 or M5/4 (the former a PEAB, the latter a Signaal system). Data sheets show the 9 AU 101 version operating at 14.9 kHz, the M5/4 version at 12.05



CSU-90 sonar suite. (KAE)

kHz. Source levels: 123 dB at 12 kHz, 124 dB at 15 kHz, 125 dB at 18 kHz. Beam widths at these frequencies: 14, 10, 9 deg, respectively.

ELAC 1BV 1A equips the 4 *Hamburg*-class destroyers and was fitted to the training ship *Deutschland*. Of these ships, the destroyer *Bayern* is fitted with the 15-kHz version and *Hessen* with the 18-kHz version; the others have the 12-kHz version. The trials ship *Hans Burkner* is fitted with 1BV 1B (15-kHz version).

ELAC 1BV/2 is an improved 1BV with higher power and with a transducer of about 4 times the area of the earlier version. It operates at 10.0, 12.05, or 14.9 kHz (fixed in each case) with peak power increased to 16 kW (but switchable to $\frac{1}{3}$ or $\frac{1}{10}$ power). Pulse width is 5–50 msec, and range scales are 1500, 3000, 6000, and 12,000 m. This version uses 2 transmitters (normal search and high power), and it is not clear whether it was associated with the 9 AU 101 FCS or with M5/4. Source levels: 131.5 dB (8.2 kHz), 133 dB (10 kHz), 134.6 dB (12 kHz), 136 dB (14.9 kHz). Beamwidths (at 3 dB points) at these frequencies: 12.6 deg, 9.6 deg, 8 deg, 7.5 deg. The 8.2-kHz version did not enter service.

ELAC 1BV2 was installed on board the *Thetis* class (2 at each frequency).

An ELAC 1BV3 was also reported, operating at still lower frequency (6.8, 8.2, or 10 kHz) but with lower peak power and with pulses closer to fixed length (20–25 msec). No applications have been reported.

ELAC (Electroacoustic GmbH) is now a division of Honeywell and no longer produces complete sonars.

◆ FAS 3-1

Krupp-Atlas's passive flank array for small diesel-electric submarines operates over the 10 Hz–2.5 kHz range. One array

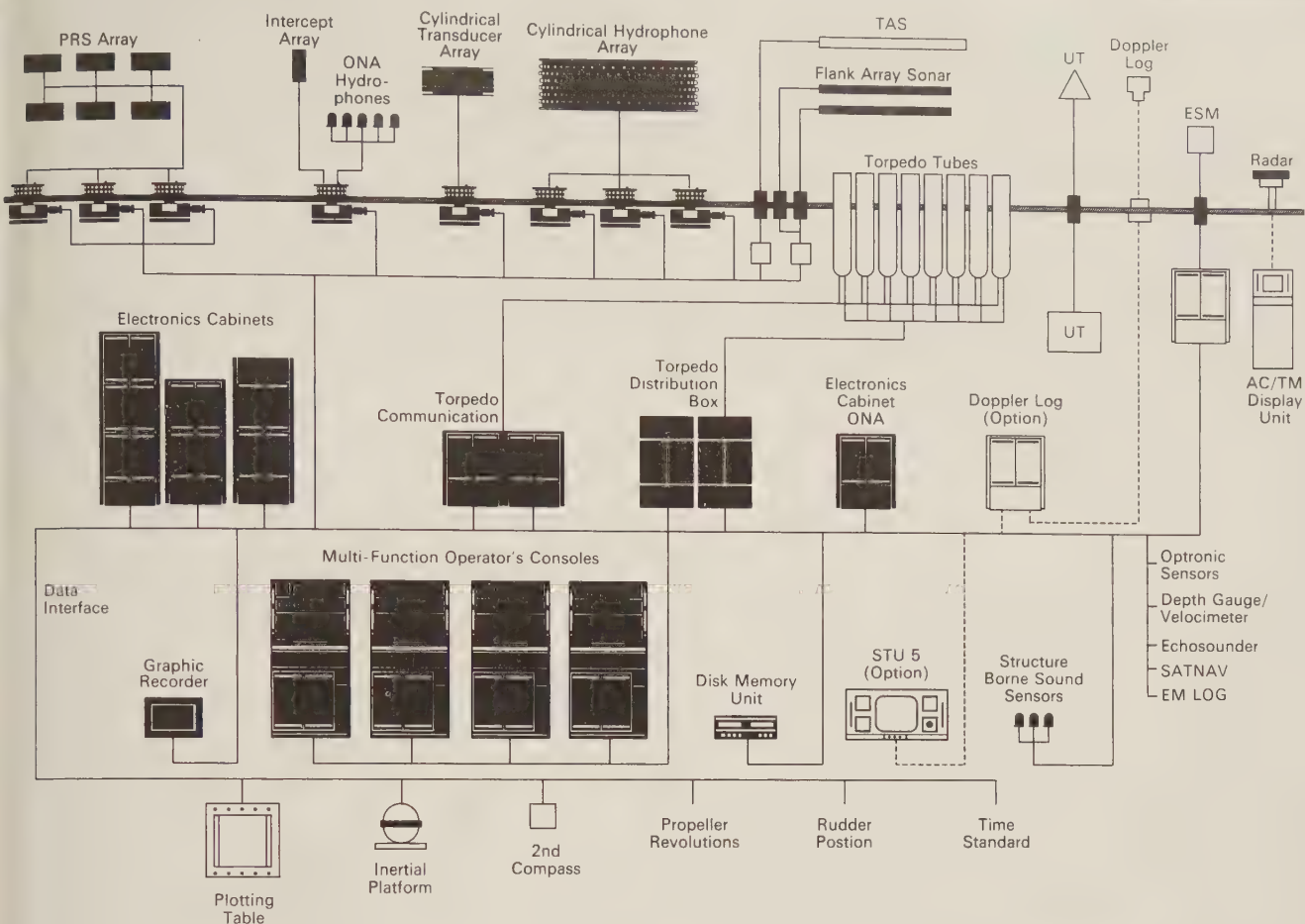
(either 20 or 48 m long, depending on the length of the submarine) is mounted on each side; a 30-m array is typical. Each contains 90 staves, for a total of 288 hydrophones. Typical accuracy is 1 deg for targets in the 90-deg sector centered on dead amidships, with lesser accuracy for bearings closer to the centerline, down to within 10 deg of dead ahead or astern. FAS 3-1 is part of the current Krupp-Atlas sonar suite, CSU-83.

◆ ISUS

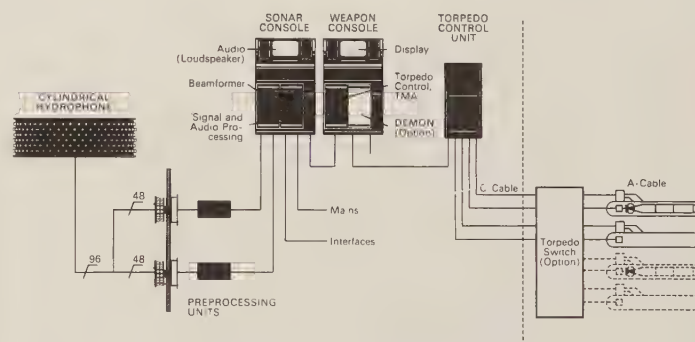
This is the display and combat system associated with the CSU-83 suite. ISUS consists of a number of Multifunction Capability Common Consoles (MFCCs) linked by databus to transfer all digital, video, and audio signals within the CSU-83 system. The associated sensors are the attack, towed-array, flank-array, passive-ranging, intercept, and passive/active operating sonars and periscopes, ESM, radar, and navigational sensors. The color-coded raster-scan displays are interchangeable between the MFCCs. Design objectives include automatic interactive detection, tracking and analysis of all acoustic signals, automatic classification and contact-motion analysis, threat and combatability analysis, and optimized control and guidance of several types of weapons. All the important processors have battery-buffered memory to guard against temporary loss of power. The system provides panoramic passive detection (PPD) of targets, measurement of bearing and level of target noise over the whole horizon, complemented by ATT information fed to the WCS. A hard copy of the ATT data is provided in the form of a time-bearing plot. The associated sonar-intercept system measures bearing, amplitude, frequency, pulse spectra, modulation type, pulse length, and PRF.

Reportedly, the multifunction consoles are the same as the standard German type now being used in the Type 123 frigate and in the CoSYS 200 CDS (see the Surveillance and Control section).

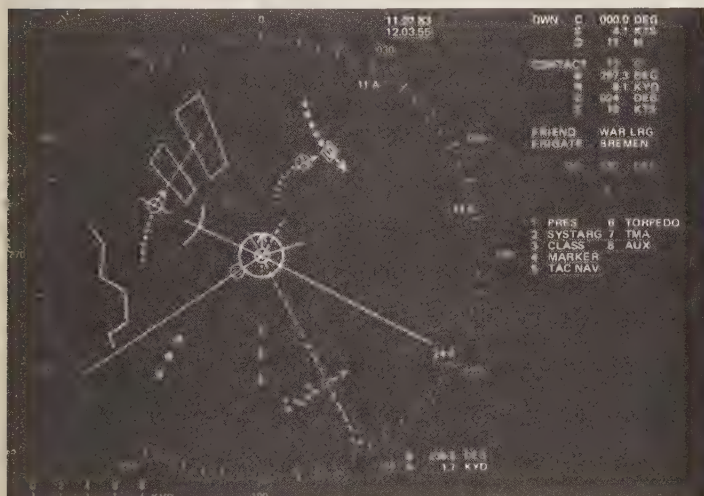
The basic version, suitable for a small submarine (less than



ISUS, showing the multifunction consoles (bottom). (KAE)



OSID configuration. (KAE)



The ISUS tactical display (synthetic-video PPI) shows target tracks (including ping histories). The small circle to the left is the contact being tracked (its parameters—bearing, range, course, speed—appear on the right). (KAE)

500 tons), supports an attack sonar, intercept sonar, ESM, and radar with 2–3 MCCs. The next step up, adding passive ranging (500–1000 tons), adds another MFCC. Adding an active sonar and a flank array (1000–1800 tons) adds another MFCC (total 4–5). A larger submarine (above 1800 tons) would support a towed array, requiring an additional MFCC.

◆ OSID

OSID is the CDS associated with the PSU 83 compact sonar. It has 2 consoles, 1 for sonar and 1 for torpedo control. Functions are north-stabilized multibeam processing, ATT, and bearing/



OSID threat-evaluation display, showing a calculated torpedo-intercept path. (KAE)

time recording for up to 120 min. The weapons-control Tactical Data-Handling (TDH) function provides target motion and threat and attack analysis. The torpedo-control functions are torpedo preparation, launching, and guidance. In effect, OSID replaces the existing Type 209 systems with new preprocessors and new consoles (including beam-formers).

◆ PRS (Passive-Ranging Sonar)

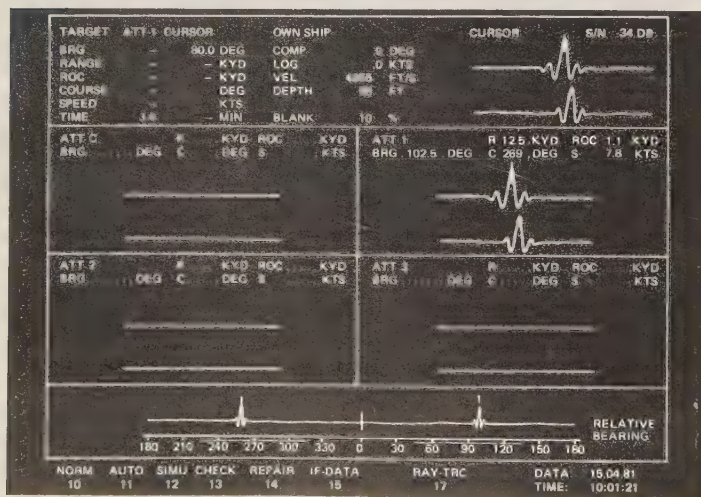
PRS is a passive complement to CSU 3-4 active/passive sonar. There are 2 types of PRS 3, each with 6 sets (3 each side) of hydrophones. Each PRS 3-15 array has 60 hydrophones in 15 staves; each PRS 3-4 array has 40 smaller hydrophones. Tracking can be either manual or automatic, following 4 targets simultaneously in manual mode. For automatic tracking, the system uses the ATT channels of the CSU 3-4. Targets can be tracked over a 170-deg arc on either beam (45–135 and 225–315 deg relative to the bow). Targets are tracked at 2–8 kHz. The combination of large arrays and a wide frequency range makes for an accuracy of about 0.5 deg over the highest performance arcs (45–135 and 225–315 deg) of PRS 3-15.

PRS 3-15 can track up to 4 targets automatically, measuring their ranges and calculating course and speed. Range is determined from the curvature of the wavefronts coming from a target, as in the U.S. PUFFS system. KAE claims that interference effects and other disturbances common in narrow-band systems are suppressed by using wide-band preformed beams. The processor calculates correlation functions between the amidships and end arrays and uses these functions to calculate time delays and then ranges. The variance of the time delay is used to estimate a range of confidence for the range estimate.

Smaller submarines can be fitted with a less elaborate passive ranging, with as few as 5 staves per array.



The overlapping preformed beams of PRS 3-15. (KAE)



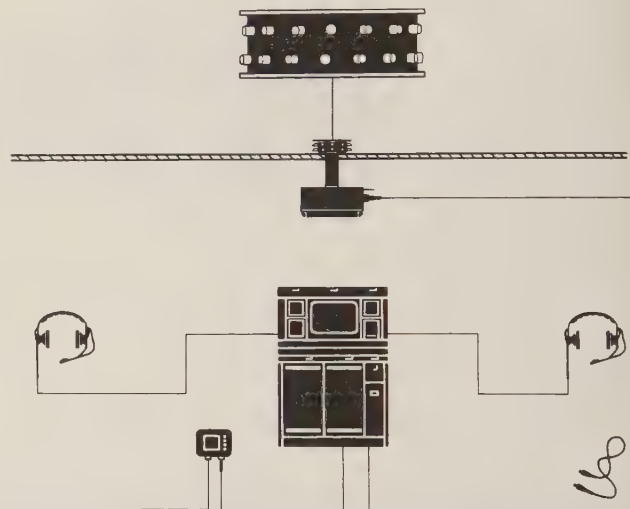
A typical PRS 3-15 ranging display. (KAE)

A PRS sonar can be used as an independent sensor (for detection, automatic tracking, ranging, and course and speed evaluation), or the sonar can be controlled automatically by the main sensor's automatic tracking channels, to measure range and evaluate a target's course and speed.

This system, roughly contemporary with CSU-4, was developed in 1961–65 and tested in 1965–66.

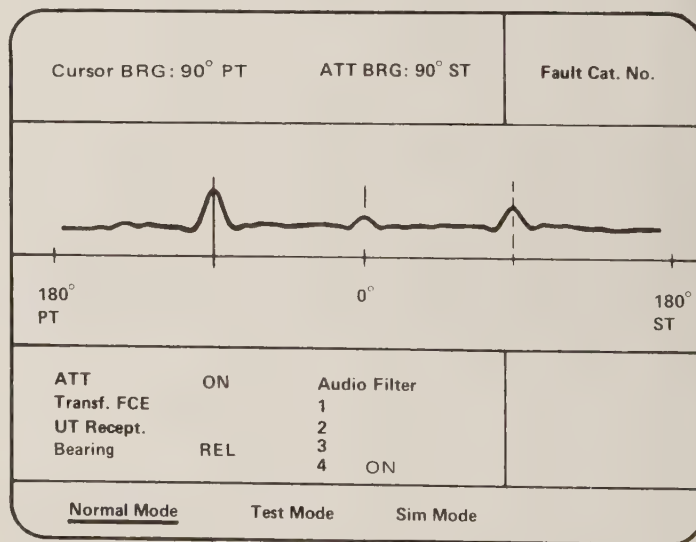
◆ PSU 1-2

This sonar for small submarines was developed for passive detection and reception of underwater telephone signals. PSU 1-2 uses a cylindrical transducer with 64 preformed beams, presenting information on a CRT in true or relative bearing. PSU 1-2 can autotrack 4 targets and is intended for a 400–500-ton submarine. Two targets can be transferred to the FCS and 1 target to the plotting table. Selected parameters are displayed on the associated digital indicator (TPD 3). The operator classifies the target by listening on the audio channel, the reception direction of which is coupled to the bearing cursor.



System set-up

PSU 1-2, the simplest system in the KAE series. (KAE)

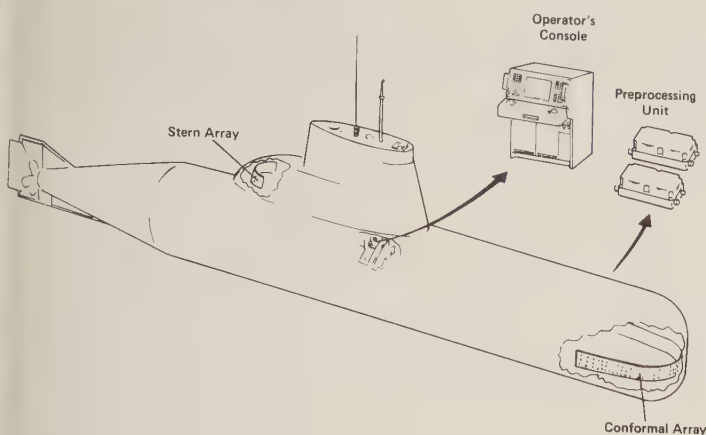


CRT display

A typical PSU 1-2 passive display, showing 3 targets.

◆ PSU-83

This sonar suite is for smaller submarines (500 tons and below) and to update existing units, working with the OSID tactical system. PSU-83 employs a conformal bow (chin) array and a semicylindrical aft-looking array (e.g., in the base of the sail), with a single display console. KAE offers a new programmable



PSU 83. (KAE)

and north-stabilized beam-former suitable to a variety of other existing arrays, so that the electronics of PSU-83 can be used for submarine modernization.

PSU-83 supports 8 independent simultaneous 2-mode ATT channels. It includes a sound-ray tracer and sound-distribution display. Target bearings are constantly predicted for emergency snap-shots, and bearing rate is measured on the electronic waterfall (bearing-time) display. The signal processor filters out intercepted sonar pulses and own-noise and also has separate selectable filters. The display is a color raster-scan CRT. There is a high-quality audio channel for classification.

Options: intercept sonar; flank array (using LOFAR processing); DEMON detection, tracking, and analysis; active pinger; passive ranger (PRS); own-noise analysis (ONA); mass storage for target data and display recording; sonar graphic recorder (bearing-time and frequency-time waterfalls); and on-board sonar trainer.

PSU-83 and the FCS FSU 83 form the submarine combat system OSID 83.

◆ SIP 3

SIP 3 is the current KAE sonar processor, for use with the fast-scanning multitarget-tracking sonars of CSU series. It is primarily for target classification, based on low-frequency detection and analysis. DEMON is used to extract low-frequency spectral information from relatively high frequency target noise. SIP 3 incorporates sound-ray path analysis. It can process up to 4 targets simultaneously, presenting them 1 by 1 on the screen. Evaluation modes: spectral analysis in various bands; automatic line tracking (ALT); automatic maneuver detection (AMD); high resolution of target bearing; ATT of targets set by the sonar, including situations when targets cross; range, bearing, and doppler measurement in the active mode. Data can be digitally recorded for later comparison with a data base.

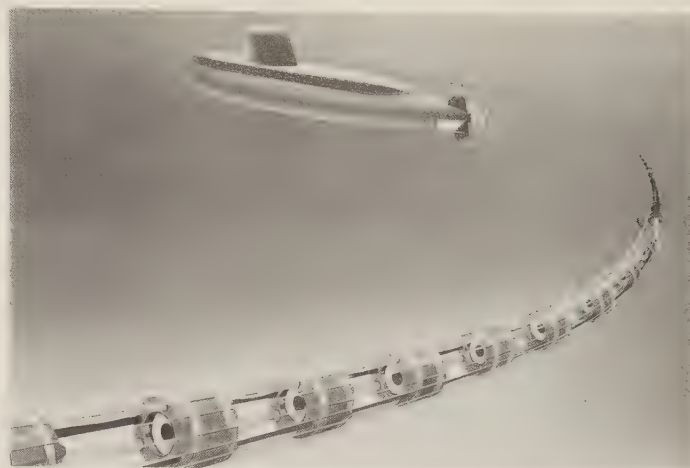
◆ TAS 83

This KAE submarine towed array is compatible with the CSU 83 system. Presumably, it is related to the array that the new Type 212 submarine will tow. There are 2 alternative clip-on wet ends, and the inboard electronics can be varied. As of 1990, TAS 83 had already been tested at sea.

◆ TASS 3-2

Krupp-Atlas is developing a towed array for German surface combatants; it will become operational, on board Type 122 and Type 123 frigates, in 1997. In theory, this array should differ from those developed for other navies since the German navy optimizes its ships for the relatively shallow waters of the Baltic and the North Sea.

As of 1990, TASS 3-2 already exists at least in a test version. The system consists of the sonar proper, TAS 3-2, and the handling system, TAMS 3-2.



TAS 83. (KAE)

FIRE-CONTROL SYSTEMS

◆ Hagenuk's Torpedo FCS

Hagenuk's torpedo FCS was developed for the first postwar German torpedo boats, Types 140 (*Jaguar* class), 141, and 142 (*Zobel* class), some of which survive in Greece, Saudi Arabia, and Turkey. The Hagenuk system controlled unguided forward-fired Mk 8** (British-supplied) torpedoes. It used an optical target designator (*Zielsaule*); the target angle and torpedo spread angle were cranked in centrally and corrected separately for each tube (typically, the forward tubes were splayed 9.5 deg from the boat's centerline, and the after tubes 15 deg from centerline). Torpedoes could be fired in salvo, either all 4 at a time or 2 (fore or aft groups) at a time. It is not clear whether target data were entered automatically from the ship's plot (CIC), which accepted radar and own-ship data. The maximum torpedo gyro angle was 30 deg. The personnel required were 2 at the target designator, 2 at the tubes (presumably, the system was follow-the-pointer rather than fully automatic), 1 at the plot, and 1 at the radar.

Although the German-built boats are sometimes credited with wire-guided torpedoes (such as SEAL), they carry forward-firing tubes that probably cannot fire such weapons; they probably still rely on the Hagenuk (rather than the more complex Signaal M11) FCS. Type 140/141 was also built for Indonesia (they are now extinct), and Type 142 (TNC 45) for Turkey (under a NATO contract, as the *Kartal* class) and for Saudi Arabia. German Type 141s were transferred to Turkey in 1975–76 and to Greece in 1976–77. Some German Type 142s (now extinct) were rebuilt with Signaal FCSs and with aft-firing tubes for German-type wire-guided torpedoes.

INDIA

◆ APSOH

Bharat Electronics's Advanced Panoramic Sonar was first installed on the Indian frigate *Himgiri*, presumably in place of a Canadian Westinghouse SQS-505. APSOH also now equips the second and third *Godavari*-class frigates. APSOH has been described as an ODT scanning sonar, developed by the Naval Physical and Oceanography Laboratory (NPOL) at Cochin. Presumably, it is comparable to (or similar to) SQS-505.

ITALY

SONARS

◆ IP-64

This integrated active/passive sonar suite of the *Enrico Toti* class incorporates a JP-64 active sonar. IP-64 is an analog system; about 1982 the Italian navy drafted a staff requirement for a digital upgrade, retaining the same array but replacing the

existing operator console with 1 based on that of the NA-18 AAW FCS.

The system consists of a conformal passive array on the chin and an active circular array on deck. A passive range-finder (MD-64, consisting of 3 hydrophones on each side) can be added. Operation of all 3 units is analogous to the IPD 70 system, the submarine using her conformal array and her passive ranger to get into attack position and then obtaining a final range by single ping. As in the MD-70 system, MD-64 can lock onto a signal to produce continuous bearing data.

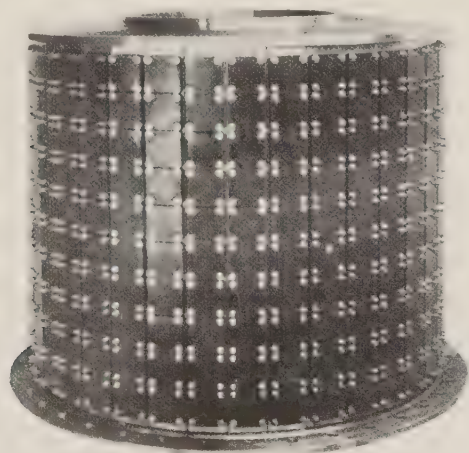
◆ IPD 70/S and SISU

IPD 70 is the integrated active/passive sonar of the *Sauro* class, using much IP 64 technology and, therefore, largely analog. IPD 70/S is a digital version for later ships of this type, the existing 2-operator console being replaced by a console based on that of the NA-18 AAW FCS.

There are 3 arrays: a conformal array of 46 barium titanate hydrophones wrapped around the lower part of the bow, for long-range detection and classification (220 Hz–7 kHz); a 36-stave cylindrical HF array in the upper part of the bow for target tracking (8–15 kHz); and (optionally) a pair of line hydrophones down the hull for passive ranging (designated MD100/S when used alone). The HF array can track 4 targets simultaneously; the passive linear arrays can range up to 3 noisy targets. Targets are tracked passively, and accurate ranges are then obtained by single narrow-beam (10-deg) HF pings (peak power 10 kW, source level 130 dB). The same array can be used for active search (ODT or RDT) if required. There are 2 sonar interceptors: 1 using the main passive array (3–15 kHz), and the other a Velox M5 (see the French entry above for details) operating in the 2.5–80-kHz range, primarily to detect active-homing torpedoes approaching from abaft.

These sonars are made by USEA/Selenia. In export form they are designated SISU-1; SISU-2 is a modified version for small (600-ton) submarines. The SISU-1 designation has also been used for the FCS of the *Sauro* class (see SEPA, below).

The IPD 70/S can be integrated with the IN100A omnidirectional and directional LF intercept sonar, ISO100 omnidirectional HF intercept sonar, TS100 underwater telephone, and CM10 acoustic range predictor.



IPD 70/S transducer. (USEA)

◆ MD 100/S

MD 100/S is an update of Selenia-Elsag's M100 passive range-finder for small to medium diesel-electric submarines. MD 100/S can operate separately or as part of IPD 70/S. MD 100/S employs 2 linear arrays, each consisting of 3 equally spaced transducers on the port and starboard sides of the hull, and can track 4 targets simultaneously within 60 deg of amidships (to either side). This sonar triangulates to obtain range and bearing on each target, using at least 2 transducers on either side, then

uses TMA for the target's course and speed (either using own data or data from another sonar). The modification program parallels that of IPD 70/S. Trials were conducted in 1981–83, and this system is installed in Improved *Sauro*-class submarines laid down from 1983 on. MD 100/S is being retrofitted in earlier Italian *Sauro*-class submarines.

◆ New Sonar Suite

ELSAG and USEA are developing a new submarine-sonar suite, including a towed array, for the next-generation Italian navy submarine (S-90). The towed array will be developed with foreign assistance (this program is already in progress). The hull sonars will operate at lower frequencies, all the acoustic sensors using a common redundant processor. The single processor will automatically correlate signals from the various arrays, and it is to incorporate AI for automatic target classification. The new suite will be integrated with the SICS (Submarine Integrated Combat System) being developed by Welse, using standard MAGICS displays.

FIRE-CONTROL SYSTEMS

◆ DLB-1

DLB-1 is San Giorgio-Elsag's analog AWS FCS, used to control the K-113 (Menon) depth-charge mortar and lightweight ASW torpedoes. DLB-1 accepts scanning sonar data and generates a solution, which is transmitted to the sonar for rate-aided tracking (as a check on the solution). DLB-1 also stabilizes the sonar. The system provides an ASW tactical display on the bridge, and it incorporates a Fire Pattern Programmer that can vary the pattern of shots by the mortar. Design studies began in 1964, and DLB-1 was first fitted on board the corvette *de Cristofaro* in 1965; 12 were made. The mortar considerably preceded the appearance of the DLB-1 system; it was presumably retrofitted on board *Centauro*- and *Bergamini*-class frigates.

◆ BSN-716 (SACTIS)

SACTIS is the standard current Italian navy integrated submarine combat system, using a single central computer (in this case a Rolm MSE 14 with disk memory). The associated sensors are the IPD-70 sonar, Thetis ESM, and BPS-704 radar. Made by SMA, SACTIS incorporates the Elettronica ELT/810 sonar-performance predictor. There are 2 display groups (each with 3 screens). Each display is a 9 × 16-in CRT, and up to 30 targets can be displayed simultaneously. Individual track histories can be selected for presentation, with 10 available as filtered targets. There are 4 presentations: the general unfiltered situation; a tactical picture; a time-bearing display; and TMA. Sonar-ray paths can be displayed, and own and target's sonar performance calculated. SACTIS can also accept both manually entered and Link 11 data.

The *Sauro* class FCS can track 4 targets simultaneously.

SMA was selected in 1981 to develop BSN-716(V)1 and -716(V)2 for the second and third batches of *Sauro*-class submarines. These systems are offered for export as SACTIS (Submarine Action Information System) 1 and 2. SACTIS 1 has 2 consoles and a computer (a Rolm MSE 14). SACTIS 2 adds a third console and has more computer power for real-time TMA calculations.

◆ SEPA FCS Mk 3

SEPA is *Societa di Elettronica per l'Automazione*, part of the FIAT group. This and other SEPA systems are based on standard ULP series mini- and microprocessors. FCS Mk 3 is the torpedo and weapons control subsystem of the larger SICS system described below. It functions as a command/control system, predicting acoustic sensor performance so that it can interpret sonar data for TMA; it also predicts counter-detection range and conducts threat evaluation and target designation. The fire-control portion of the system guides up to 6 A184 torpedoes.

Each of 3 consoles contains a circular main CRT, with 2 rectangular screens alongside (1 can be a touch-screen for com-

puter-defined action keys). These consoles are also used in the SICS system. The computers are militarized ULP microprocessors, built by SEPA.

SEPA Mk 2 is a corresponding surface ship ASW FCS.

Peru ordered SEPA Mk 3 (and A184 torpedoes) for its Type 209 submarines in June 1986, to replace the earlier M8 and SINBADs systems. A modified version, FCS Mk 3, is used as a backup to the BSN-716 system of *Salvatore Pelosi* (modified *Sauro*)-class submarines.

FCS Mk 1 is the system in the *Sauro* class, with a 2- (rather than 3-) CRT console (computation, display, and control station, or CCRG) built around a ULP 12/M minicomputer. Unlike Mk 3, Mk 1 has no small rectangular auxiliary screens (it uses arrays of single-purpose buttons). This system can handle 4 targets simultaneously; presumably, each circular CRT can handle 2 targets.

FCS Mk 2 is the corresponding surface-ship ASW FCS for A184 torpedoes on board *Audace*-class destroyers and *Maestrale*-class frigates.

◆ SICS

SICS (Submarine Integrated Combat System) is being developed by a consortium of Eltag, Whitehead, and SEPA (the Welse consortium). Like SEPA Mk 3, SICS uses several interchangeable consoles, which incorporate the system's computers.

SICS differs from SEPA FCS Mk 3 in processing sonar data directly; in the simpler system, sonar data are processed elsewhere. In addition, it provides command and common submarine services (such as navigation) that are not carried out by the FCS. A typical SICS would use 5 standard consoles, each with a pair of rectangular CRTs, lying on a data bus.

JAPAN

Japanese submarines are equipped with license-built U.S. SQS-36J active sonars. Some surface ships have SQS-35J VDS.

Development of a new tactical towed array, OQR-1, with performance to be superior to that of the U.S. SQR-19, was announced in JFY86. R&D work on a high-speed low-noise towed array began under the JFY87/88 program. There is also a surveillance towed-array project. A submarine-towed array, included in the ZQQ-5B system, was tested on board the submarine *Okishio* in 1987. In addition, work is proceeding on an

improved LF active sonar, using a new transducer and improved anechoic baffling.

Work is proceeding on a new long-range active sonar and on passive and active towed arrays, as well as on submarine-combat-system automation, including applications of artificial intelligence. The contractors are Mitsubishi and Kawasaki.

◆ HQS-101

The dipping sonar for the PS-1 maritime-patrol aircraft operates at 5 kHz. PS-1 is unusual in that it lands to dip its sonar before attacking; other patrol aircraft merely drop sonobuoy fields. The -101C version solves the problem of noise interference (from the airplane's engines) by noise cancellation.

◆ HQS-102

This is the dipping sonar of Japanese Sea King helicopters, comparable to the U.S. AQS-13. It may actually be a license-built AQS-13 (many writers claim that the Japanese Sea Kings are equipped with the latter, and that was certainly the case with early ones).

◆ OQS Series

The OQS Series are hull sonars for surface ships:

OQS-1/2/12/14 are license-built versions of the U.S. SQS-4/29; OQS-12 and -14 are developed versions, in the *Isuzu* class. OQS-12 is a modified SQS-31. Like some U.S. versions of SQS-4, OQS-12 or -14 can support a VDS operating from the same sonar stack, using an OQA-1 hoist and fish equivalent to the U.S. SQA-10 (*Isuzu* class). The current VDS is SQS-35J. In *Shirane*, the VDS is used to tow an array.

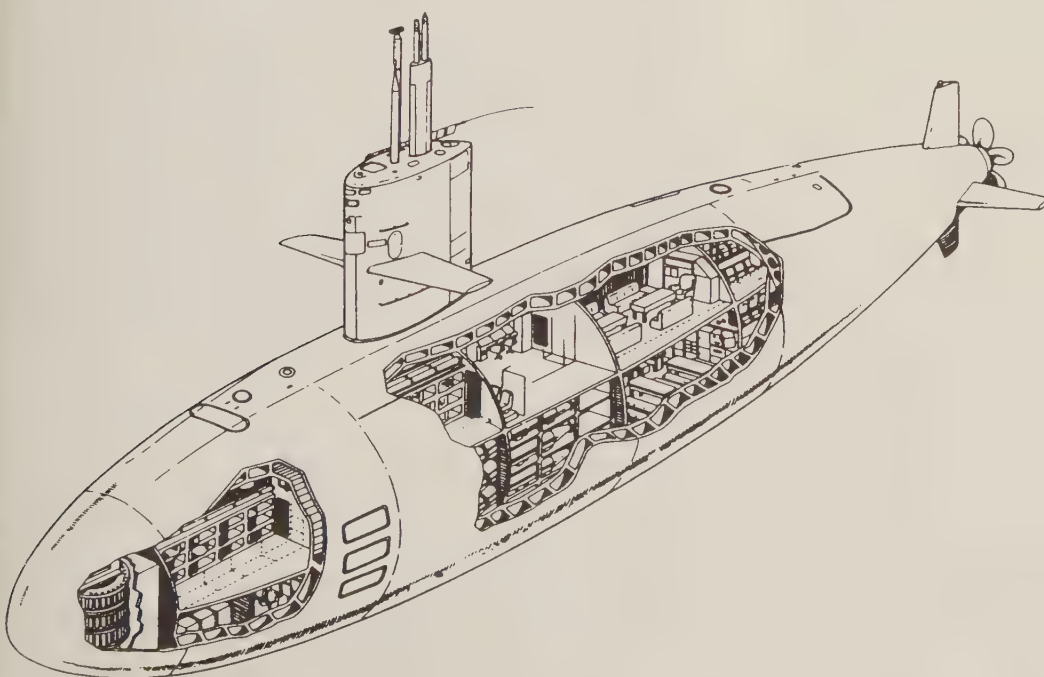
OQS-3 is a license-built SQS-23 bow sonar. It is being replaced by OQS-4.

OQS-4 is an indigenous LF design, in the *Asagiri*-, *Hatakaze*-, and *Hatsuyuki*-class destroyers, and the *Yubari*- and *Ishikari*-class frigates. OQS-4 is probably similar to SQS-23. Compared to OQS-3, OQS-4 has improved electronic components and better signal processing.

OQS-101 is an indigenous-design hull sonar, equivalent to U.S. SQS-53. OQS-101 is the hull sonar of the *Shirane* class and will be used in the Japanese Aegis destroyers.

OQS-X is a new hull sonar for the new Aegis destroyer, now under construction.

An *Uzushio*-class submarine shows the characteristic cylindrical transducer of recent Japanese submarine sonar systems. (*Ships of the World*)



◆ Submarine Sonar and Combat Systems

From the sixth submarine in the *Uzushio* class (*Takashio*) onward, the separate TDC was eliminated in favor of a system in which detected target data are processed digitally and shown on a CRT. In the *Yushio* class, the computer/display system, ZYQ-1, is greatly enlarged. For the first time in a Japanese submarine, it automatically links detection and weapons systems. It also handles submarine operations data. The system is also described as the SCDS, or submarine computer data system. Installation of ZYQ-1 required an additional 350 tons of submarine displacement (from the 1850 tons of the previous class to 2200 tons). From the *Nadashio* on, Harpoon fire control is added to the computer system. The new *Harushio* class will have a new version of the basic system, presumably ZYQ-2. Growth to 2400 tons accommodates decoys and a towed array.

ZYQ-1 in the *Uzushio* introduced a new Japanese-produced sonar array, a 10-ft diameter DIMUS cylinder consisting of 3 tiers of staves, in the bow of the submarine. The system is used for search and for precision (presumably passive) ranging and as a sonar intercept receiver. The *Uzushio* has been broken up, and the other unit with this sonar, *Makishio*, is a target services training ship. ZYQ-1 and its successors are manufactured by Oki Electric.

ZYQ-2, a modified ZYQ-1, was introduced in the *Isoshio*, the third unit of the class. Three submarines of this type are in service, 1 (*Isoshio*) as a training ship.

ZYQ-3 was introduced in the *Takashio*. She and later submarines have an MF active sonar, SQS-36(J), midway up their sails, to supplement the bow sonar.

ZYQ-4 was introduced in the *Yushio* class. In 1987 the *Okishio* of this class was the first Japanese submarine with a clip-on towed array, a purchased U.S. BQR-15. It will also be fitted on 3 other *Yushio*-class submarines. In these submarines the active sonar is closer to the base of the sail, below the sail planes. Like the earlier sonar systems in this series, ZYQ-4 employs a cylindrical bow array.

ZYQ-5 is for the new *Harushio* (2400-ton) class; it will be a new type of system, combining a bow array with a flank array and a Japanese-produced retractable (rather than clip-on) towed array. From the second unit on, the system will be the modified ZYQ-5B. This class will also be fitted with a torpedo decoy system.

NETHERLANDS

In 1990 the Signaal sonar division was amalgamated with that of Thomson Sintra; the Signaal surface-ship sonars are no longer offered for sale as such.

SONARS

As of 1989, Signaal was working on an advanced Type 209 sonar update, as well as on new sonar configurations for 2 NATO navies.

◆ CWE-10N

This 10.5- or 11-kHz searchlight surveillance radar is installed on board the German and Turkish *Koln*-class frigates and on board the ex-Dutch cruisers and destroyers in Peruvian service; CWE-10N may still be on board the Argentine carrier *25 de Mayo*. In German service, CWE-10 is associated with the Signaal M5/1 FCS. Pulse width 0–50 msec (also reported as up to 100 msec); instrumented ranges 1, 2, 3, 4, 6, 8, and 12 km; peak power 10 kW.

The manufacturer was van der Heem, part of the Philips group, which was later absorbed into Signaal. In destroyers and frigates, this sonar was associated with PAE (see below). Total installation weight was 3200 kg, compared to 3800–6000 kg for the contemporary ELAC 1BV series.

◆ LWS-20

Signaal's sonar-intercept device uses 4 arrays to cover the four 90-deg sectors, the whole device being diagonal to the centerline of the submarine. Each face carries 4 hydrophone groups, for the 4 bands in the 2–80-kHz range. The display consists of 2 CRTs, 1 for bearing and 1 for frequency, plus 15 LEDs to give signal strength (which provides a measure of range).

This device appeared in the early 1960s.

◆ LWS-30

The Signaal (HSA) passive sonar and sonar-intercept system for submarines was announced in 1973. LWS-30 could use existing transducers and hydrophone arrays. Capabilities included omnidirectional warning and multitarget autotracking, as well as torpedo warning.

Frequency ranges were: CRT display for 1.25–80 kHz (sonar intercept); torpedo warning for 20–80 kHz; direct audio for 1.25–10 kHz (synthetic audio produced for 10–80-kHz signals). All signals (1.25–80 kHz) are displayed on a CRT and are measured for analysis. The system was designed to track signals in 3 ranges: 1.25–2.5 kHz, 2.5–5 kHz, and 5–10 kHz.

Intercept ratio: between 1.25 and 10 kHz, 12.5:6 at 5-kt speed in sea-state 3; 9.5:5, when snorkeling. Between 10 and 80 kHz the respective ranges of intercept ratio are 5.5:3.5 and 5:3.

Detection range: 1.25–10 kHz at 5 kt in sea-state 3, 125–40 kyd, snorkeling, 100–35 kyd. At 10–80 kHz, 25–6 kyd at the lower end of the band and 20–6 kyd at the upper end. Signaal offered a 600-kg LF hydrophone array (height 800 mm, diameter adapted to ship dimensions) and a 40-kg HF array (200 mm × 280-mm diameter).

◆ PAE-1

Van der Heem's attack sonar (searchlight) is associated with CWE-10 (see above) and operates at 24 kHz.

Van der Heem's 24-kHz searchlight attack sonar is associated with (and shares a dome and mounting with) CWE-10 (see above). Range scales: 1, 2, 3, 4, 6, and 8 km. Pulse width: 0–50 msec (also reported as up to 200 msec). Power: 250 W. Frequency can be varied between 5 and 50 kHz.

This sonar was carried by the Swedish *Halland*- and *Ostergotland*-class destroyers (armed with Bofors ASW mortars), now extinct.

◆ PHS-32

PHS-32 is Signaal (HSA)'s search-and-attack sonar for ships of 200 tons or more. The transducer can be fixed or retractable. PHS-32 can automatically track 4 targets simultaneously (i.e., has 4 pairs of range gates, with automatic video extraction and special software that filters the resulting target positions into an accurate target track for fire control). During sea trials in 1978, in bad weather (sea-state 4, ship rolling up to 25 deg, and pitching up to 10 deg), a submarine was automatically tracked out to 14,000 yd.

The system uses an FFT processor to extract doppler information from echoes in each preformed beam. The B-scan display (bearing-range rather than PPI) is connected to a memory that stores doppler information. Signaal argued that the time-bearing waterfall made detection more likely than a conventional PPI, since the operator did not have to search ever-widening circles. In passive (LISTEN) mode, the sonar can display up to 4 targets in a 20-min time/bearing format. The associated SMR-Mu computer operates the sonar and is accessible via a light pen.

The transducer consists of 30 staves (10 spot transducers each), with 60 preformed beams (effective beamwidth 12 deg, with bearing accuracy of 1 deg; vertical beamwidth is either 12 or 20 deg, switchable during reception). Modes of operation are ODT, TRDT (tribeam), LP (long pulse option), MCC (beam widened in the vertical to maintain close contact), and LISTEN (passive). This system can automatically track up to 4 targets simultaneously. Frequency is 9.3 or 10.5 or 11.7 kHz, with 600-

Hz bandwidth. Pulse lengths are 12.5, 25, 50, 100, and 400 (optional long pulse or FM mode only) msec. Range scales are 1, 2, 4, 8, and 16 kyd; and range accuracy is 0.5–2% of full-scale range (range gate is 1/16 of the range scale). The system can maintain a time/bearing history for 20 min. The transducer's diameter is 730 mm, and total weight of the fixed hull outfit is about 7000 kg. The retractable hull outfit weighs about 2500 kg and can be lowered or retracted at up to 24 kt.

The display includes a ray-path predictor, using a sound-velocity profile from an on-line XBT. PHS-32 incorporates built-in test equipment.

PHS-32 was a private-venture development. It was reportedly the first operational sonar to use advanced digital signal processing (FFT and pulse compression). Design work began in 1974, and hardware contracts were awarded from 1975 on. The first unit was tested in 1977–78.

PHS-32 users: Korea (*Ulsan* class and some *Donghae* class, a total of 25 sets), Indonesia (training frigate *Hajar Dewantara*, *Fatahilah*-class frigates, and the PB 57-class patrol craft *Andau* and *Singla*), and Nigeria (MEKO 360-type frigate *Aradu*).

◆ PHS-36

This LF bow sonar is a derivative of the PHS series and also of the Canadian Westinghouse SQS-509. PHS-36 operates at 5.5, 6.5, and 7.5 kHz (5-kW pulses, 15-deg beam) and in 4 active

modes plus a passive mode. In the new M-class frigates, the sonar transducer is derived from that of the French DUBV 25, with PHS-36 electronics.

PHS-36 began with a Dutch navy requirement issued in the late 1970s. It was a joint venture with the Royal Netherlands Navy and the Dutch National Defence Organization (TNO). Detection, track initiation, and tracking are automatic.

PHS-36 was first tested in 1979–81 and was first installed on board the frigate *Jacob van Heemskerck*. Nine (with the French wet end) were ordered in 1987 for M-class frigates.

◆ SIASS

Signaal's Submarine Integrated Attack-and-Surveillance Sonar System was first fitted to the Taiwanese *Hai Lung* class (the Dutch *Walrus* class uses a Thomson-CSF suite). SIASS-1 has its own consoles and can interface with other systems; SIASS-2 is integral with SEWACO (see tactical-data systems in the Surveillance and Control section). SIASS consists of a cylindrical bow array (96 staves, each with 4 transducers), a 4-element HF acoustic-intercept array, a set of flank ranging arrays, and a cylindrical active transmitting array. Three square passive-ranging arrays (25 hydrophones each, arranged 5×5) are fitted on each flank of the submarine; they provide a total of 64 preformed receiving beams, counting both sides of the submarine. The bow array, with 96 preformed receiving beams, is used for narrow-band and broad-band listening, for LF acoustic intercept, and as the receiver for active operation.

A full flank array, for low-frequency coverage, is available as an option.

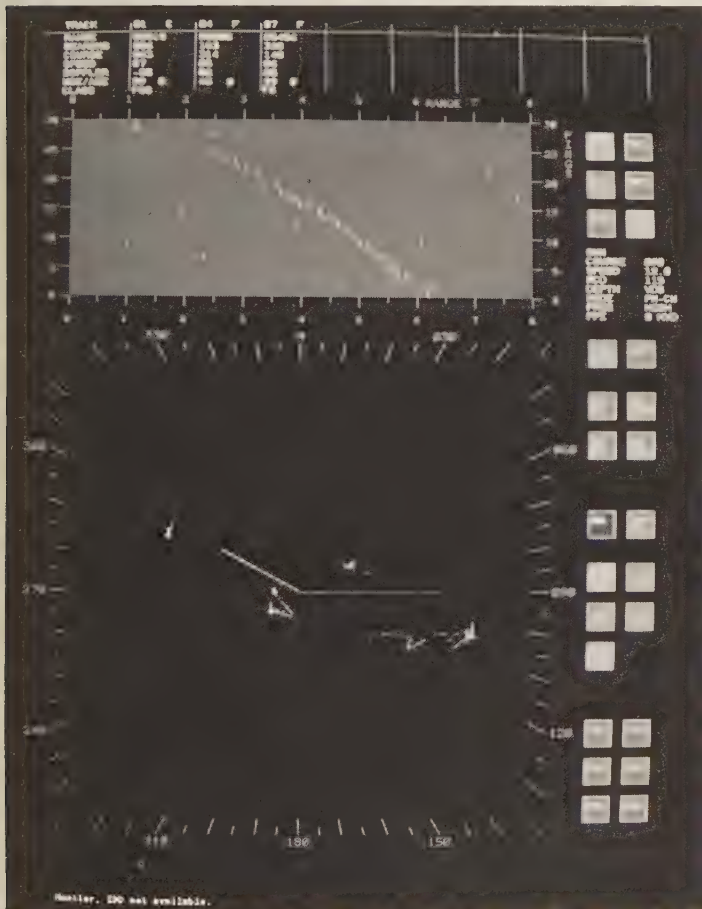
The system can store up to 35 tracks, carrying out contact-motion analysis (TMA) on up to 20 of them. The broad-band systems of the cylindrical and flank arrays each provide 4 such channels, on 8 preselected frequencies; there are 16 more for HF and LF acoustic intercept sonars, and 4 more for the active sonar. In at least some cases, tracking is based on the automatic association of inputs from different sensors operating in different frequency ranges. Each sonar has an electronic classification library of up to 300 specific platforms (100 ship classes, 100 sonar types).

The output of each of the 160 receiving channels (beams) is subject to complex FFT analysis for LOFAR, the computer holding 15 min of history on each (total capacity 2 Mbytes). This history can be displayed either as broad-band (time vs. bearing, i.e., waterfall) or narrow-band (frequency vs. bearing, or frequency vs. time for 1 beam, or amplitude vs. frequency integrated over time). Signaal claims that the ability to call up LOFARgrams at will (using the 15-min memory), rather than waiting for them to build up over time, allows their use for target detection rather than merely for target classification or monitoring. There are also enhanced classification channels, Zoom-LOFAR (high-resolution vernier analysis) and DEMON (demodulated noise, enabling the sonars to measure frequencies below 100 Hz by demodulating higher-frequency noise, such as flow noise or cavitation, to get at fundamental frequencies). DEMON allows measurement of blade and shaft rates.

The cylindrical and flank arrays can also be used for multi-target tracking, and different targets can be tracked in narrow- and broad-band at the same time, the broad-band track being by noise over a selected frequency interval, the narrow-band by specific frequency line (for automatic tracking of a crossing target). Active modes are single-ping (directional) and single- or multiple-ping ODT, and the active sonar can automatically track multiple targets.

Normally the passive-ranging sonar is slaved to the main cylindrical array in the bow, so range can be calculated automatically once a broad-band contact enters the ranging sector. The method is measurement of wavefront curvature by frequency-domain correlation, and bandwidth is varied to reject specific noise sources.

The HF intercept sonar operates up to 100 kHz, and uses an FFT processor to detect, classify, and correlate contacts. The



A PHS-36 sonar CRT shows a PPI display (lower part), a range-correlation display (upper green part), a track table (top), and light pen-operated controls (right). The operator selects the closely related pictures needed for the specific task: e.g., sonar tracks and surface-search radar tracks can be combined on 1 display. The processor conducts FM and CW processing simultaneously to cope with both noise-limited and reverberation-limited conditions. The main sonar-processor functions are auto-detection, auto-track initiation, and auto-track processing. The operator does not form part of the detection chain. This CRT is part of a General Operator Station (GOS) console, which also has access to the ship's tactical data-handling system (the Sewaco VII CDS of an M-class frigate). (Signaal)

intercept sonar incorporates a threat library and can warn automatically of, e.g., torpedoes.

Work on the system began in the early 1980s, to provide a new system for export submarines. The first production models were completed in 1982/83, the first installation being on board the submarine *Walrus* in 1985. SIASS is also installed in the 2 submarines built in the Netherlands for Taiwan. The associated combat system is Spectrum.

UNDERWATER FIRE-CONTROL SYSTEMS

◆ M5

Signaal's surface-ship ASW FCS, designed to work with a searchlight attack sonar, was broadly analogous to the U.S. Mk 105. M5/1 was a 375-mm FCS for the *Koln* class, working with its M9 torpedo FCS. Initially, M9 used the M5 analog computer. However, by 1966 M5/1 had been modified to use the digital computer of the M9/6 system. Given sonar (range and bearing) and own-ship data, M9 (see below) calculated target course and velocity so that future target coordinates could be generated. The system also kept the searchlight sonar on the submarine target and held the last target range and bearing in the event that contact was lost. M5 also incorporated a ray-path analyzer to use BT data to estimate sonar beam bending. Target course and speed were displayed on a vertical CRT, and target depth was shown on a paper printer.

M5/4 (1961) was a developed digital version controlling both rockets and torpedoes on board *Hamburg*-class destroyers and *Thetis*-class corvettes; it was also used at the German navy's underwater-weapons school. This system ran 3 separate plots: an ASW plot, a surface-target plot, and a summary plot. All fed in turn into a pair of digital computers. The search sonar and search radar fed into both the ASW and the surface-target plots, but the attack sonar and the passive sonar fed into only the ASW plot. The ASW plot controlled depth-charge racks directly, but the torpedoes and ASW rockets (Bofors 375-mm) were controlled by computer (or, in the event of a casualty, directly from the ASW plot). M5/4 used a pair of standard Signaal 4-operator (SEWACO-type) horizontal consoles for its ASW and surface-target plots. The ASW console typically had 4 operators: the ASW officer, the unguided-torpedo/depth-charge operator, the guided-torpedo/rocket operator, and the display operator (across from the ASW officer). The ASW officer could enter data from any of the 3 sonars (attack, search, or passive) or from the ship's radar, could vary the range scale (6/12/24 km), could switch to synthetic video, and could throw out the computations of either of the 2 system computers or the ray estimates based on temperature. The ASW officer could also enter corrections to a running solution. The unguided-weapons operator could preset torpedoes (speed, stratum, horizontal search, lower depth limit, homing), choose tubes, and fire depth charges. Similarly, the guided-weapons operator could choose among torpedo and rocket tubes and among rocket salvos (single, 2-rocket, or 4-rocket) and could control wire-guided torpedoes (search speed, course, depth limits, switch to active homing, fuzing). The display operator controlled 2 cursors in range and bearing. The parallel surface-target display had 3 operators: a targeting (supervising) officer, a wire-guided-torpedo controller, and a display controller. In this case the targeting officer chose among inputs from the search sonar and the 2 main radars, deciding which to enter into computation and which computer solution to accept. The targeting officer could also use the GFCS (M2/2) to control a torpedo. The torpedo operator could choose between 2 types of torpedoes (Nixe or Seal), could choose among 2 tubes, and could control such torpedo functions as search speed, direction, and the shift to active search.

When the *Hamburgs* were rebuilt, M5/4 was modified to control their Exocet missiles. These ships also had an MV2-3 GFCS controlling their 100-mm guns (M2 plus a V3 radar height-finder).

The missing Signaal project numbers (M3, M6, and M7) all refer to abortive projects.

◆ M8 Series

Signaal's (HSA's) submarine-torpedo FCS equips most Type 209 submarines. The most common version, M8/24, can simultaneously track 3 targets, prepare fire-control solutions for 3 targets, and control 3 torpedoes. The maximum own-ship speed is 40 kt, and the maximum target speed is 60 kt. M8 can control straight-running, homing/programmed, or wire-guided torpedoes.

The initial version, M8/0 (1955), used an analog computer, but M8/1 (1960), designed for the German navy, introduced a special-purpose, solid-state, digital computer. Tactical data were displayed on a PPI instead of on dials; M8/1 was an early example of the integration of AIO and FCS. Because the computer was programmable, it could be used not only to calculate torpedo lead angles but also to process all sensor data to give target positions and vectors; it could simultaneously display sonar, radar, and periscope range and heading data. Programs were developed to compute positions (either active or passive), to evaluate periscope-bearing data (with estimates of range, heading, and course), and to evaluate passive bearings (TMA, based on a stereotyped own-ship maneuver).

All versions of M8 are centralized, a command and weapons-control console being fed by all the sensors (some of which have their own dedicated operator consoles). The addition of special-purpose computers has generally increased the capabilities of M8, and these computers have ultimately added an automated plotting capability for TMA (i.e., well beyond what was needed for torpedo FCS).

Range scales on the main PPI are 5/10/20 km or 5/10/20/40 kyd. The system incorporates a ray-path analyzer, and there are local controls and gyro-setting panels in the torpedo room. The PPI can show true motion, relative motion, or off-centered motion.

Versions:

M8/0: for the Dutch *Dolfijn* class, replaced by M8/17.

M8/1: for the German Type 205 class (1960, introduced the digital computer).

M8/7: for the *Zwaardvis* class.

M8/8: for the German Type 206 class.

M8/10: for the Norwegian *Kobben* class (Type 207), replaced by MSI-70U.

M8/12: for wire-guided-torpedo tests, for the German navy (MK 37-0, Seeschlange, Seal), 1964.

M8/17: for the *Potvis* class (replaced M8/0).

M8/18: for the German *Wilhelm Bauer*, a test submarine.

M8/19: for the Greek Type 209 submarines (the first Type 209s).

M8/24: for export Type 209 submarines. M8/24 may be in the Danish *Narhvalen* class. It was the last of the series; SINBADS is the successor.

M8/41: a new system with a general-purpose digital computer, renamed SINBADS (see below).

◆ M9 Series

The M9 designation applies to 2 quite different digital systems. M9 was originally a surface-ship torpedo FCS for the German *Koln* and *Thetis* classes, working with a searchlight sonar. Later, however, the same designation was applied to a stand-alone ASW FCS that worked with a scanning sonar (such as PHS 32), primarily to control the Bofors 375-mm ASW mortar.

The original M9/1 (1958) controlled fixed above-water tubes firing unguided torpedoes, using the associated M5/1 system to generate target location and course. Other data such as the observed position of a submarine's periscope, could also be used. The maximum computed target range was 3600 m. M9/3 was the digital version (1961) actually used on board the *Koln* and *Thetis* classes.

The later M9 uses a standard Signaal horizontal 3-operator console and separate computer/interface cabinet (containing an SMR-S computer) without PPI. It collects, correlates, processes, and stores target data, solving the ASW fire-control problem. In

this version M9 is primarily a mortar-control system, but it can also control Mk 32 torpedo tubes via a Mk 264 Mod 1 control panel. Reportedly, M9 is related to the M11 fast-attack-boat system, described below.

No installations have been announced, but likely ones are Indonesia (the frigate *Hajar Dewantara* and the *Fatahilah* class and possibly the 2 fast ASW attack craft), Malaysia (the FS 1500-class frigates), Nigeria (the *Aradu*), and Spain (the *Descubierta* class, also in Egypt and Morocco). The Indonesian *Hajar Dewantara* and the fast attack craft are unique in this group because they carry SUT dual-purpose wire-guided torpedoes, which are fired from tubes facing aft. Other ships carry Mk 32 tubes.

◆ M11

Signaal's surface-ship torpedo FCS is used to engage surface targets. It is in the Argentine *Intrepida*-class (TNC 45-type) boats and probably in the extinct German *Zobel* (modernized S142) class. These boats all have or had stabilized Signaal radars in "eggs." The data below refer to the simplified VM11/2 version, which was designed about 1966 to work with unstabilized sensors (optics, ESM, and radar), controlling Seal wire-guided torpedoes. VM11 is presumably the element of the Vega systems (such as that on board Greek *Combattante-II* and *-III* attack boats) that controls German-supplied wire-guided torpedoes (Vega PCET presets the torpedoes but is unlikely to control them after firing). VM11/2 uses a special-purpose digital computer to calculate target course and speed from a series of radar observations. The system can also operate on purely passive data (computing a collision-course attack). The maximum range is 30 kyd (the maximum firing range is 20 kyd); the minimum range is 300 yd, and the maximum torpedo course change is 14 deg/sec (the maximum boat course change is 8 deg/sec). The maximum target/own-ship speed is 50 kt. On the plotter, 1 mm = 600 m. The system can compensate for the rolling of the firing boat within 30 deg (at up to 25 deg/sec) and its pitching within 10 deg (at 15 deg/sec).

◆ SINBADS

Signaal's Submarine Integrated Battle and Data System can track automatically after a firm contact has been established, based either on continuous bearing data or on range and bearing supplied intermittently by an active sonar. There is also a semi-automatic mode allowing comparison of information from various sources; this mode is capable of detecting target maneuvers and of determining the target's new parameters after a maneuver. Target evaluation is based on a target-motion-analysis display.

Like other combat systems of its time (the 1960s), SINBADS is built around a central computer, in this case an SMR-S optimized to process track data by Kalman filtering. The single operator can call up any 1 of 3 displays: a track display for target evaluation; a PPI for weapons control; and an alphanumeric display showing selected data. Alternatively, raw data from any particular sensor can be called up. The console is the standard Signaal tactical and weapons-control console used in the WM20 series (M8 uses the M20-series console, with its smaller CRT). There is a separate passive-sonar console attached to the main console. The latter carries a 16-in CRT operating as either a PPI (for active sonar or radar) or a time-bearing (waterfall, for passive sonar or ESM) display. The main console also carries a 7-in rectangular graphics display showing bearings-only data, a 7-in rectangular display of alphanumerics, and an optional 15-in tote (alphanumeric) display on top. Options include a computer-controlled Contact Evaluation Plot. SINBADS handles digital and analog torpedoes (including wire-guided ones) for up to 8 tubes. The system must be connected to amplifiers to preset analog torpedoes.

Weapons-control functions are (i) weapon assignment/torpedo setting; (ii) prediction for aiming; (iii) firing preparation; (iv) torpedo wire-guidance/monitoring. Up to 3 torpedoes can be assigned simultaneously, and SINBADS can track up to 5 targets

simultaneously and engage 3 of them. Prediction includes continuous calculation of a torpedo's course (from assignment to end of run for guided torpedoes, or until firing for nonguided ones). The system automatically tests torpedoes before firing them.

Over 20 systems were exported between 1975 and 1985. Users are Argentina (TR 1700 class), Greece (later Type 209s), Indonesia (Type 209s), Peru (later Type 209s, now being replaced by SEPA Mk 3), and Turkey (later Type 209s). SINBADS may have replaced M8/24 on board the Ecuadorian Type 209s.

◆ GIPSY

GIPSY was designed specifically for the *Walrus* class. Unlike SINBADS, GIPSY provides a separate Signaal SMR-MU computer for each of 7 interchangeable consoles. In addition, there are 2 SMR-MU computers for system management (1 on standby), and 2 SMR-MU computers for sonar-data handling. A 16-in PPI presents sonar or radar video. Contacts can be displayed in time-bearing (waterfall) form, and their movements computed by TMA.

◆ SEWACO

SEWACO is a new-generation system for submarines down to 800 tons. First installed on board the Taiwanese (GOC) *Sea-dragon* class, SEWACO developed into Spectrum.

◆ Spectrum

This combat system, developed from SEWACO for the 2 Dutch-built Taiwanese submarines, integrates the full spectrum of combat system functions, including sensor operation. Spectrum is normally associated with the SIASS integrated sonar (see above). The system is digital and software-based and provides high-resolution spectral analysis in each preformed beam to improve the probability of detection and to assist in classification. Memory suffices to store the results of this analysis (LOFAR-grams) for later display.

Spectrum is built around a data bus feeding 3 or 4 multifunction consoles. Sensor data are preprocessed before being fed into the data bus, to reduce the load on the consoles. The active transducer and cylindrical receiving array feed into a common processor (with separate preprocessors for active and passive operation); the passive ranger and acoustic-intercept arrays share a common processor (with separate front-end preprocessors); and the nonacoustic sensors (ESM, radar, periscope, and navigational aids) share a common processor. Each console is a SIGHT general-purpose workstation with a 19-in color screen and a smaller alphanumeric display. Input is by keyboard and a rolling ball, and each console contains 2 SMR-MU general-purpose computers. Besides sonar functions, the system carries out analysis of periscope data, maintains a plot, associates multiple tracks to reject false alarms, assists in navigation, and simulates sensor inputs for training. Two identical weapon-electronics cabinets each contain interfaces to control half the torpedo tubes (normally 4 each).

Spectrum can maintain 35 simultaneous tracks, and it can control 4 missiles (such as Harpoon) and 4 wire-guided torpedoes simultaneously. The classification library holds up to 300 signatures.

Spectrum II is being developed, using the standard processing and display components of the new *Karel Doorman*-class frigates. The display units have 1376 × 1024-pixel color raster screens and employ 68020-series microprocessors. They are connected by Ethernet data buses (10 Mbytes/sec), and data are recorded on 2 digital optical disks with a capacity of up to 250 Mbits each.

NORWAY

SONARS

The only manufacturer is Simrad, which entered the military market after producing fish-finding and whaling sonars. The company announced details of 4 main types in 1975-76: SU,

ST, SQ-D, and SK3-D, the largest being the SU-RS searchlight. Later the company announced the SS series.

The current sonars, in descending size order, are SU, ST, SQ4, SB2, SK3, and SL. Details are given only for those sonars known to be in current service.

◆ SQ Series

The SQ series operates at 27 kHz (SQ-D operates at 24 kHz and uses a fixed streamlined dome). Standard instrumented range is 2500 m (peak power 4 kW, which can be increased to 8 kW), and the beam is 12×16 deg.

The Simrad SQ3-D/SF is in the Swedish *Hugin* class and the minelayer/training ship *Carlskrona* and in the Finnish navy. SQ3-D/SF operates at 24 kHz (4-kW peak power) and has 5 range scales (maximum 2500 m). It can search automatically, the array training through 360 deg in bearing and through 90 deg in elevation. The usual sonar speed of a *Hugin* is 22 kt.

SQ-D is similar, but the transducer is retractable in a fixed rather than a retractable dome. SQ3-D is on board Norwegian *Vidar*-class minelayers.

◆ Simrad SS105

This scanning sonar for the Norwegian coast guard (*Nordkapp* class) provides range and bearing data to the Kongsberg NAVKIS combat-control system. The transducer consists of 48 staves and has 48 preformed receiving beams (each 10 deg wide), using split-beam processing in each beam. Frequency is 14 kHz, and total output power is 15 kW. Transmission modes are ODT and tribeam, and the range scales are 2–16 km. LEDs are used to indicate the target's range and relative/true bearing and own-ship's speed, and there is an 11-in CRT (PPI). The dome can be fixed or retractable, and the sonar can be used at speeds of up to 25 kt. Retraction, when it is provided, is by an unusual pivoting mechanism.

SS105 is also on board Finnish *Turva* and *Kiisla*-class coast guard ships.

◆ Simrad SS240 Series/ST240

This sonar for small patrol boats, developed from SS304, was announced in 1986. SS240 is an active scanning sonar using preformed beams, with ODT, sector, and RDT modes. Both transmission and reception beams may be tilted from +10 to -20 deg, and there is also an MCC mode with a broad vertical beam in both transmission and reception. The transducer is cylindrical (diameter 42 cm, weight 300 kg). Operation is at 24 kHz (7-kW pulses, pulse length 2–160 msec, both FM and CW). Instrumented ranges are 200–6000 m in 200-m steps. The PPI display shows echoes in 8 colors to indicate various signal strengths. Target data, including range, bearing, course, and speed, are displayed in green; and the operator can select true or relative motion.

SS242 is the fixed-transducer version.

ST240 is a lightweight 24-kHz towed sonar derived from SS 240. It can operate either as a VDS (towed at speeds of up to 12 kt) or as a dipping sonar. Four were ordered for Finnish *Helsinki II*-class fast attack boats, and at least 13 were ordered for the Royal Swedish Navy.

◆ SS 304 (Spira)

This searchlight sonar (operating at 34 kHz) was designed for small fast craft (down to 150 tons, up to 40 kt). The 17 preformed receiving beams cover an 85-deg sector with a single ping, and the transducer can be turned and tilted (limits +15 to -105 deg) to cover the full 360 deg. The beams are narrow in the vertical, for shallow water. The display uses 6 colors to provide a true-motion picture of the underwater situation. Maximum instrumented range is 4000 m. This sonar is used on board Swedish *Göteborg* class and *Stockholm*, in combination with the French-supplied *Salmon*, and on board the Finnish *Hel-sinki* and *Turunmaa* classes.

This sonar was developed from the SM600 fish-finder, which

was demonstrated to the Norwegian navy in December 1982 on board a fishing boat.

◆ SU Series

This series is frigate searchlight sonars. SU-RS, the Stabilized Survey Sonar, has a retractable dome and can operate at over 20 kt. SU-RS trains through 360 deg and can tilt +20 to -110 deg. It is azimuth stabilized and also stabilized against pitch and roll. SU-RS operates on 1 of 4 working frequencies (12, 14.5, 18, or 24 kHz) with range information given on a moist- or dry-paper recorder. At 18 kHz the transducer (total radiating area 1600 cm²) produces a 10.5×12 -deg beam. Peak power is 4 kW (8 kW optional, with a second transmitter). Maximum instrumented range (with a scale divided into 6 ranges) can be chosen between 3500 and 9000 m, and there is also an audio channel for watch-keeping. The sonar's center frequency is set to 1 side of the receiving filter band, leaving more room for positive (approaching) than for negative (retiring) doppler. There is also an optional PPI, which can pulse the sonar at very short range (75 or 150 m), out to a maximum of 500 m, for high-resolution survey work.

SU-R is identical but lacks stabilization in pitch and roll.

SU is used in Irish *Deirdre*-type OPVs, in the British *Hecla*-class survey ships, and in Malaysian *Spica-M* fast attack craft.

◆ Terne Attack Sonar

This stabilized searchlight tracking sonar has a maximum instrumented range of 3000 yd and a depression angle of 35 deg (with a maximum instrumented depth of 1000 ft). The minimum depression angle is 5 deg. The range scales are 1000 and 2500 yd. The sonar incorporates a horizontal-range and depth computer. This sonar can be controlled by a scanning sonar, which triggers it in range and controls it in bearing. For example, as tested by the U.S. Navy in the early 1960s, the Norwegian attack sonar, designated SQA-16 (depth determining group), was controlled by an SQS-31 or -32.

UNDERWATER FIRE-CONTROL SYSTEMS

◆ MSI-70U

Kongsberg's Multi-Sensor Interface for the *Kobben*-class submarines, MSI-70U was 1 of the first systems to employ Kalman filtering to assist in associating data from different sensors to form a fire-control solution. The associated computer is SM-3. Units being modernized are being fitted with the new MSI-90U and the Thorn-EMI D3 data-distribution system built around a 1553B bus.

◆ MSI-90U

Development of Kongsberg's automated submarine command/control system began in 1980, for new Norwegian and German submarines (*Ula* class and Type 211). The initial study was completed in 1982, and a Norwegian-German MoU signed in December 1982. The prototype multifunction display was completed in mid-1983. MSI-90U will form a common-core (federated) combat system, with each partner supplying its own sensors, and will communicate with the consoles via a new BUDOS data bus. The computer is KS900F. Because both navies expect to operate in target-rich environments, MSI-90U is designed to support multiple engagements in quick succession. It can track 12 targets simultaneously and can handle 8 weapons.

A full system consists of 4 multifunction operator consoles (each with its own computer), a computer rack (with 3 main computers), and a weapons-control unit (WCU) (with 2–3 weapons computers), all tied together by a BUDOS data bus (as in the NFT surface-ship systems). All of the computers are KS900s, and the BUDOS bus is provided with 3 multiplex terminals (MUX), each of which can connect with up to 8 users. BUDOS itself can accommodate up to 15 MUXes, far beyond the needs of the system. Each of the single-operator consoles has 2 high-resolution, color, raster-scan screens; the operator enters data

via a programmable plasma touch screen, a trackball, and a standard keyboard.

The console display shows:

- Situation and Interaction Plot (SIP), the overall tactical situation
- 4 Workplots, which can be viewed in sequence: TMA, Torpedo, Tactical, and Auxiliary

The display can show a digitized radar picture; radar data can be used for target range and bearing. Presumably, the system can easily accommodate a future optronic periscope since its raster-scanned screen has sufficient flexibility and resolution.

One console (the central command unit) is fed by the digital scan converter for the submarine's radar. It is near the steering console and the plotting table on the starboard side of the boat. The other (identical) consoles are arranged in a line on the port side, next to the sonar consoles.

The system as a whole can conduct simultaneous automatic and operator-interactive TMA on up to about 30 targets, can guide several torpedoes (the number depends on the design of the submarine) simultaneously, and can prepare and lay up to about 50 mines (registering positions, while also keeping track of up to 15 hostile mines being laid). Missile preparation and firing (1 missile at a time) is an option. Torpedo-guidance modes are line of sight, collision course, and manual.

The system carries classification data bases for radar, sonar, and platform identification, both for IFF and to plan engagements. It also conducts geographical/oceanographic modeling, forming contour maps and predicting sonar performance. Sonar ranges are used for TMA, for threat evaluation, and for weapons control. MSI-90U provides threat evaluation as well as engagement analysis. The latter function shows whether a target is within torpedo range, computes firing positions (estimating hit probability), and automatically optimizes firing parameters.

Factory tests began in 1986, and the first unit, for the Norwegian submarine *Ula*, was delivered in April 1988.

SOUTH AFRICA

The International Maritime Technology (IMT) company of Simonstown has developed a towed array, intended as a technology demonstrator. It was used in 1988 to find the flight-deck voice and data recorder from the South African Airways 747 that crashed in the Indian Ocean. This device might form the basis of a future South African navy sensor. Although no surface ASW ships are currently in service (no likely enemy in southern Africa has submarines), there has been a proposal to build a new light frigate to replace the Minister (Israeli *Reshef*)-class fast attack boats. The array might also be installed on board the South African submarines, the combat systems of which have reportedly been replaced with indigenous equipment.

SWEDEN

SONARS

◆ Bottle Cap

A joint SAAB-Simrad VHF sonar, for harbor defense, hull mounting, or helicopter dipping, Bottle Cap was announced in 1987. Bottle Cap's square-plane receiving transducer is trainable, and the beam is scanned electronically across the transducer in both elevation and azimuth. The projector is a line array below the receiver. Targets are detected automatically, out to a range of 1000 m, and several can be tracked simultaneously. The transducer can be tilted, and the sonar incorporates a compass. Bottle Cap can be bottom-mounted or used as a dipper. Pulse length is 0.1–10 msec, and the horizontal beamwidth is 1.9 deg. Vertical beamwidth is adjustable (6, 12, 18, or 36 deg), and angular resolution is 0.225 deg (mechanical step size is also 0.225 deg). Scan rate is 15 deg/sec at 200-m range (range scales are 0–5, 10, 20, 50, 100, 200, 500, and 1000 m). For automatic target designation at a range of 500 m, resolutions are about 1

deg, 2 m, and 1 kt. In the zoom mode at 500 m, resolution is about 1 m. In a typical application, the sonar might scan over a 275-deg arc using a 1000-m range scale, scanning every 20 sec. Display resolution is 512 × 512 pixels (128 colors). The scan pattern can shift range scale every 7.2 deg, providing 50 different ranges over 360 deg, and 100 such patterns can be stored. The range changes are necessary to allow for the irregular contours of a harbor bottom. The very high frequency was apparently chosen in hopes of detecting small submarines.

As of November 1990, Saab Instruments was working on a new short-range scanning system using a blue-green laser to complement or replace Bottle Cap. This underwater radar was the subject of preliminary discussions with the Swedish Defense Administration and with the Swedish military research-and-development community. At that time Saab expected to begin marketing its underwater radar in about 6 months, i.e., about May 1991. The announced Bottle Cap range, about 1000 m, would not be very far from known underwater laser performance. The Saab device would seem to be the first underwater laser radar to have been made public.

◆ 9SA100

This BEAB HF surveillance sonar was announced in 1990. It is intended for use in an upward-looking acoustic fence, as a controlled mine field sensor, or, looking down, for ship security against swimmers. 9SA100 can also be used as the active element of a mine sensor, turned on only when passive sensors on the mine detect a likely target. Presumably, it is part of current Swedish work on a rising mine. The only published brochure suggests that 9SA100 produces a relatively narrow beam and distinguishes targets only by their range (in a test, it detected 2 frogmen swimming close together).

FIRE-CONTROL SYSTEMS

◆ AI-FCS

AI-FCS is Datasub Communications's Action Information–Fire-Control System for A 17-class submarines. It uses 2 identical consoles, each of which can show any of 4 plots: contact-evaluation plot (CEP), operational plot (OP), tactical plot (TP), and fire-control plot (FCP). CEP is used mainly when TMA would be unsuitable, e.g., when a contact can be detected only sporadically, or at very long range. Collected information is shown in time-bearing (waterfall) form, covering all 360 deg and up to 2 hr vertically. The OP (in effect, a navigational plot) is used during transit to the patrol area. OP shows features such as own and enemy mine fields, mission information, coastal radars (with their parameters), the route, and the operational area itself. The OP can show 50 internally generated points, 10 target channels for TMA, up to 240 plots received externally by data link, and 32 ESM emitters or emitter modes. Normally the TP is used for TMA, while the submarine is preparing to attack; up to 10 targets can be analyzed simultaneously. In the TP, own-ship is at the center, and there are no navigational displays, although 8 reference points can be used to show, e.g., the boundaries of the patrol area. Up to 50 internally generated plots can be shown, and also a list of which sensor is tracking which target. For longer ranges, the OP is better because it shows chart information and true motion. Finally, the FCP is optimized for rapid automatic multiple engagements, controlling up to 12 torpedoes simultaneously. It normally shows relative motion (own-ship at center), but it can be centered on a torpedo. Typically 1 console is used as command station (showing CEP or OP or TP), and 1 is fire-control station.

The computer's storage capacity is 512k (32-bit words), with a storage cycle time of 750 nanosec (clock speed 1.3 MHz) and an average execution time of 2.5 microsec.

A reduced form of this system has been installed in Swedish *Sjoormen*-class submarines during their mid-life refits.

◆ NEDPS

Nacken Electronic Data Processing System, manufactured by Datasaab, is the computer-driven combat system of the Swedish *Nacken*-class submarines. Requirements were formulated in 1966–67; they included passive fire control (by TMA, which the Swedes call target-factor calculation, or TFC) on several targets simultaneously. That capability clearly required a computer. The same computer could also be used for other ship-board tasks, such as machinery control and depth-keeping, and the system evolved from weapons and sensor control to overall submarine control. A simulator, ordered in 1970, was used in 1971–74 to test and develop the requisite software. The system is built around 2 Censor 932 64-kbyte computers, feeding a pair of consoles with CRTs: a tactical plot (TP) and a fire-control plot (FCP). Between them is mounted a torpedo status board (the torpedo fire-control display, or FCD), and there is also an alphanumeric display, the general communication unit (GCU), manned by the ship's electronics officer. The consoles are equipped with keyboards and trackballs. Calculated target tracks are displayed on the TP, which replaces the conventional paper plot; it can also display the signal-to-noise ratios of various targets being tracked. The system can carry up to 50 targets, and it can automatically provide simultaneous TMA (for fire control) for up to 10 of them. Up to 12 torpedoes can be controlled simultaneously.

The Mk 2 version, for the *Vastergotland* and *Sjoormen* classes, uses 1 multifunction console with 2 side-by-side CRTs. The weapons-data boards are above the CRTs. These 3 boards also include alphanumeric displays, e.g., of data links. The system can carry up to 50 labeled targets, with 10 target channels for TMA, 240 external targets (via data link) with target numbers and identifiers, and 32 ESM lines. Ericsson has advertised NEDPS for Type 205 and Type 206 submarine upgrades.

◆ TORCI

PEAB's torpedo FCS for surface ships and fast attack craft uses a search radar. TORCI can engage 2 targets simultaneously with long-range wire-guided torpedoes. The system consists of a control panel incorporating a PPI display, a tracker, and a computer. The main system sensor, a surface-search radar, feeds both the tracker (which has a B-scope) and the main display. Alternatively, targets can be designated optically and the torpedo fired along the line of sight, with course corrections as the ship and target move.

The operator can move a bearing line and a range ring about the PPI, using handwheels. When both intersect on the desired target, it is entered into the system by means of a button. The separate tracker projects target position ahead; the projected position appears on the main PPI. The tracker operator maintains track by keeping the target centered on the B-scope, using range- and bearing-correction handwheels. The tracker also takes into account own-ship maneuvers (the system is automatically fed ship's course, ship's speed (through the water, not over the ground), and a vertical reference (presumably, to correct radar errors caused by roll). The computer continually computes the course a torpedo must follow to intercept the target; the torpedo course and the calculated interception course are both shown on the console. The console also shows projected torpedo running range. If the target is within range, torpedoes are fired from the main console.

Torpedo guidance is either automatic or manual. In automatic mode, the computer automatically transmits signals through the torpedo guidance wire. In manual mode, the torpedo is steered to starboard or port by 2 buttons. In either case, the PPI shows the dead-reckoned torpedo course, based on presets and commands sent. The system as a whole can control at least 2 targets, time-sharing its computer and tracker.

The main PPI, a true-motion display, can also be used for tactical plotting.

TORCI appeared in 1959. It was the culmination of a series of Philips torpedo FCSs. One of the first was the TCA electro-

mechanical system for destroyers, delivered in the mid-1950s. There were also a contemporary submarine FCS (TCI 101) and a motor torpedo boat system (RATSI). The latter was the first Philips system to use radar to track and localize the target. RATSI was evaluated in destroyers, leading to the development of TORCI, to control straight and wire-guided torpedoes.

TORCI was a very early example of solid-state electronics (using discrete devices). Its computer was hard-wired; even so, it weighed 205 kg. The display weighed another 165 kg, and the tracker 125 kg; the fourth component, a control panel, weighed another 120 kg, for a total of 755 kg [1664 lb]. Each component was 620 mm [24.4 in] wide, somewhat more massive than the current 19 in standard.

TORCI users: Denmark (*Willemoes* class), Norway (*Snogg* class), and Sweden (*Spica-II* class).

◆ 9TCI210

Philips's submarine torpedo FCS of the early 1960s controlled wire-guided weapons against surface targets and used a single operator. It is related to the series of fast-attack-boat systems that culminated in the 9LV series (see the AAW section). The main system sensors are a frequency-agile X-band radar with 2 magnetrons (1 on standby), the periscope, and the sonars. The single 12-in CRT can display either the radar picture or a bearing line (from the periscope or the passive sonar) or the target location (bearing and range) given by the active sonar. There are 2 target-tracking computers (i.e., tracking channels). Target bearing and/or range data are entered by push-button. The system is designed to accept intermittent target data; measurements of bearing and range can be made independently. The tracker uses time and movement between measurements to compute target speed and course. Once it is tracking, it generates a tell-back tracker symbol on the CRT. If the target is continuously presented, the tracker can operate in TWS mode. The operator can control the tell-back target symbol via a golf ball and transmit its position to the selected target tracker to correct tracker predictions.

During an attack, the CRT shows torpedo position (as a half-circle), with a course and speed vector. After the full torpedo distance is reached, this symbol is fixed, showing the location of the actual torpedo. Two symbols, a square and a circle, represent the tell-back positions of the target trackers, with the vectors representing computed course and speed. The ship's heading line is presented once every antenna scan. Torpedo and fire controls are in the panels above and in front of the CRT.

9TCI210 can present the full tactical situation in PPI form based on long-range radar search; it can designate targets to sonars and to the submarine periscope; it can present target bearing for plotting. The system can control up to 4 wire-guided torpedoes simultaneously. It can also fire up to 4 preset-angle torpedoes (straight or pattern runners).

◆ 9TC301/9TC302

9TC301 is a digital FCS for Swedish ASW helicopters, firing Tp 42 wire-guided torpedoes. A small data-transmission unit aboard the helicopter continuously and automatically transmits target course and speed to another helicopter or ship so that the latter can attack without transmitting. When controlling other platforms, the master helicopter uses its on-board radar to monitor the position of the cooperating units as well as to provide target data against periscopes or surfaced submarines. The Tp 42 torpedo can also be used against surface vessels.

9TC302 is the production version, first delivered in May 1981. Deliveries were completed in 1983. Development began in the mid-1970s. PEAB was awarded a contract for an evaluation system in 1977. It was delivered in 1978, and evaluation was completed about mid-1979.

USSR

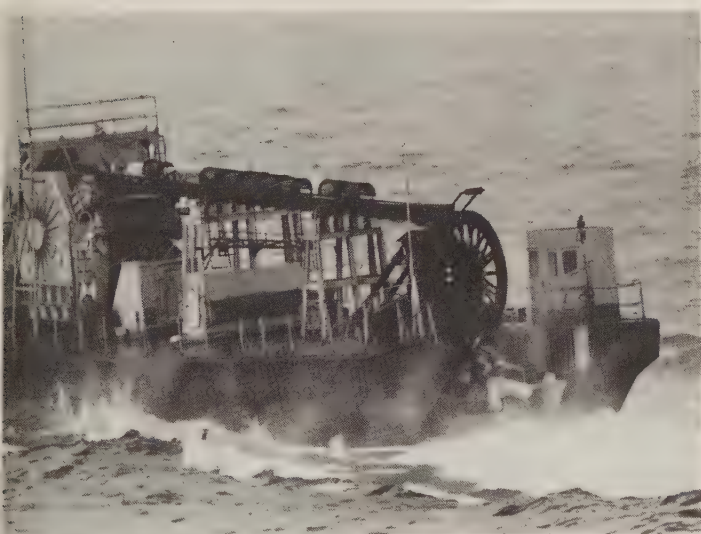
The NATO reporting designations listed below were published in 1986, and many are presumably no more than older systems renamed. Because the only list thus far published associates

Sonar code names only with ships or classes, some of the identifications below may be incorrect. No detailed characteristics of modern Soviet sonars have been published. Moreover, this list may well be incomplete. For example, early Whiskey- and Zulu-class submarines probably had wartime-developed HF passive arrays (MARS-12) that seem not to have received postwar code names. The first modern sonars, Feniks and Hercules, appeared only in 1958.

During and immediately after World War II, the Soviets had access to British and U.S. HF searchlight sonars and to German wartime surface-ship and submarine sonars, including the LF arrays that were developed further in Britain and in the United States. Presumably, the parallel development of Pegas and Tamir reflects parallel work along both U.K./U.S. and German lines for surface ships; it is interesting that the Soviet equivalent of the passive array for big submarines (presumably Trout Cheek) apparently took so long to develop.

No code designations for Soviet helicopter dipping sonars have been published. There are probably at least 2 types, an HF unit in Hormones (see Rat Tail) and 1 MF type in, presumably, Helix and Haze (see Foal Tail/Lamb Tail). There is no published indication of whether these dipping units are searchlights or scanning sonars (sector or omnidirectional).

In 1989 the U.S. Director of Naval Intelligence reported that the Soviets had short-range fixed acoustic sensors in the Northern Fleet operating area, and longer-range planar arrays (code-named Cluster Lance) in the Far East, where geography is more favorable to such devices. Presumably, the devices in Northern Fleet waters are, in effect, acoustic fences that indicate that a submarine has actually passed through them. Such fences could be used to cue nearby aircraft or other ASW platforms and could form part of bastion defenses. The sensors would probably use RAP propagation and thus could function even in relatively shallow water. The DNI also stated that the Soviets were testing a towed surveillance array similar in concept to the U.S. SURTASS, and that within a few years they were expected to deploy surveillance platforms equipped with the new array.



For some time the Soviets have been reported experimenting with, and then deploying, towed arrays. This is probably an experimental array on the stern of a Petya-I-class corvette. Note the fish in the well and the control cabin. (U.S. Navy)

None of these systems is likely to be particularly effective. The current argument within the U.S. defense community is that submarines such as Akula can defeat U.S. long-range passive systems such as SOSUS. SOSUS is likely to be more sophisticated than the Soviet systems, and U.S. submarines are quieter than current Soviet types, including even Akula.

◆ Buck Toe

See Pegas below.

◆ Bull Horn

The MF hull sonar of the Modified Kashin and at least some of the *Sovremennyy* class (others have Bull Nose), Bull Horn is also carried on board the first 2 *Kiev*-class carriers to supplement their Moose Jaw sonars. It is presumably a smaller and less effective equivalent to the bow-mounted Bull Nose of the Krivaks, as the Modified Kashins and *Sovremennyy*s are primarily antiship units requiring sonar mainly for self-defense. Bull Horn is associated with 21-in [53 cm] homing torpedoes. It may, therefore, be broadly comparable to the U.S. SQS-56 (controlling 53-cm torpedoes rather than U.S. lightweights). In the case of the first 2 *Kievs*, the big Moose Jaw is presumably associated with the long-range SUW-N-1 nuclear ASW missile. The need for a smaller sonar for self-defense (using the carrier's 53-cm tubes) suggests that Moose Jaw does not normally cover the full area around the ship, that perhaps it is limited to a selected search sector, and that it may be ineffective at close range. The 2 later *Kievs* have no MF sonar; presumably, the later Horse Jaw suffices for both close-in and distant targets.

During a U.S. visit, Soviet officers on board a *Sovremennyy*-class destroyer claimed a range of 5000 m [about 5500 yd] and stated that this sonar was connected to a computer. They also described the system as a means of self-defense.

◆ Bull Nose

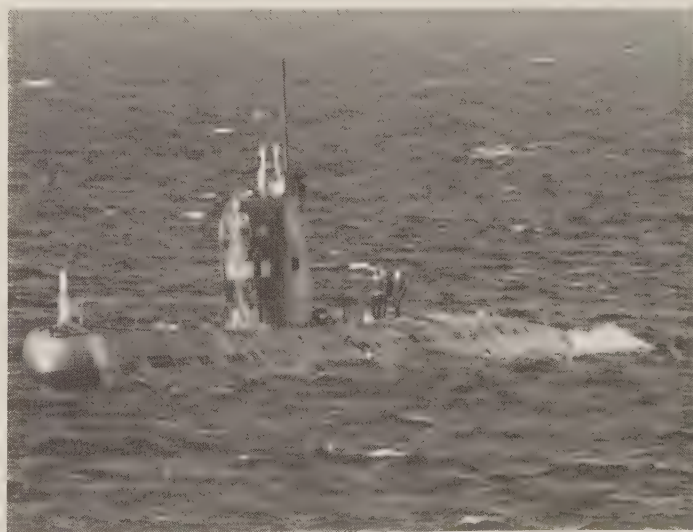
This MF bow sonar is associated with SS-N-14 in the Krivak, Kara, and Kresta-II classes, and with ship-launched ASW torpedoes in the Kanin, *Sovremennyy*, and *Slava* classes. Bull Nose is also the sonar installed on board Grisha. Bull Nose is probably broadly comparable to SQS-23. The associated VDS is Mare Tail or Elk Tail. Bull Nose is probably the 7.5-kHz sonar reported in 1960, using a 7500-yd keying interval (corresponding to its expected maximum range). Bull Nose succeeded Wolf Paw (Hercules) and, presumably, was substantially improved before it could be used to direct SS-N-14.

◆ Elk Tail

VDS for the Grisha class, Elk Tail is associated with the Bull Nose hull sonar. The associated ASW weapon is a 533-mm [21-in] homing torpedo or an RBU-6000.

◆ Feniks (Pike Jaw)

Feniks is the standard Soviet diesel-electric attack (searchlight) sonar of the past. Feniks (Phoenix) is apparently the Soviet name. It first appeared in 1956 and was, typically, combined with Tamir-5L on board submarines. Feniks is in a dome atop the bow of a submarine. Early examples showed only a single



A Foxtrot displays Trout Cheek, Feniks, and Fez, and also a row of hydrophones in the sail proper, Fin Teeth, which ONI assumed was a sonar-intercept system. The extended mast is for radio. (U.S. Navy)

dome. In later units, a narrower stalk, Fez, is visible above the main dome.

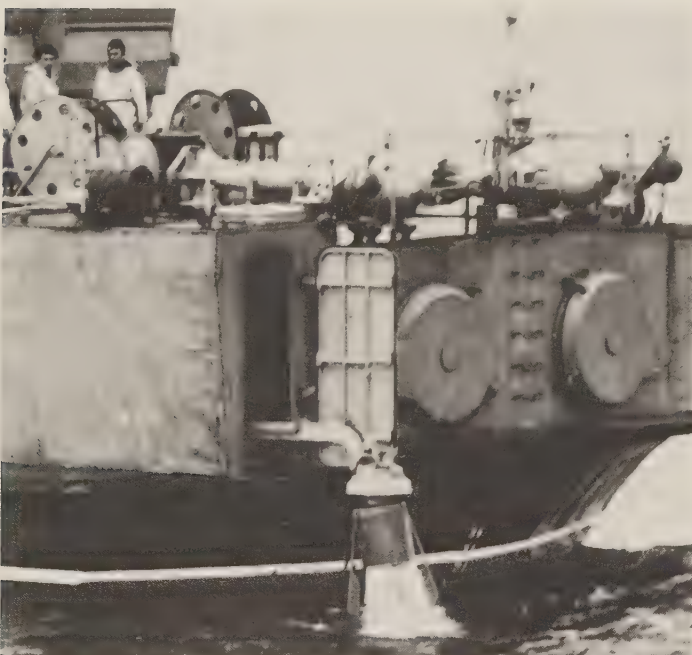
Feniks is probably the same as Pike Jaw. At least some of the submarines equipped with Pike Jaw have keel sonars; the standard arrangement may well be a pair of transducers, top and keel. The keel sonar is needed to protect the submarine when it runs on the surface. That protection was important for early Soviet missile-firing submarines, which had to fire while surfaced. Moreover, those submarines firing the antiship version of SS-N-3 had to remain on the surface to provide mid-course guidance.

◆ Fez

Fez is the HF system found in a tall narrow dome atop the Feniks domes on Soviet submarines. Fez is almost certainly an underwater telephone.

◆ Foal Tail/Lamb Tail

These Mirka-class VDSs are associated with Bull Horn and Wolf Paw hull sonars and with the Steer Hide sonar. The VDS of Mirka-II-class corvettes is a helicopter dipping sonar rather than a towed body; the connection, if any, with Rat Tail is not clear. It seems likely that the dipping sonar associated with Wolf Paw matches Rat Tail, and that the sonar associated with the MF Bull Horn is a later MF type, presumably carried by the later Helix or Haze helicopters.



Helicopter-type dipping sonar deployed from a Mirka-II-class frigate. (U.S. Naval Institute)

◆ Hercules (Wolf Paw)

This standard Soviet sonar for surface ships and submarines appeared in 1957. It operated at HF and probably introduced scanning technology to Soviet practice; thus, Hercules was presumably roughly comparable to the U.S. QHB or SQS-10 family. Hercules, apparently the Soviet name, survives on board Soviet-supplied Foxtrots (e.g., to Libya). The standard combination of the late 1950s (and on export units) is a Hercules search sonar plus a Feniks attack sonar. Hercules was also used as a sonar for surface ships, e.g., on board Petyas exported to India. The NATO Wolf Paw code name applies only to the surface-ship version.

Soviet Foxtrot-class submarines show a bulbous sonar bow, reportedly containing Hercules. Given the probable dimensions

of this sonar, it seems likely that the bulb contains an active transducer inside a larger-diameter MF passive transducer, like the U.S. BQR-2/BQS-4 combination. Foxtrots generally also have a sonar in their sails, indicated by the series of bright metal windows about halfway up.

Hercules was the standard Soviet hull sonar of the early 1960s, e.g., on board *Kynda*-class missile cruisers (as built) and some *Sverdlovs* (replacing Stag Hoof), and on board Kashin- and earlier class destroyers, replacing Buck Toe. Wolf Paw is the sole sonar on board Poti-class corvettes.

◆ Horse Jaw

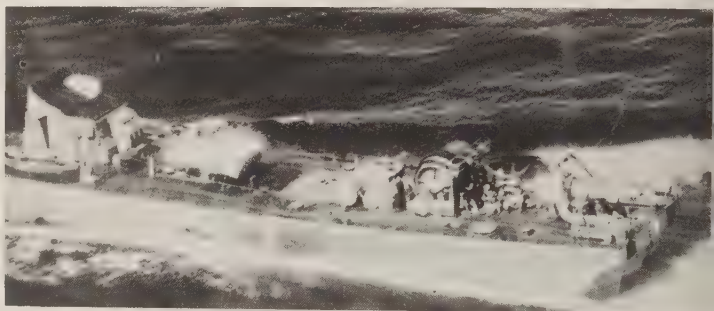
Horse Jaw is a large LF bow sonar carried by the last 2 *Kievs* (and therefore probably by the *Tblisi* class), by the *Kirovs*, and by the *Udaloy* class. It is associated with the SS-N-14 missile and with the Horse Tail VDS. In the case of the *Kiev* class, it replaces both Moose Jaw and the MF Bull Horn.

◆ Horse Tail

This LF VDS is associated with the LF Horse Jaw hull sonar. Unlike earlier Soviet VDS fish, this is saucer-shaped. It is carried by the last 2 *Kiev*-class carriers, by the *Kirovs*, and the *Udaloy*s.

◆ Mare Tail

This VDS, the first in Soviet service, is associated with the Moose Jaw hull sonar in the *Moskva* and *Kiev* classes, and with Bull Nose in frigates and destroyers. Mare Tail is an MF type, and it was tested in 1966 on board a Petya-I trials ship. The Soviet name for this system is Vega.



The prototype of the *Moskva*-class VDS, on board a modified Petya-class corvette. (U.S. Navy)



VDS "fish" of a Krivak-class frigate. (U.S. Naval Institute)

◆ Moose Jaw

This enormous LF hull sonar was first installed on board the *Moskva*. Moose Jaw is also on board the *Kiev*. In the *Moskva*, Moose Jaw is probably associated with the FRAS-1 stand-off ASW rocket and, presumably, was intended to achieve convergence-zone capability. In the *Kiev*, Moose Jaw is, presumably, associated with SS-N-14. The successor sonar in the *Kirov* is Horse Jaw. The associated VDS is Mare Tail.

Moose Jaw is retractable (on 1 occasion, *Moskva* entered the shallow harbor at Sevastopol without retracting her sonar and severely damaged it). That, and the use of Bull Horn as a supplementary (probably self-defense) sonar in the *Kiev* class, suggests that this is a sector-scan rather than an all-around sonar. It may, therefore, be a lower-frequency derivative of the British Type 177, details of which would have been obtained by the well-publicized Soviet spy ring at Portsmouth, which operated just when Type 177 was being developed. The timing would have been about right, and the Soviets would probably have found it much easier to concentrate very high power in 1 sector than in an ODT transmission. The official Soviet model of the *Moskva* shows the sort of teardrop-shaped sonar dome that would be associated with a flat-plate transducer rather than with a cylinder of the appropriate size, and the flat plate would be much easier to retract than a full cylinder.

The Soviet name for this sonar is Orion. It was credited (by the Soviets) with a range of 40 km [about 44 kyd].

◆ Pegas (Buck Toe)

The successor to Tamir, Pegas was installed on board Soviet surface combatants from the Riga class up from 1955 onward. This searchlight sonar is probably code-named Buck Toe. In larger ships it was succeeded by the Hercules scanning sonar. Compared to Tamir, Pegas was credited with better bearing accuracy and with a maximum active range of about 5000 yd. Pegas could maintain passive contact on a cavitating submarine out to about 12,000 yd and could determine a target's depth (which was essential for using the new ballistic ASW rocket launchers then coming into service). Maximum listening speed was about 20 kt, and the sonar could automatically pass its data to the approach-and-attack computer.

◆ Perch Gill

This sonar appears mainly on board Whiskey- and Zulu-class submarines, some of which lack Pike Jaw (Feniks). Perch Gill, a higher-frequency searchlight attack sonar, is probably a submarine version of Tamir, the predecessor of Feniks.

◆ Pike Jaw

See Feniks, above.

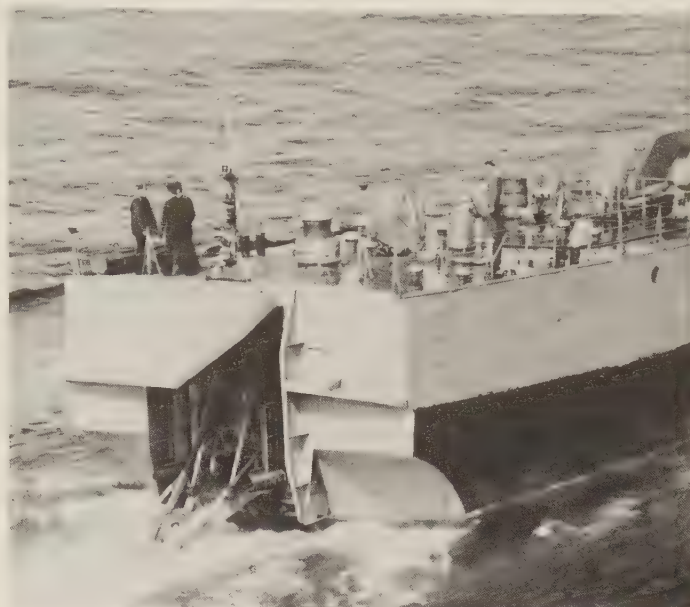
◆ Rat Tail

A VDS for Petya-class corvettes, Rat Tail is associated with the Wolf Paw HF hull sonar. Rat Tail is a helicopter-type dipping sonar, rather than a towed body, located in a temporary installation amidships. Presumably, the sonar is that of the Hormone helicopter. The relationship with Lamb Tail/Foal Tail is not clear.

The dipping sonar of the Hormone-A helicopter operates at 14–16 kHz, with a maximum range of 4000–6000 yd.

Reportedly, the Soviet designation for the Hormone-type dipping sonar is OKA-2. It can operate passively or actively. An East German article reports maximum ranges of 5500 m in active mode and 18,500 m in passive mode.

An East German account of coastal submarine-hunting tactics by helicopters mentions an average dipping search speed of 17–20 kt, the helicopters making their dips 1.25 or 1.60 of sonar range apart. The article uses an example in which sonar range is 9150 m, so its figures may be misleading. Reportedly, 6 helicopters have 0.5 chance of finding a submarine in 1 hr in a 50 × 50-km area.



A VDS streamed by a modified Petya-I-class corvette. (U.S. Navy)

◆ Sail Plates

Presumably, Sail Plates is the array of small transducers around the sail of Foxtrot and some later classes of Soviet submarines. When first observed, these transducers were identified as torpedo-warning devices (intercept receivers).

◆ Seal Skin

This sonar appears only on board Romeo-class diesel-electric submarines and Echo-I-class nuclear attack submarines (ex-strategic-cruise-missile submarines).

◆ Shark Fin

This sonar array, reportedly MF for torpedo fire control, is found in the sails of many Soviet nuclear submarines. Typically, Shark Fin is combined with Shark Teeth, although in Echo-II Shark Fin is combined instead with Pike Jaw, Trout Cheek, and Perch Gill. Tango, which is a contemporary of this generation of nuclear submarines, is also equipped with Shark Fin/Shark Teeth.

Shark Fin first appeared on board Echo-II- and Charlie-class missile submarines. Presumably, it is required to control long-range antiship weapons, such as nuclear torpedoes and the SS-N-7 missiles of the Charlie.

◆ Shark Gill

This nuclear-submarine sonar suite was introduced in 1978 on board Victor-III-class submarines and used in later types: Delta IV, Typhoon, Oscar, Sierra, and Akula. It includes a towed array, the pod for which is visible atop the tail fins of the Victor-III, Sierra, and Akula (presumably, it is paid out from the small pipe visible at the top of the Oscar fin).

◆ Shark Teeth

This LF sonar bow array is found in many Soviet nuclear submarines. Compared to Trout Cheek, Shark Teeth is much more completely faired into the curving bow of the submarine. In a November-class nuclear submarine, Shark Teeth is combined with Sail Plate and Pike Jaw, both of the latter presumably faired into the sail. This system is probably associated with the much longer attack range provided by the first Soviet nuclear torpedoes, which, presumably, were designed in tandem with the November class. The submarines had sufficient speed to get into position to attack U.S. aircraft carriers, and the torpedo had sufficient lethal radius to make such attacks profitable even without very precise targeting data. Presumably, November was equipped with a shorter-range attack sonar, Pike Jaw, so that the submarine could also use short-range straight- or pattern-

running antiship torpedoes. Pike Jaw, in turn, lacked the range to control the much longer range antiship homing torpedoes of the 1960s; hence the advent of Shark Fin.

The standard Soviet submarine sonar suite of the 1970s included Shark Teeth and Shark Fin.

◆ Squid Arm

This Alfa-class sonar suite (including also the Mouse Roar sonar) was introduced in 1970.

◆ Steer Hide

This VDS is found in the *Kiev*, *Kashin-II*, *Sovremennyy*, and at least 1 *Mirka*-class corvette.

◆ Tamir (Stag Hoof and Stag Ear)

This Soviet sonar was a copy of British wartime searchlight sets. It operated at 24 kHz. Tamir-5N (Stag Hoof) was introduced in 1947-48 and appeared on board large surface ships up through the *Sverdlovs*. Tamir-5L, for submarines, was introduced in 1950, followed by Tamir-11 and -11M (Stag Ear) in 1952. Tamir-5N was the sonar originally carried by *Skoryy*-class destroyers. In many cases it was replaced by an improved searchlight, Pegas. Stag Ear remains in service on board many smaller combatants, such as minesweepers.

◆ Trout Cheek

This sonar is presumably the large passive array in the bows of Soviet diesel submarines from the Foxtrots on. The prototype was tested on board a pair of Whiskey-class submarines about 1958. Trout Cheek probably corresponds very broadly to the U.S. BQR-2, i.e., by reflecting the use of German wartime LF array technology. When this array first appeared, the U.S. interpretation was that the Soviets had adopted the U.S. SSK (anti-submarine submarine) mission, for which the U.S. Navy had adopted BQR-2 in the first place.

The standard Soviet submarine sonar suite of the 1960s consisted of Trout Cheek and Pike Jaw.

◆ Victor Sonar (No Code Name Known)

Soviet Victor-class submarines have a large chin sonar, first revealed publicly when a Victor-I suffered severe bow damage in a collision in the Straits of Gibraltar. Presumably, this sonar is associated with the SS-N-15 weapon, just as the big U.S. spherical bow sonar, BQS-6, is associated with SUBROC. Presumably, too, the Soviets obtained at least some details of the U.S. sonar

when the Soviets obtained details of the SUBROC system (from which they developed SS-N-15). In contrast to the U.S. system, the Soviet sonar cannot easily exploit sonar propagation paths above the submarine, e.g., the bounce path off the surface. That limitation may mean that the Soviets do not expect to fire SS-N-15 at any great depth, i.e., at any depth at which such paths would be worthwhile.

The photograph of the damaged Victor-I clearly shows a horizontal row of transducers extending across the front of the sonar, suggesting a cylindrical configuration. However, at least one account refers to a sonar sphere in this class. This account would square with the photograph if the (presumably cylindrical) row of transducers were wrapped around the sphere. In that case the sphere would probably function as an analog beam-former. The most likely technology would be that of the Luneberg lens, a microwave device that forms a directional beam from an input at a particular point on 1 side. The corresponding signals measured at points on the other side of the lens have the appropriate phases applied to them. This type of technology is used in the U.S. SLQ-32 ESM/ECM system. In a sonar application, acoustic signals would be used to modulate microwaves applied to appropriate points on the side of the lens pointed toward the submarine, and the microwave signals would pass through the lens. The lens would apply the appropriate phases. On the external side of the lens, the microwave signals would be used to drive acoustic transducers (the microwave frequency would be stripped off). As a receiver, the lens/transducer combination would operate in reverse, microwaves modulating the received acoustic signals so that they could be focused onto the appropriate points on the inner surface of the lens. The advantage of the lens (or of any other similar analog beam-former) is that it avoids considerable computation, which otherwise would be required before signals in any beam could be analyzed. On the other hand, it is limited in the number and composition of the beams it can handle and so has not been used in modern Western sonars.

◆ Wolf Paw

See Hercules above.

UNITED KINGDOM

SONARS

◆ Type 162 and 162M

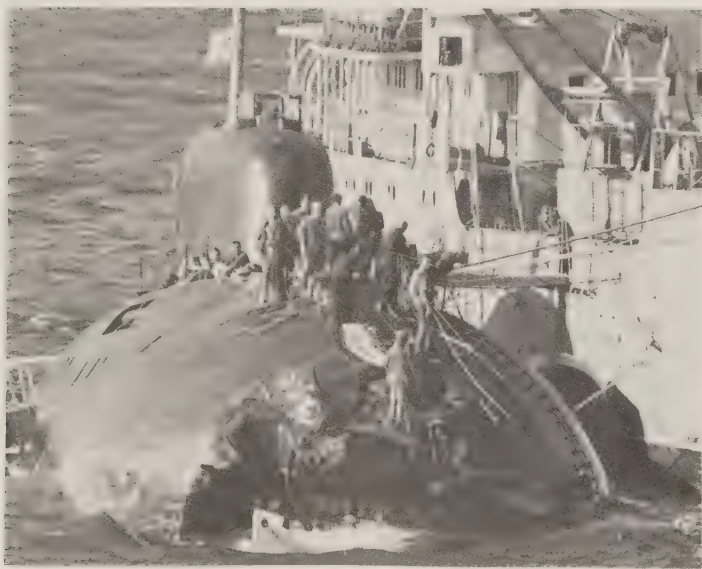
"Cockchafer" bottom-profile sonars detect bottomed submarines. Type 162 sweeps a narrow beam across the seabed and detects the shadow of an object. Three quartz-strip transducers, each producing a fan beam, are mounted horizontally, flush with the hull near the bow: 1 on the keel and 1 on either side, tilted down at a 25-deg angle. The shadow is shown on a conventional chemical range recorder. Frequency is 50 kHz. Range scales are 300 and 600 yd (Type 162M has a third, 1200-yd scale). The 3 fan beams are about 3×40 deg, and range accuracy is better than 2%.

Cockchafer entered service in 1948. In 1951 it successfully located the wreck of the submarine *Affray*. Type 162 remains in British (and foreign) service and is currently manufactured by Kelvin-Hughes and by A B Precision (Poole) Ltd.

SQS-501 is the Canadian version of this sonar.

◆ Type 164B/Type 174/Type 176

Type 164, a modernized version of the wartime Type 144, was the first postwar British production sonar (Type 144 was the first sonar to be based on wartime experience). The main improvements were the following: a transmitter using a master oscillator tube; a ship's component mechanism that corrected sonar readings for ship's motion across the target track (and thus could pass the correct bearing to a Squid mortar); a modified bearing recorder (which eliminated ambiguities in the earlier type); and a sonar repeater for the helmsman. These were improvements in wartime practice. However, as described below under Type 170, the great postwar problem was that submarines



This Victor-class submarine collided with a merchant ship near the Straits of Gibraltar in October 1985. Under emergency repair, she shows the upper line of transducers of her chin sonar (just at the waterline), as well as her characteristic torpedo tube arrangement: 2 above, 4 below. (U.S. Navy)

might be so fast that they could elude searchlight sonars altogether. The interim solution, first tried in the experimental Type 160X (on board HMS *Scorpion*), was to add a second (search) transducer, forward of the main attack transducer and separately trainable because it was mounted on a second shaft. Typically, the second sonar was limited to a range recorder because it was intended to search rather than to track. This second sonar was designated Type 174; it was a second Type 164 transducer, but it lacked the HF (38.5-kHz) Q2 strip used to maintain contact at steep angles and at short ranges specifically for attack. Type 174 was retained when Type 164 was superseded by the much more powerful Type 170 attack sonar. Ultimately, Type 174 was superseded by true search sonars, Types 177 and then 184.

Types 144, 164, and 174 all operate at 14–22 kHz, with range scales of 1.5 kyd (for attack) and 3 kyd (for search). The depth-determination limit (using the Q strip) is 1500 ft (Type 164). The Q strip produces a beam 3 deg wide, extending down to a depression angle of 60 deg. The main beam is about 10×10 deg.

Type 164 entered service in 1950. It was the standard British destroyer sonar of the 1950s, and it was widely exported. It survives on board the Chilean *Almirante Williams*-class destroyers and the Ghanaian Mk 1 corvettes. Presumably, each carries a secondary Type 174 transducer.

Type 174 survives (in combination with Type 170) on board the Bangladeshi frigate *Umar Farooq* and possibly on board the Pakistani ex-missile destroyer *Babur* (see below). In other cases, Type 174 was replaced by PMS 26.

Type 174 was used as a large-ship self-protection sonar in combination with a passive-torpedo-detection set, Type 176 (now probably extinct). Type 176 operated at 20 kHz; an 18-kt ship carrying it could detect a 45-kt steam torpedo at 2500 yd (a 24-kt ship could detect the torpedo at 1500 yd, and a 30-kt ship at 500). Type 176 had a single-operator display, typically in the Operations Room (CIC). These sets survive, if at all, on board the Argentine carrier *25 de Mayo* and the Indian *Vikrant*. Because it provided omnidirectional listening, Type 184 replaced not only long-range search sets but also the large-ship defensive sets. The sonar sometimes listed as Type 174 for the Pakistani ex-missile destroyer *Babur* is probably Type 176, working in this case in combination with Type 177.

◆ Type 170B

This set was the "4 square" attack sonar associated with the Limbo mortar. The transducer was square, arranged as a diamond, the 4 beams being compared to keep the sonar pointing at the target both in bearing and in elevation. Type 170 was conceived as part of an automated underwater FCS, analogous to an automatic tracking radar. The transducer is stabilized, and depth settings for fire control are derived from the tilt angle. Frequency is 15–25 kHz. Accuracy is 0.5 deg in bearing and tilt, 5 yd in range. The maximum range and maximum depth are about 2000 yd and 1200 ft, respectively, these figures corresponding to a 1945 Admiralty policy that new (near-term) weapons and sensors should be developed to deal with fast (15-kt) diesel submarines capable of diving to 1000 ft. These figures were changed in 1950 to 25 kt and 1500 ft; the earlier figures were incorporated in Types 164, 170, and 177. The Type 170 operator scans in depth and bearing, centering the beam using a CRT display; the CRT is flanked by separate paper recorders for bearing and range, with a fire-control unit alongside the range recorder. Limbo depth settings are taken directly from the transducer's tilt angle. Type 170B can accept visual and radar data (e.g., the location of a submarine periscope). It was to have had a means of correcting for water sound profile, but that was never developed. This production version automatically passes data to the FCS (initially UCSF 1, for both Limbo and Mk 20 torpedoes). The same stabilizer controls both the sonar and the Limbo mortar.

The Type 170/Limbo FCS staff requirement was stated in 1948, preliminary trials of the "four-square" transducer having

been conducted in 1947. Production of Type 170 began in 1952, and the first production 170Bs began trials in June 1954.

A solid-state version, Type 170M, entered service in 1974. Ships already fitted with Type 170 could be converted to 170M during their normal refits, as the transducer was not changed.

A version of this sonar, Type 171, was planned for submarines, but it was canceled.

Type 170 is used to control a Squid or Limbo mortar. Many ships in which it was the primary sonar were reequipped with PMS-26 (see that entry). Surviving Type 170 sonars: Bangladesh (*Umar Farooq*), Canada (as SQS-502), Chile (ex-HMS *Achilles* has 170B. The other *Leanders* have had their Limbos removed but may retain the sonar.), India (*Leanders*, *Betwa*, and *Trishul*), Indonesia (Tribal class), Iran (Vosper Mk 5 frigates and possibly *Damavand*), Malaysia (*Rahmat* and *Hang Tuah*), Pakistan (*Leander* class), United Kingdom (*Leander*-class frigates retaining Limbo mortars).

◆ Type 177

This set was the first British scanning sonar. Unlike U.S. cylindrical-transducer types, 177 used a flat transducer to scan a sector. This use was practical because the British transducer scanned electrically rather than mechanically, using electronic delay networks. In effect, then, 177 used preformed beams similar to those of the wartime German GHG (which in turn was the basis of the U.S. postwar BQR-2).

This sonar was designed in 1949. Sector operation was acceptable because it was assumed that the targeted submarines would be limited to a sustained speed of about 15 kt (see the note on the Admiralty staff requirement under Type 170); search rate was 40 deg/min, so a dual sweep over 80 deg took 4 min (during which time a fast submarine might move 5 kyd). Although such submarines could be tracked at long range, they had very high bearing rates at short range (typically 10 deg/sec) and were lost. When the 20–25-kt nuclear submarines appeared in the late 1950s, Type 177 had to be replaced (by Type 184).

Type 177 operated at 6, 7.5, or 9 kHz. The 4-ft² transducer consisted of 12 vertical strips (10 transducers each, in pairs, each pair being driven by a separate transmitter), producing 5 beams, each 10 deg wide. When transmitting, the sonar rippled its signal across, a technique (equivalent to RDT) also used in the later Types 184 and 2001. There were four 14-deg receiving beams (A, B, C, D). Type 177 produced a sequence of pulses: 5 long (150 msec), 5 medium (20 msec, at 225 Hz above the base frequency), and 5 short (5 msec, at 225 Hz below the base frequency). The entire sequence took 875 msec, and the pulse interval depended on the range scale: 7.5 sec for 5 kyd, 15 sec for 10 kyd, 30 sec for 20 kyd. Four pings were needed to classify a target; at 20 kyd, that series of sector scans required 2 min. A dual sweep over 80 deg took 8 min (4 min at 10 kyd, 2 min at 5 kyd). The expected performance was as follows: Under good conditions (isothermal water, sea-state 1–2), a ship at 12 kt could expect to detect a submarine beam-on at 18 kyd. In somewhat worse conditions (negative temperature gradient, sea-state 2–3), the expected detection range was 8 kyd. Under poor conditions (surface layer, sea-state 4–5), the expected range was 3 kyd. The bearing accuracy was 5 deg on doppler display, 1 deg on sector-scan display.

The displays were paper range recorders for the separate beams, plus a CRT for the doppler display and a CRT for the sector-scan display.

Type 177 was accepted for service in 1957, the first tests having been conducted in 1951 using a scaled-up Type 170 transducer. This sonar was roughly comparable to the U.S. SQS-4 series. No longer in Royal Navy service, Type 177 survives on board some ex-British ships: Chile (*Condell* and *Lynch*), Indonesia (Tribal-class frigates), and Pakistan (*Babur*).

◆ Type 181

The towed asdic repeater target (TART) responds to all sonar frequencies. TART simulates a real sonar reflection. Since its position is known (it is towed), it can be used to compare a

given sonar's measurement of range with actual range. Presumably, TART's signals show the appropriate doppler shifts, and it can, therefore, be used to calibrate the doppler features of sonars since its own speed through the water (on the end of a towing cable) is known and is measurable. In theory, TART might decoy an active-pinger torpedo seeker. However, antiship torpedoes generally use passive seekers. The TART towed body generally resembles that of the Type 182 decoy. The Graseby G 733 SLUTT (Ship-Launched Underwater Transponder Target) would seem to be an expendable version of TART.

◆ Type 182

See countermeasures below.

◆ Type 183

This emergency underwater telephone operates at 8–9 kHz. Range is about 1000 yd. Type 183P was a portable version.

◆ Type 184 and 184M/Graseby G750

Type 184 was the first operational British sonar to use a cylindrical transducer, in this case 3.5 ft in diameter (3.5 ft high) of 32 staves (each consisting of 13 barium-titanate elements). Some Type 184s may have had a slightly larger transducer (4 ft × 46 in, operating at 7.5 kHz). The dome, which can accommodate Type 177 as an alternative, is 157.25 in long, 64 in in maximum width, and 61 in deep. It is retractable.

Like Type 177, Type 184 operates at 6, 7.5, and 9 kHz, producing 45-msec pulses (originally 75-msec pulses for the special doppler sector, for narrower bandwidth). As in Type 177, Type 184 probably also has a long pulse (of 150 msec) for long range. Range scales or modes (equivalent to pulse intervals) are 5, 10, and 20 kyd. Operation is very different from that of the U.S. scanning sonars. Transmission is RDT: sets of 12 staves are excited in phase, producing an 11.25-deg (10-deg vertical width) beam, and then are excited in turn to ripple the beam around in 32 steps. A full cycle takes about 1.6 sec. For all-around reception, beam-forming networks produce 8 split beams (the complexity of the networks precludes any finer division of the incoming signal). The phases of signals received in each half-beam are compared so that directional accuracy within a beam is about 1 deg. Filtering (to avoid reverberation) blanks out passive reception for part of each pulse interval: for 5 out of 7.5 sec in Scale 5, and for the first 10 sec (equivalent to a range of 8 kyd) in Scales 10 and 20 (leaving, respectively, 5 and 10 sec for passive reception). Passive targets are displayed around the edge of the PPI. At least in the original version (using 45-msec pulses), the source level was 136 dB.

The sonar also forms a 90-deg-wide doppler sector consisting of four 22.5-deg beams (bearing accuracy is about half a beamwidth, or 10 deg). This beam can be scanned over 270 deg. It uses 21 doppler filters and can handle 40-kt doppler.

There are 2 electronic markers. One is manually set to measure range and range rate, then is rate-aided for semiautomatic tracking. The other is manually set in range and bearing. Both transmit their data to a ship's FCS. The manual marker can be used to select an audio channel in any sector.

Type 184 was conceived in 1955 as a big-ship sonar, primarily for self-protection but also for future ASW ships. It was originally intended to combine Types 177 and 176 in a single transducer on a time-sharing basis. However, tests against fast submarines (HMS *Explorer* and then the USS *Nautilus*) showed that something very different was needed. Although reliable to 8000 yd, Type 177 searched too slowly and over too narrow a sector (the fast submarines cleared it too quickly). Type 184 introduced all-around scanning, simultaneous active (against submarines) and passive (for torpedo detection) operation, and tracking of multiple targets. The 90-deg search sector replaced the 40-deg sector of a Type 177 and provided a sufficient data rate. All-around scanning overcame the tracking limitations of the earlier sonar.

Compared to Type 177, 184 achieved somewhat shorter max-

imum range (because it did not revisit any particular sector as often) but searched a much wider area. It also replaced Type 176, the passive self-protection set. An 18-kt ship equipped with Type 184 could detect a 45-kt steam torpedo at 6 kyd; the detection range at 24 kt was 3 kyd, and at 30 kt was 1.5 kyd, in each case about twice Type 176's range.

As the successor to Type 177, Type 184 was designed to make maximum use of 177's components: 30% were retained, 30% were modified, and 40% were entirely new (including the transducer).

In 1985 Graseby was reportedly supplying a modification kit that replaced the existing 8-sector display with a 16-sector display for greater accuracy. Transmission was at dual frequencies.

The main innovations in the Type 184 design were the display of echo doppler and the use of fixed transmission intervals with a dual-frequency system. A CRT was adopted for greater efficiency in target recognition and tracking and as an all-around and continuous torpedo alarm. Doppler was found particularly valuable against a fast submarine.

The Graseby G750 is an export version of the solid-state Type 184M, providing data directly to a fire-control computer. It could be supplied in both LF/MF and MF/HF versions, in each case with a 32-stave array. Sales, for installation on board *Leander*-class frigates: India (6) and New Zealand (3). The Indian ships were the first 4 *Nilgiri* class and *Godavari* (and probably the *Whitby*-class frigate *Trishul*). The *Nilgiri* sets are being (or have been) replaced by Canadian Westinghouse SQS-505s (hull and VDS). The last 2 *Nilgiris* were completed with French Spherion sonars. The New Zealand G750s remain, supplemented by FM 15/2 towed arrays.

In 1989 Graseby announced a Type 184 modernization program, originally developed for the Royal Navy. It has 3 phases.

Phase 1 is based in part on G750 experience. The original 8 Type 184 channels are replaced by 16 channels (i.e., beamwidth is reduced from 45 to 22.5 deg) for better bearing accuracy and better overall performance (there is less surrounding noise in a narrower beam). More than half the tubes in the original 184 are eliminated by the introduction of solid-state electronics. All electromechanical selectors and timers are replaced by solid-state devices.

In Phase 2, 31 accurate digital filters are inserted in each of the sonar's 4 doppler beam channels; the sonar can then measure up to ±40 kt of target doppler with a resolution of 3 kt. Solid-state power amplifiers replace the original tube amplifiers, and a microprocessor-based signal-monitoring and fault-detection system (BITE) is added. In this phase the transmitter, monitor, doppler display, and hydrophone effect (passive) systems are all replaced; this completes all major work in the sonar instrument space.

Phase 3 provides 3 separate geographically stabilized memory color displays: DD (doppler display), PPI, and HE (hydrophone effect, i.e., passive). Phase 3 is applicable to existing G750 sonars. This is the phase concerned with the sonar control room.

Total installation time is 5–6 weeks.

Type 184P modernization in the Royal Navy began in 1987. By April 1989, 29 ships had received Phase 1 improvements. Phase 2 had been completed in 4 ships. The preproduction Phase 3 model was delivered in mid-1989. The Royal Navy was reported as very well satisfied with the Phase 1 and Phase 2 improvements, the sonar benefiting from much increased availability and reliability, and the operators being pleased with smooth tracking leading to better performance. However, the program is proving protracted, not because of any problem with the prime contractor or with the equipment, but because of the multiple competitions required for each contract for each phase. As a result, total program length will be about 10 yrs, and much of the savings to be expected will be lost because of the need to maintain so many of the obsolete Type 184s for much of that time.

The 184 modernization program presumably incorporates the technology being offered separately in the form of Sea Searcher (see below).

◆ Type 185/Graseby G1732

An underwater telephone (8–9 kHz), the Graseby G1732, advertised about 1976, is a modernized version for high-speed data transmission. This system may have been associated with British work on having nuclear submarines provide direct support to surface ships, the submarine acting, in effect, as a VDS and passing its data to a nearby surface ship. Reportedly, British experiments using HMS *Dreadnought* preceded U.S. interest in the direct-support mission.

Frequency is 8.9875 kHz. Data are transmitted and recorded automatically, at up to 66 words/min.

Type 185 was superseded by Type 2008.

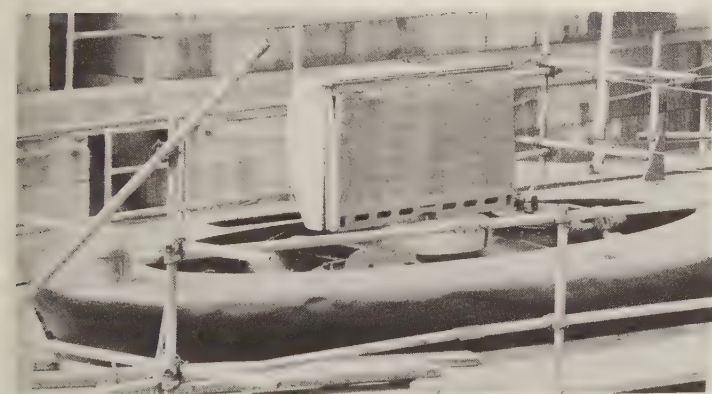
◆ Type 186

This passive MF sonar for submarines ("Knout"), introduced in 1956, was an adapted German GHG. It was, therefore, analogous to the U.S. BQR-2. One pair of arrays was on each side of the submarine, operating at about 1 kHz. Targets were sought by circling at slow speed or by following a sinuous course. With beam steering, this system became Type 2007.

◆ Type 187

An active-passive sonar for submarines (LF to MF), Type 187 is an adapted Type 718, with an added low-power mine-detection sonar. The sonar consists of a 5-ft-wide flat transducer rotated mechanically inside a streamlined dome with a maximum diameter of 72 in (length 192 in, height 57.5 in). Using split-beam techniques, this system can achieve a bearing accuracy of about half a degree.

In the Canadian SOUP refit program, the mechanically trained transducer head was replaced by a phased array.



Type 187 trainable sonar transducer with its sonar dome removed, on board a British *Oberon*-class submarine, 1988. The individual spot transducers can just be distinguished; the sonar is trained broadside. (A. Raven)

◆ Type 189

Type 189 is a cavitation indicator.

◆ Type 193

See the Mine Warfare section under countermeasures.

◆ Type 195/2069

The standard British helicopter dipping sonar was manufactured by Plessey. Type 195 was conceived in the late 1950s, ran pre-production tests in 1964–65, and entered service in 1966. The basic design was modernized in the mid-1970s, and production (of the final 195M version) ended in 1985. This sonar was a building block of Plessey's PMS 26 and 27.

The flat-faced transducer (10.8 × 38.4 × 7.3 in, 130 lb) consists of 4 vertical staves (13 elements each) covering a 90-deg sector. The staves are excited in turn to form a sweeping beam, and a delay-line network produces 3 receiving beams, each about 30 × 4.7 deg at 10 kHz. Pulse widths are 5, 25, and 40

msec. Phase comparison within each beam makes for a bearing accuracy of 3 deg. Operating frequencies are 9.5, 10, and 10.5 kHz, and range scales are 3, 6, 9, and 12 kyd. Typically, the sonar emits 2 pings in each 90-deg sector, then trains 90 deg for a new set of transmissions (an operation requiring 3 sec). Range accuracy is 1.5% of the scale selected. Type 195 was originally designed to achieve a range of 6000 yd under average conditions (3000 yd against a submarine below the layer, or 8000 yd if both transducer and submarine were below the layer), but that assumed that the sonar was deployed from a noisy piston-engined helicopter. Performance improved considerably when quieter gas-turbine helicopters entered service. In the original form, Type 195's peak power was 6.5 kW (source level was 129 dB).

The 45-lb transducer (in a 120-lb fish) is on an 800-ft cable. On-board electronics dead-reckons between dips so that the helicopter can maintain contact as it approaches its target. A doppler display is used for initial detection. The fish includes a BT to measure the sound-velocity profile. The maximum instrumented range is 8000 yd.

Type 195 is generally carried on board a Sea King helicopter. It was apparently offered to buyers of Lynx but proved rather heavy (a Dutch order was probably canceled in favor of DUAV 4). Users are Australia (Sea King Mk 50), Argentina (7 Italian-built Sea Kings and 2 Lynxes), Canada (31 CH-124s; replaced by AQS-13), Egypt (18 Sea King Mk 47s), India (Sea King Mk 42), Pakistan (6 Sea King Mk 45s), and the United Kingdom.

Type 2069 is an upgraded 195M, capable of operating at a greater depth (1000 ft) and of being integrated with an AQS-902 acoustic processor. At present the Royal Navy is the only user of the improved Type 2069 (44 purchased).

◆ Type 197

This sonar-intercept gear (French Velox system) consisted of a hydrophone atop the sail. Claimed accuracy was a few degrees, but in service this set could reportedly determine the direction of an active sonar transmission only to within a 90-deg quadrant.

◆ Type 199

A VDS, Type 199 is the British version of the Canadian SQS-504. The Canadian sonar was based on Type 170 in a towed version of the British 100-in dome. Development began in 1956, the first prototype being completed in 1961. Type 199 entered Canadian service in 1962. Although the Admiralty bought Type 199 in 1960, it did not enter British service until 1968; and all units were gone by the late 1970s. Type 199 survives in New Zealand (the frigate *Southland*). On board the Indian *Leander*-class frigate *Nilgiri*, Type 199 and the British G750 hull sonar have been or are being replaced by the Canadian Westinghouse SQS-505 (hull and VDS).

◆ Type 718

This postwar low-frequency (2.5 kHz for slow submarine speed, 10 kHz for high submarine speed) hydrophone is designed to obtain accurate bearings. Typically mounted topside, it is a split-beam. See also Type 187 above.

◆ Type 719

This postwar azimuth scanning hydrophone for submarines was designed for torpedo detection. Type 719 consisted of a hydrophone and a parabolic reflector. Originally to have been mounted in the keel, Type 719 was eventually installed in submarine sails, pointing aft. It was introduced in the postwar streamlined "T" and *Porpoise* classes.

◆ Type 2001

This British first-generation bow sonar for nuclear submarines was developed by Plessey. Type 2001 introduced conformal-array techniques. It was characterized as a bottom-bounce (rather than convergence-zone) set. Type 2001 was succeeded by Type 2020. Type 2001 was designed specifically for the prototype sub-

marine, HMS *Dreadnought*, one of whose design missions was the direct support of surface ships. It was, therefore, considered particularly important to be able to isolate or cancel out the noise of those ships. Much of the data that follows is taken from the 1958 design study, and they are probably very close to the characteristics of the set as actually manufactured.

Type 2001 was designed for both active and passive (long- and short-range) operation over a 240-deg arc around the submarine's bow, using a horseshoe-shaped array. It was initially to have been combined with a Type 719 rearward-looking passive searchlight, but that may not have been done; Type 719 would have fed the 2001 displays. The design included provision for feeding sonar data directly to the FCS (TCSS 5) and to the AIO. Because the same array had to function in both active and passive modes simultaneously, particular attention had to be paid to avoiding interference between the 2, by choice of frequency. A study showed that the optimum active frequency was 3 kHz, and the optimum passive frequency was 2 kHz for search and 6 kHz for short-range fire control.

The array itself was a 6-ft-high horseshoe about 40 ft long, its 87 staves (14 elements/stave, for a total of 1218) tilted back at an angle of about 20 deg for streamlining. The total weight was estimated at 20–30 tons. This array produced a total of 24 beams (about 10×16 deg) for active search. Normally, the beams tilted down 20 deg to compensate for the array's shape, but they could also be tilted another 20 deg for bottom bounce (the 1958 study showed no interest in either surface bounce or CZ operation). As in the major surface-ship sonars (177 and 184), the beam was rippled from one end of the array to the other. The planned source level, limited by cavitation, was about 137 dB. The pulse length was 200 msec at 3.25 kHz at range scales of 20 nm or more, or 100 msec at 10 nm. Returning pulses would be processed with 15 doppler filters, each 8 Hz wide (equivalent to a total of ± 30 kt). To catch short-range targets, a ripple of 20-msec pulses (at 3 kHz) always followed the main long pulse. It was processed in a 40-Hz filter (the doppler for ± 10 kt). There was also a separate active attack/classification mode, using a long FM pulse (1.25 sec at 3.5–3.8 kHz). Thus, at 20 nm a full scan would require 5.5 sec plus 1.25 sec for the special FM pulse. The sonar would probably require another 0.5 sec to begin to respond to echoes, so at worst it might miss targets 5800 yd away (4800 if the FM pulse were not used).

By 1958 experience with Type 177 showed that under some circumstances splash over between beams could cause problems in the ripple transmission. Type 2001, therefore, had an alternative, lower-powered ODT (broadcast) mode, in which case any target farther out than 600 yd could be detected.

The 24 long and 24 short pulses would be displayed separately on port and starboard CRTs for initial coarse target-bearing detection [range vs. bearing [waterfall] for the short pulses, doppler for the long pulses]. In 1958 CRT technology would not support large displays, and it was suggested that Type 2001 use the contemporary RAF radar technique of automatically photographing a small CRT, developing the film, and then projecting the result about 15 sec later. This technique actually was used in AIOs and probably in early Type 2001s.

Between the main displays was an additional CRT to show the sector in which the long FM pulse was used for attack or classification. This display had to be direct because a long time delay could not be tolerated during an attack. The central part of the sector display, corresponding to perhaps 160 yd in 1000, could be expanded in 8 increments for target classification (a technique equivalent to the contemporary U.S. ASPECT). Under cruising conditions the sector display would not normally be manned, its operator relieving one of the search operators. In combat, the port or starboard operator would initially detect a target and cue the sector operator onto it.

Another problem was range estimation. Type 2001 was expected to detect some targets as much as 60 nm away, and cursors were notoriously inaccurate at much shorter ranges. The solution was a range clock, set to run at the speed of sound, that clicked off every 100-yd interval. Presumably, it set a

counter when an echo was received; this was a very early approach to automatic target detection.

Type 2001 was designed to operate passively at 1.5–2.3 kHz; 2.5 would have been better but would also have suffered from reverberations from active transmissions. For greater precision, a second passive channel, at 5.5–6.5 kHz, was provided (with the second harmonic of the main active frequency, about 6 kHz, blanked off). For passive operation, the sonar formed 47 beams, each 10 deg wide, at 5-deg intervals (in active operation only half the beams were used). The passive signals were displayed on the main initial-detection displays, and there was also an audio channel for the sector-display operator.

All beams were formed by delay lines. That made for an additional problem. Ideally, the set had to be geographically stabilized to cancel out own-ship motion. However, such stabilization required continuous changes to each set of delays, an inadmissible complication (but one relatively easily handled in a fully digital beam-former of current type). The main displays, then, were stabilized in 5-deg steps. Only the sector display (for attack) was continuously gyro-stabilized.

The prototype Type 2001, evaluated on board HMS *Verulam*, had flat panels instead of individual staves; that was probably the configuration ultimately adopted. Scaled up from the version on board this ship, the transducer almost certainly consists of 24 panels, each 2 ft wide and 6 ft 9 in high and each carrying 56 spot transducers. Type 2001 was built, then, as 24 parallel sonars. Such a design should have simplified production (transducer alignment) as well as the beam-forming problem.

Type 2001 (AA) is in the eyebrow position in *Valiant*-class SSBNs. 2001 (BC) is in the chin position (*Swiftsure* class).

◆ Type 2004

Type 2004 is a submarine hull-mounted sound velocity meter, for sonar performance prediction. Such predictors are used to help sonar operators choose optimum operating modes. They also help in the interpretation of sonar data, since the predictor can estimate ray paths.

◆ Type 2005

Type 2005 is the French DUUX 2A passive range-finder.

◆ Type 2006

Type 2006 is the U.S. AN/BQQ-3 LOFAR detector/classifier (see U.S. sonars below).

◆ Type 2007

This LF passive flank array for submarines is a replacement for Type 186. Type 186 used fixed beams, but 2007 can steer them electronically. It operates at 1–3 kHz and is used for initial detection, bearing resolution, and limited TMA. Each of 2 flank arrays has 24 hydrophones. This system can also use a towed array, and existing 2007s are being converted to towed-array use. 2007 is otherwise now leaving service.

The requirement was stated in the late 1960s, and the array was developed by British Aerospace; the first unit entered service in 1971. Later units were manufactured by Graseby Dynamics. Type 2007 was bought for Australian, Brazilian, Canadian, and Chilean *Oberons*. The addition of a TAPS processor converts Type 2007AA to Type 2007AC, with greater sensitivity and better target discrimination.

When the submarine is moving so fast that noise drowns out the flank array, the Type 2007 display can be connected to the towed array.

◆ Type 2008

This HF underwater telephone ("say again" machine) replaces Type 185. This set is also used as a short-range passive sonar. Many navies apparently use their underwater telephones this way, since they provide wide-band omnidirectional reception. Type 2008 uses 3 fixed transducers and 2 small trainable ones in the sail.

◆ Type 2009

Type 2009 (UARS: underwater acoustic recognition set) is a secure multitone-simplex communications and encoding device. It is IFF and uses G-tone codes for challenge and reply.

◆ Type 2010

Type 2010 (ACUTE) is an acoustic teletype, working with Type 2008 and coding its signals for better resistance to jamming and for automatic error detection. Reportedly, tests showed that the use of an automatic error-detecting code made for 98% accurate reception and ultimately for several-fold improvement in transmission rate and in effective range.

◆ Type 2011

Type 2011 is a noise target.

◆ Type 2012

Type 2012 is a passive sonar-classification set, presumably replacing 2006.

◆ Type 2013

Type 2013 is a bathythermograph.

◆ Type 2014

An Acoustic Ray Trace Indicator (ARTI, sonar ray path predictor), this set was intended to guide ships using VDS (Types 195 and 199) in setting sonar depth. Type 2014 is now obsolete.

The ray trace is shown on a CRT, which can be photographed for record purposes. This device was marketed as ARTI (acoustic-ray-trace indicator). It was particularly associated with Type 199 but was carried by some submarines.

◆ Type 2015

Type 2015 is an expendable bathythermograph (XBT).

◆ Type 2016/2020/2028

Type 2016, an MF hull sonar introduced in the Type 22-class frigates, was the first British sonar with substantial computer assistance. In the Falklands 2016 was credited with the ability to overcome multiple reflections and, thus, to distinguish an Argentine submarine on the bottom. The Type 184 equipping other British frigates seemed to have no such capability. On the other hand, 2016 was criticized for its lack of direct output, in the form of headphones, and thus presumably for its poor passive performance.

The replacement for 177 and 184M, Type 2016 uses 2 transmitters operating at 5.5, 6.5, and 7.5 kHz; the broad variation in frequency helps avoid intership interference. Operating modes are ODT (omnidirectional transmission) and SDT (steered directional transmission). Capabilities include automatic target detection and tracking.

The cylindrical transducer consists of 64 staves, each of 12 elements. There is also an auxiliary 12-element vertical array that can be rotated around the main transducers to monitor transmission close to the transducer so that the distant transmission characteristics can be estimated. There are 2 horizontal beams, 1 nearly horizontal and 1 dipped at 7 deg, to penetrate beneath the surface layer. The horizontal beam pattern consists of 32 pairs of beams, presumably chosen so that Type 2016 can follow targets by beam-splitting. Total transmitter power is 44 kW. The associated computer is a Ferranti FM 1600B with 64k memory.

The 6-ft-diameter array is mechanically roll-stabilized, and it can retract into the hull. The sonar uses 5 electronics cabinets for receivers (4 active, 1 passive), 2 others for transmitters, and another for T/R control circuits. The signal processor occupies 3 separate cabinets with another for computer spares.

There are 3 side-by-side consoles, each with a circular CRT, keyboard, and roller ball. Units above the main CRTs are used for communications and show readouts of ship's parameters. The left-hand display is used for classification/tracking (doppler

B-scan as well as A-scan for target details, using ASPECT). This CRT can show a blow-up of part of the surveillance display, either in B-scan or as a cut through the beam in a vertical plane. The center CRT is used for surveillance (PPI), and its data can be passed to the AIO; it is also used to monitor system performance. The right-hand console is passive (including all-around torpedo warning). It is normally used for passive target tracking (bearing-time waterfalls show target histories) and to show frequency ranges. There is also an auxiliary display, on which data can be logged and such information as bottom conditions and sound speed displayed. Normally, the operator sits at the center (surveillance) PPI, supported when necessary by an operator at the left-hand (tracking) display. The system incorporates an automatic torpedo alert to AIO.

In cruising status, the system has 1 operator at the center (PPI) console, supported when necessary by an operator at the left-hand (tracking) display.

Type 2016 was manufactured by Plessey, although Ferranti is responsible for signal processing (which uses an FM 1600B computer). Ferranti began research into computer-aided sonar in 1967, working with the AUWE: the objective was to improve the operator's detection performance and the quality of sonar data passed to the computer combat system. Work on the associated sonar began in 1971, a prototype running sea trials on board HMS *Matapan* in 1971–76. An operational prototype was tested in 1978 on board HMS *Broadsword*. A total of 34 were built for Type 22 and Batch 3 *Leander*-class frigates, for later Type 42 destroyers, and for the *Invincible*-class aircraft carriers. 2016 is to replace Type 184 on board retrofitted Type 42 destroyers. Type 2016 in turn will be replaced by Type 2050. Three of 4 Type 42 Batch 3 destroyers were completed with 2016, and it has now been back-fitted in two Batch 1/2 ships.

Type 2020, a second-generation sonar for nuclear attack submarines, is the submarine version of Type 2016. 2020 is in the *Trafalgar* class, replacing Type 2001. 2020 uses steered pre-formed beams (DIMUS). Reportedly, active frequencies are 5.5–5.7 kHz, and passive operation is at 2–16 kHz. Type 2020 is designed primarily for passive detection, including the use of bottom-bounce and CZ modes. Features include automatic tracking for reduced workload. There is a manual override.

The upgraded version of Type 2020 is designated MODEX. It uses 2 Ferranti universal raster-scan (i.e., television-like) displays for both passive and active data, replacing the earlier curvilinear PPIs. Reportedly, the universal screens make for faster operator reactions during close contact or in torpedo evasion. The original hard-copy (paper) displays are retained for mission analysis. In addition, plasma touch-panel displays replace the earlier keyboards.

The Type 2020 requirement, for *Trafalgar* class, was stated in 1976–77, Plessey receiving a contract in 1977. 2020 was tested in 1981/82, the first production delivery following in October 1982 for HMS *Tireless*.

Type 2028 was a smaller version of 2016 but was not procured.

As of 1990, a bow-mounted version of 2016 (for the *Sheffields*) is out to tender.

◆ Type 2017

Type 2017 was a spectral analyzer (now obsolete).

◆ Type 2018

Type 2018 is a submarine DEMON frequency analyzer with LOFARgram output (DIANA).

◆ Type 2019 (PARIS)

This sonar intercept gear was developed under the British/French/Dutch PARIS (Passive/Active Range-and-Intercept Sonar) program. 2019 covers up to 360 deg at 2–14 kHz. It is installed in modern submarines, including *Upholder* class (in which an active pinger is added). The project began in 1965, a prototype being built in 1968–69. Thomson-CSF was prime

contractor. The Royal Navy placed its contract in 1973, testing a prototype in 1974–75 and ordering its first sets in 1977. Type 2019 is currently being modernized.

In *Trafalgar*-class submarines, Type 2019 is located forward of the sail, in a small sonar dome on deck.

◆ Type 2021

Type 2021 is an expendable bathythermograph (XBT).

◆ Type 2022

Type 2022 is an acoustic beacon.

◆ Type 2023

This towed array for ballistic missile submarines is based on the U.S. BQR-15. 2023 uses a British array and U.S./British electronics and is retrievable, the array being stowed in the ballast tankage. The requirement was stated in the late 1960s, Plessey receiving the R&D contract early in the 1970s, roughly simultaneously with 2024. Arrays were installed during major overhauls. In the early 1980s TAPS, a towed-array broad-band processing system, was added. Reportedly, it reduces the stern null, i.e., allows the sonar to form narrower beams. This array also has a 3D heading-reference sensor (by Ameeco).

Reportedly, Type 2062 was developed as a replacement, the cost of BQR-15 wet-end spares proving very high.

◆ Type 2024

A clip-on towed array for nuclear attack submarines, 2024 is installed on board *Valiant*- and *Swiftsure*-class submarines and on board the first 2 *Trafalgars*. 2024 in turn is being replaced by Type 2026. Existing arrays are being fitted with the new broad-band TAPS processor. Because 2024 is a clip-on array, at least 1 has been lost to underwater obstructions. In the Falklands War, HMS *Conqueror* reportedly used her array to track the Argentine cruiser *Belgrano* from beyond the horizon, keeping station for 2½ days.

The contract was let in 1970, followed by preprototype tests in 1974 and service in 1975. Reportedly, 2024 uses an Ameeco wet end designed by AUWE, a Plessey beam-former, and a Scientific Atlanta waterfall display. 2024 typically uses the Type 2035 processor.

◆ Type 2025

Type 2025 is an expendable bathythermograph (XBT).

◆ Type 2026

This British/Dutch second-generation towed array for attack submarines uses a stronger cable, more sensitive hydrophones, and improved reception. 2026 has a new broad-band LF processor and an updated narrow-band processor. A photograph of the display shows 3 large CRTs, a configuration that suggests that 3 octaves are covered. Type 2026 was developed in tandem with 2031(I) to replace Type 2024. As of 1986, 5 British and 5 Dutch arrays were on order.

Marconi Underwater Systems received the R&D contract for this array in 1977–78, the Royal Navy specifying a clip-on with a stronger array. 2026 was tested in 1983–85. Meanwhile the Royal Netherlands Navy negotiated for 5 (concluded late 1985). The array was approved for service use early in 1986. Type 2026 entered British service in 1987.

Type 2026 normally employs a clip-on array attached to the port stern plane. However, recently HMS *Turbulent* tested a reelable array, the winch for which was housed in a hump visible aft, above the waterline. Presumably, the array itself was stowed in the narrow space between pressure and outer hulls. The Type 2026 processor can be used to classify signals from the intercept sonar and the Type 2008 underwater telephone.

Reportedly, the Dutch version, for the *Walrus* class, uses a Signaal display processor, a Marconi beam-former, and an Ameeco wet end.

This sonar is described officially as Integrated Sonar Phase I.

◆ Type 2027

Type 2027 is a prototype passive-ranging sonar using the 2001/2020 array.

◆ Type 2029

Type 2029 is automatic digital sonar-intercept gear.

◆ Type 2030

Type 2030 is classification equipment: Spectral Dynamics's 2-channel spectrum analyzer with waterfall display (U.S. AN/BQR-22).

◆ Type 2031

Type 2031 is the British towed-array sonar for surface ships. Unlike the U.S. Navy, the Royal Navy uses its towed-array frigates not only tactically but also for surveillance; the RN, therefore, requires greater ranges, achieved by a combination of lower frequency (presumably longer arrays) and more processing. There are 2 versions: 2031(I) for 4 frigates operates at low speed and has relatively simple processing; 2031Z, for Type 22 frigates (Batches 2 and 3) operates at a higher tow speed. All combine broad- and narrow-band processing.

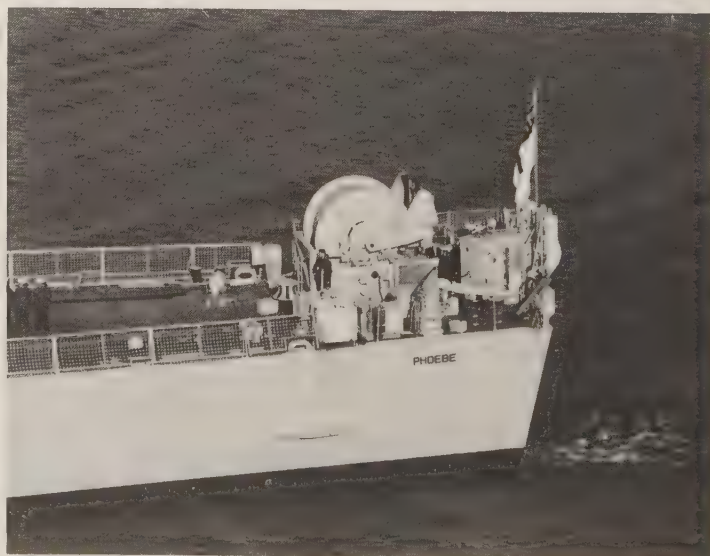
Reportedly, 2031 is a 5-octave system. Type 2031Z incorporates the newer (ca. 1983) Curtis processing architecture, which drastically cuts computer requirements. The Curtis processor is a very fast special-purpose digital computer with a fixed program and over 100 Mbytes of memory. In 1987 it was reported that 2031 is normally trailed more than 1600 m astern, at speeds of 8–10 kt down to 2–3 kt; reported range is "over 100 nm," which presumably means at least 3 CZs (105 nm in the Norwegian Sea).

Reportedly, the array is 89 mm in diameter and over 500 m long, i.e., twice the length of an SQR-19 [3.5 in × 1640 ft].

The initial R&D contract was awarded to GEC Avionics in 1971/2, followed by trials on board HMS *Matapan* and *Lowestoft* in 1978/81, four 2031(I) being installed on board modified *Leanders* in 1982. A fifth was built as a spare. Thirteen 2031Z were purchased.

The associated processor was the GEC Avionics JASOND (1976), the first British digital 360-deg towed-array processor. It was first tested on board a British submarine. JASOND was based on the earlier Sonalyzer (1974), used as a 4-channel sonobuoy mission replay unit.

Type 2031Z reportedly embodies a new (Curtis-architecture) processor, developed by AUWE, which drastically reduces weight (by 60%) and power requirement (by 80%) and is also much less expensive than its predecessors. The equivalent submarine sonar is Type 2046.



Type 2031 handling gear, HMS *Phoebe*, 1990. (Leon van Ginderen)

◆ Type 2032

This add-on package to extend the capability of a submarine's bow sonar includes a special transducer and beam-former; 2032 complements Type 2020. 2032 uses 15 modified (detuned) hydrophones within the 2001/2020 bow array for LOFAR. It was first delivered in March 1989 (Ferranti).

◆ Type 2033

Hydrographic survey-ship sonar.

◆ Type 2034/2053/Sonar 3000 PLUS

Dowty's (Waverley) dual (left- and right-hand arrays) side-scan sonar has been in British service since 1976. The current version of the towed body ("towfish") is Mk 3. Sonar frequency is 110 kHz (100-msec pulse), and range scales are 75, 150, and 300 m (PRFs of 10, 5, and 2.5 pps). Over 50 units are in current use by the RN Hydrographic Service.

Sonar 3000 PLUS is a family of side-scan devices developed from 2034, and Sonar 3010 has been proposed as a mine locator (analogous to the U.S. Klein Mk 24; see the Mine Warfare section). Sonar 3010 adds a higher-frequency (300-kHz) mode for short range and high precision (37.5-m scale) and can mark a target.

Type 2053 is the British designation for Sonar 3000.

◆ Type 2035

BQR-23 processor used with the Type 2024 array (16-channel waterfall).

◆ Type 2038

This surface-ship towed array, planned as a 2031I successor, was canceled because of the success of the Curtis-architecture 2031Z.

◆ Type 2040

This sonar for new British diesel submarines (*Upholder* class) is based on the French Thomson-CSF "Argonaute" passive system. 2040 was a British/French/Dutch development of the French Eledone (DSUV 22). The Dutch system is called Octopus.

The system as a whole consists of a circular bow transducer with a separate active transmitter (usually in the sail), plus a passive sonar interceptor (PARIS, Type 2019).

There are 3 types of bow transducers, with 32, 64, or 96 staves; but only the 64-stave version is in service in the 3 navies. The 32-stave version was proposed for the abortive CA-type French export submarine. The passive mode uses 128 preset LF channels. It can track 12 targets simultaneously, and it interfaces with the submarine's FCS. The FCS uses Type 2040 data for its TMA solution.

The original Thomson-CSF system was a new passive/active commercial venture intended for the French submarine program of the late 1960s and early 1970s. The French *Agosta*-class sonar requirement was issued in 1971, Thomson-CSF offering its Eledone system and receiving an update contract (development 1971–76, tests 1975–76, approval for use 1976 as DSUV 22). Octopus was developed specifically for the Dutch *Walrus* class, and a further development won the British competition in 1982 for Batch I *Upholder*-class submarines. Octopus was ordered in 1984.

As installed in an *Upholder*, Type 2040 has a 64-stave (3-m-diameter) cylindrical passive array on the bow forward of the torpedo tubes, and a smaller-diameter cylindrical active sonar in the sail (mechanically rather than electrically trained). The bow array differs from that of the original French system in having 3, rather than 2, tiers of staves. 2040 requires 4 processing cabinets for its 4 operating modes (adaptive, active, passive, and intercept). There are also flank arrays and a towed array. Up to 12 targets can be tracked simultaneously, data from each of the 12 threat channels feeding into the automated combat system for TMA. By using combinations of the 12 channels, the sonar can determine direction to within 0.1 deg.

The display uses a color CRT to display signals from different sensors (or from different operating modes) simultaneously, for correlation and, therefore, classification. For example, the display can easily distinguish between a helicopter's sonar (which shows up only on the intercept sensor) and a ship's hull sonar (which will be accompanied by propeller sounds, visible on the combined display).

◆ Type 2041

Upholder-class passive ranger.

◆ Type 2042

Self-protection (presumably decoy) submarine system.

◆ Type 2043/2044/2045

These are elements of the Trident integrated sonar (Type 2054). Type 2043 is the active/passive bow sonar; Type 2044 is the towed array; and Type 2045 is the sonar intercept receiver. The separate Type 2043–45 designations are no longer used.

◆ Type 2046

This core processor/display for submarines' towed arrays embodies Curtis architecture (see separate entry). It is a 3-octave system. There are 4 adjacent operator positions, each with a CRT and a flat electroluminescent panel beneath it. Type 2046 has some hardware in common with 2031Z, but is even more compact; the signal processor is housed below the displays.

Compared to Type 2024, Type 2046 reportedly provides an improved narrow-band search capability; the associated towed array uses fiber optics to transmit data from array to submarine.

The Type 2046 designation has also been applied to the submarines' towed arrays themselves, the replacements for Type 2024s. As of 1987, a total of 27 had been ordered, the first having been delivered that year.

◆ Type 2047

Plessey's wide-band hard copy (pen output) analyzer covers 5 Hz–3.2 kHz and produces up to 12 LOFARgrams simultaneously. 12-channel narrow-band processor to replace 2035. Type 2047(AC) is a 16-channel processor for the 2024 array.

◆ Type 2048 (PMS 75)

Plessey's Speedscan is a display that allows a conventional Type 193M minehunting sonar to function in side-scanning mode. The transducer is trained 90 deg on the beam, and Speedscan records the echoes obtained. Its beam-former transforms these data into a map of a strip of the bottom, using 3 pings for each point in the map.

◆ Type 2050

Ferranti's bow-dome sonar for Type 23 frigates is the successor to Type 2016 and reportedly uses the same transducer but a different signal processor (although the new bow location suggests a larger and lower-frequency sonar). 2050 is credited officially with an excellent software-based ability to reject bottom echoes, for good performance over the continental shelf.

2050 is an upgraded version of the Ferranti FMS 21 export sonar. Operating at 4.5–7.5 kHz, with sixty-four 5.5-deg beams, 2050 should be capable of BB and CZ operation. Four electronic cabinets replace the 12 of 2016. The requirement included digital operation and simpler (more maintainable) electronics. Type 2050 is a fully digital sonar; the array is sampled by the pre-processor, and signals are digitized before passing into the beam-former. The sonar requires a total of 5 cabinets, including 1 for target classification and 1 for data-display handling. Type 2050 uses Curtis architecture and has the same type of console as Type 2054; it incorporates 25 M700 microprocessors.

Unsuccessful competitors were the Plessey PMS 46 export sonar and a Marconi sonar.

Trials of a hull-mounted version began in 1986 on board HMS *Jupiter*, followed by sea trials in 1987 on board HMS *Scylla*. As of 1987, a total of 17 Type 2050s were on order, the first pro-

duction unit having been delivered in mid-1987. As of mid-1989, the Royal New Zealand Navy was evaluating a version of 2050 on board HMNZS *Tui*, prior to buying the sonar for its *Leander*-class frigates.

Unit cost of Type 2050/2051 is about \$4–5 million (1990).

◆ Type 2051 (Triton)

Type 2051 is a new sonar for the modernization of diesel-electric submarines. Plessey (with Ferranti and GEC Sonics) won the contract in 1985. 2051 is a partially integrated sonar using an active/passive bow array in a new streamlined bow dome, a broad-band bow processor, 2 conformal flank arrays (2-octave narrow-band processor), an intercept sonar, and a clip-on towed array. The bow array has 32 preformed beams in a new low-noise dome. 2051 is a full upgrade rather than a simple replacement of Type 186 by Type 2007. 2051 was the first fully integrated British sonar, using 4 Ferranti multipurpose displays with plasma touch panels. 2051 was developed to compete with a system offered by Thomson-CSF. The R&D contract went to Plessey/Ferranti/GEC Sonics for an upgraded FMS 12, leading to R&D in 1982–84.

The prototype was tested in HMS *Opossum* (which had the first British GRP submarine bow); the first production set was in HMS *Otter*. Triton is the commercial name, Plessey acting as design authority. Triton 1 is the *Oberon* suite, and Triton 2 has been offered for follow-on Type 2400s. The manufacturers claim that Triton 2 is 15% less expensive than *Argonaute* and 10% less expensive than the German CSU 3-4 used for Australian *Oberon* upgrades.

Three Type 2051s, originally ordered for the Royal Navy, were provided for refits of the 3 Canadian *Oberons*, and this sonar was also offered to Malaysia (presumably for submarines that country planned to buy). The Canadian ship sets were diverted from Royal Navy production.

◆ Type 2052

This interim clip-on towed array for nuclear attack submarines is intended as an upgrade for older units; it is derived from Type 2024. This Type number has also been used for the Marconi TAPS (towed-array processing system) broad-band signal processor. Passive broad-band towed-array sonar used with 2024 for submarines lacking Type 2007 (SSNs prior to *Swiftsure* class). This is the basis of the Marconi GETAS export system.

◆ Type 2053

Waverly's hydrographic side-scan sonar has advanced digital processing (naval version of Sonar 3000); see Type 2034.

◆ Type 2054

Plessey's sonar suite (active/passive/towed passive) is for British Trident strategic submarines. The requirement was issued in 1983, proposals following in 1984; Plessey was chosen early in 1985. 2054 includes a Sub-Harpoon missile capability. Signal processing is entirely digital, the signals being transformed to digital form before being passed to the beam-former. That process may be unusual among modern sonars. This system employs a Type 2043 active/passive sonar, a Type 2044 towed array, and a Type 2045 intercept sonar. These subdesignations are no longer used.

Plessey is responsible for the bow sonar, the beam-former, and the signal processor; Marconi for the intercept sonar; and Ameeco for the towed array. There will be 5 consoles, each with two 17-in display screens and touch-sensitive plasma control panels.

The associated sonar-activated FCS is SAFS 3. The tactical data-handling system is DCC(BN).

The preproduction version of Type 2054 was completed early in 1989.

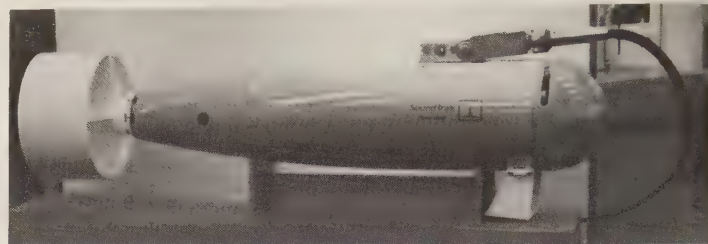
◆ Type 2057

This is a new surface-ship/submarine towed array to replace both 2031Z and 2026/2046. It is to be much longer than that of

2031Z, to operate at lower frequencies. The 2 competing teams, both of which received 18-month contracts in 1989, consist of Plessey leading GEC Avionics (Sonar Systems Division) and Ferranti (supported by the Communications Division of Dowty Marine). A winner will be chosen in 1992, and Type 2057 should enter service in 1995.

There is no announced Royal Navy program for a multiline array.

◆ Type 2058 (Soundtrak)



Type 2058 fish. (Author)

Thorn-EMI's towed sound source for acoustic ranges is proposed as a component of Vosper-Thorneycroft's Sea Serpent multi-influence towed mine-countermeasures array. The free-flooding towed body is based on that of the Type 182 decoy, and Type 2058 is towed from the Type 182 winch.

◆ Type 2059

Type 2059 is an HF sonar, developed by Edo Almondbury, used to track PAP 104 minehunting vehicles; it has also been used to track submarine rescue vehicles. The 3-in transducer is set at 22, 23.5, 25, 26, or 28 kHz, and the transponder aboard the vehicle replies at 30 kHz. The very short receiving array detects transponder-signal direction by comparing the phase differences between its receivers; the computed position of the vehicle is transmitted directly into the ship's tactical data system. Multiple frequencies allow a single Type 2059 to track 5 targets simultaneously.

◆ Type 2060

Surface-ship XBT to replace 2015.

◆ Type 2061

Waverley's single-console Curtis-architecture processor is for Polaris strategic submarines. This interim narrow-band processor is being replaced by 2046.

◆ Type 2062

The replacement for the Type 2023 SSBN towed-array sonar, Type 2062 uses a Waverley dry end based on that of Type 2031Z and an Ameeco wet end. 2062 is being replaced by Type 2046.

◆ Type 2063

Submarine self-noise monitor.

◆ Type 2064

Reportedly, minehunter tracker.

◆ Type 2065

Experimental retractable thin-line array.

◆ Type 2066

Dowty surface-ship torpedo countermeasure.

◆ Type 2067

Underwater tracking system.

◆ **Type 2068**

Gresham-CAP's sonar-environment prediction-and-display system (SEPADS) (sonar ray-path predictor) is used specifically with surface-ship towed arrays. 2068 incorporates a library of oceanographic information on a 50-Mbyte hard disk and a series of sound-propagation loss models (each taking about 1.5 sec to run) to predict ranges and to estimate the optimum array depth. The associated computer is a commercial Digital PDP-11/44, and the prediction is updated every 4 to 6 hr.

◆ **Type 2069**

See Type 195, of which 2069 is an updated version. Reportedly, it operates at much higher power at a lower frequency.

◆ **Type 2071**

Submarine noise decoy.

◆ **Type 2072**

Submarine flank-array processor.

◆ **Type 2073**

Type 2073 is an emergency underwater telephone (rescue pinger) for submarines, made by A.B. Precision (Poole), Ltd. It incorporates a 10-kHz submarine-location pinger (effective range 8000 yd), a 10-kHz communications channel, a 37.5-kHz channel for voice communication with a DSRV, a 27-kHz channel for communication with commercial submersibles, and a 43-kHz telephone channel for diver communication. Effective range: 4000 yd at 10 kHz, 2500 yd at 27 kHz, and 750 yd at 43 kHz. Type 2073 is currently in production for the Royal Navy.

◆ **Type 2074**

This fully integrated active/passive bow-array sonar, for new nuclear attack submarines, is to replace Type 2020/2027. Plessey received the development contract in February 1988. Type 2074 is derived from Type 2054. Deliveries should begin in mid-1990; as of mid-1989, contracts had been awarded for 7 units.

◆ **Type 2075**

This hull sonar for Batch 2 *Upholder*-class diesel-electric submarines (for delivery from 1991) is to replace Type 2040. The array locations would match those of Type 2040. Tenders for this contract were invited 24 August 1987, due 25 February 1988. Ferranti was awarded the contract for this system. It has a newly designed bow cylindrical array plus a transmit array, a new passive-ranging array, new intercept-array modules around the fin (which houses a new HF scanning array [see FMS 52, below] for mine detection), a stern array, standard flank arrays, and a clip-on towed array. Six of the outboard transducers are of a new Ferranti design. Each of 5 operator consoles will have 2 color screens, a trackball, and touch-sensitive plasma panel controls. The consoles will be linked by fiber-optic cables in an LAN. Each will be able to display and control any sonar function. Processing will be by a combination of 32-bit microcomputers and parallel processors (transputers), and software will be written in ADA.

The export version of Type 2075 is FIS 3 (Ferranti Integrated Submarine Sonar Suite), announced in 1989.

Type 2075 was the first Royal Navy total-sonar-suite contract offered to a single source.

◆ **Type 2076**

This projected sonar suite for the *Swiftsure* and *Trafalgar* classes is to replace Types 2001 and 2020. Competitive project-definition contracts were to be let in 1990. The Royal Navy hopes for some degree of commonality with 2078, below.

◆ **Type 2077**

The contract for this submarine obstacle-avoidance sonar was awarded to Plessey early in September 1989; it won over the Ferranti FMS 52. Type 2077 is a high-definition LPI (low prob-

ability of intercept) sonar, probably equivalent to the U.S. MIDAS of the *Los Angeles* class. As of 1989, the Plessey system had not yet been tested as a unit. However, it uses proven arrays and components, some of the latter identical to those of the Hydra selected for Swedish submarines and to those of the British Type 2074.

◆ **Type 2078**

This integrated sonar suite is being developed for the next-generation British nuclear attack submarine, SSN 20. Bids for 2078 closed on 14 September 1989, and 2 project-definition contracts were to be awarded in the spring of 1990.

◆ **Type 2093**

Type 2093 is a replacement for Type 193. See the Mine Warfare section.

◆ **Type 2095**

Type 2095 is the generic designation for the successor for the Type 195 helicopter sonar. Cormorant (see below) may be chosen as the basis for Type 2095.

◆ **Merlin Dipping Sonar (SR 6629)**

The Cardinal Points specification for the dipping sonar for the new Merlin helicopter (the British version of the Anglo-Italian EH-101) was to have been issued in February 1988, but it was not issued until about April 1989. At that time 5 months were allowed for a response, and 7 for evaluation. AQS-903 had already been selected as the Merlin sonobuoy processor, but it was no longer clear that it would also have to process sonar data. The alternatives (as of mid-1989) were HELRAS, Cormorant, HIPAS, FLASH, and Osprey. The Italians provisionally selected HELRAS for their version of EH-101 in 1984, but as of 1989 they were not yet fully committed.

◆ **SIU**

The Sonar Interface Unit federates the existing British submarine sonar suites that were designed as combinations of discrete units. The SIU allows any console to display and process data from any of the arrays. As mounted in HMS *Turbulent*, the SIU connects Types 2007AC, 2008, 2019, 2020, and 2026. This combination is presumably a standard suite.

◆ **Aal**

This experimental surface-ship/submarine towed array is being developed by Ferranti under contract to the French navy. It is being run in parallel to the British programs (1 of the 2 competitors for which is Ferranti) defining the next-generation British towed-array sonar (see Type 2057 above). Aal will be a digital array, using outboard electronics in the array proper to digitize the analog signals from the hydrophones. They are multiplexed to run along a single link back to the ship. Both electrical and fiber-optic links are to be tested. Ferranti claims that the outboard multiplexer/digitizer substantially increases array performance and makes for substantial growth potential. Although Aal is currently an experimental program, the French navy expects to buy up to 20 of these arrays for operational use.

With the formation of the Ferranti-Thomson Sintra joint venture on 31 May 1990, this is now an Anglo-French project. However, the Aal contract was awarded prior to the formation of the joint venture, and it is, therefore, listed in the British section of this book.

◆ **AS380**

Because of its high resolution, AS380 can be used both for mine countermeasures and short-range submarine detection. UDI claims that it can detect targets out to 3000 m and classify them at ranges up to 1000 m.

One was supplied in 1986 for installation on board a Swedish navy KV-107 helicopter.

An AS380E version, with electronic beam-forming, is under

development in collaboration with Marconi Underwater Systems and Marconi Maritime Applied Research Laboratories.

◆ ATAS

Active towed-array sonar, developed by British Aerospace, consists of a flex-tensional transducer towed up to 900 m astern of a ship, with a 20-m (88-mm diameter) towed-array receiver another 300 m farther aft. Transmission is omnidirectional (in the horizontal plane), with a beamwidth of 25 deg in the horizontal. The resolution of received bearings is 0.5 deg in the broadside beam.

The array is actually 3 arrays in a single fairing, so there is a triangle of transducer at each sensor point. The system automatically selects the pair with the greatest horizontal separation at any instant and, thus, has no difficulty in avoiding the right/left ambiguity of conventional (single-line) arrays.

Operating at 3 kHz, the array is 16 wavelengths long and the transducer is 2 wavelengths high.

The entire system can be streamed from a ship of 250 tons or more, at a depth as great as 200 m. Operational speed is 5–20 kt, and the array can survive towing at 30 kt.

The transmitter requires a peak power of 25 kW and is 1.2 m high, 0.7 m long, and 0.3 m wide (weight 200 kg). Frequency is 3.5 kHz. On-board electronics weigh 280 kg, and the handling system weighs 7 metric tons. The 900-m cable is 23 mm in diameter and weighs 1.5 metric tons.

Several ATAS were reportedly procured by the U.S. Navy early in 1987 to support the development of an active surveillance towed array, presumably a future SURTASS system (see the Surveillance and Control section).

ATAS was tested in the Baltic on board the Swedish mine-sweeper *Skafo*. Thomson Sintra is now collaborating with British Aerospace in this project, supplying the signal processor and a console adapted from that of the Spherion sonar.



ATAS active transducer. (Author)

◆ COMTASS

Plessey's Compact Towed-Array Sonar System is available both for surface ships and for submarines. There are 3 versions: COMTASS 1, which gives broad-band surveillance in 3 frequency bands; COMTASS 2, which adds narrow-band surveillance and classification; and COMTASS 3, which adds automatic detection. The array is 97 or 129 m long, with a diameter of 63 mm, and is towed on a 1000- or 1500-m cable (diameter 25 mm). Total wet-end weight is 2600 kg, and overall weight is

6 tons. Plessey claims that contacts can be detected at CZ range, about 30 nm.

This system was evaluated by the Royal Swedish Navy in 1986–87 on board the corvette *Malmo*, and reportedly COMTASS will be ordered for at least 8 Swedish submarines.

The COMTASS tests in Swedish waters were reportedly less than successful (the array kinked as its tower turned to avoid underwater obstacles). As of late 1990, Marconi (which now owns the former Plessey underwater-weapons division) reportedly was less than sanguine about the prospects for small-ship arrays. It was considering changing the program to emphasize the array's ability to detect and track surface targets, e.g., in an antismuggling role.

◆ Cormorant

The development of Plessey's LF helicopter dipping sonar, the first of its kind, began as a private venture in 1978. The dipping body has now (1988) completed development and can, therefore, be incorporated into a production sonar. Cormorant has been selected for evaluation by Canada, the United Kingdom, and the United States, in the last country both under a NATO Comparative Test Program and as part of the U.S. ALFS program (see below). Cormorant is the wet end of the Canadian AQS-503 (HAPS).

The sonar body is streamlined enough to be flown while trailing below a helicopter, yet in the water Cormorant is large enough to provide useful sonar beams at low frequencies. This capability is achieved by placing the stave transducers on arms that deploy outward, like gates, from the dipped body. The arms are long enough (vertically) to provide a useful degree of beam-forming in the vertical plane. As a result, in shallow water the beam can be focused more or less horizontally and, thus, can be kept clear of both the surface and the bottom, avoiding excessive scattering and reverberation. This solution cannot substitute for a large LF transducer, but Cormorant should achieve much better ranges than current small MF types.

The transducer can operate in both the active (CW and FM-slide pulses) and passive (broad-band) modes. Power is provided by transmitter modules, each of which generates 2.2 kW.

In its ALFS form, the entire system weighs only 640 lb. It



Cormorant (PMS 122) lightweight dipping sonar, with its transducer array extended. (Plessey)

operates at 1500 ft in depth (2000-ft cable), with 3 selectable frequencies and 5 selectable pulse lengths. The streamlined body sinks at 15 ft/sec (and retracts at 25 ft/sec) so that dipping time is not excessive even at great depth. Bearing accuracy reported in 1988 was 2 deg active and 5 deg passive.

Guillemot, an enlarged Cormorant (2.5 kHz rather than the 5 kHz of Cormorant), was canceled in 1990 because the smaller Cormorant achieved the performance desired from the larger array.

◆ Crayfish

Marconi Undersea Systems's private-venture line enhancer was displayed at the RNEE show in 1989. Added to a passive sonar, Crayfish extracts coherent lines and improves their signal-to-noise ratio by 10 dB before displaying them as lines on its screen; the result should be better distinction of narrow lines (submarine tonals) amidst relatively broad-band surface-ship noise. Crayfish is a 16-channel system (i.e., it can accommodate 16 beams) using the Texas Instruments TMS 320C30 general-purpose floating-point digital signal processor.

◆ Curtis Architecture

The Curtis architecture is a more efficient approach to sonar (particularly towed array) beam-forming and signal processing, developed by Dr. Tom Curtis of the ARE and applied to sonars such as Types 2031Z and Type 2046. It represents an alternative to more conventional processors such as UYS-1 and -2. As announced in 1983, the Curtis architecture was said to have reduced processor weight by 60% and processor power by 80%.

ARE work in digital beam-forming began with the large-aperture planar array tested on board HMS *Matapan* in 1968-77. The array had numerous elements, and the beam-former and signal processor required 35 minicomputers, more than one hundred 19-in cabinets. The total memory required for beam-forming was 8.5 Mbytes, carried in more than 500,000 RAM chips. New features of this system included fully electronic beam stabilization and doppler correction within an FM pulse. The *Matapan* experiment was taken to show that future active and passive systems would need throughputs of at least 250 MOPS (million operations/sec). Although the towed arrays do not have as many elements as the *Matapan* planar (2D) array, they do approach its level of complexity.

The Curtis architecture has not been described publicly, but it seems likely that the key perception was that some calculation could be avoided if, given the magnitude of the quantities involved, the results could not be particularly significant. For example, in theory, the output of every element of an array contributes to some extent to each beam. However, if the output of an element that would normally make a small contribution were itself quite small, then it may be neglected altogether and not carried forward. That in turn would eliminate later sets of calculations involving the neglected item. Such an architecture does not treat all data equally (i.e., in parallel) and, thus, requires the one published feature of the Curtis Scheme, tag-driven signal flow (each digital sample, i.e., each data point, is tagged to determine its future processing).

The ARE processors use a combination of special LSI chips and software developed for the U.S. UYS-1. The resulting modules, Control Ordered Sonar Hardware (COSH), can be combined in distributed networks to produce complete systems with throughputs of 100-300 MOPS, about 10 times that of the U.S. UYS-1. Type 2031Z uses a 250-MOPS version, and 2 twin-screen (2-operator) displays plus 1 air-cooled processing cabinet and a hard-copy printer. ARE describes the COSH modules as hardware equivalents of software macros. An executive (software) program calls up the modules in the appropriate order, a method equivalent to that of a relatively simple program using subroutines (macros).

One of the first Curtis processors was first tested on board HMS *Lowestoft*, at that time equipped with a development version (IX) of 2031I, in October 1981. As a result of these trials,

2031I was dropped in favor of 2031Z; and the next-generation surface-ship towed array, 2038, was abandoned. The test version, Type 2031Y, was installed on board HMS *Arethusa*. At £600,000, Type 2031Z cost only slightly over a quarter as much as 2031I. The other major current application of COSH technology is 2046. In that case, ARE developed the beam-former and signal processor, and Ferranti, the prime contractor, was responsible for display processing. Type 2046 uses the same terminal unit and some of the same beam-former circuit boards as 2031Z. During the Falklands War, ARE applied COSH technology on an urgent basis to augment the conventional signal processor of the nuclear submarines' Type 2024, delivering units in quantity within 6 weeks.

The current COSH LSI-technology circuit board has a throughput of 10 MOPS, approximately equivalent, reportedly, to that of the U.S. UYS-1. The 2031Z processor has a total volume of 4 m³ and weighs 2500 lb. The U.S. SQR-19/UYS-1 has a floor area of 4.65 m² and a dry-end weight of 12,900 lb. Using newer technology, ARE has been able to package a 5-octave processor in a 50-lb desktop box (ARE T56), using an IBM PC-compatible host processor. Throughput is over 250 MOPS.

Current (1989) efforts exploit the rapid improvement of electronic hardware; ARE estimates that packing density doubles every 2 yr, and that an entirely new chip technology appears every 5 yr. For example, the 4-Mbit memory chip of 1987 was a 20 million-fold increase in complexity compared to the first integrated circuits of the mid 1950s. Greater computing power can be used both for more intensive exploitation of existing arrays and also to allow for more complex future arrays (with many more elements), such as conformal ones. Longer single-line arrays will show appreciable bending, and the beam-formers will have to take their changing shapes into account. Beam-forming algorithms are being modified for a 3-4-fold improvement in bearing accuracy, the ultimate limit (set by the number of elements in the array) being a few tenths of a degree. The more powerful memory chips also make for an updated display. The current ARE desktop machines use 64k memory chips, and as of late 1989, 1-Mbit memory chips were available.

The 2 desktop machines demonstrated so far are T26 (150 MOPS), sufficient for a 2-octave towed array, and T56 (250 MOPS), for a 5-octave array. The latter is more capable than 2031Z but costs only £12,000 in a commercial-standard version (ARE estimates that a militarized version would probably cost £40,000). T56 uses a high-resolution (1536 pixel × 1280 line) monochrome display. In 1989 ARE expected future sonars (2057 and 2078) to require 3 orders of magnitude more processing power, i.e., teraflops (million million operations per second).

The new electronics should be able to cope. As of 1989, ARE had designed a 32-bit Complex Vector Processor (CVP) on a 300,000-transistor chip. Two such chips are equivalent to a complete T6-series circuit board (but operate at 10 times the speed); a complete card could have a throughput of 1400 MOPS. Such a board should be able to execute a 1024-point complex FFT in 41 microsec.

◆ Dolphin 1000-Series

Marconi's sonar processors, both broad- and narrow-band, are to upgrade submarines' existing arrays or to be installed as part of the systems of new-construction submarines.

There are 4 main processors: a broad-band processor fed by either conformal or cylindrical arrays; a broad-band line processor; a signal analyzer; and an intercept processor. The broad-band processor provides HF or LF waterfall displays (time vs. bearing, with up to 20 min shown). Several targets can be autotracked simultaneously. The broad-band line processor, which can take signals from flank, bow, or towed array, displays either the combination of these signals or else the output of separate arrays. The analyzer provides spectral data and can also apply DEMON to retrieve spectral data from broad-band noise. The intercept processor provides bearing, time, pulse parameters, and a list of intercepts.

◆ Ferranti Modular Sonars (FMS-Series)

The FMS-series was announced at RNEE 1983, and trials of the first type, FMS 12, were conducted in 1984. There are 6 series, plus a vibration-monitoring system (VIMOS):

FMS 10 Surveillance and classification (narrow-band processing) for towed or flank arrays.

FMS 20 Search and attack (active) sonars: FMS 20 (for corvette/frigate) and FMS 21 (the export version of Type 2050, for frigate/destroyer). Both use Argus M700 processors, both use FM and CW pulses, and both have passive broad-band and narrow-band capabilities for torpedo detection (torpedo alarm). Each displays target tracks and a track-history tote (alphanumeric display), and each can automatically track 40 targets simultaneously. Each also incorporates a ray-trace predictor. FMS 20 uses a 4-ft-diameter transducer with 32 preformed beams; FMS 21 uses a 6-ft transducer with 64 preformed beams. The hull arrays can be bow- or keel-mounted, and there are associated VDS designs.

FMS 30 Broad-band passive sonars. FMS 30 has a 3-ft array, and there is also an FMS 31.

FMS 40 Active intercept sonar.

FMS 50 HF active sonar (obstacle avoidance, minehunting). See FMS 52, below, and also the FMS 58 minehunting sonar.

FMS 60 Passive-ranging sonar.

◆ Ferranti FMS 12

This 2-octave narrow-band passive-sonar processor was chosen as part of the Triton (Type 2051) program (*Oberon*-class update) in 1985, to work with flank and towed arrays. The digital signal processor embodies the new Curtis architecture (see Type 2031). The reported frequency range is 10–384 Hz and 384–768 Hz. The system operates on 32 preformed beams. There is a simple multiple-beam (waterfall) display for surveillance, and a high-resolution vernier (frequency) display for classification. Self-noise can be processed out. Optional improvements are automatic target detection and classification, automatic communication with a submarine's tactical system, hard copy output, and a color display.

FMS 12 is the basis of Type 2051.

◆ FMS 13

FMS 13 is a 3-octave narrow-band passive signal processor. Both this and FMS 15 (below) use Argus M700 microprocessors and transputers for signal processing; both are capable of auto-tracking. FMS 13 is intended for submarines (the more powerful FMS 15 is intended for surface ships, which have longer arrays and, therefore, can make use of a broader total frequency range).

Although these are primarily processors, the FMS designation includes a towed-array wet end. FMS 13 is the basis of Type 2046.

◆ FMS 15

FMS 15 is a 5-octave narrow-band passive signal processor, using 32 preformed beams. Like the simpler FMS 12, FMS 15 provides both a multiple-beam waterfall display and a high-resolution (very narrow band) classification display. There is 1 operator console with 2 side-by-side screens. FMS 15/2 was ordered by the Royal New Zealand Navy for *Leander*-class updates in 1989 (for delivery in 1991). FMS 15 (8 sets) has also been sold to Korea, presumably for the new submarines.

◆ FMS 52/TG 3

This short-range, dual-frequency, high-definition sonar, for submarines, harbor surveillance, or surface ships, was announced in 1989. It had just lost out to the Plessey alternative in the Type 2077 competition. However, a version has been supplied to the German navy for the new Type 212 submarine, and FMS 52 technology is incorporated in the mine avoidance element of Type 2075. FMS 52 was itself derived from an unspecified

Royal Navy sonar, an outgrowth of TG 1, a high-definition sonar developed by the Ferranti subsidiary, USL. TG 3 is a scaled-down version of FMS 52 for ROV application, particularly in the Ferranti Integrated Mine Countermeasures System (FIMS). FMS 52 can be fin- or hull-mounted on a submarine, and it can be combined with hull-mounted side-scanning arrays derived from the Dowty 3010 (which Dowty claims can be used for under-ice topography).

Beams are electronically formed and steerable; bearing resolution is 3 deg. Each array covers up to 90 deg.

FMS 52 has been sold to both Germany (12 sets for submarines) and Korea (8 sets, probably also for submarines).

◆ GETAS

Marconi's passive towed array uses a wet end from Geophysical Company of Norway (GECO A/S). Versions for both surface ships and submarines are available, and the array can also be laid on the bottom for surveillance. GETAS is being tested for 6 months on board a Norwegian submarine; it may become part of the standard Norwegian submarine sonar suite.

◆ Plessey PMS 26/27

Sector-scanning sonars (ODT), for medium and small ships, these units are closely related to the Type 195 helicopter dipping sonar. They cover 360 deg in 4 steps and can depress their beams for MCC. The transducer is 44.5 cm wide × 99.6 cm high × 53 cm deep and weighs 100 kg. Theoretical range is 7.5 km, but effective range is about 4.5 km. PMS 26 is in a retractable dome.

MUSL (the successor to Plessey Naval Systems) currently markets a solid-state replacement called PMS 26/27 Mod 1. Operating frequencies are 9.5, 10, and 10.5 kHz; pulse widths are 250 msec and 1 sec (modes FM and CW). Range scales are 3, 6, 12, and 18 kyd. There are 4 operating modes: (i) active, (ii) active doppler, (iii) short CW pulses for short range (presumably, in addition to the pulse widths listed above), and (iv) passive. Options include passive tracking, operating at 20 kHz, an underwater-telephone mode, and an automatic interface to a CDS.

PMS 26 was marketed as a replacement for Type 164/174, which were often used in combination with a Limbo control set (170). Although PMS 26 has a maintenance-of-close-contact (MCC) feature (i.e., beam depression), it is unlikely that this sonar in itself can track in 3D or can be used to control Limbo directly. Therefore, it seems likely that Type 170 survives in ships refitted with the new set. Of 55 PMS 26s sold, 42 or 43 were reported still in service in 1987. Buyers: Denmark (*Peder Skram*- and *Nils Juel*-class frigates, fishery-protection ship *Beskæterren*, *Daphne*-class ASW craft), India (probably on board *Blackwood*-class frigates, now discarded), Indonesia (probably ex-Tribal-class frigates), Iran (destroyer *Damavand* and probably 4 Vosper Mk 5 frigates), Ireland (*Eithne* [PMS 26L]), Malaysia (probably frigates *Rahmat* and *Hang Tuah*), Mexico (probably 2, applications unknown), Nigeria (*Obuma* and Vosper Mk 3 and Mk 9 frigates), Portugal (probably the frigate *Pedro Escobar*, now discarded), Turkey (patrol boat *Girne* and probably also AB 25 class), Venezuela (probably refitted *Nueva Esparta*-class destroyers [now discarded], and 2 *Almirante Clemente*-class corvettes).

PMS 27 is the same sonar using a different hull outfit suited to ships down to 750 tons.

◆ Plessey PMS 40 Series

A new private-venture hull-sonar series, PMS 40 was announced in 1983. There are 3 versions, PMS 42, PMS 44, and PMS 46, to cover the full range of ship sizes, from patrol craft up through destroyers. PMS 42 employs a single electronics cabinet and a 27-in (diameter) transducer; PMS 44 has 2 cabinets and a 44-in transducer (corvettes and above); PMS 46 has 3 cabinets and a 78-in transducer.

These sonars are extensively automated to reduce manning, each having only a single operator. Multiple transmitting elements provide redundancy. Presumably, that redundancy means

that much of the transmitting function is concentrated in the individual staves, rather than in a centralized power source. The operator selects such pulse transmission characteristics as long/short mode (which can be interleaved) and frequency. It appears that the primary operating modes are ODT and passive, and for larger ships the beam itself can be electronically stabilized.

Simultaneous computer-aided tracking is provided for up to 10 active contacts, and there is an automatic torpedo alarm. A scanning audio channel locks onto the sources of such alarms to assist in classifying them.

PMS 46 is on board the Danish fishery protection frigates of the *Hvidbjørnen* class.

◆ Plessey PMS 56

MUSL is currently (1991) marketing this modified Cormorant as a replacement for PMS 26. Cormorant uses a series of vertical arrays of receivers with the omnidirectional transmitter below them. In PMS 26 the vertical arrays of receivers form an arc (a volumetric array) forward of the transmitter. Each vertical array carries 6 small transducers, as in Cormorant; the arrays are arranged in fore-and-aft lines (4 arrays per line), and there are 6 such lines, for a total of 24. Presumably, the operating frequency matches that of Cormorant, reportedly about 5 kHz. As in PMS 26, the system is designed for a single operator, in this case using on-screen menus to change from mode to mode. The display is a high-resolution color CRT. The operating modes are FM, CW, passive, and aural; pulse lengths are 5–1000 msec; range scales are 625–20,000 yd. Display formats are surveillance (pulse) and doppler. PMS 56 can use existing sonar domes, so, presumably, it is not too much larger than its predecessor. MUSL offers its own fixed or retractable dome as an alternative for new construction. Because it was adapted from a helicopter sonar, PMS 56 is quite small; inboard processing and display electronics weigh 120 kg altogether (with another 50 kg for the transmitter), and the hull outfit (dome) and array weigh a total of 385 kg. As in Cormorant, PMS 56 is a digital (DIMUS) sonar, sufficiently precise to support attack by lightweight torpedoes (MUSL advertises it in combination with PMW 49a, its torpedo launching system, and, presumably, Stingray torpedoes). The beams depress to maintain close contact.

In fixed-dome form this sonar is suited to ships of up to 3000 tons (speeds up to 30 kt); there is an alternative version with a retractable dome, for ships up to 1000 tons (18 kt with dome extended, 30 with dome retracted). Existing PMS 26/27 sonars can also be updated to PMS 56 standards.

PMS 56 is part of a new Hydra-series of modular sonars, some of which equip the Swedish *Sjöormen*-class submarines.

◆ Plessey Hydra

Hydra is a family of sonars using common hardware: arrays, beam-formers/signal processors, data processors, and displays, all linked by data bus. The options are:

(i) Arrays:

- Dunker (adapted helicopter LF dipping sonar)
- Lightweight Active (omnidirectional LF pinger with helicopter-type receiving staves)
- Variable Depth
- Flank
- Lightweight Passive (planar array)
- Passive (cylindrical)
- Active/Passive (cylindrical)
- Conformal
- Towed

(ii) Beam-Formers/Signal Processors

- Cabinet
- Single Shelf (in standard electronic enclosure)

Options are broad- and narrow-band, active, DEMON, aural, sonar intercept, passive ranging, mine avoidance, and underwater communications.

(iii) Data Processing

(iv) Man-Machine Interface

As examples of installations, Plessey shows a missile destroyer (similar to a British Type 42), a nuclear submarine, a diesel submarine (e.g., a Swedish unit), a midget submarine, and a patrol boat based on a *Sandown*-class minehunter hull. Each shows different Hydra elements.

The destroyer has a hull or bow array with 2 processing cabinets and a 3-operator suite of consoles.

The nuclear submarine has a large bow conformal array, an intercept array, a flank array, a mine-avoidance array (in her sail), and a towed array. It requires 10 processing cabinets (2 per array) and a 5-operator console suite.

The diesel-electric submarine has only the bow conformal array and the flank array. It has 2 shelves of processing electronics supporting a 2-operator console suite.

The midget has only a lightweight passive array (in the bow) feeding a single processing shelf and a monitor display (rather than a full-height console).

The patrol vessel has a lightweight hull active array, a dunking array, and a VDS. It uses 4 shelves of processing electronics feeding a single-monitor display.

The only announced customer is the Royal Swedish Navy: the *Sjöormen* and *Västergötland* classes are both to refit with Plessey Hydra towed arrays (129-m [423-ft] array on 457-m [1500-ft] cable) and improved hull sensors.

◆ Plessey Fiber-Optic Hydrophones

Plessey has been developing fiber-optic hydrophone arrays since about 1979. A sound wave hitting the hydrophone distorts it and thus changes the length of the optical fiber wrapped around it. Plessey claims a proprietary pulsed reflectometric interferometric technique, which multiplexes up to 50 sensors onto a single fiber driven by a single laser. Probably the laser pulse is split by being partially reflected at each sensor; that way the length distortion in each sensor can be measured separately. The array can be as much as 30 km from the laser, and sensors can be 1 m to 1 km apart. The sensor, which is 5 × 18 cm, responds equally well to signals of 5 Hz–4 kHz. Plessey advertises the optical array for seabed barriers or phased arrays and also for towed and outboard arrays.

◆ Plessey Flank Array

This submarine sonar was announced in 1989. It consists of standard modules (2.0 m long, 1.2 m high) each containing up to 12 Plessey patented large-area hydrophones embedded in a special resin fairing. Frequency range is 10 Hz–6 kHz, the upper frequency depending on beam-forming electronics and array spacing. Each hydrophone incorporates its own preamplifier and, thus, can be connected to a long cable array without loss of performance.

◆ Sea Hunter

This Graseby 10.5-kHz sonar intended for craft of over 150 tons was announced at RNEE 1989. The transducer (500-mm diameter, 560 mm high) is a lightweight 24-stave cylindrical array, and the display is a color CRT. Transmission modes are ODT and random rippled directional (RRDT), with pulse lengths of 20, 40, and 100 msec, FM modulation, and a source level of 220 dB (re 1 microPascal at 1 m). There are 12 receiver channels (i.e., beamwidth is 30 deg). Range scales are 2, 4, 8, and 16 kyd or km. Sea Hunter can auto-track up to 4 targets and can display a 5-ping history of each. Targets can also be manually tracked. Range accuracy is 1%, and bearing accuracy is within 1 deg, presumably achieved by beam switching. Sea Hunter operates over a 1-kHz audio band in passive mode, and the display incorporates an audio cursor for search and classification. The installation consists of a single display cabinet, 2 electronics cabinets, and the transducer.

◆ Sea Searcher

This new 6–9 kHz Graseby sonar was first shown at RNEE 1989. It is intended for ships of over 1500 tons and is presumably conceived as a replacement for sonars in the Type 184 class (Graseby also offers a modernization kit for Type 184). Sea Searcher uses a cylindrical 32-stave transducer. Pulse lengths are 20, 40, and 100 msec, and transmission modes are ODT and RRDT; pulse forms are FM and shaped CW. Range scales are 5, 10, 20, and 40 kyd or km. The PPI display shows 16 channels (beamwidth 22.5 deg). Up to 4 targets can be auto-tracked. Range and bearing accuracy are 1% and 1 deg, respectively. Doppler processing can handle speeds of up to 40 kt with a resolution of better than 2 kt. In passive mode the sonar has both video and audio channels. The installation consists of 7 electronic cabinets (which include the display) plus the transducer. The color CRT shows 2 or 3 alternative geographically stabilized displays, including multiple histories for all targets of interest, and speed and course of selected targets are read out numerically.

◆ Smiths Industries Hi-Scan Sonar

This high-definition scanning sonar is primarily for remotely controlled vehicles. The sonar operates at 300 kHz (600 kHz in production sonars). It transmits at HF and scans very rapidly over a limited sector to receive. The beam (2 deg wide) is scanned electronically over a 30-deg sector; range resolution is 7.5 cm. Vertical beamwidth is 7 deg, and the transducer can tilt through 90 deg. In the 600-kHz version, beam dimensions are 1.6×10 deg (but claimed resolution is better than 1 deg), the beam scanning at 15 kHz and using a 75–400 microsec pulse (source level 214 dB); PRF is 4, 8, 16, or 32 kHz. Range resolution is 5 cm. Instrumented ranges are 5, 10, 20, 40, 80, and 160 m. The transducer is a 16-element receiving array and projector, $120 \times 45 \times 60$ mm (2 kg). The display is a standard 16-color television monitor (raster scan), display information being held in a frame store and updated on a frame-by-frame basis. This scheme avoids flicker and, thus, makes the display easier to view.

Smiths Industries Hi-Scan 600 was developed to meet an MoD requirement for a mine-clearance sonar for remotely controlled underwater vehicles.

◆ SP2110

SP2110 is a GEC Avionics towed small-ship export array based on Type 2031 I and Type 2026 technology. The manufacturer claims that SP2110 will be less expensive than those earlier systems and that its modular design makes for relatively simple expansion. Basic options include DEMON (i.e., extraction of LF spectra from higher-frequency signals); narrow-band surveillance, classification, and tracking; and broad-band surveillance. Autodetection and autotracking can be provided. This system was announced in 1988.

◆ SWS 35/40

This streamer array sonar for small boats is made by Ameeco Hydrosience. The wet end is 92 mm long, carrying clustered hydrophones operating in the 25–3200-Hz range, plus 2 HF hydrophones. The array is towed on a 150-m cable. The processor forms broad-band beams using the hydrophones; and the 2 HF hydrophones (which are intended as sonar-intercept receivers, primarily against high-definition navigational sonars) have a separate display.

SWS 40 adds a vertical array that can be steered to exclude surface reflections. The vertical array produces 5 beams, over a broad frequency range (7 octaves).

Ameeco also makes a seabed horizontal array, SWS 45, intended primarily to protect offshore oil rigs. Early in 1989 it was reported that Ameeco was developing an experimental Royal Navy array using fiber optics both for data transmission and for the hydrophones proper. In theory, a fiber-optic hydrophone would detect sound by measuring the change in the length of

an optical fiber wrapped around a deformable body. The phase of a light signal sent through this fiber would vary as it stretched or contracted. This same signal could be amplified and sent back up the information-transmission cable. In theory, such information might be much less subject to electrical noise than the usual electrical signals. In addition, optical fibers should be able to carry vastly more data than conventional cables. Advances in optical computers, which are particularly well adapted to the sort of parallel processing required for ASW, might make an optical array particularly attractive. Ameeco is not alone in working on optical hydrophones, but no other projects have become public.

◆ Swimmer Detection Sonar

Plessey announced this harbor- and oil-rig-defense device at RNEE 1989. This version of the company's mirror sonar (described in greater detail in the Mine Warfare section) automatically detects both swimmers and swimmer-delivery vehicles, maintains a target velocity and track record, and provides programmable alarm levels. The sonar operates at 100 kHz and has a 1.3-deg beam scanned electronically over 40 deg (mobile installation) or 120 deg (fixed installation).

◆ Ulvertech ROV Sonars (Models 3025 and 3030)

These 2 ROV sonars, both of which use software-controlled electronic beam-forming, have been bought by the British MoD. Model 3025 is a search sonar; Model 3030 is a high-resolution target sonar (HRTS). In each, the sonar transmits over a sector, and the received signal is broken into 8 preformed beams. The transducer head moves to change sectors. Because the beam automatically scans over all 8 beams simultaneously, scanning can be much faster (the manufacturer claims 10 times faster) than for a single-beam sonar.

Model 3025 transmits at 110 kHz using a 25×12 -deg beam; the receiver breaks the reflected beam into eight 3-deg beams. Scan rate varies over 30–170 deg/sec depending on mode and range (35, 50, 100, 150, 200, 300, 400, 500 m or yd). The display is a 512×512 -pixel CRT with 16 shades of gray or color. Minimum range is 1 m, and a magnification setting gives a range resolution of 170 mm. The scanning sonar head is $250 \times 250 \times 330$ mm (20 kg). The operator controls sector width (in multiples of 25 deg) and position, display gain, transmission power, pulse length, and sonar gain.

The high-resolution Model 3030 operates at 580 kHz, forming a 5 or 10×35 deg (extending between $+5/-30$ deg) beam for transmission and eight 0.7- or 1.25-deg receiving beams. Scan rate varies over 30–170 deg/sec depending on mode and range (10, 20, 30, 40, 50, 75, 125 m or yd) selected; minimum pulse length is 50 microsec. The display is similar to that used by Model 3025. Scanning head dimensions are $230 \times 230 \times 180$ mm (13.3 kg). Target classification is achieved by the combination of a very narrow beam and a very wide dynamic range so that target highlights and shadows are visible (i.e., the 16 gray scales on the CRT).

◆ Plessey Block Floating-Point-Arithmetic Unit (BFPAU)

In April 1989 Plessey announced a new microchip specifically designed for signal processing; it is the first fruit of a British VHPIC (Very High Performance Integrated Circuit) Applications Demonstration Program. Plessey is to demonstrate the chip in two 1989 applications, a towed-array processor and an in-buoy preprocessor. In the latter application, buoys would process, filter, and distribute data autonomously, burst-transmitting to a patrolling airplane. Each buoy would use a single buoy; the surface-ship processor uses several.

The chip consists of 2 arithmetic elements and a sequencer. Each of the arithmetic elements consists of three 16-bit input registers, a 24-bit multiplier, a 48-bit accumulator, a 48-bit up-shifter, 2 rounders, a 26-bit ALU, and a 26-bit down-shifter. The 2 arithmetic elements are mounted back to back so that they can exchange data readily. The sequencer contains 128 instructions, but all need not be in the same program. It is fed with

instructions giving the initial, restart, and final steps, and also the number of loops to be executed. Plessey claims that its chip can execute 24-bit floating-point arithmetic 10 times faster than current signal processors. It incorporates a special RISC instruction set and can achieve 200 MOPS (1 GOP on a full 100 × 70-mm computer card) using 240,000 devices (1.4 micron CMOS technology). The chip itself measures 1.1 cm². The ultimate goal is 10 GOPS, a factor of 50 improvement. A typical current British sonar processor operates at 100 MOPS.

BFAU is 1 of 2 chips being developed in a joint MoD/Plessey program, financed on a 50-50 basis. The other chip, the Table Memory and Address Modifier (TMAAM), is intended to control the BFAU, scheduling data flow between RAM and the arithmetic chip. TMAAM also contains tables of transcendental functions, and it controls exponents within BFAU. Together with standard memory chips the 2 new ones will constitute a high-performance signal processor.

BFAU was designed for particularly fast beam-forming, on the grounds that beam-forming is typically 50% of the processing load of a sonar-signal processor. It is designed to implement the Curtis architecture. When design began early in 1987, it seemed that 24-bit fixed-point arithmetic would provide sufficient accuracy, but that floating-point arithmetic would make for simpler system control. The compromise solution was block floating-point arithmetic (24-bit mantissa, 8-bit exponent), which is faster than pure floating point.

Plessey also produces a series of signal-processing computer cards: a vector processor, an I/O processor, an 80386 processor, and a high-integration video generator. For example, the cards can be assembled into a spectrum analyzer accepting 48 analog inputs and processing 48 channels at up to 16-kHz bandwidth using 4k FFTs (8 selectable input bandwidths in octave steps). Integration times could vary between 1.5 and 50 sec. The video processor is based on an Intel 82786 coprocessor graphic processor chip. Each can create up to 25,000 characters/sec and can draw geometric forms at 2.5 million pixels/sec (8 bits/pixel). Two chips give a 50-MHz pixel rate. Each chip has 4 Mbytes of display memory.

UNDERWATER FIRE-CONTROL SYSTEMS

◆ TCSS 9/TDHS (DCA)

Torpedo control system (submarine)/tactical data-handling system is installed in HMS *Splendid* and later British nuclear attack submarines (DCA is the designation of the tactical data system). TCSS 9 was the first (1973) fully computerized British submarine AIO. It could manage 25 tracks simultaneously, carrying out TMA on all of them to present tactical officers with a full passive picture of nearby contacts. The displays are a pair of consoles flanking the central sonar PPI, each with a twin CRT (with light pens for operator interaction). The single Ferranti FM 1600B computer is used for TMA on 24 targets, a great improvement over manual methods that (even with a large attack team) were limited to 2 or 3 targets (and which even then took considerable time).

TCSS 9 is being phased out of service. It was originally conceived as an FCS for submarines, upgraded with a torpedo-control unit Mk 2 to control Mk 24 (Tigerfish) torpedoes. In this case the computer was used only to display target and weapons information. TDHS represented the fusion of fire control and AIO functions, the computer being used also for TMA, and the automated AIO being connected to the torpedo fire-control device.

DCA first went to sea in 1973 on board HMS *Swiftsure*.

◆ DCB

The automated submarine AIO (1978) succeeds DCA/TCSS 9, requiring fewer operators. The usual command team for a TCSS 9 submarine is 13, reduced to 8 for DCB. This system is based on 2 Ferranti FM 1600B computers. DCB has 5 displays in the submarine command center, showing waterfalls (broad-band) and LOFARgrams (narrow-band). Computer fire-control solu-

tions are displayed on 2 CRTs at the fire-control console. Weapons settings are shown in tabular form, and wire-guided torpedo feedback (tell-backs) are displayed. Dowty was prime contractor.

DCB was originally designed for the *Swiftsure* class. DCB can engage 2 targets simultaneously and can track 20. It is currently being upgraded through installation of a peripheral processor, the Gresham-CAP DCG (see below). This addition enlarges DCB's memory to 128 kbytes. There have also been considerable software improvements, reportedly 5 in the last 3 yr. DCB was originally developed to fire wire-guided torpedoes as well as air-flight missiles (single-shot or salvo); Gresham Lion is now updating DCB to fire Spearfish.

In September 1990 Ferranti was awarded a contract for F2420 computers to replace the FM1600Bs of existing DCBs. Installation requires 22 days and can be carried out during a normal maintenance period; some new peripheral devices are also added. Ferranti describes F2420 as having 6 times the processing power and 8 times the memory capacity of FM1600B.

DCB employs a 2-position AIO console and a 2-position FCS console. Each position has 2 CRTs, 1 for graphics, the other for alphanumeric. Operators interact with the system mainly through light pens. There is also an automatic contact-evaluation plotter (ACEP). DCB is essentially DCA plus an extra computer for the integrated FCS.

DCB equips all British nuclear submarines other than HMS *Swiftsure*.

◆ DCC

DCC is the automated command/control system of the British *Upholder*-class attack submarine, developed by Ferranti (with Dowty-CAP as subcontractors for consoles and fore-end hardware). Two FM 1600E computers drive the 3 consoles (1 on standby). Each of the 3 equivalent operator positions can be used for either command/control or fire control. Each console contains two 12-in circular cursive CRTs, with light pens for input. KAFS (see below) has a single 2-operator (4-CRT) console and a single FM 1600E computer, for both AIO and FCS functions. It is an export derivative of DCC, with considerable commonality with other Ferranti AIO systems. KAFS can conduct automatic TMA simultaneously on up to 35 tracks. Interaction is via light pen and keyboard, and the tactical picture can be presented either as a PPI or as a vertical display. Two or more wire-guided torpedoes can be controlled simultaneously against 2 targets. A special navigational program can be run for minelaying.

COMKAFS (DCH) (see below) is a variant, used in the RN to update existing *Oberon*-class submarines. COMKAFS is built around the Argus Compact computer.

DCC(BN) is the tactical data-handling system for British Trident submarines.

◆ DCG

An add-on processor for DCB, made by Gresham-CAP, DCG is the designation for the new Dowty-Sema SMCS and is a PDP 11/44 with an array processor intended to improve TMA capability. However, DCG is also used for simulation (for on-board training), for environmental analysis (e.g., sonar ray-path prediction), and as a command tactical aid.

Computer capacity is about 8 MFlops. The array processor is supplemented by a general purpose minicomputer to organize data and control associated devices; the latter include a high-resolution color printer. DCG incorporates a fast mass-memory to hold sonar data for long-term analysis.

◆ DCH

DCH is a replacement for TCSS 10/11 in the British *Oberon* class (Ferranti COMKAFS D). The first of 12 was delivered in 1987. DCH employs the Military Argus Compact (MAC) computer, which uses the M700-series microprocessor. It is a central-computer system using 3 multifunction, multiple high-resolution video consoles (which can be color rasters). Each console can provide weapons-control data such as target designa-

tion, weapons and tube status, weapons launch, and mid-course guidance. System options include the capability to guide more than 2 torpedoes simultaneously, an automatic plotting table, and an automatic contact-evaluation plot.

DCH was formally accepted in 1989, work having begun less than 4 yr before. In April 1990 HMS *Opossum*, the first British submarine to be fitted with the combination of DCH and the 2051 sonar, completed successful tests, including the first-ever salvo launch of wire-guided Tigerfish Mk 2 torpedoes from an *Oberon*-class submarine.

◆ SMCS

Gresham-CAP's Submarine Multiscreen Command System is to replace the existing DCB/DCC on board all future British submarines (SSN, SSK, SSBN). It uses a dual-redundant fiber-optic data bus connecting 3 or 4 multifunction consoles, a main tactical display, 2 sensor-input nodes, 2 common-service nodes, and 2 remote terminals. SMCS is a fully integrated submarine-control system, the same computers being used both for information processing and for weapons control. All consoles are identical, and all are software-configured, for maximum redundancy and flexibility. For example, in 1 role all the consoles may be devoted to sonar data; at periscope depth 1 or more may display ESM data; in another role, 1 or more may function as fire control or countermeasures consoles. SMCS is a federated system using 11 computers incorporating 80386 processors plus Transputers for parallel processing. They are linked by a high-capacity (166-Mbits/sec) fiber-optic data bus. Each fiber-optic link is duplicated; when a failure occurs, the stream of data is automatically rerouted to the intact link (the system is called self-healing). The entire system is programmed in ADA (except for OCCAM, used for parallel processing). It is intended to be able to process data not only from current sensors but also from future ones such as very long towed arrays (with many more elements than at present) and optronic periscopes. Each console incorporates a graphics input tablet and a programmable keyboard.

SMCS is the first announced dedicated military application of the Transputer, and the first naval use of the new ADA language. Gresham-CAP claims that SMCS has more than 20 times the processing power of previous conventional submarine combat systems, at lower acquisition and ownership costs (and with better than 99.9% projected availability). This sort of improvement is probably a natural and virtually universal consequence of recent developments in computer hardware, paralleling well-known civilian experience.

The common-service nodes store bulk information and carry out high-speed computation (each has 8 processing cards, each carrying 8 Transputers, for a net throughput of 50 MFLOPS).

The original specification called for a service life of 30 yr. SMCS is unusual in that it is delivered to the yard packed in containers (presumably on pallets) ready for unit installation.

Development of SMCS began with the award of a contract in December 1986 after a 3-yr competition. The first kit, for installation on board the lead Trident submarine, HMS *Vanguard*, was delivered to the Trident Tactical Weapon System Shore Development Facility (SDF) at VSEL Barrow, and completed its Part 1 Naval Weapon Harbour Trial in mid-1990 (the ship will commission in 1992). The second SMCS is to be installed as a shore trainer at Faslane. The 4-console version is to be installed on board the new *Vanguards* as well as the existing nuclear attack submarines (the oldest, however, will not be refitted with it). Presumably, it will also equip the next-generation "W" class. A 3-console version will replace DCC on board the *Upholders*. Surviving *Oberons* will not be refitted.

◆ FISCS

FISCS is the Ferranti Integrated Submarine Combat System, developed primarily for export. There is a single 6-operator console, all operator positions being identical and interchangeable.

Two wire-guided torpedoes or 2 missiles can be fired simultaneously at 1 or 2 targets; the system can be expanded to control 6 torpedoes or 4 missiles. FISCS provides sonar performance prediction and is linked directly to the submarine's bathythermograph. Oceanographic analysis is possible because the system can store so much background data.

◆ KAFS/COMKAFS

Ferranti's submarine action information and FCS was announced in 1981. KAFS stands for SSK AIO and Fire-control System, and COMKAFS is compact KAFS. KAFS was first ordered to equip Brazilian Type 209 submarines. Derived from the AIO designed for the British *Upholder* class, KAFS uses a single Ferranti FM 1600E computer (192k expandable to 256k). The prototype KAFS (1982) was a cannibalized WSA-420 surface-ship AIO/FCS console. COMKAFS D will replace TCSS 9 in the *Oberon* class.

This system was designed to handle 35 target tracks (expandable to 50), performing TMA on all of them. KAFS has 2 operator positions, the computer fitting into the bottom of the console. Each position carries 2 CRTs, a tactical display on the left and a tote (alphanumerics) display on the right; only 1 display is operated in the patrol condition. The displays are canted rather than upright so that the lengthy use of light pens will be less fatiguing.

The tactical display can switch between PPI, time-bearing (waterfall), and vertical display formats, with tactical aids including calculated CPA, rendezvous, estimated time of arrival, and angle on the bow. The tote provides 37 pages of material, including weapons-control data. The operator calls up pages by applying the light pen to a menu at the bottom of the page, and also uses the pen to designate tracks to fire control. Although most commands are made by software, some critical ones, such as the firing command, are made by special buttons and switches on the control panel.

KAFS can control 4 wire-guided torpedoes firing at 4 separate targets, and it can also fire unguided torpedoes or lay mines. In addition, the system can preheat up to 12 stowed battery-driven weapons simultaneously, monitoring their condition so that they can be loaded and fired more quickly.

◆ Series 4

The Plessey Marine combat/integrated sonar systems were announced in 1986; the name reflects the use of fourth-generation, i.e., distributed, computer architecture and data busing. Plessey claims that by using high-capacity memories and fast processors, it can radically reduce the number of different components in a typical sonar system. For example, a complete sonar suite might be built up from 10 types of electronic cards (such as a 32-bit processor and an 8-Mbyte memory), compared to about 300 different cards in Type 2020. The first Series 4 suite was Pisces 4, offered unsuccessfully for the Royal Australian Navy's new submarine.

◆ TIOS

Tactical Information Organization, Submarine, by Ferranti/Vickers/Gresham-Lion, was developed in parallel with DCB and exported to Brazil (for *Oberons*) and to Israel (for the 3 Vickers 540s). TIOS was an early example of the use of a digital fire-control computer for some AIO tasks, such as TMA, applied to 1 or 2 targets.

TIOS-B is fitted to Brazilian *Oberons*. It is based on the Ferranti FM 1600B.

TIOS-C is for IKL 500/1000-ton submarines, based on the Ferranti FM 1600B.

TIOS-D is based on the Ferranti FM 1600D.

TIOS-E uses the FM 1600E computer but differs from KAFS by using privately developed software; and -E has 1 rather than 2 CRTs at each of the 3 operator stations, the same display showing both graphics and alphanumerics.

UNITED STATES

HELICOPTER SONARS

◆ AQS-13



An AQS-13 transducer suspended from a Sea King helicopter. (U.S. Navy)

The standard U.S. dipping sonar is employed primarily on carrier-based inner-zone ASW (SH-3) helicopters. AQS-13 is manufactured by Bendix and is a development of the AQS-10 of 1955.

The original AQS-13 was an MF sonar (9.25–10.75 kHz, operating at 5 kW, with 3.5- or 35-msec pulses and with range scales of 1, 3, 5, 8, 12, or 20 kyd). The typical pulse was 180 deg wide, and the sonar scanned on reception. The dip cycle, from transducer launch to recovery, was 2–3 min; and with the helicopter hovering 50 ft up, the transducer was 450 ft below the surface. Typical range was 4000 yd, and installed weight was 775 lb. AQS-13B (625 lb) had 16 preformed beams; 200 lb was saved by using hybrid microcircuits, and a single 360-deg omnidirectional ping was adopted to speed scanning. Built-in test equipment was also added. AQS-13C added a sonobuoy interface.

Sonar pulse width is 35 msec.

AQS-13E added APS (adaptive processing sonar mode) for better performance either in shallow water (reverberation limited) or in deep but noisy water (wide-band background limited) to achieve improvements of 20 and 13 dB, respectively. The usual rectangular sonar pulse, which has a wide frequency spectrum, is replaced by a cosine-squared 200-msec pulse, which has a relatively narrow spectrum and which, therefore, can more easily be separated from the surrounding noise and reverberation by FFT techniques. The longer pulse also improves target strength since it more nearly matches the acoustic length of a typical submarine. The necessary computation is done by a specialized sonar-data computer (SDC), which also processes sonobuoy data and MAD data. When the sonar operates in this mode, the usual spiral deflection system of the PPI display is not used because considerable processing intervenes between echo reception and display. The SDC places blips on the CRT to indicate computed target range and bearing; it is also responsible for refreshing the CRT display so that it does not fade.

AQS-13F was originally a lighter version (615 lb) with a longer cable (1500 ft) and higher power, saving weight by reducing all data to digital form. Two prototypes failed their U.S. tests partly because greater pressure badly distorted the beam patterns at depth. The West German navy persisted with a modified version, AQS-18. Recently the AQS-13F designation has been revived for the dipping sonar of the new SH-60F helicopter.

All versions of AQS-13 provide for voice communications;



An SH-60F carrier inner-zone ASW helicopter dips its AQS-13 sonar. (Sikorsky)

-13A added keyed (coded) communications as well, for greater range.

AQS-13 is the most widely used Western dipping sonar. Current platforms are the SH-3/Sea King (including some built under license in Italy), Agusta-Bell 204 and 212 (ASW versions), Lynx (version for Portugal), and some versions of the Sikorsky S-70/SH-60. It is also being marketed for use on board the SH-2G (which carries only sonobuoys in its U.S. version). All of these helicopters except the AB 204 are single-package, carrying both sonar and torpedoes. AB 204s operate in pairs, 1 with the sonar, 1 with the 2 homing torpedoes. Some AB 212s and 204s carry only antishipping missiles. As of 1990, current naval users of these helicopters with AQS-13 sonars are the following:

Sea King (SH-3): Brazil (8), Canada (31 of 44 CH 124As delivered), Iran (7), Italy (25), Japan (71 of 167 delivered; some are SAR aircraft), Peru (9), Spain (10), and the United States (145). AQS-13E is the current U.S. version on SH-3Hs. German Sea Kings carry AQS-18 sonars. The Spanish Sea Kings are to be fitted with new sonars.

AB204/212: Greece (16), Iran (7), Iraq (5), Italy (27 AB212s, 12 AB204Bs for training), Peru (6), Spain (11, plus 4 for ESM), Turkey (9 AB212s, 3 AB212s), Venezuela (6).

S-70/SH-60: Taiwan (10 S-70s), U.S. Navy (175 SH-60F inner-zone ASW helicopters carry AQS-13F; some may also be installed on board LAMPS-III helicopters). AQS-13 has been offered to the other major S-70 naval user, the Royal Australian Navy.

SH-2G: A sale to Portugal was canceled. As of late 1990, it seemed likely that helicopters of this type would be sold to Argentina to equip the MEKO 140 frigates, which currently operate only Alouette-IIIs.

It is not certain whether all naval AB212s and AB204s have dipping sonars; like Lynxes, some may be limited to weapons delivery, using data links and MAD (the only other important light ASW helicopters, Alouette-IIIs, HD500s, and Wasps, are so limited).

◆ AQS-14

See the Mine Warfare section under countermeasures.

◆ AQS-18

This Bendix helicopter dipping sonar was developed from the abortive AQS-13F specifically for the West German navy, for Lynx and Sea King helicopters. AQS-18 weighs 600 lb (194 lb

for the fish alone), including a 450-m cable (allowing operation down to 440 m), operating at 9.23, 10, and 10.77 kHz (3.5- and 35-msec CW pulses, 200- and 700-msec FM pulses, range scales the same as AQS-13). Source level is 217 dB. Modes include passive and MTI. Like AQS-13F, AQS-18 uses a separate transmitter and receiver. A lead-acid battery pack is carried in the sonar "fish," but there is no capacitor to store energy between pings. Instead, the helicopter recharges the battery between transmission cycles. The power level is reportedly twice that of the original AQS-13B, and the high-speed winch (22 ft/sec average) limits the dip cycle to no more than that of the earlier sonar, although the depth can be much greater.

These data are for the current AQS-18(V) version, which is available with both 1000- and 1500-ft cables.

◆ ALFS (Airborne Low-Frequency Sonar)



The flextensional transducer (projector) of the Sanders-GEC dipping sonar. (GEC)



The dipping body of the Sanders-GEC LF helicopter sonar. It is the only 1 of the ALFS alternatives not to use extending arms for more directional reception. (GEC)

ALFS is a Naval Air Systems Command project for a next-generation helicopter dipping sonar, to replace the existing AQS-13 series. The new sonar will be installed on board SH-60F carrier inner-zone helicopters (which are replacing the existing SH-3) and, on board future LAMPS helicopters. The weight target is 700 lb, and the associated signal processor is UYS-2. Proposals have been submitted by Allied Signal (Bendix), Gould/Plessey, Martin Marietta (with Diagnostic/Retrieval Systems and Breeze Eastern), Sanders, and Thomson Sintra/Hughes. The Allied Signal, Martin Marietta, and Sanders systems are described separately in the 3 entries immediately below. Thomson Sintra/Hughes offered the French FLASH (Folding Light Acoustic System for Helicopters). See the French section for details.

The Gould-Plessey proposal is a development of the Cormorant LF helicopter dipper that Plessey has developed as a private venture since 1978. See the Plessey Cormorant entry above for details of the proposed towed body. The Gould-Plessey ALFS would achieve very long sonar ranges through a combination of LF and great depth (1500 ft, with 2000 ft available as an option). A fast winch would maintain a quick dip cycle (deploy to depth and recover to fly at trail in 180 sec). This ALFS would concurrently process active sonar and helicopter-deployed sonobuoy data. Cormorant has been accepted for the demonstration phase of the Canadian HAPS project, for the new Canadian ASW helicopter (NSA, or New Shipborne Aircraft).

◆ HELRAS

HELRASt is Bendix's (now Allied Ocean Systems) LF/long-range sonar developed specifically for the Anglo-Italian EH-101 helicopter. Like Cormorant and the Martin Marietta ALFS entry, HELRAS employs a series of stave transducers on extendable vertical arms. The projector is a stacked array of 8 or 10 LF (presumably flex-tensional) transducers, 16.3 or 20.5 ft long. It extends vertically in the water; in the air, the projector is folded inside the sonar fish, the individual transducers stacking closely 1 above the other. Above the projector is a receiving array consisting of vertical staves on extending arms. When unfolded, the dimensions are 9.2-ft diameter and 4.2-ft height. The entire fish weighs either 380 or 410 lb (depending on the number of active transducers) and is 16 in in diameter and 53 or 56 in long. Total system weight, including a lightweight reeling machine, is 662 or 692 lb, depending on the number of active transducers. This weight is light enough for HELRAS to be accommodated on board an SH-60 or NH-90 (NATO Lynx successor) helicopter. Accommodation on board the SH-60 makes HELRAS a candidate for the future LAMPS or inner-zone CV helicopter.

The long array of active transducers produces a beam omnidirectional in the horizontal plane but narrowly defined in the vertical so that, for example, it can avoid multipath in relatively shallow water by grazing both bottom and surface at a very shallow angle (and at a great distance). VLF makes for long potential range; Bendix claims that HELRAS's range is about 7 times the conventional dipping sonar's range, which implies CZ performance. Given such long sonar range (and the blank zone that range implies), Bendix proposes to fuse all other available sensor data (e.g., radar and MAD) with the active and passive data picked up by HELRAS. Bendix also claims that the necessary signal processor is powerful enough to process 16 active or passive sonobuoys simultaneously.

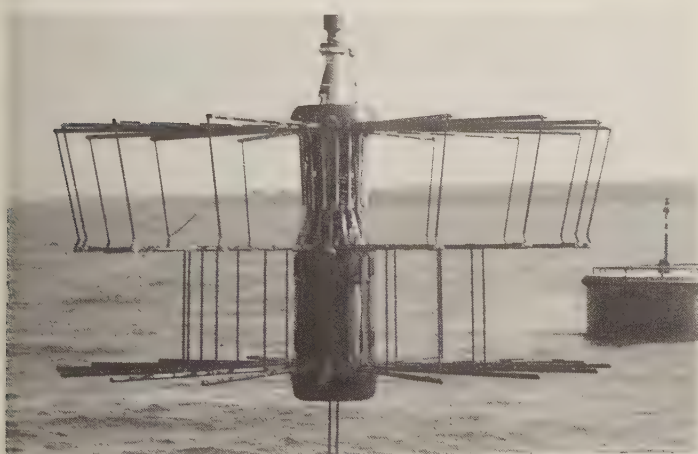
Compared to the Plessey Cormorant, which was probably the first such LF extending-array sonar, the chief differences shown by HELRAS seem to be the much lower frequency and the very long transmitting array (to focus the beam in the vertical plane).

HELRAS flew for the first time in December 1987 on board an Italian Navy SH-3D.

The ALFS alternatives were all tested in 1989 (by March, all but HIPAS had been tried at Lake Seneca and at the AUTEC Atlantic test range). By mid-year an RFP was expected by September. However, it had not yet been issued by April 1990 (it was then expected in the near future). That probably meant no selection until late 1990 or early 1991. The decision to place the sonar on board both the SH-60B (LAMPS III) and the SH-60F



An Italian Sea King deploys the Allied Signal (Bendix) HELRAS long-range dipping sonar. (British Aerospace)



Allied-Systems's HELRAS low-frequency helicopter sonar. (FIAR)

means that it must be compatible with both the standard processors, UYS-1 and UYS-2.

◆ HIPAS

Martin Marietta's High-Performance Active Sonar is a competitor for ALFS. HIPAS uses a 5-arm array in umbrella shape, with a total of 80 transducers, with a diameter of 2 m. Total weight is 540 lb.

HIPAS has also been offered for the Canadian NSA competition and for the British EH-101 helicopter; for the latter application Martin Marietta is teamed with Dowty Maritime Systems.

◆ Sanders Advanced Dipping Sonar (Osprey)

This private-venture sonar was announced in 1988, and the prototype was tested in July. It can operate at 4 frequencies, with diverse pulse lengths, types, and shapes, and can also provide broad-band passive capabilities, acoustic intercepts, and fathometer readings. This sonar can operate at depths of 1500 ft

or more, with a dip cycle of 180 sec, trail-to-trail, and a duty cycle of 10%. Total system weight is 650 lb. Reportedly this sonar operates at about 3 kHz, using a DICASS-like cylindrical array of flex-tensional transducers. Sanders's system is the only ALFS competitor that does not employ a fold-out array.

Processing would be by the standard U.S. UYS-1 (as in LAMPS-III helicopters) or by British GEC AQS-934, which has been selected for the Anglo-Italian EH-101 helicopter.

The Sanders dipping sonar and a Thomson Sintra reeler were demonstrated on board a LAMPS III helicopter in October 1988. The transducer is about 50 in long and weighs about 160 lb.

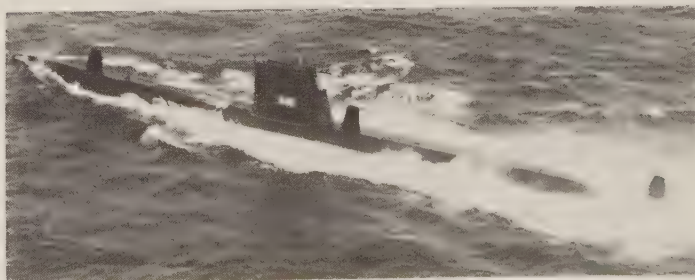
SUBMARINE AND SURFACE-SHIP SONARS

◆ BQG-4 (PUFFS)

This passive-ranging device for submarines measures range by the curvature of the wave front of the detected sound, comparing times of arrival. The typical installation consists of 3 vertical transducers: bow, amidships, and aft; and range accuracy depends on the ratio between the range and the length of the installation. The original concept was for 3 equally spaced 6-ft (vertical) hydrophones along a 250-ft baseline, operating at 200 Hz–8 kHz, to get a range accurate to within 2% against a snorkeling submarine at 10–15 kyd.

Feasibility studies [at the Naval Ordnance Laboratory, White Oak] began in 1953 as the Passive Fire-Control Feasibility Study (PUFFS). An experimental system was installed on board the USS *Blenny* in 1956, a full prototype following in 1958. It could continuously and simultaneously display all targets within range, achieving a range accuracy of 95% and a bearing accuracy of 0.5 deg at 15,000 yd. Test installations for the nuclear *Tullibee* and *Thresher* (the prototype of all later U.S. fast nuclear attack submarines) were authorized in March 1958, and in June 1959 further prototypes were planned for ballistic missile submarines (SSBNs 608 and 609). However, the rather large PUFFS vertical hydrophone arrays were not compatible with the new streamlined submarine hull forms. The compromise solution was to fit 4 point hydrophones (slower submarines used 6 hydrophones per subarray) in a parallelogram, 2 topside and 2 bottomside. The prototype installed on board the *Thresher* (BQG-2) was defeated by self-noise; it could track noisy targets only to 4000–5000 yd, and then only with the ship extremely quiet.

The solution (BQG-2A) was to install 10 hydrophones in each of 6 subarrays (3 on each side in free-flooding spaces, and all on each side in a straight line), each beam-formed and electronically steered. The 2 after subarrays were mounted on the tips of the horizontal fins, and they could act as a PUFFS pair to obtain bearings on a target within 10 deg of the stern. This performance was actually demonstrated on board the *Thresher* when she was moored at Portsmouth, but her loss precluded an at-sea evaluation. This system was tested on board the USS *Barb* in 1964, but it was not widely installed; PUFFS was limited, in the end, to diesel-electric and to slow nuclear submarines. The idea of the 2D subarray (to defeat self-noise without imposing an impossible streamlining penalty) survived in the form of MicroPUFFS (see below) and then WAA (see BQG-5, below).



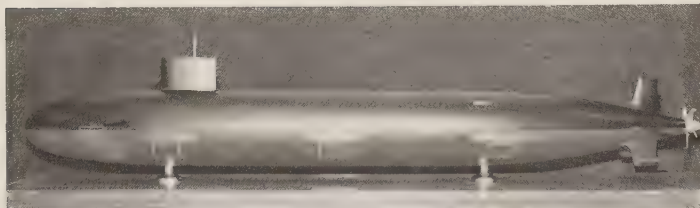
The submarine *Wahoo* shows 3 vertical PUFFS hydrophones. MicroPUFFS and WAA use 2D hull arrays instead. (U.S. Navy)

The surviving version, BQG-4A, is a modified -4 with built-in-test equipment and improved sensitivity, reliability, and maintainability.

In U.S. service, PUFFS was associated with the now-extinct Mk 45 nuclear torpedo. The torpedo had no seeker, and the firing platform had to detonate the torpedo at the appropriate range. TMA using a single sonar was not precise enough, but PUFFS could provide a good enough range. Adoption of Mk 45 was actually predicated on the success of the PUFFS tests.

A few of these devices remain in service, mainly on board submarines transferred abroad by the United States. Sperry manufactures a Micro-PUFFS for installation on board modern diesel submarines (see separate entry below). The current Martin Marietta wide-aperture array (WAA) is a lineal descendant.

◆ BQG-5/WAA (Wide-Aperture Array)



An official model of the new *Seawolf* submarine clearly shows the 3 WAA arrays on her side. (U.S. Navy)

WAA is the successor, in effect, to PUFFS and Micro-PUFFS, consisting of 3 large flat arrays on each side of a submarine. Larger array size should enable both lower-frequency operation and directivity both in depth and in azimuth, so that WAA should be able to exploit bottom- and surface-bounce paths and the CZ propagation path. The concept was first tested on board the experimental submarine *Baya* in FY71 and on board USS *Barb* in January–April 1980, presumably as part of Micro-PUFFS. By 1980 WAA was considered an essential element of any post-*Los Angeles*-type submarine. For example, in January 1977, the then secretary of defense described WAA as capable of providing bearing and range data “out to the limits of present weapons capabilities.” The current manufacturer is Martin Marietta, and WAA was tested on board the submarine *Augusta* about 1985. WAA will be fitted as a stand-alone system in *Los Angeles*-class submarines beginning with those authorized in FY89, and some will be backfitted to earlier ships. WAA will also be part of the BSY-2 system of the new *Seawolf* class.

In the past, WAA has sometimes been called RAPLOC (rapid passive localization), the “rapid” differentiating it from the much slower TMA.

As an indication of its complexity: the WAA employs 404 hydrophones per subarray (6 in all), compared to 10 per subarray in BQG-2A. Its electronics require 8 standard cabinets. The *Augusta* (SSN 710) was the trials ship.

As of early 1988, 2 BQG-5s were planned for FY89, and the total program consisted of 9 BQG-5s (plus units integrated into BSY-2 for the new *Seawolf* class).

Proposals that WAA be installed on board existing *Los Angeles*-class submarines have been scaled back because the array exceeds the very thin remaining weight margin of these ships. In June 1990 the Naval Underwater Systems Center (NUSC) announced an RFP for a demonstration low-cost fiber-optic planar array (LCPA). Two 49-element subarrays would be built in the course of a 28-month contract. As of early July, a formal RFP was expected in August 1990. The LCPA technology might ultimately be used on board an improved *Seawolf*, or it might come within the remaining weight margin of some of the *Los Angeles* class.

◆ BQH-4

Tuba II is a passive system sometimes carried by submarines collecting acoustic intelligence. About 1975 some publicity was

given to the use of *Sturgeon*-class submarines for intelligence gathering in waters near the Soviet coast, and that probably referred at least in part to the use of Tuba. Although not designed for any tactical role, Tuba was historically significant because it incorporated the first major U.S. towed array. SQR-14/15, the surface surveillance arrays, were Tubas towed by surface ships (initially *Dealey*-class frigates, in the Mediterranean, in 1969–70). The original Tuba probably used a Hughes array (for example, Hughes proposed using towed arrays for ocean surveillance as early as February 1962).

Tuba II (1971) used a combination of a retractable LF towed array on a 2600-ft cable, the submarine's own MF array (in passive mode), and its own HF subsystem in a special sonar dome. The towed array consisted of 3 subarrays (50 hydrophones each), 3 in $\times$ 258 ft, effective between 10 Hz and 20 kHz. The environmental sensors and the hydrophones modulate 52 telemetry transmitters, which are frequency-division multiplexed onto a single coaxial cable connection leading their data into the submarine. BQH-4 also used a mechanically steerable array for directional data; it consisted of 18 lead-zirconate hydrophones in a hood-shaped housing on a pedestal. All acoustic data collected were sorted and recorded on magnetic tape (by a BQH-5 recorder) for later laboratory reduction and analysis. TB-16 (of BQG-5) is a modified Tuba II array.

EDO manufactured the individual hydrophones in the Tuba array (2 in diameter $\times$ 8 in lead zirconate in a tube filled with air and elastomer).

The contract for this equipment dates from about 1969. It is unlikely that Tuba II is still used in anything like its original form, but the need for acoustic intelligence persists, and something like Tuba presumably remains in service. A Tuba III (BQH-6) program was terminated in FY78, reportedly because of cost and schedule slippage. Raytheon built 3 prototypes, and 8 production systems were planned under the FY76 budget. At that time the unit cost of a Tuba was \$937,500, slightly under half probably going for the array.

Tuba itself could not be directly adapted to any tactical role since its array design was intended more to achieve very high accuracy (in terms of sound pressure) over a broad frequency band than to achieve much directionality or directional accuracy.

Unlike the early U.S. submarine tactical towed arrays, Tuba's was retractable, probably specifically so that the submarine carrying it could operate safely in shallow water. The submarine arrays were clip-ons, the submarines having permanent inboard electronics but not permanent arrays, on the theory that fewer arrays than submarines could be purchased. Losses and damage to arrays led to the choice to shift back to retractable arrays.

◆ BQQ-5

The current U.S. standard submarine sonar suite is a digital version of the earlier BQQ-2. It is, in effect, the submarine equivalent of SQS-53, just as BQQ-2 was the submarine equivalent of SQS-26. The main improvement is DIMUS, which permits the submarine to track many targets simultaneously (pre-DIMUS spherical sonars had only 2 commutators and, therefore, could form only 2 beams simultaneously). BQQ-5 includes the BQS-13 DNA (DIMUS narrow-band accelerated active search) and BQS-14 transmitters. Compared to BQQ-2, BQQ-5 has better displays, DIMUS, improved active search, passive classification, an on-line performance monitor, and automatic fault location for quicker repair. For passive classification it uses a chin array that replaces the BQR-7 of the earlier BQQ-2. Concept formulation began in January 1969, and elements of the system were tested on board the *Pogy* (SSN 647). The prototype system was installed on board the *Philadelphia* (SSN 690). BQQ-5 was approved for service use in April 1979; an improvement program began in FY80.

BQQ-5/Mk 117 was adopted because earlier submarine FCSs were limited by inadequate sonar bearing input, by the need to plot manually for TMA, by the use of analog-digital interfaces between computer and analyzer, and by inadequate display and

retention of target information. Typical TMA range errors (10–15%) were considered unacceptable, and they could be refined only by active transmissions that would alert a target. The projected (1969) BQQ-5/MK 117, essentially an improved Mk 113 supported by a central computer complex, was expected to conduct 2 TMA simultaneously, using several TMA programs and thus eliminating the need for a manual plot. This expectation proved somewhat premature. In 1969 it was estimated that the new system would be 3 times as effective as previous ones against a standard target (a *Skipjack*).

The 2 hull arrays are the bow sphere (1241 TR-155E/BQ hydrophones) and the chin array (104 DT-276 hydrophones); later versions add a TB-16/BQ or TB-23 towed array. BQQ-5C requires 57 electronic cabinets and weighs a total of 32,000 lb. Its software comprises 311 kwords. Power requirement is 76 kW for passive operation and 566 kW for active. Active operation is at about 3.5 kHz (i.e., as in SQS-26/53), and the bow sphere operates passively at 0.5–5 kHz.

Versions:

BQQ-5 Baseline *Los Angeles*-class sonar system, using the BQS-13 sonar sphere and chin and towed passive arrays. Main components are: CP-1122 passive broad-band sonar signal processor, CP-1123 active sonar signal processor (omni, sector search, active tracker, and audio processors for each beam received from the beamformer), CP-1124 signal-classification processor, CP-1125 postclassification signal processor, J-3107 beam interface-spectrum analyzer, CV-3010 passive beam-former, CV-3011 active beam-former, CV-3035 passive beam-former, 3 control-display consoles (OJ-274), 1 performance-monitoring and fault-location console (OH-275), and 1 analog-video display (IP-1124). This version lacks a towed array; presumably, the 2 passive beam-formers operate at different frequency ranges. The chin array is for narrow-band classification (it lacks a beam-former). The active processor (CP-1123) integrates, stabilizes, and normalizes each beam received from the active beam-former. It also continuously detects 3 or 6 contiguous beams, using split beam inputs from an analog compensator to provide right/left and up/down indication and to obtain a range rate. The operator can listen to target echoes from the analog compensators, active beam-former, or active tracker processor. The passive processor (CP-1124) conditions, filters, and spectrally analyzes signals from the beam-former; its output in turn goes to a UYK-7 computer and to a classification post-processor before display. Filtered tracking data goes to the UYK-7 for automatic tracking. The CV-3035 passive beam-former uses delay-line time compression to form 25 port and 25 starboard beams as well as 2 noise beams, using signals from a BQR-7 keel array or a BQH-4 towed array. Beam steering and array selection are done at the beam-former interface unit and spectrum analyzer, which also processes the detection and tracker beams. IP-1124 uses a 10 × 10-in CRT to show any of 6 alternative presentations. IP-1125 (see below) is similar but has a 48-message projection readout switch matrix (PRASMA) instead of a 24-message PRASMA. IP-1417 is similar to IP-1125. OJ-274 is a sonar display carrying 2 CRTs, for PBB, active, DIFAR-like, or classification displays (UYK-7 outputs) selected by the operator, who also sets the system operating mode. It is controlled by a joystick. OJ-431 and -432 (BQQ-5A) are similar but somewhat larger. Later versions of BQQ-5 have later analog-video display consoles, and they lack any direct equivalent to J-3107.

BQQ-5A has improved computer capacity (in the form of an additional UYK-7) and a towed-array broad-band processor (ICC/TABP). There are 3 control consoles (OJ-431 or OJ-432) and a separate fault-monitoring console (OJ-435) and 2 analog-video displays (IP-1325 and -1417). The (V)1 version (BQS-13 sonar sphere, CP-1359 broad-band passive processor, CP-1362 active-signal processor, CP-1365 signal-classifier processor, CV-3010A passive beam-former, CV-3011A active beam-former, CV-3527 passive beam-former-processor, OJ-431 console) is for the *Los Angeles* class. (V)2 (main components as (V)1 but only 1 analog-video display, IP-1325) is for the *Sturgeon* class. (V)3 (BQS-11

sonar sphere, CP-1360 broad-band passive processor, CP-1363 active sonar signal processor, CP-1366 signal-classifier processor, CV-3521A passive beam-former, CV-3522A active beam-former, CV-3528 passive beam-former-processor, OJ-432 console, 1 IP-1326 analog-video display) is for the *Permit* class. All but some examples of the (V)3 version include a control and a remote indicator for the WLR-9 sonar intercept receiver. This sonar uses a dual-bay UYK-7 rather than the single-bay computer of BQQ-5. The interface between the beam-former and the array is changed from analog to digital, and the beam count from the beam-former is increased from 16 to 24. In addition to processing broad-band data from outside the submarine, CP-1359 and -1360 steer a pair of adjacent passive sonar beams to suppress the effect of own-ship noise. The active beam-former (CV-3011) forms a total of 600 beams, a total of 60 azimuth beams (to cover 360 deg) at each of 10 depression or elevation angles between +19 and -53 deg (for beam dimensions of 6 × 7.2 deg); it also generates the pulse waveforms for transmission. CV-3522 is similar to CV-3011 in output.

BQQ-5B has the improved control display console (ICDC, OJ-462 for (V)1 and (V)2, OJ-463 for (V)3). There is only a single analog-video display (IP-1325 in (V)1 and (V)2, -1326 in (V)3). BQQ-5B incorporates SHAB, a steerable hull-array beam-former for the chin classification array. This version is less expensive than BQQ-5A. As in -5A, the (V)1 version is for the *Los Angeles* class, the (V)2 version is for the *Sturgeon* class, and the (V)3 version is for the *Permit* class.

BQQ-5C is the major current improved version; it is an upgraded -5B, with expanded DIFAR reception (multiple interface unit/digital spectrum analyzer with 3 UYK-44 computers in 1 cabinet). BQQ-5C(V) passed operational evaluation in June 1984. The (V)1 version is for the *Los Angeles* class, and the (V)2 version is for the *Sturgeon* class. Both use the BQS-13 sonar sphere. The new passive broad-band signal processor is CP-1556 or CP-1362 (1356 only in (V)2), the new passive beam-former is CV-3770, the new passive beam-former-processor is CV-3771, and the new standard console is OJ-544 (BQQ-5C uses 4 rather than the 3 of earlier versions). The active beam-former is unchanged. (V)2 uses the same components but may have fewer than 4 control consoles. BQQ-5C introduces a separate UYS-1 spectrum analyzer (not in all (V)2s). It employs a new analog-video display unit, IP-1440 (IP-1441 in SSNs 688–99). The (V)2 version has 0 or 1 such display units.

BQQ-5D incorporates the thin-line array (TB-23) and some BSY-1 technology. Successful trials of the array were conducted in FY85. BQQ-5D completed technical evaluation in October 1988; it was operationally evaluated in November 1988 and certified in May 1989. The (V)1 version is for the *Los Angeles* class, and the (V)2 version is for the *Sturgeon* class. BQQ-5D introduces a multi-array signal beam-former and conditioner. It also incorporates a new spectrum analyzer.

BQQ-5E will incorporate TARP, a new thin-line array (TB-12X) for passive ranging. The BQQ-5E contract was awarded in December 1988. System design is focused on the localization process. BSY-1 technology in this system includes sonar for under-ice operation and mine avoidance (MIDAS, BQS-24). Technical evaluation is expected in October 1992.

The current attack-submarine version is BQQ-5E(V)3. The full-scale development contract was awarded during the first quarter of FY89, and the final hardware specification for BQQ-5E was issued during the first quarter of FY90. Future planned improvements include dual towed-array processing (presumably for a combination of TB-16D and TB-12X, as in BSY-2), lower-frequency active operation (in conjunction with the array or arrays), and a color display for the ICDC.

BQQ-5E(V)4 is a passive-only version for *Ohio*-class submarines. Work on integrating BQQ-5E and CCS Mk 2 into Trident submarines began under the FY88 program, reflecting a decision to backfit ships with complete systems rather than make incremental improvements.

BQQ-5 is associated with the WLR-9 acoustic intercept receiver, sometimes referred to as AERP (active emission receiver).

BQQ-5 procurement in recent years: 4 in FY83, 8 in FY84, 9 in FY85, 9 in FY86, 8 in FY87, 2 in FY88, 9 in FY89. This includes replacement of existing BQQ-2 systems. Existing BQQ-5s will be brought up to -5D standard.

The earlier BQQ-2 is virtually extinct. For details, see the first edition of this book.

◆ BQQ-6

The integrated sonar for Trident-missile submarines differs from BQQ-5 primarily by lacking any active element in the bow transducer. There are also a towed array and 2 flank arrays (total 100 transducers). The bow sphere includes 944 transducers. There is also an HF array consisting of 3 line hydrophones on a tracking pedestal. BQQ-6 requires 33 electronic cabinets and 430 kwords of software. About 73% of BQQ-6 components are common with BQQ-5.

Late Trident submarines will be equipped with BQR-5E(V)4, a version of BQQ-5E incorporating the thin line array but, like BQQ-6, without any active elements.

◆ BQQ-8

Rockwell's device integrates multiple passive SSBN sonars, both hull and towed arrays (BQR-2/21, BQR-7, and BQR-15), to form spherical sonar coverage. It employs multiple signal-processing techniques, automatically alerts when contacts with selectable characteristics appear, and automatically localizes and performs TMA for up to 30 separate and simultaneous contacts. All sonar data are remotely displayed in the submarine attack center, and BQQ-8 also provides a continuous equipment status display. All contact data are recorded on tape and also on hard-copy paper. There is a dual independent interface providing contact bearing data to the submarine FCS. BQQ-8 also provides geosit and target-true-motion displays (which can also show the likely results of alternative own-ship maneuvers). It incorporates a sonar performance predictor and can display own-ship and threat sonar detection-performance profiles.

Compared to its predecessors, BQQ-8 offers significantly better beam-forming using programmable beam-formers (which can take account of local acoustic conditions). It offers better search and signal-processing techniques, with integrated contact motion analysis (using several arrays together). Unlike its nondigital predecessors, it can track numerous targets simultaneously, and it introduces interactive displays. It can operate in a degraded mode and has its own performance-monitoring and fault-location element. The associated computer is UYK-20. BQQ-8 employs 3 sonar data processors and 2 spectrum analyzers, none of them standard components. There are 3 sonar-operator display consoles and 1 remote sonar-display console.

BQQ-8 was developed under a 1977 contract, and the data above date from 1980.

◆ BQQ-9

Rockwell International's towed-array signal processor can operate either as a stand-alone system or as an auxiliary to a federated submarine combat system. Rockwell claims that its advanced software and data-processing techniques allow an operator easy access to all system capabilities, with minimum training. The result, according to the company, is increased passive detection range. BQQ-9 incorporates built-in test equipment, and as of 1984 the system had passed all of its sea trials and operational evaluations. The current U.S. application is to SSBN (pre-Ohio) towed arrays.

BQQ-9 is equivalent to BQQ-8, for BQR-7E and BQR-15 sonars. It is built around a UYK-20A computer and a spectrum analyzer and has a single sonar-operator display console and no remote console. BQQ-9 uses the same memory set and the same sonar operator console as BQQ-8, but the sonars are used as separate entities (in BQQ-8, their hydrophones feed directly into the data processors and consoles of the BQQ-8 system).

◆ BQR-2B/21

BQR-2 was the passive sonar of early U.S. postwar fast attack submarines, and in its BQR-21 form it equips pre-Ohio-class strategic submarines. BQR-2B survives on board some ex-U.S. diesel submarines. The array consists of 48 staves (43-in line hydrophones) in a 68-in circle. The hydrophones of BQR-2B and -2C are lead-zirconate-titanate DT-168Bs with a nominal operating frequency of 300 Hz–15 kHz. Signals are filtered to limit them to the 0.5–15-kHz band, and twenty-four 18×30 -deg (at 5 kHz) beams are formed, the sonar using 12 left and 12 right beams for target following by BDI. BQR-2B originally had no bearing-time (waterfall) indicator, but that feature became standard in the -2E version. Bearing-time information is recorded for the 0.7–1.4-kHz band, and the BDI was accurate to within about 0.1 deg. Modes: MTB (maintain true bearing), GTT (generate target track), ATF (automatic target following), and automatic on-target slewing. There were 2 consoles (stacks) for simultaneous acquisition and processing of multiple targets and independent, continuous, recorder scanning. Sweep rates were manual or 4 rpm for each beam (recorder beam 1 or 10 rpm).

About 1960 BQR-2B was credited with a range of 15–20 nm against a snorkeling Guppy in the deep Atlantic; it was estimated that a quiet platform would be able to increase this range to 50 nm.

BQR-21 is a solid-state, passive, narrow-band, DIMUS sonar using the existing BQR-2 array. It equips U.S. strategic submarines prior to the Ohio class. BQR-21 has 96 preformed detection beams. There are 2 parallel processing subsystems, digital and analog. The linear analog beam may be trained manually or set into ATF to track as in BQR-2; the sonar has a bearing deviation indicator (BDI) as a manual-tracking aid. The cursor of the linear analog beam is presented on the digital displays. The digital subsystem converts the hydrophone signals into digital form, sums and delays them to form the 96 equally spaced preformed beams providing 360-deg coverage. Signals from each beam are averaged over 3 different periods (long, intermediate, and short), and these data are continuously available for display on 2 of the 3 CRTs. The CRTs can also display combinations of short and intermediate or long time-averaged data. The remaining CRT displays system operation modes and quantities of interest such as fire-control data. There are also 4 channels of digital ATF, so BQR-21 can track a total of 5 targets simultaneously, accurately enough for weapons delivery. The array consists of 48 DT-532/BQR-21 or DT-303/BQR-2D hydrophones arranged in a cylinder. Compared to BQR-2, BQR-21 enjoys reduced self-noise, partly through the installation of an array baffle. The sonar data processor is CP-1146(1)/BQR-21, and the display console is OJ-213/BQR-21. The system requires a total of 6–10 electronic cabinets and weighs 2100 lb.

BQR-21 equipped 13 pre-Permit-class nuclear attack submarines, now extinct. BQR-21 also works with the BQR-15 towed array and the BQR-19 receiver set and with BQQ-9. The Honeywell West Covina division received the development contract in June 1972, with sea trials of the first development model following in 1974. Procurement ended in FY82, a total of 66 having been purchased (59 tactical units, 8 trainers, and 1 configuration control unit). A planned SPAD (Signal Processing and Display) project to make fuller use of the signal-gathering ability of the array was canceled in 1974.

◆ BQR-3

This directional hydrophone occupies a small deck sonar dome on board many former U.S. submarines. BQR-3 is a trainable 5-ft line array with a 22-deg beam (but with sum/difference bearing-deviation indication for accurate direction). Typical range on a snorkeling submarine was given in 1956 as 18,000 yd.

◆ BQR-7

These conformal passive arrays (52 hydrophone groups, each of 3 hydrophones, covering a 270-deg arc) are on board pre-Ohio-

class strategic submarines. The hydrophones are lead-zirconate-titanate DT-276 or -276A (2.88 in diameter $\times$ 9.4 in). In its original form, the 50 Hz–5 kHz array was scanned mechanically at 1 or 20 rpm. Late versions (certainly BQR-7E, the final version) use DIMUS processing. The associated bearing-time (waterfall) recorder operates in the 0.5–2-kHz band. Overall system accuracy is about 1 deg, but sometimes with a 3-deg offset to take signal integration time into account. The associated bearing-deviation indicator is accurate enough for passive fire control. The array runs back about 45 ft from the submarine's bow.

In 1960 it was estimated that, on board a quiet submarine, a BQR-7 would be able to detect a snorkeling Guppy at 75 nm.

This and BQR-2/21 are the passive hull sonars of U.S. strategic submarines prior to the *Ohio* class. BQR-7 is integrated with the BQR-15 towed array by the BQQ-8 or BQQ-9 described below.

◆ BQR-15

BQR-15 was the first operational U.S. submarine towed-array sonar, on board SSBN 608- and 616-class ballistic-missile submarines. It also worked with the BQQ-3A(V) and BQQ-3B(V) passive classification system associated with the now-extinct BQQ-2 attack-submarine sonar. The short (about 120 ft) 3.5-in array carries 42 hydrophones, and the inboard electronics require 9 cabinets. The large array diameter is due in part to the use of a relatively simple technology, twisted pairs to carry the hydrophone outputs. Total weight (probably only of the array proper) is 950 lb. In addition to submarine signatures, BQR-15 can receive underwater telephone signals (from UQC-1 and WQC-2). BQR-15 was introduced largely to give strategic submarines the ability to detect targets on aft bearings, hidden in the baffles of the bow sonars. BQR-15 incorporates the BQR-23 signal processor. It is associated with the new BQQ-9 processor.

The JMSDF tested this array on board the submarine *Okishio* in 1988–89, to integrate it with ZQQ-5 or -5B.

◆ BQR-19 (Top Hat)

Raytheon's mast-mounted short-range navigational sonar for SSBNs is designed for evasion while surfacing. Its array is a 24-stave cylinder (DT-374/BQR-19 hydrophones), and inboard electronics consists of 3 cabinets, weighing a total of 1000 lb.

◆ BQR-20A/22/22A

Spectral Dynamics's signal processor for improved narrow-band detection and classification is based on the SQQ-23 passive receiver, with added passive-classification equipment. It is found on board all U.S. pre-*Ohio* strategic submarines as well as *Los Angeles* and earlier attack submarines; it is also in British service. Work began in the late 1960s; the BQR-20 contract dates from 1971, and BQR-22 from 1974. The parent firm, Scientific Atlanta, has proposed that BQR-20 be replaced by the more capable BQR-23. BQR-22 is similar. It can be connected to a dual-channel hard-copy (LOFARgram) recorder. BQR-22A can be used as a dual-channel system and adds a remote range-rate indicator. BQR-20 and the improved BQR-22 require 1–5 electronic cabinets, weighing a total of 500 lb.

BQR-20A is the SQQ-23A passive signal processor. It entered service as such in 1975.

◆ BQR-23

BQR-23 is a towed-array signal processor manufactured by Scientific Atlanta (originally by Spectral Dynamics), used with the BQR-15 and -25 arrays and as part of BQQ-5. It provides at least 64 channels of data simultaneously in real time, with a visual display. Sonar signals are classified by LOFAR analysis.

The original BQR-23 contract was awarded in 1974. Versions: BQR-23, -23A, -23A(V)1 through (V)6.

◆ BQR-24

BQR-24 is a signal processor and beam-former added to BQS-11, -12, and -13 sonars on board SSN 594/637-class submarines as

an alternative to installation of the full BQQ-5. In effect it is the first stage of conversion from BQQ-2 to BQQ-5. It is described here as an indication of the sort of capability improvement BQQ-5 entails. The earlier BQQ-2 formed beams in analog fashion. The wiring from the individual sonar transducer elements was led to equivalent elements in a pair of small spheres. Commutators moved over the surfaces of the spheres to form beams, picking up signals from the sphere elements with the appropriate relative phases. In this sonar (as in BQQ-5) the mechanical commutators and their small analog spheres are eliminated. They are replaced by a digital beam-former, for full DIMUS operation. BQR-24 provides the earlier spherical bow sonars with a preformed-beam, passive, broad-band, detection capability (DIMUS); a high-resolution, wide-frequency-range, narrow-band, spectral analysis and display capability (digital LOFAR); a frequency-line tracker capability; improved TMA capability; computation and display of acoustic propagation paths, ray-path trace and associated environmental data, and self-contained test and training capability. BQR-24 consists of a signal-data processor, a passive DIMUS beam-former, a recorder, and 2 monitors; total weight is 2100 lb. BQR-24 was approved for service use in 1974, and 11 were bought under the FY76 program.

◆ BQR-25 (STASS)

This was the original stand-alone Submarine Towed-Array Sonar system, predating the TB series integrated with BQQ-5 and -6. The clip-on "wet end" was made by Gould. BQR-25 consists of a beam-former and a 298-ft (2–2.4-in diameter) DT582/BQR acoustic array towed on an 800-ft (1-in cable). The 550-lb array consists of 4 LF hydrophone modules, 1 stabilization module, and 2 VIMs (150 and 300 lb). The signal processor is BQR-20A, BQR-22, or BQR-23. BQR-25 is used on board some SSN 594/637-class submarines and was previously on board SSBN 598-class strategic submarines; in 1981 it was on board 18 SSNs and 3 SSBNs. Inboard electronics consists of 3 cabinets, weighing a total of 200 lb.

◆ BQS-4

The successor to SQS-4 for submarines, BQS-4 consists of 7 vertically stacked cylindrical transducers inside a passive sonar (BQR-2C) that acts as receiver. Vertical stacking permits beam movement in the vertical plane. BQS-4 operates at 7 kHz, and typical range is 6–8 kyd. BQS-4 is found in older U.S. diesel and nuclear submarines.

◆ BQS-13

The bow-sphere sonar of the BQQ-5 system, this DIMUS narrow-band accelerated-search (DNA) sonar superseded the mechanically scanned unit (BQS-6 and successors) of the earlier BQQ-2. The effect of DIMUS was to greatly increase the number of targets that the sonar could track; BQS-6 was limited because it had 2 commutators. As an approximate measure of BQS-13 performance, BQS-6 transmitted at about 3.5 kHz (i.e., like SQS-26/53) and listened at 1–2.8 kHz. Rated output was 75 kW, and sphere diameter was 15 ft.

◆ BQS-14/15

Under-ice and mine-avoidance sonars, these HF sets are part of BQQ-2, -5, and -6.

Hazeltine's BQS-14 was on board 22 *Sturgeon*-class submarines in 1981. It employs a cylindrical transducer with 30 dual staves, as well as a projector (TR-215/BQS), an HF transducer (TR-217), and 7 LF transducers (TR-216). Internal electronics occupy 6 cabinets, and the system as a whole weighs 2200 lb. BQS-15, the under-ice sonar of the *Los Angeles* class, consists of 3 line projectors, tracking pedestals, 2 HF transducers (TR-282), 4 LF transducers (TR-281), and 4 cabinets of inboard electronics, for a total of 3300 lb.

◆ BQS-()

This is a new submarine sonar with significantly better mine-hunting and under-ice-navigation capability. No details have been published.

◆ BQS-24 (MIDAS)

This HF minehunting and under-ice-navigation sonar for *Los Angeles* and *Ohio* classes is part of BQQ-5E. Specifications were finalized in FY89, and development began in FY90. Full-scale engineering development is scheduled for FY91, with a full-scale development award due in October 1991. The MIDAS concept had already been tested on board the *Richard B. Russell* about 1986; MIDAS probably occupied the large dome mounted aft at that time. Released paintings of the new *Seawolf* show a sonar window in the appropriate position at the upper forward part of the sail. MIDAS, Mine Detection and Avoidance Sonar, is sometimes linked with SADS, Submarine Active Detection Sonar, as SADS/MIDAS.

◆ BSY-1 (SUBACS)

The submarine integrated combat system replaces BQQ-5 in the last *Los Angeles*-class submarines. It was originally designated BYS-1 and apparently redesignated as the result of a typographical error; BSY-1 is now pronounced "busy-one." It appears to have been conceived as a submarine equivalent of the SYS series of systems on board AAW ships and also of the SQQ-89 on board newer ASW ships: a system that would automatically detect targets on a variety of arrays and meld these data (obtained in various frequency ranges) into a single usable tactical picture. One advantage of such detection would be the ability to range passively on a target detected simultaneously (in different frequency ranges) by several arrays, e.g., by a towed and a flank array. As in SQQ-89, the minimum required for integration is that adjoining consoles be able to show the output of any array, for comparison and correlation. That in turn requires that sonar data be carried by a data bus available to each console. As in

SQQ-89, once passive target data have been fed into the central computer system, multiple targets can be tracked automatically. In BSY-1, unlike its predecessor (BQQ-5/Mk 117), there is sufficient computer power to allow the operators considerable interaction with the evolving computed TMA solutions. Given that degree of interaction, operators are much more willing to forego the paper tracking previously demanded (and, as it often turned out, needed) as a check on the computer.

BSY-1 incorporates a new Combat Control System (CCS Mk 1), which replaces the Mk 117 of earlier submarines. The arrays match those of BQQ-5, but the sphere uses new transducers (TR-217/218 for the sphere). BSY-1 also incorporates WAA (BQG-5) and the thin-line towed array.

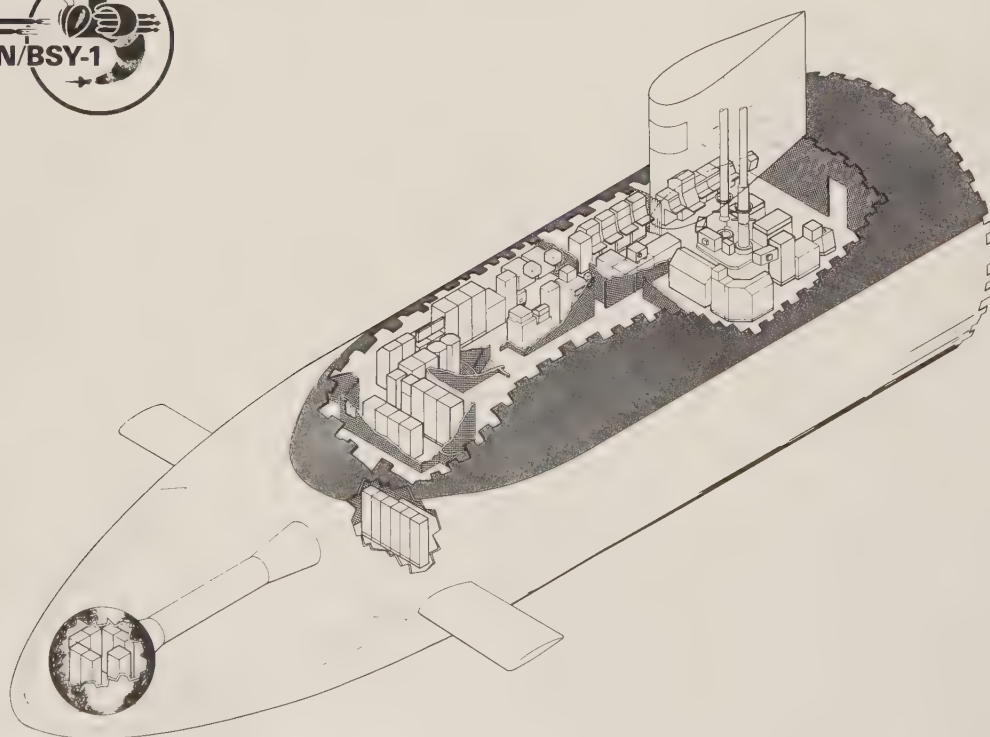
IBM was responsible for overall system design, with Hughes developing combat-system displays, Raytheon the CCS and the WAA, and Rockwell the own-ship data-set group. The 2 basic elements of the system were a multipurpose console incorporating a new densely packaged electronic card, and the high-capacity fiber-optic data bus tying the consoles together. A submarine would have 11 such consoles arranged side by side, but only 4 would be required for operation. It would be unnecessary to perform maintenance during a patrol; any console that failed could be taken out of line and replaced by 1 of the others. The adoption of the multipurpose consoles replaced the separate FCS of the past with a CCS embedded in system software.

In practice the dense packaging proved much more difficult than had been expected, and the data bus also encountered difficulties. BSY-1 had to be recast. It now employs a variety of different consoles: 4 control-display units, 2 different multipurpose units, 4 weapons-control consoles (3 Mk 81 Mod 3, 1 Mk 81 Mod 2), 1 command launch-control console, and 4 weapons launch-control consoles (1 vertical). There are 3 tactical data processors and 1 UYK-7 computer. BSY-1 incorporates 2 graphic plotters (Mk 23 Mod 0), 2 computer plotters, and 1 Mk 19 Mod 20 (see the Mk 101 FCS for a description of the original Mk 19). There are 2 signal conditioners, 1 for the bow sphere and 1 for multi-arrays (WAA and towed array, presumably). There is also a console for acoustic support (presumably, for the intercept receiver or receivers).

As of 1985, the program had been split into 3 versions:

SUBACS Basic, for FY83 submarines (scheduled for delivery

BSY-1 configuration, showing both the bow sphere and the chin array (the latter is not highlighted). There is also a towed array. (IBM)



1987): distributed acoustic processing, UYK-44 computers, thin-line towed array, and SADS/MIDAS active sonar for submarine and mine detection.

SUBACS A (FY86 submarines for delivery 1989) added an enhanced modular signal processor (EMSP), distributed combat control, a piloting and combat system (PACS), a combat-system display console (CSDC), and common displays. SUBACS A employs a new bus interface unit and is an application of VHSIC technology. The term PACS suggests some measure of automatic maneuvering, presumably for torpedo evasion or perhaps for faster and more precise TMA.

SUBACS B (FY89 submarine, the new *Seawolf* class) added the WAA and improved ESM and external countermeasures (presumably antitorpedo decoys).

In fact, as noted, this program could not be met and had to be split between BSY-1 (which IBM retained) and BSY-2 (which went to GE).

The first BSY-1 was delivered in July 1987, for installation on board the attack submarine *San Juan* (SSN 751). BSY-1 represents an improvement in passive sonar capability and in some weapons control. A further post-completion upgrade, for the *San Juan* and the next 4 *Los Angeles*-class submarines, will be installation of new UYK-43 computers, new software, active sonar improvements, under-ice capability, and new weapons capability (presumably Sea Lance). This 2-phase approach was chosen when the SUBACS program was restructured in May 1985. From SSN 756 on, submarines will be completed with the full BSY-1 suite.

BSY-1 uses distributed processing to support a combat-control subsystem and an acoustic subsystem. This integrates BQQ-5, SADS/MIDAS (see below), the thin-line array (TB-23), and CCS Mk 1 (Mk 117 plus OTH-T). The system will initially use the improved control-display consoles (ICDC) and Mk 81 WCC (weapons-control console) of the BQQ-5/CCS Mk 1 system, the UYK-7(V) computer of BQQ-5/CCS Mk 1, tri-advanced signal processors (TRIASPs), and the active emission-receiver processor (sonar-intercept receiver) of BQQ-5. New features are the weapons-launch system (WLS), the common beam-former cabinet (CBC), and a modified plotter Mk 19.

IBM describes BSY-1 as the first military application of distributed architecture on a large scale. BSY-1 employs 1 UYK-7 and 1 UYK-43, supported by 2 UYK-44 minicomputers; presumably the retention of the older UYK-7 reflects commonality (in some software) with earlier *Los Angeles*-class systems. There are also 5 linear beam-formers, 2 digital (DIMUS) beam-formers, and 6 advanced signal processors (in the form of 2 TRIASPs). Overall, the system has 30 MCOPS in raw general-purpose computing power, supported by 60 Mbytes of on-line RAM storage and 400 Mbytes of disk storage. The computer power required for signal processing dwarfs general-purpose power: 120 MCOPS of signal processing, 800 MCOPS of linear beam-forming (for towed arrays, presumably), and 2 GCOPS (giga-COPS) of DIMUS beam-forming. All of this power requires about 4,519,000 lines of instruction code. Total weight is 32 tons, and total power requirement (aside from the transmitter) is 142 kW. The system occupies 117 units with 11.5 miles of wiring. Presumably, the enormous amount of wiring reflects the failure of the optical-fiber data bus originally planned.

Improvements over BQQ-5 include much better fault detection and a greatly reduced number of logic cards.

BSY-1 is to be upgraded with a new CCS Mk 2, a program awarded to Raytheon/General Dynamics in September 1988. See below.

The BSY-1 Operational Requirement (OR) was issued on 17 April 1980. As of November 1988, a total of 21 BSY-1 were on order or had been delivered (20 for submarines, 1 as a trainer). FY88 deliveries were for SSN 752 and 754. FY89 deliveries: 753, 755-57. FY90 deliveries: 758, 759-62. FY91: the program is completed with SSNs 763-69. The first full-function model was delivered in February 1989 for the *Miami* (755). SSN 751 will be the first of the first 4 BSY-1 to be retrofitted to full-function standard. Techeval and opeval were scheduled for 1990.

This was the first U.S. submarine sonar system formally to integrate sonar and fire-control functions; in this sense it is analogous to SQQ-89/Mk 116.

Unit cost is \$43 million.

◆ BSY-2

BSY-2 is the combat system of the new *Seawolf*-class submarine. The program was split from BSY-1 when the latter encountered severe problems in 1985-86. BSY-2 retains the original goal of largely distributed processing, with multifunction consoles (MCCs) and combat-system display consoles (CSDCs), a horizontal plotter (HP), and a tactical-situation display (TACSIT). A published drawing (1989) shows 6 ship data displays and 11 consoles, 3 of them for the CCS. Software is to be written in ADA.

The major system sensors are a large spherical bow array (LSA, spread over the surface of the bow), an LF bow array inside the bow (LFBA), an active hemispherical array (AHA) below the LFBA (using a transmit group, TG), an HF array (HFA) in the sail (for SADS/MIDAS), the WAA (BQG-5), a long thin-line (TB-12X) towed array, and a shorter TB-16D array. The long thin array is associated with TARP, the towed-array range processor. The same system processes all 7 arrays to form a coherent tactical picture. As in earlier integrated sonars, passive targets are detected primarily by automatic line integration (when the strength of a line exceeds a threshold, the target is detected and inserted into the system). BSY-2 differs from its predecessors in the number of lines and frequency ranges it can surveil simultaneously. All sonar output flows into array processors for signal conditioning and beam-forming. Outputs go into signal processors (UYS-2s) and also into the workstations/functional processors. The latter also receive processed signal data. The workstations are connected with the weapons launch system by a flexnet data bus, and they also feed into the combat system's display consoles. There is no central computer. The system as a whole comprises 61 enclosures, and it requires a total of 570 kW and a maximum of 157 gal/min of cooling water.

General Electric is the prime contractor; the company received the BSY-2 full-scale development (FSD) contract in March 1988. Librascope is responsible for multifunction displays, and Martin Marietta makes the WAA.

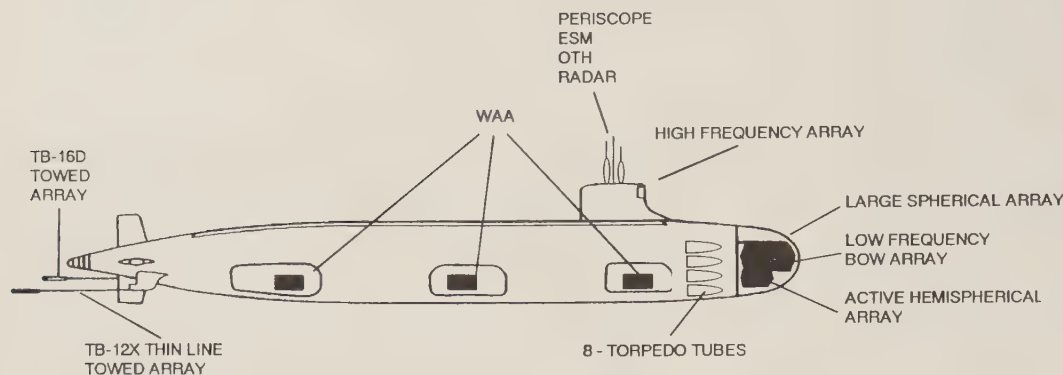
The first unit is scheduled for delivery in May 1995. As of December 1989, there was some fear that the initial unit would be 12-16 months late, largely because GE might not be able to train enough ADA programmers quickly enough. The navy's approach has been to develop the software in modules (threads), so that the initial *Seawolf* will have at least the minimum required capability. Since the feared limitation is in software rather than hardware, later upgrading to full capability should be simple and inexpensive.

BSY-2 uses about two hundred 68030 microprocessors. It is broken down into 4 subgroups: acoustics, command/control, weapons, and display. The system is made highly redundant through the use of common hardware running different software. In the weapons section, each of the 4 processors has a designated backup. In each of the other groups there are 2 or 3 spares. Thus, each cluster can shift to other processors within itself as not all are used simultaneously. If necessary, any function can be shifted to processors within another cluster (other functions are slowed or stopped). The loss of functions is prioritized.

◆ QBE-3

This 18-25-kHz searchlight sonar, with a typical range of 1 kyd (max indicated range 5 kyd), was standard aboard U.S. 83-ft coast guard cutters transferred abroad. It reportedly survives at least in the Turkish navy. QBE is a converted passive sonar in a fish-type retractable dome, using a 15-in-diameter transducer. In the U.S. World War II system of designations, QB denoted a sonar with a rochelle-salt transducer.

AN/BSY-2 SUBMARINE COMBAT SYSTEM ON SEAWOLF (SSN21)



ARRAYS PROCESSED

LARGE SPHERICAL ARRAY (LSA)
 LOW FREQUENCY BOW ARRAY (LFBA)
 WIDE APERTURE ARRAY (WAA)
 TB-12X THIN LINE TOWED ARRAY
 TB-16D TOWED ARRAY
 ACTIVE HEMISPHERICAL ARRAY (AHA)
 HIGH FREQUENCY ARRAY (HFA)

WEAPONS EMPLOYED

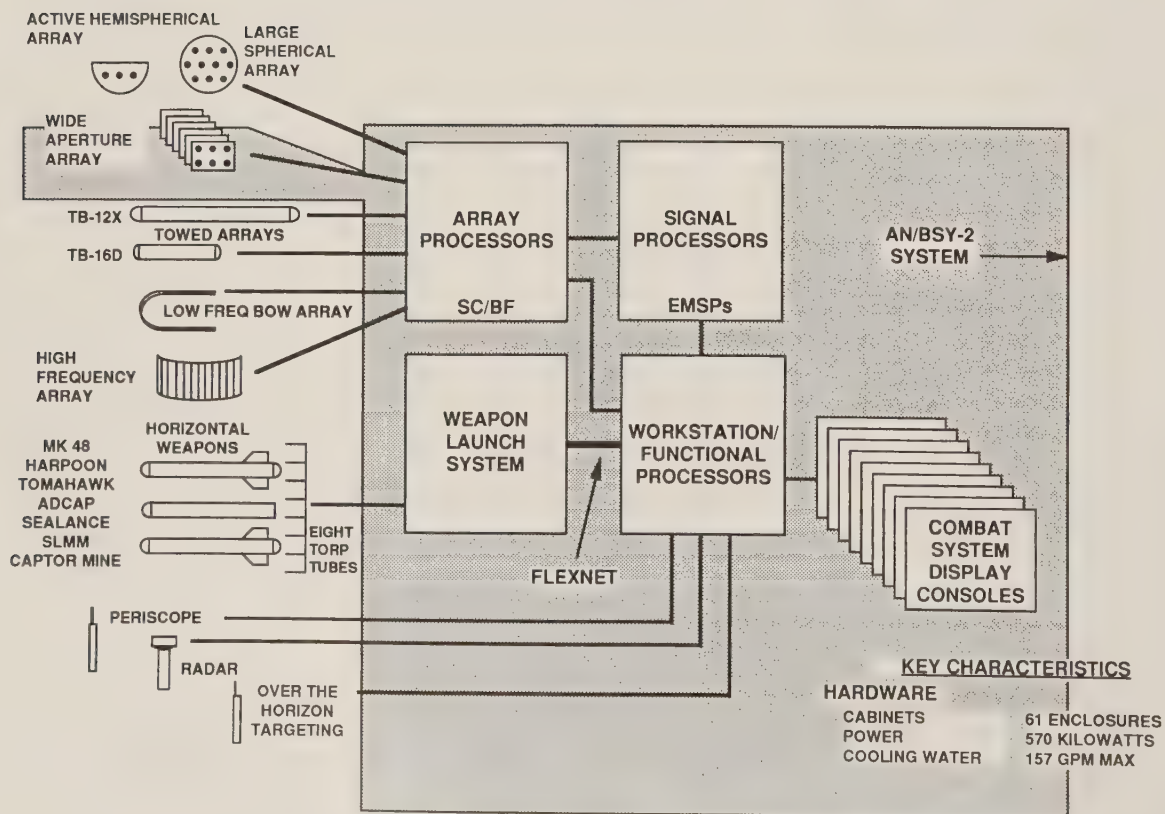
MK 48
 ADCAP
 TASM
 TLAM
 HARPOON
 SEALANCE
 SLMM
 CAPTOR MINE

ARCHITECTURE PARTITIONED

TACTICAL RECONFIGURATION
 GROWTH POTENTIAL
 TACTICAL CHANGE
 HIGH AVAILABILITY
 WORKSTATION

BSY-2 sensors. (U.S. Navy)

AN/BSY-2 SUBMARINE COMBAT SYSTEM



The BSY-2 system configuration. (U.S. Navy)

◆ QCU-2

This World War II searchlight sonar is still in use in a few U.S.-built ships of that period and in some small patrol craft transferred postwar. Frequency is 17–27 kHz (centered on 25 kHz). Range scales are 1, 2, 4, and 6 kyd (associated pulse lengths 25, 75, 75, and 200 yd, respectively). In the U.S. World War II system of designations, QC denoted a sonar with a magnetostrictive transducer.

Current installations: Greece (*Cannon*-class frigates), Italy (*Albatros*-class corvettes), Portugal (*Joao Coutinho* class), Spain (P311-class patrol boats), Thailand (PC 461 class). This sonar was also supplied to foreign navies on board ex-U.S. 95-ft coast guard cutters and their PGM derivatives. QCU-1 was standard on board the PGM 39 and PGM 53 classes. This sonar may also survive on board other ex-U.S. warships. SQS-17 was, in effect, the successor sonar. On board PGMs, however, it was limited to a few special ASW units for the Iranian and Turkish navies.

◆ SQQ-14

See the Mine Warfare section under countermeasures.

◆ SQQ-23

See SQS-23 below.

◆ SQQ-25

This high-definition 3-D sonar is found on board the submarine rescue ships *Ortolan* and *Pigeon*. SQQ-25 uses a 7-kHz chirp. Active range is 2500 yd; passive, 1000 yd.

◆ SQQ-28

The LAMPS-III shipboard processor is the successor to SQS-54. SQQ-28 was later extended to LAMPS-I support, for *Perry*-class frigates assigned to Naval Reserve units. SQQ-28 can process all buoys up to and including VLAD (SSQ-77).

◆ SQQ-30

See the Mine Warfare section under countermeasures.

◆ SQQ-32

See the Mine Warfare section under countermeasures.

◆ SQQ-34

This is a CV-ASW module, part of a carrier's CDS. It is a semi-automated system, the primary source of external data to the battle group ASW commander. It also provides all information for the carrier's own ASW aircraft (S-3, SH-3, and SH-60F). This system was originally the CV-Tactical Support Center and was renamed in 1979.

◆ SQQ-35

See the Mine Warfare section under countermeasures.

◆ SQQ-89

General Electric's integrated surface-ship sonar and fire-control suite is analogous to the submariners' BQQ and BSY series. Each version includes an on-board trainer, SQQ-89T(V). The first ship fitted with SQQ-89 was the *Spruance*-class destroyer *Moosebrugger*, which also had the prototype SQR-19 towed array (1985); she was followed in 1987 by *Fife*, *Fletcher*, and *Spruance*, 5 more ships following in 1988. The first FFG 7-class frigate to receive the new system was *Curtis* (1985), followed in 1986 by *Elrod* and *Simpson* and then by 5 ships in each of 1987 and 1988. From the *San Jacinto* (CG 56) on, newly completed Aegis cruisers will have SQQ-89 as initial equipment.

SQQ-89 was conceived under the ASW Combat System Integration (ASW-CSI) project, to handle the much larger number of passive contacts provided by the modernized SQS-26 (SQS-53) sonar and the towed array. Nothing short of a computer could keep track of several passive targets, conducting several TMA analyses simultaneously, so existing manual ASW

CDSs had to be replaced. The track-keeping computer is part of the Mk 116 Mod 5 or later FCS embedded in SQQ-89 (the *Perry*-class version lacks the Mk 116, but instead uses a weapons alternate processor [WAP] as its track-keeping computer). SQQ-89 also includes SIMAS (UYQ-25), which helps estimate the effective range of the passive sensors. The sensor side of SQQ-89 was originally developed as SIADS (sensor integration and display sharing); a shore test site was established at NUSC New London in 1980.

Presumably, SQQ-89 supersedes the experimental Mk 119 digital surface-ship underwater FCS, which employed submarine consoles (such as Mk 81), and which was installed at NUSC San Diego about 1980.

SQQ-89 is the latest and by far the most successful of several attempts to produce an ASW equivalent to the highly automated AAW-oriented CDSs; it might be considered an ASW equivalent to Aegis. It requires about twice as many lines of source code as does the Aegis system, mainly for the multiple-target TMA.

All versions of SQQ-89 employ SQR-19 towed arrays and LAMPS III helicopters (SQQ-28) as their passive sensors; most versions also incorporate SQS-53B/C sonars. The display consoles are OJ-452/UYQ-21s. The combination acts as a sort of underwater equivalent to NTDS. Operators at the OJ-452 (UYQ-21) displays detect the targets (i.e., decide when passive sensors are showing real targets) and enter them into system memory. The Mk 116 (Mod 5 or later) computer (WAP in a *Perry*-class frigate) compiles what amounts to a full tactical picture and conducts the multiple simultaneous TMA. Mk 116 in turn inserts target data into the ship's NTDS system.

The sonar supervisor has some of the role of the track supervisor in NTDS but generally does not have a dedicated console (only versions now in development provide the supervisor with a dedicated console, and there is some disagreement as to whether that is a wise development).

Mk 116 also receives data (particularly ESM and radar data) from the ship's NTDS. These data can be used to eliminate nonsubmarine contacts, or to identify potential surface targets (which can be detected by their sound emissions, beyond the visual or radar horizon). Mk 116 automatically inserts its contact data into NTDS, which in turn can pass targets for Harpoon targeting.

Sonar data are fed through (and controlled by) UYK-20 computers and 1 (*Perry* class), 2 (1 master, 1 slave), or 3 OL-190/UYQ-21 acoustic-data converters, each of which can support 2 OJ-452/UYQ-21 acoustic-display consoles. Each sensor subsystem uses 1 or more UYS-1 spectrum analyzers. SQQ-89 includes the UYS-1 processor of LAMPS data (the other sonars include their own processors). Any UYQ-21 console can display data from any of the sonars. For example, an operator can switch between an SQR-19 display showing a CZ contact and an SQQ-28 display showing a LAMPS helicopter prosecuting that contact. Each UYQ-21 shows only 1 sensor at a time; it is provided with 2 screens so that different frequency ranges (or bearing-time and frequency-time) can be displayed at the same time. Any 2 sensor outputs, then, can be displayed side by side (on 2 UYQ-21 consoles) for visual correlation by a sonar supervisor. For example, a passive (SQR-19) and an active (SQS-53) picture of the same contact can be shown side by side. In the version using Mk 116 Mod 7, an acoustic sensor console can also be used to replace the Mk 116 display.

Side-by-side comparison was impossible in earlier systems, which relied on paper LOFARgrams and lacked any electronic memory. SQQ-89 achieves its high performance because several operators can see the same displays together; a total of 7–9 people work the ASW problem together. Moreover, the system uses LAMPS III as a sensor, fully equivalent to the 1 or 2 hull sensors because the data link has such a wide bandwidth and, thus, can transmit sonobuoy data so fully.

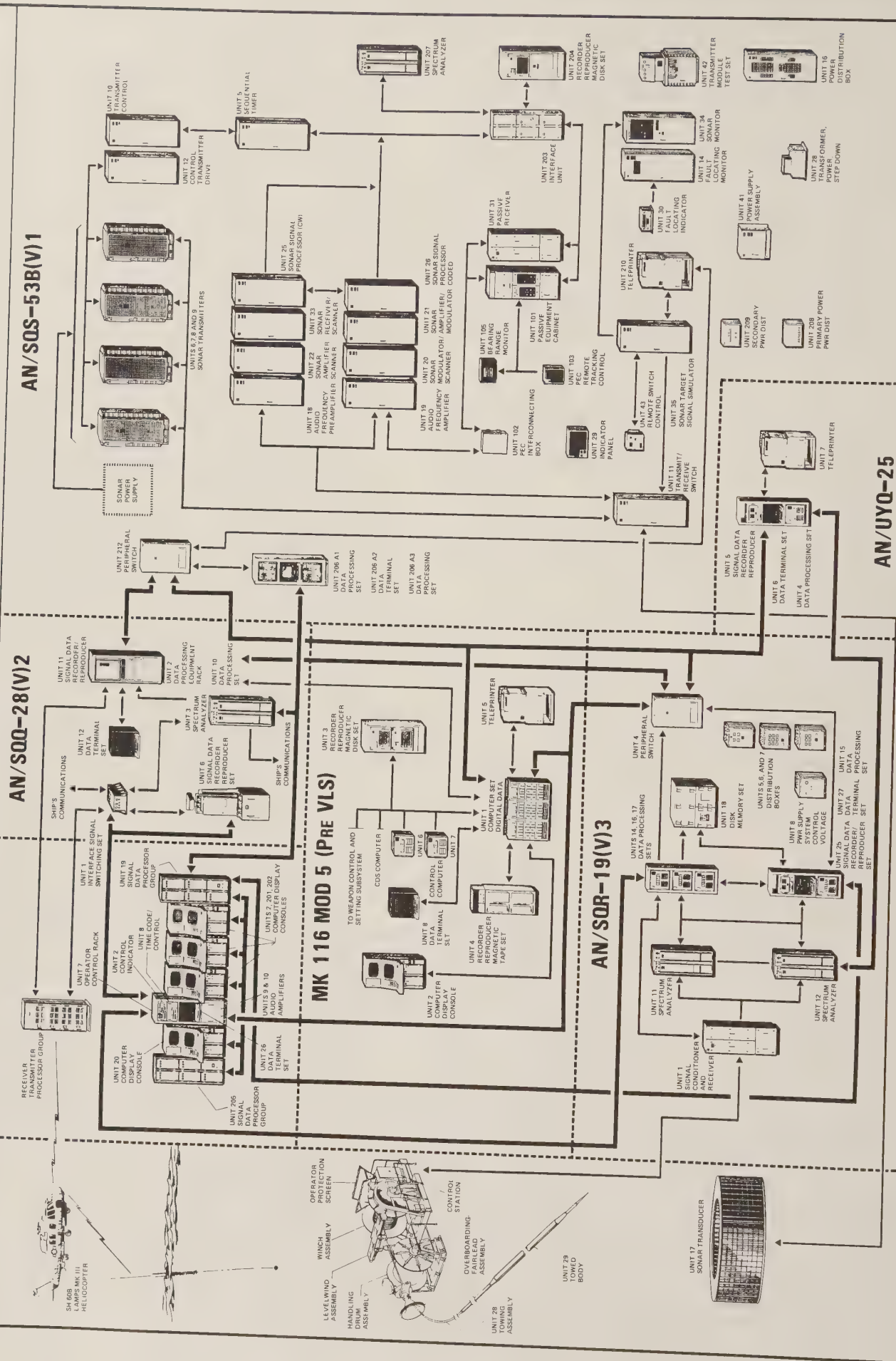
In a typical version, a (V)3, 3 of the UYQ-21 consoles are lined up together, separated from the fourth by an equipment rack

AN/SQQ-89(V)1

SURFACE ASW COMBAT SYSTEM

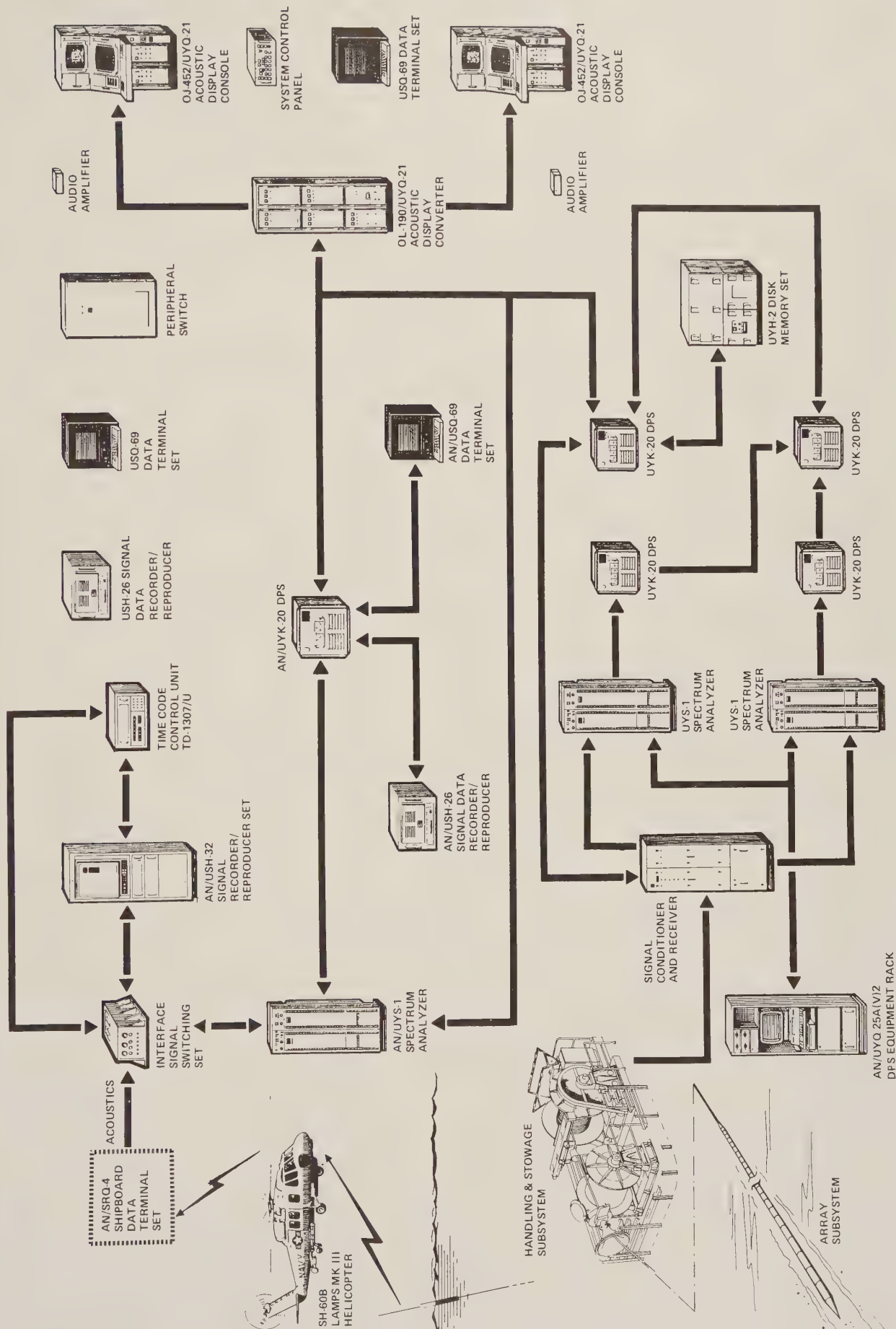
NAVAL SEA SYSTEMS COMMAND (PMS 411)

Undersea
Systems
Department



SQQ-89(V)1 configuration. (GE)

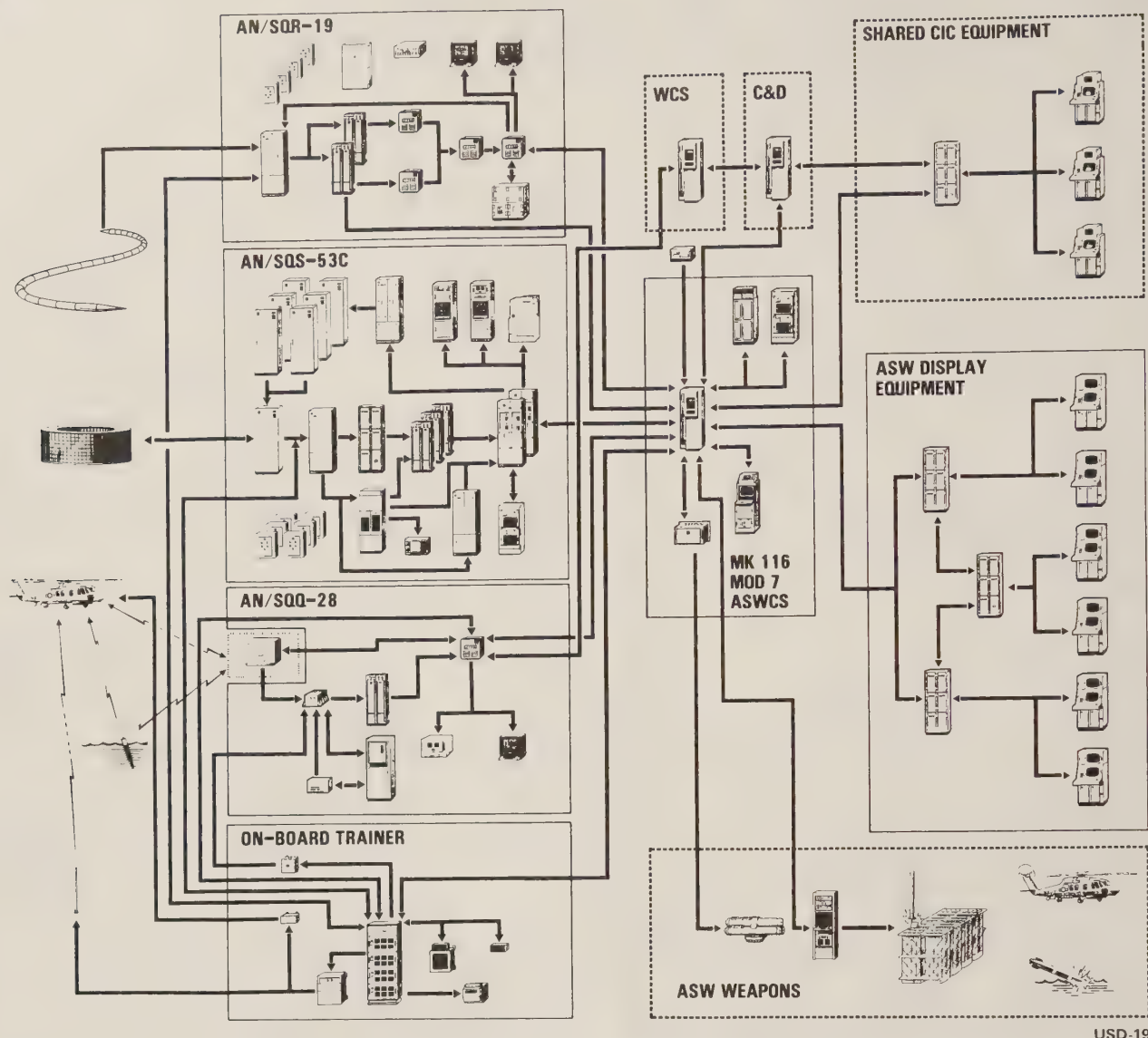
AN/SQQ-89(V)2
FY86 EQUIPMENT CONFIGURATION

Undersea
Systems
Department

SSQQ-89(V)2, the version for frigates, without a large hull sonar. (GE)



AN/SQQ-89(V)4 SURFACE ASW COMBAT SYSTEM



USD-19

SQQ-89(V)4, the fully integrated version of the system, in which the Mk 116 element is nearly vestigial. (GE)

containing a control indicator, a time code/control box, a data terminal set (UYQ-69), and a pair of audio amplifiers. The 2 acoustic-display converters are at the ends of the row of display consoles. The 3 consoles working together might be divided into 2 for SQS-53 and 1 for SQR-19, with the fourth also used for SQR-19. Presumably, 1 of the SQS-53 consoles would be switched to SQQ-28 when a helicopter was launched to prosecute a contact.

SQQ-89 was originally a combination of multipurpose sensor displays weakly integrated with a track-keeping computer in a modified Mk 116 FCS. Only in the later versions, (V)4 and above, is the distinction between sensors and fire control eliminated (as in Aegis).

Each sensor has its own embedded UYS-1 and UYQ-21 separate from SQQ-89. These UYQ-21s are for the *sensor* operators; they are equivalent to the radar repeaters. The SQQ-89 UYQ-21s are for target detectors inserting targets into the combat system, a very different role.

The latest improvement to the SQQ-89 series is the insertion of an acoustic video processor (AVP) into the lower drawer of the UYQ-21 to provide better graphics. This is display, not signal processing, technology.

The SQQ-89 unit cost was \$27–28 million (FY90). R&D began in FY76, with interface definition in FY78. Concept formulation was completed in FY79, and full-scale development in FY81. Initial operational tests were conducted on board the *Moosebrugger* in FY84, and the first production model was installed in FY86; full-scale procurement began in FY87. Design of the version using the UYK-43B computer was completed during FY86.

Versions:

Prior to (V)6, destroyers and frigates all have SQQ-28(V)2; cruisers and Aegis destroyers have SQR-28(V)3. SQQ-89(V)5 and later all have SQQ-28(V)9, a version that shares a UYK-44 computer with the SQR-19 array; the computer is called a signal-data processing unit (SDPU). All versions from A(V)3 onward use UYQ-25A(V)2; only (V)2 and (V)3 use UYK-20 for SIMAS (the others use the non-Mil-Std 9020C version). Versions of SQQ-89 differ in the versions of Mk 116 around which they are built. As of November 1990, plans called for installations on board 19 CG 47, 39 DDG 59, 30 DD 963, and 51 FFG 7 class units; there are apparently no plans for installations on board DDG 993-class ships. Numbers already certified (number in process in parentheses): CG 47, 11 (2); DD 963, 13 (5); and FFG 7, 26 (2). There are also 8 stand-alone SQQ-28s that will become part of SQQ-89s when other subsystems are installed. UYQ-25A(V)2 installations at present: 13 for the CG 47 class, 12 for the DD 963 class, and 21 for the FFG 7 class.

(V)1 for DD 965, 980, and 992 uses Mk 116 Mod 5 with SQR-19(V)3, SQS-53B(V)1, and UYQ-25A(V)2. There are 4 OJ-452(V)8/UYQ-21(V) consoles in the sonar-control space, with an OJ-452(V)11/UYQ-21(V) in CIC near the weapons-control panel (Mk 329). Two of the OJ-452s in sonar control flank a computer unit including a USQ-69. In this version, sensor data are fed into a group of 4 OJ-452/UYQ-21s fed by 2 OL-190/UYQ-21 acoustic-data converters: 3 adjacent display consoles plus a running spare and a data terminal (USQ-69). The system employs 2 UYS-1 spectrum analyzers, 1 of them connected directly to SIMAS. This version incorporates 4 UYK-20 computers, 3 for the spectrum analyzers and 1 for the signal conditioner and receiver (feeding into a UYH-2 disk memory set). The 3 UYK-20s feed into the SQQ-89 acoustic-display converter. The associated Mk 116 Mod 5 uses an additional OJ-452/UYQ-21 display and a 3-bay UYK-7 computer. First installation was in the *Moosebrunner* (DD 980).

(V)2 is the version without any integrated SQS-53 or Mk 116. There are 2 subvariants: (V)2 CG for CG 54 and CG 55 only, with SQR-19(V)1 and UYQ-25; and (V)2 FFG for FFGs 7-9, 11-13, 15, 28, 29, 32, 33, 36, 38-43, 45-49, 53, and 55-61, with SQR-19(V)2 or -19A(V)2 and UYQ-25A(V)2. In the CG version, 2 OJ-452(V)9/UYQ-21(V)s, for ASO and ASO-ALT (acoustic-sensor operator and acoustic-sensor operator/alternative), flank a computer console carrying the USQ-69. The relevant consoles in CIC are 2 OJ-194(V)4/UYA-4(V)s, for the underwater-battery supervisor (UBS) and for the ASW air supervisor (ASAS), and the standard horizontal console (OJ-197/UYA-4) for the surface-warfare coordinator (SSWC). In the FFG version, sonar control includes a similar pair of OJ-452(V)8/UYQ-21s flanking a console carrying USQ-69, plus an SQS-56 console, tape recorders, and a UYQ-25A and a UYK-20X(V). CIC includes the training console and another UYQ-25A. This version uses a weapons alternate processor (WAP, in effect replacing Mk 116). First installation was in the *Curts*.

(V)3 with Mk 116 Mod 6 has 2 variants: (V)3 CG for CGs 56-64, with SQR-19(V)1 or -19A(V)1, SQS-53B(V)2, and UYQ-25 or -25A(V)2; and (V)3 DD for DDs 963-964, 966-968, 970, 971, 973, 975, 981, and 991, with SQR-19(V)3/A(V)3, SQS-53B(V)1, and UYQ-25 or -25A(V)2. A(V)3 for CG 65 only uses Mk 116 Mod 7 with SQR-19B(V)3, SQS-53B(V)2, and UYK-25A(V)2. The CG version has 5 OJ-452(V)s in a row, 2 of them flanking the USQ-69 console. CIC contains an OJ-452(V)10, 2 OJ-194(V)4s, and the usual horizontal OJ-197 console. The destroyer version has 4 OJ-452(V)8s in sonar control and an OJ-452(V)11 (with the Mk 329 panel) in CIC. A(V)3 is the first version with a UYK-43 computer (instead of UYK-7). First installation was in the *San Jacinto* (CG 56). This version is very similar to (V)1.

(V)4 for DDG 51 (the *Arleigh Burke*) only uses Mk 116 Mod 7 with SQR-19B(V)3 and SQS-53C(V)1. Sonar control contains 5 OJ-452(V)9s, 2 USQ-69s, and the UYQ-25A(V)2; CIC contains an OJ-452(V)9 (for the ATS/FCO) and 2 OJ-451(V)s (for the ASWC and the ASAC). This version has 3 acoustic-data converters, serving 6 OJ-452s: 4 for the acoustic operators, 1 for the sonar supervisor (SS), and 1 for the ASW-control system operator (ASWCSO). In addition, the system is connected to 2 OJ-451/UYQ-21s in CIC, for the ASW evaluator (ASWE) and the fire-control operator (FCO); they are connected via a fourth acoustic-data converter. The computer is UYK-43(V)7: 1 for the weapons-control system (WCS), 1 for command and display (C&D), and 1 for the Mk 116 Mod 7. Mk 116 Mod 7 uses nearly 215,000 lines of computer program code. The UYQ-21 display formats include NTDS-style PPI as well as bearing/frequency analysis and TMA.

(V)5 with Mk 116 Mod 8 is for DDs 966-968, 970, 971, 973, 975, and 980-982; it uses SQR-19(V)3 or -19A(V)3 and SQS-53B(V)1. Ships are to be upgraded to this standard after FY90. The equipment in CIC and in sonar control corresponds to that in the (V)3 destroyer version. The computer is UYK-43(V)8.

(V)6 uses Mk 116 Mod 7 or (for DD) Mod 7/VLS. There are 3 variants, (V)6 CG for CGs 68-73 and (V)6 DDG for DDGs 52-58, both with SQR-19B(V)1 and SQS-53C(V)1; and (V)6 DD for DDs 978 and 985-988, with SQR-19B(V)3 and SQS-53C(V)2. The equipment configuration matches that of (V)3 (for destroyers and cruisers) and (V)4 (for Aegis destroyers). The computer is UYK-43(V)7.

(V)7 with Mk 116 Mod 7 is for CGs 66-67, with SQR-19B(V)1 and SQS-53B(V)2. The equipment configuration matches that of the (V)3 cruiser version. The computer is UYK-43(V)7.

(V)8 with Mk 116 Mod 8 for VLS ships and Mod 9 for non-VLS ships is for DDs 969, 972, 974, 976, 977, 979, 982, 983, and 997, with SQR-19B(V)3 and SQS-53B(V)1. The equipment configuration matches that of the (V)3 destroyer version. The main computer is UYK-43(V)8 and (V)9. A projected A(V)8 version has OJ-653/AVP instead of OJ-452 displays and also has a UYK-43(V)9 computer.

(V)9 for FFGs 14, 20, 30, 31, 34, 37, 50-52, and 54 lacks any version of Mk 116. It works with SQR-19B(V)2. The equipment configuration matches that of the (V)2 frigate version.

(V)10 is the future projected version for the DD 963-class and later Aegis destroyers, with OJ-653/AVP instead of OJ-452 displays. The main processor is UYK-43(V)7.

(V)11 is the future projected FFG version, with OJ-653/AVP instead of OJ-452 displays.

◆ SQQ-89I (SQY-1)

SQQ-89I, i.e., SQQ-89 Improved, is the next-generation surface-ship sonar system, incorporating the new technology of an LF active source and a multiline towed-array receiver. The TOR was issued in February 1985, and the OR that December. The system uses the UYS-2 processor and the OJ-535/AVP display.

FY89 efforts included classification algorithms, systolic adaptive processing/beam-forming techniques and evaluation of competing *Perry*-class SQQ-89I FFG technical proposals. The FY90 program included fabrication of advanced development models of low-cost towed arrays and the development of an advanced model of a sonar optical signal processor.

There are 2 parallel versions, an austere type for convoy escorts (i.e., for the *Perry* class), and an advanced version for Battle Group Escorts (BGE), i.e., CG 47/DDG 51/DDG 993/DD 963. The program is phased in blocks. Block 1 is essentially a software upgrade; Blocks 2 and 3 are the hardware upgrades.

For the *Perry* class, Block 1 provides all the improvements needed to satisfy the OR, except for the active upgrade. Block 1 for the BGE consists of upgrades based on mature computer algorithms already, in some cases, in use in air or submarine systems. *Perry*-class Block 1 installations should begin in FY90.

Block 2 is the *Perry*-class active upgrade. The experimental frigate *Glover* has been modified with an active LF emitter in her bow dome (installed FY88 and tested FY89). Competitive design-definition contracts were awarded in FY88, and FSED should begin in FY90. The first *Perry*-class Block 1 system should be delivered in the second quarter of FY93 (i.e., early 1993), and operational and technical evaluation should be completed in the first quarter of FY94 (late 1993). Production Block 2 deliveries should begin in the third quarter of FY97.

Block 3 is the active upgrade to the BGE. As in the case of the frigate, FSED should begin in FY90. As of early 1989, first Block 1 (BGE) production deliveries were scheduled for the first quarter of FY96, with Block 3 (BGE) following in the third quarter of FY98.

Efforts beyond Block 3 will be devoted to the development and evaluation of multistatic sonar (see also BGMSS).

As of 1990, there was speculation that SQQ-89I would be limited, at least at first, to only a few ships. There was some suggestion that it might be installed only on board FFG 7s and future air-capable battle-group escorts, on the theory that early DDG 51s, which cannot operate helicopters, cannot fully ex-

plot it. The 2 competitors were GE and Westinghouse, but in the spring of 1990 GE was dropped because it was unresponsive and its costs were too high.

The Westinghouse team includes Bendix, Honeywell, Link-CAE, Norden, and Singer-Librascope.

SQQ-89I was redesignated SQY-1 late in 1990.

See also SSATS, below.

◆ SQR-13

PADLOC (Passive-Active Detection and Localization), the first U.S. multi-array (and microcircuit) system, uses 2 arrays in separate domes. SQR-13 is incorporated in SQQ-23. PADLOC is a technique rather than a specific device; it was first tested using an SQS-29 and a submarine-type BQR-2B on board the destroyer *Glennon* in 1959, and PADLOC variants were proposed for use with SQS-26 during the 1960s.

◆ SQR-14/15

These very long range towed arrays are for surveillance. SQR-14 was designated the interim towed-array surveillance system (ITASS). SQR-15 was an improved version, intended as a backup to SOSUS. Instead, the U.S. Navy procured a longer-range SURTASS system. Both SQR-14 and -15 were produced by Gould. They are similar to, but not interchangeable with, BQR-15. Compared to SQR-18/19, SQR-14/15 use much longer arrays and operate at either much lower frequencies or with much narrower beamwidths.

The first SQR-14 was produced under the FY68 program. Tests were run in the early 1970s, and systems upgraded to SQR-15 configuration in 1974. SQR-14 was manufactured by Chesapeake Instrument Co. Six operational SQR-14As were bought under the FY72 program, after 1969 tests with a Tuba array. This 480-ft array could be towed by a destroyer, a frigate, a minesweeper, or a chartered commercial ship. Further versions were proposed: SQR-14B (1200 ft) for strategic and broad-area surveillance, and SQR-14C (525 ft) for surface escort. They all used 3-in-diameter modules, and all were speed-limited. SQR-15 was bought instead of SQR-14B, and SQR-18/19 in place of SQR-14C. There was also a proposed interim towed-array system, ITASS (3 in × 490 ft low-cost array, with better self-noise characteristics, but cumbersome handling gear, ca. 1973). SQR-14 is no longer in service.

Gould bought Chesapeake Instrument in 1975 and manufactured 6 SQR-15s (the last under the FY78 program) and 1 trainer. The first were aboard FFs 1037 and 1038 in 1975, and then 6 were carried by FF 1040-class frigates. One unit was lost in 1983 (when a Soviet Victor-III-class submarine cut through the tow cable with her propeller). The arrays were removed from their original platforms in 1983/84 and moved onto new ones (*Spruance*-class destroyers, 3 on each coast). SQR-15 electronics are carried in a van, for cross-decking. The OA-8705/SQR-15 array consists of 1 DT-541 (3 in × 29 ft) and 4 DT-540 (each 3 in × 29 ft, consisting of 6 ceramic elements) hydrophones, plus pressure transducers, 2 VIMs, and a drogue.

SQR-16 was an unsuccessful improved version of SQR-15, using a Gould wet end; only 1 was made.

◆ SQR-17

This family of shipboard sonar processors evolved from the SQS-54 LAMPS-I processor. SQR-17(V)1 is a 4-channel sonobuoy processor for the LAMPS-I, working with LOFAR, active, and BT buoys. SQR-17 can also process data from buoys dropped over the side of a ship, and also from a towed array (SQR-18). Acoustic data are displayed in either A- or B-scan and also in standard hard-copy form (e.g., LOFARgrams). The standard main console has 3 screens, a central 19-in acoustic-data display (for LOFARgrams) flanked by two 9-in screens for menu prompts, selection of operating mode, and monitoring of the status of multiple sensors. SQR-17(V)2 is an upgraded version to process towed-array data via an interface kit. The latter includes a digital multiplexer encoder/decoder (DMED) that converts the 32 channels of towed-array data, plus own-ship course,

speed, and track bearing, into high-density digital format for tape recording. SQR-17(V)3 adds frequency domain adaptive line enhancement (FDALE), an adaptive filter that makes weak lines more detectable within broad-band noise. FDALE was the first adaptive line enhancer in a fleet ASW processor. All of these systems were followed by SQR-17A(V)1 and (V)2, which add more sophisticated sonobuoy capabilities: 8 LOFAR channels or 2 DIFAR/DICASS channels. These versions can process VLAD array buoy data. Adaptive line-enhancement software is embedded in the system, which can also conduct TMA (MATE/MLE).

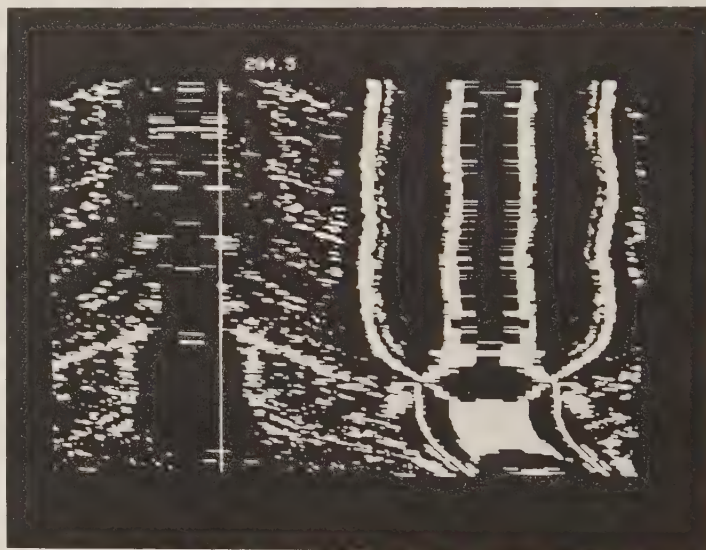
Subsystems are the SKR-4 link receiver, AKT-22 link, ARR-75 sonobuoy receiver, and UYS-1 processor. In 1988 this system was being modified to include a torpedo-warning capability.

These systems, which equip every LAMPS ship, are all manufactured by Diagnostic Retrieval Systems (DRS), Inc.

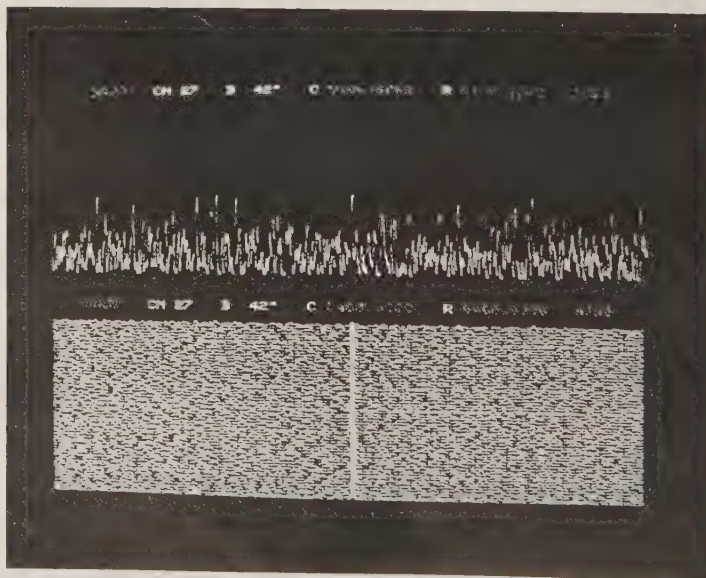
As of about 1989, 97 SQR-17s had been procured for shipboard use, and 16 were being procured for Mobile Inshore Undersea Warfare units. SQR-17 is to be modified for torpedo warning.

◆ SQR-18

The interim escort towed-array surveillance system (IETASS) was developed under the escort towed-array sensor (ETAS) program. SQR-18 was conceived as a simpler alternative to



SQR-18 broad-band display, with waterfall (for target motion in bearing) at right. (EDO)



SQR-18 LOFAR and ALI display. (EDO)

SQR-14/15. Work began under the FY68 program. One Patterson experimental array (PEA) was bought in FY72, leading to a specific operational requirement in FY73. IETASS was tested on board *Knox*-class frigates and a minesweeper, leading to the ETAS (program established FY75) and then to the TACTASS (tactical towed-array sonar) programs. Contracts for 2 IETASSs were awarded in August 1974. In FY80, 12 were retrofitted into *Knox*-class frigates, 4 more following in FY81.

The original SQR-18 was towed at depths of up to 366 m, at the end of a 1706-m cable. SQR-18A was the original production version, towed from an SQS-35 fish at the end of a 1524-m cable. SQR-18A(V)1 is an improved version deployed on board *Knox*-class frigates, towed from their SQS-35 VDS fishes on a 730-m cable. A modified version, SQR-18A(V)2, which does not require a sonar fish, uses a special depressor and a 5300-ft cable. SQR-18A(V)2 is towed by those *Knox*-class frigates that were never fitted with VDSs and by some *Perry*-class frigates. SQR-18(V)2 uses the same array-handling system, OK-410, as does SQR-19. The array itself consists of 32 vibration-isolated hydrophones (8 modular hydrophone sections), with preamplifiers in the fish; it is 730 ft long and 3.25 in in diameter. SQR-18 is towed at depths up to 366 m on a 1706-m cable.

SQR-18A(V)2 can use an EDO-developed short-scope tow, an alternative to a critical-angle tow requiring much less towing cable. The longer critical-angle tow is generally needed to isolate the noise of the towing ship from the array. However, EDO developed an own-ship noise canceler that can subtract the measured self-noise of the towing ship from the output of the array. The array is held down by a special depressor, a low-drag winged body with a V-tail and trailing-edge flaps on the tail fins, weighing 265 lb. The array passes through the depressor shell, for easy handling. This device was tested at sea in July 1981 on board the research vessel *Athena*, a former fast motor gunboat, at up to 34 kt, and then on board the surface-effect craft JEFF-A in August 1981 (at over 40 kt).

Late in 1981 the upgraded SQR-18A entered service. The 800-ft array consists of an 8-module acoustic aperture, vibration-isolation modules, a tow cable, and a rope drogue. The upgraded version enjoys better flow-noise damping, is more rugged, and suffers from less self-noise. Given the modular design of the array, 1 section can be replaced if it fails (a ship can carry spare modules); formerly, the entire array had to be replaced.

SQR-18As have been fitted with EDO's ALICE (adaptive line canceler and enhancer), consisting of an SQR-18A embedded post-beam-former interference canceler (EPIC) and an SQR-17 adaptive line enhancer (ALE). EPIC cancels a companion ship's sound so that submarines can be detected when a towed-array ship is escorting a very noisy ship. The engineering-development model was completed in February 1982.

SQR-18 entered service only 5 yr after initial demonstration and suffered from unreliability. Compared to the original SQR-18, SRQ-18A, the production version, has a low-noise array, an interference canceler, and an improved tracker. Production began in 1978, and an improvement program began in April 1981. The Dutch (2) and Japanese (6) navies have bought this system.

Produced by EDO, and also now manufactured by Gould, SQR-18 was initially to have been replaced altogether by the superior SQR-19; but development continued as insurance against any problems in the -19 program, and the -18 is now an alternative standard.

SQR-18 was first tested on board USS *Moinester* in 1975; -18A was tested in 1978. The initial results were that -18 was effective (but unreliable) in the first CZ, and that -18A corrected the demonstrated deficiencies. Only 2 SQR-18s were built, virtually all arrays being SQR-18A.

The newest projected version, SQR-18A(V)3, will use the EDO AMSP parallel processor.

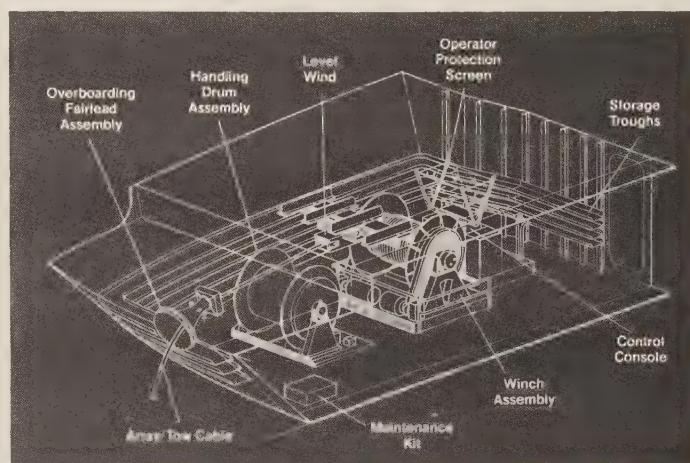
Unlike SQR-19, SQR-18A has never used a standard nomenclature beam-former or processor. Instead it uses a 2-screen Diagnostic/Retrieval unit related to SQR-17. Inboard electronics consist of a signal conditioner, a digitizer, and a signal processor, for both narrow- and broad-band. SQR-18A can operate

in both broad- and narrow-band simultaneously, tracking by means of an automatically stabilized tracker beam and automatic target-following circuits. All processed data are stored electronically; the system does not use LOFARgrams. Each display can show up to 4 LOFAR channels; the results of signal measurement (frequency and amplitude of tonals, harmonic ratio, and tag frequencies) are shown as alphanumerics.

◆ SQR-19

SQR-19 is the current standard U.S. Navy tactical towed array, generally installed as part of the SQQ-89 suite. Development was protracted, largely because of early failures in the processor (the "dry end"). SQR-19 automates many of the detection, classification, and contact-management functions performed manually in SQR-15 and -18. These features permit 2 operators and the sonar supervisor to detect contacts reliably even in high-density acoustic environments. Unlike SQR-18, SQR-19 does not require a fish or other depressor.

The 800-ft array is towed on a 5600-ft (3.25-in diameter) cable, at depths as great as 1200 ft, to achieve ranges that cover multiple CZs. This is a lengthened version of the original 490-ft (1700-lb) array, modified after experience in 1983 showed that it was necessary to go to much lower frequencies to meet the silencing of new Soviet submarines. The acoustic aperture was doubled in length (to 16 modules), and a fourth aperture (8 VLF modules) added. The other 3 apertures, which are nested, con-



Typical towed-array handling gear (OK-410/AN/SQR-19). (Gould)



The tube running down one side of the submarine *Olympia* houses a towed array; there is no space within the single hull for anything so massive. Such stowage in turn limits the maximum length of the array. (U.S. Navy)

sist of 8 acoustic modules (4 LF, 2 MF, 2 HF), each of which, about 40 ft long, consists of 48 equally spaced hydrophones. In addition to the acoustic aperture, the array includes separate heading, depth, and temperature modules (HDTMs) monitoring ambient water conditions and a telemetry drive module (TDM); and the array proper is isolated from the tow cable by 3 vibration-isolation modules. There is also a drogue. Each hydrophone module contains its own amplifier, and the data are multiplexed for transmission, by the towing cable, up to the towing ship.

SQR-19 uses 2 UYS-1 processors (spectrum analyzers) and 2 OJ-452/UYQ-21 standard displays; typically its 2 display consoles are embedded in an SQQ-89. They are separated by an equipment rack holding a data terminal set (USQ-69) and a system control panel. A typical SQR-19 also incorporates 4 UYK-20 computers (later versions presumably have UYK-44s instead). Signals from the array pass through a standard signal conditioner and receiver, and the output of the 2 UYS-1 processors passes through an OL-190/UYQ-21 signal data processor (acoustic data converter) for display on the consoles.

Embedded programs filter data to reduce them to manageable proportions and provide computer-aided detection (presumably based on automatic line integration), visual alerts, optimum search display formats, special classification display formats, and special data-processing techniques. The 3 basic display formats are search, classification, and true bearing. The search format is a bearing-time record (waterfall) with some auxiliary frequency data (integrated lines). The classification display is a series of LOFARgrams. The true-bearing display is a series of bearing-vs.-time tracks, based on bearing cuts.

The system continuously monitors its own performance and can be reconfigured around failed elements without being taken out of service. Consequently, it has an estimated availability of 0.993 (which means all but 3.5 hr out of a typical 210 days during a year), with an MTBF better than 600 hr, a maximum fault-detection time of 1 min, and an MTTR of less than 20 min. The array itself is modular, for quick replacement of faulty elements, and it has an MTBF of better than 2000 hr.

The engineering-development contract for SQR-19 was awarded in December 1977, the first ship installation (DD 980) following in November 1981. The array was evaluated in November and December 1982, and approval for limited production was granted in March 1983. Full-scale production was approved on 26 December 1984 after the army had demonstrated a 2000-hr MTBF. SQR-19(2X), a lengthened array to detect lower-frequency tonals, was tested in FY87.

Versions:

- (V)1 two OJ-452(V)9 consoles, one OL-190(V)5
- (V)2 two OJ-452(V)8 consoles, one OL-190(V)4
- (V)3 two OJ-452(V)8 consoles, one OL-190(V)5

General Electric makes the onboard electronics ("dry end") and is responsible for system integration. Martin Marietta makes the "wet end" (array and handling gear) (Gould, the original manufacturer, sold its towed-array division in 1989). NUSC Newport is responsible for overall technical development.

◆ SQS-4/SQS-29 through -32/SQS-39 through -42/SQS-43 through -46/SQS-49 through -52

SQS-4, essentially a scaled-up version of the wartime QHB, was the first major U.S. LF sonar. The earliest type operated at 14 kHz with 3 alternative pulse widths: 6 msec (50 kW), 30 msec (30 kW), and 80 msec (5, later 10, kW). This version became Mod 4; later lower-frequency versions were Mod 1 (8 kHz), Mod 2 (10 kHz), and Mod 3 (12 kHz). The nominal range, against a submarine in the layer (and from a 15-kt destroyer), was 5500 yd (Mods 1 and 2) or 4500 yd (Mods 3 and 4). A target below the layer could be detected at about 1500 yd, and contact could generally be held out to 7500 yd (2500 yd below the layer). The range scales were originally 1, 2, and 5 kyd, but the demonstrated long-range performance led to recalibration (to 2/4/6/8 kyd, and then 1/2.5/5/10/15 kyd). The 48-stave transducer

(9 elements each) was scaled up from that of the earlier QHB (25.5 kHz) to produce beams of similar width (15×15 deg).

SQS-4 scans at 150 cycles/sec (900 rpm), compared to about 29 cycles/sec (1750 rpm) in the earlier QHB. This high scanning rate is achieved by scanning a rotor (with 16 contacts) at 3000 rpm; the outputs of each group of 8 staves go to separate left/right beam-forming networks. The outputs of the 2 networks differ in phase, and this difference can be used for target tracking, a technique called SSI (sector scan indicator). The staves are driven by 3 transmitter power amplifier cabinets (in groups of 16). Because of differences in wavelength, Mods 1 and 2 use a larger transducer than Mods 3 and 4; the transducer fits in a 145-in dome (a 100-in dome for Mods 3 and 4). There are 2 receiving channels, 1 video (on a PPI that can function in either ship-centered or target-centered format) and 1 audio. Later versions have 2 video channels. The video channel is considered preferable for tracking, the audio for target classification. Each channel requires its own scanner because the audio channel must be pointed at a target detected by video.

SQS-4 originally operated only in ODT mode; an RDT mode was added later in the 4 Mods. There are 2 modes: (i) search and (ii) maintenance of close contact (MCC), i.e., depressed beam mode (to keep contact on an approaching submarine). The outer 4 stave elements have search windings only; the next 2 above and below the center have both search and MCC windings; and the center element has 1 search and 2 MCC windings. In the MCC mode, the upper 3 MCC windings are energized. The lower 3 MCC windings are used for depth-finding. The sonar can transmit in either search, MCC, or depth-finding mode and can receive in search or MCC mode. The combination of 2 MCC circuits is DMCC (dual MCC).

An associated device, SQR-8 (tested in 1955) used the MCC/DMCC windings to measure the target's depth. It introduced a variable delay between the outputs of the lower stave elements (via their MCC windings). Each delay corresponded to an elevation angle (as in a phased-array radar), and the reception beam was scanned vertically between $+7.5$ and -45 deg. Given the target's depression angle and slant range as measured by the basic sonar, SQR-8 computed the target's depth automatically. The display was a quadrant of a spiral-scan PPI similar to the main video display.

MCAR (multiple-channel aural reception) was a modification for broader-beam reception to improve the capability against fast targets (3 beams 7.5 deg apart instead of the single 10 -deg receiving beam).

SQS-29 through -33 were modified SQS-4 Mods 1 through 4, respectively, with RDT and passive-search capability. Pulse lengths were 2, 7, 30, or 120 msec (4–50 kW), and range scales were 1, 2.5, 5, 10, 15, and 30 kyd. The effect of RDT was to increase the source level (by 1 account, from 117 to 133 dB) and thus to increase the range against a submarine in the layer by about 50%. Typical nominal ranges (for targets in the layer) were 7500 yd for SQS-29/30 and 6500 yd for SQS-31/32. SQS-29 could detect a target below the layer at about 2100 yd. In the RDT mode, the beam sweep could be set to cover 30 – 300 deg, oriented around the ship's bow. Later SQS-4 series sonars were modified for tribeam transmission with higher power; the nominal range was then 8000 yd. This series introduced ASPECT (acoustic short-pulse echo-classification technique: a burst of short steered pulses gives an indication of a target's shape) and built-in test equipment. In the passive mode, the outer $\frac{2}{3}$ of the PPI was used, and the sweep recycled at the rate used for the 5-kyd scale. For ASPECT, a transmit-beam control and programmer-recorder were added; the returned echoes were printed on a recorder chart. SQR-8 was eventually removed from most sonars of this type. At least some sonars in this series (mainly SQS-31 and -32) were modified for operation with SQA-10 VDS; the hull and VDS transducer could operate alternatively off the same stack. The VDS fish accommodated a full-size (48-stave) SQS-31 or -32 transducer or a half-size SQS-29 or -30 transducer.

SQS-39 through -42 were modifications of SQS-29/32 with

steered directional transmission (SDT) and MARK (maintainability and reliability kit). MARK entailed changes in the audio-frequency amplifier (preamp), the control indicator, the receiver-scanner, and the sonar transmitter cabinets. The maximum power was increased to 2.8 kW per channel (for a total of 134.4 kW).

SQS-43 through -46 were SQS-29B/C through -32B/C modified with MARK and SDT and capable of operating a VDS off the same sonar stack.

SQS-49 through -52 were SQS-4 Mods 1 through 4 with MARK.

SQS-4 was first tested in 1951, and it entered fleet service in 1954; 250 were made. The VDS version was first studied in 1960-61. Some SQS-4s were installed on board submarines, and many SQS-4s and modified versions were transferred to Allied navies. SQS-4 was made by Sangamo Electric; the later versions (SQS-39, -43, and -49 series) were modified by Philco-Ford.

SQS-5, an abortive alternative developed by EDO, was the basis of the Canadian SQS-503. SQS-5 introduced tribem transmission for faster search (than conventional RDT), operated at 7-15 kHz (pulse widths of 5, 14, 35 [60 kW], and 100 msec), and scanned at 100 cycles/sec (6000 cycles/min). The range scales were 2, 4, 6, and 8 kyd. This sonar was first tested in 1955.

SQS-4 sonars in the Taiwanese navy (and probably in others) have been replaced by Krupp-Atlas DSQS-21s. Sonars of this type reportedly survive in the following navies: Brazil (SQS-31 and -44 in FRAM II destroyers), Chile (SQS-40 in FRAM II destroyers), Greece (SQS-4 and -29 in FRAM II and *Fletcher*-class destroyers), Iran (SQS-29 in FRAM II destroyers, Italy (SQS-39 in the cruiser *Caio Duilio* and in *Impavido*-class destroyers), South Korea (SQS-29 series in FRAM II destroyers, SQS-4 in the surviving *Fletcher*), Turkey (SQS-29 in FRAM II *Sumner*-class destroyers and probably on board the *Robert H. Smith*-class destroyer minelayer), and Uruguay (SQS-29 on board the former *Dealey*, now *18 de Julio*). In many of these cases the identification of the sonar is by series rather than by precise type.

◆ SQS-10/11

These sonars were modernized postwar versions of the late-war QHB scanning sonar, the first scanning sonar in U.S. service. One QHB may survive; all known examples of this series are SQS-11s. SQS-10 was initially designated QHB-3; it was, in effect, a higher-frequency (20-kHz) SQS-4. SQS-11 was a 25.5-kHz equivalent. SQS-10 produced 6- (50 kW), 30- (10 kW), and 80- (3 kW) msec pulses, scanning at 150 cycles/sec with a 19-deg beam (range scales, respectively, were 1000, 3000, and 6000 yd). SQS-10A had a capacitor to provide a peak power of 30 kW at a pulse width of 35 msec. Alternative pulse widths: 7, 35, 100 msec. SQS-11A was analogous to -10A, also with the boost capacitor. Typical SQS-11A performance was 1600 yd/800 yd for targets in/below the layer (probability of detection 0.25) at 15 kt, and 1300/800 yd at 18 kt. These sonars were specified for U.S. destroyers and frigates in the mid-1950s, to replace QHBs installed from about 1950 on. SQS-4 was generally used instead.

SQS-11 seems to have been revived in the late 1960s, presumably in modernized form. From then into the 1970s it was installed on board the Japanese target-service ship *Azuma*, the Thai *Cannon*-class escort *Pin Klao*, and the Turkish *Berk*-class frigates. The Canadian *St. Laurent* group of destroyers all originally had SQS-10 or SQS-10/11 short-range scanning sonars in addition to their longer-range SQS-503s and their SQS-502 attack and -501 bottom-search sonars. SQS-10/11's range corresponded roughly to that of SQS-502. These sonars survive on board the *St. Laurents* and Improved *St. Laurents* (modified *Restigouches*). These ships also have the SQS-504 VDS. These ships were to have been fitted with SQS-505, but that has not yet been done.

◆ SQS-17

A scanning sonar for small ships, SQS-17 was conceived in 1954 as a searchlight sonar to replace QCU for ships such as the 173-ft PC. Although the U.S. Navy used only a few (possibly

only 2), SQS-17 was widely exported (see below) and was manufactured under license in France. SQS-17 was the first modern sonar manufactured in France, and experience with it led directly to the modern French scanning sonars. It operated at 12, 13, and 14 kHz with 16-, 35-, and 60-msec pulses (peak power of 1-6, 22, or 30 kW; source level of 134 dB) and used a 24-stave, 19-in-diameter array (originally using crystal transducers) comparable in size to that of SQS-31 (with a 100-in dome). SQS-17 was simpler than the SQS-4 series; the transducer elements were packaged together in such a way that the beam could not be elevated electronically. SQS-17 was an ODT sonar, although an RDT version was tested about 1957-58. The beam-former rotor tapped 8 staves, rather than 16 as in SQS-4. The scan rate was about 3500 rpm. SQS-17 was developed by EDO, and SQS-35 was conceived as an SQS-17 transducer in an SQA-13 VDS fish. Versions: SQS-17A and -17B which differed slightly in frequency.

Applications include: Chile (PC 1638 class), France (*Commandante Rivière* class, some of which were transferred to Uruguay), Iran (PF 103-class corvettes), Philippines (*Cannon*-class escorts and *Auk*-class corvettes), Portugal (*Commandante Rivière* class), Taiwan (*Auk*-class corvettes), Thailand (*Tacoma*-class frigates and PF 103-class corvettes), and Turkey (PC 1638 and PGM 71 classes). This sonar was installed on board Iranian PGM 71-class gunboats (now lost) and was probably installed on board exported World War II-era PCs modernized in the 1960s with fixed Mk 32 tubes.

◆ SQS-23/SQ-23/PAIR/PADLOC

SQS-23 was the LF replacement for SQS-4, associated with the ASROC stand-off weapon. SQS-23 was first installed in 1958 both in FRAM-I destroyers and in new construction, and it was also built under license in Italy and in Japan.

SQS-23 was the "reliable 10,000 yd sonar" specified for ASROC ships designed in the late 1950s. It is currently credited with a maximum range of 14-15 kyd under ideal conditions; the LORA version has a limited CZ capability (probably only in the Mediterranean).

Base frequencies are 4.5, 5, and 5.5 kHz; and the operating frequency can be varied around a base frequency to limit inter-



SQS-23 installed as a bow dome, USS *Barry*, 1959. This ship was the test installation. (U.S. Naval Institute)

ship interference. Pulse lengths are 2 (later 5), 30, and 120 msec, with range scales of 1, 2.5, 5, 10, 20, and 40 kyd. The mechanical commutator scans at 150 cycles/sec. The cylindrical array consists of 48 staves, each containing 2 transducers, for a total of 96 channels; and the sonar beam can be depressed electronically. In the long-pulse, wide-sector RDT mode, SQS-23H transmits 60 kW for 4.3 sec. Current versions employ both fixed-frequency and FM-slide pulses.

A typical SQS-23 source level (in the initial version of the sonar) was 244 dB.

Signal modes: ODT, RDT, SDT (9.25-deg beam, on a bearing chosen by the sonar operator, using a separate transmit scanner, for target tracking), MCC (broadened vertical beam, used with any other mode except handkey), and handkey (uses 4 staves about 90 deg apart, for underwater CW communication). Typical operating modes are search (RDT), search-analyze (long-pulse SDT beam on operator's chosen bearing), attack-RDT (operator controls width of pulse sector and slaves sector bearing to CRT tracking cursor; this mode allows target tracking but allows operator to observe a broad area around the target); and attack-SDT (for the late phase of an attack, when the operator concentrates on the target).

Numerous SQS-23s have been modernized by the addition of Raytheon's solid-state transmitters (SSTs); see the entry for the Raytheon DE 1191 below.

The major reliability/maintainability improvement program was TRAM, for test, reliability, and maintenance. The transmitter was split into parallel A (stave elements 1, 2, 3, 8, and 9) and B (stave elements 4, 5, 6, 7, and 10) groups. Each transmitter cabinet drives 8 (out of a total of 48) staves. PME (performance monitoring equipment, an 83-track tape recorder) has been added.

There were also performance improvement programs:

—MIP, modest improvement program, reducing CRT clutter caused by background reverberation and providing an FM transmission mode.

—LORA, long-range addition, largely by self-noise reduction (e.g., a rubber dome) to give SQS-23 a CZ/BB capability (presumably in the Mediterranean) for Atlantic Fleet ships only.

Versions:

SQS-23 Original version operating at 5 kHz only, using 6 electronic cabinets (with 6 audio-frequency amplifiers AM-2077/SQS-23) for 96 channels. Special features, compared to earlier sonars, were RDT and electronic control of beam elevation and depression. One audio and 1 video channel. The transducer was TR-144. SQS-23 was equipped for dual MCC and depth determination (by electronic beam depression and elevation). There are 2 scanners: fast (738.8 rpm) and slow (54 or 13.5 rpm). These figures seem to apply to all versions of SQS-23 through -23C. Later scanners were redesigned for better reliability and maintainability and, presumably, also for the much higher scanning speed indicated above.

SQS-23A This version introduced multiple operating frequencies (4.5, 5.0, 5.5 kHz). Each operating frequency could be varied over ± 250 Hz. This version used piezoelectric rather than magnetostrictive transducer elements, and it incorporated automatic power-level control.

SQS-23B This version reverted to fixed-frequency (5 kHz) operation but introduced a steered beam transmission (SDT) mode in addition to RDT. It, therefore, needed a new oscillator-programmer (O-956/SQS-23B in place of O-844/SQS-23A and O-576/SQS-23).

SQS-23D Center frequencies 4.55, 5.05, and 5.55 kHz (380-Hz bandwidth in each case), with 48 channels. Modes: CW and 400-Hz FM slide (chirp) with 5-, 30-, and 120-msec pulses. 150-Hz video scanning rate. This version incorporated training, reliability, and maintainability improvements as described above. This version and its successors are capable of rotating-beam steered-directional transmission (TRAM). As in earlier versions, it uses 6 power amplifiers for its 6 cabinets

(AM-2077B). The oscillator-programmer is O-956B/SQS-23B. SQS-23D is SQS-23 with TRAM.

SQS-23E Characteristics match those of SQS-23D above, but the oscillator-programmer is O-956C. SQS-23E is SQS-23A with TRAM.

SQS-23F is SQS-23B with TRAM.

SQS-23G is SQS-23C with TRAM.

SQS-23H Characteristics match those of SQS-23D above, but this version employs a solid-state transmitter. Transmission is accomplished by 3 solid-state cabinets in place of 21 vacuum-tube cabinets and 10 motor generators. The transmitter uses solid-state linear amplifiers and has automatic fault localization. There are only 48 channels because each is capable of powering a complete stave (it took 2 channels per stave in earlier versions). The transducer is designated TR-225 (SQS-23D and -23E used a transducer assembly, not a transducer proper). The oscillator-programmer is O-956B, as in -23D. There are only 2 audio-frequency amplifiers (in this case, AM-6740/SQ) with 3 power-distribution transformers (rather than 6 amplifiers operating in parallel).

SQS-23J/K/L Solid-state versions comparable with SQS-23H. SQS-23J uses O-956C; -23K and -23L use O-956D.

SQQ-23 (PAIR, performance and integration refit) is a modified version that incorporates passive tracking by a second transducer and PADLOC (passive-active detection and localization). Compared to SQS-23, PAIR adds a second operator console, as well as built-in test equipment. Output is 160 kW for 160 msec in ODT mode and 60 kW for 5.6 sec in RDT mode at 4.3–5.7 kHz, using 48 channels (1 per stave rather than 2 per stave, as in SQS-23). SQQ-23A uses simplified solid-state equipment (3 solid-state cabinets for transmission rather than 21 vacuum-tube cabinets and 10 motor generators). SQQ-23 uses a rubber rather than a steel dome for better sonar transmission.

SQQ-23A has 2 separate domes, 60 ft apart, which give a 60-ft baseline for triangulation of noise sources. SQQ-23A was evaluated in FY71 and entered service in FY73. This version applies to the *C. F. Adams* and *Mahan* classes.

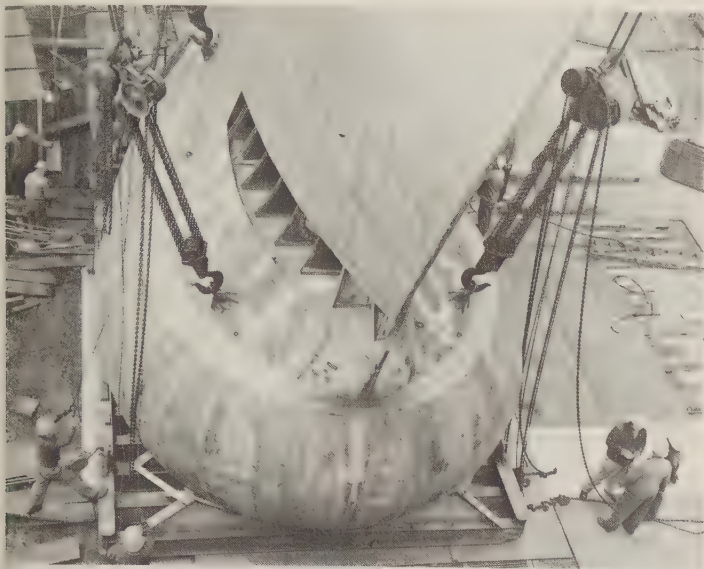
SQQ-23B (*Leahy* class, *Bainbridge*, and *Long Beach*) has a single dome in which the 2 transducers are 4 ft apart. Targets are detected by correlogram, as in PUFFS (BQG-4) and micro-PUFFS (see separate entry). The broadside coverage is about 60 deg. SQQ-23B was evaluated in FY77 and entered service in FY80.

All active U.S. SQS-23s were converted to SQQ-23; the last active example was an SQS-23H on board the *Tatnall* (DDG 19), which was scheduled for conversion to SQQ-23A under the FY89 program. SQS-23D survives on board *Forrest Sherman*-class gun destroyers in reserve. SQQ-23 is limited to U.S. ships; all foreign examples of the sonar are SQS-23s.

Current users (many with DE 1191 solid-state transmitters) are Australia (the *Adams* class: SQS-23F), Brazil (2 FRAM Is), Greece (SQS-23D on 6 FRAM Is, SQS-23 on 1 FRAM II DDR), Italy (SQS-23G in the *Vittorio Veneto*, SQS-23 in the *Andrea Doria*), Japan (SQS-23 in the *Amatzukaze*, the *Takatsuki* class, the *Yamgumo* class [some as OQS-3], and the auxiliaries *Akizuki* and *Teruzuki*; as OQS-3 in the *Haruna* and *Chikugo* classes), Korea (5 FRAM Is), Mexico (2 FRAM Is), Pakistan (SQS-23D in 4 FRAM Is), Spain (4 FRAM Is, replaced in 5 *Baleares*), Taiwan (12 FRAM Is, 2 *Gearing* FRAM IIs [DE 1191]), and Turkey (2 ex-*Carpenter*-class ships, 7 FRAM Is, 1 *Gearing* FRAM II).

◆ SQS-26/53

SQS-26 was the culmination of U.S. LF sonar development, operating at about 3.5 kHz. It receives at 1.5–4 kHz, in 4 bands (7 channels). Power output is 192 kW. Like the earlier and higher-frequency SQS-4 and SQS-23, SQS-26 scans its beam using a mechanical commutator, so it can track only 1 target at



Installation of an SQS-53 sonar dome. (U.S. Navy)

a time. The transducer is about 16 ft in diameter and 5½ ft high and weighs about 60,000 lb; the sonar dome is generally described as comparable in size to a 60-ft personnel boat. Each of 72 transducer staves consists of 8 elements, and the beam can be electronically elevated and depressed, both for stabilization and for BB and CZ operation. The sonar forms 72 beams (5 deg wide).

SQS-53 is the solid-state successor to SQS-26, using 1 version of the SQS-26 transducer. SQS-53 and SQS-26 are the current standard U.S. long-range sonars, the only active surface-ship types credited with BB and CZ capability (in the Atlantic as well as in the Mediterranean).

Feasibility studies began in 1955, and the prototype XN-1 model was installed in 1961; the engineering-development model (XN-2) was delivered for installation in the USS *Wilkinson* in November 1961, and the pilot production models were delivered in August 1962, for the *Bronstein* class. Three parallel versions were built: -26AX by General Electric, -26BX by EDO, and -26CX by General Electric. The contract for 12 SQS-26AXs was let in 1961. The contract to EDO for 16 SQS-26BXs followed in 1963, and a contract to GE for SQS-26CX followed in October 1964 (the first SQS-26CX entered service on board the *Knox* in 1969). SQS-26CX became the production standard. The AX and BX sonars were not altogether successful, and a series of major modifications was approved in January 1965. CX deliveries began in December 1967, and General Electric modified existing -26AX sonars to -26AXR standard. The sonar itself was approved for service use only in November 1968, after considerable difficulties, and for some years SQS-26 was not credited with being able to achieve its theoretical performance (SQS-23 often did better in service).

Major improvements included much higher power, a rubber (rather than steel) sonar dome, and more reliable electronics. By the mid-1970s, SQS-26 was reliably achieving the BB and CZ performance for which it had been designed.

The rubber dome was a very significant improvement, later extended to other sonars, such as SQS-23. A steel dome limits sonar performance by passing machinery and hull vibrational noise to sonar; by corroding (corrosion creates flow noise); by vibrating (flow causes the plating to vibrate); and by attenuating signals (through plating and structural framing). BuShips let a contract to B. F. Goodrich in June 1963 for the design, manufacture, and test of a prototype rubber window dome (steel dome, rubber window, SDRW). At that time it was the largest molded rubber part ever built: 36 ft long, 20.5 ft wide, 8 ft high, 9.2 tons. The prototype was installed on board the USS *Willis A. Lee* early in 1965 and tested for 2 yr. A follow-up contract for DE (later FF) 1040, DEG-1, and DE (FF) 1052/1078 domes

was let in June 1967, and the domes were approved for service use in September 1968. By late 1969 both Goodrich and Good-year were qualified producers, Goodrich winning the first production contract in June 1970. The dome is a wire-reinforced membrane, whose shape is maintained by internal pressurization. The first production dome was installed on board the USS *Bradley* (FF 1041), beginning in December 1971.

All SQS-26/53 sonars either have been or are being modified to incorporate Probe Alert. The Probe Alert modification provides 1-way acoustic communication to submerged submarines having Probe Alert receiving equipment. Under this mode, the sonar system is dedicated to the projection of encoded signals into the water. Probe Alert entails modifications to the A-scan console, the sequential timer, and the transmitter control unit. It was first delivered in 1986.

Probe Alert is the latest of several attempts to use SQS-26/53 for underwater communication.

Versions:

SQS-26AXR in CGN 35 (*Truxtun*), FF 1037 class, FF 1040/FFG 1 class, and FF 1098 (*Glover*). This modification restores the sonar power supply to its original configuration. It has 3 consoles (surface channel, A-scan, and target tracking) and 2 sonar-signal processors (for coded and CW signals). The transducer is TR-198. The first 2 were installed on board the USS *Garcia* and *Brumby*. The transducer in this version was TR-198.

SQS-26BX is in all *Belknap* class except *Belknap*, also in some FF 1040/FFG 1-class frigates. This is a DIMUS sonar with a beam-former. It has only a target-tracking console and 1 signal processor. The transducer is TR-203, consisting of 576 individual elements. Each element is 5.75 in × 23 in (8 × 8-in face) and weighs 50.5 lb.

SQS-26CX is in all *Knox* (FF 1052) -class frigates and in *California*-class cruisers and was the basis for SQS-53. It has 3 consoles (but different units than in -26AXR). The transducer is TR-313 (there was also an earlier TR-227A). TR-313 has 576 elements and is 16 ft diameter × 5 ft 9 in and weighs 60,000 lb; it has 576 barium-titanate elements. It is fixed in a ship's hull, but the modified TR-313A is mounted on a turntable capable of limited rotation. Like -26AXR, -26CX has 2 sonar-signal processors.

SQS-53A in *Belknap*, *Virginia*-class cruisers, and *Spruance* class. This sonar is a solid-state version of SQS-26CX (it uses the same transducer) with better signal processing (using a UYS-1 signal processor, UYK-20 computers, and UYQ-21 displays). It has a digital interface with the Mk 116 FCS. As in -26AXR and -26CX, there are 3 consoles (surface channel, A-scan, and target tracking) and 2 signal processors. Delivery began in October 1972.

SQS-53B Phase I of SQS-53 improvement program, for the *Spruance*, *Ticonderoga*, and, potentially, the *Kidd* class. Analog controls and displays of SQS-53A are replaced by standard navy digital components to permit integration with SQQ-89. This version provides the capability to detect, localize, and track submarines at long range in both active and passive modes. It incorporates multiple-target tracking and classification aids and reduces manning by 60%. Improvements include: reduced insidious degradation (to detect calibration and alignment drift in the display subsystem, which could occur without the operator's knowledge), improved data association (for detection, classification, and tracking of simultaneous multiple active and passive contacts), dedicated passive LOFAR (eliminates dependency on SQR-17 or -18 by providing a UYS-1 signal processor), improved reliability and maintainability, and improved fault location. SQS-53B introduces digitized broad-band (Unit 31) in place of an earlier analog device that was very unreliable.

SQS-53B (and probably earlier versions as well) is capable of ODT and variable-depression operation (3 modes of receiver processing: search, tracking, and SSI/TDI). It has 3 receiving modes: PPI, preformed beams, and SSI/TDI. The sonar can op-

erate in passive narrow-band and broad-band modes. Inboard electronics: 2 OJ-452(V)4/UYQ-21(V), 1 OL-190 signal processor, and 1 UYS-1 (analyzer-detecting set). As in earlier versions, there are separate signal processors for pulse and coded (FM slide) signals. The (V)1 version has OJ-452(V)8 consoles, the (V)2 version has OJ-452(V)9 consoles. This version uses a UYQ-69 digital display, and it is controlled by a UYK-20 computer. SQS-53B was technically evaluated on board the USS *Moosebrugger* (DD 980) in August and September 1982, and an associated narrow-band passive capability was successfully demonstrated in November 1982. The first new-construction installation is on board the *San Jacinto* (CG 56). Another was installed on board the USS *Spruance*, and SQS-53B will be retrofitted to other *Spruances* and earlier *Ticonderoga*-class missile cruisers during their regular overhauls. The initial (quick-reaction) SQS-53 improvement program began in 1975; it included the installation of wide-band elements under the FY78 program as well as SIMAS (UYQ-25). The formal SQS-53 improvement program (IP) began in September 1977, to ensure commonality with SQQ-28 and SQR-19. Hughes received a contract for 2 EDMs in June 1979, 1 for a land-based test site (FY81) and the other for a *Spruance*-class destroyer (FY82). Claimed reliability: 200-hr MTBF (the goal was 500 hr) and 30-min MTTR.

SQS-53C Phase II of the SQS-53 improvement program, first tested on board the USS *Stump* (DD 978): the engineering-development model was installed in August 1986, and the full-production model was tested March–October 1987. Characteristics include: improved active performance (partly because of higher power), multiple-target capability, automatic target tracking, and quick reaction time. *Arleigh Burke* (DDG 51)-class destroyers will be completed with SQS-53Cs, and these sonars will later be installed on board *Spruance*-class destroyers and *Ticonderoga*-class cruisers. Compared to SQS-53B, -53C has half the space and weight devoted to shipboard electronics, largely thanks to the use of SEM cards. The remaining 1960s electronic technology of the -53B is replaced by new standard digital equipment. SQS-53C uses UYS-1 to process both active and passive signals, UYK-44 to control the sonar and display, and UYQ-21 as its display. The transducer has greater power output and a wider bandwidth, with 1 amplifier per transducer element. The beam is stabilized in all active modes.

Reportedly, SQS-53C has a stealthy active mode. Presumably, that is similar in concept to stealthy radar operation (as SPS-503) secured by long-time pulse compression, i.e., by spreading the pulse over a wider range of frequencies (hence the significance of the sonar's wider bandwidth).

Versions: (V)1, (V)2, (V)3. They may use a modified transducer.

The standard displays of sonar data in the SQQ-89 system (in which SQS-53C is embedded) are being improved by the insertion of 2 Advanced Video Processors (manufactured by Diagnostic/Retrieval Systems) in each OJ-452/UYQ-21 display cabinet.

The unit cost of an SQS-53B was \$6.3 million in FY87, compared to \$3.4 million for SQS-53C.

◆ SQS-35/36/38

The standard U.S. independent VDS, found on board some *Knox*-class frigates, is now significant primarily as the depressor for SQR-18 towed arrays. SQS-35 operates at 13 kHz, with a peak power of 30 kW, and uses 12 preformed RDT beams and a total of 24 reception beams (the transducer has 24 staves). SQS-35V is a solid-state version.

This sonar, developed by EDO under a 1966 contract, was derived from SQS-17. SQS-35(J) is a version license-built in Japan (by NEC).

SQS-36 is a hull-mounted equivalent of SQS-35. SQS-38, which equips U.S. *Hamilton*-class coast guard cutters, is a solid-state version. It operates at 11.9, 13, and 14.1 kHz and has an MCC mode, the last 2 (lowest of 9) transducers on each of its



SQS-35 VDS fish. (U.S. Navy)

24 staves being depressed to turn the beam down when desired. Nominal range is 12,000 yd.

Current users:

SQS-35: Japanese *Shirane* class, *Takatsuki*-class destroyers, and *Minekumo*; 5 *Chikugo*-class escorts; Spanish *Baleares* class.

SQS-36: Italian *Pietro de Cristofaro* class (with SQS-35 IVDS), Japanese submarines (as SQS-36J), Norwegian *Oslo* and *Sleipner* classes (being replaced by French *Spherion*).

◆ SQS-54

The shipboard processor for the LAMPS-I helicopter (1969) is built by Diagnostic Retrieval Systems, Inc. The helicopter itself carries no sonobuoy processor, acting merely as a sonobuoy and torpedo-dropping platform and as a relay for acoustic data. Thus, the helicopter's effective range depends, not on its fuel capacity, but on its ability to transmit data back by digital link to the deploying or controlling ship. LAMPS-I ships, therefore, have characteristic data-link antennas as high as possible, for maximum range. SQS-54 evolved into SQR-17(V)1 (see above).

◆ SQS-55

This is a special HF (100-kHz) sonar developed and used by the Naval Coastal Systems Laboratory, Panama City, to track underwater objects at short range. It is a high-precision, short-range DIMUS sonar, using an acoustic lens to form an array of sixty 2×10 -deg beams. Pulse width is 1 or 2 msec; range scales are 300 and 600 m. Nominal power is quite high, 218 dB. SQS-55 probably dates from 1972.

◆ SQS-56 (DE-1160B)

The hull-mounted direct-path sonar of the *Perry* class is built by Raytheon. SQQ-23 was originally chosen for these ships. Then the Canadian SQS-505, whose performance was not much worse but whose cost was much less, was chosen. SQS-56 was conceived as private-venture, a solid-state duct sonar whose weight, performance, size, and cost would roughly match those of SQS-505. Engineering design was completed in October 1977. Production began in 1979, following tests in 1975 and then in 1978. An upgrade program is currently being formulated.

The sonar is entirely digital in both active and passive modes. Operation is at 5.6, 7.5, and 8.4 kHz (36 kW).

DE-1160B is the export version. DE-1160C provides more power (with an extra electronic cabinet). Spain has upgraded her DE-1160Bs to 1160C standards. DE-1164 is the corresponding VDS, which can be trailed at depths as great as 600 ft.

Spain designates the sonar being installed in the *Baleares*



SQS-56 transducer and its sonar dome.

class as SQS-56LF rather than DE-1160LF. It is being produced largely by Inisels, under license.

◆ SQS-58

See Raytheon's DE-1167 below.

◆ LAMPS

The U.S. Light Airborne Multi-Purpose System is carried by a helicopter. LAMPS is listed here because it is conceived as a direct extension of a surface ship, rather than as a stand-alone device. LAMPS was conceived primarily as a means of acquiring and then attacking CZ contacts. A ship cannot fire a weapon directly at such contacts because the CZ is too broad. LAMPS was, therefore, conceived as the Light Airborne ASW Vehicle (LAAV); it gained the multipurpose designation because its tasks soon extended to assistance in OTH-T and ASMD. However, it is primarily an ASW sensor.

In the case of LAMPS I (the SH-2F Seasprite helicopter), which is intended to operate within 50 nm of a ship (for about 1 hr), the acquisition sensors, the sonobuoys, read out their data directly to the ship, which commands the helicopter into position to attack. The requirement for shipboard processing amounts to a limitation to line-of-sight operation, i.e., first CZ. A LAMPS I helicopter monitors 4 sonobuoys simultaneously (it carries a total of 15), using a single ARR-75 receiver. It also carries an LN-66 radar, and the shipboard sonobuoy processor is SQS-54.



An SH-60B LAMPS III helicopter. The sonobuoy rack is on the side, above the empty torpedo rack, and the flat ESM arrays are in the nose. (Sikorsky)

LAMPS I is the redetection/prosecution sensor associated with the SQR-18A towed array.

LAMPS III (there was no LAMPS II), the SH-60B, carries its own sonobuoy processor (UYS-1) and, thus, can operate beyond the ship's line of sight, out to the second and third CZ (nominal radius of action is beyond 100 nm, with 2½-hr endurance). However, it, too, is intended primarily for direct operation from a ship's CIC, its sensors controlled by an acoustic-sensor operator (ASO) in the sonar room; a remote-radar operator (REMRO) in CIC (who receives the helicopter's radar output via data link, and who can directly control radar range and operating mode); an EW operator (EWO) in CIC; and the air-tactical control officer (ATACO). The helicopter carries a pilot; an airborne tactical officer (ATO), who takes over from the ATACO as directed (e.g., when the helicopter passes out of radio range); and a sensor operator (SO). The line-of-sight data link is duplexed for voice and digital data, with low sidelobes for ECCM.

LAMPS III carries 25 buoys (though 12 would be used on a typical mission), 2 ARR-75 receivers, and an APS-124 radar. LAMPS III is the redetection/prosecution sensor associated with the SQR-19 towed array.

In each case, the usual final attack sensor is an ASQ-81(V)2 MAD, whose output is read out on board the helicopter. LAMPS I can also use active buoys for final attack data; it carries a paper range recorder sufficient for 2 SSQ-47 omnidirectional buoys or, presumably, 1 SSQ-62 DICASS. The LAMPS I sonobuoy chart recorder (RO-114) is controlled by an ASA-26B box. Range limitations at low chart speed (1 hr for recording) are 50 yd mini-



The small radome on the lower mast platform of this Spanish *Perry*-class frigate (mast at right) houses the directional data link for her LAMPS III helicopter. LAMPS I uses a vertical omnidirectional antenna. (S. Terzibaschitsch)

mum and 15,000 maximum; at high chart speed (30 min), 50 and 7500 yd. In the SH-60B, the chart recorder, which is an attack aid, is replaced by a general-purpose UYS-1.

As modified for operations in the Persian Gulf, LAMPS I helicopters were fitted with AAQ-16 FLIRs, ALQ-144 IR jammers, ALE-39 decoy dispensers, and door-mounted M60 machine guns.

Both LAMPS types are subject to upgrade programs. The current LAMPS I upgrade (SH-2G) provides an on-board sonobuoy processor (UYS-503), a secure ship-to-helicopter or helicopter-to-helicopter data link, a 99-channel sonobuoy receiver, and a 1553B bus. The current data link is AKT-22(V)7. The ASN-150 tactical system can display acoustic, radar, MAD, FLIR, or tactical (PPI) data. Because the helicopter is fitted with a data bus, sensors can be installed in modular fashion. For example, the bus can accommodate a FLIR. In trials, it has also supported a Cormorant dipping sonar and, reportedly, a classified British minehunting system tried out in the Persian Gulf. The current ESM system is ALR-66(V)3.

The LAMPS III Block I upgrade (1987, beginning with Lot 9) includes provision for the Penguin missile and the Mk 50 torpedo, a 99-channel sonobuoy receiver (to replace the current 31-channel unit), the ARC-182 radio, and a 5-channel GPS receiver. The helicopter will also be able to receive and display images from Standoff Land Attack (SLAM) missiles, to guide them farther beyond the launching ship's horizon. A new 1553B bus supplements the existing 1553A.

Development of a Block II upgrade should begin in 1991. It will include the airborne LF sonar (ALFS) and an ISAR modification to the existing APS-124 radar. The UYS-2 processor will replace the current UYS-1. Block II will also include a secure UHF burst tactical exchange link, to transfer data either to a ship or to a LAMPS I or LAMPS III helicopter relieving a helicopter on station. Presumably, the new link will offer greater security, greater flexibility (helicopter-to-helicopter as well as helicopter-to-ship), and more bandwidth (to transmit ISAR images).

Ships are being fitted with a "I/III Switch" that allows them to operate or to monitor either type of LAMPS helicopter.

LAMPS III incorporates an acoustic target tracker (ATT) developed by IBM to automate the manual tracking process of the past. Past sonobuoy tracking was based on bearing fixes generated by pairs of buoys and on the tacit assumption that the submarine was not maneuvering. IBM's goal was to reduce localization time and the operator's localization work load by 50%, and also to provide a real-time solution even if the submarine maneuvered.

In the manual system, contacts are manually updated as the submarine runs through the buoy field (ideally, down a lane of buoys). The bearings are converted into fixes that then become a course and speed determined by least-squares fit. Because the LAMPS III system was automated, IBM could add doppler information from the buoys, measuring a submarine's radial speed relative to them. The tracker maintains a real-time estimate of a target's position by filtering both frequency and bearing measurements from the buoys; there is no least-squares fit and, therefore, no need to assume straight-line motion. The algorithm begins with a crude estimate of submarine location based on bearings. Once that has been made, data are fed into parallel bearing and frequency trackers, which feed the target tracker.

Tests showed that the automated tracker could reach a consistent target-location solution very quickly, reaching attack criteria about twice as fast as the least-squares tracker and compensating automatically for the target's maneuvers. Often the least-squares tracker took as much as 10 min merely to come within 90 deg of the target's course, whereas the automated tracker could come within 15 deg in that time.

◆ AIS

Acoustic intercept system is a transient processor proposed in 1990 for all U.S. antisubmarine aircraft. Current airborne signal processors are intended to detect steady sounds by spectral anal-

ysis; AIS would seek transients such as the sounds of sudden maneuvers, sudden releases of steam, or torpedo ejection. This capability already exists on board submarines. In the case of aircraft it requires a second processor, which may add unacceptable weight. Funds were appropriated in the FY88/89 budget, and a draft RFP was issued; as of April 1990, a formal RFP was expected in May or June. The likely competitors are IBM/Allied Signal/AAC, Norden/Magnavox, and possibly Control Data.

◆ ALOFTS/LFAS

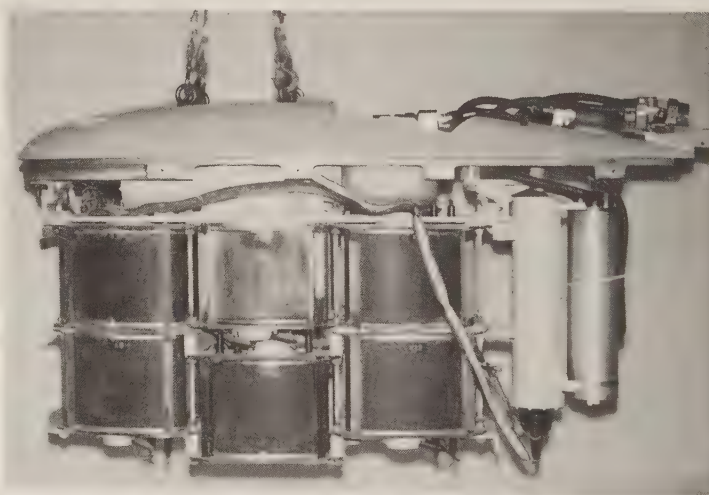
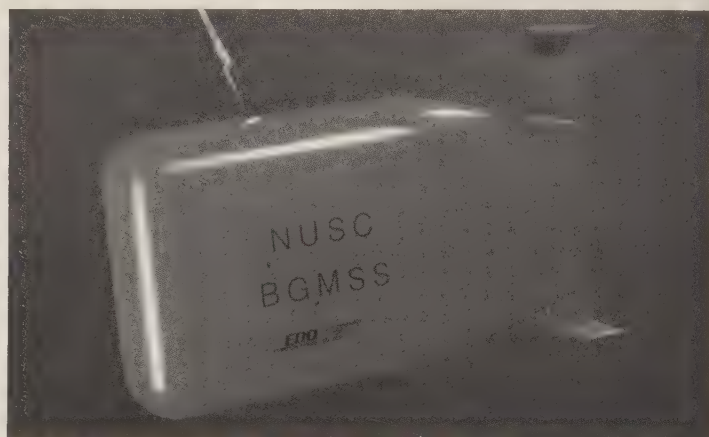
EDO's experimental Active Low-Frequency Towed Sonar was first tested in 1983. It is interesting as a harbinger of future LF systems. EDO used a standard 13/7-kHz fish carrying a flexensional transducer, and a multiline towed array was used as receiver. The system was tried on board a Second Fleet ship (using a single-line array) about 1984, then revived by NUSC New London in 1986 (with the 3-line array).

The projected Low-Frequency Array Sonar would be a production version of ALOFTS, perhaps using a larger fish, suitable for ships such as *Knox*-class frigates. A drawing of this system was displayed at the U.S. Navy League show in 1989.

See also SSATS/LFA/RMES below, and SQQ-89.

◆ BGMSS

EDO's Battle Group Multi-Static Sonar is a NUSC New London program. A drawing of the active element, a towed vertical body



Long-range active sonars must operate at low frequencies. One approach is to use a separate towed array or arrays as receivers, as in BGMSS (an experimental towed body is shown). The EDO/NUSC active low-frequency towed sonar (ALOFTS) is shown, with its cover removed. It uses flexensional transducers. The experimental system on board the USS *Glover*, LFAS (low-frequency active sonar), has used both a billboard active hull transducer and an EDO fish similar to that of ALOFTS (which has a lower source level but can be maneuvered into a more favorable position acoustically). In both cases the receiver was a multiline towed array, 3 SQR-18 arrays in vertical formation. At-sea tests began in 1988. One major discovery was that the array could be streamed and recovered easily without tangling. (EDO)

carrying an array of flextensional transducers, was displayed at the U.S. Navy League show in 1989. This type of system is one way of overcoming Soviet silencing.

An RFP was issued in January 1991. At that time the reported bidders were GE, Lockheed, Martin Marietta, Raytheon, TRW, and Westinghouse. Hughes was reportedly bidding only on the receiving system. The RFP may have called for only a combination of a pinger and a receiver suited to multiple receiver configurations because this system reportedly involved not only surface ships but also airplanes laying sonobuoy fields, as well as submarines. For the airplane, the passive buoys would act as receivers for echoes from a separate pinger. A submarine might receive echoes from a remote pinger, perhaps 1 on board a UUV and would share much the same processing problem. BGMSS has been called "son of SQY-1," a name that might imply the use of a receiver far from the pinger (SQY-1 would use a pinger plus an array receiver towed by the ship doing the pinging).

◆ SADS/MIDAS

SADS (Submarine Active Detection System) and MIDAS (Mine Detection and Avoidance System) are portions of the BSY-1 sonar suite.

SADS is reportedly an upgrade to the transmitter of the spherical bow sonar, to burn through jamming and other countermeasures. Reportedly, it and other current U.S. sonars employ both chirps (stepped frequency-variation) and continuously variable frequency pulses (slides) for a combination of target discrimination and reduced probability of interception. Such frequency variation within a pulse would be effective only in an environment free of multipath transmission, i.e., at long ranges. These waveforms offer much the same advantages as pulse compression in radar. SADS also integrates the spherical sonar with other special-purpose active sonars such as those used for ice and mine avoidance. Reportedly, too, SQS-53 shares some of the advanced waveforms and the power advantage of the SADS sonar.

Presumably, MIDAS is a relatively high frequency active minehunting sonar. To the extent that it is integrated with the bow sphere (and to the extent that the latter can operate over a wide range of frequencies), the sphere may act as a receiver for the secondary HF transmitter.

◆ SIMAS (UYQ-25)

Sonar In-Situ Mode Assessment System, a sonar performance predictor (essentially a very sophisticated ray-tracer) incorporated in SQS-53 and SQQ-89. It is particularly valuable for passive operation since it provides an operator with an estimate of CZ range and also with likely signal strength from various CZs (as well as from alternative signal paths, such as bottom or surface bounce). SIMAS is embedded (rather than separate) in SQQ-89(V)4 and later versions.

The original UYQ-25 of 1978 used a UYK-20X(V) computer, a USQ-69 data terminal, and a teleprinter. It was programmed by magnetic tape and weighed 1165 lb. The current UYQ-25A (1986) uses a DTC I desk-top computer (HP 9020) with 16- and 55-Mbyte disk drives and 0 or 1 spectrum analyzers (HP 3582A), a streaming tape drive (HP 9144A), a Thinkjet printer, and a color graphics terminal (HP 2627A). The same computer runs the Fleet Mission Program library. UYQ-25A(V)1 includes the spectrum analyzer and is used for SQR-18A(V) acoustic predictions and equipment-mode selection. UYQ-25A(V)2, for SQR-19 (part of SQQ-89), has no spectrum analyzer. UYQ-25A(V)3, with no spectrum analyzer, is for SQR-18(V).

◆ Optical Towed Array (AOTA)

In July 1989 Litton was awarded a navy contract to develop an all-optical towed array, i.e., one using optical fibers as its transducers. Acoustic signals cause minute changes in the length of the fibers and can be detected by interferometry. In theory, an all-optical array should support many more elements since different detectors can operate at many slightly different optical

frequencies (wavelengths). The results can be passed through an optical computer. If the signals from the different transducers are at different wavelengths, then the same processor may be able to handle them simultaneously. The program calls for a proof-of-concept array for laboratory and then sea tests, with delivery to the navy for an at-sea demonstration in a second phase. The entire contract is to be completed late in 1990. Litton developed the fiber-optic acoustic sensors and the all-optical telemetry involved. In this project, Litton is teamed with Bendix Oceanics.

◆ SMLTA

The Submarine Multi-Line Towed Array, now under development, is intended as successor to the very long single-line array (TB-12X/TB-29). Presumably SMLTA corresponds to the new surface-ship multiline arrays. SMLTA seems to have been first displayed in late 1990.

◆ SSATS/LFA/RMES

Surface-ship advanced tactical sonar is a generic term for the next-generation U.S. surface-ship sonar. It will probably be an active/passive suite, consisting of a multiline towed array (for greater gain/discrimination) and an LF transmitter, probably in the hull; there will probably also be a hull receiving array. The towed array will be the primary receiver for the LF pinger. For a time this sonar, under preliminary design by Martin Marietta, was associated with the U.S. FFX next-generation escort project.

LFA is the LF active test array, installed in FY88 in the bow of the *Glover*, a 3-line SQR-18 being used for reception. This system was later described as an FY88 new start, in collaboration with Britain, which will furnish a test ship and the instrumentation. The goal is a shallow-water (presumably continental-shelf) capability. Canada may join this program.

RMES is the Gould reconfigurable multiline towed-array evaluation system (contract awarded April 1987), a means of testing future towed-array configurations. Parallel lines of arrays provide increased gain without the geometric distortion associated with a single very long array and can also help solve the left-right ambiguity problem. However, it is not clear that these arrays can easily be handled at sea: hence the need for a test device.

Gould is supplying both the wet end (including a tow body) and the shipboard processor/beam-former.

See also SQQ-89 (improved).

◆ SURTASS (UQQ-2)

See the Surveillance and Control section.

◆ TARP

Towed-Array Range Processor is a term that apparently applies both to a form of signal processing and to a new long array used for passive ranging. In principle, an array either can be used as 1 leg of a triangulation device (the hull or bow array forming the other) or can be divided into elements and those elements used for triangulation. During FY87 a TARP model (presumably a processor using an existing array) was developed for at-sea testing, and a developmental TARP array was scheduled for tests during FY89. TARP is part of BQQ-5E, which is described officially as a quantum improvement in long-range detection and localization.

TARP system-processing capabilities were reduced and full vernier and TMA capability delayed because of reductions in FY88 funding.

◆ Towed Bodies (TB)

This series includes both towed arrays and other towed bodies:

TB-1/2/3/4/5 TB-1 is the towed body for the SQA-10A sonar hoist (on board FRAM II destroyers, carrying the VDS array associated with versions of the SQS-4 sonar), 1961: approx. 11 ft 10 in × 5 ft 5 in × 5 ft 5 in. The transducer inside is stabilized

so that it remains horizontal if the body pitches, and it can be prevented from pivoting. The body is free-flooding. There is also a TB-1A version. TB-1B is 142 × 48 (high) × 39 in and weighs about 6000 lb. Cable length is typically 600 ft. TB-2 is a version of TB-1 for the TR-170 or TR-170A (TB-2A) transducer. TB-3 carries the TR-171 transducer, TB-4 the TR-188, and TB-5 the TR-189. Some of these towed bodies remain in service in foreign navies.

TB-6 Towed submarine radio buoy for SSBN 608 class and later strategic submarines, for the BRA-8 radio antenna (1963).

TB-8 Towed submarine radio buoy for BRC-5 LF loop antenna and transceiver (54 × 57 × 16 in), 1969.

TB-9 Towed submarine radio buoy for BRA-8A radio antenna (122 × 41 × 65.062 in, 1000 lb), made by ITT Federal Laboratories, 1966. It is similar to, but not interchangeable with, TB-6/BRA-8. It has been modified to give external access to the pressure transducer.

TB-10 Towed body for SQS-35 sonar (97.5 × 26 × 58.5 in, 3000 lb).

TB-12 Array for BQH-4 (see separate entry).

TB-12X New long thin array. It is *not* related to TB-12. See entry below. See TB-29, below.

TB-13 Rope stabilizer (50 ft long, 2-in diameter) for SQR-15 array (OA-8705/SQR-15), operating at 2–15 kt.

TB-14 Towed body of the SLQ-25 countermeasure.

TB-15 Submarine towed loop-antenna housing for BRA-8C radio (1974). Dimensions: 122 × 65 × 41 in (1200 lb). Similar to TB-9/BRA-8A but not mechanically interchangeable.

TB-16 Submarine towed array (see below).

TB-17 Spears submarine towed radio-antenna housing, for the receiver group OR-197/BRR-6. Dimensions: 90 × 36 × 41 in (1400 lb).

TB-18 Spears submarine towed radio-antenna housing, for the OE-306/BRR antenna group, carrying it nearly to the surface. Similar to the larger TB-17/BRR-6. Dimensions: 97.5 × 30.0 × 37.88 in (1225 lb).

TB-19 ALQ-141 helicopter mine-countermeasure towed sonar body.

TB-20 Submarine towed array (see below).

TB-21 Towed body for the SLQ-33 countermeasure.

TB-22 Sonar body for the AQS-14 helicopter-towed minehunting sonar.

TB-23 Thin-line towed array (see separate entry).

TB-24 A Mk 6(B) Mod 5 acoustic device in SLQ-37 mine countermeasures.

TB-25 A Mk 4(V) acoustic device in SLQ-37 mine countermeasures.

TB-26 A Mk 6(B) towed body in SLQ-37.

TB-27 A Mk 4(V) towed body in SLQ-37.

TB-28 BRR-7 towed radio antenna body, similar to TB-18.

TB-29 Long thin-line array (TB-12X); see separate entry.

◆ TB-12X/TB-29

This new, long, thin, submarine towed array is part of BQQ-5E and BSY-2. The designation does not indicate a new version of an earlier TB-12; rather, it seems to mean an array with an acoustic aperture 12 times as long as that of TB-16, and reportedly it is more than 3 times the length of TB-23. That probably means about 2500 ft (12 TB-16s would be 2880 ft long, but the

TB-16 acoustic aperture must be shorter than the total array length). Compared to TB-23, TB-12X is credited with improved passive detection and ranging and improved LF performance; it is described officially as a quantum improvement in long-range detection and localization.

TB-12X is part of BQQ-5E, superseding the TB-23 of BQQ-5D, on board *Los Angeles*- and *Ohio*-class submarines. In the new *Seawolf*, TB-12X will be combined with the shorter TB-16D.

Preliminary sea trials were run during FY89, when the final TB-12X specification was drawn up. A full-scale development contract was awarded in the second quarter of 1990, with sea trials in October 1990 and October 1991, and technical and operational evaluation scheduled for 1993.

The TB-29 designation appears to have been applied to the new 12X array late in 1990; it may still be unofficial. TB-23 was the earlier 4X thin-line array.

◆ TB-16/BQ

This submarine towed array is a component of BQQ-5; it can also be used as a stand-alone device. The designation was assigned in 1974. Typically, TB-16 is stowed in a tube running outside the pressure hull, the reel, cable, and winch being located in the forward main ballast tank. The array is streamed out of a tube leading from the port horizontal stabilizer. This installation was designed for SSN 637-class submarines, the early 688s being fitted with a permanently streamed (clip-on) array. The 688s were later provided with reelable arrays using tube stowage, operational experience having shown that the fixed array could be damaged during high-speed runs.

The original TB-16 acoustic array is 240 ft long and 3.5 in in diameter (1300 lb), towed on a 2600-ft cable (0.37-in diameter). It consists of 2 vibration-isolation modules (VIM), 1 transverse VIM, 1 sensor module, 5 acoustic modules (presumably of varying frequencies) with a total of 50 hydrophones, and 1 array-stabilization module. Hydrophone signals are amplified, conditioned, and modulated, then frequency-multiplexed for transmission to the submarine via the tow cable. The modular design of the array allows for complete interchanging of acoustic module positions within the array, including the unique spare module, provided no 2 with the same channels (indicated by part number) are used in the same operating configuration, and proper channel cards are substituted in the LF receiver processing the signals transmitted by the array.

TB-16A (1403 lb with a 450-lb cable, 1982) is modified for reduced self-noise, so that the array can be towed at greater speed without loss of sensitivity, or can be towed at the same speed as TB-16 with greater sensitivity. Its tow cable is about 2600 ft long. TB-16B (1986) is a modified version embodying ECP 59 (engineering change proposal 59) for further reduced flow noise. In its case (and probably the cases of other versions) the acoustic module is 186 ft long. The current version is TB-16D, the chief improvement being a shift from analog to digital signal transmission. Compared to a thin-line array, the shorter but thicker TB-16 should suffer less self-noise at a given speed but should also be effective only at higher frequencies. In some cases it is being superseded by the longer and thinner TB-23, but BSY-2 incorporates both TB-16D and a long thin-line array (TB-12X).

TB-16 is the production version of TB-16(XN-1)/BQ developed under a 1973 contract. The array was originally made by Chesapeake Instrument Co., which was then taken over by Gould, and then by Martin Marietta, the current manufacturer. Gould received a contract for 24 TB-16s in August 1982 (for BQQ-5 and -6 installations), and late in 1982 the company received a contract to integrate this array and the mine detection-and-avoidance systems (MIDAS and SADS) into BQQ-5. In FY84 a total of 27 TB-16s were authorized (3-yr procurement). TB-16 is an improved version of the Tuba II (BQH-4) array, offering a much wider frequency range than the earlier nonretractable STASS (BQR-25). This retractable array was selected in preference to a proposed much longer nonreelable type, SITTAR (a 500-ft aperture on a 1000–2000-ft cable).

◆ TB-20/BQ

Hughes's developmental submarine thin-line towed array (1983) is presumably the loser in competition with TB-23. The array proper, 1500 ft long and 1 in in diameter, carrying 96 hydrophones, is towed on a 2500–5000-ft cable. Data are transmitted down the cable in pulse-code modulated (PCM) form. Array components: 4 vibration-isolation modules (VIM), 1 electronics module, 4 LF modules, 2 MF modules, 2 HF modules, 1 clock module, and 2 aft termination modules.

◆ TB-23/BQ

This thin-line submarine towed-array sonar has an overall length of 4000 ft (2450 lb); maximum diameter is 1.1 in, except 1.14 in at intermodule couplings, 1.15 in at VIMS, and 1.2 in at array-termination module. Total length includes the length of the tow cable, probably 2500 or 2600 ft (as in TB-20, above). The array, which is made by Bendix Oceanics, consists of 2 VIMS, 1 environmental module, 4 LF modules, 2 MF modules, and 2 HF modules, plus an array-stabilization module and an array-termination module. This array contains 98 hydrophones.

TB-23 was introduced in FY83 *Los Angeles*-class submarines. It was tested in 1987. Current plans call for this system to be installed not only in *Los Angeles* but also in *Ohio*- and *Sturgeon*- (SSN 637) class submarines. Development of the latter's thin-line handling equipment (TLHE) was completed in FY88.

◆ UUVs

This is DARPA's project to develop unmanned (autonomous) underwater vehicles, mainly for use from submarines. Two Scout vehicles are being built by the Charles Stark Draper Laboratory, for demonstration runs in 1990. Although the current design is too large (44-in diameter) to fit torpedo tubes, a later version might fit the 30-in tube planned for the new *Seawolf*.

DARPA is developing vehicles and subsystems for the Pathfinder, submarine escort/decoy, and UUV-deployed hydrophone array roles. Pathfinder is a semiautonomous mine-avoidance capability, the UUV guiding a submarine through a mine field. It is also designated MSS (mine-search system). Escort/decoy is a submarine simulator that will decoy the threat and communicate intruder information. It is designated TAS (tactical acoustic system). DARPA awarded the MSS contract to Lockheed in January 1990 and the TAS contract to Martin Marietta in February 1990. The third variant, the remote surveillance system (RSS), was not awarded and may be killed for the present. As of mid-1990, DARPA hoped to hand over UUV technology to the navy for full-scale development in October 1990.

NRL began the first U.S. UUV project, the 2460-kg UFSS (unmanned free-swimming submersible) in 1975, to test laminar flow. It also had a doppler sonar and some pattern-recognition artificial-intelligence, to permit it to find objects on the ocean floor. NOSC San Diego developed the 182-kg EAVE-West (experimental autonomous vehicle), with a side-looking sonar, a magnetic pipeline follower, and a fiber-optic communications link. The parallel EAVE-East project, conducted by the University of New Hampshire Marine Systems Engineering Laboratory (MSEL), was designed to inspect underwater structures and to map the underside of Arctic ice cover. Several EAVE-Easts were used together in a DARPA multiple autonomous undersea vehicle (MAUV) project, which was canceled in 1989. Since 1985 Martin Marietta has developed its own 9-m (29.5-ft) mobile undersea test device (MUST).

◆ EDO 610 Series/CWE-610

This LF (6-, 7-, or 8-kHz) hull sonar is for frigates and larger ships. 610 uses preformed 10-deg beams both for reception and, in directional-transmission modes, for transmission. Modes are ODT, search (120-deg sector), and attack (50-deg sector). Maximum instrumented range is 32 kyd, and 610 can measure target doppler up to 40 kt. There is also a passive display for long-range detection. Beam width is 10 deg vertical and horizontal, and range scales are 2, 4, 8, 16, and 32 kyd.

The 36-stave hull transducer is 1245 mm in diameter and 1067 mm high (weight 2500 kg).

This sonar is designed so that it can be used in conjunction with the EDO 700/701 VDS. An improved 610A appeared in 1972. EDO 610E is a solid-state version incorporating SQS-38 experience.

Development began in 1963, for the Royal Netherlands Navy, of the first EDO sonar designed specifically for a foreign customer. A prototype was completed in 1966; the first production model completed its sea trials in 1969. This work incorporated EDO's experience with SQS-26. Applications: Brazil (Vosper Mk 10 frigates have 610E; ASW ships also have EDO 700E VDS), Italy (*Audace* class; some export *Lupos* have 610E), Netherlands (*Tromp* and *Van Speijk* classes). In Dutch service this sonar is designated CWE-610. The Canadian SQS-505 sonar is derived partly from CWE-610. CWE-610 was conceived as a much lighter and much more compact alternative to the very heavy SQS-23.

◆ EDO 700/701/DDE-700

This VDS was developed in parallel with the 610-series hull sonar, also for the Royal Netherlands Navy; 700 can be used in combination with the 610. Model 700E is a solid-state version incorporating SQS-35(V) technology (1972). Dutch *Van Speijk*-class frigates modernized with EDO 610 hull sonars were also fitted with this VDS, designated PDE-700. The Brazilian Vosper-Thornycroft frigates are fitted with the related EDO 701 VDS. EDO 700/701 technology was incorporated in the U.S. SQS-35(V) sonar.

The 24-stave transducer is 495 mm in diameter (787 mm high) and weighs 397 kg. The hoist and towed body together weigh 8250 kg. Frequency is probably 13 kHz.

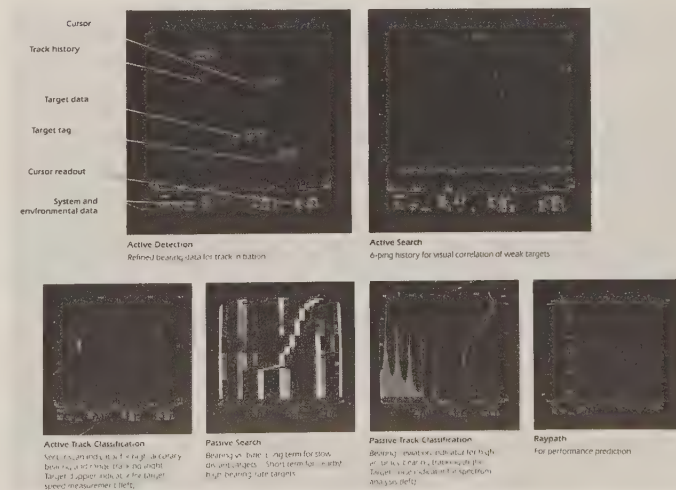
Users: Brazil, Japan (presumably MSA), and Indonesia (ships now transferred by the Netherlands).

◆ EDO 780 Series (780, 786, 796, 795, 7860, 7960, 7950)

This modular series of hull and variable-depth sonars ranges from a lightweight VDS (780) up to a large LF hull sonar (795/7950). Each model uses the same basic console, transmitter, receiver, and data-storage and control unit. Given this modularity, any hull sonar in the series could be supplemented by a VDS, or vice versa. The original EDO 780 was a small VDS; 786 was the same sonar in a hull-mounted version. 796 and 795 were lower-frequency hull sonars.

EDO's 7860, 7960, and 7950 are all combinations of a 13-kHz VDS and, respectively, a 786, 796, and 795 hull sonar.

The standard display has a dual CRT, and display data are all stored internally, so that alternative displays can be called up



Typical modern sonar displays, in this case from an EDO 780 series sonar. The passive search display is a waterfall. At right in the passive track classification display is a time-integrated LOFAR (a spectrogram). (EDO)

EDO/780-Series Characteristics

	MODEL			
	780	786	796	795
Frequency	11.9/13/14.1 kHz	11.9/13/14.1 kHz	6/7/8 kHz	4.3/5/5.7 kHz
Source Level (Higher Level was available as an option):				
SRDT	232 dB	226 dB	231 dB	232 dB
TRDT	226 dB	226 dB	225 dB	226 dB
DT	224–232 dB	218–226 dB	223–231 dB	224–232 dB
ODT	217 dB	217 dB	216 dB	217 dB
MCC	199 dB	201 dB	210 dB	210 dB
Weight:				
Inboard	2188 kg	2176 kg	2436 kg	2436 kg
Outboard	7300 kg	1365 kg	3045 kg	5000 kg

at will. Tracking is by ball-located cursor on a display. Alternative displays are: ray-path predictor; active detection (range vs. bearing); active search (6-ping history to make weak targets stand out visually); active track classification (sector scan range vs. bearing and target doppler side by side); passive search (bearing vs. time waterfall; either long-time for slow targets or short-time for fast ones); and passive track classification (bearing-deviation indication for high-accuracy tracking and target spectral analysis side by side). All of these displays show processed, rather than raw, video.

All sonars in the series have 24 preformed beams, and all employ 10-, 30-, and 60-msec CW pulses and 60-msec FM pulses. Each sonar provides its operator with the choice of 8 acoustic-intercept bands. Accuracy is $\frac{1}{2}\%$ of the range scale, 1 deg in active bearing, and 0.5 deg in passive bearing. Range scales are 2, 4, 8, and 16 kyd, with 32 kyd added in the 2 lower-frequency sonars.

For the 2 HF sonars, the passive band is 5.8–10.6 kHz; for the 2 lower-frequency sonars, it is 2.8–5 kHz.

The original EDO 780 was derived from the company's experience with SQS-35 and appeared in 1976; 780 is installed on board 4 Israeli *Sa'ar-II*-class missile boats, controlling light-weight torpedoes. EDO 786 (1979) is derived from EDO's experience with the corresponding hull sonar, SQS-38. 786 is installed on board Korean frigates; it replaces the SQS-42 on board Indonesian *Claud Jones*-class escorts. EDO 7867 and 7957 are improved versions of 786 and 795 (1984). EDO 796 (7 kHz) has been selected for the new Israeli *Sa'ar-V* class. It differs from earlier EDO sonars in using a standard Israeli console.

The EDO 780-series displays were based on experience with BQQ-5. Compared to SQS-56, they show more attention to passive detection, with waterfalls (time vs. bearing displays).

◆ EDO 787

This compact 7-kHz VDS uses the same fish as the 13-kHz EDO 780. The electronics are common to, and compatible with, Models 786, 795, and 796.

The transducer operates at 6, 7, or 8 kHz, with source levels as follows: ODT, 215 dB; DT, 219–226 dB; TRDT, 220 dB; SRDT, 226 dB. Pulse widths are 10-, 30-, or 60-msec CW, or 104-msec long FM (pulse-compressed). The active receiving bandwidth is 500 Hz, and the passive bandwidth is 2.8–5 kHz. The operator can specify 8 acoustic intercept bands. There are 24 preformed beams. Instrumented ranges are 2, 4, 8, 16, and 32 kyd. Accuracy: active range, $\frac{1}{2}\%$ of range; active bearing, 1 deg; passive bearing, 0.5 deg.

Transducer dimensions: diameter 22 in, height 31 in. Unlike most cylindrical transducers, 787 is not constructed of a series of vertical staves. Instead, square spot transducers are arranged in a spiral over its face. EDO claimed that this new transducer design was what made it possible to provide a 250-ton patrol boat with a useful LF sonar.

Model 787 was announced together with a new EDO Advanced Modular Signal Processor, which could be used by other 780-series sonars. That processor, in turn, was the basis for a

linear FM coherent signal processor that was expected to improve performance substantially in the face of noise or reverberation. Signals were linearly broken down into pulse compressed signals and displayed in a clutter-free computer-driven display.

◆ EDO 900/910

These units are underwater-object locators and mine-detecting sonars for submarines. The difference between the 2 models is that in Model 900 the scanning head is above its drive mechanism, whereas in Model 910 the scanning head is below; Model 910 is a 900 adapted as a minehunting sonar. Dimensions and the display (a 7-in ship-centered CRT) are identical. The signal is a continuously transmitted FM slide, which gives a clear audio presentation. The transducer is 368 mm in diameter.

This sonar was sold to Germany for use on board Type 206 submarines.

◆ EDO 1102/1105

This is a solid-state version of the old standard U.S. BQR-2B/BQS-4 suite for the Peruvian *Abtao* class (1976). It combines the original arrays (with a passive transducer 1244 mm in diameter and an active transducer 330 mm in diameter) and cabinets with new electronics. Visual display modes are bearing vs. time (waterfall), range vs. radial speed (doppler), and self-noise. In the passive surface-ship detection mode, processing prior to display shows ranges (computed, presumably, by TMA with automatic speed estimation by blade count) out to 30,000 yd and bearings accurate to within 0.5 deg. The first 2 sonars were fitted in chin domes, but they increased the submarines' draft too much, and the last pair received large bow domes above decks. The first 2 submarines were later refitted with above-decks domes.

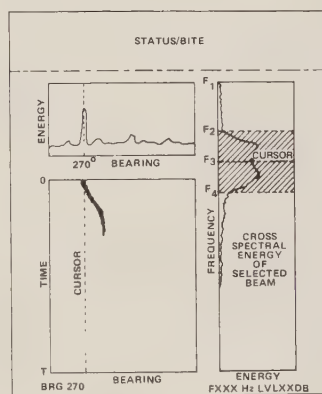
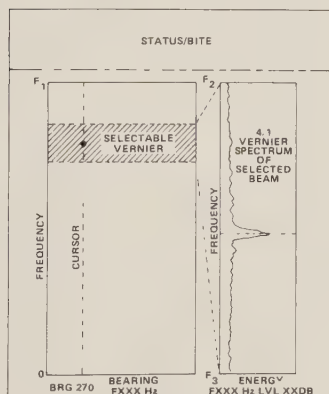
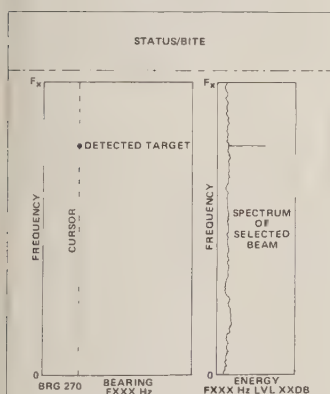
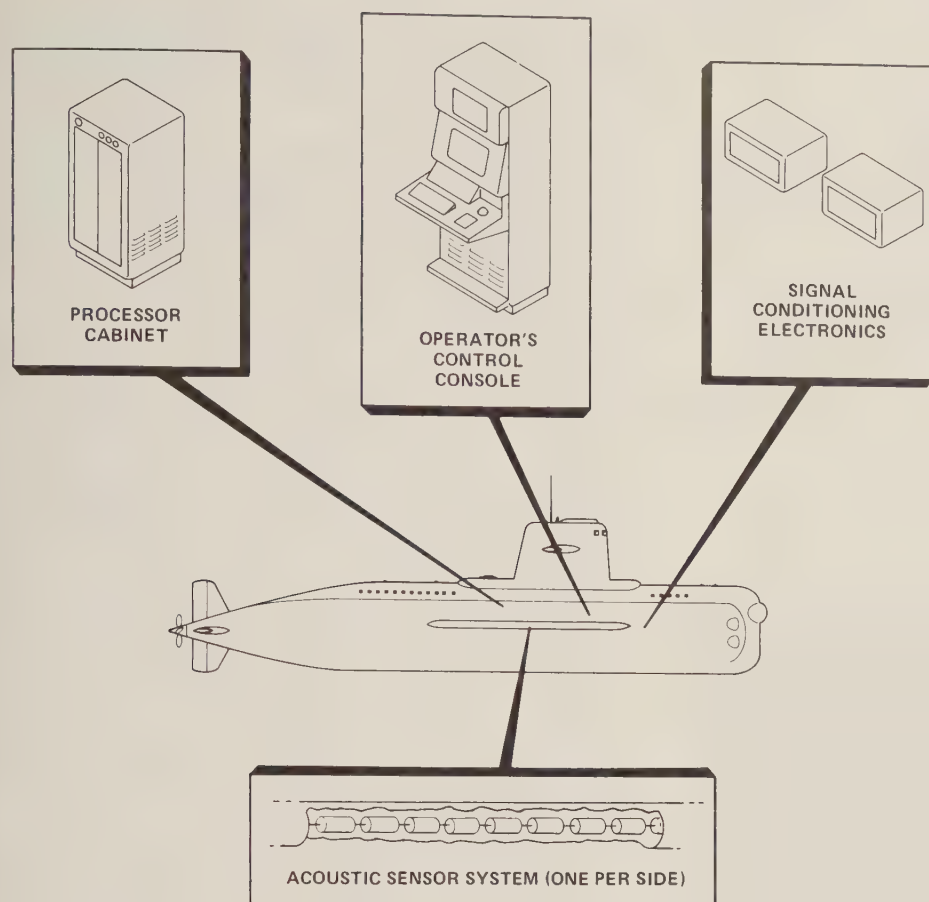
◆ EDO 1110

Model 1110 is a flank sonar for submarines, consisting of a linear transducer array. 1110 is intended as an adjunct to existing sonar, combat, and fire-control systems. This sonar uses LF beam-preforming, split-beam correlation (for accurate pointing), and spectral analysis; and 1110 can track more than 15 targets simultaneously, using broad- and narrow-band processing interpolation. Selected targets can be assigned to "high quality" track processors for improved positional accuracy, and these tracks can be maintained even when targets cross the submarine's path (passing from the FOV of 1 array to the other). The operator initiates track by using a cursor at the console.

There are 2 high-resolution color displays, options including frequency vs. bearing and bearing vs. time.

This system appeared in 1985. EDO describes 1110 as based on operational experience in the U.S. and foreign navies, so the capabilities above may be typical of existing passive hull arrays.

This sonar was sold to an undisclosed foreign customer. It will be delivered during 1991.



(Above) EDO 1110 submarine flank-array sonar. (EDO)

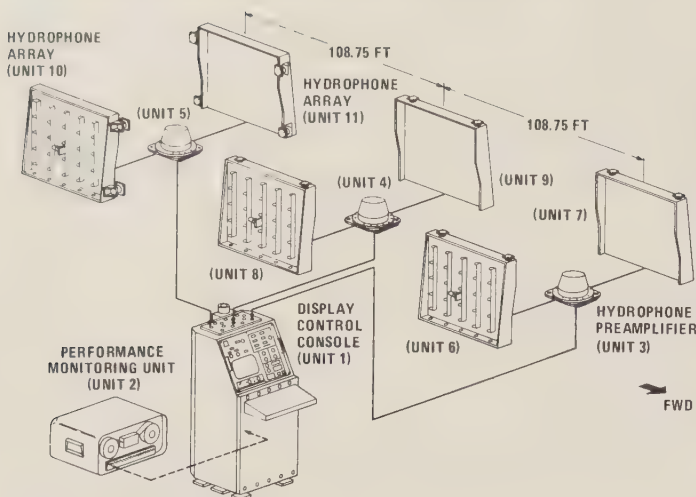
◆ Micro-PUFFS/PASLAN/BQG-501

Sperry's passive ranger for submarines is a micro-circuited version of the earlier BQG series, using baffled hydrophone arrays. Because Micro-PUFFS employs 3 transducers along the hull, it is inherently much quicker than TMA; on the other hand, range is limited by the length of the baseline. PUFFS itself was developed by the U.S. Navy and by Sperry in 1956-60 (and Sperry produced 54 units in 1960-66). Micro-PUFFS was developed specifically for the Royal Australian Navy (1972-76), and in 1979 Sperry began work on a similar system for the Royal Navy. As BQG-501, Micro-PUFFS was incorporated in the Canadian *Oberon* upgrade program (SOUP), Micro-PUFFS electronics replacing that of the earlier Type 719 sonar. In the Canadian ships, Micro-PUFFS is visible in the form of 6 red-outlined soft patches along the sides of the upper casing (Stations 15 to 18a-19a, 64b to 69a, and 103 to 110, all port and starboard). This sonar was also installed on board the *Barb* (tested 1980).

The 3 hydrophones on each side of the submarine form 5 continuously processed preformed beams (5 beams per array); targets are tracked automatically. Ranging is by cross correlation of the same signal as received by the 3 arrays, the 2 time differences being converted into bearing and range data. The range solution is, therefore, both instantaneous and continuous. Each triplet of hydrophones covers a 150-deg sector. In an Australian *Oberon*, the hydrophones are 108 ft 9 in apart. Each hydrophone is a square array (5 staves, each carrying 5 spot hydrophones). Sperry estimated that the range error on a target directly abeam at 6000 yd would be about 2.5%, rising to about 11% 60 deg off the beam. The error would be about 5% at 12,000 yd (directly abeam).

Sperry claimed that Micro-PUFFS could more efficiently reject background noise because it used correlation and preformed-beam techniques. Early sea experience suggested that MTBF might be as great as 3600 hr, with 30 min (or less) MTTR.

PASLAN (Passive Ranger) was a modified Micro-PUFFS delivered to the U.S. Navy in 1979 and tested on board the nuclear submarine *Haddock* from July 1979. The arrays are larger than



MicroPUFFS arrays. (Sperry)



MicroPUFFS display. The CRT shows 2 correlograms, 1 for each pair of adjacent arrays on 1 side. The upper line shows 150 deg of bearing on the starboard side; the lower, 150 deg on the port side. Targets appear on 1 or the other, and a control stick can be used to position a cursor on the target. When the operator aligns the peak of a correlogram with 3 dots on the display and presses a button, the system begins to track the target automatically in bearing. The operator can begin to track automatically in range when the peaks of the 2 correlograms are aligned (i.e., when triangulating on the same target). Contact data are displayed in the upper right-hand side of the panel, including true bearing, relative bearing, bearing rate, and range. Target's course and speed are indicated continuously through TMA. (Sperry)

those of Micro-PUFFS, and the system can track quieter targets at greater ranges. Presumably, PASRAN was an alternative to WAA.

◆ Raytheon DE 1160 Series

As of 1988, over 100 of these Raytheon export sonars were in service. All share common computer hardware and software, common displays, common transmitter amplifiers and power supplies, common circuit cards, and common interface units. Unit cost is \$3.5 to \$4.5 million. In 1988 DE 1167 cost \$2 million each.



DE 1164 fish shown after it had been streamed and recovered by the Italian frigate *Maestrale*, March 1982. (Raytheon)

DE 1160 is a medium-range direct-path sonar for corvettes and larger ships. See the entry below for DE 1160B details.

DE 1160C is the standard U.S. SQS-56 frigate sonar (see above). 1160C weighs 12,800 lb, compared to 11,600 for DE 1160B; and peak power is 90 kW (average 10 kW) rather than 30 kW (10 kW average). Both B and C have the same transducer and the same sonar receiver, but DE 1160C adds an additional transmitter (unit 13) and a dummy load (unit 14). Both sonars provide simultaneous active and passive detection. This is the sonar of the Spanish *Descubierta* and *Perry* classes.

DE 1160LF is a larger LF version, in the Italian carrier *Giuseppe Garibaldi*.

DE 1163 is a VDS version of DE 1160. Peak power is 35 kW (average 7 kW).

DE 1164 is an integrated hull-mounted VDS variant, combining DE 1160 and DE 1163. In hull sonar form 1164 equips the new *Animoso*-class destroyers. In VDS form, 1164 is installed on board Italian *Maestrale*-class missile frigates. This sonar also equips the *Alpine* class. Peak power is 35 kW (average 7 kW).

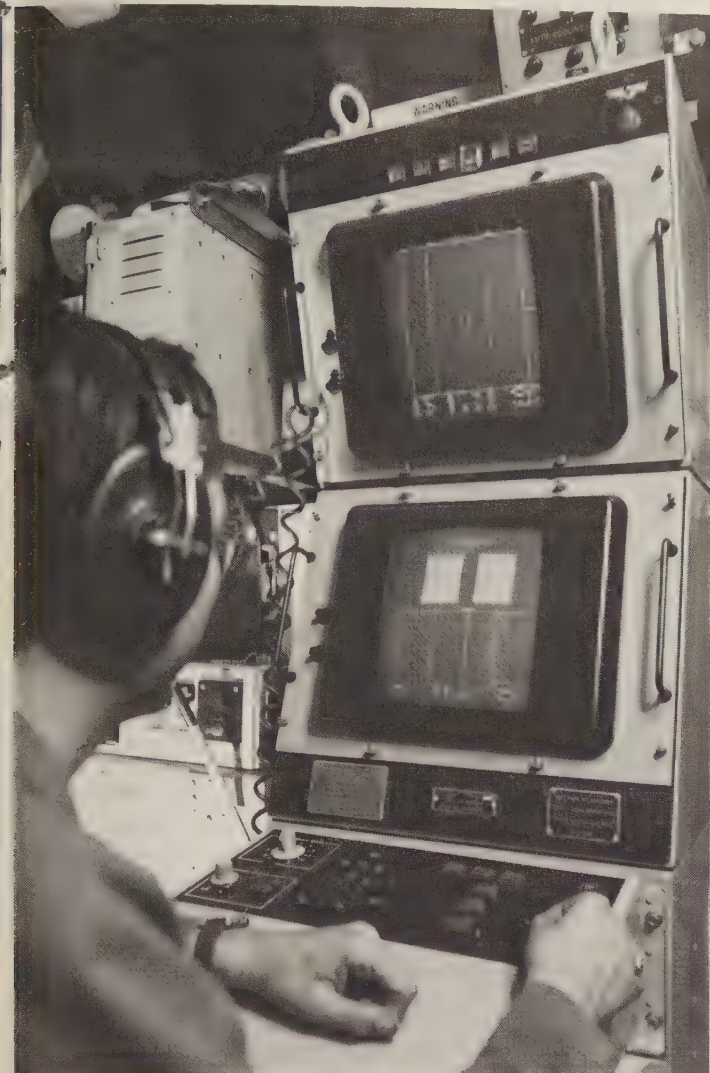
DE 1165 (see entry below) is an integrated submarine sonar.

DE 1167 is the latest version, smaller and lighter for fast patrol craft and similar types. 1167 exists both in hull and in VDS versions (and also in a hull/VDS combination version). Total weight of the hull version, including the dome, is 1460 kg; total weight of the VDS version is 10,260 kg. There is also an LF version for larger ships that cannot accommodate DE 1160 B/C. DE 1167 (MOD) is used to modernize existing SQS-23s: the receiver and console and a new 48-kW solid-state transmitter (SST) are added to the existing dome and transducer, adding a minimum of 10 dB in performance.

DE 1191 is a new solid-state transmitter suitable for SQS-23 modernization (see entry below).

◆ Raytheon DE 1160B

Raytheon's hull sonar has an optional VDS extension. 1160B operates on 6.7, 7.5, and 8.4 kHz, with a bandwidth of 400 Hz (FM or CW). The beam can be depressed/elevated at 12.5 or 25 deg. Operating modes (active) are ODT (5.0–160 msec pulses, source level 218 dB), Single RDT (5.0–2180 msec pulses, source level 232 dB, over a 20–120 deg sector), Triple RDT (5.0–1940 msec pulses, 227 dB), and wide (5–700 msec pulses, 30–120 deg sector, 225 dB). Reception modes (600-Hz bandwidth) are search (36 fixed beams, 12.5-deg depression/elevation, 2-deg resolution in azimuth, 2-yd resolution in range on 2.5-kyd scale, 16-yd resolution at 20 kyd) and tracking (2 steered-independent 20-deg beams, range gates 625 and 1250 yd using a sector-scan indicator).



The standard dual console of a DE 1160 sonar. The lower screen is a dual B-scan (range vs. bearing). (Raytheon)

and target doppler indication; one 14-deg independent audio beam, accuracy 0.5 deg in azimuth, 1.1 yd in range, and 2 kt in doppler). The sector-scan indicator (SSI) and target doppler indicator (TDI) are target-following aids, respectively comparing the phase differences on either side of a beam and showing target doppler.

There is also a passive mode using 18 fixed beams (18×21 deg) at 3–6 kHz, with audio on 1 selected beam. This mode uses a DIMUS processor (signals are clipped, processed digitally, and then filtered through short-term averaged and long-term averaged smoothing filters). The displays are all B-scans; active track data are presented on an expanded B-scan (20 deg in bearing $\times$ 625 or 1250 yd), and both long- and short-term averaged data can be presented separately, in waterfall form.

Peak power is 30 kW (7.2 kW average). The hull transducer is 121.9 cm (diameter) $\times$ 96.5 cm (weight 2268 kg). Total system weight is 5302 kg.

DE 1160/SQS-56 export users: Australia (SQS-56), Greece (4 DE 1160s), Italy (4 DE 1160s, 1 DE 1160LF), Morocco (1 DE 1160), Saudi Arabia (7 SQS-56s), Spain (6 DE 1160s, 5 DE 1160LFs [for *Baleares* class], and 4 SQS-56SPs), and Taiwan (6 SQS-56s).

DE 1164 users: Greece (4 VDSs for MEKO 200s), Italy (10 delivered, 2 DE 1164LFs on order for *Animoso* class).

◆ Raytheon DE 1167 (SQS-58)

Raytheon's hull and variable-depth sonar for smaller ships (hull, fish, or combined) operates in a 2-kHz band around 12 kHz, and there is also an 18-kHz version. The passive-search band is 2

kHz wide, centered on 4.5 kHz. Reception is on 36 preformed beams, with a selectable 10×13 deg sum beam for listening. Comparison of half-beams allows a tracking accuracy of 2 deg. Range resolution is 8–64 yd. The active display operates on 256 range cells and 180 bearing cells (2 deg each), with 2 intensity levels. Pulses are FM slides covering 1 kHz (6.25, 50, 100, 200 msec). Source levels are 225 dB (triple beam) and 215 dB (ODT). The ODT mode is limited to 5-kyd range, to maximize data rate on the most urgent threats. The more concentrated triple beam is necessary to provide enough energy for greater ranges. The display can show a 3- or 6-ping history. Range scales are 2, 4, 8, and 16 kyd.

In search operation, the sonar interlaces tribeam and ODT ping modes, the tribeam mode consisting of 12 transmissions in sequence to cover the full 360 deg. In this mode the sonar usually transmits 200-msec pulses, although it can use 50-msec pulses. In the evaluation mode, the sonar transmits ODT pulses, with lengths of 6.25, 50, and 200 msec. There is a listening (passive) mode and an optional passive mode, which can operate simultaneously with the active mode (at lower frequency).

The display is a CRT that can be used in various formats: a B-scan (with over 300 lines of sonar data) for active search, a restricted B-scan for sector scanning (showing target doppler), a passive waterfall (which shows both short- and long-term averaged data), and a variety of alphanumeric.

The VDS weighs 10,260 kg (6.4 m³). The hull sonar weighs 4375 kg (12 kHz) or 3920 kg (18 kHz). Only 1 operator is required. MTBF: 1 hr of service is required for 60 days of operation. MTTR is 30 min. The sonar uses built-in test equipment.

Another version, DE 1167LF, operates at 7.5 kHz (and can support a 7.5- or 12-kHz VDS). The 7.5-kHz hull array is 48 in in diameter, compared to 28.2 in for the 12-kHz array. The 7.5-kHz VDS fish weighs 50,300 lb; the 12-kHz fish, 23,550 lb. As of 1985, 2 DE 1167LF/VDS had been sold to Egypt, to equip *Descubierta*-class frigates. As of 1986, a total of 25 DE 1167 had been sold. Some parts are made in Italy by Elsag.

SQS-58(XN-1), on Raytheon's test ship *Sub Sig-II*, is a DE 1167. The U.S. Navy uses the DE 1167 engineering model to track nuclear submarines on their sea trials; Raytheon claims that the model has operated for more than 8000 hr and that it has "perhaps more 'ping time' against live submarines than any other surface ship system anywhere." Raytheon currently refers to the hull version of this sonar as DE 1167HM. It incorporates the operating techniques and processing power of the larger DE 1160/1164 series but can be installed on board ships displacing as little as 200 tons.

Users: Egypt (2 DE 1167LF/VDS), Italy (9 DE 1167LFs and 4 DE 1167 for corvettes), Japan (4 DE 1167LFs, presumably for the MSA), and Korea (26 DE 1167s).

◆ Raytheon DE 1191

Raytheon's hull sonar combines features of the DE 1190 transmitter, the DE 1160 receiver and display, and a new LF transducer. The solid-state transmitter (DE 1190 SST) is sold as an SQS-23 upgrade. DE 1191 includes a 48-kW transmitter (14-dB improvement over SQS-23) and eliminates 40 cabinets and boxes of vacuum tubes and 10 motor generators, saving 450 ft³. DE 1191 requires 5 cabinets. It uses the same dome and transducer as SQS-23, so no drydock work is required for installation. Typically the SST is installed first, then the more expensive receiver/display. Features include memory-refreshed B-scan and multiping storage.

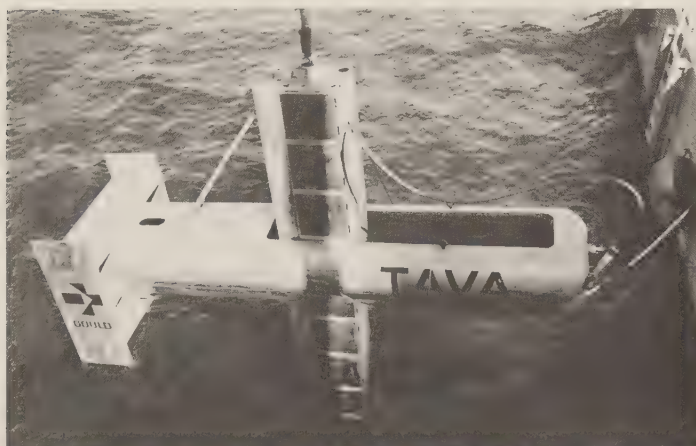
DE 1190 is offered in 12-, 24-, 36-, 48-, 72-, and 96-kW versions, using 1-kW transmitter modules. Peak power is 28–56 kW. DE 1191 peak power is 120 kW (average 10 kW).

The DE 1191 transmitter costs \$1 million. By November 1989 Raytheon had sold 80 transmitters. Known buyers were Australia (3 for DDGs), Germany (3 for DDGs, later replaced by DSQS-21s), Greece (3, plus an option on 3, for FRAMs), Pakistan (6 for FRAMs), Korea (8 for FRAMs), Taiwan (12 for FRAMs), and the United States (48 for ships with SQS-23 sonars, including the DDG 37, CG 16, CGN 9, and CGN 25 classes).

◆ TAVA

Gould's Towed Active Vertical Array is for a joint NATO SACLANT/NAVSEA/NUSC program. TAVA was tested in the Mediterranean in October–November 1986. The transmit array was 16 Sanders Model 30 flexensional transducers in 2 vertical struts, providing left/right cardioid patterns. The beam could also be steered vertically. Signal strength was 226 dB at 1125 Hz. The receiver was towed separately, using a critical-angle tow. The first 2 weeks of the sea trial were spent on acoustic and hydrodynamic tests; the third was spent operating with a *Glavkos*-class (Type 209) submarine, and the fourth week was spent acquiring environmental data.

This program was established in January 1986.



The transducer "fish" of the Gould TAVA (towed active vertical array), showing the vertical column of 16 flexensional transducers in 2 vertical struts (for left/right patterns; the beam could also be steered vertically). When not in use, the column could swing back into its recess to reduce drag. (Gould)

◆ WQRSS

Whitehall's Quick-Reaction Surveillance System is a containerized towed array proposed by Whitehall Corp. about 1985. The navy leased 3 units under its FY86 program, operating them very successfully; this system was, in effect, SURTASS without the command/control aspects. Whitehall manufactures the "wet end" of the SURTASS sonar (UQQ-2) and has made numerous hydrophone arrays for oil exploration.

◆ POS Ship (ASW Ship) Upgrades

Secretary of the Navy Garrett listed recommended upgrades to existing U.S. ASW surface combatants (protection of shipping [POS] ships), the *Spruance*-class destroyers, and the *Perry*- and *Knox*-class frigates on 16 August 1989. Given insufficient funds, he expected that the *Spruances* and *Perrys* would be upgraded, but that the *Knox* class will be relegated to reserve without modernization. The lists are presented here as indications of the sort of systems the U.S. Navy is likely to buy as it modernizes existing ships. Although not all of the items are ASW-related, many of them are. In the case of the *Knox* class, although it is unlikely that the U.S. Navy will carry out the list, the projected program suggests what likely foreign buyers may need. First priority went to the dual-role (battle group and POS) *Spruances*, and second to the *Perry*-class, the main POS force with the longest remaining service life.

Spruance Class

(a) Programmed

—Tactical towed array, acoustic processor, and ASW helicopter data link (SQQ-89(V)1 system with SQS-53C sonar and SQR-19 array; trials ship was DD 980, 1985). DD 966 had an SQR-15 surveillance array during a Western Pacific cruise in 1985. The Mk 116 Mod 5 underwater FCS is to be fitted, as well as a new underwater telephone, WQC-5.

—LAMPS Mk III with dual RAST on all ships.

—Mk 41 vertical launcher on 24 of 31 ships (Tomahawk in 2 quad armored box launchers on the others). The 61-cell vertical launcher replaces the ASROC forward; without a vertically launched ASROC or Sea Lance, these ships lose their all-weather standoff capability. They will ultimately carry up to 45 Tomahawks plus 16 vertically launched ASW weapons. The box-launcher ships, which retain standard ASROC, are DD 974, 976, 979, 983, 984, 985, 989. DD 963 and 990 were the first vertical-launcher ships. The Mk 41 system can also accommodate Sparrow or Standard (AAW) Missiles.

—CIWS Block I upgrade.

—Mk 50 torpedo handling and stowage.

—Radio D/F to support OTH-T.

—ECM upgrades (SLQ-32(V)2 replaced by (V)3).

—TAS (and other acquisition systems) for ASMD (TAS Mk 23 was on board half the class as of 1985). This program also envisages replacement of the current SPS-40 by SPS-49.

—Survivability and stability improvements.

(b) Recommended Additions

—Improved towed array with LF active transmission and reception and full-spectrum processing.

—Improved antimissile hard-kill systems (RAM).

—Added missile fire-control channel (perhaps in connection with missiles carried in vertical launchers forward).

—Integration of hard and soft kill for missile defense (RAIDS, see the anti-aircraft section).

—Survivability upgrades.

Perry Class

—Improved towed array with active transmit/receive subsystem (i.e., active adjunct) and full-spectrum processing.

—SYS-2(V).

—Mk 92 Mod 6 (CORT).

—RAM missiles (to be fired from the Mk 13 launchers).

—ECM upgrades: RAIDS and Sidekick.

—Survivability improvements.

Knox Class

(a) Completion of Existing Upgrade Programs

—Towed array for 43 of the 46 ships.

—Digital hull sonar (SQS-53 vice -26).

—Torpedo countermeasures.

—Silencing.

—ESM upgrades.

—Radar upgrades.

—LAMPS tacnav system (to accommodate modernized LAMPS I).

—Baseline CIWS.

—Baseline Harpoon.

(b) Warfighting Improvements

—ASW detection and target-classification improvements.

—Full spectrum acoustic processors, multimode acoustic array (i.e., active adjunct to towed array).

—FFISTS and JOTS (see the Surveillance and Control section).

—Tactical plotting system (NC-2) replacement.

—Digital upgrade to underwater FCS.

—State-of-the-art tactical-decision displays.

—ECM upgrades.

—Detection-to-engagement improvements (i.e., a more automated combat system for faster reaction).

—CIWS Block I.

The principal warfighting improvement is FFISTS, in effect a small-ship ASW-oriented automated combat information system (it does not include an automated interface to weapons). The FY83 program included installation of an ASW Tactical Data System (TDS) on board all the *Knox*-class frigates, but that was not done, and there were several proposals. FFISTS was (or is being) installed on board 11 ships. Now many of the ships are probably to be transferred in the near future, and their buyers may well find similar modernization attractive, particularly since CDSs are becoming so much less expensive.

UNDERWATER FIRE-CONTROL SYSTEMS

◆ Mk 101

The first U.S. post-World War II submarine FCS survives in small numbers (see the list of versions, below). It is worth describing in detail because it is typical of the technology developed during the first postwar decade, examples of which survive alongside the much later electronic systems. The limitations inherent in the mechanical Mk 101 explain the importance of the transition to digital computers. The basic architecture of Mk 101 carries over into the later systems through Mk 113. Contracts for Mk 101 and the parallel surface Mk 102 were let in 1948, and Mk 101 entered service in 1952. Mk 101 used the new Mk 55 computer-analyzer (also in contemporary surface-ship ASW systems) and an automatic plotter (which replaced the older DRT). Mk 101 was part of a modular program. It was built around Analyzer Mk 7 Mod 0. Mods 1 and 2 were used in the much simpler Mk 106 system (described below). Similarly, Mk 101 used Position Keeper Mk 1 Mod 0; the now-extinct surface system, Mk 102, used Mk 1 Mod 1.

As in other contemporary underwater FCSs, Mk 101 consisted of an analyzer (Mk 7), a position keeper (Mk 1), and an angle solver (Mk 11). The position keeper projected ahead (generated) target position (bearing and range) and motion (course and speed) on the basis of the course and speed estimated (from sonar, radar, and periscope observations) by the analyzer. It constantly fed these data back to the analyzer for comparison with actual observation, and thus for correction. The same data were also fed to the angle solver, which used them to calculate appropriate torpedo gyro and speed settings, based on known torpedo ballistics and also on the desired torpedo spread. These torpedo settings were fed to the torpedoes via a relay transmitter and amplifiers. Because the torpedo ballistics were present in the angle solver in analog form, that instrument had to be modified physically to handle any torpedo very different from those originally planned.

Analyzer Mk 7 estimated (solved for) target course and speed, assuming that the target followed a straight course. It could work from 3 discrete target bearings and 1 input of either target range or speed, or (if both own-ship and target were moving) target course. The accuracy of the solution depended on the time intervals between bearings and on the bearings themselves. Total analysis time was limited to 20 min. The operator could discard the second or third bearing while the analyzer ran, inserting a preferred observation later on (the starting point could be changed by pushing a reset button). Range, target course (target angle), or target speed were entered by hand crank; all 3 functions varied when the hand crank was turned. A generated (calculated) range from the position keeper could be input automatically. When a range, course, or speed was inserted, the computer obtained the unique solution, taking own-ship motion into account. This solution differed from most types of bearings-only solutions obtained by earlier systems in that own-ship maneuvers were not restricted to fixed course and speed during the analysis period.

Alternatively, the analyzer could work from a pair of end points (target bearing and range), a method called end-point analysis.

The position keeper projected ahead target motion on the basis of the analyzer solution. This projection could be used as a check on target motion. For example, a target turn could be detected when observed target bearings began to deviate from those estimated. The position-keeper displayed target course and speed; target angle; target relative course; ratio of target relative course to range; range; own-ship course; bearing of 1st, 2nd, 3rd observations introduced into the 3-bearing method; analysis time from first observation; time interval between 1st and 2nd observations in the 3-bearing method; and number of bearings inserted (not counting number dropped).

Unlike the analyzer, the position keeper could project ahead on the assumption that the target was turning: turning radius and turning rate were inserted by a knob. On this basis it could

calculate target track curvature (change in target course per unit travel) as well as bearing, range, target speed, and target angle. Normally the analyzer fed the position keeper automatically, but in the event that the computer failed the position keeper could be fed manually, based on the last known values for corrections (which were displayed on the dials until the operator used them).

Unlike the earlier underwater FCS computer (Torpedo Data Computer Mk 4), Mk 101 solved for only 1 torpedo nest at a time. That was practical because the angle solver reached a solution much more quickly (and without swinging around the final solution, as in earlier systems), and because it could very rapidly set the electrically set torpedoes. The angle solver had a switch to select torpedo tactical data to suit the particular Mk and Mod of torpedo to be fired; this switch allowed for up to 7 sets of torpedo data. The firing panel could allow for either angular or linear spreads. A stratum depth-warning system lit a warning indicator when own-ship maneuvered into the depth operating range of her homing torpedoes.

Some key torpedo parameters were still set manually, in the torpedo room: torpedo enabling run and running depth.

The chief improvements over earlier underwater FCSs were automatic reception of all target data, automatic transmission between units, nearly instantaneous synchronization to incoming data, automatic analysis of target course and speed, longer position-keeping range (34,000 yd), addition of a frozen display of bearing and range corrections and time for accurate mental analysis, nearly instantaneous angle-solver solution, longer angle-solver torpedo run (20,000 yd or 15 min), rapid changing of torpedo tactical data inputs in the angle solver for various types of torpedoes, and addition of curved-course solutions.

Both the quicker solution and the provision for curved target course were essential in a system intended to deal with the new generation of very fast and very maneuverable submarines. Target curvature was transmitted automatically to the angle solver.

The original Mk 101 could handle straight-running torpedoes Mk 14 and Mk 18 (electric) as well as Mk 27 Mod 4, Mk 28, Mk 35 Mods 2 and 3, and Mk 37 homing torpedoes. It was modified for 3 major new torpedo generations: wire-guided homing weapons (particularly Mk 37), the nuclear Mk 45, and the much faster Mk 48.

Wire guidance required a new device, Torpedo Director Mk 37. It was used to fire the abortive Mk 39 Mod 1 torpedo in a bearing-rider mode (rather than in a predicted-fire mode, as in earlier fire-and-forget systems). The operator manually steered the torpedo to keep it on the bearing line between submarine and target. The wire carried indicated torpedo speed back to the submarine, and a computer used this speed and the series of guidance commands sent out to the torpedo to dead-reckon torpedo position in the water (there was, and for that matter almost certainly is, no feedback to compensate for factors such as currents between the submarine and the target). The same computer converted relative target bearing (e.g., as determined by a passive sonar) into true target bearing for comparison with true torpedo position and bearing. Concentric dials on the face of the director showed true torpedo bearing and true target bearing, and the operator turned a STEER knob on the director to match them. The commands went simultaneously to the torpedo and to the director (for further dead-reckoning). The torpedo's own passive homing system took over when it began to hear signals from the targeted submarine.

Bearing-riding was relatively simple to implement, but it imposed severe limitations. First, the torpedo necessarily followed an energy-inefficient pure-pursuit course; there was no attempt at a torpedo equivalent of proportional navigation. That limited the effectiveness of a slow torpedo such as Mk 39. Second, since the torpedo always lay on a line between submarine and target, it always produced a noise strobe pointing back toward the launching submarine. That was not a very serious issue for a very quiet torpedo such as Mk 39 or its successor, Mk 37, but it could become important for a fast noisy one. Wire guidance could in theory allow for dog-leg courses, but such tactics re-

quired a much more elaborate plot or computer, permitting the operator to visualize the tactical situation. Dog-legging and proportional navigation could also help overcome whatever countermeasures, such as bubble screens and decoys, a submarine might leave in her wake since in these cases the torpedo might well approach from other than a stern aspect.

The Mk 37 torpedo, the wire-guided version of which entered service in the early 1960s, was designed for more varied trajectories, and it used a more sophisticated director, either a later version of Mk 37 or the new angle solver Mk 18 Mod 0 (which was developed specifically to control the new nuclear Mk 45 torpedo, ASTOR, which entered service at that time). Mk 18 was developed (by Sperry) as part of the program for ASTOR (Mk 45), the fast nuclear torpedo, but it replaced both the earlier angle solver (Mk 11) and torpedo director Mk 37 in FCS Mk 101. In the simpler Mk 106 (described below), Mk 18 Mod 1 and a transition section replaced the angle solver in the system's torpedo data computer Mk 4 (which was then reduced to functioning only as a position-keeper). Mk 18 differed from earlier angle solvers mainly in its ability to provide steering information for wire-guided torpedoes. Unlike Mk 37, it could guide a torpedo either in bearing-rider mode or in corrected-intercept mode. The latter was not a pure dog-leg, but it placed the torpedo ahead of the target in a position to be steered into it. As in Mk 37, the operator steered the torpedo directly and so could control only 1 torpedo at a time. Because it was used to control a nuclear torpedo, Mk 18 also provided a special display (a counter showing error in run-to-burst) and dial to correct the enabling run set when the torpedo was launched.

Mk 18 could change torpedo course in 2-deg increments, and enabling run in 100-yd increments. Limitations: torpedo speed 15–60 kt, torpedo run 300–35,000 yd, target speed 0–40 kt, own-ship speed 0–40 kt, target range 0–35,000 yd, torpedo depth 0–1400 ft. Like its predecessors, Mk 18 was still an analog computer with special components for particular sets of torpedo ballistics, in this case for torpedoes Mk 14 Mods 3A and 5, Mk 16 Mods 6 and 7, Mk 27 Mod 4, Mk 28 Mods 2 and 3, Mk 37 Mods 0 and 1 (the last with the angle solver modified), Mk 39 Mod 1, Mk 45 Mod 0, and standoff mines Mk 27 Mods 0–3.

By the early 1960s submarines were fitted with angle solver Mk 18 Mod 2, which could handle the later version of the Mk 45 nuclear torpedo. Modernization to handle the Mk 48 torpedo required another change, to angle solver Mk 18 Mod 4.

By this time, too, submarines were commonly using TMA, which was far beyond the capabilities designed into analyzer Mk 7. Hand-plotting techniques seemed less and less attractive as sonars improved and as weapons ranges increased to and beyond 10,000 yd. Several automatic or semiautomatic plotters were developed about 1959, of which Mk 19 survived in this and later submarine FCS installations. Plotter Mk 19 is a DRT modified to perform 1 of several TMA plots called the strip plot. The strip plot is a true navigational plot showing a series of bearings (typically 1/min) from own-ship. If the target submarine is running in a straight line, its course is represented by a straight line on the true navigational plot. A plastic strip for assumed target speed, calibrated in yd/min, is placed across the bearing lines until a best fit is obtained between minute markings on the strip and minute bearing lines. The line drawn along the edge of the speed strip is the target's track; its direction is the target's course; and the distance from its intersection with the last bearing line is the range. Use of the wrong speed strip will yield a fairly accurate course but an inaccurate range (in error by the same percentage as the speed). If the target zig-zags, the wrong speed strip will yield a discontinuous estimated course, and that will eventually show that the wrong speed strip is being used.

Mk 19 receives continuous own-ship course and sonar bearing data, displaying true target bearing as the direction of 2 small arrowheads optically projected onto a sheet of white paper on the plotting surface. Midway between the arrowheads is an optically projected light spot representing own-ship's present position. At 30-sec intervals an internal timer clicks audibly to alert

the operator. The operator then lays a straight edge along the 2 arrowheads and draws a line in the direction of true target bearings. After having drawn 3 or more lines, the operator uses plastic speed strips to determine the target's course. At the ranges and speeds common in the late 1950s, the operator could generally obtain a solution in 5 min. The plot is a record of own-ship's past and present position, target's present course and position, target's range, target's angle on the bow, and CPA.

Mk 19 is still in use, despite the advent of more automated means of TMA, because it gives a manual check on a computer solution that can go badly awry.

Where noted below, modification to fire Mk 48 torpedoes generally involved addition of tone generator Mk 47 Mod 0, control console Mk 66 Mod 1, weapons simulator Mk 22 Mod 0, and plotter Mk 19 Mod 0 or 1 as well as a new angle solver (Mk 18 Mod 4).

Versions (dates, where given, are dates on which nomenclature was assigned or system makeup officially changed; they are not necessarily dates on which physical changes were made):

Mod 1 Installed in the attack teacher Mk 7 at New London.

Mod 2 Installed on board the *Grampus* (SS 523). Modified 1963: position keeper Mk 1 Mod 0 changed to Mod 2; angle solver Mk 11 Mod 0 replaced by Mod 2; torpedo director Mk 37 Mod 1 added. At this time approximate weight was 10,400 lb. This version was similar to Mod 3 but lacked the Type 6 periscope input (via stadimeter) and had to control more tubes. In this ship Mod 2 was replaced by Mod 13. The *Grampus* was the only U.S. World War II-built submarine fitted with the Mk 101 system.

Mod 3 Original FCS of the *Tang* class (SS 563–66, 568); replaced by Mods 13 and 14 and then by Mod 18. This was the main version of the system. Unlike the other versions, Mod 3 required a range converter Mk 3 Mod 0 because the submarine was equipped with a Type 6 periscope (which incorporated a stadimeter and, thus, converted subtended angle automatically to range, given a manual input of target masthead height).

Mod 4 FCS of the SSK 1 (*Barracuda*) -class ASW submarines. Compared to Mod 3, Mod 4 lacked the stadimeter input and controlled fewer tubes. Modified in 1963 analogously to Mod 2. Approximate weight was 5400 lb.

Mod 5 Not assigned.

Mod 6 FCS of the first 2 nuclear submarines, *Nautilus* and *Seawolf*. They were modified to fire Mk 45 torpedoes and then, in December 1965, to fire Mk 48.

Mod 8 This version was modified for Mk 45 and then for Mk 48 torpedoes (December 1965). *Seawolf* (SSN 575) FCS.

Mod 10/16/20 Mod 10 was the original fire control of the *Barbel* class, incorporating torpedo director Mk 37 Mod 0. Modified to control Mk 45 torpedoes (torpedo director and angle solver Mk 11 Mod 4 replaced by angle solver Mk 18 Mod 2), it became Mod 16. This version incorporated plotter Mk 19 Mod 0. Approximate weight was 5500 lb. Modified to control Mk 48 torpedoes, it became Mod 20 (December 1965). Mod 20 is currently installed on board the *Bluefish* (*Barbel* class), which will probably be transferred abroad.

Mod 11 This was the FCS for the large nuclear submarine *Triton*. It was originally fitted to fire Mk 45, and it was ordered modernized to fire Mk 48 in December 1965 (but the ship had long been decommissioned, and she was not modified).

Mod 12 This version was originally fitted to fire Mk 45 and then was modified in December 1965 to control Mk 48 torpedoes.

Mod 13 This version, introduced in 1957, superseded Mods 2 and 3. About 1960 it was fitted to fire Mk 45 torpedoes. Angle solver Mk 18 Mod 0 was replaced by Mod 2 (October 1963). Total weight was about 5200 lb.

Mod 14/18 This was a Mod 3 modified to control wire-guided torpedoes (1959). About 1963 the Mk 18 Mod 2 angle solver was fitted, to control Mk 45 torpedoes (in the *Trigger* the new angle solver replaced a Mk 37 Mod 0 torpedo director, and in the *Gudgeon* it replaced a Mk 18 Mod 0 angle solver). Approximate weight was 6500 lb. This was probably the system initially installed on board the *Gudgeon*. Modified to fire Mk 48 torpedoes (December 1965), it became Mod 18, which survives on board *Tang*-class submarines in Turkish service.

Mod 15/19 Modified October 1963 to control Mk 45 torpedoes, using angle solver Mk 18 Mod 2 instead of Mk 11 Mod 4 and torpedo director Mk 37 Mod 0. One plotter Mk 19 Mod 0 was added. Approximate weight was 6500 lb. Modified to fire Mk 48 torpedoes (December 1965), it became Mod 19, the final *Skate*-class FCS.

Mod 17 *Skipjack* class: Mod 13 modified (December 1965) to control Mk 48 torpedoes.

◆ Mk 105

Mk 105 was a simpler alternative to the Mk 102 fitted to early postwar antisubmarine destroyers, such as the DDEs. It was first tested in 1952, using a QHB scanning sonar. Surviving examples use SQS-4 or its variants. It controlled Hedgehogs, both fixed and trainable, the Weapon Alfa rocket projector, torpedo tube Mk 25 (for non-wire-guided torpedoes), and depth charge racks and throwers. Mk 105 survives on board ships fitted with Hedgehog projectors. In some ships, such as early FRAM I destroyers, it was installed alongside the later Mk 111. In FRAM II destroyers, it is the sole ASW FCS, combined with a special panel (Mk 264) that enables it to fire lightweight torpedoes from Mk 32 tubes.

Mk 105 is built around Librascope's attack director Mk 5, its electromechanical computer. Mk 5 replaced the earlier attack plotter Mk 1 as a basic attack aid. It generates target position data for position keeping (target-motion prediction) and for aided sonar tracking (which allows the sonar operator to detect target turns). The series of target positions provided by the ship's active sonar is automatically analyzed to yield target's course and speed, and incremental values of target bearing and range are transmitted to the sonar for aid-tracking. They are also used internally to project ahead target position (position keeping). If sonar contact is lost or interrupted during tracking, and the sonar tracking mark switches opened, the attack director automatically changes its mode of operation to position keeping and continues to generate the present position of the target and to predict the future position of the target based on the last known course, speed, and position of the target. The attack director thus serves as a position keeper for the ASW system so that attacks can be conducted with intermittent sonar contact or even after contact has been lost. Inputs are received as synchro signals or are entered manually: relative sonar bearing, sonar range, own course, own speed, and sonar range correction (from the range recorder). Constants and spot corrections are entered through hand cranks.

Mk 105 was designed from the beginning to control both trainable and fixed weapons (fixed Hedgehogs and depth charges). It, therefore, generates solutions for both types of attack simultaneously and accepts attack constants for both types of attack. Manual inputs are (i) attack data: target depth and target turn; (ii) constants for fixed attack, parallax plus effective range, dead time plus time of flight, sinking rate; (iii) constants for trainable attacks, parallax, dead time plus time of flight, sinking rate.

Not only does the attack director generate a continuous solution for the stern-dropped DC attack but it also indicates at each instant how far to the right or left of the target advance position the charges will be dropped if own-ship continues on the present course. The depth-charge attack dial shows the lateral attack error in yards.

The attack director solves as readily for a curved-course as for a straight-course attack. If the target is observed going into a

turn during an attack, a target's course spot correction can be entered manually. When such a value is entered, the instrument corrects the input values of target's angle and speed to the ballistics section of the attack director to compensate for the effect of turn on the ballistic outputs.

Mod 0 tracked targets out to 3000 yd (the maximum effective range of World War II-type sonars such as QHB and QCU-2).

Mod 1 added hand cranks for manual inputs for testing (relative sonar bearing, sonar range, own-ship course, and own-ship speed). Target's maximum speed was changed from 20 to 25 kt.

Mod 2 was Mod 1 modified to provide for transmission of relative sonar bearing and horizontal sonar range. It was developed to permit synchro transmission of generated range and bearing to ballistics computers and to provide for increased range. Maximum sonar range was increased from 3000 to 6000 yd. Own-ship's maximum speed was 30 kt, and target's maximum depth was 1200 ft.

Mod 3 was compatible with the new SQS-4 sonar; it could transmit target's course from attack director to sonar repeater scope. That made for the most effective use of target aspect as seen on the repeater scope since aspect could be compared directly with the course of the target as determined by the attack director. That in turn was expected to make for greater accuracy and speed of target-course analysis and early-turn detection.

The associated Mk 1 A/S attack plotter (ASAP) shows the attack situation on a CRT. It is fed by the ship's dead-reckoning analyzer, sonar, and gyrocompass; the CRT shows own-ship's course, the path of each sound beam, and the position of the underwater target when contact is made. Because the target blip persists, the CRT shows a series of such blips in succession, and the target course can be estimated by drawing a line through them. The CRT also shows firing range and forward bearing for a Hedgehog, so that the correct train and firing time can be estimated.

The World War II destroyer escorts not fitted with Mk 105 had only the ASW attack plotters (Mk 1 Mod 2). Presumably, that applies to the 4 ships in the Greek navy and to 1 in the Uruguayan navy, which have never benefited from ASW modernization. Ecuador and Mexico both operate high-speed transports converted from destroyer escorts, probably equipped with ASW attack plotters. The other surviving destroyer escorts have all been modernized: 2 in the Philippines, 1 (and 2 very similar frigates) in Thailand, plus 1 in the Taiwanese navy (and 9 former high-speed transports converted to frigates). They, the PC-class corvettes, the PF 103-class frigates built for export, and the *Auk*-class corvettes in the Taiwanese and Thai navies, are all probably equipped with versions of Mk 105.

Versions (many extinct):

Mod 1 Destroyer-escort (DE 696, 697, 700) version with trainable Hedgehog (Mk 15) and 19-charge depth-charge pattern. It used attack director Mk 5 Mod 0, stabilization computer Mk 59 Mod 2, and attack plotter Mk 1 Mod 6.

Mod 2 Destroyer-escort version (DE 699 was prototype) for 2 fixed Hedgehogs (Mk 10) and a 19-charge pattern. The computer was Mk 23 Mod 4. This was the version on board modernized destroyer escorts.

Mod 3 Destroyer-escort version (DE 532) with 4 fixed Hedgehogs (Mk 11) and a 19-charge pattern (1951). The computer was Mk 59 Mod 2.

Mod 4 Destroyer-escort version (DE 152, 535, 644) with 2 trainable Hedgehogs Mk 15 and a 19-charge pattern, 1951. The computer was Mk 59 Mod 2.

Mod 5 For *Forrest Sherman*-class destroyers, to control 4 heavy torpedo tubes, 2 Hedgehogs Mk 11, and an 11-charge pattern (1953), using attack director Mk 5 Mod 2, computer Mk 59 Mod 7, angle solver Mk 17, and torpedo-course indicator Mk 3 Mod 1. There was no attack plotter, but this version did include plotter Mk 12 Mod 2. Mk 12 was used to smooth submarine-target depth data. An electronic stylus burned a small hole in

the paper to indicate a depth measurement, and the operator placed a horizontal cursor across the estimated average of a series of such holes. A second cursor could be used to estimate depth rate of change. In each case, cursor position and angle were automatically translated to the system computer.

Mod 6 For *Dealey*-class escorts, to control Weapon A (Mk 108) as well as depth charges, using attack director Mk 5 Mod 2 and computers Mk 59 Mod 8 and Mk 68 Mod 0 (for Weapon A). There was no attack plotter, but this system did include plotter Mk 12 (1954). This version was later converted to Mod 33, 37, and 38 (see below).

Mod 7 For DER 142, 244, 318, 333, 316, and 317, to control trainable Hedgehog (Mk 15) and depth charges, using attack director Mk 5 Mod 0 or 1 and computer Mk 59 Mod 8. There was no attack plotter (1954).

Mod 8 For converted *Gearing*-class DDEs, to control Mk 15 trainable Hedgehogs and depth charges, using attack director Mk 5 Mod 3 and computer Mk 59 Mod 8. There was no attack plotter (1954).

Mod 9 For DERs 133, 386, 393, 397, 539, 540, to control trainable Hedgehog (Mk 15) and depth charges, using attack director Mk 5 Mod 2 and computer Mk 59 Mod 8. There was no attack plotter (1954).

Mod 10 For *Sumner*- and *Gearing*-class destroyers and *Smith*-class minelayers (1955), using attack director Mk 5 Mod 3 and computer Mk 59 Mod 6. There was no attack plotter. Mod 10 was also installed on board some modernized *Fletchers*.

Mod 11 Shore-training version (1955), using attack director Mk 5 Mod 1, for the U.S. Naval Academy; there was no stabilization computer, but there was an attack plotter Mk 1 Mod 5 or 6.

Modes 12–13 Shore-training versions (1955), using attack director Mk 5 Mod 3; there was no stabilization computer or attack plotter.

Mod 14 For DDRs 711 and 742 classes (1955), replacing Mod 10; it controlled depth charges and 2 Hedgehogs Mk 10 or 11. The attack director was Mk 5 Mod 3, and there was no stabilization computer or attack plotter.

Mod 15/16 For *Forrest Sherman*-class destroyers (DD 945-series) with SQS-4 sonar; converted to Mod 16 when SQS-23 was installed (1955).

Mod 17 Maintenance-training version (1965).

Mod 18 For ASW destroyers *Carpenter* and *Owens*, equipped with 1 Weapon Alfa; it is a converted Mk 100. This system was removed in 1965 when the ships underwent FRAM conversion.

Mod 19 For ASW destroyers *Epperson* and *Basilone*, equipped with 2 Weapon Alfa; it is a converted Mk 100. This system was removed in 1965 when the ships underwent FRAM conversion.

Mod 20 For later and modernized *Forrest Sherman*-class destroyers, controlling 2 Hedgehog Mk 10 or 11 and 1 stern depth-charge rack; it was used on board ships where the requirement for electrically set torpedoes had been deleted. The system included attack director Mk 5 Mod 3 and computer Mk 59 Mod 7. There was no plotter (1960).

Mod 21 For FRAM II conversions of *Sumner*-class destroyers, using attack director Mk 5 Mod 5, computer Mk 59 Mod 10, and angle solver Mk 17 Mod 2, with torpedo-control panel Mk 264 Mod 1 (with 2 torpedo-course indicators Mk 3 Mod 1) to control 2 Hedgehog Mk 11, 2 torpedo tubes Mk 25, and 2 torpedo tubes Mk 32. Total weight was about 6000 lb (1964). See also Mod 34 below.

Mod 22 For FRAM II conversions of *Sumner*-class destroyers, equipped to fire Mk 37 Mod 1 wire-guided torpedoes; this version was tested on board *Robert K. Huntington* (DD 781) in 1960. It controlled 2 Hedgehogs Mk 11, 1 stern depth-charge

track; 2 torpedo tubes Mk 25 (for Mk 35 Mod 3, Mk 37 Mods 0 and 1 torpedoes), 2 Mk 32 tubes (for Mk 43, 44, and 46 torpedoes), and a DASH torpedo-dropping drone helicopter. The major components were attack director Mk 5 Mod 5, torpedo director Mk 37 Mod 1, angle solver Mk 17 Mod 0, computer Mk 59 Mod 10 or Mk 108 Mod 0, torpedo-course indicator Mk 3 Mod 1, a geographic display plotter (in effect, a PPI), and coordinate converter. Total weight was about 3714 lb (1960). See also Mod 34 below.

Mod 23 For FRAM II destroyers (DD 764 class), to control 1 trainable Hedgehog Mk 15, 2 torpedo tubes Mk 25, and 2 lightweight tubes Mk 32. The major components were an attack director Mk 5 Mod 5, a torpedo director Mk 37 Mod 2, angle solver Mk 17 Mod 2, computer Mk 108 Mod 0, computer Mk 110 Mod 0, coordinate converter Mk 54, and plotter NC-2 (1964). See also Mod 35 below.

Mod 24 Combination Terne/Hedgehog system, tested in DE 1035 and 1036 (1964).

Mod 27 For FRAM II destroyers (DD 805 class), controlling 2 Hedgehogs Mk 11, 2 torpedo tubes Mk 25, and 2 torpedo tubes Mk 32. Major components: attack director Mk 5 Mod 5, torpedo director Mk 37 Mod 2, angle solver Mk 17 Mod 2, computer Mk 108 or Mk 59 Mod 10, torpedo course indicator Mk 3 Mod 7, plotter NC-2, and coordinate converter Mk 54 (1964). See also Mod 37 below.

Mod 28 Maintenance trainer (1965).

Mod 30 For high-endurance coast guard cutters (*Hamilton* class), to control 2 fixed Hedgehogs (Mk 10 or 11) and Mk 32 torpedo tubes. The main components are attack director Mk 5 Mod 3 and control panel Mk 264 Mod 1; as these ships are modernized this system is superseded by Firing Panel Mk 309.

Mod 33 For modernized *Dealey*-class ships, replacing Mod 6, for use with SQS-23 sonar and Mk 32 torpedo tubes. Major components are: attack director Mk 5 Mod 5, computer Mk 68 Mod 0, computer Mk 59 Mod 8, and control panel Mk 264 Mod 1. There is no plotter (1966).

Mod 34 Mod 21 and 22 (FRAM II destroyers) with Mk 37 torpedo capability deleted (1968); the system controls 2 Hedgehogs Mk 11 and 2 Mk 32 tubes. Major components: attack director Mk 5 Mod 5, computer Mk 59 Mod 10 or Mk 108 Mod 0, and control panel Mk 264 Mod 1.

Mod 35 Mod 23 with Mk 37 torpedo capability deleted (1968). Major components: attack director Mk 5 Mod 5, computer Mk 108, computer Mk 110, and control panel Mk 264 Mod 1.

Mod 36 Mod 27 with Mk 37 torpedo capability deleted (1968). Major components: attack director Mk 5 Mod 5, computer Mk 59 Mod 10 or Mk 108 Mod 0, control panel Mk 264 Mod 1.

Mod 37/38 Mod 6 without Weapon Alfa capability, for DEs 1014 and 1021: attack director Mk 5 Mod 3 or 5, computer Mk 59 Mod 8, and control panel Mk 264 Mod 1 (to control Mk 32 tubes). Approximate weight is 1534 lb (1970). Mod 38 is the equivalent for DEs 1015, 1022–30.

◆ Mk 106

This postwar FCS was for older submarines that could not accommodate the full Mk 101. The system was built around the earlier Torpedo-Data Computer (TDC) Mk 4. The TDC itself was introduced before World War II to provide continuous (synchronous) solutions for torpedo gyro angle (lead angle) in terms of target range and bearing so that torpedoes could be fired at any time. In the absence of a TDC, the torpedo gyro angle had to be calculated on a slide rule before firing, the submarine maneuvering to the proper position and bearing to await the target. TDC Mk 4 differed from Mk 3 in adding a receiver section, for target range and bearing from sonar and radar. In both cases, estimated target angle on the bow and estimated target speed were inputs. The receiver section of Mk 4 includes a

sonar-data converter (to correct for parallax due to target motion while the ping makes its round trip, or while passive sound travels from target to sonar, and also to allow for variable sound speed). Other possible inputs are periscope and radar data. Own-ship data are taken from the gyrocompass, the pit log, and the dead-reckoning analyzer.

These data flow into a position-keeper, which projects ahead relative target position (bearing, range, and target angle); the position-keeper also provides the initial estimate of target course. All of these estimates are based on intermittent observations. Given these data, the other main element of the TDC, the angle solver, generates torpedo gyro angles, estimated running times, and track angles (it provides solutions for both the forward and after tubes simultaneously). Own-ship and target dials show calculated gyro and track (target course relative to own-ship) angles. Mk 4 accepts torpedo speed settings of 18–55 kt and values of torpedo run differences from –100 to +150 yd; torpedo spreads can be up to 900 ft forward and aft of the estimated target mid-point position.

The major difference between Mk 106 and the earlier submarine FCS was that it could send gyro angle and enabling-run orders directly to electrically set torpedoes as 400-cycle synchro signals; it could also mechanically set older torpedoes. Mk 106 generates (calculates) target's position as a function of problem time; solves for the impact point of the target and torpedo; calculates torpedo's gyro angle; and sets synchronous gyro-angle functions into the torpedo, together with the synchronous depth and enabling-run functions and the nonsynchronous stratum function. These functions sufficed for free-running torpedoes, but the advent of homing weapons (particularly Mk 37) required more (see Mod 5, below).

The TDC itself is limited in that it maintains an estimate of target position but not of target course and speed (which are only indirectly estimated). In the more elaborate Mk 101, the position keeper was combined with a target analyzer. The target analyzer calculated target speed and course from bearing and range (and own-ship) inputs; target course was displayed in the form of a dial marked to represent the heading of the target (a similar dial showed own-ship heading). This information was fed back into the position-keeper part of the system to improve overall system accuracy. Some versions of Mk 106 had a separate analyzer (Mk 7), but it had no direct electrical connection back into the associated TDC; it acted instead as a manual check on the accuracy of the solution being developed by the TDC. See the description of FCS Mk 101 for analyzer Mk 7. Analyzer Mk 7 Mod 1 was specially designed for Mk 106. Mod 2 (for Mk 106 Mods 2, 3, 4, and 6) is identical to the Mod 0 of Mk 101 except that it operates on 60-cycle synchro inputs.

Mk 106 transmits gyro angle directly to electrically set torpedoes (TDC Mk 4 transmitted it to an indicator in the torpedo room, and it was set mechanically into the torpedo), also transmitting enabling run and ordered (running) depth. Presets for homing torpedoes are entered via a control panel. The system also incorporates a monitor to check whether these automatic settings are in fact transmitted correctly.

The original versions, Mods 2 through 9, differ mainly in the number and arrangement of torpedo tubes they control. Like Mk 101, Mk 106 was designed to track targets at ranges up to 30,000 yd, and it could provide initial gyro angles and enable ranges for torpedo travel up to 15,000 yd. In the later versions, maximum target depth was 1000 ft, and maximum target speed was 40 kt.

Mk 106 was designed to control both mechanically set (torpedoes Mk 14, 16, 18, 23, and 28 and mines [homing torpedoes] Mk 27) and electrically set (torpedoes Mk 14 Mod 5, Mk 16 Mod 5, Mk 18 Mod 4, Mk 27 Mod 4, Mk 28 Mod 2, Mk 35 Mods 2 and 3, and Mk 37 Mod 1, and mine Mk 27 Mod 4) weapons. Mk 37 Mod 1 was wire-guided. Later Mk 106 was modified to accept passive-range data from PUFFS (BQG-4) and to control newer wire-guided torpedoes (Mk 37 and the nuclear Mk 45, ASTOR). This capability was associated with torpedo director Mk 37 or with angle solver Mk 18.

The final versions controlled the Mk 48 torpedo. They were all equipped with Mk 66 torpedo-control consoles, which set the torpedoes and controlled them after launch, supplementing the existing FCSs. Mod 0 weighs about 750 lb; Mod 1 weighs about 365. Mod 1 at least suffices to monitor, display, control, and command-guide 2 Mk 48 Mod 0 torpedoes in their tubes and in the water. It is generally associated with a Mk 47 tone generator. Mods 0 and 1 are used with FCSs Mk 101, 106, 112, and 113; Mod 2 is used only with Mk 113 Mod 10 and later systems. It is designed to work with digital FCSs. The earlier wire-guided torpedoes, particularly Mk 37 Mod 1, used a relay transmitter and an amplifier to produce the necessary DC signals. Presumably, the use of a tone generator indicates that Mk 48 uses digital rather than analog steering signals. These versions all included plotter Mk 19 (see FCS Mk 101, above).

All of the original versions were built around TDC Mk 4 Mod 24, which incorporated synchro transmitters to both the torpedoes and the position-keeper section. Existing Mod 24s were ordered converted to Mod 28 in 1964, a change that well illustrates the very tight limits imposed by electromechanical computers. The angle solver in Mk 106 (and the similar 1 in Mk 101) were designed to deal with relatively fast torpedoes (the speed limits were 18 and 55 kt) and relatively short runs (479 sec, corresponding to 4790–14,600 yd for these speeds).

When the Mk 37 torpedo was adopted, the existing ballistic cams and plugs delivered for Mk 35 Mod 3 (seawater battery) were initially used, but the TDC had a torpedo-run limit of 7000 yd (Mk 37 actually ran as much as 23,000 yd at 17 kt [2435 sec] and 10,000 yd at 25 kt [720 sec]). The TDC had a minimum speed limit of 18 kt, corresponding to a maximum range of 4600 yd. The use of an improper speed made for a calculated run 6% short of the target-impact point. As a makeshift, operators used proportioned speed factors, solving a scaled problem on the TDC (increasing torpedo's speed, and, in proportion, increasing target's speed just before firing to maintain accurate position keeping for the greatest possible time). TDCs were modified about 1959 to allow for a run of about 8000 yd, but that was still hardly enough. Only in 1959 was a solution proposed: a switch (actually an electromechanical shifter on the target's speed shaft connecting the position keeper to the angle solver) that could convert the angle solver to lower-speed operation by scaling down target's and torpedo's speed inputs by a factor of 1.8 (the problem was geometrically similar). In this case the maximum allowable torpedo run was scaled by 1.8 to 862.38 sec, but target's maximum speed (40 kt in the unmodified TDC) was scaled down to 22.2 kt, and the torpedo's speed range was scaled down to 10–30.55 kt. The increased allowable running time allowed for ranges of 8253 yd at 17 kt and 12,137 yd rather than 6743 at 25 kt. This modification was clearly less than completely satisfactory, but its acceptance suggests just how difficult anything more complete would have been. Even this change took 3 days to install.

Versions:

Mod 1 Evaluation model.

Mod 2 For fleet submarines converted to radar pickets. The 6 forward tubes were modified to accept electrical setting commands from the FCS. Total weight was about 4900 lb.

Mod 3 Special version for *Grouper* (SSK 214), to test the wire-guided Mk 35 Mod 1 torpedo. It included analyzer Mk 7 Mod 1 and weighed about 6100 lb. Two forward and 4 aft tubes were modified for electrical setting.

Mod 4 Guppy IIA conversions. Some were later converted to Mod 14. Analyzer Mk 7 Mod 2 or 3. All tubes were modified for electrical setting.

Mod 5 Guppy I, Guppy II, and fleet snorkel submarines (austere modernization), without any analyzer; TDC Mk 4 Mod 26. Only 2 forward and 2 aft tubes were modified for electrical setting. Mod 5 became obsolete with the introduction of torpedoes, such as Mk 35 and Mk 37, that required more complex settings.

About 1958 a new control panel (Mk 155) was introduced in the torpedo rooms to set 5 preset torpedo functions: homing mode, exploder, speed, horizontal search, and vertical search. One panel in each torpedo room. The existing control unit Mk 65-0 provided a sixth function, stratum. Some Mod 5s were later converted to Mod 14. Mod 5 is probably the version in a Peruvian submarine (ex-SS 406).

Mod 6 SSK (ASW conversions of World War II-built fleet submarines). TDC Mk 4 Mod 24 was superseded by Mod 26 and then by Mod 34 (1964). Torpedo director Mk 37 was added, then replaced by angle solver Mk 18. This version was ultimately modified to control Mk 48 torpedoes (angle solver Mk 18 Mod 4, console Mk 66 Mod 1, tone generator Mk 47 Mod 0, plotter Mk 19 Mod 1). Four forward and 4 after tubes were modified for electrical setting.

Mod 7 Tunny (SSG 282) only; this version lacked the analyzer. Only the 4 forward tubes were modified. Total weight was about 4600 lb.

Mod 8 Canceled version planned for a minelayer conversion of war-built submarines.

Mod 9 Attack teacher at New London.

Mod 10/18 For *Sailfish*-class submarine radar pickets (TDC Mk 4 Mod 10). Mod 18 is modified for wire-guided torpedo control (TDC Mk 4 Mod 37 vice Mod 28, angle solver Mk 18 Mod 3, plotter Mk 19 Mod 0); total weight approximately 4500 lb.

Mod 11 For the *Darter*, which was later fitted with Mk 101. Modified 1965 to control Mk 48 torpedoes (TDC Mk 4 Mod 39 replaced by Mod 47).

Mod 12 Wire-guided torpedo-control version, with TDC Mk 4 Mod 37 and angle solver Mk 18 Mod 4. Modified 1965 to control Mk 48 torpedoes (TDC Mod 45, angle solver Mod 5).

Mod 13 Modified 1964 to control wire-guided torpedoes (TDC Mk 4 Mod 37 vice Mod 28, angle solver Mk 18 Mod 3, plotter Mk 19 Mod 0). Total weight 5800 lb. Originated 1957. This version was redesignated Mod 17 when modified to control Mk 48 torpedoes (but see also the separate Mod 17 entry).

Mod 14/15 Modified Mod 4 and Mod 5 (1962) for wire-guided torpedoes: TDC Mk 4 Mod 36, angle solver Mk 18 Mod 3, plotter Mk 19 Mod 0. Total weight was approximately 6500 lb. Mod 14 modified to control Mk 48 torpedoes was designated Mod 18 (but see Mod 10/18 above). Mod 14 is the version in 2 Brazilian submarines (ex-SS 351 and 425) and in 2 Turkish submarines (ex-SS 344 and 346).

Mod 16 Modified Mod 5 (1964) with TDC Mk 4 Mod 40, torpedo director Mk 37 Mod 1; total weight approximately 6200 lb. This is the version on board 2 Taiwanese (ex-SS 426 and 478) and 1 Venezuelan (ex-SS 525) submarines.

Mod 17 Modified Mod 4 (1963) with TDC Mk 4 Mod 42 in place of Mod 28, and with torpedo director Mk 37 Mod 1. Total weight approximately 8500 lb. This is the version on board 1 Greek (ex-SS 365) and 5 Turkish (ex-SS 394, 402, 410, 418, and 421) submarines.

Mod 19 Modified Mod 4 or Mod 15 controlling wire-guided torpedoes (TDC Mk 4 Mod 37, angle solver Mk 18 Mod 3, plotter Mk 19 Mod 0) (1965).

Mod 20 Modified Mod 14 or Mod 16 controlling Mk 48 torpedoes (TDC Mk 4 Mod 44 or 46 vice 36 or 38, angle solver Mk 18 Mod 5 vice Mod 3). This is the version on board 1 Greek submarine (ex-SS 487).

Mod 21 Mod 18 modified to control Mk 48 torpedoes (1965): TDC Mk 4 Mod 45, angle solver Mk 18 Mod 5.

Mod 22 Mod 14 (originally Mod 14 interim) modified to control wire-guided torpedoes (TDC Mk 4 Mod 36, angle solver Mk 18 Mod 3, plotter Mk 19 Mod 0, range conversion scale Mk 1 Mod

0, 2 sub attack-course finders Mk 1 Mod 3). The last are circular slide rules used to determine whether or not a desirable firing position can be reached, add to aid in reaching that position; a pointer disc represents periscope angle. Total weight is about 6100 lb.

◆ Mk 111

This solid-state digital ASROC and torpedo FCS (using the Mk 38 attack console) was widely installed in the late 1950s and early 1960s, e.g., on board FRAM destroyers. The early digital system was considerably less reliable than the analog computer of the somewhat later Mk 114, which superseded it during the 1960s. Mk 111 could control ASROC but was not rigged to control existing Hedgehogs. Ships carrying Hedgehog, therefore, retained versions of the earlier Mk 105 described above.

Mk 111 receives target position data at discrete intervals, plus continuous inputs of own-ship course, and various manual inputs such as parallax, target depth, and curvature of target track. It computes target position, true wind, aim point, launcher train and elevation orders, time of flight, velocity at motor separation, time to airframe separation, and true polar coordinates of the weapon's water-entry point. The group includes an analog stabilizer.

Physically, Mk 111 is similar to the Mk 114 described below, with a large CRT alongside its ballistic computer; in this case the dual console is Attack Console Mk 38. The digital computer can handle ranges out to 32,000 yd, target depth to 1400 ft, and target speed to 35 kt. It can engage only 1 target at a time. The system (as opposed to computer) range limit is 35,000 yd. These are 1959 figures, but they are unlikely to have improved since. Total system weight is 2815 lb, including the 2255-lb attack console.

Mk 111 initially used a magnetic drum memory, but in 1960 BuOrd introduced new technology in the form of a 20-kbit magnetic core memory (12 kbits of which were initially used). Although this unit was originally described as insurance against the possibility of problems with the rotating drum, later it became standard. Even with its reliability problems, Mk 111 enjoyed an advantage over the analog Mk 114 because it could be reprogrammed (rather than physically changed) to accommodate the Mk 46 Mod 1 torpedo (about 1966). New operational program tapes (ORDALT 5719) provided ballistic data for the new torpedo as well as the earlier Mk 44 and the Mk 17 nuclear depth charge. However, the firing panel had to be changed physically, and the opportunity was taken to make human-factors engineering improvements to follow practice in the slightly later Mk 114 system.

Only the first 53 ASROC installations were Mk 111s. This system was planned for the *Leahy*, *Belknap*, *Bronstein*, and *Garcia* classes, but all of them were completed with Mk 114 instead. The initial (FY59 and FY60) FRAM I destroyers retained their Hedgehogs, which were controlled by Mk 105 FCSs retained alongside Mk 111.

Versions:

There was initially some confusion: Mod 1 was initially described as Mod 0 and was initially applied to the FRAM I destroyers. The designations given below are the current ones.

Mod 1 The prototype, on board the *Norfolk*, using SQS-23 sonar and Mk 56 GFCS, with the Mk 16 Mod 2 ASROC launching group and Mod 5 torpedo tubes.

Mod 2 On *Adams*-class missile destroyers (DDGs 2-15), using SQS-23 (now SQQ-23) sonar and Mk 68 GFCS, with the Mod 1 ASROC launching group and Mod 5 torpedo tubes. These ships have FCS Switchboard Mk 32 Mods 11-13 and 15. Originally, Mk 111 was planned for the entire class, but DDGs 16-24 were completed with Mk 114 instead. This designation was originally applied to at least 2 of the *Mahan* class (DLGs 11 and 15, later redesignated DDGs 42 and 46).

Mod 3 Designation canceled in 1969: it would have applied to Typhon missile cruisers (DLGN) and would have been the only version using SQS-26 sonar.

Mod 4 On *Albany*-class (CGs 10–12) missile cruisers, using SQS-23 sonar and Mk 56 GFCS, with the Mod 2 ASROC launching group and Mod 5 torpedo tubes. Mod 4 is now extinct. Unlike the *Norfolk*, these ships had Mk 56 added as an afterthought, and it was probably not integrated with Mk 111 (they were probably designed to use their missile-tracking radars to spot the fall of ASROCs).

Mod 5 The *Long Beach* (CGN 9) system, parallel to Mod 4. Unlike the *Albanys*, the *Long Beach* class had an early version of NTDS. This version incorporates FCS Switchboard Mk 32 Mod 32.

Mod 6 The *Bainbridge* (CGN 25) version, using SQS-23 (later SQQ-23) sonar and Mk 63 GFCS, with the MK 3 ASROC launching group and Mk 5 torpedo tubes. As in the cruisers, the GFCS was an afterthought, and the missile tracking radars are presumably used to spot the fall of ASROCs. This version has FCS switchboard Mk 32 Mod 14.

Mod 7 The FRAM I destroyer version, using SQS-23 sonar and Mk 37 FCS. Mk 111 survives on board the former DDs 785, 786, 788, 790 (with Mk 105 Mod 10), 826, 841 (with Mk 105), 853, 887, and 890 (with Mk 105). This version controls the Mods 1–3 ASROC launching groups and Mk 5 torpedo tubes.

Mod 8 The *Mahan* (DDG 37)-class version, using SQ-23 (now SQQ-23) sonar and Mk 68 FCS (as in the *Adams* class), controlling the Mod 1 ASROC launching group and Mod 5 and 6 torpedo tubes. This version incorporates FCS switchboard Mk 32 Mods 5 and 16.

Mod 9 Replacement for Mod 4 on board the missile cruiser *Albany*, whose SQS-23 sonar was upgraded to -23B. The *Albany* was fitted with NTDS. The original version of the ASROC launcher and the torpedo tubes were retained.

◆ Mk 113

The Librascope Mk 113 FCS was designed to operate with the BQQ-2 sonar, but versions for strategic submarines operate with their simpler sonars. Mk 113 incorporated the first submarine digital fire-control computer, Mk 130, with Mk 129 for leveling and for SUBROC missile calculations. Although the system was digital, it could control analog-set weapons, particularly SUBROC. Later versions of Mk 113 were also the first use of CRT displays in a submarine, in analyzer console Mk 78. This interactive display was intended to increase the number of targets the system could handle simultaneously. Work on a Mk 48 torpedo capability began in 1964 (improvements to Mods 2 and 5).

The main attack-center element of the Mk 113 system is an attack console consisting of an attack-control console (Mk 50), an attack director (Mk 75), and an analyzer console (Mk 51, later Mk 78). Mods 9 and 10 also have a signal-data converter, and Mod 9 has a digital interconnection box. Versions equipped to fire Mk 48 torpedoes also have a torpedo-control console (Mk 66), and a tone-signal generator (Mk 47).

Architecturally, Mk 113 was similar to Mk 101; the analog analyzer console Mk 51 was equivalent to the analyzer of the earlier system. Each console could track 1 target. The attack-control console was broadly equivalent to the position-keeper. The attack director was analogous to the angle solver of the earlier system. Unlike the earlier system, Mk 51 was designed primarily for passive operation. Its 3-point solution was based on 3 target bearings, continuously input own-ship course and speed, and 1 input of range, target speed, or target course. Alternatively, it could accept a series of discrete range/bearing combinations. In either case, like Mk 7, Mk 51 required an initial assumption that the target was following a straight or curved course.

The analog-computer attack director functions as a target position-keeper, a torpedo-order computer, and a wire-guided torpedo position-keeper and controller. It can accept data from either the analyzer or any of the sonars, and also from the ship's

navigation system. As a target position-keeper, the Mk 75 computes and displays present bearing and range, as well as bearing and range rates, using the most recent values of automatically or manually inserted bearing, range, course, and speed. As a torpedo-order generator, the angle-solver section computes gyro angle and enabling run for the electrically set torpedoes. Run depth is set manually. The angle solver also provides information to operators of wire-guided torpedoes and dead reckons the torpedo after firing. The attack director also stores the ballistics for the arsenal of preset and wire-guided torpedoes fired by the system.

Mk 113 was introduced as fully passive fire control (TMA), and therefore plotting became more important. The conning officer generally watched the developing plot but had a poor view of the analyzer console and the attack director (attack console Mk 50 was on the left, next to the analyzer console, with the attack director on the right). However, in effect the conning officer was the means of integrating the electronic and paper portions of the overall system. That integration was considered so important that the Mod 5 version (for strategic submarines) was physically rearranged (1967, ORDALT 6538) to improve the conning officer's view of the analyzer and the attack director (the attack director was repositioned between the analyzer console [on the left] and the Mk 66 control console used for Mk 48 torpedoes).

Like their predecessors, the Mk 113 consoles displayed their data on a series of dials (showing relative target and own-ship headings) and digital readouts. The heading dials were originally devised largely as a visual check of the likely accuracy of generated fire-control solutions. However, the arrangement of data suitable for the fire-control operations of the 1950s was ill-suited to the elaborate TMA of the next decade. The system did indeed collect the required data, but they were spread over numerous dials and readouts. The solution was what amounted to a "glass cockpit," in which a CRT (analyzer Mk 78 in Mk 113 Mod 9) could switch from display to display, to quickly provide a TMA team with what it needed. The same CRT could display several alternative solutions for interactive analysis.

The CRT was necessarily associated with a digital computer. TMA was particularly important for ballistic-missile submarines, and the CRT-equipped analyzer was devised for them. Its digital computer was the geoballistic computer of the Poseidon missiles the submarines carried.

In this version, the attack console contains 4 independent sections: (i) Plotter section with a CRT displaying the geometry of targets, own-ship, and either a consort vessel or wire-guided torpedoes; it also controls nonsynchronous presets. (ii) Consort tracker, which contains the displays and controls used to insert data from a consort vessel into the Poseidon computer for target analysis. (iii) Firing panel section, which displays torpedo and tube conditions and controls tube firing; it includes angular and linear spread pattern controls. (iv) Own-ship section, which receives own-ship course and speed information to convert relative to true bearings. The system has an inherent ability to accept data from a consort vessel (such as an escorting submarine) that is tracking the same target.

TMA provides location data at discrete intervals, and a position-keeper projects target position forward based on TMA estimates. These estimates are periodically compared with new TMA estimates. The analyzer operator selects a sensor system (e.g., passive sonar) and develops a target range solution, using the digital ballistic computer in the analyzer.

Analyzer data are fed to the attack-control console. It provides a geographic display (geosit) showing target, own-ship, and the dead-reckoned torpedo position(s), the last based on commands issued to the torpedoes by the torpedo director, which actually controls the wire-guided torpedo or torpedoes. The attack-control console is the decision position of the system. Torpedo-tube firing sequence and certain presets are selected at this section. The firing panel assigns the torpedo director to a tube and sets the angular or linear spread of the torpedoes. The attack-control console is also used for missile firing. Mod 2 adds Mk

48 torpedo ballistics to Mod 0 (for Mk 113 Mod 6); similarly Mod 3 adds them to Mod 1 (for Mk 113 Mod 7). Mod 4 (Mk 113 Mod 8 FCS, 1970) could keep track of 2 targets and could also be connected to a digital computer for sound-path computations. Mod 5 is a modified Mod 3 (1981) using a corrosion-resistant cooling system, for Mk 113 Mods 9 and 11, on board ballistic-missile submarines. It can be used to control Mk 48 Mods 3 and 4 torpedoes.

The attack directors are fed with own-ship and target data; they track the target and any wire-guided torpedo fired at it. These directors compute torpedo ballistics and develop control orders; they also supply data to the leveling computer (Mk 129) for SUBROC ballistic calculations. The attack-control console is the system tactical display and torpedo-room status panel.

Each torpedo-control console is assigned to a torpedo tube. Its controls (a) select 1 of 4 groups of preset tactics; (b) individually preset the trajectory mode, anti-self-homing (ASH), pre-enable speed, search speed, search mode, acoustic mode, doppler enable, ping interval, pitch angle, search depth, floor setting, ceiling setting or operational depth setting, and target mode parameters; (c) command readback of functions set into the torpedo; (d) select 1 of the 2 function memories in the console and the tone-signal generator; (e) select the most desirable laminar distance for the torpedo; (f) command changes after launch to search depth, pitch angle, pre-enable speed, search speed, acoustic mode, search mode, doppler enable, and keylock parameters; (g) check torpedo acceptance of presets; and (h) monitor continuity of guide wire after launch. All torpedo presets except gyro angle are set at this console (gyro angle is set by the attack director and monitored by the torpedo-control console). Run-to-enable is set at the director and received at the torpedo-control console for setting into the torpedo. The console has 2 memories, so it can preset 2 torpedoes.

Versions (even numbers for attack submarines, odd for strategic):

Mod 1 could track 4 targets and engage 2 simultaneously (using 2 attack directors Mk 75), 3 analyzer consoles Mk 51 Mod 0 and 1 Mk 51 Mod 1. This version also employed a leveling computer (Mk 129) for SUBROC, 1 attack console Mk 50 Mod 0, and 1 Mk 19 plotter. This was the version installed on board *Thresher*; total weight was about 10,300 lb.

Mod 2 was the production version for attack submarines (*Sturgeon* and *Permit* classes plus *Narwhal*). Principal components: 2 analyzer consoles Mk 51 Mod 0, 2 attack directors Mk 75 Mod 0, 1 attack-control console Mk 50 Mod 0, 1 digital computer Mk 130, 1 leveling computer Mk 129, and 2 plotters (1 prior to SSN 612) Mk 19. This version was limited to tracking 2 targets at a time. Total weight was about 8500 lb.

Mod 3 (not used) was limited to a single target. It was similar to Mod 2 but had 1 analyzer console Mk 51 instead of 2. Otherwise it was similar to Mod 2.

Mod 4 (not used) could track 2 targets at a time but engage 1 (because it had only a single attack director Mk 75). It was otherwise similar to Mod 2.

Mod 5 (SSBN 616 and 640 classes) was limited to a single attack director. It was designed to control torpedoes (Mks 14, 16, 27, 37, and 45), with space and weight reserved for SUBROC capability. This version used the submarine's missile fire-control computer (DGBC) for TMA. The Poseidon system required a sufficiently powerful computer, and the advantage of relying on a general-purpose digital machine was that it could be reprogrammed as TMA techniques changed. In this version the analyzer console monitored data going in and out of DGBC, selected which sonar was to supply data, and displayed measured range and bearings from that sonar. The analyzer controlled the mode of target analysis performed, i.e., bearings-only, range and bearings, constraints, etc. It also displayed the computed DGBC outputs of target bearing, range, course, and speed.

Principal components: 1 analyzer console Mk 51 Mod 2, 1

attack director Mk 75 Mod 1, 1 attack-control console Mk 50 Mod 1, 1 plotter Mk 19 Mod 1. Total weight about 4000 lb (1965).

Mod 6 is a Mod 2 altered in the submarine. It adds Mk 48 torpedo-control capability, using 2 torpedo-control consoles Mk 66-2 (early applications of MSI/LSI technology to submarines) and 2 tone-signal generators Mk 47 (1 per torpedo fired, 1 torpedo to a side). Mk 66 presets the torpedo; the tone generator provides guidance signals. The attack directors in this version are 2 Mk 75 Mod 2, each a Mod 0 with Mk 48 ballistics added. Mod 8 is a newly manufactured equivalent, for later *Sturgeon*-class submarines. Main components: 2 analyzer consoles Mk 51 Mod 3, 1 attack console Mk 50 Mod 4, attack director Mk 74 Mod 4 (also used in Mod 10).

Mod 7 is a converted Mod 5 (ORDALT 6538). Attack director Mk 75 Mod 3 replaces Mod 1, adding Mk 48 torpedo ballistics to the existing system. Control console Mk 66 Mod 0 (which can supply instructions to 1 or 2 Mk 48 torpedoes) and 1 tone generator Mk 47 are added.

Mod 9, for strategic submarines, was the first digital-display submarine FCS. It is a converted Mod 7 (with ORDALT 6857). Analyzer console Mk 78, with its 16-in circular CRT, replaces the Mk 51 target-motion analyzer of earlier versions. Mk 78 conducts and displays TMA calculations using synthetic video rather than dials. The ASW programs are executed by the main Poseidon geoballistic computer (Mk 88). The Mk 78 console contains enough digital readouts to permit operation (at reduced capability) in the event the CRT fails. The console also contains a 1024-word (24-bit word) memory unit to refresh the cursive CRT display. This FCS could control SUBROC missiles. It used attack director Mk 75 Mod 6, a modified Mod 3, which could compute and transmit weapons orders for Mk 48 Mod 3 and 4 torpedoes, and which supplies data to attack-control console Mk 50 Mod 5. Principal components: attack-control console Mk 50 Mod 3, attack director Mk 75 Mod 3, torpedo-control console Mk 66 Mod 0, tone-signal generator Mk 47 Mod 0, and plotter Mk 19 Mod 6, 7, or 8. Mod 9 was the submarine equivalent of the "glass cockpit" for aircraft, and its appearance, about 1967 (in connection with the Poseidon refits of existing strategic submarines), had considerable impact. Experience with it was the basis for the decision to go ahead with a digital attack center in the *Los Angeles* class, primarily to make better use of the only passive attack technique usable at long range, TMA.

Mod 10, for attack submarines, is an intermediate step toward the full digital Mk 117. It might almost be described as Mk 117 plus an analog element dating back to Mk 113; it lacks the direct digital interface to the digital sonar characteristic of Mk 117. Mod 10 employs 2 Mk 81 consoles (see Mk 117 below for details) but combines them with a series of older-type consoles: 2 Mk 75 position-keepers flanking a Mk 50 for weapons control. In Mk 117, all 3 are replaced by a single Mk 81. The analog consoles calculate deflection angle and pass it to the analog weapons; the 2 Mk 81 are used for TMA based on bearing-rate data passed from the sonar. Digital data are converted to analog by a system data converter Mk 73. In a Mk 117, the digital-to-analog conversion occurs between the analog weapons and the 3 Mk 81 (it is a weapons data converter). Mod 10 can track multiple targets, storing the resulting data for analysis. As in Mk 117, operators can interact with the system in real time during TMA. The computer memory allows recall of earlier target data. A sonar performance-prediction display makes for better passive range and depth estimates. There are also digital training and diagnostic aids. For the last 2 *Sturgeon*-class submarines (SSN 686-87), Mk 113 Mod 10 controls Mk 14 and Mk 37 torpedoes. For all units, it controls Mk 48 torpedoes and SUBROC and Harpoon missiles. In the last 2 *Sturgeons*, this system was installed with a single-frame UYK-7 (the *Los Angeles* class have a dual-frame UYK-7). These 2 ships also have 3 Mk 81 Mod 0 consoles (as in Mk 117, see that entry for a description). The *Los Angeles* version has 2 Mk 81. Both ver-

sions have 2 attack directors Mk 75 Mod 5 to convert analog signals and events to digital form for the digital displays, plus the usual pair of Mk 47 tone generators for Mk 48 torpedoes and Mk 66 torpedo-control consoles. This system (and its successor, Mk 117) was powerfully influenced by NTDS and used NTDS symbology in their digital displays.

Mod 11 is a modified *Mod 9* for ballistic-missile submarines. Like *Mod 9*, it uses attack director Mk 75 Mod 6.

Mod 12 is fitted for Mk 48 TELCOM guidance and incorporates 2 Mk 81 CRT consoles (see Mk 117 entry) and a Mk 87 signal data converter. *Mod 12* was developed for use with BQS-13 under a shipboard-requirements improvement program (SHRIMP) for 31 SSN 594/637-class submarines. The remaining submarines were fitted instead with *Mod 11*. Ultimately these ships were all fitted with Mk 117.

Libroscope is currently supplying new sections to Mk 78 consoles of *Mod 9* systems, including UYK-44 computers and new CRTs. These are presumably equivalent to the *Mod 12* described above. *Mod 9* was significant because it introduced CRTs into U.S. submarine FCSs. With the advent of SUBROC, submarines had to conduct TMA at much greater ranges, using their new spherical bow sonars. Much of the relevant sonar data was fed into the FCS, but it appeared on a variety of dials and could be summarized only on a plot. The digital computer within the system was already keeping track of the tactical situation. Given a more flexible display, that picture could be made more immediately available, for much more efficient plotting. This facility was particularly important for strategic submarines, which tended to depend almost entirely on their passive sensors (and which were the first U.S. submarines to receive towed arrays).

Virtually all surviving examples are on board strategic submarines. Attack submarines had their Mk 113s replaced by Mk 117s, presumably at the same time they were fitted with central computer complexes and BQQ-5 digitally steered sonars.

◆ Mk 114

This analog solid-state ASROC/torpedo FCS replaced the digital Mk 111. Mk 114 is now widely used on board U.S. frigates and cruisers, and also by navies that obtained destroyers and frigates from the United States.

The main unit is the Mk 53 attack console, located in underwater battery (UB) plot, containing the analog computer and the operating controls. It receives sonar data directly and is connected to a stabilization computer (Mk 134). It communicates with ASROC via the launcher captain's control panel (Mk 199).

An additional unit, position-keeping computer Mk 143, would have controlled surface-launched wire-guided torpedoes, which were to have been carried by many U.S. ships. This computer probably has been fitted only on board Spanish *Baleares*-class frigates, which incorporate fixed torpedo tubes in their transoms.

The attack console (Mk 53) consists of an attack plotter and a ballistic computer (Mk 134). The plotter consists of 2 dial units and the plotter proper (a 20 × 20-in CRT). The plotter screen can represent 4 × 4, 10 × 10, or 20 × 20 kyd; it displays own-ship and target positions, a weapon in flight, and a water-entry point. The screen is refreshed on each sonar sweep; because the blips are persistent, it shows (in effect) target and own-ship courses. The operator can align the cursor with the target images to read off target course and can adjust cursor length to measure target speed. This type of manual analysis was considered more accurate than computer analysis because it entailed relatively long time averages; contemporary computer solutions were unstable, and capacity was not sufficient to provide filtering. Readouts from the CRT are passed automatically to the associated ballistic computer.

Once Mk 114 has solved the relative-motion problem (i.e., is predicting submarine position), it provides rate-aided target-tracking data (position-keeping) back to the associated sonar,

providing a check on the accuracy of the solution. The predicted target position appears on the sonar PPI, and the sonar operator can use manual controls to transmit corrections back to the FCS. Without rate-aided tracking, the sonar operator would have to transmit each detection back to the Mk 114; the operator would be unable to examine other sonar contacts. However, if the rate-aided track is accurate, the operator need not continue to feed target positions back on a sweep-by-sweep basis but can investigate other contacts, in what amounts to TWS operation.

Critical attack information is set on a series of dials above the big CRT: this section also receives information automatically from the ship's own sensors (pit log, anemometers, gyro). In addition, the upper unit displays some sonar data, which can help an ASW officer decide on attack tactics.

The ballistic computer is alongside the CRT section, to the right. It includes a weapons-mode selection panel, a torpedo preset panel, and the firing panel. Dials also show attack quantities, ballistic data, and weapons-control information generated by the computer. The panel also displays ASROC weapon status.

The ballistic computer positions the launcher and sets the missiles and the torpedoes they carry. The torpedo presets are not computed data; they are manually set by the operator. They are, however, sent along the same data path as the ballistic computer outputs.

The stabilization computer translates sonar data from the rolling and pitching plane of the sonar to the horizontal plane in which the ballistic computer calculates.

In action, the plotter and the ballistic computer are separately manned, the ASW officer standing behind both operators. The ASW officer estimates target depth, usually selecting best submarine depth to avoid detection; depth has little effect on the overall solution.

Versions:

Mod 0 Early *C. F. Adams*-class missile destroyers (DDG 2–15).

Mod 1 *C. F. Adams* class (DDG 16–24) and *Leahy* class (CG 16–24), for use with a 400-cycle SQS-23 sonar, controlling ASROC and over-the-side Mk 44 and Mk 46 torpedoes. This version uses the Mk 53 *Mod 0* attack console. Total weight is approximately 2600 lb.

Mod 2 Equivalent to *Mod 1*, for FRAM I converted destroyers. It could control the DASH drone as well as ASROC and torpedoes. Total weight was approximately 2500 lb.

Mod 3 FRAM I destroyers DD 825 and 827 (former special ASW destroyers, DDE). It could control the DASH drone as well as ASROC and torpedoes. Approximate weight was 2900 lb.

Mod 4 Version for FY64 FRAM I destroyers except for DD 825 and 827, controlling DASH, ASROC, and torpedoes. Approximate weight was 2700 lb.

Mod 5 *Mitscher* class converted to missile ships, with SQS-23 sonar. It could control ASROC, lightweight torpedoes (Mk 44 and 46), and heavy torpedoes (Mk 37 *Mod 0* and 1 as well as EX-10, which became Mk 48). Provision for Mk 48 required an FCS ORDALT, which was never carried out. It incorporated computer Mk 143 as well as Mk 134. Approximate weight was 3900 lb.

Mod 6 *Mitscher* class converted to missile ships, with SQS-26 sonar. It controlled the same weapons as *Mod 5* but had 2 computers Mk 134 (plus 1 Mk 143). Approximate weight, 4050 lb.

Mod 7 For the *Bronstein* class (FF 1037 and 1038), which have SQS-26 sonars. This version controls ASROC, DASH, and lightweight torpedoes; it has 2 Mk 134 *Mod 0* and 1 Mk 134 *Mod 1* computers. Approximate weight, 3300 lb.

Mod 8 For *Garcia*-class escorts (FF 1040–45) and the experimental escort *Glover*, with 2 Mk 134 *Mod 0* and 1 Mk 143 *Mod 0* computers, controlling ASROC, DASH, lightweight torpe-

does, and torpedoes Mk 37 Mod 0 and 1 (these ships were designed with torpedo tubes in their transoms). Approximate weight, 4300 lb.

Mod 9 For *Belknap* class (CG 26 and 27) with SQS-26 sonar, to control ASROC, lightweight torpedoes, heavy torpedoes Mk 37 Mods 0 and 1, and DASH. It employs 2 Mk 134 Mod 0 and 1 Mk 143 Mod 0 computers. Approximate weight, 4600 lb. Attack console Mk 53 Mod 1, used in this system and in Mk 114 Mod 12, differs from Mod 0 in that it has a new firing panel that permits firing ASROC from a Terrier launcher (Mk 10 system). It weighs approximately 2150 lb.

Mod 10 For *Brooke* (FFG 1-3)-class escorts, with SQS-26 sonar, to control ASROC, lightweight torpedoes, heavy torpedoes Mk 37 Mod 0 and 1, and DASH, with 2 computers Mk 134 Mod 0 and 1 Mk 143 Mod 0. Approximate weight, 4300 lb.

Mod 11 For *Garcia*-class escorts (FF 1047-51), with SQS-26 sonar, using computer Mk 143 Mod 0 to control ASROC, DASH, lightweight torpedoes, and heavy torpedoes Mk 37 Mods 0 and 1; approximate weight, 4000 lb.

Mod 12 For *Belknap* class (CG 28-34) and *Truxtun* (CGN 35), with SQS-26 sonar, using computer Mk 143 (no Mk 134s) and attack console Mk 53 Mod 1 (also see Mod 9) to control ASROC, DASH, lightweight torpedoes, and heavy torpedoes Mk 37 Mods 0 and 1. Approximate weight is 4200 lb.

Mod 13 For *Brooke* class (FFG 4-6) with SQS-26 sonar, using computer Mk 143 Mod 0 (no Mk 134s), to control ASROC, DASH, lightweight torpedoes, and heavy torpedoes Mk 37 Mod 0 and 1. Approximate weight is 4000 lb.

Mod 14 For *Knox*-class escorts (FF 1052-61) with SQS-26 sonar and computer Mk 143 Mod 0 (no Mk 134s), controlling ASROC, DASH, lightweight torpedoes, and heavy torpedoes Mk 37 Mods 0 and 1 (these ships were not actually fitted with the heavy torpedo tubes).

Mod 15 For *Glover*, the experimental escort, fitted with SQS-26AX, SQA-13/SQS-35 VDS, and SQR-13 (PADLOC), to control ASROC, DASH, lightweight torpedoes, heavy torpedo Mk 37 Mod 0 (interim for Mk 46), and with provision for Mk 48. It used both Mk 134 and Mk 143 computers and included a Tactical Assignment Console and a modified Mk 53 Mod 0 attack console. Approximate weight was 4850 lb (1966).

Mod 16 For later *Knox*-class escorts (FF 1062-87), with SQS-26C and SQA-13/SQS-35 sonars, to control ASROC, lightweight torpedoes, and heavy torpedoes Mk 37 Mod 0 (interim for Mk 46), with provision for Mk 48 (which was not used). It used computer Mk 143 Mod 2 (no Mk 134) and attack console Mk 53 Mod 0. Approximate weight was 3600 lb (1966).

Mod 17 For *Forrest Sherman*-class destroyers converted to missile ships (DDG 31-34), with SQS-23A sonars, using computer Mk 134 Mod 0 (no Mk 143) to control ASROC and lightweight torpedoes; approximate weight was 2600 lb (1966).

Mod 18 For *Forrest Sherman*-class destroyers modernized for ASW, with SQS-23A and SQA-13/SQS-35 sonars, using computer Mk 134 Mod 0 (no Mk 143) to control ASROC and lightweight torpedoes. Approximate weight was 2800 lb (1966). Mod 19 was for DD 933 only, with similar sonars and equipment.

Mod 20 For modernized *Leahy*-class cruisers, with SQS-23 sonar, using attack console Mk 53 Mod 0 and computer Mk 134 Mod 0, to control ASROC, lightweight torpedoes, and DASH. Approximate weight was 2550 lb (1966).

Mod 21 For Italian missile cruisers equipped with SQS-23 sonars, controlling ASROC and lightweight torpedoes, using the Mk 53 Mod 1 attack console and computer Mk 134. Approximate weight is 3180 lb (1973).

Mod 22 For the Brazilian navy (FRAM I destroyers with SQS-23 sonar), to control ASROC and lightweight torpedoes; it uses

the Mk 53 console and the Mk 134 computer. Approximate weight is 2850 lb (1973).

Mod 23 For the *California*-class cruisers, with SQS-26 sonars, controlling ASROC and lightweight torpedoes, using attack console Mk 53 Mod 0. Approximate weight is 2500 lb (1973).

Mod 24 Mod 20 (*Leahy* class) modernized by replacement of console Mk 53 Mod 0 with modernized Mk 53 Mod 2. This is now a digital/analog system controlling ASROC and lightweight torpedoes on board *Leahy*-class cruisers. Total weight is 4375 lb (1989). The digital Mod 2 incorporates an embedded OL-335(V) Data Processing Group (an embedded UYK-44), a color CRT, and NTDS symbology. The new console weighs 1000 lb.

Mod 25 Mod 9 modernized by replacement of console Mk 53 Mod 1 with Mk 53 Mod 3, on board the missile cruiser *Josephus Daniels* (1989). This is now a digital/analog system. Total weight is 4475 lb. The digital Mod 3 console incorporates an OL-335(V) processor, a color CRT, and NTDS symbology.

Mod 26 Mod 12 modernized by replacement of console Mk 53 Mod 1 with digital Mod 3 (see Mod 25 above) for *Belknap*-class missile cruisers (CG 28-34). Total weight is 4475 lb.

Mod 27 Mod 23 modernized by replacement of console Mk 53 Mod 0 with modernized Mod 2 (see Mod 24 above) to form a digital/analog system for the *California* class. Total weight is 6075 lb (1989).

No Mod number has been assigned to the modernized FCS, using the digital Mk 53 Mod 4 attack console, projected for *Knox*-class frigates (FF 1052-98). The new console includes 2 computer processing subassemblies (CAPS and CBPS, both OL-335(V)s) and corresponding display subassemblies A and B. It has a color CRT and NTDS symbology, and it weighs about 1000 lb. Mod 4 is an upgraded Mod 2 providing additional sensor interfaces.

The shift from digital technology back to analog was made because the digital computers of the late 1950s and early 1960s were still expensive, slow, and relatively unreliable. The underwater ASW problem was well enough defined to make an analog computer attractive. As digital technology improved, it became overwhelmingly more attractive, particularly because a digital system was much easier to update to match new weapons, sensors, and target characteristics. For that reason the U.S. Navy adopted the digital Mk 116 to succeed the analog Mk 114.

◆ Mk 116

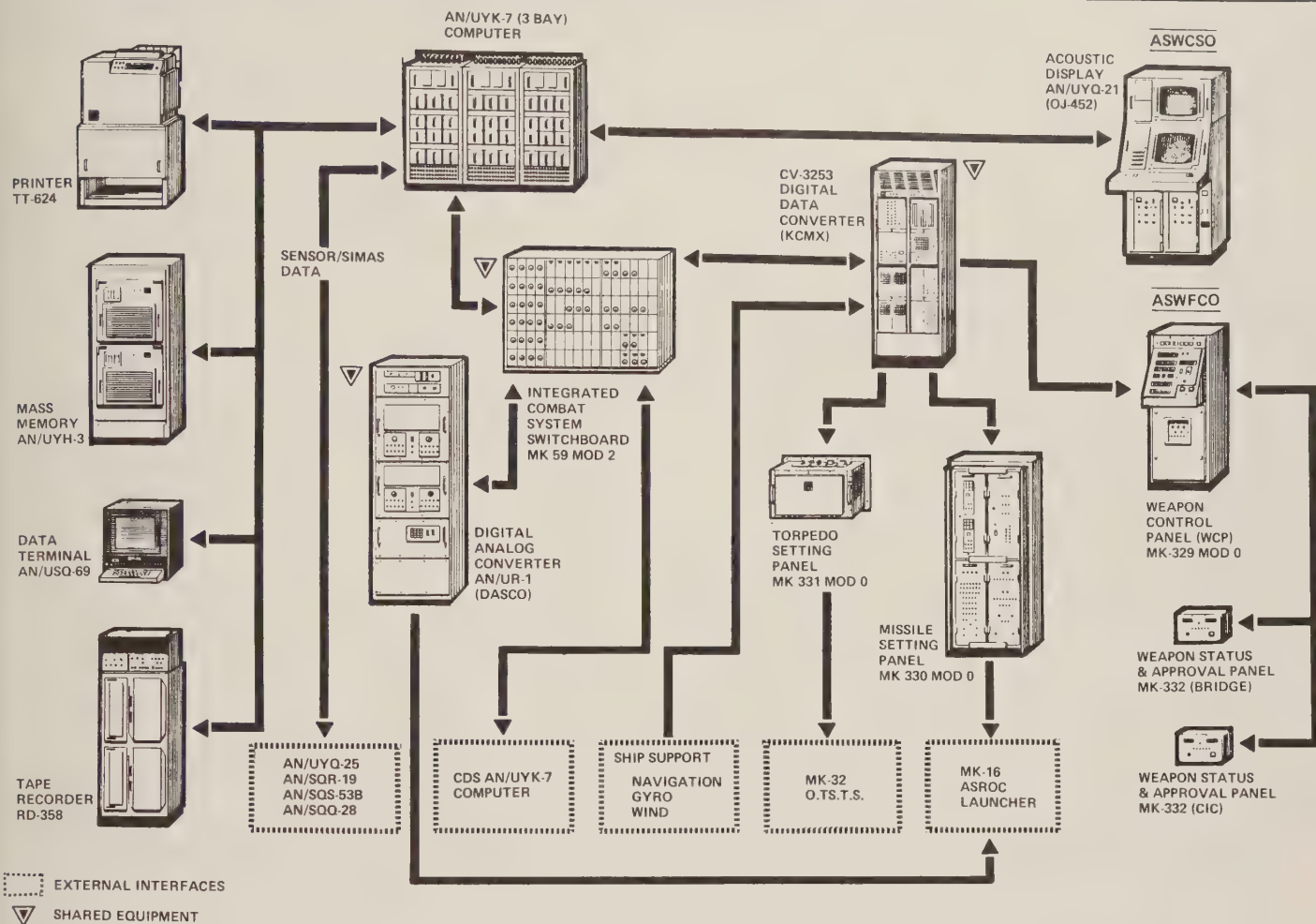
This all-digital surface-ship FCS, made by Librascope, uses the SQS-53A sonar. Unlike earlier ASW FCSs, Mk 116 uses a standard UYK-7 digital computer, for simplified logistics. Mod 1 is in *Virginia*-class cruisers and *Kidd*-class destroyers. The weapons-control panel is Mk 329 Mod 1, controlling 2 missile-setting panels (Mk 330) and a torpedo-setting panel (Mk 331). The main input is an SQS-53A, fed into the UYK-7 computer. Its output goes through a fire-control switchboard, which also feeds the sonar PPI console. Mod 1 was approved for service use in October 1980.

Mod 1 has a Computer Processing Subsystem (CPS) and a Weapons Control and Setting Subsystem (WCSS), as well as a digital fire-control switchboard and an underwater fire-control switchboard. The ASW officer (ASWO) console is a standard OJ-194/UYA-4 (as in NTDS), with a PPI that displays synthetic video, stored in PPI format. The system is run by its own UYK-7 computer, separate from that of the ship's NTDS. The associated SQS-53 sonar feeds into the digital fire-control switchboard, not directly into the CPS. The switchboard connects sonar, command/control, CPS on 1 side, WCSS on the other. Weapons-control panel (WCP) Mk 329-1 selects Mk 116-1 mode (attack, training, local test), selects weapon type and launcher (including TT barrel), and also selects search depth, search mode, or gyro angle presets for ASROC or TT torpedoes. It includes the launch key.



ASW CONTROL SYSTEM MK 116 MOD 5 PHYSICAL EQUIPMENT CONFIGURATION

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ASW control system Mk 116 Mod 5. (GE)

There are 4 target channels: 2 by sonar, 1 by command/control subsystem (NTDS), and 1 manually by the ASW officer at the ASWO console. The associated UYK-7 computer stores the target's track history, conducts TMA, and displays target symbols on the ASWO PPI. It displays track-history points. The ASW officer initiates an attack upon receiving the order from the ship's command/control system (NTDS); the order is displayed on a digital-readout panel. The order identifies the target by channel number and recommends which weapon to use. A supplemental engage order can be used to attack a second target simultaneously (one with ASROC, the other with TT). A single target is engaged remotely by the ASWO using the WCP. A second target can be engaged by TT from the ASWO console. Local mode means firing from the torpedo setting panel (TSP).

The post-firing display on the PPI shows the computed water-entry point for ASROC; the depth-charge symbol is retained and position-kept for 30 min. In a torpedo attack, by ASROC or tube, the torpedo symbol is retained and position-kept for its run time.

Normally, Mk 116 is integrated with NTDS, but there is a standby mode for use when NTDS is not operating (there is no channel 3). In this case all orders are passed verbally, and associated aircraft and helicopter drop points are relayed verbally using readouts from the ASWO console. The torpedo setting panel (TSP) is normally unmanned and is used to pass prelaunch

and launch instructions from the WCP. The TSP can be used locally for the emergency or 2-target attack mode.

As of 1975, WCSS MTBF had been tested at 1200 hr and was probably 3255 hr; average MTTR was 0.20 hr, maximum 1.08 hr.

Versions:

Mod 0 is the original version for the *Spruance* class, controlling both ship-launched weapons and a LAMPS helicopter.

Mod 1, for the *Virginia* class, differs from Mod 0 mainly in using the Mk 26 missile launching system.

Mod 2 is the version in the *Kidd* (DDG 993) class. It is Mod 1 modified to be compatible with the DDG 993 combat system.

Mod 3 is Mod 1 modified for installation on board the missile cruiser *Belknap*, replacing that ship's Mk 114. The ASROC launcher is a Mk 10 Mod 8 system rather than the ASROC box of Mod 0 ships.

Mod 4 is Mod 1 modified for Aegis ships. Total weight is 1930 lb (1977).

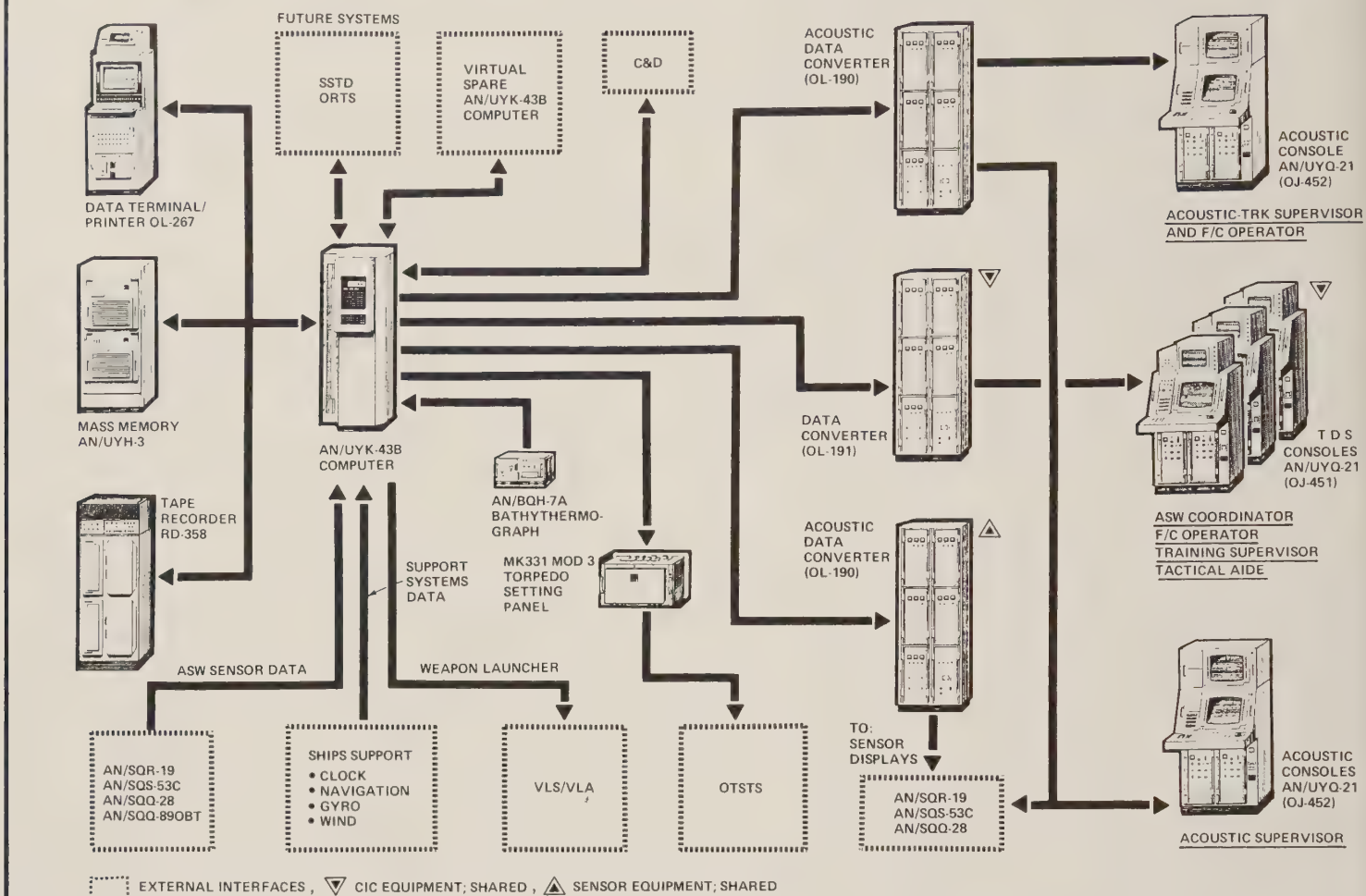
Mod 5 introduces computer tracking capacity, to handle multiple targets. The new SQQ-89 sensors (SQS-53B/C and SQR-19) have so much more range that a ship equipped with them will often detect several submarines simultaneously. They are suitable for active/passive fire control (plus contact management, localization, and correlation). Mod 5 was evaluated on board the *Moosebrugger*, August–November 1982. DD 965 is the lead ship for production Mod 5s. This version embodies the



ASW CONTROL SYSTEM MK 116 MOD 7

PHYSICAL EQUIPMENT CONFIGURATION

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USD 13

ASW control system Mk 116 Mod 7. (GE)

ASW capacity required by Operational Requirement SAS-84 (to interface with and support the improved SQS-53, SQR-19, SQQ-28, and UYQ-21). The combination was called a federated ASW combat system, and presumably it amounts to SQQ-89. Mod 5 employs a 3-bay UYK-7 computer and an OJ-452(V)/UYQ-21 acoustic display console. Total weight is 6200 lb.

Mod 6 is Mod 5 adapted to the requirements of the vertical launching system. It is introduced in CG 56, which carries vertically launched ASROC. Total weight is 5000 lb.

Mod 7 introduces the UYK-43B computer, for CG 65 and later cruisers and for *Arleigh Burke*-class destroyers. DD 978 is the lead ship for the Mod 7 computer program. DD 976 is the prototype for versions of Mod 7 for non-VLS ships (DD 963/CG 47/DDG 993 classes). There are 2 OJ-452 consoles. Total weight is 7300 lb.

Mod 8 is Mod 6 with a UYK-43B computer in place of the 3-bay UYK-7: DD 977 is the prototype. Total weight is 4700 lb.

Mod 9 is the non-VLS version of Mod 8. DD 974 is the lead ship. Total weight is 5900 lb.

Mod 10 is the non-VLS version of Mod 7. Total weight is 7600 lb.

The data below refer to Mod 5.

The system is designed to accept all the contacts (and asso-

ciated data) generated by SQS-53B, correlating them with each other and with manually entered data inputs from the CDS to generate track files with at least a 70% probability that all contacts reported back to the CDS are unique. Mk 116 aids the operator in target classification and annotates the contact range after the first tagged active contact is returned to the ASW control system.

In the passive mode, Mk 116 estimates contact range and recommends maneuvers for TMA to improve that estimate. 116 creates track files accurate enough for fire control. The test requirement is that, using up to 4 pings to determine a contact's course and speed, 116 must obtain track files of sufficient quality that the CO/TAO can determine that the threat is within active sonar range (as predicted by SIMAS, the sonar performance monitor). The attack that follows is based on active confirmation of the estimated range.

These requirements were met in the 1982 trials.

UYK-43B in Mod 7 adds integrated acoustic-performance prediction and sensor supervision.

◆ Mk 117

Mk 117 was the first all-digital FCS, begun in 1971 and tested on board *Narwhal*, for installation on board SSN 700 and later U.S. attack submarines. It was initially known as the all-digital attack center (ADAC). All sonar data are input in digital form, as are target data from other submarine sensors and own-ship data. The decision to buy all-digital systems made the analog

SUBROC missile obsolete, although there was an attempt to retain it (note Mk 117 Mod 8, below).

This system (and probably earlier U.S. submarine FCSs) is as much a command-integration as a pure fire-control device. The individual sensors all feed the central computer, which forms the integrated picture of the sea volume around the submarine, much as NTDS integrates the radar and sonar pictures around a surface ship.

The console of the ADAC consists of 3 elements side by side: 2 WCCs Mk 81, 1 attack-control console (with a control panel), and a third WCC. Each WCC incorporates a computer-driven CRT switchable between several display formats. WCC functions include multiple target track; data storage and evaluation; multiple-mode tracking; multiple (alternative) TMA solutions for single targets for high solution confidence; weapon attack evaluation; and generation of computer-recommended weapon presets based on weapon model, target solution parameters, and environmental data. The standard CRT display is divided vertically into an auxiliary readout area (alphanumerics), a tactical display area, and a lower control label area. The main area is used, for example, for TMA analysis. In the manual adaptive TMA evaluator (MATE) mode, the console is set up so that the operator can determine target course, speed, and range by trying alternatives, matching the bearings they would imply against the actual bearings measured by the sensors.

Other display formats include a full tactical picture (geosit) similar to that of NTDS or of a radar PPI.

Although this system is served by a powerful digital computer, it still bears strong marks of its analog past. For example, bearing-time recorders (waterfalls) are used as the primary sonar displays (there are 4 combinations of elevation and depression, as well as different integration periods). Target bearing rate is still often obtained by measuring the slope of the curve on a waterfall display (now, by using a strobe rather than a ruler). Similarly, the classic fire-control display, a set of dials showing target and own-ship courses (used as a visual check of the correctness of a solution), is reproduced in synthetic-video form. The sheer amount of information available in the attack center still tends to be integrated only in the minds of the operators, and this problem worsens as the number of arrays increases. New programs such as BSY-2 and SOAS (see below) address this issue. The solution is not simple because of the sheer complexity of the sonar data, and also because so much of the data is buried in noise.

The attack-control console (Mk 92) between the Mk 81s monitors the tubes and the status of their contents, displaying the type of missile or torpedo in each. Its desktop contains the firing key and the tube selector. Mk 92 can launch Mk 37 Mod 2 and Mk 48 torpedoes and Harpoon and SUBROC (Mk 117 systems Mods 2 and 3 only). A control panel (Mk 362) contains preset switches; it can set and monitor 2 torpedoes simultaneously, 1 port and 1 starboard. Presets are homing type (off, passive, active, or combination), stratum (below limit, no limit, and above limit), anticapture (set between 1 and 8), speed (low, low/medium to high, and high), and horizontal search pattern (circle left, straight, circle right, and automatic). The system also presets initial gyro angle, running depth, and enable run.

Versions:

Mod 0 For SSN 700–15, using 1 attack-control console Mk 92 Mod 0 or 2, 3 WCCs Mk 81 Mod 1 or 2, and a dual-frame (2-bay) UYK-7 computer with double density memory. This version has a weapons-data converter (digital-to-analog) Mk 82 Mod 0, 3, or 5 but lacks the leveling computer Mk 129 otherwise associated with SUBROC.

Mod 1 Backfit for SSN 594–96, 603–7, 612–15, 621, using 1 attack-control console Mk 92 Mod 2, 3 WCCs Mk 81 Mod 2, a leveling computer Mk 129 (not in Mod 0), and a dual-frame UYK-7. This version includes weapons-data converter Mk 82 Mod 2 (replaced by Mod 4 when Mk 48 torpedo TELCOM capability is installed).

Mod 2 Backfit for SSN 637–39, 646–53, 660–70, 672–77, using 1 attack-control console Mk 92 Mod 0 or 2, 3 WCCs Mk 81 Mods 1 or 2, a leveling computer Mk 129, and a dual-frame UYK-7. This version includes weapons-data converter Mk 82 Mod 1 or 2 (Mod 4 when Mk 48 torpedo TELCOM capability is installed).

Mod 3 Backfit for long-hull SSN 637-class submarines (SSN 671, 678–87) using 1 attack-control console Mk 92 Mod 0 or 2, 3 WCCs Mk 81 Mod 1 or 2, a leveling computer Mk 129 Mod 0 or 1, and a dual-frame UYK-7. This version includes weapons-data converter Mk 82 Mod 1 or 2 (Mod 4 when Mk 48 torpedo TELCOM capability is installed).

Mod 5 Replacement for Mod 1, with Tomahawk capability and a digital navigation system (DMINS). The leveling computer is deleted, and the Mk 92 console is Mod 3 or 4. For SSN 596, 604–6 and 612–15, this system directly replaced Mk 113 Mod 6. The dual-frame UYK-7 has double-density memory. This version includes weapons-data converter Mk 82 Mod 4 (for Mk 48 TELCOM torpedoes).

Mod 6 Mod 2 plus digital navigation (ESGN) for Tomahawk, for SSN 637–39, 646–53, 660–70, and 672–77. The leveling computer is deleted, and the Mk 92 console is Mod 3 or 4. The dual-frame UYK-7 has double-density memory. For SSN 637, 647, 650–53, 661, 664, 672, and 675–77 this system directly replaced Mk 113 Mod 6. This version includes weapons-data converter Mk 82 Mod 3 or 4.

Mod 7 Mod 3 plus ESGN and Tomahawk, for SSN 671 and 678–87. The leveling computer is deleted, the Mk 92 console is Mod 3 or 4, and the dual-frame UYK-7 has a double-density memory. For SSN 678, 683, and 685–87 this system directly replaced Mk 113 Mod 6 or 8. This version includes weapons-data converter Mk 82 Mod 3 or 4.

Mod 8 For new FY77 and 78 submarines (SSN 716–20), providing Sea Lance/SUBROC/Tomahawk capability and the submarine integrated attack center (SIAC) with 4 (rather than 3) Mk 81 attack consoles. This version includes weapons-data converter Mk 82 Mod 3.

◆ Mk 118

The Trident (*Ohio* class) all-digital defensive FCS is based on Mk 117 but is simplified because it controls fewer types of weapons, and also because it makes greater use of digital equipment. Mk 118 controls Mk 48 torpedoes, 3-in and 6-in countermeasures, and MOSS (mobile submarine simulators) fired from catapults in torpedo tubes. The basic control consoles are the 2 SIDs (standard information display, OJ-326(V)3/UYK) in the submarine command/control center. They perform TMA analysis of the target and generate weapons orders. Each has a single CRT, and they flank the ACC (attack-control console) Mk 92 Mod 1 (Mod 1 is similar to the Mod 0 of Mk 117 systems except that it can control countermeasures). The ACC in turn connects to the external countermeasures launchers and to the 3-in countermeasure-control and-display unit.

Either of the 2 SID operators uses the ACC to select a weapon or countermeasure and fire it. This was the first time the SID console was used in an FCS; it expanded on the capabilities of the WCC Mk 81 of FCS Mk 113–10 and FCS Mk 117 to provide an operator-interactive, digitally driven CRT display. One SID operator is primarily for TMA. The other develops orders to preset and control Mk 48 torpedoes and countermeasures. Either may view the other's display; the functions of the 2 consoles are completely interchangeable, and either can perform full fire-control functions. The system uses the bearing/range indicator (BRI) Mk 116, similar to that in FCS 117, to remotely display target-position data for the submarine commander. The associated computer is a 3-bay UYK-7 in the ship's computer complex.

At the other end of the system, in the torpedo room, the Defensive Weapon Launch Console (DWLC) consists of 2 TT

control panels flanking an unmanned weapons-launch console (WLC) Mk 96-0. This arrangement is markedly different from (and simpler than) previous torpedo-room equipment. Mk 118 eliminates most switching and analog interfaces, with fewer types of weapons and use of digital equipment (it is almost totally a digital system). Mk 96 converts digital signals from the control room consoles to analog for Mk 48 and MOSS and also replaces several other equipments, to greatly reduce cabling. The fire-control switchboard of earlier submarines is eliminated altogether. Rather than using a single firing circuit with tube-select switch, Mk 118 uses a separate circuit in each tube, with 1 control per tube in Mk 92. The weapons-select switch is eliminated because there are only 2 types, Mk 48 and MOSS. To switch a tube, the cable connecting the breech door with weapons-launch console Mk 96 is disconnected at the console and mated with a different console connector dedicated to the weapon involved. The result is only 45 cables in all, compared to over 200 in the *Lafayette* class Mk 113-9. All countermeasure launching is controlled at the Mk 92 panel, which can remotely control 3-in countermeasures.

Software is similar to that developed for Mk 113-10 and Mk 117. It processes data for multiple contacts, using various techniques for determining contact and target position and motion. Typically, it initially uses Kalman automatic sequential TMA (KAST) for a rapid estimate of relative location; the operator refines the estimate on the SID console. The options include KAST edit, manual adaptive TMA evaluation (MATE), Ekelund ranging, and depressing/elevation (angle) ranging. The SID software also provides analysis of the environment; it can show search and avoidance modes, i.e., areas favoring disclosure of a target and areas providing greatest chance of avoiding counter-detection. The software also includes evasion tactics and a system alert module.

Mk 118 is superseded in more recent Trident submarines by CCS Mk 2 Mod 3.

◆ Mk 309 Fire-Control Panel

Despite its designation, this is a compact ASW FCS. It is essentially a means of self-defense: torpedoes are fired, and the bridge is advised of the appropriate evasion course. Mk 309 receives 3 synchro inputs (target range, bearing, and own-ship course), and transmits only 1 synchro output (own-ship heading error). It also transmits torpedo presets to the torpedo tubes and displays tube/torpedo status signals.

The console does not incorporate a computer. Instead, a computer ashore was used to generate numerous situations involving a submarine and a frigate. Each was simulated to find an optimum ship evasion course, and the courses were grouped into evasion envelopes for targets at various courses and speeds. The result was a firing doctrine that could be stored in the limited memory of the Mk 309 panel. Given a situation defined by the 3 synchro inputs, Mk 309 selects the appropriate evasion envelope.

The sonar operator tracks the submarine and transmits bearing and range by synchro, providing verbal estimates of target aspect and speed; alternatively, these data are taken from the NC-2 (DRT). They are entered manually into the panel, which recalls the appropriate doctrine, transmitting a course-to-steer to the bridge. The panel also displays maximum, optimum, and minimum torpedo-firing ranges. It also recommends a lead angle. The operator enters torpedo presets and fires the weapon.

Versions: Mod 0 (75 lb) for the WHEC 715 coast guard cutters and for the Saudi *Badr*-class missile corvettes. Mod 1 (340 lb) is for the *Perry* class. The Mod 0 designation was assigned in 1968.

Other torpedo-control panels cannot operate independently; they are elements of larger underwater FCSs. Mk 264 Mod 0 is part of FCS Mk 105. It selects the Mk 32 barrel and presets initial search depth, search floor, and gyro angle. Mod 3 is part of Fire-Control Group Mk 111. Mod 2 was developed for the experimental ASW hydrofoil *High Point*. Mk 309 replaces the combination of EX-290 and panel Mk 264.

This fire-control panel is also used on board the Saudi missile corvettes (*Badr* class).

◆ CCS Mk 1

Combat-Control System Mk 1 was begun in FY73; it combines the digital Mk 117 with the submarine central-computer complex. It uses a 2-bay UYK-7 computer. Installation began with SSN 700 (backfit into SSNs 688-99). Total weight is 11,000 lb. CCS Mk 1 was approved for service use in 1980.

Mod 1 adapts Mk 117 to control Tomahawk missiles against OTH targets (based on Outlaw Shark experience) and was approved for service use in July 1980.

Mod 2 is similar to Mod 0 but supports the submarine vertical-launching system. It employs 2 UYK-44 computers and controls Mk 48 Mod 1, 3, and 4 torpedoes, Tomahawk, and Harpoon; the associated sonar is BQQ-5C. This and later versions include 3 Mk 81 Mod 2 and 1 Mk 81 Mod 3 WCCs and a Mk 92 Mod 4 attack console. The Mk 81 Mod 3 is an enhanced Mk 81 adapted to Tomahawk missile control on board *Sturgeon*- and *Los Angeles*-class submarines. It has a console data bus, a 32 bit × 32k display refresh/bulk memory, an alphanumeric keyboard, an edit capability for keyboard and list set functions, and a UYK-20 emulator for target correlation and processing. The console, therefore, has quicker responses, gains real-time access to expanded data bases on board the submarine (which are needed for Tomahawk flight planning), gains internal refresh capability, and has a reserve for future growth.

Mod 3 is Mod 2 with Mk 48 ADCAP capability, for SSN 719-25 and 750.

Mods 4 and 5 add Sea Lance capability. When installed on board *Sturgeon*-class submarines, Mod 4 can control SLMM mobile mines.

◆ CCS Mk 2

Raytheon's Combat-Control System Mk 2 is the successor to CCS Mk 1 in *Los Angeles*-class submarines. In these systems a new Common Display Console Mk 130 replaces the Mk 81 WCC and SID (situation information display) of earlier systems. It is a multifunction workstation based on the Raytheon SC-2000 series, which in turn is derived from the Silicon Graphics 4D/20 Personal IRIS Workstation. The workstation incorporates special-purpose processors to convert analog PPI data to raster-scan; to convert sonar data to LOFARgrams, waterfalls, and A-scans; and to superimpose synthetic data on raw video. The 19-in color CRT has 1280 × 1024 pixels (24 bits per pixel, refreshed at 60 frames/sec). The screen can show as many as 16 simultaneous windows. The embedded 32-bit RISC computer, which uses a VME bus, has a throughput of 8 MIPS. An associated image memory generates alphanumerics, symbols, and graphics. The earlier consoles used cursive CRTs. Outputs include 2 NTDS channels (Type H). The operator controls are variable-action switches, a programmable flat panel (with switch overlay), a keyboard, a keypad, and 4 track marbles with entry switches and label readouts. Optional features are a second CPU, a graphics processor, and bulk memory.

A Mod 1 version is used for OTH-T. It is similar to Mod 0 but adds 2 more NTDS channels (Type B). Mod 2, for Trident submarines, is similar to Mod 0 but has a 17-in monochrome CRT, Type B NTDS channels, and no keypad or track marbles. Mod 3, also for Trident submarines, is similar to Mod 0 but has a 17-in monochrome CRT, 2 additional NTDS channels (Type B), 1 trackball, 8 multifunction switches, and no keypad or flat panel display.

Probably much more important is the modular software design, which permits Raytheon to offer versions of CCS Mk 2 for all 4 current U.S. submarine types (see below). One requirement is sufficient computing power to support a powerful emulation mode, so that the workstation can replace several current consoles without any impact on existing interfaces.

The existing weapons-launch console, weapons-data converter, and TT-control panel (all located in the torpedo room) are retained (in BSY-1 they are replaced by a new weapons-

launch-system console). These systems incorporate a new submarine random-access-data storage set, SUBRASS (BYH-1), which replaces the earlier UYH-2. Submarines with vertical tubes but without BSY-1 have an additional set of Tomahawk control panels and interface consoles in a separate missile-control room (not required for Tomahawks loaded in standard torpedo tubes).

The CCS Mk 2 Tomahawk targeting subsystem is based on a UYK-44 and a parallel processor and operates 20 times faster than its CCS 1 equivalent.

Raytheon won the CCS Mk 2 contract in September 1988. The first should enter service in 1992.

CCS Mk 2 is part of a more general program to merge submarine FCSs into more comprehensive combat-control suites combining sonar operation, TMA, tactical display, weapons control, navigation, and communications.

Versions:

Mod 0 is for *Los Angeles*-class submarines without vertical launch tubes (SSNs 688-718). One UYK-44 computer of the earlier CCS Mk 1 is retained, but the previous UYK-7 computer is replaced by a UYK-43B. The former Mk 81 consoles are replaced by 4 Common Display Consoles Mk 130 Mods 0/1 (the single attack console Mk 92 Mod 5 or 6 is retained). The associated sonar is BQQ-5E(V)3, and the system is compatible with an HP 9020 (DTC I tactical decision aid) computer.

Mod 1 is for *Los Angeles*-class submarines with vertical-launch tubes (SSNs 719-25 and 750).

Mod 2 is for later *Los Angeles*-class submarines with vertical-launch tubes (SSNs 751-79). There is no attack console; instead there is a weapons-launch console (WLC) designated 2015-2020. These units are equipped with BSY-1.

Mod 3 is the SSBN version, controlling only torpedoes and countermeasures (it replaces Mk 118). Since it does not control Tomahawk and Harpoon missiles, it lacks the UYK-44 of the other versions. It has 4 new common display consoles (Mk 130 Mod 0) but retains the single attack-control console (Mk 92 Mod 1) of the earlier system. The associated sonar is BQQ-5E(V)4.

◆ Combat Control System (*Los Angeles* Class)

The *Los Angeles* was the first U.S. submarine to have a combat system built around digital computers. It employs a central computer complex (CCC) with a UYK-7 computer to conduct a variety of combat-system functions. The CCC processes attitude signals (converted into digital form). It receives raw velocity data from the inertial navigation system and computes own-ship velocity north and east. There is also an underwater log and an analog dead-reckoning analyzer/indicator (DRAI). The CCC conducts TMA using primarily sonar inputs and navigational data, under control of the FCS. The BQQ-5 sonar transmits data directly to the CCC, which then provides this information to the fire control-signal data converter (FC-SDC) for use by FCS analog devices. The BQS-15 active sonar transmits analog target data directly to the fire-control analog devices and to the CCC computer for TMA. The CCC computer combines the target and own-ship data through target localization and TMA computations and, thereby, allows ship's personnel to evaluate the tactical situation. Simultaneously with target and own-ship data entry into the CCC, the FCS digital display subsystem (DDSS) provides the computer with the operational program control necessary to perform target localization and TMA. The DDSS also provides various display techniques, such as numerical, geographic, vectorial, or tabular display and analysis, during the target localization and TMA process. Manual TMA calculations may also be performed by fire-control and sonar-system operators. These calculations are primarily performed at the navigation/sonar (NAV/SONAR) plotting station. They may also incorporate ECM bearing data and periscope range data.

When the *Los Angeles* class was conceived, it was assumed that TMA would be automated. However, it was soon discov-

ered that sonar data were always somewhat fuzzy, and that automated solutions were often misleading. Computer capacity was insufficient to allow for operator modification of a running solution, so it became standard practice to run TMA solutions by hand in parallel to the machine. Human interaction requires enormous computer capacity, which is why word-processing (perhaps the epitome of human intervention in machine operation) was entirely impractical until the early 1970s, and then only on very powerful mainframe computers. The jump in computer capacity represented by BSY-1 finally allows operator intervention on a scale sufficient to make automated TMA well worthwhile.

Classification is usually by target acoustic or electromagnetic characteristics; and BQQ-5 can conduct automatic classification. These data are routed directly to the CCC.

Weapons and tactic selection are by the weapons order subsystem (WOS), supported by the CCC computer. The system includes 2 attack directors, 2 torpedo-control consoles, 1 firing console, 1 own-ship data console, and 1 leveling computer. WOS programs the Torpedo Mk 48 for launch. The assigned attack director uses analog TMA solutions from FC-SDC to compute torpedo orders. The attack director also computes and transmits the torpedo gyro angle to the torpedo. The torpedo-control console monitors attack-director functions and generates additional preset data as required. For SUBROC, the attack director provides target parameters and own-ship data to the leveling computer. The latter processes these data and transmits ballistic preset signals to SUBROC; the leveling computer also provides prelaunch alignment signals.

The WOS firing console initiates launch of preselected weapon(s). In the case of Mk 48, WOS continues to guide the torpedo. For SUBROC, WOS provides post-launch position-keeping calculations, for evasion or re-attack.

The original CCC was installed on board SSNs 688-99; an updated version appeared on board SSN 700 and was backfitted on board earlier *Permit*/*Sturgeon*-class submarines, presumably in connection with the installation of BQQ-5.

◆ FFISTS

Frigate integrated tactical system for the *Knox* class, intermediate in capability between the current manual system and SQQ-89 (see the Surveillance and Control section for details).

◆ SOAS

GE's Submarine Operational Automation System is being developed under a 5-yr contract with DARPA awarded in February 1990. It is intended to provide a commander with a much better and much more current picture of the tactical situation, to enable quicker reaction. SOAS differs from current systems in its use of AI and knowledge-based systems to interpret and integrate sensor data. In theory, a system like SOAS is needed because passive detection ranges are shrinking, so submarines may more often suddenly encounter each other. In such circumstances, reaction time, rather than careful TMA, determines whether a submarine will survive. The recent increased emphasis on submarine torpedo countermeasures is probably motivated by the same development.

The central requirement is to improve a submarine commander's image of the tactical situation. The main sensor is passive sonar, and the problem is that the acoustic environment is extremely complex (and quite noisy). The AI approach is to develop several alternative hypothetical situations corresponding to the known acoustic data, then compare them to find the most likely. Such a comparison takes advantage of known negative information. The SOAS system may also be able to recommend specific maneuvers that can clarify the situation. The kind of computer logic that juggles several alternative hypotheses is also suited to planning with uncertainty, for example, seeking actions most likely to improve the tactical position, or the safest paths to disengagement.

Probably much of the SOAS effort will be devoted to developing the computer approach to problem solving in an uncertain environment.

AI is an obvious candidate for integrating the mass of information available to a submarine, but there is still a very real fear that a computer program may misinterpret that fairly ambiguous data. Such misinterpretation has been experienced in much simpler cases, such as calculations of sonobuoy ranges. It seems likely that SOAS was initially intended to react automatically to particularly threatening circumstances, but that the program was (or will be) ultimately scaled down to the presentation of a more integrated sensor picture, perhaps also providing tactical advice (e.g., illustrating the consequences of alternative actions). SOAS may also be able to assess the acoustic consequences (flow and other self-noise) of particular maneuvers, and to integrate that assessment into its tactical advice. It is also to assist in emergency damage control.

In theory, SOAS should make for a smaller and more effective submarine crew. The current submarine command and decision process involves about 28 people and 4 console/workstations. GE plans a command center with 4 large-screen displays: 1 for ship systems status, 1 for weapons status, 1 for command tactical planning, and 1 for command situation assessment. Sensor information would flow into the situation assessment display, which would generate a "world scene" feeding into the tactical planning position. This position would also accept platform "scene" (status) information from the ship systems status board. Plans generated at this position would be presented to a tactical executor (CO), who in turn would issue platform and weapon orders. The command and decision team would be reduced to seven: the CO, the tactical planning officer (TPO), the situation assessment officer (SAO), the ship's systems coordinator (SSC), the weapons-control coordinator (WCC), the damage-control coordinator (DCC, also responsible for signature management), and the OOD, supervising both the SCC and the WCC. SOAS would also accommodate a sonar supervisor, a radio-room officer (RRO), and an OTH operator.

Program goals are a tenfold reduction in all assurable self-signatures in tactical situations; a tenfold reduction in scene description ambiguities and errors; a fourfold reduction in reaction time in "pop-up" situations; a threefold reduction in classification time; improved classification accuracy; provision of multiple alternatives at all critical decision points; a twofold improvement in weapons effectiveness; and the possibility of using new, previously unexecutable, tactics.

GE won the SOAS contract after a 6-month competition against Martin Marietta, McDonnell Douglas, Lockheed, IBM, and Raytheon. SOAS is part of a DARPA submarine technology initiative authorized in 1988.

◆ SUBACS

See BSY-1 above.

◆ AMSP/2

EDO's Advanced Modular Signal Processor (Series II) has been adopted for SQR-18A(V)3. It is a new type of parallel processor made up of 3 hardware modules: processors (digital signal processors, DSPs), cross-bar data-transfer network, and mass-storage memory expansion. All of the elements are compatible with standard external buses and with internal VME backplanes. Each cross-bar is a bus for up to 15 devices. Each connector can be programmed to be directional (so that data flow in a direction determined by software), and data can be transferred both port-to-port and in a broadcast mode (to any N ports). Destination ports can be programmed on line.

Each processor has its own memory unit so that there is no need to switch in and out of a central (global) memory during processing. All of the elements on any 1 cross-bar effectively communicate simultaneously, and the system can change its internal relationships as it executes a problem. The entire processor communicates with other equipment via an Ethernet bus. AMSP uses a tree architecture. For example, 1 input into

a cross-bar might communicate with another 5 devices on 1 side of the next cross-bar; they communicate with another 8 on the other side, which also communicate with 7 more on the other side of the next cross-bar, and so on. In contrast to some other parallel processors, each processing element operates independently because it need not send its product directly to (or receive input directly from) any other element. This programmed flexibility makes it possible for the AMSP cross-bar network to simulate virtually any network topology.

The cross-bar communicates with each processing element (PE) at 7.2 Mbytes/sec via first-in/first-out (FIFO) buffers. They, in turn, communicate with the PE manager module at 28.8 Mbytes/sec; the module operates at 15 MIPS/30 MFLOPS and has its own PROM and RAM. The PE arithmetic processor operates at a similar speed, using its own PROM, in which signal processing or other mathematical algorithms are stored. A memory-expansion module is associated with each PE.

EDO claims that the use of a few simple modules greatly reduces both cost and technical risk. Special PC-compatible programs are available to develop the subprograms used in the PEs. AMSP was first developed as a coherent processor for the EDO 780 export sonar (1983). It was also adopted for the SQR-18A(V)1 and SQR-18(V)2. SQR-18A(V)3 will be the first production application of the new AMSP/2.

◆ Kanaris System

UNISYS is developing a new FCS for half of the Greek *Kanaris*-class submarines, in collaboration with the Hellenic Navy Research and Development Center (GETEN). The system consists of a main control console (MCC) consisting of 2 side-by-side, color, multifunction tactical modular displays (TMDs), 2 sensor peripheral units (SPUs), and 2 operator control units (CUs); plus a 2-cabinet firing distribution unit. Each combination SPU/TMD/CU has a UYK-44(V) computer embedded in it, and a channel connects the 2 computers. The TMD displays the tactical situation as well as digitized radar and sonar video. The associated control unit contains a trackball as well as manual entry buttons, e.g., for FCS data entry and also for the display of FCS status. There is also a 12 × 40-character plasma display/touch entry panel.

Sensor and other input data pass through junction boxes into the 2 SPUs, which feed the TMDs. Decisions made at the TMDs in turn are fed to the firing and distribution unit, which incorporates actual fire-control calculation.

The SPU is essentially an analog-to-digital and discrete-to-digital converter, with 24 single-speed synchro input channels, 2 linear analog-to-digital input channels, 2 single-speed synchro output channels (with growth to 6), 8 discrete inputs (with growth to 24), and 8 discrete outputs (with growth to 24). Data are provided to the UYK-44s of the TMDs via a 16-bit A-NEW bus. Radar data are provided directly to the TMDs.

Each TMD contains a 19-in color CRT (1024 × 768 pixels), with 8 memory planes for data prioritization; it is capable of displaying 8 colors or intensities for radar video. The TMD incorporates a special high-speed sequencer and 2 pages of graphics image memory for fast graphics. The value of the 2 pages is that the operator can rapidly flip between them. The TMD has separate display and graphics processors, the latter translating the former's tables into pixel data for actual display. The operator can interact with the computer by touching the screen (finger-on-glass, or FOG, operation). The associated version of UYK-44 has a 128k ROM and 256k of nonvolatile read/write memory (protected by battery backup); throughput is 800 KOPS.

The firing and distribution unit selects, presets, and guides torpedoes; it also passes firing data to the 2 missile-data processors used to fire Harpoons.

The entire system is 2-sided, for redundancy, and the FDU can operate as an independent FCS if the TMDs fail.

Basic system functions are divided into surveillance and tactical evaluation (including contact and track display, track correlation, identification, classification, prioritization, and targeting); motion analysis (including automatic tracking, interactive

tracking using graphics, and tracking solution endorsement); navigation; engagement and guidance; maneuvering (threat and own-weapon avoidance); and attack evaluation (including simulated weapon runs and action recommendation). The system tests, presets, launches, and controls 4 weapons types, presumably 3 torpedoes and Harpoon. The system will be able to control 6 torpedoes simultaneously. The Greek navy has ordered 5 systems, 1 for training and 4 for submarines.

◆ ST-50

Star array processor, the second fastest commercially available array processor, has a throughput of 50 MFLOPS (the fastest is the Star ST-100, 100 MFLOPS). Eight were sold in 1989 to NOSC San Diego, to be used in 3 real-time acoustic-signal processors, 2 on ships and 1 on land at NOSC San Diego. They are rack-mountable (19 in wide), can accommodate 2 additional interfaces, and can handle up to 64 Mbytes of memory. Presumably, ST-50 is an alternative to UYS-2 for SURTASS ship upgrades. It exemplifies the variety of commercial machines proposed as alternatives to UYS-2.

◆ Rockwell Combat System (ACS)

The combat system of the Australian Type 471 submarine was developed by RSSA (Rockwell Submarine Systems Australia). Reportedly, Rockwell is also responsible for the combat systems of the projected Israeli diesel-electric (German Type 209) submarines and *Sa'ar-V*-class corvettes. Presumably, all 3 share some of the same technology. Singer-Librascope is supplying the multifunction consoles, which are the same as those of the SFCS described below.

As in the SFCS, ACS is based on multifunction common consoles (MFCC) and 1 command-plotting (CP) console. The ESM cell is, however, separate to maintain its security. Each of the 7 MFCCs is capable of handling all combat-system functions, primarily surveillance (detection, classification, contact-data management) and threat prosecution (including review of surveillance data). Each console contains two 19-in touch-screen color CRTs. The CP, which is horizontal, has a 39-in color CRT, for tactical analysis or for reproduction of 1 of the MFCC displays. There are also 4 supplementary plasma displays, 2 for supplementary alphanumeric data, such as weapons status, and 2 used as remote presetting, testing, and control panels for the port and starboard sets of torpedo tubes.

The entire system is tied together by a Rockwell fiber-optic Expanded-Service Ship-Data Multiplexing System (ESSDMS), derived from the new U.S. Navy USQ-82(V) multiplexing system.

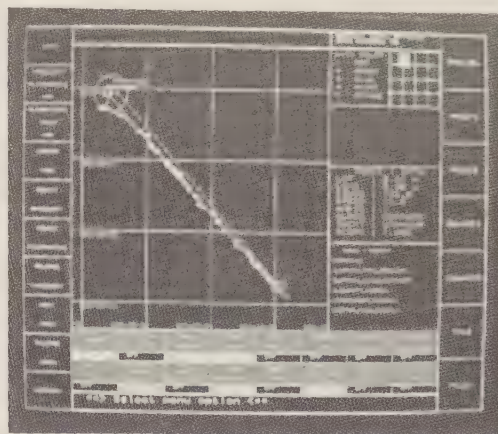
Reportedly, the Advanced Combat System (ACS) can detect more than 1000 targets, initiate tracks on 200, and localize 25 or more; and engagements are limited only by the nature of the torpedo tubes.

◆ SEAS/Seawitch

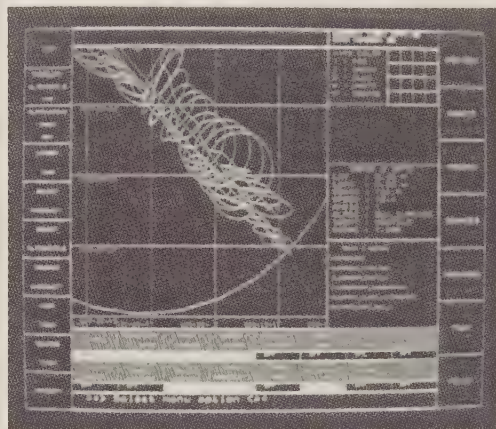
UNISYS's privately developed expert data-fusion systems are for ASW data analysis. Seawitch is the overall in-house program, and SEAS is a Submarine Expert Analysis System using techniques developed for Seawitch. Presumably, these prototypes represent technology being offered as part of SQQ-89(I).

Different sensors have different ranges of errors and, thus, present somewhat different pictures of the same tactical situation. Moreover, it is not always possible to determine what is happening in a complex tactical situation in which, for example, tracks cross (track identity is easily lost). Seawitch presents the operator with several different possible scenarios for actual tracks based on the variety of available data from the different sensors and on probabilities assigned to different possible interpretations of the data (e.g., alternative identifications for tracks emerging from a crossing). A multiple-hypothesis algorithm is used to determine the most probable interpretation. Seawitch can show uncertainty ellipses around the actual correlated track and also around the hypothesized track.

Data fusion becomes increasingly important as the variety of



Seawitch shows the effect of artificial intelligence in an ASW combat system. Here it presents the operator with several possible interpretations of target track data. (UNISYS)



Seawitch can present the operator with uncertainty limits (ellipses) around the alternatives it hypothesizes. (UNISYS)

available sensor inputs (e.g., sonars at different frequencies, off-board sonar data, sonobuoys) increases. Moreover, tactical decisions must be made more rapidly because targets can move very rapidly and, more important, because they can suddenly fire very high speed weapons. SEAS takes the output of Seawitch, which is a traditional plot, and analyzes the situation (using expert systems methods) to provide a list of target intents and future actions. UNISYS plans to extend the system to provide recommended actions; SEAS then becomes the UNISYS ASW Tactical-Decision Aid (ASWTDA). The company planned to test SEAS, using actual ASW data inputs, during 1989. This application of data bases to recommend action is somewhat analogous to the extension of NTDS to ACDS Block 1 described in the Surveillance and Control section.

◆ Singer-Librascope SFCS Mk I

The Librascope SFCS Mk I is a digital FCS that is in service in the Australian and Canadian navies and that is now (1988) being installed on Indian navy Type 209 submarines. The company claims that Mk I was the first all-digital SFCS. It reflects the company's experience in U.S. Navy systems such as Mk 113 (see above) and presumably reflects some U.S. Navy practice. Librascope described SFCS Mk I as closest in technology to Mk 118. In 1977 the U.S. Navy stated that SFCS Mk I had proven much less expensive than a comparable system purchased under standard DoD procurement rules.

Design objectives were automation (reduction of operators from 10 to 3), integration (all sensors can be coordinated by 1 operator using a multifunction console), improved availability, and adaptability to new weapons (torpedoes Mk 8, Mk 23, and Mk 48-3). The system uses computers to perform TMA and to



Librascope's SFCS Mk 1 consoles, showing an active sonar B-scan at left and a tactical summary plot (PPI) at right. (Librascope)

Elements of Librascope's SFCS Mk 1 Mod 0, including the tactical plotter. (Librascope)



generate firing orders. It can detect 20 targets, track 4, and engage 2. The 3 manned positions are the command-display console in the control room (which must be manned continuously) and the 2 fire-control consoles, each with its own CRT. The latter are manned only in action and standby conditions. Normally, 1 of the fire-control consoles provides contact motion analysis, the other controlling weapons and TT status. Input into these consoles is by both light pen and keyboard.

The system is based on a command-display console. It contains a sensor-data converter (SDC) that accepts data from 15 sensors and that has 9 passive sonar tracking channels. The display itself is a 20×24 -in paper plotter. Sonar operators can designate sonar bearings by means of 1 of the 3 sonar-assignment units at each sonar console, or the operator may designate 1 of the 9 sonar-data channels. Such designation causes the system to store all data from that channel (for the most recent 30 min) in the computer's memory. Any 4 of the 9 channels may be designated threats and, therefore, be subject to TMA. Typically a tactical analyst at the CRT of a fire-control console carries out threat assessment (e.g., TMA), normally at the right-hand console (with the left-hand console—which is functionally interchangeable—reserved for weapons control).

For TMA, passive sonar measurements are sampled every second and averaged over 20-sec intervals. The submarine can maneuver to improve TMA ranging, and both automatic and manual target solutions can be obtained. There is also an acoustic environment display (ray-path predictor).

The basic computer is UYK-20 (64k, 16-bit words, 1.3-MHz clock rate, with a 400k hard disk, average access time 18.4 msec).

Claimed MTBF is 400 hr (98% on-line availability).

Before the merger of Librascope into Singer, this system was called LFCS Mk I (Librascope submarine fire-control system Mk I). Development began after Librascope won a design competition in September 1974. The first system was delivered in mid-1978. SFCS I was also supplied to the Canadian navy, to modernize Canadian *Oberons*.

◆ Singer-Librascope SCCS Mk II

Submarine combat-control system Mk II is a developed SFCS Mk I. SCCS Mk II consists of up to 8 multifunction consoles



Librascope's multifunction console for SFCs Mk 2 (which uses 3 of them). (Librascope)

fed by a 5-MHz fiber-optic combat data bus, a single command (summary) display, a sensor-data converter/processor, and a weapons-data converter/processor. The system is federated: all processing associated with the sensor-data converter/processor is carried out in that unit. Each combat-control display has 2 separate screens: an upper plasma screen with an IR touch overlay and a lower 19-in CRT with a light pen. The display also includes a keyboard and a joystick. The summary display is identical with the plasma display of the combat-control console.

Because all the control consoles share the same data stream (which includes data from all available sensors and from any data link to which the submarine can have access), individual operators can be assigned to concentrate either on particular targets or on overall surveillance. All sensor data are automatically entered into a combat data base for processing and recording. For example, data can be selected for up to 25 simultaneous target-motion analyses.

Four targets can be engaged simultaneously with wire-guided torpedoes, and the system can also support submarine-launched missiles such as Sub-Harpoon.

All elements of the system are sized to fit through a standard 650-mm hatch, so existing submarines can be upgraded with the system without having their hulls opened.

Singer-Librascope's work on the Australian submarine combat system (in collaboration with Thomson-CSF and Rockwell International) is based on SCCS Mk II. The Australian project began late in 1985.

Librascope considers the Australian system Mk III. Mk I was the Australian/Canadian system; Mk I+ was the Indian system. Mk II was an abortive system proposed to Israel. Mk III+ was a system proposed to Canada for the abortive Canadian nuclear-submarine program. It will presumably be revived as a possibility for the diesel submarines that Canada will probably buy.

SUBMARINE PERISCOPES

Although they are not ASW sensors, submarine periscopes seem most naturally to belong in this section since they are among the sensors feeding most submarine combat systems. Because sonar may be limited in its ability to detect and track surface craft, periscopes are often the submarine's primary surface-search sensors. They are changing radically. Until the last decade, all were optical, and most submarines had 2 types, a wide-angle search periscope and a narrow-angle attack scope, the latter intended to leave the narrowest possible wake so as not to reveal too easily the position of the submarine. A submarine commander would obtain the surface picture by making a quick sweep with the search periscope, the duration of the sweep determining both the quality of that picture and the extent to which the commander exposed the submarine to detection. Much of the submarine officer's training (e.g., in the British "perishers" course) was devoted to the ability to form a coherent surface picture after the briefest sweep.

Very compact optics were developed to provide such facilities as alternative air and surface search in the same narrow tube, as well as stadimetric range finding. A stadimeter measures the angle between the horizon and the top of an object; if the height (usually the masthead height) is known, the range can be calculated. From a submarine's point of view, the advantage of stadimetry is that the baseline is the object being measured, rather than the range-finder (which must be quite small, so as to be unobtrusive). The horizontal equivalent of stadimetry, using the observed length of the target, is impractical because most targets will not be at right angles to the line of sight of the periscope. Many attack periscopes incorporate range-only radars that supplement their optical range-finders. The alternative, particularly in optronic masts, is a laser range-finder.

There are also special night periscopes with greater light-gathering power. Some search periscopes are binocular, with duplicated windows at the top. At one time many search periscopes provided for air search, but now air warning is more usually the function of an RWR found atop the search periscope.

Two major developments are associated with the post-1945 revolution in submarine design and performance, the combination of high underwater speed and indefinite submerged periods (snorkeling when required). The first development required search and radar periscopes that could be extended at relatively high speeds (the U.S. Navy called for periscopes extendable at 14 kt). High speed in turn induced severe vibration, and images had to be specially stabilized. The second development required sextants for taking navigational fixes to be incorporated in search periscopes. Conceivably, this requirement will lose its urgency with the rise of very accurate and universally available navigational systems such as GPS, but surely the sextant will always be desirable as a backup against the destruction of the satellites.

Optronics is an outgrowth of television and FLIR technology. Periscopes were initially provided with these sensors, such as image intensifiers (LLTV), to extend their usefulness to lower light levels. However, as with surface-ship and aircraft applications, the potential of converting the image into an electromagnetic signal is much greater since the image itself can be processed. In surface or air applications, the emphasis is usually on processing for tracking. In a periscope, the emphasis is more on processing the image to extract all of its information content and even to merge it with other relevant data.

The 2 applications of such cameras are quite different. A conventional or LLTV camera can be inserted in the bottom of the periscope, taking the same image as the eyepiece, on much the same principle as a single-lens reflex camera. However, an IR sensor is best placed at the top of the periscope since thermal photons traveling all the way down the tube would suffer from added noise. Moreover, the optical components of the periscope will not focus or reflect IR radiation as they do light itself. Thus, a conventional periscope cannot be converted to IR operation by simply installing a new crosshead, whereas that periscope can relatively easily be provided with an image intensifier.

IR operation requires installation of a thermal camera at the head of the periscope. The IR sensor must be cooled, and the coolant led up a very narrow periscope tube (or else a very compact refrigerator must be incorporated in the small periscope head).

Existing optronic periscopes employ a camera analogous to the window of the periscope, fixed rigidly to a tube that the observer rotates. However, there is no reason for the observer to memorize the scene as quickly as the periscope can be turned. In principle, the sensor can make a very quick scan (or even look simultaneously in several directions), and the image can be stored either digitally or in a video recorder, for display as desired on a CRT. The newer sensors can provide images of optical periscope quality. That capability, in turn, opens up some very interesting possibilities.

The exposure associated with a periscope depends on 2 factors: the sheer size of the head and the time during which the head projects above water. Optronics probably always requires more space than simple optics, but optronics can also greatly reduce exposure time since observation need not coincide with exposure. The submarine commander can view the resulting images for a protracted time, well after they have been created. Modern digital CRTs can display these images alongside other sensor data, such as ESM data collected at the same time by the same mast. The officer viewing such a windowed CRT can fuse the data from these various sources to form a much better tactical picture. In theory, the same CRT could also display relevant sound data, again adding to the overall tactical picture in a way impossible for a conventional optical system.

Perhaps at least as important, the commander of the submarine would no longer have to be the operator of the periscope sensor, just as the commander is not the operator, but rather the supervising user, of the various other acoustic and non-acoustic sensors on board a submarine. The skipper could obtain the full tactical picture without having to concentrate all attention on the necessarily fleeting periscope image. Those manufacturers offering digital optronic or photonic periscopes, such as Dowty, Plessey, and Kollmorgen, tend to suggest radically revised arrangements for submarine control rooms or operations rooms, in 1 case with the periscope image on a large screen on 1 bulkhead, surrounded by relevant data-base readouts (e.g., the characteristics of the ship shown on the screen, to the extent that the expert computer system connected to the data can identify the contact).

An optronic sensor might also be far lighter than conventional periscope-head optics and, thus, might be much easier to stabilize and even to control in an autotrack mode.

Moreover, there is no reason why an optronic or photonic sensor must be mounted on a mast penetrating into the control room of the submarine. In some submarines, such as the German IKL designs, all masts other than the periscopes are already nonpenetrating; they telescope out of the sail of the submarine. Nonpenetration reduces structural stress in the submarine's hull and can simplify mast design since the body of the mast no longer needs to be pressure tight. Instead, most of the mast can be free-flooding. That design would allow the use of non-metallic (i.e., non-radar-reflecting) materials. Moreover, there are considerable advantages (both in drag and in radar cross section) to be gained by using a noncylindrical mast (which is acceptable if the head, rather than the entire mast, rotates).

A control room or CIC served by an optical periscope must be directly under the sail, and that requirement complicates the arrangement of the submarine. For that matter, the central position of the optical periscope greatly complicates the internal arrangement of the control room or CIC; in theory, a much more efficient arrangement is possible. Presumably, the ultimate simplification would be to eliminate the mast altogether, placing the optronics and other sensors in a towed body that the submarine could launch and recover and that would use some inertial device (such as a ring-laser gyro) to locate itself relative to the hull of the submarine. In theory, such a development would greatly reduce the drag and noise of the sub-

marine's hull, and the submarine could remain much farther below the surface at what would amount to periscope depth.

In practice, submariners have resisted total dependence on any form of electronics; an optical periscope will still work even if electrical problems have put computers and displays out of action. Attempts to eliminate the submarine's sail altogether have been quite frequent, at least in the U.S. Navy, but have generally failed because the sail is needed for some other quite essential purposes: for good depth keeping near the surface in relatively shallow water (but this requirement does not apply to a submarine with her foreplanes on her hull); for navigating on the surface (e.g., when entering port); and for supporting the snorkel.

FRANCE

◆ Pivair

This SAGEM/SOPELEM optronic periscope incorporates a CTX thermal imager usable under day and night conditions. The optical and IR channels are both biaxially stabilized. The mast-head carries an ESM antenna and the gyro-stabilized unit for both conventional optics and the IR camera. Besides the usual binocular optics, the base of the mast carries a sextant, a 35-mm camera, and the IR monitor. Optical magnification is $1.5\times$ or $6\times$ ($12\times$ optional) (FOVs: 26, 9, 4.5 deg). The angle of elevation of the FOV is $+80/-10$ deg. The FLIR operates at 8–12 micron (3×6 -deg FOV, and the same sighting angle).

SAGEM offers a range of optronic periscopes with 8–12 micron FLIRs, all of which can operate in an IR surveillance mode (360-deg scan) and all of which have biaxially stabilized optical and IR channels (so that high magnification can usefully be employed). These periscopes are insulated against vibration at high speed. The FLIRs are cooled by refrigeration (Joule-Thomson effect), and their images can be observed either by eyepiece or remotely. All periscopes incorporate both sextants and GPS receivers, the sextant data being automatically processed (using a built-in ephemeris). These periscopes can be connected so that target designation (elevation and true bearing) and range are automatically transmitted to the WCS.

These periscopes still penetrate the submarine's hull. SAGEM also offers a new generation of nonpenetrating optronic masts, each carrying a FLIR and a high-definition television, with slow automatic rotation. Both image channels are gyro-stabilized, and magnification can be controlled. The mast is pressure-proofed.

◆ SOPELEM Periscopes

Optical attack and search periscopes are manufactured by SOPELEM. The standard search periscope can incorporate a gyro-sextant, a range-only radar, and an RWR. There is generally an integral 35-mm camera (containing 250 frames of film in the case of PIVAIR, described above). Typical types are:

Attack Periscopes

ST3 for the *Daphne* class.

ST5 for the *Agosta* class. Magnifications $1.5\times$ and $6\times$ (corresponding FOVs 30 and 7 deg); elevation limits $+30/-10$ deg. The operator is provided with a seat.

Search Periscopes

M41 for the *Daphne* class.

J hull-penetrating periscope for the *Agosta* class. It incorporates the APA-4 attack-radar antenna and the AUD omnidirectional ESM antenna. Magnifications: $1.5\times$ and $6\times$ (corresponding FOVs: 20 and 5 deg).

K incorporates a light intensifier. Magnification is $5\times$, FOV 10 deg, elevation limits $+10/-10$ deg. Daylight magnifications are $1.5\times$ and $6\times$ (corresponding FOVs: 36 and 9 deg); elevation limits $+80/-10$ deg.

SOPELEM designed a special, integrated, nonpenetrating periscope system for the projected CA-class low-manning export submarine. The system is interesting because, unlike all other existing periscopes, it is integrated with other sensors and

mounted in the side of the control room rather than in the center.

The submarine has 3 nonpenetrating masts: an optical periscope, an optronic periscope, and an ESM antenna; all are contained in a single watertight chamber outside the pressure hull, with the optronic and optical masts side by side. The hull is penetrated only by electrical cables, hydraulic piping (by means of which the masts are raised), and the optical path from the optical periscope. The last is arranged so that it feeds a fixed binocular eyepiece, no matter in which direction it turns. The eyepiece is part of a console, the other side of which carries 2 CRTs for the optronic mast. Each position carries a handwheel to power-turn the mast. The advantage of this arrangement is that the periscope observer can easily compare the image with those presented optronically. Moreover, the observer is located close enough to other instruments to be able to see the consoles and other displays used for navigation. However, because the optical image is viewed only through an eyepiece, such comparison and reference cannot be direct. Nor is there any provision for windowing, i.e., for presenting several different displays simultaneously on the same CRT. That limitation probably means that the optronics is still analog rather than digital. The periscope console is still under the mast (which is off the centerline of the boat), and the console can still be viewed only at very close range.

The CA-submarine project was never sold, but its SOPELEM periscope console would seem to present an interesting intermediate point between the current conventional optical periscope, which dominates control-room arrangement, and the currently proposed pure-optronic arrangements.

◆ SSBN Periscopes

SAGEM is working on 2 periscopes for the next-generation French SSBN: a new optronic search periscope and a nonpenetrating optronic mast. The search periscope carries a thermal imager (using CCDs), and optical magnification is up to $24\times$. The companion mast carries a navigational radar, an LLLTV, a high-resolution TV, a FLIR, and an ESM sensor.

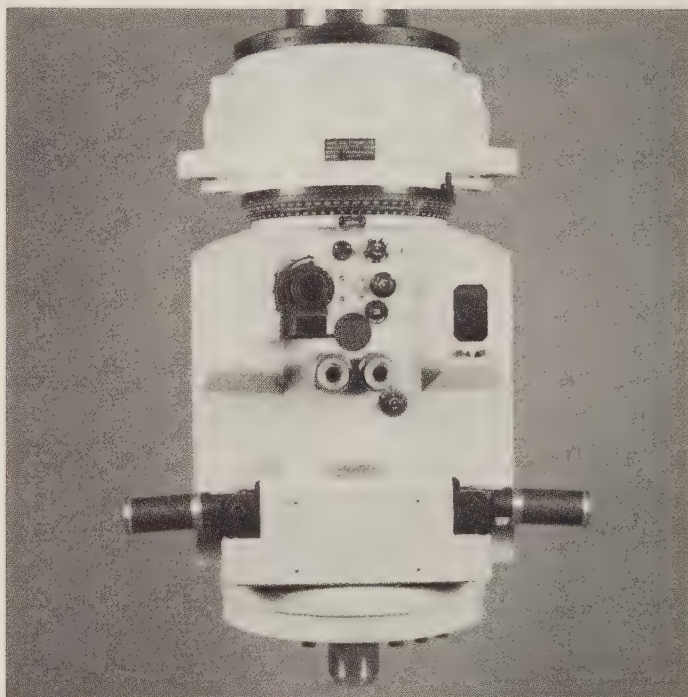
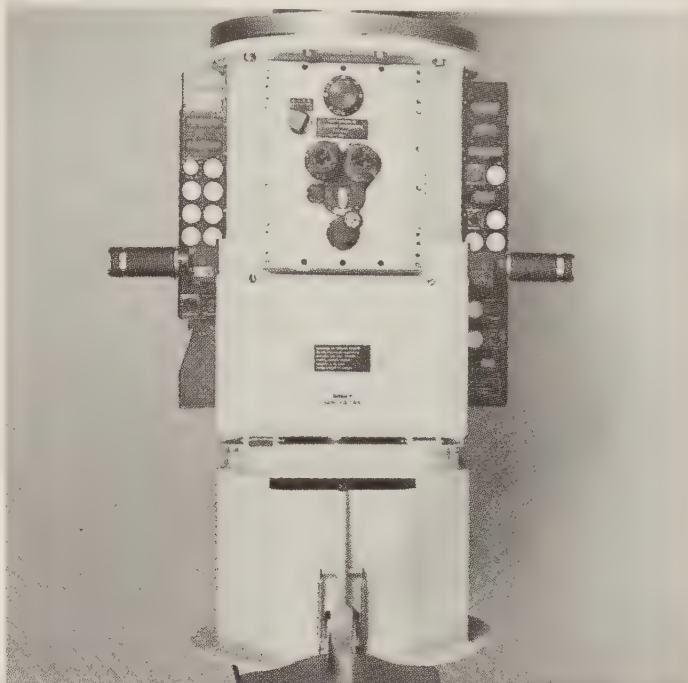
GERMANY (WEST)

◆ Series 80

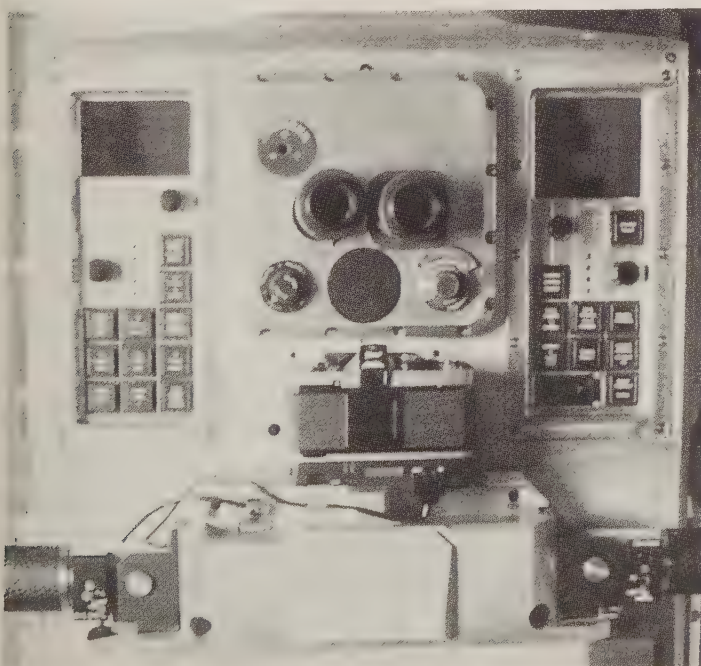
Carl Zeiss optronic search and attack periscopes incorporate FLIRs, laser range-finders, and 2-axis stabilization.

UNITED KINGDOM

Barr & Stroud, a division of Pilkington Optronics, is responsible for submarine optical periscopes. Attack periscopes are desig-



(Above and left) Standard Barr & Stroud eyepieces for the 254-mm attack periscope, the 254-mm search periscope, and the 190-mm attack periscope. (Pilkington)



nated in a CH series, search periscopes in a CK series. There are 3 current types: 127-mm periscopes for small submarines (300–400 tons), which may have only 1 periscope, and 190-mm and 254-mm for larger ones. The large diameters were adopted to increase stiffness and so to reduce vibration at high speed. Existing earlier search periscope types are CH74, 75, 77, and 81; the current types are CH84, 85, and 86.

All of the current periscopes are fitted with a patented device permitting use at up to 16 kt, although 12 kt is more usual. At least in the latest search periscopes, the optics are arranged to reduce the effects of vibration by splitting the optical path at the point at which the periscope enters the submarine's sail. The standard periscope television vidicon tube is a 16-mm monochrome SIT unit.

The image intensifier available for all the current Barr & Stroud periscopes is a 50/40-mm Mullard Type xx 1332, pro-

viding a gain of up to 30,000 times. It employs an auxiliary large-aperture (110-mm, 4.3-in) window, which remains below the surface in daylight (to avoid glint). The system operates at a magnification of $6\times$ (7-deg FOV); elevation limits are $+15/-7.5$ deg. This device has been installed in Canadian *Oberon*-class submarines, and the Australian and Chilean *Oberons* are likely candidates.

As an alternative to an image intensifier, Barr & Stroud has packaged 8–13-micron-band FLIRs into its periscopes, beginning in 1978. It uses the same 110-mm window, but this time 1 made of germanium.

The standard laser range-finder is a NdYAG accurate to within 10 m, using a 10-nanosec Q-switched pulse.

◆ CH84/85/86

CH84 is the attack periscope of the *Trafalgar* and *Upholder* classes; the other 2 are related. Foreign sales include the new Australian submarines.

These periscopes often carry keypads on both sides of the binocular eyepiece so that the officer at the periscope can transmit periscope data to the FCS. The optics are quasibinocular to reduce eyestrain. These periscopes are fitted with image intensifiers (between head and eyepiece) and with laser range-finders. A television camera can be fitted in the rear of the ocular box (opposite the eyepiece), transmitting the periscope image to a remote monitor that may be connected to a video recorder. When the periscope is fitted with a FLIR, the image goes directly to the remote monitor. Relative bearing is taken from an optical encoder in the periscope crosshead, and the left eyepiece can display the corresponding true bearing. If the laser range-finder is fitted, its range data are displayed in the eyepiece. Otherwise, a stadimeter is used, and a target's range is computed automatically (given that the target's height is keyed in manually on a remote unit).

The main tube's diameter is 254 mm [10 in], with a 70-mm [about 2.75-in] upper tube; total height is about 14 m [about 46 ft]. Available magnifications are 1.5 and 6 (corresponding FOVs are 32 and 6 deg).

◆ CH99

This is a 190-mm attack periscope, which can be equipped with a thermal imager or an LLLTV camera. The FLIR is mounted at the head of the periscope, behind a separate germanium-coated window; the eyepiece carries a CRT to display the image. Magnifications are $1.5\times$ and $6\times$.

◆ CK34/35/36

These are Barr & Stroud's current standard search periscopes. CK34 is for the *Trafalgar* and *Upholder* classes; the others are modified versions. Operation is quasibinocular with 4 magnifications: $1.5\times$, $3\times$, $6\times$, and $12\times$ (FOVs: 24, 12, 6, and 3 deg). The periscope carries a sextant, the new AHPS 4 (artificial-horizon periscope sextant). This device automatically prints out the observed altitude, bearing, and time of observation. As in the case of the imager in the attack periscope (and in this one) this capability is 1 step away from complete integration with other submarine systems: the sextant could, at least in theory, feed the submarine's digital navigation subsystem directly.

As in the case of the attack periscopes, the images in the eyepiece can be captured by a television camera for display on a remote monitor. Overall tube diameter is 254 mm [10 in] and height is about 14 m [about 46 ft].

◆ CK40

This combined-purpose (search and attack) 127-mm periscope for small submarines is large enough to accommodate an image intensifier (starlight scope) and a stadimetric range-finder. Unlike the larger-diameter (binocular-eyepiece) periscopes, CK40 has a monocular eyepiece, and the line of sight is not stabilized. It lacks provisions for range conversion or transmission and cannot accommodate an ESM antenna, a television camera, or a FLIR. CK40 cannot be power-driven. There is no true bearing

scale and no digital bearing readout; CK40 has only a relative bearing scale. Like the larger-diameter Barr & Stroud periscopes, CK40 has a heated window and eyepiece and a microphone.

◆ CK59

This is the search version of the 190-mm periscope. The head is large enough to accommodate an image intensifier (starlight scope) at its head. The image intensifier can be moved into or out of the optical path. There is also provision for a FLIR. Rotation can be by power, at a speed between 0 and 12 rpm. Elevation limits: $+35/-10$ deg (up to $+74$ deg with half the FOV). FOVs at high/low magnification are 8 and 32 deg.

CK59 has all the features of the 254-mm series, except for provision for a FLIR and relative bearing readout.

◆ Optronic Masts

Barr & Stroud has developed an optronic masthead carrying a FLIR, a television camera, ESM, and communications. Diameter is about 340 mm [13.4 in] but can be reduced to 220 mm [about 8.7 in] if a reduced elevation (up to a 50-deg limit) is accepted. This masthead has been selected for the *Vanguard*-class Trident-missile submarine. In the spring of 1989 Barr & Stroud claimed that by the end of that year it would have put its optronic mast to sea on a foreign submarine.

Plessey now offers its own optronic periscope on a nonpenetrating mast originally developed for submarine communications.

◆ SSN 20 Periscope

Three teams have submitted proposals for an optronic mast for the next-generation attack submarine (SSN 20). Two are to be chosen for parallel project-definition contracts. The choice was scheduled for April 1990, but it has been delayed because of budget problems. These masts may run trials on board a diesel boat. Reportedly, the first 7 SSN 20s will have conventional optical periscopes to back up their optronic units.

The specification calls for high-definition, low-light, color TV cameras; thermal imagers; and ESM and communications antennas. The mast is to be capable of continuous rotation, with



Plessey's optronic mast, with its 2 independent sensors. (Plessey)



The Barr & Stroud (Pilkington) optronic mast, with ESM ports atop the wake-reducing fairing. (Pilkington)

a wave-following (i.e., low-wake) profile, and provide stabilized line of sight for the optronic sensors.

The teams are

- Dowty (Gresham Division)/Kollmorgen, using the latter's standard vertical head (see Model 86 in the U.S. section).

- Pilkington Optronics/Logica Space and Defense: a vertical arrangement with spiral DF antennas below the optics.

- Plessey Naval Systems: a conical ESM antenna atop an elevating cylinder with lenses side by side rather than vertically spaced. It is based on the company's communications mast, using RAM for stealth and a faired shape to avoid vibration.

The Pilkington Optronics mast shows a TV/visual window, with a thermal-imager module below it. The mast carries an omnidirectional ESM antenna at its head, and 6 DF antennas below the rotating thermal module, atop the nonrotating part of the mast. Below it is the circular de-plumer, and below that is a nonrotating fairing. The mast incorporates stabilized zoom optics, and it may employ a new Ferranti miniature video camera, using an MOS sensor, with 400-line resolution, a 28-mm lens, and zoom aperture limits of $f/2.8$ and $f/250$.

UNITED STATES

Kollmorgen and Sperry Marine manufacture all U.S. Navy periscopes. Attack submarines carry 1 attack (Type 2F, replacing Type 2D) and 1 search (Type 18 and 18B, replacing Type 15, which in turn replaced Type 8) periscope. Type 15 introduced search receivers integral with the periscope. *Permit/Sturgeon*- and early *Los Angeles*-class submarines are equipped with Type 15D. *Ohio*-class strategic submarines are unusual in carrying 2 general-purpose periscopes, Types 8L and 15L.

Unlike Barr & Stroud, the U.S. Navy did not increase periscope tube diameter to counter vibration at high speed. The U.S. approach was to build a hydrodynamic fairing around the outside of the periscope, retaining the small diameter of earlier types. This choice would have been a major advantage in the large U.S. post-1945 submarine modernization (Guppy) program.



Typical U.S. faired periscopes aboard a *Los Angeles*-class submarine off Norfolk, October 1986. (Jürg Kürsener)

◆ Type 2

The original Type 2 attack periscope was introduced in 1942. It had a long slim (1.4-in) neck and a very small head; a range-only radar, ST, was added during the war. A new Type 2D (1959) incorporated postwar advances in optical design and optical coating and is the basis of current U.S. attack periscopes. Type 2D contains a tilting head prism (elevation $+74/-10$ deg) and is bifocal, for 2 magnifications ($6\times$ and $1.5\times$; FOVs 8 and 32 deg). The stadimeter at the periscope head can be used at both powers, and the head window and eyepiece are electrically heated to avoid fogging and ice formation. A camera adapter can be fitted. Overall length is 45 ft 2.875 in (optical length 43 ft 3 in), and the outer tube diameter is 7.5 in.

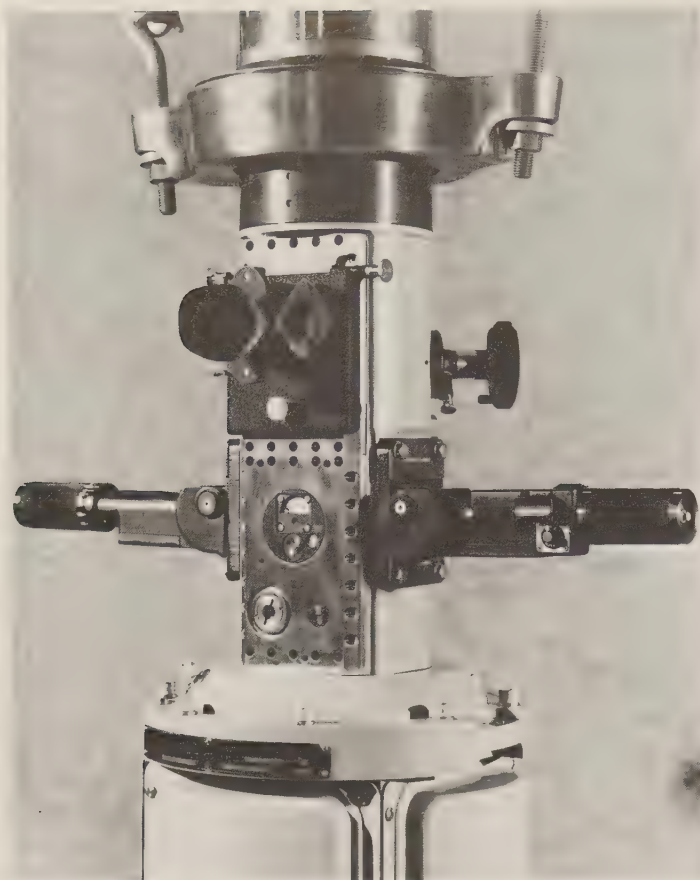
◆ Type 8L Mod (T) and Type 15L Mod (T)

This combination equips *Ohio*-class strategic missile submarines, Type 8L to starboard (carrying the ST range-only radar) and Type 15L to port (carrying ESM). Elevation limits are $+60/-10$ deg, and magnifications are $1.5\times$ and $6\times$ (FOVs 32 and 8 deg). Each periscope is 46 ft long. Television camera and still-photographic camera attachments are available.

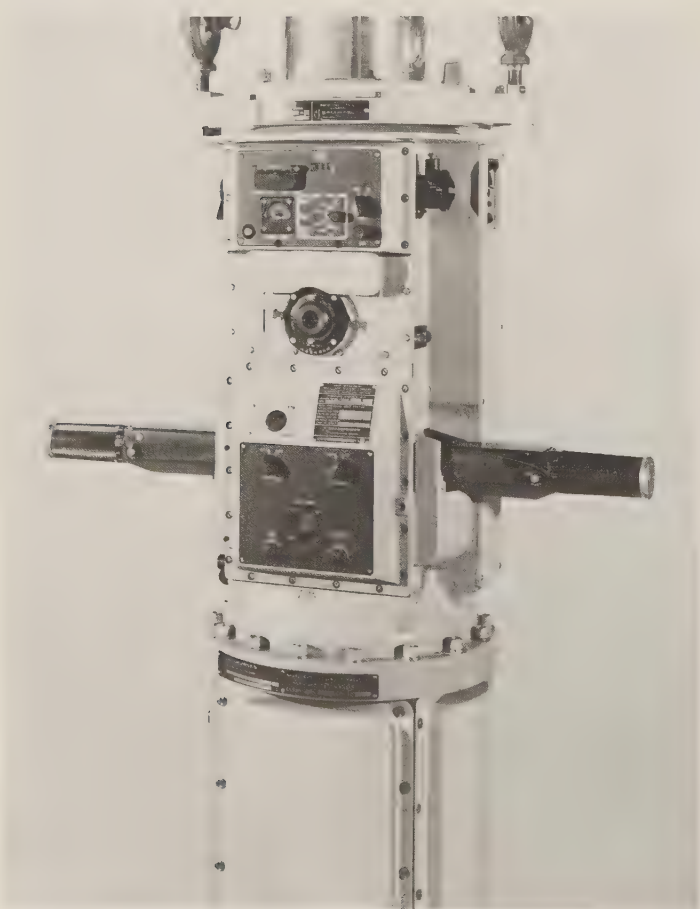
◆ Type 18

The current U.S. search periscope carries ESM intercept antennas above its gyro-stabilized optics and can provide image intensification and LLLTV for low-light operation. Train is power-assisted. There are 2 versions. Type 18B has an overall length (to top of radome) of 36 ft 10 in (optical length 36 ft from the center of the eyepiece to the zero-elevation line of sight at the prism in the head). Type 18D is 42 ft overall (optical length 41 ft 4 in). Magnifications: $1.5\times$, $6\times$, $12\times$, $24\times$ (FOVs 32, 8, 4, 2 deg). Elevation limits: $+60/-10$ deg. The LLLTV provides a 525-line format interlaced 2:1, 30 frames/sec, using a minimum of 16 gray scales; the sensor is a silicon-intensified target vidicon. Periscope functional modes are day, night, visual, TV/visual, IMC (image-motion compensated), camera, and gyro.

Sperry Marine's Type 18 Periscope ADF Group is the associated ESM system; it has been adapted to surface craft as



The eyepiece of a Trident submarine's periscope (probably Type 15L). (Kollmorgen)



The eyepiece of a Type 18 periscope, as installed on board *Los Angeles*-class submarines. (Kollmorgen)

Guardian Star (see the Antiaircraft Warfare section). It is a UYK-44-based system with a touch screen. There is no formal AN-series designator. Production is competed on an annual basis, and AEL recently won the second production lot.

Sperry Marine was selected to design Type 8J Mod 3 for the new *Seawolf*-class submarine. As of early 1991, the contract for the *Seawolf* search periscope had not yet been let.

◆ Model 76

Kollmorgen's export periscope is made in both search and attack versions; both have binocular eyepieces with split optics. Model 76 periscope ship sets are designated by separate Model numbers, e.g., 322 and 323 for the Italian *Pelosi* class (1 incorporating a laser range-finder), 324 for Italian navy *Sauros*, and 374 for Turkish Type 209s. These periscopes are also used on board the Brazilian Type 1400, the Indian Type 1500 (*Shishumar* class), and the Swedish *Nacken* class, among others.

Magnification: $1.5\times$ and $6\times$ (FOVs 32 and 8 deg); elevation limits are $+74/-10$ deg in the attack version and $+60/-10$ deg in the search version. Optics are line-of-sight stabilized. Overall diameter is 7.5 in.

The attack version carries a broad-band RWR with a display on the control unit of the periscope. The head carries a stadimeter. Optional features include a $12\times$ telescope, power rotation, a television camera feeding a remote unit (carrying a 9-in CRT), an image intensifier, a FLIR, and a video, laser, or radar range-finder. The optics can be focused down to a minimum range of 50 m.

The search version has the same powers of magnification as the attack version. Higher magnification in the form of a $2\times$ Galilean telescope (mounted in the inner structure of the mast) is available as an option. Like the attack version, the search version incorporates a stadimeter transmitting range electronically to an SFCs. The search version can carry a sextant, LF communications antennas, a satellite navigation antenna, and an ESM early-warning antenna, as well as laser and radar ranging, thermal imaging, and image intensification.

The image intensifier is mounted in the mast. In the night mode, the cube containing it is rotated 90 deg, placing the intensifier in the main optical path of the periscope and feeding the eyepiece. Typical performance, based on a ship with a vertical dimension of 10 m (a corvette), with target reflectivity of 17% is (with probability 0.85).

Illumination	Detection	Recognition	Identification
Starlight	1.5 km	0.7 km	0.5 km
Quarter Moon	2.5 km	1.3 km	1.0 km
Full Moon	4.5 km	2.4 km	1.7 km

A FLIR can be mounted between the periscope's optical head and the ESM antenna. Kollmorgen offers a serially scanned 8–12-micron SPRITE unit with a $12/4$ -deg FOV and a 0.2-mrad beamwidth. It is cooled by a split Stirling/closed-cycle refrigerator, and Kollmorgen claims that a target can be detected at 15 km, recognized at 5 km, and identified at 1.9 km.

Kollmorgen offers a television video range-finder ("stad monitor") as a complement to the television video monitor, performing split-field ranging. When the operator presses the INIT button, the image doubles vertically; the operator moves the upper image to place the mast of the lower image on the waterline of the upper one. The operator dials in the masthead height of the target, and the range is automatically computed and presented in the eyepiece.

The radar range-finder uses a slotted-waveguide antenna below the optical window of the periscope. Kollmorgen claims that the radar can be used to track surface ships. The laser range-finder is mounted in the base of the periscope, opposite the viewing optics, with a swinging mirror (as in a single-lens reflex camera) to bring its beam into the main optical path.

Kollmorgen offers a broad-band antenna with a crystal video receiver integrated into the top of the attack periscope head, with omnidirectional coverage (2–18 GHz, sensitivity -35

dBm). Indication is by LED (band, CW, or pulse) and audio alarm, the indicators being mounted on the periscope crosshead. Alternatively, a more elaborate (and more massive) ESM/DF antenna can be mounted in the head of the periscope, covering the same frequency range but providing either quadrant or 10-deg directional accuracy. This system can connect to other submarine systems.

The sextant uses the periscope synchro to read off its line of elevation from the deck plane, the target-bearing transmitter to measure the target's direction relative to the submarine, and a built-in vertical reference to determine tilt and cross tilt angles so that the sextant can measure star altitudes relative to the true horizon. The corrected altitude angle, bearing angle, and time are displayed and printed.

The basic periscope can also be fitted with a microphone, allowing the user to communicate with other parts of the submarine while making observations.

◆ Model 86

Model 86 is the nonpenetrating 2-stage optronic mast currently under development by Kollmorgen. There are 2 windows arranged vertically, 1 for television, and below it 1 for a FLIR. The main television sensor is a color CCD, but prisms can direct the optical path down to a light-intensifier. A mirror behind the FLIR window directs the thermal path down the axis of the periscope to a thermal camera. The entire photonic system is

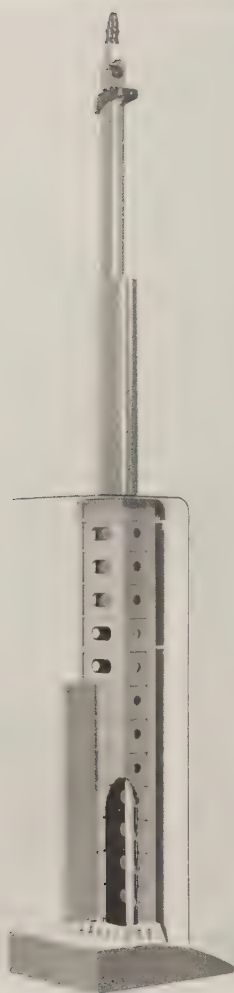
2-axis stabilized. The CCD television camera has 3 FOVs, 22.8, 10, and 4.4 deg; elevation limits are +74/-10 deg. The 8-element SPRITE FLIR system has 2 FOVs (2 magnifications), 10 and 4.4 deg; elevation limits are +55/-10 deg. It operates at 8-12 microns (with 3-5 micron operation an alternative option). The head should be capable of a sector scan in less than 2 sec, and a full scan in 5 or 6 sec (or less using a black-and-white camera). Kollmorgen expected to evaluate a new color CCD camera for the U.S. Navy early in 1990. The ESM coverage requirement depends on the customer but is typically 1-40 GHz, with a DF accuracy of 5 deg, and with threat analysis and identification. The ESM head can also accommodate a GPS antenna.

Late in February 1989 Kollmorgen announced a joint venture with Riva Calzoni of Italy to develop a new generation of nonpenetrating mast and sensor systems for future submarines. Riva Calzoni has supplied numerous nonpenetrating masts, both to the Italian navy and to other NATO and non-NATO navies, since 1967. The head of the Riva Calzoni-Kollmorgen periscope will be based on that of the Kollmorgen Model 86. The mast is a new 2-stage type based on the current Riva Calzoni 1-stage nonpenetrating mast. Video connections would be by fiber optics (work is proceeding on a rotary fiber-optic joint), and there would be no waveguide connections (the ESM sensor may use a copper cable; in future, the ESM array may digitize its data at the masthead and send it down in optical form).

The U.S. version of the periscope will use a Raytheon or Singer Librascope console; the Italian version will use the Selenia MAGICS console.

An artist's concept of a next-generation submarine control and imaging center, fed by a nonpenetrating optronic periscope. (Kollmorgen)





(Above and right) Kollmorgen's Model 86 nonpenetrating periscope. (Kollmorgen)

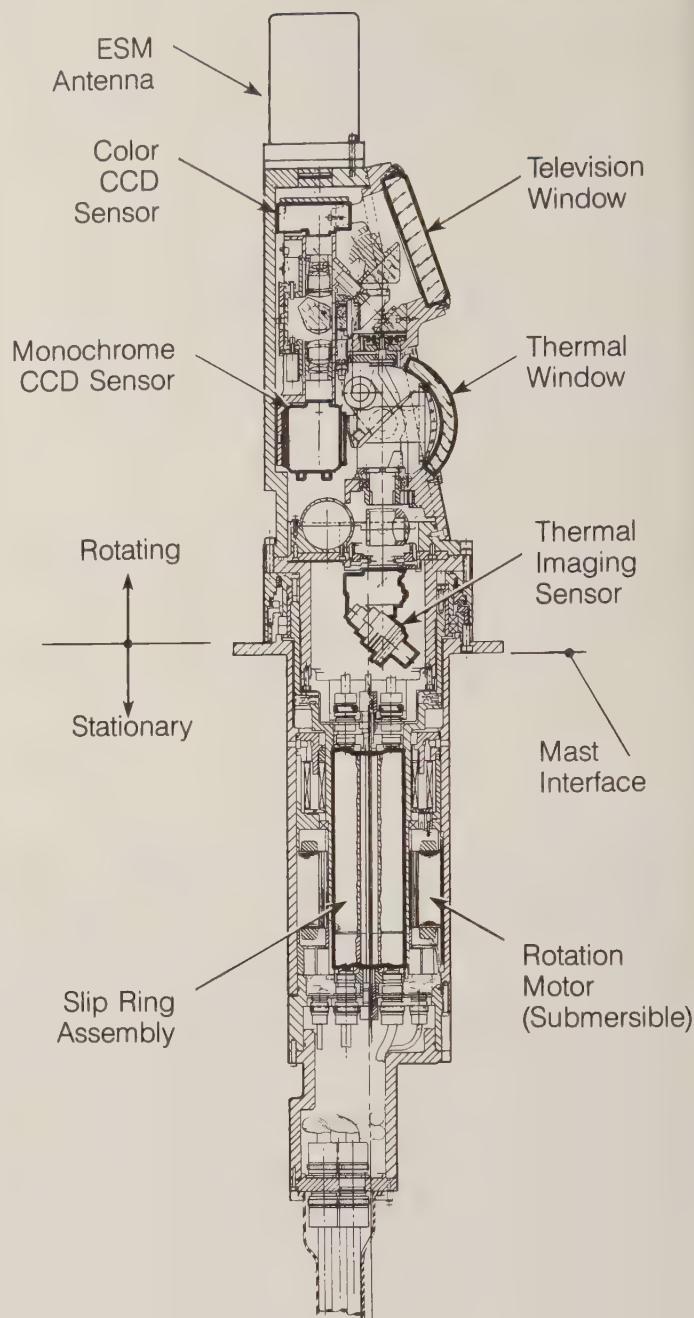
◆ Other Optronic Periscopes

The U.S. Navy does not currently use any optronic periscopes. However, in recent years there has been considerable interest in the subject. An R&D (technical demonstration) optronic-scope project, Dark Eyes, was begun about 1979 and was tested at sea but never entered production, and by about 1984 Dark Eyes had been retired. Dark Eyes suffered because it was a special-purpose system (limited to the 8–12-micron band) and because installation in the sail of a submarine proved extremely expensive. It did employ a nonpenetrating mast.

The broader-spectrum optronic ("photonic") concept is now being pursued. An experimental electro-optical periscope image-storage system is operational at NUSC New London. About 1985 the U.S. SSN 21 (*Seawolf*) program became interested in a nonpenetrating photonic mast. A research program, begun in 1986 under navy auspices, was soon taken over by DARPA, the latter awarding Kollmorgen a \$3.5 million prototype contract early in 1989. This prototype was to be installed on board the experimental submarine *Memphis* early in 1990.

Early in February 1989 Dowty (of the U.K.) announced a collaborative venture with Kollmorgen to develop optronic replacements for existing Royal Navy (and, later, other) optical periscopes. Dowty described the joint venture as a combination of Kollmorgen's electro-optical skills with its own command, control, and display expertise. In this case the mast would also be nonpenetrating, its head carrying both optical and IR cameras. Images would be transmitted into the hull by fiber-optic cable.

The DARPA, Riva Calzoni (Model 86), and Dowty projects are all separate. DARPA and Dowty are concentrating on the



requirements of, respectively, the U.S. and Royal Navies, whereas the Riva Calzoni project is for wider commercial application. Prior to these announcements, Kollmorgen had advocated optronic nonpenetrating periscopes for some considerable time, publicly at least since 1986.

SONOBUOYS AND AIRBORNE SIGNAL PROCESSORS

Most Free World sonobuoys are built to a standard "A"-size ($4\frac{7}{8}$ in $\times$ 36 in) to fit the buoy ejectors of such aircraft as the Nimrod, P-3 Orion, and Atlantique. "B"-size is $6\frac{7}{8}$ $\times$ 60 in (ERAPS size); "C"-size (9 in $\times$ 60 in) was used only by Britain; and "D"-size is 3 in $\times$ 15 in (projected for submarine underwater signals). "E"-size probably refers to a projected D-size sonobuoy. "F" is a dwarf (A/3) size ($4\frac{7}{8}$ $\times$ 12 in) now used by the Royal Navy and for some French buoys. The U.S. Navy is considering an A/2 size ($4\frac{7}{8}$ $\times$ 16.5 in), which may be designated "F." "G" is A/2 size ($4\frac{7}{8}$ $\times$ 18 in), but it was discarded because a filler was needed between 2 buoys in a launch tube: hence the choice of the 16.5-in length.

In 1973 the Space Development Corp. announced that it had developed a smaller-diameter (conventional length) equivalent

of SSQ-41, several of which could be loaded side by side into a standard A-store tube and which, therefore, could be launched in any order, unlike Dwarfs. See the entry for SSQ-41 below.

The other major factor in sonobuoy operations is the number of available radio channels (for the link with the airplane), typically either 31 or 99. As sonobuoy range decreases because of submarine quieting, the number that must be laid to gain contact (or to search an area) increases; therefore, more channels are needed. About 1984 the major improvement was the increase from 31 to 99, as reflected (in the U.S. Navy, for example) by replacement of the 31-channel ARR-72 receiver with the 99-channel ARR-78.

In these notes, LOFAR (low-frequency analysis and recording) is spectral analysis using time integration to pick up stable narrow-band signals amid the surrounding noise. CODAR is a correlation-display analyzing recorder, which measures the time difference between reception of the same signal by 2 buoys. As in the PUFFS passive ranger for submarine fire control, CODAR can obtain the direction of a signal relative to the 2-point hydrophones that pick it up, given knowledge of the spacing of the buoys (which were dropped at specified points by intervalometer). If the time of the signal's origination is known, CODAR also gives a range. The system of dropping a signal depth charge and then using CODAR to pick up the echoes of the explosion off a submarine is code-named Julie. Originally Julie was developed by the U.S. Navy as a way of using existing

passive buoys despite silencing of Soviet submarines in the late 1950s. (Reportedly the name Julie honored a stripper who could "make a passive buoy active.") It was largely abandoned in favor of a new passive technology, LOFAR (code-named Jezebel). The necessary signal-processing technology has survived, however, and Julie probably has not been altogether abandoned.

A LOFAR buoy differs from other passive buoys in that it has a narrow frequency range since the processor will concentrate on frequencies around the particular line of interest. Signals within the prefiltered narrow range will be transmitted very precisely, for further analysis on board the airplane. The buoy behaves much like a crystal-video ESM receiver, limiting its response to a zone of interest but not providing precise data within that zone. Although a submarine may emit strongly at only a very few frequencies, acoustic conditions on a given day may make it easier to detect some harmonic of 1 of those lines. Typically, then, a searching airplane drops XBT and background noise buoys, and then the LOFAR buoys are set for the line sought. Thus, although a LOFAR buoy may have a frequency spectrum of many octaves, in practice it is set for a much narrower range of frequencies; the actual range (which is related to the precision of the processor) is classified. A LOFAR-CODAR buoy can be set for either narrow or broad frequency range operation.

DIFAR is directional LOFAR. A DIFAR buoy has 2 beam patterns, at right angles to each other; it, therefore, measures 2 components of the signal it detects. It sends 2 LOFAR signals (corresponding to its 2 beams) up to the monitoring airplane, plus a sense signal to resolve the 180-deg ambiguity in the 2 beams. Thus, from a signal-processing point of view, 1 DIFAR buoy equals 2 LOFAR buoys. Signal processing includes comparison of the 2 signals, generally using an arctan function to derive an angle. The resulting direction is not precise because the 2 beams overlap to a limited extent, but target direction can generally be found within about 10 or 15 deg.

There are also command-activated pinging buoys, either omnidirectional (range-only, or RO, also called CASS, for command-activated sonobuoy system) or directional (e.g., the U.S. DICASS and the British CAMBS). Typically, active CW is used to measure target speed (doppler). FM pulses (equivalent to pulse compression in radar) are used for range resolution. Typically, the pulse length can be varied by command; a longer pulse gives longer maximum range but can suffer from reverberation.

Sonobuoys require a number of settings. When they are launched from within an airplane's pressure cabin (as in the British Nimrod, for example), the crew sets them at launch time. The U.S. P-3C carries them externally, in sonobuoy



B-size Stretch A A-size G-size F-size A/6
The range of sonobuoy sizes. (Sparton)



Standard A-size sonobuoys being loaded. The vanes protruding from their heads are rotochutes, which slow the buoys as they descend. (U.S. Navy)

launch containers (SLCs) set before flight time. If the launchers are inside the pressure cabin, then the cabin must be depressurized if multiple buoys are to be launched (the Nimrod uses a 6-rnd launcher) or else launched 1 by 1 through a special pressurized launcher. An airplane intended to launch buoys from high altitude (e.g., while monitoring a large field) must almost inevitably use external launchers.

In the case of the P-3C, the aircraft tactical system is aware of which buoys are set in which way and selects the ones it wants. This method becomes less satisfactory as the number required to prosecute a contact grows toward the total on board, and as the buoys themselves become more flexible in their operation (so that setting involves more tactical judgment, made at the scene of prosecution). The 2 available solutions are a command down-link and remote setting on board the airplane.

AUSTRALIA

SONOBUOYS

◆ Barra (SSQ-801/SSQ-981)

Barra is an A-size (914 mm × 123.8 mm, 12.7 kg) broad-band (10–2000 Hz) array sonobuoy, employing 25 hydrophones in a horizontal configuration (planar array consisting of 5 outstretched arms). The 60 beams formed by the array can be steered horizontally, and bearing data are provided by an internal magnetic compass. Because the beams can be quite narrow, the manufacturer, Sonobuoys Australia, claims that a single Barra can provide detection, classification, and unambiguous bearing information. Two units should, therefore, provide rapid passive localization.

Array depth is either 21.5 or 128.5 m, and operating life is 0.5, 1, 2, or 4.5 hr. Fifty VHF channels are available; data are transmitted at 136–173.5 MHz (channels are spaced 0.750 MHz apart), the data-sampling rate being 8.29630 kHz.

Processing is done by either an AQS-901 (RAAF Orion or RAF Nimrod) or the combination of a UYS-503 sonobuoy processor and an AQA-801 side processor in a helicopter (RAN Sea Hawk).

SSQ-981 is a version for the U.K. MoD, developed by Plessey, which claims that its manufacturing techniques reduce unit cost. Dimensions match those of the original SSQ-801, but weight is reduced to 11 kg. Alternatives for the operational life span are 1, 2, 3, or 4 hr, and the operating depth is 21.5 or 121 m.



BARRA sonobuoy. (Plessey)



BARRA array deployed underwater, looking down. (Plessey)

Compass resolution is 0.36 deg, and accuracy is 1.0 deg at less than 65 deg in latitude. At least in the case of the Plessey version, the airborne processor forms 60 beams.

The program began in 1969 as Project Barra, full development being approved late in 1974. Initial production was completed by Amalgamated Wireless late in 1981.

The Barra production rate for the Royal Australian Navy in 1981–89 was 2000/yr, but as of 1989, it was rising to 2500/yr, to provide for exports to the Royal Navy. By 1989 a total of more than 30,000 had been manufactured.

Sonobuoys Australia is now developing a variant of Barra (E Barra, i.e., E-sized Barra) with a VLSI in-buoy processor, allowing it to operate without a dedicated Barra airborne acoustic processor. The same in-buoy processor also forms part of a completely new buoy, as yet unnamed, that the company is developing under a contract from the Australian Defense Science and Technology Organization (DSTO).

CANADA

SONOBUOYS

◆ SSQ-512 and -520

Julie buoys (for explosive echo ranging) are A-size, with a lifetime of $\frac{1}{2}$ hr or $1\frac{1}{2}$ hr. The hydrophone depth is 60 or 600 ft, and the buoys have 31 radio channels.

◆ SSQ-517 and -518

These passive A-size LOFAR/CODAR buoys operate omnidirectionally (10 Hz–10 kHz). SSQ-517A has a lifetime of 1 or 3 hr; -517B lasts $\frac{1}{2}$ hr or $2\frac{1}{2}$ hr. Both have a hydrophone depth of 100 ft. SSQ-518 and -518A are much longer lived, respectively, $13\frac{1}{2}$ and 8 hr. All report on 1 of 31 radio channels.

◆ SSQ-519 and -521

These passive A-size LOFAR/CODAR buoys are for ships' use; SSQ-521 has a 13.5-hr lifetime, -519 over $2\frac{1}{2}$ hr. Hydrophone depth is 100 ft. Reporting is on 1 of 31 channels.

◆ SSQ-522

This active range-only buoy, manufactured by Sparton of Canada, Ltd., is equivalent to the U.S. SSQ-47B. More than 175,000 had been delivered by FY85, and production was proceeding at 5000–7000 per year for export. SSQ-522 is license-manufactured in Japan, Norway, and the United Kingdom; and the buoy is also used by Italy, the Netherlands, South Korea, Spain, and Taiwan (GOC).

Lifetime is $\frac{1}{2}$ hr, with the hydrophone at 80 or 600 ft, and

there are 12 radio channels. Acoustic frequencies are 13.0, 14.2, 15.4, 16.6, 17.8, and 19.0 kHz.

◆ SSQ-523

The CANCESS command-activated sonobuoy has 6 HF sonar channels (short, medium, long CW pulses, linear FM sweeps) and is controlled by a 12-channel UHF radio. Dimensions are 5 in × 3 ft. Depth is 60 or 800 ft. Sparton received a contract for an enhanced version in 1973, and 20,000 were ordered through 1986.

This buoy is roughly equivalent to the U.S. SSQ-50.

◆ SSQ-525

SSQ-525 is the Canadian equivalent of the U.S. SSQ-77 VLAD.

◆ SSQ-527 A/B

This passive omnidirectional A-size buoy is manufactured by Sparton of Canada. Weight is 21 lb, and hydrophone depth is selectable (98, 328, or 984 ft), with a lifetime of 1, 3, or 8 hr. The buoy uses 31 RF channels.

These buoys are equivalent to the U.S. SSQ-41B.

◆ SSQ-530

This passive directional LOFAR buoy (DIFAR), made by Sparton of Canada, is equivalent to the U.S. SSQ-53B.

◆ SSQ-531

This passive line-array directional buoy is made by Sparton of Canada.

◆ Microbuoys

In parallel with the U.S. LCS program, the Canadian DREA (Defense Research Establishment Atlantic) has been conducting a microbuoy program since 1983. It seeks buoys small enough to be carried by RPVs and by light aircraft. The initial goal was an A/20 buoy, which would be individually launched from an A-size launch container.

The manufacturers are Sparton and Hermes, and the buoys are fully programmable omnidirectional LOFARs. They were test-dropped by an Aurora maritime-patrol aircraft in the fall of 1988. An A-size container held 12 Hermes or 16 Sparton buoys. The Hermes shape resembles a hockey puck and transmits real-time data by frequency-sharing a standard channel with the other microbuoys. Sparton's is relatively long and slender with wedge-shaped cross section. It transmits intermittently in burst form (time-sharing sequentially). Both use a novel ejection scheme. The inflation of the surface float forces the buoy from the container with sufficient velocity to clear the slipstream; the float itself then slows descent.

The emphasis on use by an RPV or light aircraft, i.e., by a vehicle not designed for ASW, requires that the buoy do more of the work. In the Canadian case, the buoy incorporates an FFT spectrum analyzer, so it sends, not raw acoustic data, but rather spectral data. These data are digitized, compressed, and burst-transmitted to the aircraft; the system uses time-division multiplexing so that all buoys from 1 launch can share the same radio channel. These buoys deployed down only to 100 ft since cable space within them was limited.

As of 1989, both contractors planned to enlarge their buoys to A/6 size for better performance; they will be able to suspend their hydrophones to 1000 ft and also operate at lower frequencies.

As of 1989, it was not clear whether DREA would continue to fund this work or whether the contractors would seek U.S. funding under the ELCS/ILCS program (see LCS, below).

The original program goal was to package a usable LOFAR buoy in A/20 size. Sparton developed such a Microbuoy in 1984; it was wedge-shaped and 18 cm high, so 5 stacks of 4 each could fit inside a standard A-size container. Sparton also pursued a Miniature (A/12) LOFAR-buoy program, transmitting real-time or processed data (as commanded by a UHF channel). It is 28 cm tall, and performance is comparable to that of SSQ-41B in

low sea-states. Sparton developed a variety of seeder magazines for its small buoys.

SIGNAL PROCESSORS

◆ UYS-502

Emerson Electric's CALYPSO (computerized acoustic analyzer processor) sonobuoy processor is for Canadian CH-124 (Sea King) helicopters. It has 32 time-multiplexed channels and uses parallel multiple arithmetic units for pulse compression, digital translation and filtering, FFT, display scaling, and other post-processing functions.

◆ UYS-503

Computing Devices Co.'s airborne signal processor is used by Australia, Canada, Sweden, and the United States. UYS-503 uses denser memory components than its predecessors. This processor suffices for all buoys except the complex broad-band Barra; that buoy requires a Side Barra Processor, SBP 1-1. This combination is part of the Australian RAWS (role-adaptable weapons system) of the Seahawk helicopter.

UYS-503 stores 20 min of LOFAR data from each buoy (4 DIFAR or 8 omnidirectional) in 4 modules (1 unit). Alternatively, each module can be used with 1 DICASS or 1 range-only buoy (the former with CW or FM pulses, the latter CW only). UYS-503 can also process expendable bathythermograph buoys or a dipping sonar (1 "slice" per 90-deg sector). Each 44-lb unit includes 8 standard buoy receivers.

UYS-503 and AQS-902G were tested in April 1987 as alternative processors for the SH-2F LAMPS-I helicopter; there was no U.S.-produced alternative. Late in 1988 UYS-503 was selected for new-production SH-2G helicopters. It will be installed on board existing SH-2Fs as they go through a SLEP program. The stated reasons for the preference for UYS-503 were its signal-detection performance and its better bearing accuracy (when working with DIFAR buoys). Both presumably reflect faster arithmetic. Better signal detection would be achieved by quicker calculation of FFTs with better frequency resolution (i.e., using more points). Better directionality would mean more accurate comparison of the 2 DIFAR-buoy beams, which again is a matter of more precise arithmetic.

In an SH-2G, UYS-503 is integrated with the ASN-150 tactical system by a CDC Interface Converter Unit (ICU). The ASN-150 multifunction display can show both radar and sonobuoy video. UYS-503 is also the basis of the Canadian HAPS (Helicopter Acoustic Processing System) for the new EH-101 helicopter; it uses 2 UYS-503 to handle 8 DIFAR, 16 LOFAR, or a combination of the 2, plus the Cormorant LF dipping sonar.

UYS-503 has been selected as the sonar processor of the new Swedish *Göteborg*-class corvettes. It is also the processor of the Canadian SQS-510 sonar and of the SQR-501 towed array. UYS-503 has also been selected to equip the Fokker Maritime Enforcer Mk 2.

Computing Devices Co. was formerly Computing Devices of Canada.

◆ HIPADS/HAPS

Helicopter integrated processing-and-display system/helicopter acoustic processing system is the Canadian next-generation sonobuoy processing system. HIPADS is being developed by Canadian Marconi, Computing Devices Co., and Litton Canada. HAPS is being developed by Computing Devices Co. and uses the Plessey Cormorant dipping sonar.

◆ SBP 1-1

The Barra processor works with the UYS-503 processor. SBP 1-1 can also function as a stand-alone processor, consisting of 4 subprocessors. Each subprocessor can handle 8 omnidirectional buoys or 4 DIFAR or DICASS. In the passive mode, SBP stores 20 min of LOFAR data on each frequency channel; the operator can call up and display the stored data on the CRT. The unit includes a patented demultiplexer that allows digital

sonobuoys to be used with a standard analog receiver. A second SBP 1-1 can be connected in parallel to double the processing capacity.

The first SBP 1-1 was delivered in the summer of 1984, and the unit was bought for Canada and Sweden (and for Australia, in conjunction with a UYS-503).

The Barra Side Processor has been sold to the U.S. Navy for the P-3Cs of the specialist Beartrap squadron. It operates with the usual UYS-1. UYS-503s have been installed for evaluation on board the same aircraft.

FRANCE

As of 1989, the French navy was evaluating a system comparable to the U.S. LAMPS I, i.e., a helicopter dispensing buoys but transmitting their output back to the ship for processing. The Lynx helicopter would carry an Alkan pod launcher, with 18 F- or G-size buoys.

SONOBUOYS

◆ DSTA-3

CIT-Alcatel's active buoy operates at depths of 65 or 330 ft; it transmits at 9, 10, or 11 kHz and reports on 1 of 16 radio channels. DSTA-3 works with a DSAA-4 processor, which can handle 2 buoys simultaneously.

Development began in the late 1950s, with trials in the mid-1960s and service in 1968-70. There were large orders in the 1970s and early 1980s, and later buoys were modified for better sensitivity. Reported production through 1986 was 15,000. The current version is DSTA-3E (123 mm × 914 mm, 16 kg, depth 30 or 135 m, 4 sonar and 8 VHF channels, lifetime about 20 min).

◆ DSTV-4L/M (MSR-810) (TSM 8010)

Thomson-CSF's passive buoy (124 × 914 mm, 8 kg or less) is also produced in Italy by Misar as MSR-810. DSTV-4L, the passive counterpart to DSTA-3, operates at 65 or 330 ft (with an additional 990-ft option in the -4M version), is omnidirectional (10 Hz-20 kHz), and has a lifetime of 1, 3, or 8 hr. DSTV-4L/M reports on 1 of 31 radio channels. The -4M version is more reliable and more sensitive.

DSTV-4L was developed in the early 1960s, trials following in the late 1960s. The -4L version was procured in 1963 and 1968.

This buoy, which replaced DSTV-2K, is broadly equivalent to the U.S. SSQ-41A/B.

As of mid-1989, Thomson had delivered more than 130,000 TSM 8010 (DSTV-4M) buoys to the French navy and export customers. MISAR (Italy) has a license-production agreement.

◆ DSTV-4N

This ambient-noise measurement buoy is analogous to the U.S. SSQ-57.

◆ DSTV-7 (TSM 8030)

An A/3-size (124 × 305 mm, 4 kg) version of DSTV-4M, DSTV-7 incorporates a radio-frequency synthesizer so that buoy radio channels need not be set before flight. Instead, they can be set manually on the airplane from among a preselected 34 of the total of 99 channels, separated by 375 Hz, ranging from 136-173 MHz. Frequency range of the buoy is 10 Hz-20 kHz (optimally 5 Hz-20 kHz); the hydrophone depth is 20 or 100 m (with an optional 300-m setting). Lifetime is 1, 3, or 8 hr. The buoy can be dropped from 150-10,000 ft, at 80-250 kt.

DSTV-7 is probably a LOFAR buoy. It entered production in 1986. In 1986 the French navy decided to develop a DIFAR buoy.

As of mid-1989, 30,000-40,000 TSM 8030 (DSTV-7A) had been made.

◆ TSM 8040

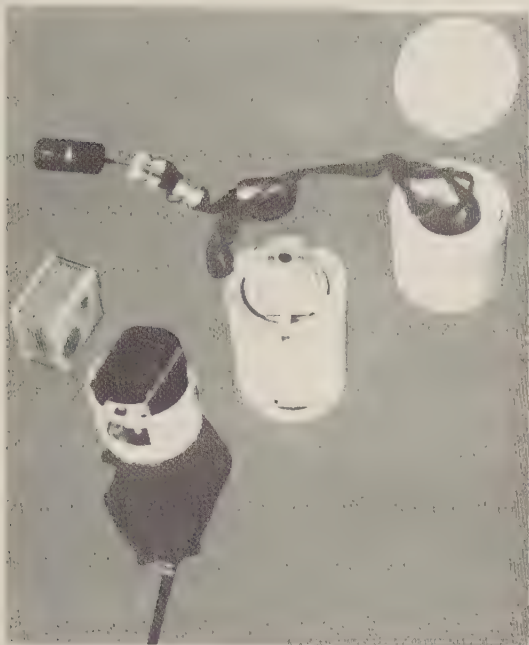
Thomson Sintra's A-size (124 × 915 mm, 17.6 kg) DICASS buoy operates at 6.5, 7.5, or 9.5 kHz with either CW pulses (0.1-0.5



Standard French sonobuoys: DSTV-4M at left, the A/3-size DSTV-7B in the middle, and a range-only active buoy at right. The buoy on the left shows the rotochute that slows its descent. The other 2 show the inflated floats that keep their radio antennas above the surface. (Thomson Sintra)



DSTV-7X mini-Jezebel (LOFAR) buoy. (Thomson-CSF)



Components of a Thomson DSTV-7 omnidirectional buoy (A/3 = size). (Thomson Sintra)

or 1 sec) or 1-sec FM pulses; pulses can repeat with intervals of less than 1 sec. Beam modes are ODT, cosine, or sine. Depth, remotely selectable, is 20 m or 150 m (450 m optional). The buoy reports on 1 of 31 VHF channels, and it is controlled by UHF (291.4 MHz). Power is supplied by a lithium cell, with an operational life of 30 min at 20 m, 20 min at maximum depth (50 sec of emission).

Production began in 1986.

◆ TSM 8050

Thomson Sintra's A-size range-only buoy entered production in 1989. Weight is 17.69 kg. Acoustic frequency is 6.0, 6.71, 7.5, 8.4, 9.4, or 10.5 kHz. The buoy emits either CW pulses (4 pulses in a train, total duration 100 msec) or FM pulses (1 pulse lasting 320 msec), in each case with an 11-sec recurrence rate. The hydrophone is at a depth of 20 or 150 m (TSM 8050A) or at 20 or 450 m (TSM 8050B). Total operational life is 30 min, using a lithium cell and a magnesium/lead-chloride battery. The buoy reports to the launching aircraft by VHF on 1 of 12 possible channels spaced 750 kHz apart (162.25–170.50 MHz), at a power level of 0.25 W (compared to 1 W for the passive DSTV-7). Presumably the lower power level corresponds to the planned tac-



Components of a Thomson TSM 8050 range-only buoy, showing its parachute, its electronics, and its transducer. (Thomson Sintra)

tical use of the buoy, as a means of localizing a submarine detected by a relatively large field of passive buoys (some of which might have to be monitored from a considerable distance).

◆ TSM 8060

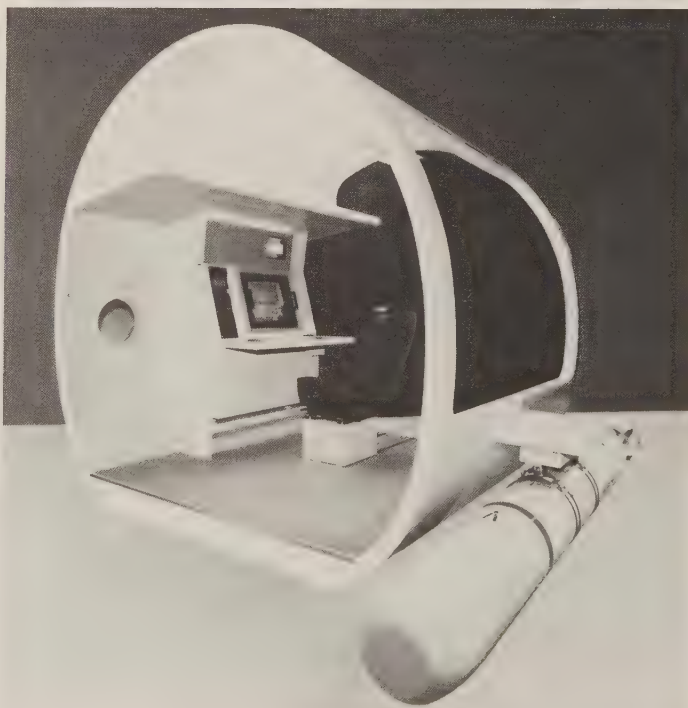
This family of G-size DIFAR buoys is under development; all major components are tailored to a future F-size version.

◆ Low Cost Buoy

As of 1986, Thomson-CSF was beginning work on a future low-cost sonobuoy, presumably comparable to the U.S. LCS.

SIGNAL PROCESSORS

◆ DSAX 1 (SADANG, TSM 8210)



Sadang 1000, a lightweight acoustic processor for small maritime-patrol aircraft. (Thomson Sintra)

DSAX 1 is the signal processor of the Atlantique-2 maritime-patrol aircraft. SADANG means *Système Acoustique de l'Atlantique Nouvelle Génération*. This system is oriented toward processing omnidirectional buoys. It has 2 operators and can process 16 sonobuoys simultaneously (each processor has 8 LOFAR channels, equivalent to 2 DIFAR channels). Processing capability includes DEMON (recovery of LF lines by demodulating broad-band noise). This processor uses CODAR (discrepancies in amplitude, frequency, time, or phase between 2 or more buoys) to determine lines of bearing and range.

TSM 8210, the export version, is lighter and has 1 processor and 1 operator. Total weight is about 140 kg.

◆ TSM 8200 (SECBAT)

Thomson Sintra's airborne signal processor for the Atlantic-1 works with active or passive buoys, with ambient-noise buoys, and with XBTs. TSM 8200 uses a 99-channel VHF receiver and a UHF transceiver for active-buoy control. There are 2 operators.

◆ TSM 8220 (Lamparo)

Thomson Sintra's acoustic-signal processor for small maritime-patrol aircraft or helicopters is derived from DSAX 1. Lamparo employs 1 operator and can simultaneously process 4 or 8 sonobuoys. This processor can also be integrated with an HS 12 dipping sonar. Processing techniques are LOFAR, CODAR, DEMON, and range-only. TSM 8230 is a modified version that can support a dipping sonar as well as sonobuoys.

Lamparo has been adapted to the AS 332F Super Puma and to the AS 365F Dauphin-2 helicopter (as in the Saudi frigates). It can also be carried by small maritime-patrol aircraft. Brazil bought it for installation on board 20 EMBRAER Bandeirantes (10 more are on order), and it has probably also been installed on board up to 9 Chilean aircraft of this type. Lamparo may also have been installed on board the 8 modernized Brazilian S-2 Trackers. If in fact China bought HS 312 (as opposed to HS 12) for its Zhi-8 helicopters, then China, too, operates Lamparo.

A new system is under development as part of FLASH (Flexible Lightweight Acoustic System for Helicopters).



Lamparo LOFARgram display. The curved white area is a reflection from the pilot's helmet; the display proper shows the usual vertical lines, spread out over the frequency spectrum. The operator seeks lines that remain stable over time. (Thomson Sintra)

INDIA

In 1978 Hindustan Aeronautics, Ltd., reported that it was producing a sonobuoy for the Indian navy, based on a design by the Naval Physical Oceanographic Laboratory at Cochin. The buoy is retarded by rotochute, and it lowers its transducer to a depth of 30 m. Lifetime is 8½ hr, power being provided by a nickel-cadmium battery; and data are transmitted by VHF (162.25–172.5 MHz). Presumably, the buoy is A-size, to fit Western-supplied helicopters and aircraft, and its long life suggests fully passive operation.

India is currently developing an Advanced Light Helicopter which is to be built in separate sonobuoy and dipping sonar versions.

ITALY

◆ BI Series

The BI series are Olivetti's buoys. BIT-3 is a 5 in × 36 in omnidirectional buoy, operating on 31 channels, at 65 or 330 ft; lifetime is 1–3 hr. BIT-8 is similar but adds 10 more channels. BIR is intended for light helicopters (4.5 in × 24 in, 1-hr lifetime, 65-ft maximum depth).

Work on these buoys began in the mid-1970s to replace U.S. types. After trials in the late 1970s the buoys entered service in 1979–80; about 12,000 were manufactured through 1986. They were intended specifically for the Mediterranean, with its shallow surface layer.

An earlier Julie-Jezebel buoy, BI 68, was announced about 1974. Dimensions were 91 × 1220 mm (weight 8 kg), and the manufacturer, USEA, claimed that BI 68 could operate on twice the usual number of channels. Maximum depth was 60 m. Presumably, this buoy never entered service.

◆ MSR 810/910

MSR 810 is a license-produced version of the French DSTV-4L/M LOFAR buoy. Misar is currently developing MSR 910, a range-only active buoy.

JAPAN

◆ HQS-3D

Japanese Julie (explosive echo-ranging) buoy, manufactured by Oki, is equivalent to the U.S. SSQ-23.

◆ HQS-5

This BT buoy is equivalent to the U.S. SSQ-36. HQS-5D operates down to 1500-ft depth, and -5E down to 4000 ft.

◆ HQS-6B

Oki's LOFAR buoy is equivalent to the U.S. SSQ-41.

◆ HQS-12

Oki's DIFAR buoy is equivalent to the U.S. SSQ-53.

◆ HQS-21B

Oki's acoustic-reference buoy is equivalent to the U.S. SSQ-57.

◆ HQS-31

NEC's active buoy is equivalent to the U.S. SSQ-47.

◆ HQS-32

NEC's active buoy is equivalent to the U.S. SSQ-50 CASS (omnidirectional).

SWEDEN

The Royal Swedish Navy uses moored sonobuoys, deployed from specialized surface craft, as mobile hydrophone arrays. The buoys are locally manufactured but are descended from about 50 Dowty buoys purchased several years ago.

USSR

It is very unlikely that the following catalog is complete; rather, it is an indication of past progress and of past design practice. Soviet warships are equipped to receive sonobuoy data.

According to a Soviet book on helicopter ASW (1985), helicopters typically drop sonobuoys in pairs, from the lowest possible altitude, across or near the expected target track. At least at the time of publication, Soviet doctrine was to use sonobuoys only in bad weather, when helicopters could not use their dipping sonars. Reportedly, of all current Soviet ASW helicopters, only Helix A has full all-weather and night capability. Other types require a horizontal visibility of at least 50 m.

Sonobuoys are typically dropped across or near the expected target track, at variable depths. Soviet publications describe square and circular sector barriers, the latter to be used when more time is available. Active sonobuoy range is reportedly 1850–5550 m, and passive range is about 10,000 m.

These tactics and ranges are reminiscent of Western pre-LOFAR practice, the buoys being used primarily for target prosecution rather than for search. Presumably, the appearance of Soviet LOFAR buoys (Type 75, see below) will radically change tactics, but only for platforms equipped with the appropriate processors. It is possible that only Bear-Fs are so fitted, and indeed that Bear F was introduced as part of a LOFAR system.

Land-based helicopters, such as those used by the East Germans, typically form 2-helicopter (search and attack) teams, the search helicopter doing post-attack assessment. Again, such practice is reminiscent of earlier Western practice, preceding the appearance of single-package ASW helicopters and aircraft. It may also be required by the great weight of Soviet homing torpedoes. The preferred helicopter-borne weapon is reportedly the homing torpedo, depth bombs being used only against surfaced or periscope-depth targets. There is also a nuclear depth bomb.

◆ RGB-56/64

RGB-56/64 were the first Soviet sonobuoys, the numbers presumably indicating dates of design. RGB-64 (6 × 37 in, 33 lb) was a somewhat miniaturized version of RGB-56 (which was approximately 8.75 × 48 in, with a total weight of 60 lb). Both buoys are omnidirectional, with detection ranges of about 2000–4000 yd. RGB-56 operates over the 4.4–6.4 kHz range; RGB-64 operates between 3 and 11.5 kHz. The data link is 18-channel AM (49.2–53.45 MHz), each buoy being preset before launch.

RGB-56 was first seen in September 1959. It was dropped at low altitude (500–1000 ft) and low speed (150 kt) and was par-

achute-retarded (lanyard activated). This procedure helped avoid drift. The hydrophone's beam was 17 deg wide in the vertical.

In each case, the buoy does not transmit unless target noise (in effect, integrated over its bandwidth) exceeds 1 of 7 (RGB-56) preset threshold levels. The monitoring helicopter, therefore, continuously tunes over the 18 channels, automatically locking onto a transmitting buoy and locating it using a VHF/DF built into the sonobuoy receiver. The operator can listen, e.g., for a turn count, and then resume tuning or can hand-tune. The operator can obtain a rough fix by comparative listening, or try to estimate a submarine's speed by turn-counting.

The threshold procedure also extends the buoy's life, which (in RGB-56) could be as great as 4 to 5 days (given battery strength; the buoy was designed, however, to scuttle in 24 hr).

U.S. observers compared RGB-56 with the first U.S. postwar broad-band buoy, SSQ-2, and also noted that RGB-56 had the beam pattern appropriate to bistatic operation with an active sonar, the transmission biasing necessary to prevent transient interference, and the center frequency (5 kHz) and band pass well suited to such operation. Presumably, the wider bandwidth of RGB-64 showed that the Soviets did not intend to use their buoys that way, at least at the time.

There were also marker buoys (RBM-100 and -200).

By 1962 U.S. naval intelligence was reporting that the Soviets had stated a requirement for a directional buoy to replace RGB-56. RGB-56 components had appeared, by that time, in a variety of old mine, buoy, and paravane casings, presumably to monitor U.S. and NATO exercises.

◆ BM-1

This passive omnidirectional sonobuoy was manufactured about 1966–70. BM-1 uses a line hydrophone. Dimensions are 6 in × 50.5 in. The 29-channel FM-radio data link is at about 171 MHz (channels separated by 150-kHz intervals). Internally,



Standard Soviet sonobuoys: 3 RGM (RGB-56) on the left, RGBN (RG-64) on the right. All are still in use. (U.S. Navy)



BM-1 (left) and BM-2 (right) sonobuoys, with BM-1 hydrophone at lower left and BM-2 array at lower right. (U.S. Navy)

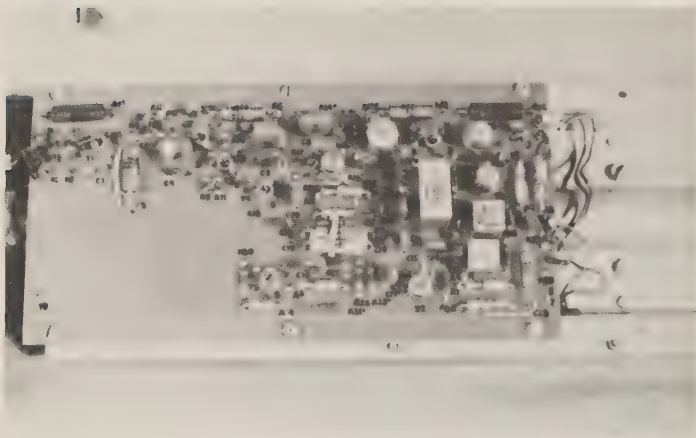
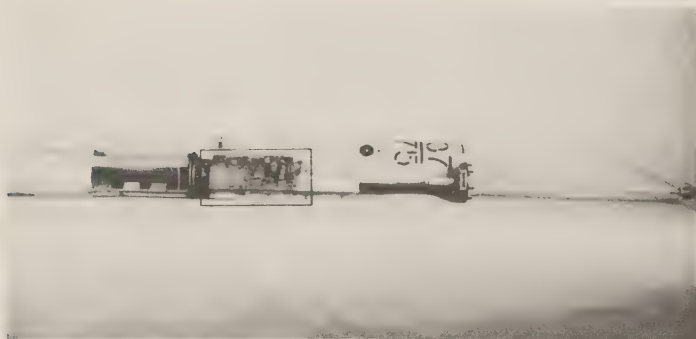
this buoy uses printed circuits and transistors, but it has no integrated circuits. BM-1 and -1A (1968) dimensions: 6 × 47.5 in, 33 lb. There is also a BM-2 (1969, 9 × 57 in, 97 lb).

Because BM-1 and BM-2 were associated with the Wet Eye radar (used on board May ASW aircraft), the buoy was not back-fitted into Hormone shipboard helicopters. These buoys are also associated with Bear F.

◆ Type 75

In 1988 the U.S. DoD released a photograph of a Soviet Type-75 sonobuoy that had electronics similar to those of the U.S. SSQ-41B, albeit in a much larger package. The conclusion seems to be that, since 1975, the Soviets have had LOFAR buoys. This conclusion would be consistent with sightings of Soviet listening devices, short cylinders covered with spot hydrophones, from about that date onward. LOFAR or LOFAR-like techniques, in distinct contrast to earlier passive techniques, operate on the basis of the detailed structure of the submarine's signature. They, therefore, entail an intelligence effort to obtain such signatures and then to match them against particular types of submarines. That effort would account for the bottom-laid devices, which are generally near NATO-submarine operating areas and bases. These devices are not themselves surveillance devices but rather are a means of collecting the information required to make the surveillance devices, such as LOFAR buoys, effective. The existence of such buoys also implies that the Soviets have the necessary signal processors, which in turn could be adapted to monitor towed passive arrays.

Type 75 entered service in the early 1980s. It is associated only with Bear-F aircraft.



In 1988 the U.S. DoD released these photographs of the Soviet Type 75 sonobuoy, which was described as similar to the U.S. SSQ-41B, i.e., to a LOFAR buoy. (*Soviet Military Power*, DoD)

UNITED KINGDOM

SONOBUOYS

◆ SSQ-904

This mini- (5 in × 12 in) Jezebel (LOFAR buoy) is made by Dowty. SSQ-904 operates at 10 Hz–6 kHz, at a depth of 60, 300,

or 450 ft, with a lifetime of 1, 4, or 8 hr. SSQ-904 can signal on 1 of 31 or 99 channels, operating with an AQA-5 or an AQS-901, -902, or -903 processor. This design resulted from MoD studies of the late 1970s, followed by field tests in 1979 and production in 1980; reportedly 12,000 buoys had been ordered through 1986.

In 1983 Ultra, which then manufactured SSQ-904, was reportedly working on a short 11-element vertical-line-array buoy for better shallow-water performance.

As of mid-1987, Dowty had manufactured a total of 550,000 sonobuoys for the RN, the RAF, and overseas customers, making the company the largest manufacturer in Europe. Customers that year included India and Sweden.

Dowty proposed SSQ-904 in 1978 as a reduced-size buoy for helicopters. The success of this buoy led in turn to the 1984 proposal for the G-size SSQ-954, which entered service in 1985. An enhanced F-size SSQ-904 Jezebel buoy entered service in 1988. It has 99 RF channels, selectable depth, and selectable lifetime (1, 4, or 8 hr).

Dowty claims that its passive buoys operate at significantly lower frequencies than do any others within NATO. That capability might be increasingly important as submarines become quieter.

◆ SSQ-905

This mini- (5 in × 12 in, 10 lb) Jezebel (LOFAR) buoy operates at 10 Hz–6 kHz; at a depth of 60, 300, or 450 ft; with a lifetime of 1, 4, or 8 hr; and on 31 or 99 channels. SSQ-905 is a calibrated version of SSQ-904.

◆ SSQ-906 and -907/SB112

These F-size (4.875 × 12 in) miniature Jezebel sonobuoys (weight 9.5 lb) have selectable lifetimes of 1, 4, or 6 hr; their hydrophones are carried at a preselected depth of 30 or 140 m (other combinations can be provided). The operating range is 4 Hz–6 kHz, buoy response being shaped to an inverse ambient sea noise curve to overcome average sea noise. Dowty describes this buoy as providing the lowest-frequency coverage in NATO. Buoys report by VHF radio on any of 99 channels (minimum output power 1 W). The buoy can be dropped from altitudes of 150–30,000 ft and at speeds of 60–300 kt.



Dowty sonobuoys, with 3 miniatures in the background and standard A-size buoys in the foreground. The buoy on the left is the SSQ-906 omnidirectional passive type; it is flanked by a BT buoy and by SSQ-954B. The 2 buoys in the foreground are a Dowty-made SSQ-47B and SSQ-963A CAMBS. (Dowty)

SSQ-906, introduced in 1988, is a -904 developed for reduced self-noise so that it can operate down to lower frequencies; it has significantly better LF performance than SSQ-906. The French navy currently purchases -906 from Dowty. As of 1989, Plessey and Dowty had contracts for a total of nearly 90,000 SSQ-906 buoys.

SSQ-907 is a calibrated version of SSQ-906.

Dowty is currently working on a new passive buoy to replace SSQ-904.

SB112 is a special moored version of SSQ-906 by Dowty.

◆ SSQ-937

SSQ-937 is an F-size XBT buoy. Lifetime is 5 min, and the buoy gives temperature down to 1000 ft (sink rate is 5 ft/sec). SSQ-937 operates on 1 of 3 preselected channels. Plessey's SSQ-937A measures down to 1500 ft in 6–12 min. It operates on 1 of 6 preselected channels.

◆ SSQ-947B

This British version of the U.S. SSQ-47B range-only buoy is omnidirectional. Frequency range is 13–19 kHz, and SSQ-947B reports on 12 channels.

About 1985 Plessey received a study contract for a new active buoy.

◆ SSQ-954/SB113

Plessey's G-size DIFAR buoy was announced in 1985. The hydrophone depth and operational lifetime of SSQ-954A can be remotely selected. Dowty describes the improved SSQ-954B as an Autonomous Function Selection (AFS) sonobuoy using a microprocessor to control the fully synthesized VHF transmitter, the operational lifetime (1, 4, or 6 hr), and the hydrophone depth (30, 140, or 300 m). Commands are transmitted via multifunction push buttons, and choices are indicated by light-emitting diodes (LEDs) when a "verify" button is pressed. Output power is 1 W, and shelf lifetime is 5 yr. The buoy can transmit on 1 of 99 channels, spaced 375 kHz apart. DIFAR compass accuracy is within 5 deg, and the buoy can also function in omnidirectional mode. The buoy can be dropped at speeds of 50–300 kt from altitudes of 150–30,000 ft.

Compared to SSQ-954 and -954A, -954B has a single button (rather than 3) to select frequency, depth, and lifetime. As of 1989, Plessey and Dowty shared contracts for more than 70,000 of these buoys.

SB113 is a special moored version of SSQ-954B by Dowty.

◆ SSQ-963

Dowty's Command A-size Active Multi-Beam Sonobuoy (CAMBS III) is currently in production for the RAF and Royal Navy. CAMBS uses 31 radio channels. Both the transmitter and the receiver are directional, and the transducer's depth can be varied on radio command. The buoy can operate either in directional passive or directional active modes; in the latter case it emits an omnidirectional pulse and receives with a separate directional array. Dowty describes SSQ-963A as representing an unspecified radically different but proven technical approach, compared to 2 earlier generations of CAMBS buoys. The buoy can be launched from altitudes of 200–8000 ft and at speeds of 60–300 kt. There are 3 selectable depths, and lifetime is 1 hr, with automatic or command scuttling. Shelf life is 5 yr. SSQ-963 costs about a third as much as CAMBS II but has better acoustic performance.

Plessey is currently working on a new active buoy.

In 1985, in connection with a proposal to equip Lynx helicopters with sonobuoys (to localize submarines detected by towed array), GEC Avionics claimed that a 3-CAMBS pattern would enable a helicopter to cover more than two-thirds of the area swept by a dipped sonar. The Lynx, however, could accommodate only 9 A-size buoys, and CAMBS could not be miniaturized because it depends on large batteries.

◆ SSQ-981

SSQ-981 is Barra: see the Australian SSQ-801.

◆ SSQ-991

Plessey's A-size air-launched sonar transponder (ALST) buoy was developed for British ASW helicopters, to serve as a reference point for their Type 195M dipping sonars. The buoy carries an octahedral radar reflector, optimized for X-band (cross section is 3–12 m², depending on elevation angle). Although the buoy is delivered preset to 195M frequency, it should also permit a shipboard operator to correlate radar and sonar pictures and, thus, to vector a torpedo-delivery helicopter more accurately. Such correlation becomes more important at greater sonar ranges. For example, in the early 1960s, when the U.S. Navy wanted to extend the range of its DASH delivery drone to maximum direct-path sonar range (about 20,000 yd), it had to develop a transponder buoy, Lorelei. The British frigate helicopter delivery system, using Lynx helicopters, is analogous (the main difference is that the pilot on board the helicopter greatly increases its reliability), and presumably ALST is partly a means of extending effective Lynx range (Lynx has no reacquisition sensor on board). The acoustic transponder floats 20 m (about 66 ft) below the surface, and its effective range is about 8000 yd. Operating modes include CW, shaped CW, doppler simulation (frequency-shifted pulses), and FM pulses. Buoy lifetime is 12 hr, including 3 hr of active operation.

Plessey offers a modified form of this buoy as a pure radar datum point, ALRT (air-launched radar target). ALST weighs 8.6 kg; ALRT weighs 7.0 kg. ALST can operate up to sea-state 3, in surface winds up to 15 kt.

AIRBORNE SIGNAL PROCESSORS

◆ AQS-901

GEC Avionics's signal processor for British Nimrod and Australian P-3 aircraft is adapted to Barra buoy processing. AQS-901 replaces the U.S. AQA-5. The full installation consists of 2 sets, each capable of processing 8 sonobuoys, connected by a data bus. The associated computer is GEC's 920 ATC with up to 256 kwords, capable of performing an FFT on 2048 points in 11.25 millisecc.

The associated receiver is tunable to 99 channels, and there is a command system to operate active buoys (it controls pulse width, pulse type, and PRF). The displays are CRTs and hard-copy chart recorders. The system can be set to alert an operator automatically when a target has exceeded a preset threshold.

AQS-901 was first delivered in March 1979. Production ended in the fall of 1986. Total production: RAF, 83; RAAF, 60.

◆ AQS-902 (LAPADS)/AQS-920 Series

Lightweight Acoustic Processing-and-Display System, in British Sea King helicopters, uses some AQS-901 technology but is only about 20% as large. LAPADS can also process dipping sonar data. AQS-902 entered service in 1980 on board Sea King helicopters, and in 1983 DIFAR processing capability was added. In 1985 GEC designed a new CRT to replace the paper recorder, to save another 20 kg and allow the processing capacity to be doubled.

As displayed in 1984, LAPADS was a passive analyzer for the 0–3.2-kHz band, with both LOFAR and A-scan displays. The main stated advantage was LAPADS's ability to combine wide-band (surveillance) with narrow-band (LOFAR, target classification/tracking). AQS-902 has 12 verniers (800, 400, 200, 100, and 25 Hz wide) that can be positioned anywhere in its displays, and it can display 12 LOFARS simultaneously. A harmonic cursor allows the operator to compare a line with its harmonic. Up to 1.5 hr of LOFAR history can be stored, for line enhancement.

Variants:

902A, described by GEC as essentially a digital equivalent to the U.S. AQA-5, is limited to hard-copy grams for pas-

sive omni buoys. Capacity is up to 4 buoys. This system replaced the U.S. AQA-5 in British service.

902B is 902A plus a CRT display, for the Fokker Maritime Enforcer. It has 2 units plus a central console for tactical integration.

902C is the version for the Indian navy's Sea King helicopters. It is capable of processing directional buoys (4 LOFAR and 1 BT or 4 DIFAR buoys); it has a CRT display. The total weight is 112 lb.

902D is the Royal Navy's version for Sea King HAS.2 and HAS.5. The Type 195 dipping sonar operates independently. This version is being updated to 902G-DS standard (see below).

902D-DS is 902D plus a processor for dipping sonars.

902F is capable of processing 4 LOFAR, 1 BT, and 4 range-only buoys; or 4 DIFAR and 2 DICASS; or 4 VLAD buoys. It is the version adopted for the Turbo-Tracker conversion.

902G was the version proposed for the U.S. SH-2G program, but it was defeated by UYS-503.

902G-DS is a new Royal Navy version (the contract was awarded to GEC in 1987) with a CRT and a sonar processor. One of the displays, the acoustic localization plot, allows the sonar operator to check the validity of the data before passing them to the observer's tactical plot. The tactical plot of the range and bearing information derived from the buoys provides current and predicted target information and track. In all, 112 processors are to be modernized.

The AQS-920 series, the export version, is typical of modern practice. A detailed description is available; the reader should assume that other current airborne processors are broadly comparable (e.g., in integration time).

The 2 current versions of AQS-920 are AQS-924 and -928; their maximum buoy-processing capabilities are

	AQS-924	AQS-928
LOFAR/DIFAR/VLAD (Omni)	4	8
DIFAR/VLAD (Cardioid)	4	4
Calibrated Buoys	1	1
DICASS	2	2
Range Only	4	4
BT	1	1

Passive processing modes are LOFAR/DIFAR/VLAD omnidirectional, DIFAR/VLAD pseudo-omnidirectional, DIFAR/VLAD single cardioid, DIFAR/VLAD triple cardioid, CODAR, DEMON (demodulated noise), BT, ambient-noise measurement (ANM), and signal-to-noise ratio (SNR). Active modes are DICASS (CW/FM), range-only (CW), and dipping sonar (CW/FM/BT/Depth). The processor can display passive buoy data either in LOFARgram form or in automatic line integration (ALI) form (i.e., integration can be either by eye or by machine). The advantage of using a LOFARgram is that the eye may detect an intermittently transmitted but fairly regular signal, whereas line integration may show little indication above the surrounding noise. Active formats are range/doppler/bearing, range/time history, bearing/time history, and range correlogram (using FM signals).

For detection, the system can perform simultaneous wide- and narrow-band analyses, cardioid detection gain, and automatic alerts. For classification, the system provides harmonic multipoint dividers, so the operator can compare the same line in several harmonic forms. For localization, the system can provide narrow-band frequency/bearing trackers, semiautomatic CPA/doppler fixing, and an acoustic localization plot (ALP).

The system has 4 or 8 channels to handle buoys in the 10–2400-Hz frequency range and can handle 10 narrow bandwidths or resolutions. The display covers a time history of up to 64 min, and integration time (for ALI) is selectable at 3.75, 7.5, 15, or 30 sec. The maximum number of analyses processed

is 8 BBAs (broad-band analyses: 688 cells) plus 24 VWs (vernier widths, i.e., narrow-bandwidths: 180 cells).

Total system weight, excluding the sonobuoy receiver itself, is 52.5 kg. That weight includes one or two 625-line CRTs and a hard-copy unit (for passive buoys only, to print out LOFARgrams).

AQS-902 is the standard Fokker Maritime Enforcer processor. Users of the Enforcer are Angola (1), the Netherlands (2, used by Fokker for system development), Nigeria (2), Peru (1), the Philippines (3), Spain (3), and Thailand (3). Of these countries, Angola has probably not been permitted to buy AQS-902, and Thailand has not installed a sonobuoy processor.

Users of this series of airborne signal processors are Greece (LAPADS in 14 HU-16Bs), Italy (update of Atlantic Mk 1 with AQS-902 and IGUANE radar), India (Sea Kings), Pakistan (projected Atlantic Mk 1 modernization with AQS-902), Sweden (6 AQS-924s ordered in 1984 for patrol boats, AQS-928 ordered for similar installation in 1990, plus probably 3 on aircraft), Taiwan (32 Turbo-Tracker conversions with AQS-902F), Turkey (projected Turbo-Tracker conversion of 18 S-2Es with AQS-902F), and the United Kingdom (Sea King HAS.6 helicopters). A projected Korean program for 36 Turbo-Trackers will almost certainly be canceled in favor of new P-3s.

◆ AQS-903

AQS-901's successor, made by GEC Avionics, employs VHSIC technology, for the EH-101 Merlin helicopter. AQS-903 can process Barra and CAMBS sonobuoys. This processor weighs about 160 kg, about one-third lighter than AQS-902, with up to 5 times the processing power. With 1 operator, AQS-903 can handle as many buoys (16) as the 3-operator AQS-901 and can provide each buoy with 8 times the processing power (e.g., to handle much more bandwidth).

The distributed processing architecture employs "pipelines," each of which handles a certain number of buoys. The manufacturer claims that 4 such lines give 8 times the power of an AQS-901 at a quarter of its weight.

GEC's AQS-930 series is presumably related to AQS-903 as the AQS-920 series is related to AQS-902. The announced versions are AQS-932, -934, and -938, the differences presumably being in the number of "pipelines." Announced maximum processing capabilities are

	AQS-932	AQS-934	AQS-938
LOFAR/DIFAR/VLAD (Omni)	16	32	64
DIFAR/VLAD (Cardioid)	8	16	32
Barra	2	4	8
DICASS	4	8	8
Calibrated Buoys	1	1	1
CAMBS	3	6	6
BT	1	1	1
Weight	66.5 kg	74.5 kg	82.5 kg
(including APU)	32.0 kg	40.0 kg	48.0 kg

Here APU is the acoustic processing unit; all of the other components (acoustic control unit, two 12-in 625-line acoustic display units, a common control unit, and a roller ball control/stiff stick control) are common to all versions.

Processing modes are as in AQS-924/928, except that the 930-series uses DIFAR/VLAD 4-cardioid rather than triple cardioid, and a Barra broad-band option is added.

Added detection aids (compared to AQS-924/928) are narrow/broad-band AGC (automatic gain control), broad-band power/bearing (DIFAR/Barra), and display enhancement. The additional classification aids are predictive (ratio) dividers and recorded data recall. Added localization/tracking aids are broad-band bearing trackers, automatic/manual CPA/Hyfix, and a coordinated tracker for multiple contacts. The LOFARgram display can show up to 60 min of history. No data are provided concerning maximum integration time.

Both the AQS-930 series and the AQS-920 series can process dipping sonar data.

UNITED STATES

SONOBUOYS

The total U.S. Navy sonobuoy purchase in FY89 was 376,000, including 15,000 SSQ-36 XBTs. Current U.S. policy is to use directional buoys (DIFAR, DICASS) only and not to purchase omnidirectional buoys. Although more expensive than the omnidirectional type, the directional units are not needed in the same quantities. The problem is that, in peacetime, maritime-patrol aircraft must often track submarines for protracted periods. In wartime (for which the systems were designed), tracking would continue only long enough to make an attack. Thus it was common for a patrol airplane to drop as many as 60 buoys while tracking a submarine during an 8-hr period. In recent

years, tracking has required such great expenditures that some have suggested that a period of prewar tension (requiring sustained tracking) would exhaust sonobuoy reserves. The low-cost sonobuoy was proposed in part as a solution to this problem since in theory it could be made and used in great quantities at affordable prices.

The table below (released early in 1990) shows U.S. annual sonobuoy procurement and consumption (in thousands), historical and planned, with consumption in parentheses. Unit cost is given below consumption.

The FY90 figures were later increased by Congress, which added \$45 million for procurement, increasing the total to \$160 million. Reportedly, the navy expends about \$130-\$150 million worth of sonobuoys per year.

◆ MCSS

The active moored buoy (moored CASS) is deployed over the side; the hydrophone is deployed at a depth of 20-700 ft. MCSS is rechargeable for continuous operation and is tunable to 1 of 3 channels.

◆ SSQ-23

Although no longer in U.S. service, SSQ-23 is produced in Japan by Oki as HQS-3D. It is an A-size (16 lb) passive omnidirectional buoy, covering the acoustic range between 400 Hz and 6 kHz, used for Julie explosive echo ranging. The Julie system became operational about 1957.

◆ SSQ-36 (XBT)

This expendable bathythermograph is designed to establish acoustic conditions in a sonobuoy field. SSQ-36 has a cable probe down to 1000 ft and is A-size (18 lb). Although the XBT is not a sonobuoy, it is essential to sonobuoy-field operations and, therefore, is listed here. Lifetime is 5 min, and SSQ-36 reports on 1 of 3 RF channels.

◆ SSQ-41

The standard U.S. A-size (14 lb) omnidirectional LOFAR buoy is a line hydrophone operating at 10 Hz up to 20 kHz at a depth of 60 or 300 ft, with a lifetime of 1, 3, or 8 hr. SSQ-41B (Jezebel wide-band) operates at up to 10 kHz (with improved dynamic range) at a depth of 60-1000 ft, reporting on 1 of 31 channels between 162.250 and 173.5 MHz or 99 channels between 136 and 173.5 MHz. Weight is 14 or 15 lb. SSQ-41B can be launched at up to 370 kt and at altitudes as high as 30,000 ft. SSQ-41A's maximum weight is 21 lb; -41B's, 29 lb.

In 1988 the U.S. DoD published a photograph of a Soviet Type 75 sonobuoy that was said to resemble SSQ-41B, albeit in a larger envelope.

SSQ-41 replaced SSQ-28, the first LOFAR buoy (1960), in 1965. SSQ-41 had sufficiently broad response to be usable in



Sonobuoy stowage on board a P-3C of VP-22, NAS Adak, November 1987. (Jürg Kürsener)

FISCAL YEAR

	87	88	89	90	91	92	93
SSQ-36	31.9 (35.2)	28.2 (23.2)	30.8 (33.3)	0 (32.3)	14.2 (32.6)	8.4 (28.4)	2.8 —
	—	\$145.39	\$165.58	—	\$204.22	\$238.10	\$357.14
SSQ-53	273.3 (204.4)	267.3 (205.9)	213.8 (275.6)	223.8 (284.2)	148.6 (296.9)	88.4 (255.4)	55.0 —
	—	\$274.22	\$329.28	\$315.46	\$356.00	\$424.20	\$503.64
SSQ-57	17.7 (22.8)	44.6 (13.6)	54.4 (21.0)	0 (28.5)	0 (29.5)	2.2 (22.7)	2.1 —
	—	\$207.26	\$157.34	—	—	\$500.00	\$523.80
SSQ-62	20.9 (17.8)	44.6 (19.8)	23.7 (22.1)	21.4 (28.6)	20.8 (41.0)	9.9 (40.9)	5.8 —
	—	\$957.46	\$974.68	\$1037.38	\$1533.65	\$1333.33	\$1568.97
SSQ-77	85.8 (23.7)	51.7 (24.4)	45.5 (48.5)	46.6 (52.8)	49.9 (54.1)	27.5 (44.5)	13.9 —
	—	\$646.03	\$472.53	\$487.12	\$494.99	\$589.09	\$726.62

Julie and was described as a Julie-Jezebel buoy. SSQ-41 is the most widely used Western buoy.

◆ SSQ-47B

This active (range-only) A-size sonobuoy (29 lb) uses a hydrophone at a depth of 60 or 800 ft and has a life of 30 min. SSQ-47B is tunable to report on 1 of 12 channels, so that up to 6 buoys can be used simultaneously in a single field. SSQ-47B is a deep-operating version of the SSQ-15, incorporating solid-state electronics, controlled transducer beam, and VHF antenna patterns. Command is possible from 0–10 nm and from 500–10,000 ft, at up to sea-state 5. The operating mode is automatically keyed CW; because this buoy is not command-activated, its life is so short.

The last U.S. Navy production orders were in 1982; in 1988 this buoy was manufactured only for foreign military sales.

◆ SSQ-50

Command-Activated Sonobuoy System (CASS) is now superseded in U.S. service by SSQ-62 (DICASS). The signal is omnidirectional. Lifetime is 1 hr (half an hour for SSQ-50B), and the hydrophone depth is 60 or 1500 ft. There are 31 radio channels. Acoustic frequencies are 6.5, 7.5, 8.5, and 9.5 kHz.

◆ SSQ-53/SSQ-73 (DIFAR)

The directional LOFAR buoy (DIFAR) operates at a depth of 90 or 1000 ft, with a lifetime of 1 or 8 hr, at a frequency of 10 Hz–2.4 kHz. SSQ-53 is A-size, weighing 26 lb, and was standardized in 1969. SSQ-53B, the current version, weighs 22 lb (Sparton version), and its hydrophone operates at a depth of 100, 400, or 1000 ft; lifetime is 1, 3, or 8 hr, and reporting is on 1 of 99 RF channels. SSQ-53B reduces the LF mechanical noise found in SSQ-53A, and the operating parameters are chosen by push button (verified by light-emitting diodes on the buoy). The sonobuoy can be launched at up to 370 kt and from as high as 40,000 ft. The first SSQ-53Bs were delivered early in 1984.

In 1989 the unit price of an SSQ-53B was \$240, a figure Magnavox reached by using a robotic production line. After FY89, -53D will supersede -53B.

SSQ-53C is a full-function DIFAR buoy in Dwarf (G) size (16.5 in long but with an A-size diameter), fully equivalent to SSQ-53B (but launchable only from 30,000 ft or below). Weight is 11 lb.

SSQ-53D is a dwarf version with its frequency range extended

to lower frequencies. It also enjoys lower self-noise, largely by decoupling the hydrophone from the rest of the buoy assembly.

SSQ-73 was an experimental deep DIFAR buoy (A-size). It was described as the deep suspended DIFAR (DSD), and it was superseded by VLAD.

Sparton has developed a Dwarf DIFAR (A-size diameter but 12 in long; 10 lb). Operating depth is 90–1000 ft, and operating life is 1 or 4 hr; the buoy is tuned to 1 of 99 channels. No standard designation has been released.

◆ SSQ-57A

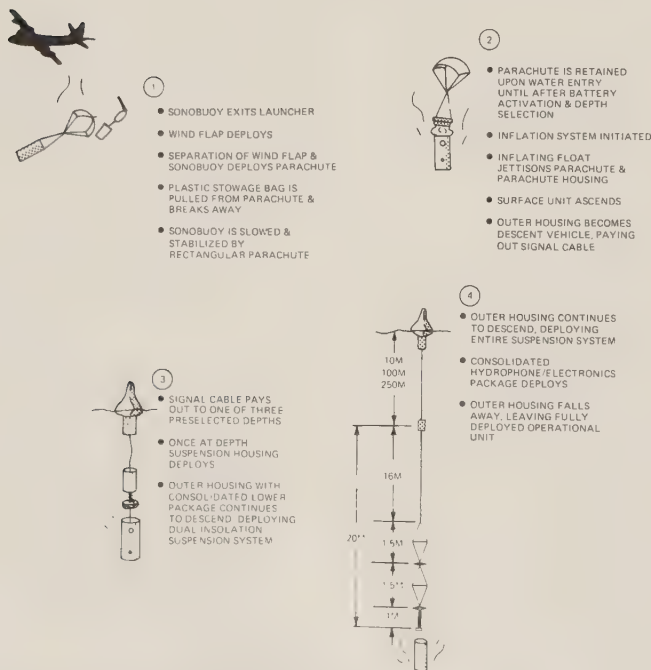
This low-cost passive A-size buoy (14 lb) operates at 60 or 400 ft; lifetime is 1, 3, or 8 hr. SSQ-57A operates on 1 of 31 channels. The hydrophone is Sparton-designed, the company claiming smooth response up to 20 kHz. The company claims that the buoy is effective at ranges of up to 10 nm and is launchable from 100–30,000 ft at 45–370 kt, into seas up to sea-state 5.

This buoy is used either for calibrating ambient sea noise (which is why smooth response is important), for monitoring exercises, or for collecting acoustic intelligence (where a smooth response can reproduce an unknown submarine signature, a narrower-band buoy might miss important parts of the spectrum). SSQ-57A is similar in mechanical design to SSQ-41. FY88 procurement was 11,947; FY89, 12,378. SSQ-57A has been sold at least to Australia.

As of mid-1989, an SSQ-57B was in the design stage; it was described as an SSQ-41 replacement with slightly greater bandwidth. Magnavox was to make 43,000 under the FY89 program.

◆ SSQ-58A (MIUW)

This special moored buoy for Mobile Inshore Undersea Warfare is an element of a movable surveillance system. MIUW consists of a 36-in diameter, 24-in deep, foam-filled fiberglass float, from which are suspended its mooring and its hydrophone assembly, and from which projects its antenna. MIUW is deployed over



Typical deployment sequence of an SSQ-53 sonobuoy. (Sparton)



SSQ-58A buoy for mobile inshore underwater warfare. (Sparton)

the side of a boat or small craft, typically in depths between 40 and 110 ft (an optional deep mooring kit allows for a depth of 600 ft). Minimum hydrophone depth is 20 ft. There may also be a deeper-mooring version, since earlier literature listed MIUW with a maximum hydrophone depth of 700 ft. The buoy can survive in tidal currents of up to 3 kt and in surface currents of up to 6 kt. Frequency range is 50 Hz–10 kHz, and the hydrophone is omnidirectional (with a flow shield). Operation is continuous because the buoy carries a 12-volt commercial rechargeable lead-acid battery; lifetime between recharging is 100 hr. The buoy reports on 1 of 31 VHF channels, and it carries a radar reflector atop its quarter-wave antenna. There is also a navigational warning light, which can be enabled or disabled as required. As of 1989, MIUW was in limited production by Sparton.

The SSQ-58 designation originally applied to a LOFAR buoy that could be anchored in up to 500 fathoms of water (3000 ft) and had a 30-day lifetime, to operate in currents up to 5 kt and in sea-state 5 (and which could survive 40-kt seas in sea-state 6).

◆ SSQ-62 (DICASS)

Directional command-activated active sonobuoy (DICASS) is used for localization of a submarine detected by passive buoys. On command, DICASS can determine a submarine's range, bearing, and speed (from doppler). SSQ-62 uses FM or CW pulses; their lengths and intervals can be chosen via 1 of 4 preset acoustic channels. Transmission is ODT, but reception is directional. DICASS operates at 60 or 1500 ft and weighs 39 lb. The feasibility contract was let to Sparton in 1968.

The current SSQ-62B weighs 34 lb and has a lifetime of 30 min. SSQ-62B adds a third depth: its transducer operates at 89, 396, or 1518 ft (as commanded), and -62B reports on 1 of 31 RF channels. The surface unit employs a seawater battery; the submerged pinger uses a lithium battery. SSQ-62B replaces the SSQ-48B Miniature Range-Only Buoy and is a follow-on to SSQ-50. Current procurement: FY88 was 12,229; FY89 was 17,464.

Raytheon, the developer, claimed that SSQ-62 was the first of its kind to be compass oriented, providing aircraft with true bearing on a target.

◆ SSQ-71

See submarine communications systems in the Surveillance and Control section.

◆ SSQ-75 (ERAPS)

Expendable RAP active buoy began development in 1961. ERAPS is command-activated, uses 2- or 5-sec pulses, and has a 3-hr life (power for 100 ping-seconds). SSQ-75 uses an LF pinger and a volumetric (circular array of vertical dipoles) receiving array, sufficiently directive to provide target bearing as well as range; target speed is estimated from doppler. Depth could be 60 down to 16,500 ft (typically 15,000 ft in the Atlantic, 6000 ft in the Mediterranean). Maximum range is about 15 nm.

Buoy dimensions are 10 × 91 in (325 lb); the buoy will be carried on a weapons rack rather than in a buoy chute. Presumably, 1 of the advantages of the new P-7A, with its enlarged weapons bay, is that it can carry a useful number of ERAPS buoys.

The preliminary design was reviewed in FY82, airdrop mechanical tests and over-the-side acoustics tests were conducted in FY83, 315 ERAPS buoys were bought for operational tests in FY84/85, and an airdrop succeeded in FY85. In 1986 Congress directed that the program be restructured for FY87, the goal being a unit cost of \$6000 for a production run of 10,000 buoys. Tests were scheduled for completion during FY88, with production to follow in FY89.

This program has been delayed. In November 1987 Magnavox and Sparton formed a joint venture, ERAPSCO, for ERAPS. They received a 53-month full-scale engineering-development contract in 1988. Overall subsystem integration was to be completed by July 1990. Technical and operational evaluation

should be conducted in 1992–93, and the navy will probably procure about 2000 ERAPS buoys per year beginning in 1993.

In an FY83 experiment, an ERAPS receiving array was used as a baseline high-gain array, as a first step in developing an advanced localization buoy.

◆ SSQ-77 (VLAD)

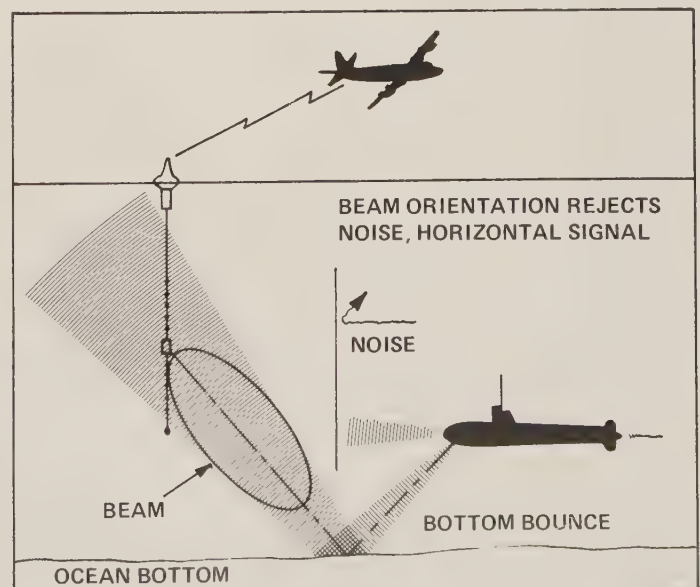
VLAD, a vertical-line-array DIFAR buoy (A-size, 29 lb), uses 9 omnidirectional hydrophones and 2 geophones in place of the single DIFAR hydrophone of its predecessor, SSQ-53B. A conventional DIFAR hydrophone mounted at the array's phase center provides bearing data, and the other hydrophones are used to detect BB signals and to discriminate against shipping noise from the surface. The entire array is carried in a faired cable, the fairing reducing cable noise ("strum"); and the array is held vertical by a terminal weight and is stabilized in direction by a 15-ft drogue, a water-filled plastic bag acting as a sea anchor. Depth is 1000 ft; lifetime is 1 or 8 hr; and frequency range is 10 Hz–2.4 kHz. Each buoy can be preset to 1 of 99 radio channels.

The signal format is identical to that of the SSQ-53B DIFAR, so the buoy is compatible with existing AQA-7 processors, found on board P-3s. All beam-forming is performed within the buoy. Apparently the vertical orientation of the beam is preset; a sketch provided by Sparton shows a buoy adjusted to detect BB signals, rejecting surface noise and horizontal signals.

During the mid-1970s VLAD was chosen for production instead of the alternative DSD (SSQ-73) buoy. Both buoys reflect the ASW concepts of the late 1960s and were attempts to overcome the improved silencing then expected of the new generation of Soviet submarines (Charlie, Victor, Yankee) and their successors. Sippican acquired rights to manufacture SSQ-77A, a modified version, from Hazeltine in March 1984. Modifications made for production included redesign of the surface float. Pilot production began in May 1984, full-scale production following in 1986. Sippican's description involves 11 omnidirectional hydrophones (and no geophones) and alternative lifetimes of 1, 4, or 8 hr, but it is not clear whether these are changes specific to SSQ-77A.

VLAD buoys were initially manufactured in alternative BB and horizontal-beam versions, the latter intended to avoid shipping noise in the surface layer. VLAD was initially unpopular because users were unfamiliar with BB operation. Current VLADs can be set to different beam angles before they are launched.

In FY76, 2000 SSQ-77 service-test models were bought; operational evaluation was successful, and the buoy was approved



Operating geometry of the SSQ-77A VLAD buoy. (Sparton)

for service use late in FY78. Production began in FY80 with 1000 units, followed by 7000 in FY81 and by 23,000 in FY82. Recent procurement: FY87, 98,812; FY88 request, 51,663; FY89 request, 34,874.

A long-life commandable version of VLAD was tested in FY81 and FY82.

◆ SSQ-79 (SVLA)

This steerable vertical-line array (SVLA), in A-size, operates at 1000 ft, for a 4- or 8-hr lifetime. This buoy is also called the Passive Advanced Directional Sonobuoy (PADS). Hazeltine received the advanced development contract in FY76 and began work in FY77. SSQ-79 uses a third-generation sensor, VLADFA (VLAD Frequency Analysis), with a digital uplink. Developmental test and evaluation (Phase II) was completed in FY83. In FY86 (ca. March 1986) the estimated requirement was 480 prototypes and 2000 initial-production buoys for completion of tests through FY87.

This buoy was developed under a Passive Advanced Detection System program begun in FY70.

◆ SSQ-83

SSQ-83 is a SAR (sea-air-rescue) up-link buoy (ULC).

◆ SSQ-86

SSQ-86 provides down-link communications, DLC. See submarine communications systems in the Surveillance and Control section.

◆ SSQ-90

An active multiple ping (AMP) B-size (103-lb) buoy, SSQ-90 is currently in limited production.

◆ SSQ-101

A buoy with a horizontal-line array (HLA), SSQ-101 was initially dropped in favor of vertical-line arrays. However, because it can form horizontal beams, it can block out noise, and in theory it can achieve long search ranges. HLA is being developed both as a long-range passive buoy (for battle-group screening and for large search areas) and as the receiver of the ADAR system (see below), using LF active sources. It is now being developed to meet the new quiet submarine threat. HLA should enter full production in 1995. An Operational Requirement was issued in November 1985, and in mid-1986 the navy sought bids for full-scale engineering development, including production of 400 buoys. Previous development efforts included packaging and acoustic tests in FY81, over-the-side tests in FY82, and over-the-side performance tests in FY83.

◆ SSQ-102 (TSS)

Hazeltine/Sippican and Boeing/Magnavox/TRW are competing to develop this tactical surveillance sonobuoy (TSS) for completion by February 1994. SSQ-102 is to be a long-duration (in-water life at least 5 days) A-size buoy for wide-area surveillance. A processor in the buoy selects and records signals of interest, which are played back at high speed upon interrogation by an airplane. Each individual buoy will not cover a very large area, but the command playback permits 1 airplane to monitor a very large field since it need not be simultaneously within radio range of each buoy. From a functional point of view, a field of TSS buoys would appear to be equivalent to the defunct RDSS.

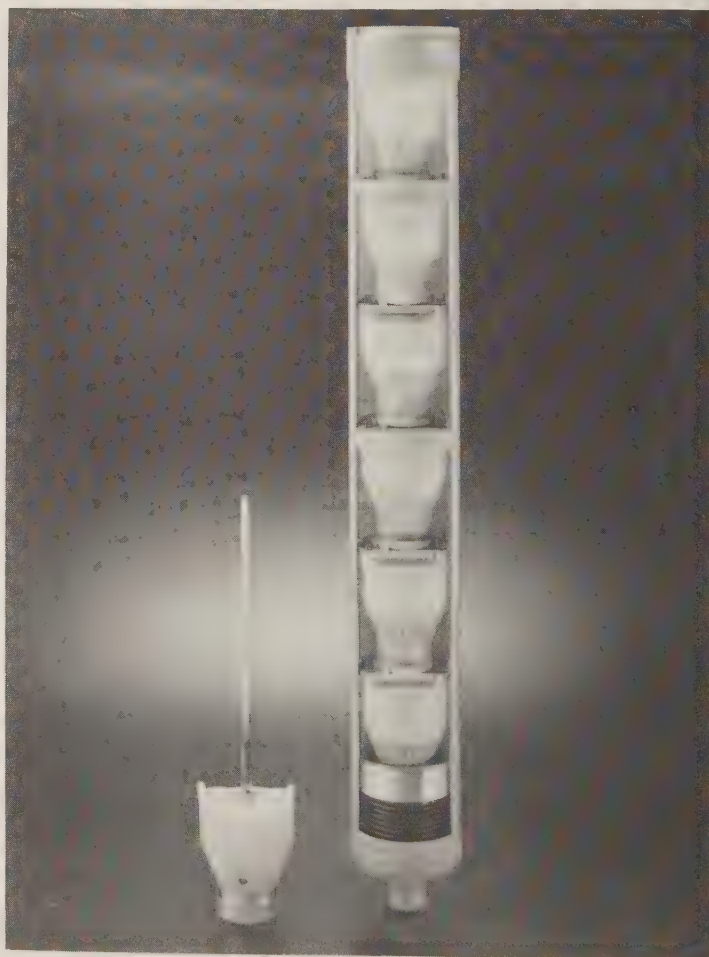
A projected enhanced version (ETSS) should increase system gain by using a better array or by incorporating an in-buoy trigger modification.

Tentative Operational Requirements for TSS and ETSS were issued in June 1985. System definition was completed in FY86, and both competitors were awarded FSED contracts, each calling for 625 buoys for technical and operational evaluation in 1989. Overall system design was completed in FY88, and ETSS engineering development began in FY90. One of the 2 TSS alternatives is to be selected in 1992.

◆ SSQ-103

This low-cost sonobuoy (LCS) may replace earlier LOFAR types. In Sippican's version, SSQ-103 is one-sixth of A-size and is intended for deployment in dense fields. Unlike a LOFAR buoy, which measures a detailed acoustic spectrum for analysis on board a monitoring airplane, an LCS measures gross (broad-band) noise nearby, integrating (in effect) over much of the spectrum. That scheme cannot match the range sometimes achievable with LOFAR, but LCS should be able to detect the noise of water flowing over the hull of a nearby submarine, a noise that is essentially impossible to eliminate. Because detection range is likely to be very limited, a detection by an LCS should indicate that a submarine is quite close, and that indication in turn may be a sufficient attack criterion. Alternatively, a detection may lead to a second phase during which more sophisticated buoys can be dropped. Ironically, the LCS brings sonobuoy operation back to the early 1950s, when passive buoys were all broad-band. At that time, simple silencing measures (such as intermittent snorkeling) seemed likely to overcome such buoys, and active alternatives (Julie) were proposed. LOFAR made passive buoys viable, and only now, more than 3 decades later, does the potential of passive operations seem about to be exhausted.

LCS does differ from the primitive buoys of the 1950s, which were not nearly sensitive enough to detect flow noise at useful ranges (and which relied on the noise of snorkeling). LCS deploys a passive multi-element array down to a depth of 300 ft and continuously compares the received energy level in the water to a measured figure, thus reducing the effect of background noise. Each buoy is 4.5 in × 5.5 in long, and 6 are packaged in each A-size launcher. The cost limit is one-tenth the cost of a conventional passive buoy, and the projected production rate (from the late 1980s) is 500,000 units per year.



Low-cost sonobuoys (SSQ-103), individual and stacked in an A-size casing. Not shown is the array deployed 300 ft below the buoy. (Sippican)

Both Sippican and Sparton have developed alternative versions of SSQ-103. Sippican's is coffee-cup shaped; Sparton's is cylindrical. Each is essentially A/6-sized, and each is designed for laying in a very dense field. Sippican's can be tuned to any 1 of 330 channels. Sparton's can be tuned to 1 of 66 channels and, presumably, is intended to come in any 1 of 5 versions (a smaller number of tunable channels would mean a simpler and, therefore, less expensive frequency synthesizer in the buoy).

Quite aside from the need for new tactics to counter very quiet submarines, the LCS project is sometimes justified on the grounds that existing buoys cannot be bought in sufficient numbers for protracted operations. One fear is that submarine surveillance during a lengthy crisis, which might or might not lead to war, would exhaust stocks of the sophisticated buoys, leaving nothing for the war emergency. In theory, LCS might be a way of doing surveillance (as opposed to tracking up through an attack) at a lower cost, the better buoys being reserved for wartime. In this view, LCS cannot in itself provide sufficient localization for attack. In wartime, then, the more sophisticated buoys might be used for localization after area detection by LCS.

These projects seem to have been outgrowths of an Advanced Passive Sensors project for wide-area buoy search and advanced means of localization. LCS was intended as a follow-up to VLAD, using either a horizontal-line array (HLA) or STRAP (Sonobuoy Thinned Random Array Processing). A low-cost sonobuoy field would be a particularly simple form of STRAP, involving simpler, rather than more complex, processing. The problem in STRAP is that buoys cannot be laid in a precise pattern amenable to conventional acoustic processing. Therefore, the beam-former must adapt to the buoy's position, and that position must be precisely known. The technique in STRAP was to provide 4 of, say, 20 buoys with low-power emitters that could be picked up both by the airplane and by the other buoys. Each buoy would, then, transmit a mixture of acoustic and positional data, and the airplane could locate each one. Given these data, a powerful computer (UY-1) could develop appropriate beams. Lockheed conducted the first feasibility demonstrations, and sea trials followed in 1986.

STRAP was initially a broad-band buoy field evaluated first with SSQ-53 buoys. The effort then shifted to advanced manufacturing technology for the LCS needed to make STRAP practicable. The low-cost effort began in earnest in FY84 but was shifted to other projects in FY85.

It appears that development initially emphasized better signal processing and greater array gain. However, it would appear that work was redirected about 1983 (when ASW policy was reviewed), the expensive high-gain buoys being abandoned in favor of a relatively dense field of short-range buoys. Presumably, the current LCS program represents a further retreat from the ideal, of increased range through signal processing, that was represented by a DIFAR (SSQ-53) buoy: i.e., a further acknowledgment of the effect of submarine silencing.

The LCS program was planned in 3 stages: LCS, enhanced LCS (ELCS), and improved LCS (ILCS). LCS passed its Milestone I late in FY83 (i.e., in mid-1983), and an Operational Requirement for this buoy was issued in March 1985. The OR for ILCS was issued in May 1986. LCS was killed in favor of ELCS, and the FY89 budget included ELCS system studies as well as the appropriate modifications to the scanner of the ARR-78 sonobuoy receiver. However, by January 1989 the entire LCS program had been canceled, reportedly because sufficiently capable buoys could not be produced at a low enough cost.

The people that advocated LCS have not disappeared, and it seems certain that the program will reappear under a new name. As of mid-1989, the Naval Air Development Center was conducting an ELCS/ILCS (Enhanced/Improved Low Cost Sonobuoy) program for a "microbuoy" with on-board processor and auto-detection algorithm. Four teams completed parallel studies: Magnavox/Boeing, Sparton/Lockheed, Hermes/Lockheed, and Sippican/IBM.

◆ Advanced Buoys

Several advanced buoys are under development:

AAA Air Active Adjunct This device is a modernized Julie, in which a sound source is dropped in a field of passive buoys. During FY88 development options were examined for an Advanced Active Sonobuoy/Air Active Adjunct (AAS/AAA). The Tentative Operational Requirement for this buoy was released in April 1987.

AAS Advanced Active Sonobuoy A replacement for DICASS (SSQ-62). The Tentative Operational Requirement for this buoy was released in May 1986, and an RFP was issued in 1990.

ADAR Air Deployable Active Receiver There is also an HLA active receiver. The latter uses an HLA buoy as a multistatic receiver of shipboard and deployed acoustic sources, for detection and localization. This system should be ready for evaluation about FY92 and should be introduced in service by 2000. Initial over-the-side demonstration was conducted in FY88. Array alternatives were studied during FY89. The ADAR Operational Requirement was issued in November 1986.

AE Active Enhancement Program demonstration was scheduled for FY89. This program is also called DE, Doppler Enhancement. The program's improved low-doppler detection technique is ultimately to be incorporated into SSQ-62 or AAS buoys as an engineering change (ECP). Flight tests were completed in FY88.

AIS Acoustic Intercept Sonobuoy System integration began development in FY88. The tentative operational requirement for this buoy was released in August 1985. As of early 1989, 2 full-scale engineering development contracts were planned for FY90, with hardware development tests to follow in FY91.

ETSS Enhanced Tactical Surveillance Sonobuoy Trade-off studies were conducted during FY88. The Operational Requirement for this buoy was released in February 1986.

ITSS Improved Tactical Surveillance Sonobuoy The Operational Requirement (OR) for this buoy was released in February 1986.

TAS Tactical Arctic Sonobuoy A conventional sonobuoy is encased in a bomb-shaped chemical ice penetrator, which reacts with the ice, eating it away. Eventually the buoy falls into the vertical position and sinks through the hole made by the chemical penetrator, guided by fins in the penetrator's tail. The usual inflatable retarder keeps the buoy afloat in the water crater left by the penetrator. The U.S. program employs a solid lithium compound penetrator; the U.S. Navy signed a prototype contract with Sparton in mid-1987. A parallel Canadian program, using a nonlithium penetrator, began officially on 1 January 1988. The penetrator-encased buoy was first displayed at the 1989 U.S. Navy League show.

The Tentative Operational Requirement for the TAS was issued in July 1985.

◆ SDC Buoys

In 1984 the Space Development Corporation announced a new small-diameter (54-mm) LOFAR buoy equivalent to SSQ-41B; see the comments at the beginning of the entries on sonobuoys for SDC's claimed advantages. The buoy was conceived about 1972, to be fired by destroyers using Loki rockets (to ranges of about 60 nm); but although 1973 tests were successful, no orders followed. However, the small-diameter buoy became more attractive as smaller and smaller aircraft were proposed for maritime patrol. Early in 1984 Beech Aircraft took a sonobuoy on tour with the patrol/ASW version of its B200 Super King Air.

AIRBORNE SIGNAL PROCESSORS

◆ AQA-3/4

These LOFAR (Jezebel) signal processors for, respectively, S-2D and -2E Tracker aircraft are no longer in U.S. service but are

used in several Allied navies. Earlier versions of the S-2 lacked any Jezebel capability. They had, at best, an AQA-1 sonobuoy indicator. S-2E introduced a coordinated tactical navigation system to solve tactical problems, combining memory, display, and automatic computation.

AQA-3 and -4 were also carried by P-3A Orions.

These processors used paper (hard-copy) readouts (four 3-in-wide grams, for 4 buoys) and could also conduct CODAR analysis: the time of arrival of the same sound at 2 buoys could be used to give a line of bearing, so 2 pairs of buoys could give a cross fix. These were the first airborne LOFAR (Jezebel) acoustic processors.

LOFAR spectra were obtained by time compression. The sonobuoy signal had to be subjected to a series of matched narrow-band filters, the output of each filter appearing as a darker or lighter spot on the LOFARgram. It was impossible to apply the filters in sequence as the sonobuoy signal was received: each filter imposed a finite analysis time, and it would have been impossible to follow changing signals. The solution was time compression. The incoming signal was tape-recorded and transferred to a secondary analog memory that could be scanned very rapidly. In AQA-3, the secondary memory was a round magnetic tape about 5 in in diameter, which rotated slowly past an erase head and then past a recording head on its outer side. Pickup heads for analysis rotated rapidly on the inside; Bell claimed that this system was the earliest example of having recording on 1 side of a medium and pickup on the other side.

The compression ratio is the ratio of recording speed to pickup speed. Effective analyzer bandwidth is the full bandwidth of the fixed-frequency filter divided by this ratio. The faster the pickup rotational speed (which is fixed by strength of material), the narrower the bandwidth per filter and thus the greater the signal-processing efficiency of the system as a whole. The fixed-filter bandwidth cannot be shrunk.

The next step, then, was to go from a mechanical to a solid-state system, Deltic (Delay-Line Time Compressor). Deltic was incorporated in AQA-5. It was proposed at the Scripps Institution of Oceanography and initially implemented by Bell Labs, the basic patents being filed in 1956. A Deltic contains a digital memory and a delay line. Incoming acoustic data are digitized and recirculated. On each pass back through the analyzer, the oldest digit is dropped and another added. The product of clock rate and delay-line length is the multiplication factor. Greater multiplication factors could be applied both to multibuoy operation and also to better resolution in the analysis of each buoy. AQA-5 introduced Deltic. Compared to AQA-3 and -4, AQA-5 enjoyed an increased compression factor of about 17.

The LOFARgram paper printing mechanism corresponds to these electronic techniques. A single fine stylus sweeps across a paper, marking frequencies detected in the signal under analysis. Its sweep rate across the paper corresponds to the rate at which the signal is analyzed. The paper itself moves to indicate changes over time. The darkness of the marks corresponds to the strength of the frequency components in the signal, and clearly there is a tacit assumption that all or most of the signal remains steady over the time it takes the stylus to move across. The more resolution the system requires, the further the stylus must move in a given time (to provide enough indication per channel). Targets are detected by visual integration.

In contrast, a CRT display created by a digital analysis technique (FFT) will create the entire LOFARgram essentially instantaneously, all frequency components being developed at the same time rather than in sequence.

Deltic was still fundamentally an analog device, in that the time-compressed signal still went through a series of narrow-band filters. The next step was a fully digital device, a digital analyzer using FFT techniques. FFT was introduced in the OL-82 of the S-3A and probably also in the AQA-7 of the P-3C.

AQA-3 and -4 could handle a maximum of 4 buoys (4 LOFAR or 2 CODAR in AQA-3, 4 LOFAR or 2 LOFAR and 2 CODAR in -3A and -4). AQA-4 was similar to -3 except that it used a

single internal band to cover both broad-band and narrow-band signals.

AQA-4 was made by Western Electric.

Users are as follows:

In the P-3A: Spain (6 delivered, but 4 replaced by 5 P-3Bs bought in 1987). All 73 surviving U.S. P-3As and P-3Bs in Reserve service are being deactivated. The Spanish P-3As and -3Bs are being modernized to P-3C standard, with APS-134 radar and, presumably, AQA-7 processors, by Boeing. See also IPADS, below.

In the S-2E: Argentina (6), Italy (8 S-2Fs), Korea (36), Peru (9), Turkey (18 or more, subject to Turbo-Tracker modernization), and Venezuela (8); possibly also Brazil (8). The Argentine aircraft have been fitted with tactical computers, but apparently not with new sonobuoy processors, since 1982. The Turkish aircraft listed above were refurbished in 1985 and, thus, may well have AQA-7 processors like S-2Gs. Thailand still operates S-2Fs but is retiring them (rather than modernizing them) because of severe structural problems.

Both S-2Es and S-2Gs (AQA-7) incorporate ASW data links (2.2-GHz AKT-19), transmitting their sonobuoy data down to the operating ship for analysis. Presumably, the Argentine and Brazilian carriers have this capability.

◆ AQA-5

The signal processor for P-3B aircraft was later installed in British Nimrod, French Atlantic, and Japanese PS-1 and P-2J aircraft. AQA-5 was a development of AQA-3/4. AQA-5 had an improved Deltic (delay-line time compressor) processor and somewhat greater sensitivity and used surface-wave processing. A P-3B carried 2 AQA-5s. Compared to AQA-3/4, AQA-5 achieved improved classification by using a narrower effective bandwidth, a wider display, and better frequency resolution. AQA-5s were also used ashore, in ASW analysis centers (ASCACs) and on board aircraft carriers, to analyze sonobuoy data collected by ASW aircraft.

AQA-5 could handle up to 8 buoys: 8 LOFAR, or 6 LOFAR and 1 CODAR, or 4 LOFAR and 2 CODAR, or 2 LOFAR and 3 CODAR, or 4 CODAR.

An improved AQA-5, WAP II (Wide-band Acoustic Processor II), was used on board some frigates to process SQR-15 towed-array data. WAP III is used by IUWGs (Inshore Underwater Warfare Groups) in TSQ-108 vans.

These processors were built by Western Electric and Emerson. In British service they were replaced by AQS-901; in French, by SADANG (TSM 8210). Emerson Electric delivered its first AQA-5 in 1964 and produced a total of 650. A modified version was delivered to Australia, Britain, and Germany.

Deltic Jezebel was fitted to the 111th and later P-3As. It was associated with the ASA-50 ground-speed and tactical-bearing computer. The (V)2 version was used in the P-3B. Both were replaced by AQA-7.

AQA-6 was an abortive Magnavox digital sonobuoy processor containing 8 line integrators and 8 time compressors; it was intended to replace all existing airborne acoustic systems (1965), processing SSQ-28 (LOFAR) and -48 buoys.

Users are as follows:

In the Atlantic MK 1: France (30 in 1989), Germany (14), Italy (18, modernized with AQS-902 in 1988-90), Pakistan (4). The Dutch Atlantics were all discarded.

In the P-3B: Portugal (6 ex-Australian, designated P-3P), Spain (5 ex-Norwegian; see P-3A under AQA-3/4). The U.S. Naval Reserve P-3Bs are all being retired. The RNZAF P-3Bs have all been modernized with new acoustic systems as P-3Ks.

In the P-2J: Japan (28). The PS-1s have all been discarded.

◆ AQA-7(V)

AQA-7 was the basis of the P-3C, which carried 2 of these processors. S-2G Trackers (which are still operated by Uruguay as shore-based patrol aircraft) carry 1.

AQA-7 introduced DIFAR processing (using SSQ-53 buoys). Compared to AQA-5, -7 is more sensitive and has expanded frequency coverage. AQA-7 incorporates ALI (automatic line integration), which should permit automatic detection of a strong and consistent line. Signals are multiplexed in the sonobuoy with compass information. Within the AQA-7, they are demultiplexed and routed to a frequency translator compressor (FTC), where the frequency band of interest is translated to a processing band, sampled, and time-compressed independently in 8 channels. FTC outputs are spectrum-analyzed to provide target bearing (for a DIFAR or DICASS buoy) and to supply both paper (LOFARgram) and CRT displays.

(V)1, (V)2, and (V)3 use 2 frequency-multiplier-storer units instead of the FTC of the original AQA-7. (V)4 introduced the FTC. (V)5 uses a frequency multiplexer-storer. Versions differ in the FFT analyzer they use (see below).

With 8 LOFAR channels, AQA-7 can simultaneously process up to 8 LOFAR buoys, or 2 CASS active buoys, or 1 DICASS active buoy.

AQA-7 was first delivered in 1969. Five generations appeared between then and 1989, major improvements being single and then triple vernier, provision for DICASS, and provision for passive tracking. Broad-band algorithms were tested in AQA-7(V)13/14/15 between 3 January 1983 and 16 July 1985. All of these systems are manufactured by Magnavox.

Versions:

(V)1 analyzer MX-8440

(V)2 analyzer MX-8440

(V)3 analyzer MX-8440

(V)4 analyzer TS-3542. This version introduced single vernier analysis (1975). TS-3542/AQA-7(V) processes time-compressed signals by conducting a narrow-band search for frequency lines of interest; the signal's amplitude at each frequency increment is supplied to output as a digital word. Two complete DIFAR analyses are conducted in less than 1.25 sec with decreased time required for range signals. Its output consists of 16 time-compressed signals, 2 real-time signals, plus clocks and control lines from other parts of the AQA-7(V) system. Output information is stored in shift registers and supplied as required.

(V)5 analyzer TS-3542

(V)6 triple vernier added to (V)4, at the suggestion of the Operational Test and Evaluation Force (January 1979). Three portions of the spectrum are examined simultaneously. This and later versions use analyzer TS-3807. TS-3807/AQA-7(V) receives time-compressed LF signals from a frequency translator compressor, performs a narrow-band search for discrete frequency lines, converts the signal's amplitude at each frequency increment to a digital word, and stores the analyzed data in shift registers for output. Two complete DIFAR analyses are conducted in less than 1.25 sec with decreased time required for range signals. Input to the spectrum analyzer-quantizer consists of 72 time-compressed signals, 2 real-time signals, plus clocks and control lines from other parts of the AQA-7(V) system. Output information is stored in shift registers and supplied as required. The modified unit receives 72 time-compressed signals, whereas the previous spectrum received only 16 time-compressed signals. Additional modifications to input gating and to timing have been incorporated.

(V)7 triple vernier added to (V)4

(V)8/9 added DICASS capability (1980). These versions use frequency translator-compressor CV-3610.

A(V)10/11/12 are modified AQA-7A(V)8 and 9 with passive

tracking (PTA) added (1984). Bearing frequency control is deleted and a new bearing computer (CP-1532) and signal data recorder (RO-547) added. Enhancement 1 (TAC-NAVMOD) to AQA-7A(V)10/11/12 improves the man-machine interface (using an interactive control panel), provides Passive Tracking Algorithm (PTA—see LAMPS) capability (using an embedded processor), and improves communication between the processor and the airplane's CP-901 computer. Each ICP contains 2 control display terminals (CDT), each with over 100 programmable switch locations and a plasma display panel. The enhanced display modification proposed for naval reserve aircraft (IPADS) provides a 15-in diagonal CRT. Eight real-time LOFARgrams can be displayed simultaneously.

A(V)13/14/15 are modified A(V)10/11/12 with broad-band processing, using 4 channels of cross- or auto-correlation processing band with 3 operator-selectable input bandwidths. FFT techniques are used to perform the correlation processing and also to remove tonals. The latter is necessary to eliminate the interfering banding effects on the correlogram caused by narrow-band signals, and it solves a problem present in earlier broad-band processors. Affected processors can be reprogrammed on board, so little new hardware is needed. The earlier narrow-band and PTA features remain. New features are a demultiplexer (TD-1400), a new frequency translator-compressor (CV-3921), a new signal-data recorder (RO-574), and a new bearing computer (CP-1683 in (V)15). In (V)13 and 14, CP-1532A/AQA-7(V) performs automatic line integration, computes bearings and intensities for displays, and computes statistical parameters for automatic thresholding and data correction and tracking. It cross correlates and autocorrelates the broad-band signal as a function of the controls from the signal-data-recorder plasma panels. CP-1683 (for (V)13, 14, and 15) is functionally but not electrically similar to CP-1532.

B(V)18/19 IPADS processors for modernized P-3B aircraft. IPADS doubles the number of LOFAR channels provided by (V)11/12 (32 rather than 16), with 3 verniers per channel (all DIFAR and LOFAR rather than LOFAR only). As in (V)11/12, IPADS has 2 embedded PTA processors (8 channels). It doubles the number of doppler bearing tracker channels (16 vice 8) and provides 32-channel frequency alert (none in (V)11/12, 32 of post-processing in Update III CHEX). As in Update III CHEX (but not (V)11/12), there is a trackball. There are 99 sonobuoy channels (compared to 31 in the earlier (V)11/12).

◆ OL-82/OL-5004

OL-82 is Sanders's FFT sonobuoy processor for S-3A aircraft. OL-82 differs from its predecessors in lacking any paper print-out, and frequencies are presented logarithmically rather than linearly.

OL-5004 is a modified OL-82 for Canadian Aurora aircraft. It adds vernier displays and can measure ambient sea noise.

Both OL-82 and OL-5004 represent the beginning of a new generation of narrow-band systems, using FFTs to determine the spectral content of an acoustic signal. Incoming signals are converted into series of points (signal intensity at closely spaced time intervals) in digital form, and the spectrum is read off in digital form for further representation or analysis. FFT is now the standard means of spectral analysis in passive sonar applications, including those on board ships and on board submarines. Spectral analysis should be particularly well adapted to data-based systems, in which data pass from 1 console to another in digital form.

◆ UYS-1

IBM's Advanced Signal Processor (ASP), the first and current standard U.S. Navy acoustic-signal processor, is intended to re-

place a variety of special-purpose devices. Therefore, like many other current systems, it emphasizes programmability and can be upgraded by changes in software rather than by rewiring.

Production began in 1981, the 250th unit being delivered in October 1984. The initial requirement, as stated in 1981, was for 500 units.

UY-1 is a very high speed linear-flow computer, currently used in aircraft (P-3C UPDATE III, S-3B, SH-60B), submarines (BQQ-5C, BQQ-9, SUBACS), and surface ships (SQS-53B/C, SQR-19, UQQ-2 SURTASS); this computer is also used by the air force and army. The current version has a program memory of 128k 32-bit words, expandable to 256k with an engineering change. Bulk storage is up to 1024k 32-bit words, organized in 64-bit double words with 8 error-correction code bits.

Processing rate is 10–20 MFLOPS, with a total input/output rate of 1.25 Mwds/sec. Demonstrated MTTR is 12 min; predicted MTBF is 775–1100 hr, depending on configuration.

I/O is organized in up to 8 programmable channel pairs (combination of NTDS and Proteus).

In its aircraft form, UY-1 is 57.32 × 23.44 × 11.19 in, weighs 240 lb, and requires 1530 W of power.

Three ASP are packaged together as TRIASP, for the BQQ-5C Expanded DIFAR.

The UY-1 was designed for upgrading, given the very rapid evolution of computer technology. For example, as of 1984 ASP memory technology was already in its fourth generation, having evolved from 4k (bits per chip) to 64k. Improvements between the start of production, in 1981, and 1984 included doubling the central processor's control memory (2k to 4k 32-bit words), doubling the arithmetic processor's storage (2k to 4k 64-bit words), doubling the arithmetic processor's working storage (2k to 4k 32-bit words), doubling the program's storage (128k to 256k 32-bit words), and improving programmability using distributed program architecture microcode. Many of these improvements resulted from the replacement of 1k static memory by 4k read/write memory, cutting the net number of modules.

In November 1983 IBM completed its first VHSIC chip, capable of 100 MFLOPS, 10 times more than any previous reported chip, with 37,000 circuits on 64 mm² of silicon. Applied to an acoustic brassboard (VHSIC acoustic brassboard, May 1984), this type of chip permitted DIFAR signal multiplexing for twice as many sonobuoys as are currently available. A brassboard is not, of course, a working airborne computer, but this type of performance must have been important for the massive dwarf sonobuoy fields envisaged under the LCS program (see SSQ-103 above).

ASP software is currently being upgraded to match a simplified and improved programming method (Signal Processing Graph Notation, SPGN) developed for the more powerful UY-2. SPGN was demonstrated in a program called ECOS (EMSP common operating system). The ASP Common Operational Support System (ACOS) is a programming methodology by which acoustic engineers can implement signal processing graphs into ASP (UY-1) code without extensive computer training. ACOS Phase I SPGN applications development tools were implemented in FY88.

◆ UY-2

The enhanced modular signal processor was developed by Bell Labs (AT&T). UY-2 is intended for use by air, surface, submarine, and shore platforms, in acoustics, radar, EW, image processing, and communications. However, because UY-2 was conceived as an ASW signal processor, it is included here. The design concept called for a family of processors, with varying volumes and burst multiplication rates:

EMSP A 35 in³, 400 MFLOPS
 EMSP B 30 in³, 200 MFLOPS
 EMSP C 25 in³, 150 MFLOPS
 EMSP D 15 in³, 100 MFLOPS
 EMSP E 5 in³, 25 MFLOPS

High net speed is achieved by parallel processing (which AT&T called "multithread control architecture"). The EMSP is designed around 6 functional elements (FE), each consisting of a group of standard electronic modules (SEMs): a scheduler; a global memory (intelligent memory providing storage and memory management, in 2-, 4-, 6-, or 8-Mword modules); a data-transfer network; a command program processor; an arithmetic processor; and an I/O processor. Words are 16 bits long.

Predicted MTBF is 1250 hr for the largest configuration or 4000 for the smallest; predicted MTTR is 0.25 hr. The computer design can exploit future VHSIC or VLSI technology.

Planned UY-2 applications include the BSY-2 submarine CDS (6 UY-2 per submarine), the P-3C/P-7, and SQQ-89. NAVSEA claimed that in the P-3C, 1 UY-2 was equivalent to 14 UY-1s in the same size box. A UY-1 can handle 5 DIFAR buoys; a UY-2, at least 64.

EMSP is 1 of the first DoD VHSIC insertion programs (AT&T 1986–87). VHSIC was used for a new arithmetic processor with 46% more throughput than its predecessor and has been in units produced since 1988 for the BSY-2. Formal approval for production was granted in August 1989.

During 1989 there were some attempts to kill EMSP (UY-2) on the grounds that commercial processors could outperform it. EMSP had, after all, been conceived a decade earlier. Although UY-2 has 6 times the processing power of UY-1, some potential user programs bought UY-1 instead for fear that UY-2 would be canceled. Exponents of EMSP could point to the virtue of standardization, and also to the machine's capacity for later improvement. There was also some question as to whether most UY-2s bought would be built out of the SEM-B cards initially planned, or out of more capacious SEM-E cards (so that the machine would be built out of fewer cards). In April 1989 it was decided that the SEM-B version would be limited to about 180 machines, out of a total planned purchase of 750–1000. It seemed likely that the 180 SEM-B versions would be those required for the 30 *Seawolf*-class submarines.

In January 1989 AT&T received a contract to redesign UY-2 using larger SEM-E cards (6 × 6 in). These cards hold 3 times as many microchips and other components as SEM-Bs, and they use high-density gate array and memory devices. The SEM-E version should be small enough to fit aircraft such as the P-3C UPDATE IV. The SEM-B unit is 6 × 2 × 2 ft. The SEM-E unit designed for the P-3 will measure about 4 × 4 × 2 ft and will weigh only a quarter as much as -B. It will incorporate a second processor to correlate acoustic data with nonacoustic (e.g., radar) to distinguish submarines from surface ships. Planned future improvements include a Matrix Array Processor.

The SEM-E prototype should be delivered in April 1990.

◆ ASAP

Martin Marietta's Advanced Systolic Array Processor is proposed as a fast-time analyzer, e.g., for the 20 shore-based ASWOCs. ASAP is a massively parallel processor; the manufacturer claims 300 MOPS on each computer board. The range of equipment based on ASAP includes a generic workstation (SMS-20V), a neural network computer (SNAP), and a variety of special boards. ASAP can be programmed in ADA and can incorporate a VME bus.

Martin Marietta also has a Linear Mapped Array Processor (LMAP), which may be offered as a coprocessor for UY-2.

◆ ASUTAA/P-3C Modernization

In April 1989 it was reported that an upgrade to P-3C aircraft, ASUTAA (Acoustic System Upgrade to ASW Aircraft), would probably be proposed under the FY92 budget. ASUTAA is an attempt to achieve something close to UPDATE IV capability, doubling the DIFAR capability of the P-3C UPDATE III to 32, with 100% memory and 60% throughput reserve, plus post-processing and display capability to fully exploit the new buoys. In contrast, UPDATE IV will be able to handle 54 DIFAR buoys simultaneously. The ASUTAA program was announced in September 1988, and a draft RFP written in 1989. An RFP had

originally been expected in FY90, but reportedly it was delayed so as not to compete directly with the new UPDATE IV program. Early in 1989 it appeared that the program would first be funded in FY92. As of early 1990, it appeared that ASUTAA (UYS-1) would be revived as the P-7/UPDATE IV schedule slipped.

ASUTAA is related to the P-3C Modernization Program, a series of upgrades to system computer (CP-901) and ASP software. The current UYS-1 hardware/software configuration is integrated with Passive Tracking Algorithms (PTA—see the discussion under LAMPS); a 32-channel half-bandwidth capability (Channel Expansion—CHEX); constant resolution (CR) modes; broad-band, digital track (post-CHEX); and 99-channel on-line sonobuoy radio-frequency monitor capability. This program also integrates advanced sonobuoys and detection algorithms, which are contained in the modular-software-design airborne Air Common Acoustic Processing (ACAP), into upgraded P-3C ASP and CP-901 tactical computers.

The FY88 program included completion of P-3C UPDATE III CHEX implementation. The CHEX and ACAP version 4.0 development tests were conducted during the summer of 1989. The next version of ACAP, version 5.0 (constant resolution, broad-band, SSQ-53D buoys), was defined during FY89, and this software was released in June 1989.

The FY89 program included preliminary research work on an airborne transient processor, which was to transition to development in FY91.

◆ IPADS

Improved Processing and Display System, a proposed upgrade to the AQA-7s of Naval Reserve P-3A and -3B aircraft. As of 1990, there is some question as to the future of IPADS, as there have been proposals to retire the P-3As and -3Bs. The counter-argument is that the fleet has insufficient P-3Cs and that it will be many years before enough P-7s appear. Hence the value of at least a P-3B upgrade. IPADS was envisaged as a sixth-generation AQA-7, a less expensive alternative to the UYS-1 of the P-3C UPDATE III. IPADS began as a 1985 congressional initiative, supported by the Naval Reserve Association. Magnavox received the development contract in July 1987 for delivery by May 1990 for July–September 1990 flight tests. Factory tests were completed by the fall of 1989, and the first full suite was installed toward the end of the year. Tests on board a P-3B (using signal generators rather than real inputs) were described in May 1990 as quite impressive.

IPADS is designed to double the number of buoy processing channels (from 16 to 32 LOFAR, or from 8 to 16 DIFAR), to double the number of verniers (to 96), to quadruple the number of DICASS buoys supported (to 4, with extended doppler, equivalent to 8 range-only buoys), and to support a new capability, ERAPS (2 could be processed). Extended doppler was needed to counter faster submarines. IPADS also incorporates the Passive Acoustic Detection and Classification (PADC) algorithms already operational in the active fleet by 1985. Physically, the IPADS system doubled up, providing 4 chart recorders (for LOFARgrams) as well as 2 CRTs. That made for increased reliability since there were 2 entirely independent processing paths.

IPADS has enjoyed very strong support from reservists, but the current (May 1990) official navy position is that it will be too expensive and that the P-3As and -3Bs that might receive it will be retired within 2–3 yr, to be replaced by P-3Cs (when the P-7 is introduced). IPADS was identified by Congress in 1989 as "a matter of special interest." One current issue is whether reserve P-3Bs are in better condition than the active P-3Cs scheduled to replace them.

◆ P-3C UPDATE Programs

The series of P-3C UPDATE programs parallels drastic improvements both in sonobuoys themselves and in the computers processing their data. Many navies (and many U.S. naval reservists) still operate P-3B Orions updated to some approxima-

tion of the P-3C. Late production P-3Bs had a strengthened airframe (135,000 rather than 127,500 lb as a maximum take-off weight), and improvements included a fourfold increase in acoustic processing capacity, a better tactical navigation system, and, in 1981, an IR detector and a Harpoon-missile capacity.

As an indication of the increased computing power of the original P-3C, it was said that the electronics part count in 1 P-3C equaled the total in all 144 P-3Bs. The P-3C could process 16 buoys simultaneously, compared to 8 in a P-3B and 4 in a P-3A. The P-3C had 48 externally loaded sonobuoy chutes (plus 4 reloadable in flight), compared to 9 chutes in a P-3A or -3B. The P-3C also introduced the dual-antenna APS-115 radar, for full 360-deg sea-surface coverage, and used a low-light television instead of the searchlight of the predecessors. The 43rd production P-3C introduced the ASQ-81 MAD.

The UPDATE I program was begun before the first aircraft joined the fleet and entered service in 1974. UPDATE I increased the computer's memory sevenfold (by adding a 384k-auxiliary magnetic drum) and added an additional tactical display for acoustic sensor operators, acoustic processor improvements, a crash locator (beacon), and the Omega navigation system.

UPDATE II doubled the capacity on the acoustic tape recorder (ATR) and added a sonobuoy reference system, the Harpoon antiship missile, and a FLIR to replace the earlier LLLTV. The sonobuoy reference system consists of antennas, located around the fuselage, that locate buoys by recording the phase differences in the signals received by adjacent antennas; the airplane no longer has to overfly buoys to locate them. This system was developed for the S-3A Viking. UPDATE II entered service in 1978 (the first such aircraft joined the training command in September 1977).

UPDATE II.5 replaced some systems with more reliable equivalents (INS, doppler, VHF, VOR/ILS, TACAN, ESM); it integrated aircraft-to-submarine acoustic communications (via buoy); it added a MAD compensation group adapter and a tactical coordinating officer (TACCO) auxiliary IR display; it standardized wing pylons and improved fuel-tank venting.

UPDATE III added an advanced sonobuoy receiver (the 99-channel ARR-78 in place of the 31-channel ARR-72), a single advanced signal processor (ASP: UYS-1), transparent logic units (XLUs), and an acoustic test signal generator (ATSG). An extra lower UHF antenna was added, plus environmental improvements (better cabin-air distribution, a heat-exchanger water spray system, and increased-capacity engine-driven compressors for air conditioning). In this version the airplane has 3 sensor stations (displays) plus a TACCO display. The airplane can monitor 16 different sonobuoy signals on 99 channels. The XLU designation refers to lighter-weight logic units that are functionally equivalent (i.e., transparent) to their bulkier predecessors, using integrated circuit technology. These logic units leave space for later installation of an AYK-14 computer.

UPDATE III incorporates a new 99-channel sonobuoy reference system, ARS-5, replacing the ARS-3 of UPDATE II. In contrast to the earlier reference system, it uses its own computer rather than the overall system computer (ASQ-114). The capacity of the embedded computer makes the reference system a more general-purpose VHF/DF, which can be extended for use in communications intelligence. The manufacturer, Cubic, offers the new version as a stand-alone Sonobuoy Reference System (SRS) with COMINT potential.

In UPDATE III, a digital computer, Proteus (UYS-1, also called ASP), replaces the hard-wired AQA-7. It displays buoy data, either analog or digital, on 2 CRTs, each of which can show 8 buoy channels. Each channel can be broken down into 3 narrow-band (vernier) windows. UYS-1 is heavier than its predecessor, and some reduction in airframe weight (such as by using lightweight floorboards) was needed to compensate. On the other hand, improvements in hardware made it possible to dispense with 1 of the 2 computers originally planned.

Perhaps the most important tactical difference between

UYS-1 and AQA-7 is that UYS-1 provides no paper LOFAR-grams, only a magnetic tape of buoy outputs. In the past, post-mission analysis of grams, generally by eye, often disclosed submarines not detected by crews in flight (e.g., in cases in which a line varied slightly in frequency over time, and thus was obvious to the eye but not to a line integrator). The submarines moved slowly enough that a later flight, briefed to look at the appropriate frequency, could find them.

Continuing work on UYS-1 includes integration with passive tracking algorithms (PTA—see the entry on LAMPS above), broad-band capability, 32-channel half-bandwidth capability (channel expansion), 99-channel on-line capability, and provision for advanced buoys (using modular software).

UPDATE IV introduces a very different distributed architecture, developed by Boeing as UDACS (universal display and control system), initially for the RNZAF Rigel I P-3B modernization program. An UPDATE IV P-3C has 5 UDACS operator consoles containing 68020 microprocessors. The acoustic processor is EMSP (UYS-2). The entire system is tied together by a high-speed maxibus (192 Mbits/sec, using 32-bit words) as well as a 1553B bus. The distributed architecture should make for easier system expansion and modification, and it should also be fault tolerant. The system is expected to have sufficient computing capacity to permit some measure of automatic classification of passive signals.

The new standard UYS-2 processor has increased (currently 99-channel) capacity, presumably to handle both future array buoys and large numbers of low-cost (LCS successor) buoys.

Compared to UPDATE III, UPDATE IV has 2.5 times the acoustic data throughput, 8 times the bulk memory, 30 times the display memory, and 5 times the MTBF. Increased display memory presumably allows an operator to sample the multiple beams available from such new array sonobuoys as HLA and ERAPS. UYS-2 can handle 54 DIFAR buoys simultaneously. The associated high-volume data recorder can accept 30 Mbits/sec for 7.4 hr.

Aside from the acoustic sensors, UPDATE IV aircraft will have an APS-137 ISAR nose radar (there is no tail radar), an AAS-37 FLIR, ALR-66(V)5 ESM, and more precise navigational sensors (Omega/GPS/GPS-aided inertial).

The program began formally with a 1 June 1984 memo by the secretary of the navy. It was approved by the Navy Acquisition Review Council in November 1984. Boeing and Lockheed competed for the contract, and Boeing was awarded a demonstration/validation contract (in competition with Lockheed) in November 1985. The Boeing avionics demonstration began in October 1987, and the company was awarded a full-scale engineering-development contract on 10 July 1987. Lockheed, the P-3C manufacturer, had been responsible for all previous UPDATES. Boeing is to deliver the first UPDATE IV airplane in mid-1990.

In this version the internal arrangement of the airplane is again modified, the TACCO (tactical coordinator), navigator/communicator, and acoustic operators occupying positions similar to those in the P-3B while leaving the nonacoustic operator in the P-3C position. In this arrangement, the TACCO can view all the sensor stations simultaneously, for better coordination.

Existing UPDATE II aircraft are to be modified to UPDATE IV standard, so ultimately the P-3C fleet will consist entirely of UPDATE III and IV. In addition, UPDATE IV is the combat system of the new Long-Range ASW Aircraft, LRAACA (the Lockheed P-7A).

Aircraft are continuously modified, so P-3Cs nominally of earlier UPDATE standard often receive equipment developed for later ones.

See also ASUTAA and IPADS.

◆ TD-1135/A

This Sparton processor is installed in French Atlantic Mk 1 maritime-patrol aircraft, which are fitted with omnidirectional LOFAR processors, providing them with a DIFAR capability. It demultiplexes DIFAR buoy signals to provide LOFAR outputs

from their 2 beams (north-south, east-west) plus their omnidirectional sense outputs, to find target direction. Maximum processor analysis bandwidth is 1 Hz. Time constants: 0.1, 1.0, 10 sec. Minimum MTBF is 1500 hr.

Sparton also manufactures its own low-cost FFT (LOFAR) processor (spectrum analyzer). Input dynamic range is 80 dB. It operates over a frequency range of 14–912 Hz, in 2 bands: 14–114 Hz with 0.25-Hz resolution, 112–912 Hz with 2-Hz resolution. The output is 400 spectral estimates per band.

NONACOUSTIC ASW SENSORS

For ASW radars (for periscope or snorkel detection), see the Strike/Surface Warfare section. Virtually the only current non-acoustic ASW sensors are Magnetic Anomaly Detectors (MAD). However, in the past some ASW aircraft have carried chemical detectors of snorkel exhausts ("sniffers," code-named AUTO-LYCUS in Britain); and Sweden is currently interested in the Australian LADS described below.

MAD is the only sensor on board many helicopters that deliver torpedoes but are directed by shipboard sonar. It is lighter than a dipping sonar, but even so it may be too heavy to combine with a lightweight dipper in a small helicopter. MAD is useful because sonar range often does not correspond precisely to the distance at which the helicopter attacks; the reason is that the sonar beam is bent as it passes through the sea. This consideration applies to the Alouette-III, to the McDonnell Douglas/Hughes 500M (used by Spain), to the McDonnell Douglas/Hughes 500MD/ASW Defender (used by Korea and Taiwan), and to many Lynx helicopters (at least for France, Germany, and the Netherlands). The Royal Navy originally did not carry MAD in its torpedo-delivery helicopters but has added it in the new HAS.8 version. Wasp helicopters apparently lack MAD and are entirely radar/sonar-directed. The Royal Navy originally did not install MAD in its Sea King helicopters (which have dipping sonars and radars), but it was an option (9 MAD kits were supplied during the Falklands War), and it is a feature of the current HAS.6 version. Similarly, MAD was originally an option in Lynx helicopters. British policy would make it unlikely that exported Sea Kings (for Australia, Egypt, Germany, India, and Pakistan) are fitted with MAD.

Reportedly, although the Western powers use MAD as a final-attack confirmation sensor, it is Soviet practice to use MAD instead as a search sensor, flying a tight pattern over the narrow strait through which a submarine is expected to pass. No details of Soviet MAD systems are available.

It is also possible that some nations use magnetic loops for harbor protection; this technology dates from before World War II. The Crouzet MAD buoy would seem to be a current application.

AUSTRALIA

◆ LADS

Not conceived as an ASW system, the Laser Airborne Depth Sounder is an underwater survey system developed to help map the Australian continental shelf. LADS is said to be able to penetrate 50 m of water under all sea conditions, and the device has flown in a Fokker F-27. Reportedly, Sweden has been interested in LADS as a means of detecting small submarines in very shallow water under poor acoustic conditions.

The stabilized LADS laser scans a 240-m-wide swath at a rate of 168 pps, producing a grid pattern of spots 10 m apart. A contract for an operational LADS was awarded to the Australian company BHP Engineering Pty Ltd in May 1989; it is expected to enter RAN service in 1992. LADS was developed during the mid-1970s by the Defence Science and Technology Organization South Australia; the R&D versions (WRELADS) flew about 500 hr from 1981 on.

In April 1988 it was reported that a Larsen 500 airborne Ladar (Laser Radar) bathymeter had been tested by the U.S. Navy Coastal Systems Command, Panama City, and by the U.S. Naval Systems Center at San Diego, and that the device would be

tested as a mine detector in the Persian Gulf. This Ladar was developed by Optech Systems of Downsview, Ontario, and it has demonstrated detection of mines down to about 100-ft depth. It uses a pulsed beam and backscatter to determine the position of the water's surface. The Larsen 500 was developed for the Canadian hydrographic service and has been used for coastal surveys since about 1985. Reportedly, the Ladar has been tested against submarines, torpedoes, nets, mines, and submarine wakes.

There is a long (and unhappy) history of attempts to use blue-green lasers for submarine detection, beginning with the discovery, about 1962, that such lasers could indeed penetrate sea water to a considerable depth. For example, a primitive laser radar figured in advanced U.S. ASW development in the early 1960s; and in the late 1960s such a device, UDACS, manufactured by Kollsman, was publicly described. By that time it was fairly clear that, although the beams were good enough for 1-way communication down to a submarine (albeit not down to great depths), there was not enough of a backscattered signal for useful detection or tracking. Even so, lasers remain attractive in really shallow water.

See also the Northrop ALARMS in the Mine Warfare section.

CANADA

◆ AIMS (ASQ-504)

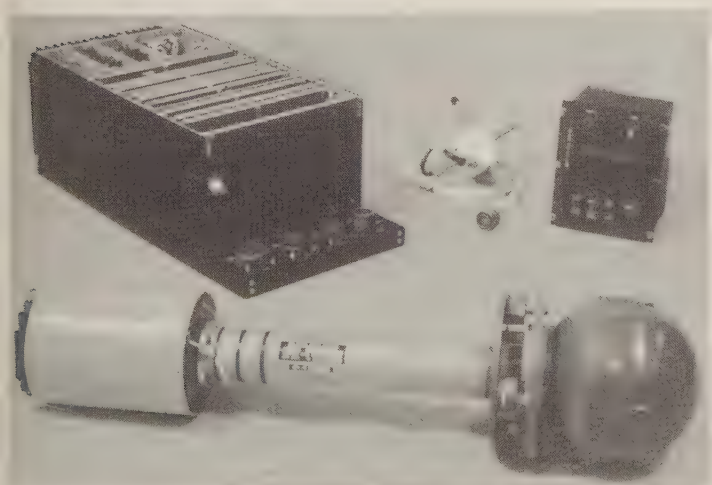
The Advanced Integrated MAD System was devised by CAE Electronics, Ltd., of Canada. Unlike other helicopter-borne MAD gear, AIMS is carried on board the helicopter; CAE claims that this arrangement frees the crew of the operational restrictions associated with towing a conventional MAD body. Moreover, because the MAD detector is not towed, it is very easy for the helicopter to shift from dipping sonar to MAD operation. The company also claims increased detection range, with a sensitivity of 0.01 gamma in flight. Total weight is 50 lb.

The integration in AIMS is between a very sensitive magnetometer and an advanced compensator to take into account the magnetic field of the aircraft (as well as geological magnetic noise). CAE has been developing sensitive compensators since the 1960s; CAE's AN/ASA-65 is currently the Free World's standard MAD compensator, with 900 units in service.

Detection is by optical pumping of directionally oriented cesium, and interference from the helicopter is canceled out by compensating upon takeoff, the compensating terms being computed in 8 min using an on-board vector magnetometer.

Users include Britain (242 units for Sea King and Lynx HAS.8 helicopters and for Nimrod MR 2 aircraft), and a total of 75 others for Canadian CP-140s, Australian SH-70s, and Australian S-2 Trackers. ASQ-504 was selected for the Turbo-Tracker, currently in Taiwanese service (and probably selected for Turkey), and for the Fokker Maritime Enforcer Mk 2.

See the previous edition for details of the earlier ASQ-502.



ASQ-504. (CAE)

FRANCE

◆ DHAX-1/DHAX-3

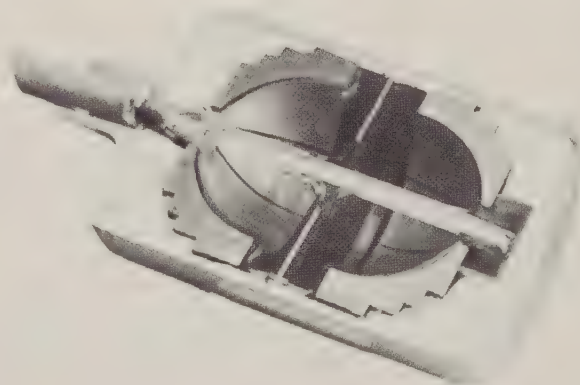
DHAX-1, the MAD that is found in the Atlantique Mk 1, uses 4 cesium-vapor paramagnetic resonance cells. DHAX-3 is an improved towed version, for helicopters. It uses 6 rather than 4 cesium-vapor cells.

Applications include French navy (and presumably other) Alouette-III torpedo-delivery helicopters and Saudi Dauphins.

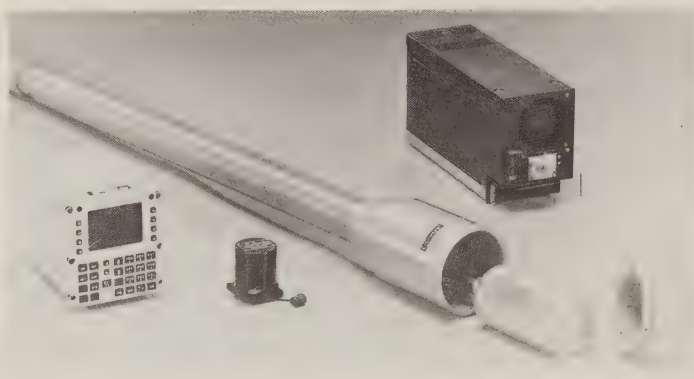
◆ Crouzet MAD Systems

Crouzet uses electronically pumped NMR, in contrast to the optically pumped U.S. and Canadian systems that are based on electron spin resonance. The company claims extreme simplicity and reliability for this approach: there is no optical exciter; and the system uses a liquid rather than a gaseous medium, so there is no vapor to be created before the MAD can operate. Moreover, the output is easily read as a resonant frequency. Crouzet also uses a distinctive signal-processing technique. Instead of threshold detection, the system compares the received signal with a model of the expected target signal, a method the company calls MAD-SADE (Self-Adaptive Detection/Estimation). A simple dipolar model of the target suffices, and the SADE method gives both a confidence level and a fix of the target's position. Experiments both in the Mediterranean and in the English Channel in 1979-80 showed that MAD-SADE improved net detection probability and that, for a given probability, the method increased detection range, so that in about 60% of cases the airplane detected the submarine before passing over it.

The current version is Mk 3, which equips the Atlantique Mk 2 maritime-patrol aircraft and has been tested in Lynx helicopters. The detector is 125 × 1250 mm and weighs 5.5 kg. The entire system weighs 15-20 kg. Sensitivity is within 0.1 gamma. In the Atlantique, twin sensors are used in tandem, to detect any change in the aircraft's signature, canceling it out.



Crouzet MAD sensor, cut away to show its cavity. (Crouzet)



Crouzet MAD Mk 3, showing the probe and its casing. (Crouzet)

This system was tested in 1983, and production began early in 1985. In helicopters, it is towed on a 70-m cable.

In 1989 Crouzet began developing a MAD buoy, seen as a replacement for current passive buoys in the face of future very quiet submarines. The company argues that, even if the Soviets build their craft of nonmagnetic titanium, no submarine can avoid having a large mass of magnetic material, e.g., in the power train. The counter argument is that magnetic detection generally depends on the motion of the submarine relative to the detector. That motion is considerable with an airplane but much less so in the case of a submarine passing a static buoy at low speed. Even so, it is worth recalling that magnetic loops were the standard means of harbor defense before World War II. A submarine passing over the loop generated a current, and that signal could be picked up by a shore station. Controlled mines could be detonated in response. Presumably, Crouzet can do much better in terms of range, given modern highly sensitive techniques of magnetic detection (loops detected at very short range, which was just what was needed to activate the right controlled mines).

INTERNATIONAL

There is an ongoing NATO nonacoustic ASW project, listed by the U.S. government as an FY88 new start. Participants, with expected contributions, are Canada (\$2 million), Germany (\$6 million), Norway (\$10 million), the United Kingdom (\$28 million), and the United States (\$50 million over 5 yr). The first at-sea experiments, in Norway, were conducted in July 1988, with British experiments expected in the summer of 1989. The Norwegian and German navies are presumably particularly interested in nonacoustic ASW because acoustic conditions in the fjords and in the Baltic are so very bad. The brief published description of the program suggests that it is basic physical research, the U.S. government finding it useful to be able to estimate the effect of particular sensor characteristics on submarine detection without having to carry out experiments with actual submarines. That arrangement would, for example, permit a measure of nonacoustic development without having to reveal the sensors and their performance.

JAPAN

◆ HSQ-101

This is the MAD in P-2J aircraft. Presumably, it is related to the U.S. ASQ-10 (the contemporary PS-1 carried ASQ-10A). The later P-3 and SH-60J both carry versions of ASQ-81.

USSR

In contrast to Western navies, the Soviet Union reportedly considers MAD a search sensor, to be used to detect submarines passing through relatively narrow straits. Presumably, this practice explains intense Soviet interest in submarine degaussing. Such a practice would recall the Anglo-American MAD barrier flown over the Straits of Gibraltar during World War II. MAD was used in that case because the layering of the water (caused by the interpenetrating Atlantic and Mediterranean currents) precluded conventional acoustic search.

Reportedly, the helicopter MAD, which is towed on a long cable, is designated APM-60. Effective range is 300–700 m.

UNITED STATES

◆ ASQ-10

The MAD in P-3A/B and late-production S-2 aircraft, ASQ-10 is a saturable-core magnetometer that was introduced about 1960. ASQ-10A was installed in British Nimrod MR.1s (no longer in service).

◆ ASQ-81

Texas Instruments's MAD is currently the standard U.S. Navy system. ASQ-81 uses optically pumped metastable helium. There are 2 configurations, a towed MAD for helicopters and a



ASQ-81 MAD stingers on a line of P-3 Orions. The radomes below the MAD boom carry the rear antenna of the APS-115 radar, so that a 360-deg search can be maintained without the drag associated with hanging a radome below the airplane. (U.S. Navy)

fixed tail MAD for airplanes. Both have been in use since 1970. In 1979 it was reported that ASQ-81 had triple the effective range of earlier MADs, about 3000 vs. 1000 ft. However, other reports suggest that the range of the earlier MAD was only doubled. ASQ-81 incorporates an improved means of maintaining alignment with the earth's magnetic field and has automatic target detection, which ASQ-10 lacks.

Versions are (V)1 for the P-3C, (V)2 for the SH-3H and SH-2D helicopters, (V)3 for the S-3A, and (V)4 for LAMPS-III helicopters.

The helicopter version can be towed at 10–140 kt and can be reeled at 50 or 200 ft/min, the limiting length of the cable being 80–180 ft. ASQ-81 can typically be turned on in 1.5 min, and sensor noise in-flight is generally about 0.24 gammas. Gain can be set at 0.1, 0.2, 0.4, 1, 2, 4, 10, 20, or 40 gammas full-scale.

Users include U.S. and foreign operators of the P-3C and SH-3; the U.S. Navy for the S-3, SH-2, and SH-60; Germany and the Netherlands for the Lynx helicopter; Japan for the HSS-2 helicopter; and Korea, Spain, and Taiwan for the 500M/500MD helicopter.

◆ ASQ-208(V)

This is a digital version of ASQ-81. The microprocessor used to compensate for the aircraft's magnetic field has a 3-channel filtered display and threshold processing. Existing ASQ-81 wiring is retained, but signal recognition is improved. As in the existing unit, targets are automatically detected. However, in this version a range/confidence estimate is provided. Aircraft electronics is simplified. Texas Instruments offers both inboard and towed versions.

The version in the new P-7A has a shorter tail boom than the ASQ-81 of the P-3C because the new airplane has no tail radar antenna and so lacks the metal mass there.

◆ Periscope Detector

In the summer of 1990 the navy was expected to issue a Tentative Operational Requirement for a periscope detector for the SH-60F inner-zone ASW helicopter. There was some speculation that it would be the APS-137 radar, but weight is limited, and the radar would provide much more information than periscope detection requires. SH-60F currently has no radar at all. There has been speculation that the periscope detector might be a blue-green laser, reacting to reflections from the glass in the periscope head. Any periscope detector would be integrated with the helicopter's ASN-123 tactical data system. Re-

portedly, the requirement for the LF dipping sonar to be carried by the SH-60F calls for 3 arithmetic processors, with more computing power than is required for buoys, a dipper, and a radar.

Periscope detection is important for the inner-zone role because many submarine commanders will want 1 look before exposing themselves by firing a torpedo. In difficult sonar conditions, moreover, a submarine is as hampered as a surface ship, so the sub will need to use a nonacoustic sensor (i.e., a periscope) to establish a firing solution. The inner-zone periscope-detection requirement is very different from that imposed on aircraft like the S-3 because it is vital to achieve a very high probability of detection on a fleeting target. In contrast, periscope detection is one of several possible ways an S-3 can detect a distant contact, and the consequence of a failure to detect is not very serious; at such a range the battle group enjoys a layered defense. The SH-60F is the innermost layer of that defense and must, therefore, be extremely effective.

MISSILES

AUSTRALIA

◆ Ikara

Dimensions: length 3.43 m, span 153 cm; overall height 157 cm [135 × 60.2 × 60.8 in]

Weight: about 1300 lb (stated as less than 600 kg)

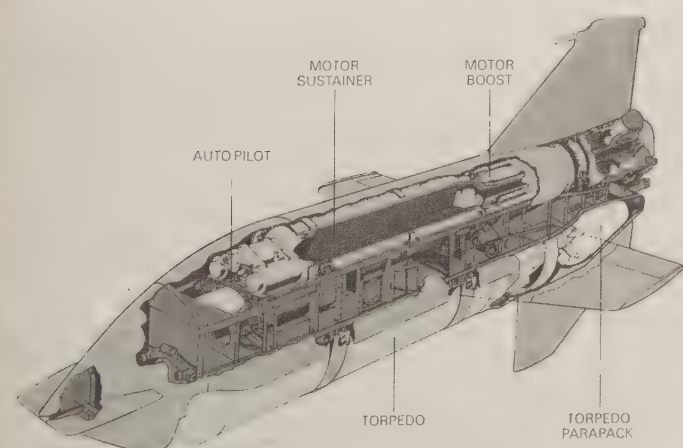
Warhead: homing torpedo (Mk 44 or Mk 46)

Propulsion: dual-thrust (boost-sustain) Murawa solid-fuel rocket

Speed: subsonic (about Mach 0.75) **Range:** approx 20,000 yd

Ikara is a radio-controlled rocket-powered glider carrying a lightweight torpedo, adopted by the Royal Australian Navy, the Brazilian navy, and the Royal Navy, and sold to the Royal New Zealand Navy. The existing systems employ a single launcher (55-deg launch angle in all cases) and a magazine of reloads. The missile's transponder is tracked by the launching ship, and the missile is commanded to drop the torpedo. The missile then continues in flight, diving into the sea far enough away so as not to interfere with the torpedo's search pattern. To maintain stability after the torpedo has been dropped, the missile deploys 2 small fins at its rear end. The guidance receiver/decoder is housed in the missile's upper fin. The manufacturer claims that hit probability is substantially improved because Ikara continues to receive sonar update information as it flies toward its target. Flight altitude of 300 m [about 1000 ft] is maintained by barometer.

In the British ships, 1 of which is now in New Zealand service, missiles are stowed in 2 parallel rows, without their wings and tails. Each is on a shock-mounted stool, is extracted manually by an overhead grab on a monorail in the magazine's roof, and is lifted onto a trolley running between the rows. The missile is raised by hoist to an assembly room on the upper deck immediately forward of the bridge and then finned before being moved tail-first onto the launcher. Since the missile has no de-



Ikara. (British Aerospace)



Ikara. (RAN)

icer, it cannot be stored on the launcher for very long, but missiles can be stored in the assembly room.

Ikara was inspired by (but is unrelated to) the French Malafon. Work began in 1959, and the basic design was settled by mid-1960. Trials (using a short-burn solid-fuel motor) began in February 1961, and the first all-up prototypes were ready at the end of that year, using the Murawa boost-sustain motor. The first sea trials, using Mk 44 torpedoes, were conducted early in 1964 on board HMAS *Stuart*. Britain had shown interest in the program from the start, and an Admiralty mission arrived in Australia in December 1964, a formal agreement being signed in March 1965 for the missile to be used on board the new *Bristol*-class missile destroyer. At this time the Royal Navy expected to use a new lightweight torpedo, Mk 31, which was substantially heavier than the U.S. Mk 44 adopted by the Australians, and a new version of Ikara had to be designed. At this time the missile was modified so that it could launch any of 4 alternative payloads, 1 of which was a high-explosive bomb. Another was probably a nuclear depth bomb; the other 2 would have been alternative homing torpedoes. British Ikara trials began in April 1967. There was also U.S. interest; in 1966 there were joint U.S.-Australian trials off Hawaii, during which Ikara-borne torpedoes hit 2 submerged submarines operating at 9 kt.

Ikara is currently used by the Australian, Brazilian, and Royal New Zealand navies. The Brazilian version is called BRANIK (Brazilian Ikara). The Royal Navy adopted Ikara as GWS.40, but it discarded its last 2 Ikara ships during 1989; the New Zealand ships use the British version. BRANIK uses a lightweight semi-automatic launcher. Without Ikara, the Royal Navy no longer has any all-weather standoff ASW capability.

There are several versions. The original Australian Mk 1 and British Mk 2, neither of which entered service, were designed to carry the abortive British Mk 31 lightweight torpedo. Mk 2 and 3 (British and Australian, respectively) carry the U.S.-supplied Mk 44, and Mk 4 and 5 the U.S.-supplied Mk 46. One objective of the Ikara redesign program was to simplify the missile so that it could carry a wider variety of lightweight torpe-



Ikara on board the Australian destroyer *Brisbane*, on the small launcher on the side amidships. The main radars are SPS-40 (foremast, with SPS-10 below it) and SPS-52 (the flat plate aft), with 2 SPG-51 missile-guidance radars below. The big radome atop the bridge is the Ikara guidance link. (U.S. Naval Institute)

does with less variation. The thousandth Ikara was delivered in 1977.

Several new versions have been proposed, none successfully. Basset (1981) was a boxed version. Super Ikara was to have been a boxed version with folding wings and a turbojet power plant, for longer loiter near the target. A prototype, produced in collaboration with British Aerospace, flew in September 1986, but in July 1987 the Australian partner, Government Aircraft Factories, was dissolved. Super Ikara differed from the original version in that control could be passed to a helicopter near the target. The helicopter could, therefore, devote its entire payload to sensors and fuel. Super Ikara was originally a collaborative project with OTO-Melara, but that company dropped out to work on MILAS (see the French section below).

CHINA (PRC)

◆ CY-1

Dimensions: 41 cm × 5.5 m [16.1 × 216.5 in]
Weight: 700 kg [1540 lb] **Propulsion:** rocket
Range: 5–18 km [5500–20,000 yd]

This ballistic antisubmarine missile was first displayed at ASIINDEX in November 1986. No details were given, other than that CY-1 will be fired from a multicell launcher on board surface ships. Externally the missile resembles ASROC, and CY-1 is credited with ASROC-like performance. However, unlike ASROC, CY-1 reportedly may be carried by helicopters and maritime-patrol aircraft. It is not clear how the missile would be targeted in that case: perhaps the Chinese expect to operate aircraft in cooperation with submarines that would provide target data. Nor is it clear whether the Chinese currently have an MF sonar suited to such a weapon, and no Chinese warship carries the requisite launcher. However, drawings of a destroyer offered for export do show a pepperbox launcher. In 1988 the Chinese displayed 2 new sonars, perhaps operating at lower frequencies, at ASIINDEX in Beijing (ESS-1 and -2).

FRANCE

◆ Malafon

Dimensions: 651 × 5877 mm; span 3190 mm (booster: length 2135 mm, span 1800 mm) [25.6 × 231.4 × 125.6; 84.1 × 70.9 in]
Weight: 1000 kg [2200 lb] after booster separation; booster: 330 kg [727 lb] **Warhead:** L 4 homing torpedo
Propulsion: glider, after boost; booster burn time 2.8 sec, impulse 35,000 kg-sec [77,140 lb-sec]

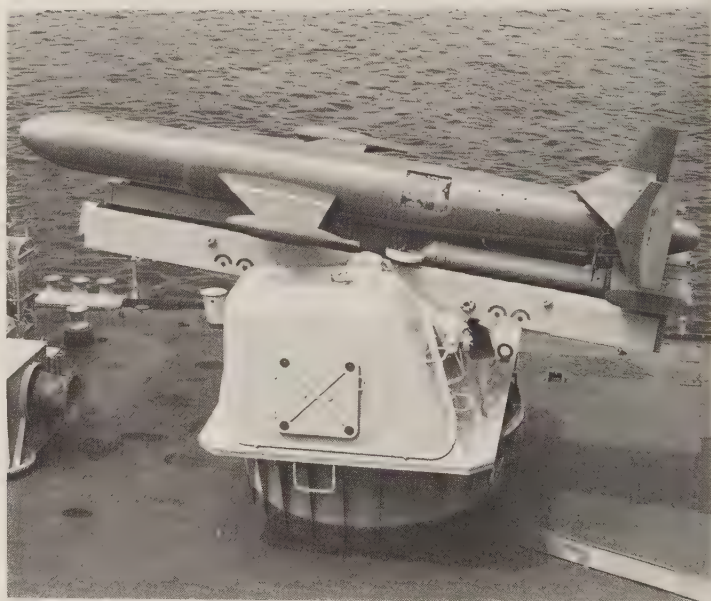
Speed: at end of boost, 280 m/sec, decreasing to 100 m/sec during flight [918 ft/sec, decreasing to 328 ft/sec]
Range: 3000–15,000 m; maximum 20,000 m [3300–16,400 yd; maximum 21,900 yd]

Malafon is a ship-launched standoff weapon carrying an L 4 homing torpedo and using a gun direction radar for guidance. The missile is tracked using 2 flares in its wingtips. Malafon is a glider gyro-stabilized in roll and pitch; at the end of its flight (800 m short of the predicted position of the submarine), the missile is commanded to level off, the torpedo is unlocked, and the missile is braked by parachute. The torpedo continues on and enters the water.

Malafon is stowed without its wings and tail fins, the booster fins being folded. One missile is usually held on the launcher, ready to be fired, and the missile can be launched within 30 sec. A second launch can follow 60 sec later, and then the firing rate can be up to 1 every 90 sec. Typically a ship carries 13 missiles; the launcher proper weighs 10,500 kg.

Malafon's development began in 1956, and the missile was first tested in 1958, with sea trials following in 1962 on board the experimental destroyer *La Galissonière*. Initial operational tests were conducted in 1964. As of about 1978, it was reported that 370 Malafons were in service and that further missiles were being manufactured to replace those expended in training. Eight ships now carry Malafon, the last system having been installed over a decade ago. With Masurca, Malafon is a survivor of the French post-World War II naval missile program.

Malafon's guidance systems were modernized in 1986–87 by SENA and now use solid-state components instead of vacuum tubes. As a result, Malafon should remain in service to the end of the century.

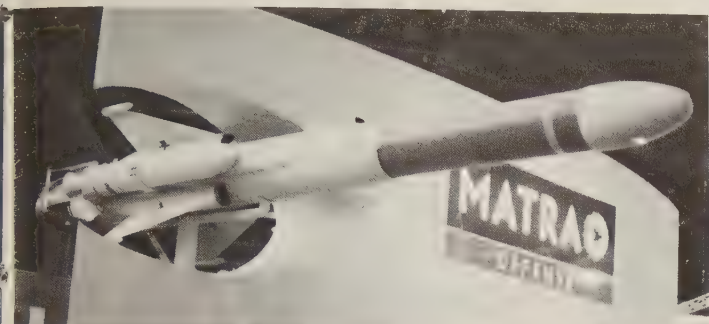


Malafon on its launcher. Reloads are stowed in the deckhouse on the right. (U.S. Naval Institute)

◆ Malafon Replacement (MILAS)

Dimensions: 460 mm (1060 mm with boosters) × 6 m [18.1 × 41.7 × 236 in] **Weight:** 800 kg including torpedo [1760 lb]
Warhead: Murène or A290
Speed: 300 m/sec at 20 m in altitude [984 ft/sec at 66 ft]
Range: 40 km (time from launch to splash at about 20 nm is less than 3 min) [44,000 yd]

In 1986 two teams competed to produce a replacement for Malafon that would carry the new Murène lightweight torpedo (and, for export, a variety of equivalent foreign weapons). The basic requirement was formulated in the late 1970s, after the French naval staff had decided to abandon such weapons in favor of helicopters. Tactical experience showed that a helicopter's



MILAS. [Author]

reaction time was about 15 min, and the French navy asked for a CZ standoff missile.

Matra and OTO-Melara offered a modified Otomat Mk 2, with a range of over 40 km, designated MILAS. The missile's warhead is replaced by a lightweight torpedo. Like Otomat, MILAS can receive mid-course guidance instructions. Recent accounts of MILAS mention a Franco-Italian requirement formulated in 1985, but it is not clear whether this formulation was the beginning of the OTO Melara-Matra project or an official decision.

Aerospatiale offered a torpedo-carrying Exocet, about 6.38 m long, which could be launched from a submarine as well as from a surface ship. With a suitable booster, this Exocet could be fired by ASW helicopters and airplanes.

MILAS was chosen in the summer of 1987, and a French-Italian development MoU was signed in September 1987. Given its limited dimensions, MILAS will probably be carried in a deck container (canister launcher) rather than in the magazine used for Malafon. The first production MILAS is to be delivered in 1992, and the French and Italian navies have both indicated an initial requirement for 200.

Maximum range is nearly 60 km in a straight line. For a flight of 35 km, the elapsed time is less than 3 min. Cruise altitude is 200 m. It is estimated that in-flight course corrections can increase the probability of target acquisition by as much as 15% at long range. After turbojet cutoff, the delivery system, retarded by a parachute, separates from the torpedo, and another parachute lowers the torpedo into the water.

MILAS will arm French F67-class destroyers (probably 12 launch units each), replacing Malafon; MILAS will also arm 7 C70 during mid-life refits (6–8 launch units each) and will be added to Italian *Maestrale*s and other major Italian warships during their mid-life updates. All future French and Italian ASW warships will be armed with this weapon.

As of mid-1989, aerodynamic testing had been completed, and about 10 firing trials (without torpedo) were to be conducted in 1990–91; the missile can be in service by about 1994. Besides France and Italy, another NATO navy is reportedly interested.

INTERNATIONAL

◆ NLCAW

The NATO low-cost ASW weapons project was inspired in part by the experience of the Falklands. False contacts were numerous, and in many cases the only sure means of classification was to fire a weapon (a real submarine runs away). Since weapons are increasingly expensive, the preferred technical approach seems to be a rocket- or mortar-thrown intelligent depth charge or low-cost, low-performance torpedo. The program also presumably builds on work done during the 1980s on a homing depth charge, to be fired from the standard Terne or Bofors 375 launcher. The system consists of a simple rocket or mortar (i.e., ballistic) launcher, a semi-intelligent weapon, and an FCS. In at least some cases, the weapon is also to be deliverable by helicopter.

A former European participant in the program considered it remarkable that, a year after laughing off the requirements (Pk,

range, price), industry was able to meet them. The surprise was just how many weapons already met the specifications; the NATO group brought the weapons makers together with those producing the standoff missiles or rockets. For example, Whitehead produced a torpedo with a diameter of about 8 in, with a very reasonable kill probability, and with a unit cost of about \$50,000; 3 torpedoes could be fired out of a standard Bofors 375 mortar, and the Whitehead weapon was not really too much larger than a standard A-size sonobuoy. The existence of really cheap ultra-lightweights called into question the rationale for standard lightweight torpedoes.

Sweden tried to join the group with its Elma, but it was rejected because its range was much too short. The most widely used unguided weapon, the Bofors 375, was rejected because it was not sufficiently accurate; its 6-shot salvo was credited with a Pk of less than 0.5, although it was considered useful as a means of forcing a submarine to flee.

The NATO project (under Project Group 34) was formulated in 1989, the partners at that time being the United States, Norway, Germany, and Italy. As of 1990, reportedly 12 teams (led by Diel, AEG, MBB, NFT, Whitehead, Honeywell ELAC/Honeywell USA, Krupp MAK, Royal Ordnance, Martin Marietta, General Dynamics, FMC, Loral) had submitted concepts, and 6 had been labeled "serious." Two of the teams include a German prime contractor. One of them consists of KAE, Dynamit Nobel, Dyno, and Lockheed, with Marconi as consultant. It will presumably use a variant of the Lockheed Lightweight Torpedo described in the U.S. torpedo section, below. Whitehead is developing an inexpensive lightweight torpedo to meet the NATO requirement (see LCAW, below).

USSR

◆ SS-N-14 (Silex)

Dimensions: length 7.6 m [25 ft] **Warhead:** homing torpedo
Propulsion: solid-fuel rocket **Speed:** Mach 0.95
Range: 30 nm (4 nm minimum)

The Soviet equivalent of Malafon or Ikara, SS-N-14 is a powered missile that carries a homing torpedo. SS-N-14 might be considered the direct nonnuclear successor to FRAS-1, arming most Soviet ASW ships of destroyer or greater size. Except for



A Krivak-class frigate shows her quadruple SS-N-14 launcher, with a pair of RBU-6000s just abaft it. The 2 shrouded antennas on lattice mast above the bridge are the Eye Bowls controlling the SS-N-14 missiles; above them is a Don Kay surface-search radar, with Head Net C at the masthead. The shrouded object immediately over the bridge is Pop Group, to control SA-N-4 anti-aircraft missiles. (U.S. Naval Institute)

on the *Kirov* (which has a unique reloadable twin launcher), SS-N-14 is carried in 4-missile sets.

When the launchers first appeared, in the Krivak class, this missile was identified as a short-range antiship missile and designated SS-N-10. No such weapon exists, although SS-N-14 has a secondary antiship capability that uses an explosive charge in the airframe. In 1983 it was reported that SS-N-14 carries an alternative nuclear warhead, presumably a nuclear depth bomb, of about 5-kT yield.

The missile is command-guided, either by a special antenna (Eye Bowl) or via a set of Head Lights SAM control radars. Flight altitude is reportedly about 80 m [about 260 ft]. Krivaks have an MF sonar, which is unlikely to provide data sufficiently accurate for attack beyond about 10,000 yd (as in the case of the U.S. ASROC). Ships equipped with lower-frequency sonars should be able to mount attacks at about twice that range. If these ships detect targets at CZ range (20–35 nm, depending on water conditions), then probably helicopters with sonobuoys or dipping sonars must reacquire the target before the ship fires.

◆ SS-N-15 (Starfish)

The Soviet equivalent of the U.S. SUBROC is armed only with a nuclear warhead. SS-N-15 was copied from the U.S. weapon, reportedly compromised about 1964, and was probably intended as the primary weapon of the Victor-I-class submarine. Maximum range is 21.6 nm.

If SS-N-15 is a SUBROC equivalent, then its rocket is fired after it is ejected from the torpedo tube. Guidance is inertial, based on prelaunch sonar data (U.S. practice was to track the target passively, then use a single ping to obtain an accurate range; this method reduced the target's warning time). In the U.S. weapon, the warhead had to be nuclear because the combination of the single ranging ping and the sound of the motor firing underwater provided the target with some warning. Analysis showed that a submarine could escape the acquisition range of a Mk 44 torpedo launched in this way, but that it could not escape the lethal volume of the warhead. SUBROC was initially conceived as a shore-bombardment weapon, and it is possible that SS-N-15 has a secondary shore-bombardment or antiship capability. In the 1960s the antiship threat presented by a possible Soviet SUBROC was a major factor in driving U.S. anti-missile-defense projects.

◆ SS-N-16 (Stallion)

This missile is a dual-capable successor to SS-N-15. Because all Soviet homing torpedoes are substantially larger and heavier than the U.S. lightweight torpedo that SUBROC could carry, SS-N-15 is almost certainly much larger than a 21-in tube and is probably responsible for the adoption of the 65-cm torpedo tube in recent Soviet submarines. The shift from SS-N-15 to -16 may be responsible for the greater length of the Victor-II-class submarine, to accommodate a better combat system.

Maximum reported range is 54 nm, far beyond any usable acoustic range. This figure may have 2 quite different significances. One is that a missile capable of flying 54 nm will reach tactical ranges (perhaps of the order of 10 nm) quickly enough to keep the prospective target within torpedo-acquisition range. The other would be that the weapon might have an alternative antiship or even shore-attack role.

UNITED KINGDOM

◆ SUGW

A British staff requirement formulated about 1986 called for an Ikara successor (Surface-to-Underwater Guided Weapon), a weapon that could exploit towed-array detection and that was, therefore, capable of attacking out to the second CZ. In the fall of 1987, however, the Ministry of Defence announced that this program had been shelved for at least 3 yr because of a lack of funds.

The 2 alternatives under consideration in 1986 were Super Ikara and Tarpon (McDonnell Douglas/Marconi), the latter us-

ing Harpoon to project a Stingray torpedo. Tarpon has also been suggested (in the United States) as an ASROC or SUBROC successor. Reportedly, Dowty and McDonnell Douglas were also proposing a vehicle that would lay sonobuoys at long range, making it possible for a surface ship to prosecute contacts at or beyond the CZ even if she could not launch a manned helicopter.

UNITED STATES

All SUBROC missiles have been retired; the last was operational in the fall of 1988. These missiles were presumably retained for a time in reserve since the warhead (W45) was retired only in the fall of 1990. For details of SUBROC, see the first edition of this book.

◆ ASROC (RUR-5A)

Dimensions: 13.25 × 177.4 in (33-in fins)

Weight: Mod 3, 949–57 lb; Mod 4, 1071–73 lb

Warhead: Mod 3, Mk 44 torpedo; Mod 4, Mk 46 torpedo; Mod 5, Mk 17 Depth Bomb (nuclear: W44 warhead)

Range: maximum about 10,000 yd [minimum range is 900 yd for the torpedo version and 3500 yd for the nuclear version]

The Antisubmarine Rocket is the current U.S. standoff ASW weapon for surface ships; ASROC has also been transferred to many Allied nations, in many cases on board ex-U.S. ships. It carries either a Mk 46 torpedo or a Mk 17 nuclear depth bomb; existing ASROCs will probably be upgraded to carry Mk 50 lightweight torpedoes.

ASROC was conceived as part of a system including a reliable 10,000-yd sonar, SQS-23. The later SQS-26 has higher per-



A torpedo-carrying ASROC being fired. (U.S. Navy)

formance; and an extended-range version, ERA, was designed to exploit its greater direct-path range (nominally about 20,000 yd). Although ERA was tested in 1967, it was never produced, presumably because it had too low a priority in the face of severe fiscal problems during the Vietnam War. VLA is, in effect, a vertically launched ERA, although the technical details are very different.

The usual Mk 112 launcher is trainable, but it fires at a fixed 45-deg elevation, 2 of the 8 cells elevating together. Range is determined by fixing the point of booster separation.

ASROC can also be fired from the Mk 10 launchers of *Belknap*-class cruisers and of the *Truxtun*, and from the Mk 26 launchers of *Virginia*-class cruisers and early Aegis cruisers; these launchers, too, fire the rocket at a fixed angle of elevation. In *Knox*-class frigates 2 cells of the ASROC box were modified



A standard ASROC box launcher on board the Japanese destroyer *Haruyuki*, 1989. (W. Donko)

to fire Standard surface-to-surface (later Harpoon) antiship missiles.

About 12,000 ASROCs were manufactured between 1960 and 1970, when production ended.

The nuclear version of ASROC (W44 warhead) was retired by September 1989.

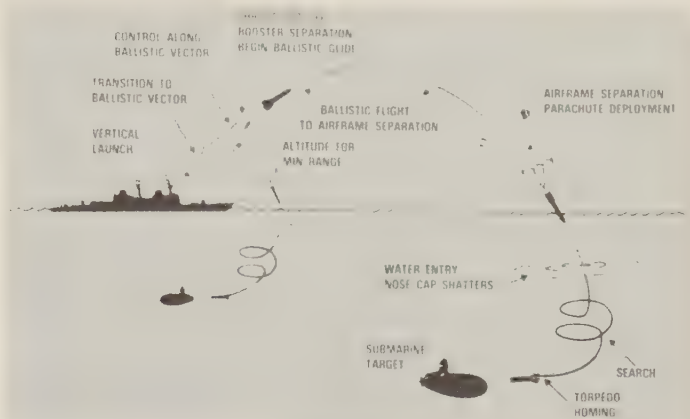
♦ Vertical Launch ASROC (VLA)

VLA is ASROC modified for firing by the new vertical-launching system (Mk 41). The initial units will be produced by Loral, with Martin Marietta as the designated second source. Compared to the original ASROC, VLA has increased range (to exploit the greater direct-path range of SQS-53, compared to SQS-23) and can carry a somewhat heavier payload (Mk 46 or Mk 50 homing torpedo). VLA or some equivalent is essential because ships fitted with vertical launchers generally cannot accommodate the earlier ASROC box launchers; without VLA these ships would not have any all-weather standoff weapon.

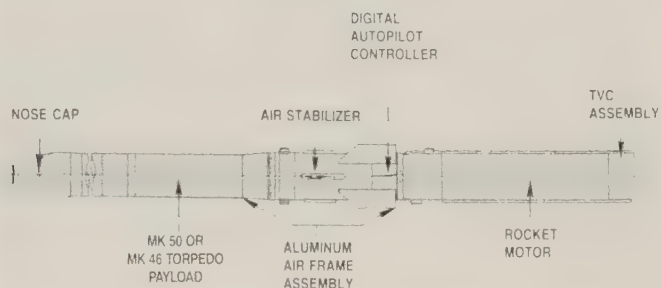
Dimensions are 14.1 × 200 in, and weight is 1650 lb. These figures are still within the limits imposed by the existing ASROC and Mk 26 launchers. As of 1987, the navy demanded a minimum range of about 5 kyd and a maximum range of at least 15 kyd. The first all-up demonstration/validation shot was fired at China Lake in July 1984.

The basic design was carried out by the navy, with development by Goodyear (whose naval division was later sold to Loral). The missile is pitched over into its ballistic trajectory by autopilot-controlled thrust vectoring. As in ASROC, trajectory is controlled further by ejecting the booster at the appropriate moment, the torpedo payload continuing on a ballistic path into the water.

This missile had been expected to enter service in 1989, but Congress authorized none in either FY88 or FY89, the FY89 request for 340 being deferred to FY90. In 1988 Sea Lance was adopted as the single standoff weapon for both submarines and



VLA MISSILE SYSTEM



VLA operating sequence and missile. (Martin Marietta)

surface ships, and VLA was demoted to interim status (Congress ordered 300 bought). However, VLA was revived in 1990 as the primary surface-ship standoff ASW weapon, Sea Lance (both versions) having been canceled.

Japan has also ordered this weapon for its new Aegis-equipped destroyers (which lack conventional ASROC box launchers).

Combined at-sea development and operational tests of VLA were conducted by the *Hewitt* in December 1988.

♦ Sea Lance (UUM-125A)

Dimensions: 16.0 × 228.0 in (capsule: 20 × 244.23 in)

Weight: 2282 lb (total with capsule: 2793 lb)

Warhead: Mk 50 torpedo

Range: probably comparable to SUBROC

The digital replacement for SUBROC, Sea Lance was developed as the ASW standoff weapon (SOW). For a time, it appeared possible to combine SOW with the VLA requirement, to produce a Common ASW SOW; but this approach proved impractical, and the 2 programs were separated in 1982. In 1988, however, the 2 programs were again being merged. Stated requirements included the ability to launch at up to 80% of a submarine's test depth, as well as stealthy operation. It was decided, therefore, that Sea Lance would be launched in a capsule, like the Tomahawk cruise missile, emerging only after reaching the surface. Such buoyant launch is much quieter than the use of a rocket motor underwater.

Flight characteristics have not been released, although ranges as great as 105 nm (3 CZs in the Norwegian Sea) have been reported (e.g., by the developer, Boeing, in a brochure). These ranges are almost certainly aerodynamic rather than effective tactical ranges. It is much more likely that the effective tactical range is much like that of SUBROC, dictated by a submarine's ability to track a target (i.e., by direct-path range). The long reported range would correspond to the very energetic rocket motor required to minimize the flight time to the targeted submarine.

Sea Lance has a role very different from that originally envisaged for SUBROC. As Soviet submarines become quieter, it becomes less and less likely that they will be tracked at very long ranges. However, U.S. submarines will operate in or near Soviet



Sea Lance capsule being loaded onto an attack submarine. The submarine's HF sonar transducer is in the forward edge of the sail, and the surface-search radar is atop the sail. (Boeing)



Sea Lance prototype in flight, January 1989. The payload must be shrouded (which is not the case in ASROC) because the missile is so fast. (Boeing)

waters in wartime. Soviet submarine commanders will know that, if they run at high (loud) speed, or if they use their active sonars, they will provide the necessary targeting data. Thus, the

existence of a submarine standoff weapon may in itself inhibit Soviet submarine commanders from running out into their patrol areas at high speed, or, for that matter, from seeking out U.S. submarines by active sonar search. Given this mode of operation, Sea Lance had to be usable without high-level authorization, i.e., the weapon had to be nonnuclear. In December 1986 the development program was reversed, the primary version switching from a nuclear depth bomb to a Mk 50 torpedo payload. Presumably, this choice was justified, at least in part, by the demonstrated lethality of the Mk 50 warhead and by the longer acquisition range associated with Mk 50, as compared to Mk 46.

One important argument in favor of the use of Sea Lance on board surface ships is that the missile's long maximum range can be exploited by using a LAMPS helicopter as a targeting platform. The helicopter localizes the submarine target within the box defined by the ship's long-range sensor, and the ship can fire multiple rounds into that box. In this way the overall effectiveness of the ship/helicopter weapons system is not limited by the torpedo-carrying capacity of the helicopter, and the helicopter can gain endurance by carrying extra fuel.

Boeing received the Sea Lance contract in April 1981, and as of 1988, plans called for 2400 missiles. Boeing received a full-scale development contract in July 1986. Flight trials of the Sea Lance missile began at White Sands in the summer of 1988, and the first successful sea test (dynamic launch, all-up except for a short-burn motor) was fired from San Clemente on 22 February 1989. The first full-up full motor test was scheduled for White Sands in the summer of 1990.

The program was delayed during FY89, presumably in part because of the dual-use decision. It was then canceled late in 1989. Explanations vary; originally it was merely stated that the budget was too tight to accommodate a weapon otherwise clearly desirable. Then there was a suggestion that Boeing had asked for a 2-yr delay (and about \$900 million more). However, advocates of Sea Lance argued that the delay was really more like 2 months, and the additional cost only a few million dollars. Early in 1990 an OSD official suggested that the Sea Lance mission might be shifted to a modified Tomahawk, and there was also an official suggestion that Mk 50 might be modified to replace Sea Lance. Such comments suggest that cancellation was originally a bureaucratic error, made on the misunderstanding that Sea Lance was primarily a nuclear missile, and that later explanations were attempts to avoid embarrassment.

Although DoD canceled Sea Lance, in mid-1990 both the House and the Senate proposed to restore funding in the FY91 budget.

TORPEDOES

CHINA (PRC)

The current production antiship torpedoes are designated Yu (Fish) 4A and 4B. They are officially described as derived from foreign torpedoes, most likely Soviet types. Development was conducted by Xian Independent University, and these weapons were standardized in February 1984.

In 1988 it was reported that the PRC program to manufacture the U.S. Mk 46 Mod 5 has been delayed because of difficulties in translation to metric units. Reportedly, the current PRC lightweight torpedo is the Italian A-244, about 40 of which were acquired.

In January 1990 the PRC announced first tests of a new Type C43 heavy torpedo off the Fujien coast in the Taiwan Straits. It is said to have wire mid-course and active/passive terminal homing, and it presumably uses an Otto engine similar in concept to that in the Mk 46. C43 is a dual-purpose torpedo, which can be fired by surface ships and submarines. It was developed by the Electronics Industry Division under the Chinese Academy of Sciences (Academia Sinica), with technical assistance reported from IBM, NEC, and Wang Computers. As of mid-1990, C43 is not yet in production, but it is presumably intended to replace the current Yu 4/5.

There was no previous public mention of any PRC submarine-launched antisubmarine torpedoes.

FRANCE

An indication of the current production rates of torpedoes for the French navy is that the 1984–88 budget called for orders for 70 torpedoes (presumably all heavy) in 1984/85 and for an additional 190 in 1986–88, with 278 torpedoes delivered in 1984–88, and another 170 after 1988. Presumably, these figures are all heavy torpedoes since Murène is not yet in production. Reportedly, the initial production rate for Murène is 20 per year.

◆ E 12/E 15

	E 12	E 15
Dimensions:	550 mm × 7.0 m [21.7 × 276.0 in]	550 mm × 5.9 m [21.7 × 232.3 in]
Weight:	1650 kg [3637 lb]	1387 kg [3057 lb]
Speed/Range:	25 kt/12,000 m [13,000 yd]	25 kt/12,000 m [13,000 yd]
Warhead:	330 kg [727 lb]	300 kg aluminum tolite or HBX-3 [660 lb]
Power Plant:	battery	nickel-cadmium battery, 50-kW motor

E 15 is the export version of E 12. E 12 was developed on the basis of wartime German technology (such as the T-5 homing torpedo) that fell into French hands in 1944–45. Both E 12 and E 15 are CIT-Alcatel's submarine-launched passive-homing torpedoes, for use against surface ships or submarines at periscope depth (target depth down to 18 m [59 ft]). The torpedo has a contact or magnetic fuze. A fire-control solution is required to bring the torpedo within about 700 m [770 yd] of its target. The E 15's homing system duplicates that of E 14; the hull is a lengthened form of that of the E 14.

This torpedo was placed in production after another submarine torpedo development program, V (for *vitesse*) 11, had been abandoned in 1958. V 11 was a fast, straight-running, oxygen-alcohol torpedo intended for a range of 15,000 m [16,400 yd] at 55 kt.

See the E 14 entry for a modification program.

◆ E 14

Dimensions:	550 × 4279 mm [21.7 × 168.5 in]
Weight:	927 kg [2043 lb]
Speed/Range:	25.5 kt/5000 m [5500 yd]
Warhead:	200 kg tolite [440 lb]
Power Plant:	nickel-cadmium battery (40 kW)

The submarine-launched passive-homing torpedo by CIT-Alcatel is in effect a smaller version of E 12, designed primarily to arm the small French antisubmarine submarines, now extinct. E 14 uses contact or passive magnetic proximity (range about 4 m) fuzing. This weapon is intended for use against surface ships or shallow submarines (e.g., submarines at periscope depth), using settings of 6–18 m [20–60 ft] for the depth of its run; E 14 can run at depths as great as 300 m [984 ft]. Compared to E 12, E 14 trades endurance for a more powerful warhead.

This torpedo has the same propulsion and hull as L 3, but E 14 homes passively, using a bank of 4 transducers operating by phase comparison within a 1-kHz bandwidth. Enable range is 350 m [383 yd]; average acquisition range is 500 m [550 yd]. The battery has 76 cells (E 15 has 120).

E 14 was introduced in 1960, and about 100 were made.

DCN is developing a modification kit for the E 14, E 15, and L 3 torpedoes. The existing nickel-cadmium battery is replaced by a silver-zinc battery (which doubles the range); the propulsion system is improved (to add 10 kt); and the homing system is replaced (AH 8 vice AH 7, for 50% greater acquisition range).

In 1990 CNIM announced that it was modernizing French L 3, E 14, E 15, and Z 16 torpedoes to E 15 Mod 2 standard, adding the AH 8 homing head and silver-zinc primary battery already operational on the F 17 Mod 1 torpedo. As modified, the torpedo searches at 25-m depth and has a detection range of 2000 m; attack depth is 6–18 m (presettable), and maximum depth is 300 m. Performance is 31 kt/12,000 m, and the warhead

is 300 kg of tolite aluminum. Those torpedoes are lengthened to 5900 mm [232.3 in].

◆ E 18

Dimensions:	533 × 5230 mm [21 × 205.9 in]
Weight:	1230 kg [2711 lb]
Speed/Range:	35 kt/18,000 m [19,700 yd]
Power Plant:	battery

E 18 is a dual-purpose torpedo for surface ships. E 18 has passive homing (i.e., usable against a noisy submarine) and a maximum depth of 500 m [1640 ft].

◆ F 17

Dimensions:	550 mm × 6 m [21.7 × 236 in]
Weight:	1410 kg [3108 lb]
Speed/Range:	35 kt/18,000 m [19,700 yd]
Warhead:	250-kg HBX-3 (equivalent to 500-kg TNT) [551 {1100} lb]
Power Plant:	zinc-silver oxide battery (contraprops)

This wire-guided dual-purpose torpedo was introduced in 1973 by DTCN. F 17 has active-passive terminal homing (active for antisubmarine, passive for antiship). There is a special shallow-water mode that can be preset before launching (sonar scan is limited in elevation). The stated diving limit is 600 m.

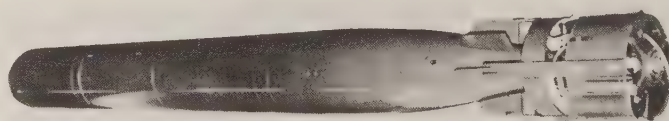
F 17 Mod 1 has dimensions of 550 × 5900 mm [21.7 × 232 in], has a speed/range of 35 kt/22,000 yd, and can run at depths as great as 500 m [1640 ft]. This torpedo is launched from both submarines and surface ships.

F 17 Mod 2, in service 1988, has dimensions of 533 × 5384 mm [21 × 212.0 in], a weight of 1397 kg [3079 lb], and a speed/range of 40 kt/20,000 m [22,000 yd] (because of its more powerful—85 kW—motor). Maximum operating depth is 600 m [1968 ft].

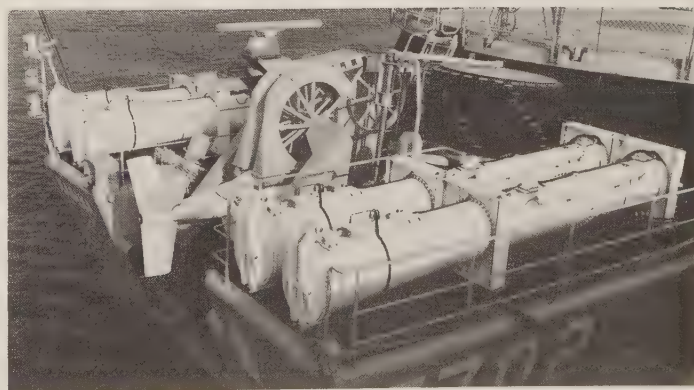
F 17P Mod 2, in service 1985, has dimensions of 550 × 5620 mm [21.7 × 221 in], a weight of 1320 kg [2909 lb], and a speed/range of 35 kt/32,000 yd. 17P Mod 2 is launched from submarines only, against surface ships.

Spain has an agreement with SOFMA to convert 16 E 15 torpedoes to F 17 Mod 2 standard.

Thomson Sintra has tested fiber-optic (as opposed to the current wire) guidance for torpedoes. The first trial, using 2 km of cable, occurred on 22 December 1987; a second trial (20 km) was conducted on 9 February 1988. The tests were mainly to



F 17 wire-guided torpedo. (Thomson Sintra)



F 17 torpedo tubes on board the Saudi frigate *Al Madinah*. Western navies have found it is easier to operate a surface-launched wire-guided torpedo from stern tubes, the wire running out as the ship steams away. That arrangement applies also to several U.S. attempts to combine wire guidance with surface ships and to the Italian A-184. (Thomson Sintra)

determine whether information could be transmitted over very long distances without error; in these tests the information transmission rate was 41 Mbits/sec. Thomson Sintra claims that these were the first experiments of their type.

The main current version is F 17 Mod 2, which has a speed of 40 kt and can operate below 600-m depth. The torpedo carries 18,000 m of guidance wire. A typical French submarine torpedo tube has a dispenser for another 4000 m (8000 m in German-built submarines such as Type 209). Mod 2 can be launched at any depth down to 400 m, and it searches at 1 of 4 depths (attack/ceiling depth, preset at 6–20 m, 30 m, 100 m, and 200 m). It can be set to attack surface ships at a depth between 6 and 20 m. Max trim angle is ± 40 deg, and max turn rate is 12 + deg/sec. The warhead is 250 kg of HBX-3.

The original version, Mod 1, was passive only. It was developed into F 17P (polyvalent, i.e., active or passive) and also into a reduced-cost passive F 17S1. F 17P in turn was developed into Mod 2 (which equips current French submarines) and into a less expensive active/passive F 17S2. Mod 1 and S1 are effective only against surface ships. S1 and S2 have speed limited to 35 kt, and operational range 18,500 rather than 20,000 m. S1 costs 60% as much as Mod 2, and S2 costs 75% as much. S1 also has reduced countermeasure resistance.

◆ L 3

Dimensions: 550 × 4320 mm [21.7 × 170.1 in]
Weight: 910 kg [2006 lb] **Speed/Range:** 25 kt/5000 m [5500 yd]
Warhead: 200-kg HBX-3 or TNT [440 lb]
Power Plant: nickel-cadmium battery (40-kW motor, 2 contra-props)

L 3 is an active acoustic-homing, submarine-launched, anti-submarine torpedo (for target speeds up to 20 kt) that uses a contact or active-acoustic (range 20 m) fuze. L 3 is usable in depths down to 300 m [984 ft]. The torpedo's angle of pitch is limited to +10 to -40 deg. Acquisition range is 1000 m [1100 yd], using a 32-kHz active seeker. The torpedo runs at 30 m [98 ft], executing a sinuous (snake) search after reaching its enable point.

This torpedo was introduced in 1960, and it was first displayed in 1968. L 3 was manufactured by DCN, which now offers a modification package (see E 14 entry above) including a new homing device, AS 15, instead of the earlier AS 3. A 21-in [533-mm] version was designed but never entered production. This version was 4318 mm [170 in] long and weighed 900 kg [1983 lb]. About 600 L 3s were made.

L 3 replaced an earlier antisubmarine torpedo, the straight-running K 2 (oxygen-alcohol propulsion, speed/range 50 kt/1000 m [1090 yd], maximum depth 300 m [984 ft]). K 2 was a straight-runner, launched in salvos of 3 with preset tune (i.e., depth) fuzing. It was the equivalent of such contemporary rocket-fired depth charges as the British Limbo, the Italian Menon, and the U.S. Weapon Alfa, using a torpedo power plant instead of a rocket to propel the torpedo to the desired point. Dimensions were 550 × 4400 mm [21.7 × 173 in]; weight was 1104 kg [2433 lb] with a 280-kg warhead [617 lb]. K 3 entered service in 1956, and it remained in service until about 1976.

French surface ships generally carry a combination of L 3 (short-range) and L 5 (long-range) torpedoes, both launched by compressed-air catapults rather than from torpedo tubes (2 in an A69, 4 in a larger ship).

◆ L 4

Dimensions: 533 mm × 3.13 m [21 × 123 in]
Weight: 525 kg [1157 lb]
Speed/Range: 30 kt/5000 m [5500 yd]
Warhead: 150 kg [331 lb] **Power Plant:** battery

This French lightweight antisubmarine torpedo is designed to attack submarines running at or below 20 kt. L 4 is used by aircraft and as the warhead of the Malafon missile. The torpedo uses active acoustic homing with an AS-4T seeker, at 32 kHz, with an average acquisition range of 1000 m [1094 yd]; L 4 has



L 4 BS

L 4 BS torpedo. (Direction des Constructions Navales)

a circular (helical) search pattern. This torpedo is produced by DTCN and entered service in 1964.

A modernized version can operate in shallow water, and another version is suitable for launching from surface torpedo tubes (3.3 m long, 570 kg [130 in, 1256 lb]).

◆ L 5/ L 7

Dimensions: 533 mm × 4.4 m [21 × 173 in]
Weight: 935 kg [2061 lb]
Speed/Range: 35 kt/7000 m [7700 yd]
Warhead: 150 kg [330 lb] **Power Plant:** silver-zinc battery

L 5 was a response to the major increase (approximately quadrupling) in sonar range associated with the new standoff weapons of the 1960s (such as ASROC, Malafon, and Ikara). The program began in 1960; compared to E 14, L 5 was expected to have twice the capability against both surface ships and submarines. In the same volume, L 5 achieves 10 more knots and greater range, partly by adopting a silver-zinc battery and a 2-rotor electric motor (of twice the power). This torpedo is also more difficult to countermeasure. L 5 was initially conceived as 2 torpedoes, 1 primarily ASW and 1, of greater range, primarily to attack surface ships.

Mod 1 is a ship-launched antisubmarine or antiship weapon. Mod 2 did not enter service. Mod 3 (5500 mm long [216.5 in], 1300 kg [2865 lb]) is submarine-launched against submarines; it was a direct replacement for E 12 and E 14. However, Mod 3 was deemed insufficiently effective against surface ships, and that led in turn to the wire-guided F 17. Mod 4 can be launched either by submarines or by surface ships, to attack fast submarines. It is a simplified version of Mod 1. Mod 4P is dual-purpose. The data above refer to Mod 4. Produced by DTCN, all versions are active-passive. Mod 4 has both acoustic and contact fuzes. Maximum operating depth is 500 m [1640 ft]. L 5 entered service in 1971.

L 7 is a major modification of L 5, a dual-purpose torpedo with a heavier warhead, for submarines. L 7 appeared about 1980.

◆ Z 13/Z 16

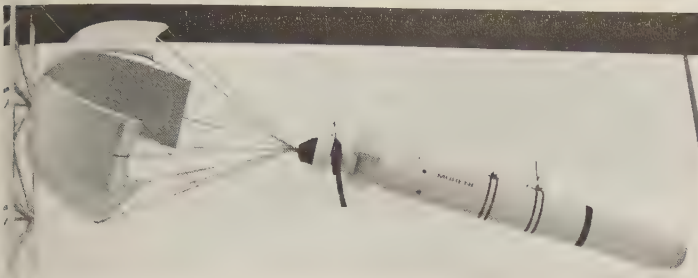
Dimensions: 550 × 7120 mm [21.7 × 280 in]
Weight: 1715 kg [3780 lb]
Speed/Range: 30 kt/10,000 m [10,900 yd]
Warhead: 300 kg [660 lb] **Power Plant:** battery

This submarine-launched pattern-runner was based on captured German technology (particularly that of the LUT torpedo). Z 13 has contact and magnetic fuzes. Running depth, set prior to launch, can be as deep as 18 m [59 ft], and the torpedo can be fired from depths as great as 180 m [590 ft]. Made by DTCN, Z 13 entered service in 1960; Z 16 is the export version of Z 13. These torpedoes are now obsolescent.

◆ Murène (NTL-90)

Dimensions: 324 mm × 2.6 m [12.75 × 102.4 in]
Weight: 250 kg [551 lb]
Speed/Range: 38 kt search, 53 kt attack; endurance over 10,000 yd at maximum speed (6 min at maximum speed, or 12 min at mixed speeds, gives approximately 10,000 yd at 53 kt and probably about 12,000 yd at mixed speeds)
Warhead: 50-kg shaped charge [110-lb]
Power Plant: aluminum-silver oxide battery (2-speed 136-HP engine-driving pump jet)

This lightweight torpedo was conceived as a replacement for the current Mk 46, for the L 5 shipboard self-defense weapon, and for L 4, the Malafon warhead. Homing is active/passive using multiple frequencies. Murène is expected to enter service



Murène. (Author)

in 1992. Early in 1988 the manufacturer, DCN, was claiming that this torpedo was 5 times as cost-effective as existing ASW torpedoes; presumably that statement refers to existing Mk 46s.

Information released thus far is that Murène is intended to attack targets at depths of 40–1000 m [approximately 130–1300 ft]; late in 1988 sea trials demonstrated that it could attack targets as shallow as 30 m [about 100 ft].

The torpedo sonar consists of a 30-transducer planar array, 2 side (left/right) arrays, and a depth finder (to avoid the bottom in shallow water). These sonars operate at 3 separate frequencies to overcome reverberation and countermeasures. The search pattern is rectilinear when Murène is launched from a ship and circular when it is dropped from an airplane or helicopter. The use of a straight-line search path and the statement that the torpedo can generally find a target during a single 360-deg pass suggest that it can look to the side (Mk 46, with only a nose transducer, albeit with a wide beam, must run in a snake pattern rather than a straight line). Presumably, then, the 2 side spot transducers are used to form a synthetic-aperture (side-looking) image, like a synthetic-aperture radar. However, 1 account suggests that the role of the flank transducers is to maintain contact while the torpedo comes abeam of the target.

Murène is said to be capable of tracking 12 targets (10, according to 1 account) simultaneously, the on-board computer predicting the target's course and estimating hit probability. This tracking is also used to distinguish decoys behaving unlike true targets, which is why the large track capacity is required.

Murène initially heads directly for the target, but then its

tracking element estimates target velocity and adopts proportional navigation. It is designed to hit at mid-beam (which DCN claims is a unique virtue). In trials, a Murène warhead striking at an angle of 50 deg to a simulated pressure hull cut through 20 mm of outer hull, 2 m of water ballast, and then 40 mm of pressure hull, and the torpedo would still have cut through another 300 mm of steel.

The combination of digital signal processing and target tracking requires considerable computer power. The homing-head signal processor is a Mangouste 50-MOPS computer, incorporating three 68000 processors, 2 buffer memory units, and 1 common memory. The central command unit (CCU), Capitole, incorporates four 68000 processors with a common memory. Total memory is 732k 16-bit words, and total throughput is over 60 MOPS.

The battery is silver oxide/aluminum with a potassium-hydroxide (caustic soda) electrolyte, stored in solid form and dissolved in seawater when the torpedo is running. A motor-driven pump delivers the electrolyte at a constant rate via a closed circuit that includes a heat exchanger and a gas extractor for the generated hydrogen. Such a system does not normally start instantly, but Murène required immediate power to drive it out of a steep dive when it was dropped in shallow water. The solution was to add 2 auxiliary batteries, 1 for the electrolyte pump and rudders, the other for the guidance unit. Thus the torpedo enters the water under full control. The propulsor is a pump jet with a 7-blade rotor; the fins are forward of the propulsor.

This torpedo began in 1976 as an Anglo-French project, but Britain withdrew in 1982 to develop Stingray independently. The French navy had bought U.S. Mk 46s in 1981 as interim weapons.

Murène light torpedo program's cost escalated 56% between 1982 and 1989 because of increased development costs. As of 1989, estimated unit cost was FFr 3.4 million [\$535,000]. However, in 1988 it was reported that total program cost (for 1000 torpedoes) would be FFr 10,000 million, or about \$1.7 billion (\$1.7 million each). The difference is presumably in the definition of unit cost.

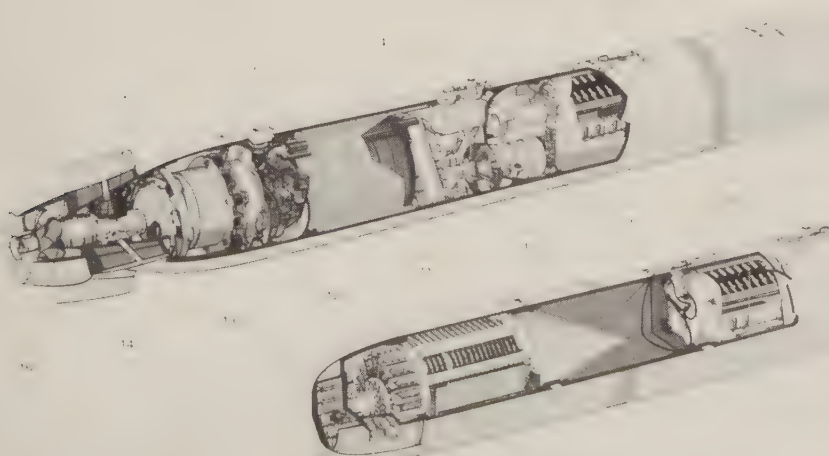
In 1989 Chile became the first export customer, buying 20 Murènes for delivery beginning in 1992. In October 1990 the French announced that they wanted to merge Murène with the Italian A290 program. However, as of early 1991, this did not seem entirely likely. Reportedly, the French proposal was that the French-designed shaped-charge warhead be manufactured in Italy.

TORPEDO LAUNCHERS

◆ KD 59

Compressed-air catapult launcher for heavy torpedoes, typically in the superstructures of French destroyers. On board *Cassard*

Murène. Key: (1) stator (of pumpjet), (2) rudder actuator, (3) motor, (4) electrochemical unit (battery), (5) priming valve, (6) auxiliary batteries, (7) command central unit, (8) warhead (shaped charge), (9) motor-pump set, (10) acoustic head (signal processor), (11) degasser, (12) side array, (13) planar array, (14) control surfaces, (15) rotor (of pump jet). Seawater runs into the priming valve, is pumped through an electrolyte (caustic soda) and into an exchanger. A temperature-control valve adjusts the mixture of electrolyte and fresher water (from the exchanger) that enters the electrochemical unit. Electrolyte is pumped back out of the electrochemical unit, degassed, and then mixed with fresh seawater at the priming valve. (DCN)



there is a double set of KD 59E launch cradles carried athwartships, with a total of 10 L 5 Mod 4 torpedoes, and a device to transfer torpedoes from side to side.

◆ K69

New launcher optimized for the Murène torpedo, in single (KU69), double (KD69), and triple (KT69) versions, for launch at 0–30 kt. These launchers are compatible with the Mk 46 torpedo.

There is also a short 21.7-in torpedo tube on board the *Com-mandante Rivière*-class frigates, for L 3 torpedoes.

Daphne-, *Agosta*-, and *Le Redoutable*-class submarines have 21.7-in tubes; the nuclear attack submarines have 21-in tubes. The *Agosta* class can fire either 21- or 21.7-in torpedoes. These tubes employ pistons to expel torpedoes, a system introduced by the German navy during World War II. The piston is actuated by air, so this mechanism, like pure air ejection, suffers from depth limitations. Its advantage is that it is covert: no air bubble is released.

GERMANY (WEST)

Krupp-Atlas makes an AWD wake-detector for heavy torpedoes. It is not clear for which German-built torpedo(es) the wake-detector is built.

◆ DM1 Seeschlange

Dimensions: 533 × 4150 mm (4620 mm including wire reel) [21 × 163.4 {181.9} in] **Weight:** 1370 kg [3020 lb]
Speed/Range: 33 kt/6000 m; maximum range 12,000 m [6600/13,100 yd] **Warhead:** 100 kg [220 lb]
Power Plant: silver-zinc battery (contraprops)

This wire-guided (2-way link) ASW torpedo entered service in 1975 after tests in 1972–73. DM1 has much in common with Seal, but only about half the battery capacity, so that a 3D active sonar can be accommodated. Moreover, Seeschlange is much shorter than Seal and so can be accommodated in a small Type 206 submarine.

The initial design concept was a single universal homing head, suited to both active and passive homing, and realized in the later SUT (see below). Fuzing in both torpedoes is combined impact and proximity. Both Seeschlange and Seal have preset search programs to be used in the event the guidance wire breaks before the target is acquired, as well as re-attack logic (e.g., circular search in the event of target loss).

Wire guidance was adopted specifically to suit Baltic conditions, especially the shallow water and the very long detection ranges provided by modern radars and sonars. Torpedoes had to be fired at such great ranges that they could not be expected to home until well into their run; similar logic explains the wire-guided version of the U.S. Mk 37.

The name means Sea Serpent.

◆ DM2A1 Seal

Dimensions: 533 × 6550 mm (6080 mm in the original DM2) [21 × 257.9 {239.4} in] **Weight:** 1370 kg [3020 lb]
Speed/Range: 33 kt/20,000 m [22,000 yd]; also a lower-speed setting **Warhead:** 250 kg [551 lb]
Power Plant: silver-zinc battery (contraprops)

Seal is the antiship equivalent of Seeschlange, in service in 1969. Like Seeschlange, Seal is wire-guided, but it homes passively; and it has a larger warhead suited to antiship attack. The range is long so that the attacking platform can remain out of re-attack range, and the wire is a 2-way link. Fuzing is a combination of impact and proximity. When fired from surface platforms, these torpedoes are launched back over the stern, the tail pointing forward, the wire reeling out over the stern.

◆ DM2A3 Seehecht

Dimensions: 533 × 6600 mm [21 × 259.8 in]
Weight: 1370 kg [3020 lb]
Speed/Range: 35 kt/20,000 m [22,000 yd]
Warhead: 260 kg [573 lb] **Power Plant:** battery

Seehecht is a joint AEG/Elsag program to upgrade existing Seal/Seeschlange torpedoes. The seekers were upgraded first (DM2A3), then the propulsion (DM2A4). Selenia is responsible for the new homing head (as subcontractor to AEG). This torpedo entered service in 1987, initially for German Type 206A and Type 211 submarines and for the Norwegian *Ula* class. DM2A4 is scheduled to replace Seehecht in 1998.

◆ DM3

DM3 is the German designation for the U.S. Mk 37. The original armament of German submarines was Mk 37 for ASW and the British Mk 8** for antiship work. Mk 37 may have received a special German designation because of having been modified to German requirements.

◆ SST-3/SST-4 Seal

Dimensions: 533 × 6080 mm (6550 mm including wire reel) [21 × 239 {260} in] **Weight:** 1414 kg [3116 lb]
Speed/Range: 35 kt/24,000 yd; 23 kt/56,000 yd
Warhead: 260 kg [573 lb] **Power Plant:** battery

This antiship homing torpedo is fired by surface ships and submarines; SST-3 can be fired from a depth of 100 m [330 ft]. This torpedo entered service in 1972. The improved SST-4, with approximately the same characteristics, entered service in 1980. SST-4 was the torpedo carried (and fired) by the Argentine submarine *San Luis* in the Falklands. SST-4 differs from SST-3 in having 3 speeds (35 kt/12,000 yd; 28 kt/22,000 yd; 23 kt/40,000 yd). SST-4 can be fired by both submarines and surface craft.

This torpedo has probably been license-produced by IPTN of Indonesia since 1978. Users are Argentina (with the U.S. NT-37C), Greece, and Indonesia (probably superseded by SUT).

◆ SUT

Dimensions: 534 × 6390 mm [21 × 252 in]
Weight: 1414 kg [3116 lb]
Speed/Range: 34 kt/12,000 m; 23 kt/28,000 m [13,100/30,600 yd]
Warhead: 260 kg (claimed equivalent to 500-kg TNT) [573/1100 lb]
Power Plant: battery

This dual-purpose (surface and underwater target) wire-guided torpedo has active/passive terminal homing. SUT combines the features of the earlier Seeschlange and Seal. In 1978 AEG claimed that active acquisition range was 2000 m [2200 yd] and that passive acquisition range was 4000–6000 m [4400–6600 yd]. The seeker/control incorporates re-attack logic. Torpedo attitude is controlled by a free gyro acting directly on the control surfaces.

SUT was the result of a series of export developments. Seal (above) led to the export SST-4 antiship torpedo, which in turn inspired the dual-purpose SUT. SUT was announced in 1975, ran trials in 1976, and entered service in 1980. In 1986 Indonesia signed a contract for license production. An earlier dual-purpose torpedo, NIXE, was canceled in 1972 because of excessive cost. NIXE characteristics: dimensions 534 × 7200 mm [21 × 283.5 in], weight 1545/1800 kg with a 300-kg warhead [3405/3967 lb, 660-lb warhead], speed/range 50 kt/20,000 m [22,000 yd] with 8-cylinder Otto motor.

Users are Colombia, Chile, Ecuador, Greece, and Indonesia (for both submarines and surface ships). SUT is probably used by Argentina, India, Turkey, and Venezuela.

In 1978 it was reported that AEG was developing a light-weight SUT, as an alternative to Mk 46. This development never entered service.

◆ G7e

Dimensions: 53.3 cm × 7.0 m [21 × 275.6 in]
Weight: 3870 lb **Speed/Range:** 30 kt/8200 yd
Warhead: 617 lb **Power Plant:** battery

Norway reportedly still uses ex-German G7e torpedoes, modified for wire guidance, in coastal forts. This type of torpedo was manufactured by Whitehead as late as the early 1970s and may still remain in Italian war reserves. The Italian navy used

a wire-guided variant, carrying a Mk 44 homing torpedo, reportedly under the designation G6ef (Kangaroo), until A 184 entered service. In the designation, "G" indicates 21-in diameter and 7 is the length in meters; e indicates electric propulsion. The data above refer to one version of the wartime German weapon (TIIIa); the Norwegian torpedoes presumably have better batteries and motors.

TORPEDO LAUNCHERS

Virtually all German-designed submarines have swim-out torpedo tubes, a type selected by the main design organization, IKL, because it was more compact and also more efficient than any positive-ejection alternative. Compactness was particularly prized because of the tonnage limit imposed on the new German submarines. The standard MaK tube is 750 mm [29.5 in] or 775 mm [30.5 in] in diameter (the wider tubes are the 4 closest to the submarine's centerline). There are 4 sections: a narrow-diameter inboard tube (2.5 m long), a section (of the same diameter) penetrating the pressure hull (1.2 m long), a conical section (0.3 m long), and then a maximum-diameter outboard section (3.75 m long for 775 mm tubes, 3.5 m long for 7.5 mm tubes). These tubes are installed in a hull with a circular shape that greatly reduces flow into the tubes and, thus, makes swim-out much easier. The larger bow diameter is needed to provide sufficient flow as the torpedo accelerates out of the tube (less space is needed for the initial flow over the propellers). These tubes were made by Krupp-MaK; as of early 1988, the company had made 786 tubes since 1961.

Swim-out does impose some limitations. Since the torpedo leaves the tube at very low velocity, the launching submarine must move slowly and cannot maneuver freely while firing. Cavitation in the tube (because of the drag of water flowing between the tube wall and the torpedo) may reveal the submarine. Because the torpedo does not fill the tube, it may hang up (as reportedly occurred on board an Argentine submarine on trials during the Falklands War). A swim-out tube cannot be used for energetic internal-combustion torpedoes because their toxic exhausts will vent into the submarine. Finally, a swim-out tube cannot easily launch missiles (although for a time at least Whitehead was offering a compact electric motor to swim Harpoon capsules out of tubes).

The new German Type 212 submarines will have positive-discharge tubes designed as such. Krupp-MaK, the manufacturer of the new system, considered compressed air (rejected because it imposed depth limits), electric (too heavy), and hydraulic systems. One hydraulic type uses water pressure. One piston, which pushes the water out, is provided for each nest of 3 or 4 tubes, and one hydro-accumulator can be provided for each tube. This system launches torpedoes at a minimum speed of 12 m/sec at any depth, at a submarine speed of up to 12 kt. The firing interval, for a 6-torpedo salvo, is 5 sec. Alternatively, the system can fire 3 double shots at an interval of 10 sec. It takes less than 5 min to refill the accumulators. Work on this design began in 1983, and a prototype in a simulated submarine-section was under test until the end of June 1988. This is the type adopted for Type 212.

An alternative, which has apparently been adopted for the new Israeli *Dolphin*-class submarines, uses a hydraulically impelled thrust arm. This version achieves maximum launch speed (better than 10 m/sec) in about 1.5 sec and can run at a lower speed (0.2 m/sec) to launch mines. Development work began in 1986, and work on a prototype began in 1988. Because the thrust arm does not fill the tube, torpedoes can also swim out of it. Tube diameter is 710 mm [28 in], leaving a 90-mm [3.5-in] hydraulic cylinder at the bottom.

MaK supplied an air-expulsion system for existing swim-out tubes in Greek submarines, specifically to fire sub-Harpoon missiles. Tubes III, IV, VII, and VIII, which are already equipped to lay mines, are fitted. A caliber ring is mounted just inside the muzzle door to achieve a favorable pressure distribution during expulsion.

INDIA

◆ NST-58

In 1986 India announced that this torpedo, developed by the Naval Science and Technology Laboratory in Vishakhapatnam, was in production to replace the lightweight A-244/S in Indian service. No details were provided.

ITALY

◆ A-184

Dimensions: 533 mm × 6 m [21 × 236 in]

Weight: 1265 kg [2788 lb]

Speed/Range: 36 kt/10,000 m or 24 kt/25,000 m [11,000/27,300 yd]

Warhead: 250 kg [550 lb]

Power Plant: silver-zinc battery

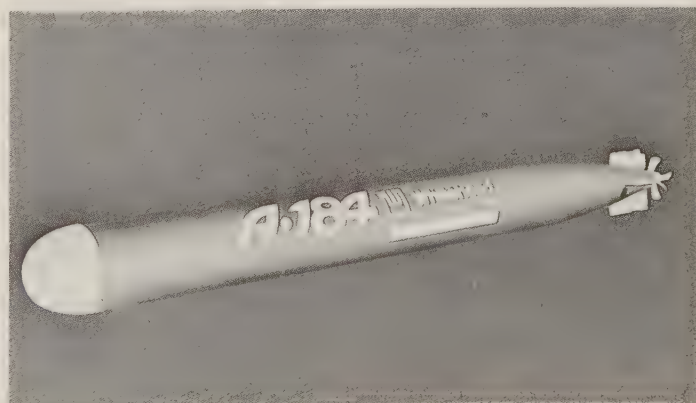
The Whitehead-Motofides A-184 replaces "Kangaroo" (Cangaro), a shipborne antisubmarine torpedo consisting of an ex-German G6e, wire-guided, which in turn launched a Mk 44 homing torpedo upon approaching the submarine target. A-184 can be fired both from submarines and from surface ships.

A-184 is wire-guided, with digital active and passive terminal homing using 2 semicircular arrays, 1 in the vertical and 1 in the horizontal plane, for wide sector coverage. The torpedo employs contraprops and can be fired from both surface and submerged torpedo tubes.

The G6e/Kangaroo replacement requirement was issued in 1971, and the A-184 prototype tested in 1973. It entered service the following year. This torpedo has been exported to both Peru and Taiwan (GRC), the latter in 1986. Peru reportedly bought A-184 in preference to the German SST, the latter having failed in Baltic tests after the Falklands War. Reportedly, SST was unable to maintain its depth while under wire control.

Whitehead was the only pre-1943 Italian torpedo producer, and it is likely that some of the company's old straight-running 18- and 21-in torpedoes were exported postwar, e.g., for torpedo boats. It seems unlikely that any of these weapons have remained in service. Postwar, Whitehead either built or reconditioned German G6e electric torpedoes and developed Cangaro, which was the first postwar Italian torpedo. G6e was apparently the standard Italian submarine torpedo until A-184 replaced it.

The requirement for a G6e replacement was stated in 1971, and the A-184 prototype was tested in 1973; the torpedo entered service with the Italian navy, for both submarines and surface ships (the *Audace* and *Maestrale* classes), in 1974. Peru and Taiwan ordered A-184 in 1986. Whitehead has also discussed the purchase of A-184 with Chile, Indonesia, and Venezuela, with unannounced results. Of these countries, Indonesia decided to license-build German torpedoes, and Chile now manufactures Tigerfish. The Venezuelan Type 209 submarines are being refitted by their German builder, which would seem to imply that they will continue to carry German torpedoes.



A-184. (Whitehead)

◆ A-244 and A-244/S

Dimensions: 324 mm × 2.75 m [12.75 × 108.3 in]
Weight: 220 kg [235 kg for A-244/S] [485/518 lb]
Speed/Range: 30 kt/6000 m [6600 yd]
Warhead: 34 kg (blast) [75 lb]
Power Plant: lead-acid battery

A-244 was conceived as a replacement for Mk 44 Mod 2; this torpedo is sometimes described as an improved Mk 44-2. A-244 entered service in 1971, and the improved A-244/S in 1984. A-244 homes passively/actively using a single frequency. A-244/S homes actively/passively using triple-frequency pulses and a programmable seeker (search patterns and standard maneuvers). A-244/S's new CIACIO-S seeker may differ from that (Elsag AG70) of A-244 by using multiple preformed beams, the shape of which can be changed to suit acoustic conditions (spatially adaptive beam patterns). The pulses are coded FM slides. The manufacturer claims that its computer analyzes the structure, doppler, shape, and time-space coherence of returning echoes to reject clutter, multipath or mirror effects (from the surface or the bottom), and echoes from the bottom, and even to detect submarines (as opposed to natural formations) on the bottom. Mod 1 is for helicopter launch, Mod 2 for aircraft.

The A-244 requirement was issued in 1968; research was completed in 1973; and production began in 1975.

Work on CIACIO began in 1964 after Selenia gained experience with the Mk 44 seeker during license production. The company described the seeker as using principles not previously used in underwater detection and called the seeker compatible with future light- and heavy-weight torpedoes. A 60-kHz CIACIO 60 was completed in 1966, using the transducer of the Mk 44 (but with new operating principles). CIACIO 30, operating at 30 kHz, was completed in 1968; and it led to CIACIO-S, which appeared in 1972. CIACIO-S was tested in the laboratory in 1973, with static sea trials following in 1974 and live trials (using Mk 44 torpedoes) in 1975. Very shallow water trials were carried out in 1977-78.

A-244/S Mod 1 was ready for delivery in 1987. Export customers are Argentina, Ecuador, Greece, India, Indonesia, Iran, Iraq, Libya, Nigeria, Pakistan, Peru, Singapore, Taiwan, Turkey, and Venezuela. Estimated unit cost is 70% that of a Mk 46, i.e., about \$140,000; A-244/S probably costs \$145,000.

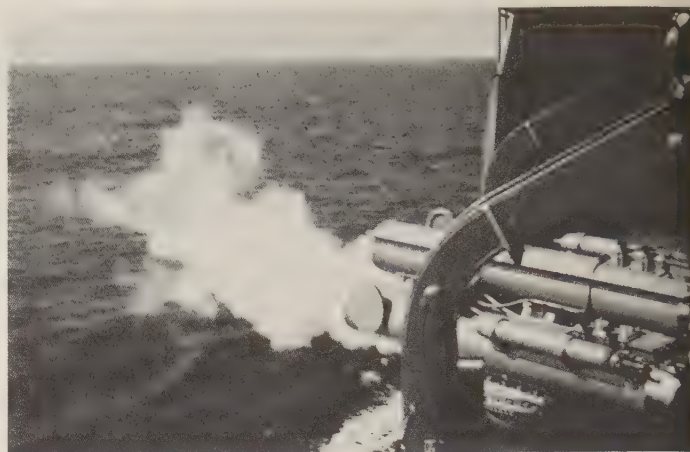
Before developing A-244, Whitehead developed A-243 (presumably a replacement for Mk 43), which did not enter production. The company also made about a hundred Mk 44s under license.



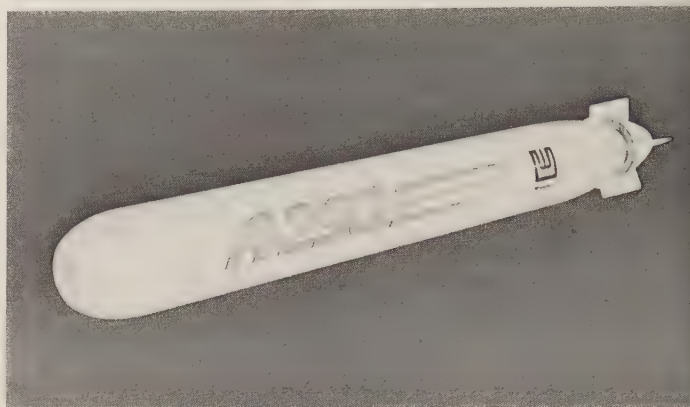
A-244/S at Farnborough, 1990. The shroud ring (used instead of fins for directional control) suggests its relationship with the earlier U.S. Mk 44. The object in the foreground is a dummy Mk 11 depth charge; in the background is a Stingray torpedo. (Author)

◆ A-290

Dimensions: 324 mm × 2.75 m [12.75 in × 108.3 in]
Speed/Range: 50 kt/ca 10 km [10,900 yd] (speed also reported as 40-45 kt)
Warhead: shaped charge
Power Plant: aluminum-silver oxide battery



A B515 triple tube launches an A-244S Mod 1 torpedo. (Whitehead)



A-290. Note the pump jet. (Whitehead)

The A-244 replacement, A-290 is to enter service in the 1990s. This torpedo will incorporate some A-244 technology including the CIACIO-S seeker; subsystem tests began in 1987. Development began in 1981. Improvements will include greater power (for a speed of 40-45 kt), a pump jet, improved tracking range, better passive capability, and a greater ability to classify shallow targets in warm water. The manufacturer, Whitehead, states that the design emphasizes improved signal processing (for greater acquisition range) rather than greater speed.

In 1988 the major question in the A-290 program is reportedly which of several alternative computers to use. The A-290 torpedo was displayed publicly for the first time at the Mostra Navale exhibition at Genoa in May 1989. It is to enter service in the Italian navy early in 1992.

◆ LCAW (A200)

Whitehead's Low-Cost Antisubmarine Weapon is a very simple torpedo intended mainly to help classify targets. At present, the only safe way to deal with a possible target is to drop a homing torpedo on it, either to kill it or at the least to make it run (and thus to confirm that it is a real target). That was the role of the depth charges of the past, but they are no longer viable, and homing torpedoes are considered much too expensive to be used as classifiers. Dimensions: 123 mm × 1 m (15 kg, 4-kg shaped-charge warhead). Performance: 18 kt for 3 min (range 2+ km). LCAW has an active seeker.

TORPEDO LAUNCHERS

◆ B.512

Whitehead submarine torpedo tube.

◆ B.515/ILAS-3/SPS 104

ILAS 3, the standard Italian lightweight-torpedo launching system, consists of a Whitehead SPS 104 FCS system (for torpedo

presetting and launch control) and 2 sets of B.515 triple tubes. In its most elaborate form, SPS 104 incorporates a computer. It displays the tactical picture and torpedo presets and automatically transmits the order to fire; it can be integrated into a larger FCS. SPS 104 exists in 3 versions: (i) manually controlled via a remote-control panel in CIC; (ii) controlled directly by the CDS; and (iii) connected directly with the sonar (for a ship without a CIC), computing target course and speed and choosing optimum presets. The panel selects the tube and presets and fires the torpedo. Firing is by compressed air, and the tubes have heaters. Whitehead also makes a lightweight FCS in 2 versions: (i) for helicopters with dipping sonars, and (ii) for maritime-patrol aircraft and helicopters without dipping sonars.

◆ B.516

Whitehead heavy torpedo tube for surface ships, typically firing aft over the stern (for wire guidance). There is also a B.516/A version.

JAPAN

Japan currently uses Mk 44 and Mk 46 lightweight torpedoes and Type 80 heavy torpedoes.

◆ Type 80

Type 80 is a wire-guided ASW torpedo comparable in size to the U.S.-supplied Mk 37, but with better performance; speed is over 30 kt. Type 80 is about the same size (19-in diameter and short length) as Mk 37. Type 80 was developed from the GRX-1 experimental torpedo, but it also drew on data from the ongoing GRX-2 program. Research began in JFY65, the designation Type 80 being applied in JFY80. Production began in JFY84. At that time the equipment designator G-11 was applied.

This torpedo is carried by the *Uzushio* and *Ushio* classes. Type 80 replaced the Japanese version of Mk 37, Mk 37-0-N.

◆ Type 89

This new standard heavy (submarine) thermal torpedo is roughly equivalent to the U.S. Mk 48. Reported maximum speed is 70 kt, with a range of 30,000 m [32,800 yd]. It was developed in parallel with the electric (silver-zinc) GRX-1. Development was protracted; as of 1983 GRX-2 was to have been ready for designation (standardization) in JFY85, but that occurred only in JFY89. Despite the delay, Japan did not seek license production of either Mk 48 or Mk 48 ADCAP.

The current R&D program includes work on counter-countermeasures improvements for this weapon.

◆ GRX Series

These are experimental torpedoes. When a torpedo is adopted for service, its GRX designation is replaced by a Type number indicating the JFY in which it is applied. GRX-2 became Type 89 in 1989. The current research program includes a new torpedo launching system.

GRX-4 is a new lightweight torpedo broadly comparable to the U.S. Mk 50, with a shaped-charge warhead, a SCEPS power plant, and a propulsor. A development contract for this torpedo was awarded to Mitsubishi Heavy Industries in March 1987. GRX-4 is apparently being developed as an alternative to a Japanese production program for Mk 50. Its shaped-charge warhead

was tested successfully against a double-hull submarine section in July 1989; apparently the guidance system is designed to ensure that the torpedo hits at right angles to its target.

GRX-4 supersedes GRX-3, an earlier, experimental, air-launched, electric, lightweight torpedo developed as an alternative to Mk 46. Begun in 1975, GRX-3 was abandoned as too large and too heavy.

The 2 current developmental torpedo programs are GRX-5 and -6.

TORPEDO LAUNCHERS

The standard submarine tube in the *Uzushio* class is HU-602; it was succeeded by HU-603 in the *Yushio* class and by HU-603B in the new *Harushio* class. From the 5th *Yushio* (*Nadashio*), the HU-603 tubes are fitted to fire Harpoon missiles as well as torpedoes (the earlier units were later modified). HU-603 can also launch torpedoes at greater depths than can its predecessor.

The Japanese version of the U.S. Mk 32 triple tube is designated Type 68.

SWEDEN

◆ Type 42 Series

Dimensions: 400 × 2440 mm [2620 mm with wire dispenser] [15.75 × 96.1/103 in] **Weight:** 250/298 kg [550/657 lb]

Speed/Range: 25 kt/20,000 m (10,000 m at high speed) [22,000/10,900 yd] **Warhead:** about 50 kg [110 lb]

Power Plant: battery (2-speed motor)

Type 42 is a lightweight electric ASW torpedo (with secondary antiship capability) that can be launched by submarines, surface ships, and helicopters. It was originally designed for direct homing (using a passive sonar scanning both in depth and in azimuth), but it is adapted for wire guidance. In this form Type 42 is unique among modern lightweight weapons in being wire-guided; that guidance is necessary to assure homing under difficult acoustic conditions (e.g., in shallow water). Type 42 has both impact and proximity fuzes.

Type 42 entered production about 1976, succeeding Type 41, which had similar dimensions and performance (400 × 2440 mm, 250 kg, 25 kt/20,000 m [22,000 yd]). Presumably, Type 42 introduced the 2-speed motor, for a higher-speed attack.

Current versions are the following:

Type 422 (298 kg, ranges as above), 1983. Compared to the original Type 42, this version has a better wire data link and a better signal processor.

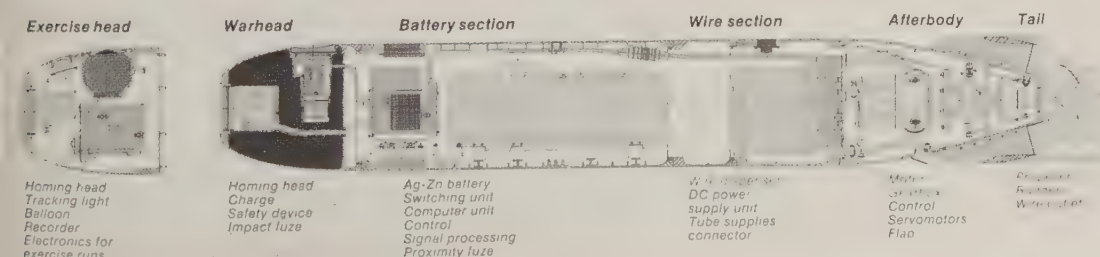
Type 423 (290 kg [639 lb], 400 × 2850 mm [15.75 × 112 in]).

Type 427 is the current export version of 422/423 (400 × 2600 mm [15.75 × 102 in], 298 kg, silver-zinc battery). Total weight is also given as 310 kg [683 lb], length as 2.85 m [112 in]. This version has been in service since 1982. It incorporates some Type 617 technology.

There is a special "incident" version of Type 42 with a less lethal warhead, to force a submarine in Swedish waters to surface. This development parallels that of Elma and Malin (see unguided weapons below).

Type 43 is descended from Type 41, a homing (dual-purpose) weapon introduced about 1960. Type 41 was developed into Type 411, for the *Abborren*-class submarines (now discarded), which were then being rebuilt for ASW, and then into Type 412, for the *Sjoormen* class. A projected Type 413 was not pur-

(Below) Type 43 torpedo. (FFV)



sued. Instead, a new series was begun with Type 42. Type 421 was a specialized ASW torpedo carried by the *Nacken* class, and the wire-guided Type 422 was carried by helicopters. The abortive Type 423 was intended specifically for the *Vastergotland* class. The next series, Type 43 (described below), introduced data programming at transmission, an autopilot, and a 3-speed motor. Type 431 is designed for use by both the *Vastergotland* class and the corvettes. Type 43X0 is the export version. A new lightweight torpedo is expected about 1990. It should have improved performance and better counter-countermeasures features, within smaller dimensions.

FFV claims that a lightweight torpedo suffices for ASW because the tamping effect of the water surrounding a submarine will amplify the effects of its 30–70-kg warhead. FFV considers at least a dual-speed motor necessary because the same torpedo may have to deal with moderate-speed (diesel) and high-speed (nuclear) targets. The company considers wire guidance, for 3D maneuvers, essential, even though other lightweight ASW torpedoes are entirely self-guided.

◆ Type 43X0/Type 431/Type 432

Dimensions: 400 × 2850 mm [15.9 × 112 in]
Weight: 350 kg (280 kg in helicopter version) [771 {617} lb]
Speed/Range: range 32,000 yd
Power Plant: silver-zinc battery; 3-speed motor

Type 431 is an improved Type 427 optimized to attack very quiet submarines in shallow water. Development was ordered early in 1984. The new digital computer, which is programmed in Pascal, is smaller than its predecessors, and the guidance wire carries more information. Signals sent to the torpedo control speed, depth, and course and provide target data. The torpedo reports its position, speed, course, depth, homing system parameters, and target radiated noise. The on-board computer calculates expected target position and can independently initiate 1 of several search patterns if the guidance wire breaks. Speed options are 15, 25, and 35 kt, the last faster than the high-speed option of Type 42.

Type 43 differs from Type 42 in being of modular construction, to accommodate a special warhead or battery. The basic air-launched version is Type 432, which has a lighter battery than the ship-launched version (Type 431); capacity is 4.2 rather than 5.6 kW-hr. In both cases, the battery is more durable than that of Type 42, capable of 30 rather than 10 exercise firings between overhauls. Type 43X0 is an export version, which can be delivered with a different battery.

The first Swedish navy order for Type 431 was announced early in 1986. This torpedo entered service in 1987.

The Swedish navy recently (1990) ordered Whitehead A-244/S torpedoes to gain experience with active seekers. It was very impressed by the torpedo's ability to detect and attack a bottomed submarine in difficult underwater terrain, i.e., on the bottom next to a steep rise. The Type 43 series successor, now designated Type 45, will probably have an active/passive seeker.

At Defendory in October 1990 FFV announced the first order for Type 45, from the Swedish Defense Materiel Administration. Type 45 will have the Type 43 hull with a new seeker and a better signal processor. The first Type 45s are to be delivered in 1993.

◆ Type 61

Dimensions: 533.4 × 7025 mm [21 × 288 in]
Weight: 1765 kg [3890 lb]
Speed/Range: 45 kt/20,000 m [22,000 yd] (some sources claim maximum speed is over 60 kt)
Warhead: 250 kg [551 lb]
Power Plant: hydrogen peroxide/alcohol (350-kW 12-cylinder engine)

This long-range wire-guided antiship torpedo is fired from both submarines and surface ships. The manufacturer, FFV, claims that the HTP propulsion system provides 2 or 3 times the range of conventional thermal or electric torpedoes. This torpedo is also wakeless. Course and speed are maintained within 0.3% during the run to the target. Wire guidance is necessary to exploit the very long range of the torpedo; Sweden was 1 of the first countries to employ submarine-launched wire-guided torpedoes operationally.

Later versions (613/617), capable of longer ranges, have terminal acoustic homing (wake homing in at least some cases). Two alternative fuzes (inertial or acoustic proximity) are available.

Type 61, whose data are listed above, entered service in 1968. The prototype was Type 611; Type 612 was the first production version (dimensions 533 × 7500 mm [21 × 295 in]).

Type 613 is the current Swedish navy service version (533 × 7025 mm, 1765 kg [21 × 277 in, 3890 lb]). It incorporates a digital computer that can be programmed to suit particular environmental and threat conditions. This version increased range from 20,000 to 30,000 m [22,000 to 32,800 yd], partly as a result of adopting a 2-speed motor, the additional range being exploited by the introduction of terminal homing and, therefore, 2-way wire guidance. Production began in 1983, with first deliveries following in 1984.

Announced in 1982, Type 617 is the export version of 613. 617 entered service in 1984. Length is 6890 mm [271 in]; weight is 1860 kg [4099 lb]; and estimated performance is 60 kt/30,000 m [33,000 yd]. The warhead weighs 240 kg [529 lb].

This torpedo has been exported to Denmark and Norway.

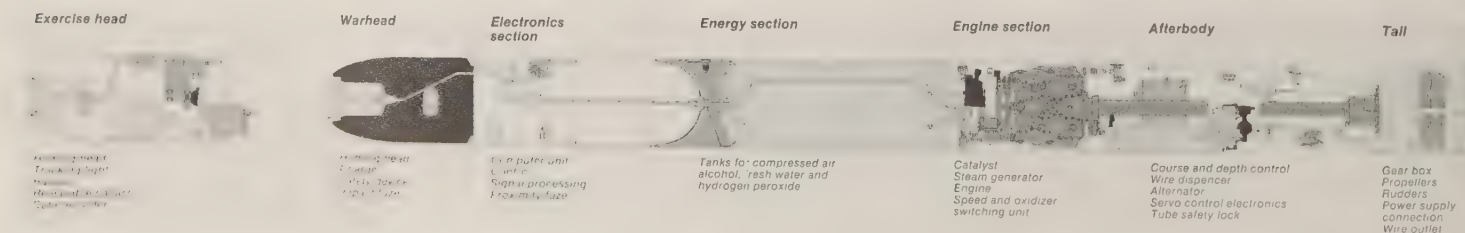
Swedish work on heavy HTP torpedoes began about 1955, with the surface-launched Type 14, from which were derived a straight-running Type 141 and a wire-guided Type 142. About 1960 a corresponding submarine torpedo, Type 27, was introduced. From it were derived Types 271 and 272, the latter entering service about 1964. About 1970 a single torpedo, Type 61, for both surface and submarine launch, was produced. Type 611, a wire-guided HTP weapon, was derived directly from Type 272. From 611 evolved Type 612 (swim-out launch; about 1975); from Type 612 were derived the noisy, fast Type 618 (about 1980) and then the homing Type 613, with data transmission along its guidance wire and with a 2-speed motor. Type 617 is the export version of Type 613.

Type 61 is unique among modern Western wire-guided torpedoes in being suitable for forward firing from surface ships (the German torpedoes, A-184, and the abortive surface-launched version of the U.S. Mk 48 all had to be fired aft, over the stern). Presumably, Type 61 accelerates fast enough to carry its wire clear of the firing ship.

◆ 2000 'S'

FFV announced this next-generation, dual-purpose, wire-guided, export torpedo, now under development, in 1990. Endurance may be over 1 hr at a maximum speed of 60+ kt. The new semiclosed-cycle, HTP, swashplate power plant drives a pump

(Below) Type 617 torpedo. (FFV)



jet propulsor. The new AT-96 seeker can be used either passively or actively, and there may also be a wake-following mode.

◆ Angler

Angler was a Swedish program for a hand-launched torpedo or intelligent depth charge, to be used primarily against intruding mini-submarines. Announced in 1987, Angler was intended to fill a gap between conventional torpedoes and the Elma depth charge. Two U.S. companies, Lockheed (the Lockheed Lightweight Torpedo) and General Dynamics (the Self-Propelled Depth Charge), competed. See the U.S. section for more details of the Lockheed weapon. The Swedish navy reported that it had a design speed of 6–7 kt (demonstrated speed was 2–3 kt). It used a fiber-optic link to relay its sonar and color television pictures. The General Dynamics weapon used a different technology (no details are available). Although the Royal Swedish Navy was impressed with the fiber-optic link, it found the Lightweight Torpedo too slow, and the program was canceled in favor of the alternative versions of Elma described below. The Lockheed weapon was also considered for mine countermeasures. Both the Lockheed and the General Dynamics weapons were private ventures, although the U.S. Navy was kept aware of program progress. Work probably began about 1985 under the auspices of the Swedish National Defense Research Institute.

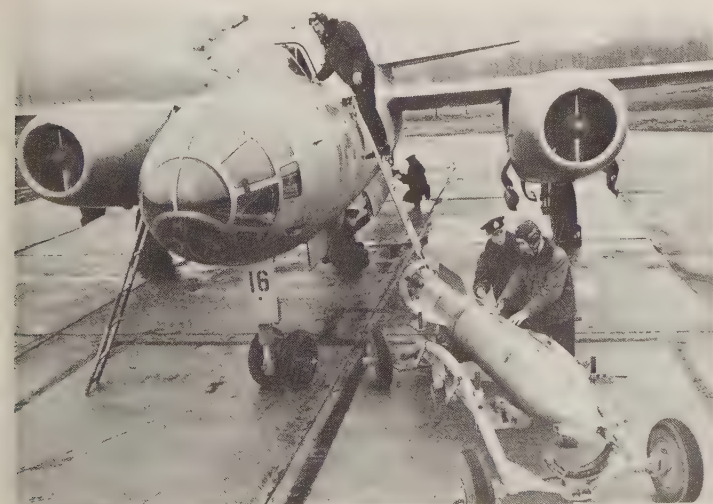
During the mid-1980s there was at least 1 project to develop an intelligent depth bomb for the standard Bofors 375-mm mortar. It may have helped inspire the current NATO low-cost ASW weapons program.

USSR

Data below are necessarily incomplete. Information on torpedoes deployed since about 1958 is unofficial, from a few recent publications. Material on earlier Soviet torpedoes is taken from a mix of Soviet official sources and declassified Western intelligence data.

For thermal (e.g., steam) torpedoes, the standard designation indicates the caliber and the year of origin, e.g., 53-39 is 53-cm caliber and originated in 1939. Designations of electrical torpedoes vary; the earliest was ET-80. More recent types appear to follow thermal torpedo practice, with the prefix E. There are also other special designations (see below).

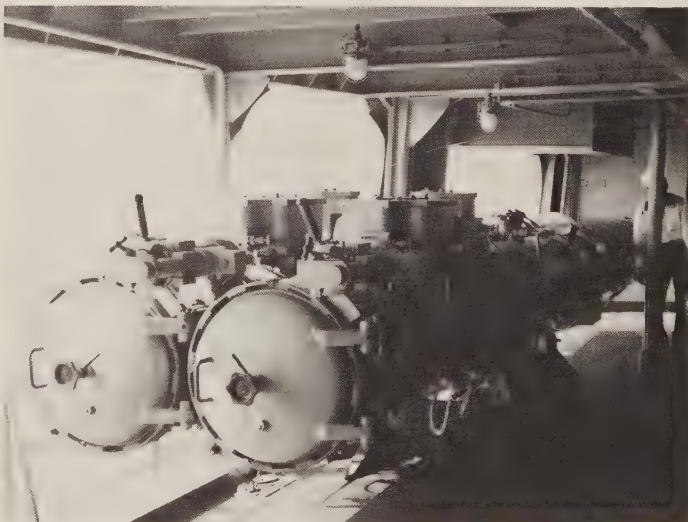
Most of the information on the most recent Soviet torpedoes listed here comes from a 1987 publication, but the reader is



The Soviet Union was unique in developing a series of torpedoes specially adapted to be dropped from high altitude and long range. One example, this rocket-propelled torpedo has a special nose break to reduce the impact of hitting the water. Although the torpedo has a tail shroud, it has no propeller. This torpedo is the conceptual ancestor of the long-range antiship missiles of the AS series. Although this photograph is dated 1971, it was probably taken in the late 1950s; the airplane is an IL-28T. This weapon was designated RAT-52. It was also used by the PRC. (TASS from SOVFOTO)



Quintuple torpedo tubes, on board the cruiser *Kerch*, 1989. The loading trolley is under the muzzles of the tubes. (Eric Grove)



Twin torpedo tubes on board the *Sovremennyy*-class destroyer *Bezuprechnyy*, 1990, showing presetting ports. (Eric Grove)

cautioned that none of the torpedoes there described came into service later than 1981.

The very brief notes are taken from material released by the U.S. Navy in 1990. The reader is cautioned that the designations given below are a mixture of actual Soviet designations and *Soviet-like* designations applied by Western navies (torpedo caliber and IOC date).

The 1987 article did not list surface-ship torpedoes. Most Soviet surface combatants, from light frigates up, carry 53-cm antisubmarine and antisurface torpedoes. There is now a 53-cm wire-guided ASW torpedo: the evidence is that Grisha-V-class corvettes, which entered service from 1985 on, have had their torpedo tubes lengthened to allow for the wire dispenser.

Reportedly, some portions of the Mk 48 torpedo design were compromised to the Soviets in the late 1970s. It seems likely, then, that the Soviets now have reasonably quiet thermal piston engines for homing torpedoes equivalent in speed and endurance (but probably not in acoustic performance) to Mk 48 and to Mk 46.

◆ Type 65

Dimensions: 650 × 9140 mm [25.6 × 359.8 in]
Speed/Range: 50 kt/54,000 yd; 30 kt/109,000 yd [50,000 and 100,000 m, respectively]
Warhead: 900 kg approx [1980 lb]

This torpedo, which is probably an enlarged 53-65, became operational in 1981; the Soviet designation is, therefore, probably something like 65-80. Type 65 has attracted very considerable attention in the West because it has the sort of warhead required to sink a carrier and because wake homing is virtually impossible to counter by means of a towed or thrown decoy. Presumably, the torpedo is fired on a gyro course toward the expected target position, the wake-homing feature considerably enlarging the effective target length and thus making very long firing ranges (as indicated above) useful. In this sense Type 65 might be regarded as an underwater cruise missile, supplementing antiship cruise missiles flying through the air.

This torpedo marks a drastic change in Soviet torpedo size and, therefore, can be fired only by recent submarines. It seems likely that Type 65 was designed because 65-cm tubes had already been selected for Victor-II and later submarines, to fire the SS-N-16 ASW cruise missile. The SS-N-21 also seems to use this tube.

Victor-III-class submarines are fitted with four 65-cm and two 53-cm torpedo tubes, the 2 smaller-diameter tubes mounted over the 4 larger ones. The continued use of smaller-diameter tubes suggests that some special 53-cm weapon, which cannot be fired from the larger tube (i.e., using a liner), is carried. The most likely candidate would be a nuclear torpedo that would be carried more or less permanently in the tube for security reasons. That possibility in turn would refute reports that the 65-cm torpedo has a nuclear warhead. Alternatively, the smaller-caliber tubes might be reserved for wire-guided ET-80A (1980) ASW torpedoes, for close-in defense, or for large-caliber decoys.

A nuclear version of the 65-cm torpedo has been reported. From Victor-II onward, most Soviet submarines have tubes with 65-cm diameters, so it would be reasonable to imagine that the Soviets have produced 65-cm weapons in all 3 major torpedo categories: antiship (as here), nuclear, and electric antisubmarine. To limit the arsenal to existing smaller-caliber weapons (fired, presumably, using unwieldy tube liners) would be to disregard the considerably greater volume (e.g., for endurance, guidance, or both) offered by the larger torpedo caliber.

◆ 53-27L

Dimensions: 21 in × 23 ft **Weight:** 3800 lb
Speed/Range: 43.5 kt/4570 yd **Warhead:** 550–600 lb
Power Plant: air-steam

This torpedo was carried postwar by North Korean motor torpedo boats, and it may have been exported to other Soviet client states. The L may have indicated manufacture at Leningrad. Running depth was 16–40 ft.

◆ 53-38/53-38U

	53-38	53-38U
Dimensions:	533 × 7200 mm [21 × 284 in]	533 × 7450 mm [21 × 293 in]
Weight:	1615 kg [3560 lb]	1725 kg [3800 lb]
Speed/Range:	44.5 kt/4000 m; 34.5 kt/8000 m; 30.5 kt/10,000 m [4400; 8700; 10,900 yd]	
Warhead:	300 kg [661 lb]	400 kg [882 lb]
Power Plant:	HPT, 2-cylinder horizontal engine	

These 2 were the standard surface and submarine torpedoes in service at the outbreak of World War II; 53-38U was a rein-

forced version of the basic weapon. There were several major wartime modifications. A proximity fuze (NVS) entered operational service about 1943. Running depth was 16–40 ft.

◆ 53-39

Dimensions: 533 × 7488 mm [21 × 294.8 in]
Weight: 1780 kg [3923 lb]
Speed/Range: 51 kt/4000 m; 39 kt/8000 m; 34 kt/10,000 m [4400/8700/10,700 yd]
Warhead: 317 kg [699 lb]
Power Plant: HPT, 2-cylinder horizontal engine

An improved 53-cm [21-in] torpedo, 53-39 entered service in July 1941. 53-39 had a more powerful engine and greater air, kerosene, and oil capacity. This weapon introduced a new MO-3 gyroscope permitting angled fire (from 0–90 deg port or starboard).

◆ 53-51

Dimensions: 533 × 7800 mm [21 × 307 in]
Speed/Range: 51 kt/4000 yd; 39 kt/10,000 yd
Warhead: 400 kg [882 lb]

53-51 was the postwar Soviet submarine torpedo, a straight or pattern runner. Maximum launch depth was 106 m [348 ft]; maximum operating depth was 14 m [46 ft]. The exploder was impact or magnetic (proximity).

◆ 53-56

Dimensions: 533 × 7740 mm [21 × 305 in]
Speed/Range: 51 kt/9000 m; 39 kt/18,500 m [9800/20,200 yd]
Warhead: 400 kg [882 lb] **Power Plant:** HTP/fuel (open cycle)

53-56, the first operational Soviet torpedo with an unconventional engine, was a modified 53-51.

◆ 53-56V and 53-56VA

Weight: 1900 kg [4188 lb]
Speed/Range: 51 kt/4000 m, 41 kt/8000 m
Warhead: 400 kg **Power Plant:** air-stream (piston)

These are standard Soviet export torpedoes. 53-56VA is a torpedo-boat weapon, reportedly 276 in long, weighing 3960 lb, and with a speed/range of 28–30 kt/6000 yd. Both torpedoes have pattern-running modes based on the wartime German FAT. Data on 53-56V come from a 1986 Soviet book on torpedoes. In the book, 53-56V is described as a well-known type, along with 45-36N and 53-39PM (pattern-running). Presumably, all have been exported.

◆ 53-?

Dimensions: 533 × 7200 mm [21 × 283.5 in]
Speed/Range: 50 kt/11,000 m; 32 kt/21,000 m [12,000/23,000 yd]
Warhead: nuclear, approx 15 kT
Power Plant: HTP/fuel (open cycle)

The nuclear version of the 53-56 carries a 15-kT warhead. This torpedo became operational in 1959 or 1960, so the designation is presumably 53-59 or 53-60. This torpedo was almost certainly the weapon element of the November-class SSN weapons system, the submarine being fast enough to reach a firing position off the bow of the fast target (e.g., an aircraft carrier). The torpedo did not home; it exploded at a set range as indicated by the propeller turn count. The propeller count was also used to arm the warhead after the torpedo passed a set enabling range. There was an anticircular turn mechanism to protect the firing submarine.

At one time it was suggested that this torpedo was also the first Soviet naval strategic nuclear weapon because it could be delivered to enemy harbors.

There is some evidence that Soviet nuclear torpedo warheads were unsafe. In February 1972 a Soviet submarine off the North American coast suffered crew casualties because of radiation leakage from torpedo warheads. The 2 nuclear torpedoes on board the Whiskey-class submarine that grounded in Sweden in 1981 had noticeable radiation signatures.

◆ E53-66

Electric gyro (straight- and pattern-runner) torpedo for submarine and surface launch.

◆ E53-75 and -79

Electric torpedoes for air and missile delivery. It is not clear to what extent these 53-cm torpedoes replace (or are replaced by) E53-79.

◆ E53-70

Submarine- and surface-launched thermal pattern-runner.

◆ E53-83

Follow-on to E53-68: submarine- and surface-launched thermal antiship torpedo (wake-follower). This weapon presumably incorporates the Mk 48 propulsion technology compromised in the 1970s.

◆ E53-?

This submarine-launched electric dual-purpose torpedo entered service in 1983. It is officially listed as a 53-series rather than an E53.

◆ ET-80A/SAET-50/SAET-60

Dimensions: 21 × 307 in **Speed/Range:** 23.3 kt/8000 yd

Warhead: 600 lb TNT

Power Plant: 46-cell lead-acid battery; 56-HP motor with contra-props

ET-80A was the first Soviet homing ASW torpedo, a modified version of the earlier ET-80. ET-80A was fired only by submarines.

ET-80A could acquire a cavitating submarine (21 dB at 24.8 kHz) at about 700 yd. The torpedo could be set to run as deep as 325 ft, although it could dive to 500 ft when homing and could attack a target either above or below its set depth. The exploder was a modified version of the wartime German TZ-5 with 2 additional horizontal receiving coils, with a range of 100 ft (above, below, or alongside).

ET-80A first appeared about 1961. As of 1962, the U.S. evaluation was that it was an interim weapon pending the use of the same passive-homing device in a smaller and more modern torpedo with greater maneuverability. That torpedo was presumably the earliest version of the 40-cm torpedo described below. A passive homer of this type could be used against surface ships as well as against noisy submarines.

As applied to this weapon, ET-80A was an ONI, not a Soviet, designation.

The Soviets have published details of SAET-50, which they describe as their earliest homing torpedo and which may correspond to ET-80A. Dimensions are 530 × 7454 mm [20.9 × 293.5 in]; weight is over 1600 kg [over 3520 lb]; warhead is 375 kg [827 lb]; and performance exceeds 40 km/hr over 7000 m [21.6 kt/7650 yd]. A 1986 Soviet book states that SAET-50 can be set for circular or sector search. In the latter mode, the torpedo turns to 1 side for a period of several seconds. If no target is detected, the torpedo swings back onto its initial straight course. There is no indication of a helical search mode. The torpedo sonar consists of 4 nickel-plate (magnetostrictive) transducers operating at 25 kHz and forming a line across the nose of the torpedo.

SAET-60, which entered service in 1965–66, has been described as the first Soviet antiship homing torpedo. Its dimensions match those of the ET-80A listed above: 533 × 7800 mm. However, performance is higher: 35 kt/15,000 m [16,400 yd]. The warhead is 400 kg [882 lb]. The power plant is a silver-zinc battery. Operation is passive at 25 kHz. The exploder is impact or acoustic proximity.

◆ ET-80(66)

Dimensions: 533 × 7700 mm [21 × 303 in]

Speed/Range: 35 kt/10,000 m; 20 kt/40,000 m [11,000/43,700 yd]

Warhead: nuclear: 20 kT

Power Plant: silver-zinc batteries

A quieter (but slower) nuclear antiship torpedo, ET-80(66) replaced the nuclear version of E53-56. Maximum running depth was 305 m. A deep run would tend to increase the area affected by the nuclear burst, thus reducing the effect of any aiming error by the submarine.

◆ SET-65

Dimensions: 533 × 7800 mm [21 × 307 in]

Speed/Range: 35 kt/10,000 m; 24 kt/20,000 m [11,000/22,000 yd]

Warhead: 272 kg [600 lb]

Power Plant: battery

SET-65 is a submarine-launched torpedo, operating down to 400 m. It became operational in 1967.

◆ E53-65

Dimensions: 533 × 7800 mm [21 × 307 in]

Speed/Range: 55 kt/14,000 m; 40 kt/24,000 m [15,300/26,200 yd]

Warhead: 400 kg [882 lb]

Power Plant: HTP/fuel using new multipiston engine

This torpedo reportedly introduced both a new power plant (probably semi-closed-cycle, reusing exhaust gas) and wake-homing into Soviet practice. E53-65 was the first Soviet thermal torpedo capable of homing, and it became operational in 1968.

◆ E53-68

Dimensions: 533 × 7200 mm [21 × 284 in]

Speed/Range: 45 kt/15,000 yd **Warhead:** nuclear: 20 kT

Power Plant: HTP/fuel closed-cycle (wakeless)

This torpedo, a modernized nuclear version of E53-65, became operational in 1970. E53-68 can be launched from as deep as 106 m [348 ft], and it can run down to 300 m [984 ft]. As in the earlier thermal nuclear torpedo, E53-68 is a straight-runner using propeller turn count to measure the distance to a preset detonation.

◆ E53-VA

The standard Soviet export antiship torpedo, E53-VA reportedly had a 562-kg [1240-lb] warhead and a magnetic influence fuze.

◆ ET-80A

Dimensions: 533 × 7800 mm [21 × 307 in]

Speed/Range: 35 kt/15,000 m; higher speed for 12,000-m range [16,400/13,100 yd] **Warhead:** 272 kg [600 lb]

Power Plant: battery

The ET-80A designation has already been used; this torpedo presumably has some other designation, as yet unpublished. This torpedo was probably a modernized SET-65; it was the first Soviet wire-guided torpedo. It also had an improved power plant. Submarine-launched, ET-80A can operate down to 400 m.

This torpedo became operational in 1977.

A wire-guided torpedo with similar performance is probably in limited production.

◆ E45-70A

Dimensions: 450 × 3900 mm [17.7 in × 153.5 in]

Speed/Range: 28–30 kt/10,000 m [11,000 yd]

Warhead: 90 kg [198 lb]

E45-70A is the payload of the SS-N-14 missile. This torpedo executes an up-and-down helical search, down to 305 m [1000 ft].

◆ E45-75A

Dimensions: 450 × 3900 mm [17.7 × 153.5 in]

Speed/Range: 38 kt/9000 yd **Warhead:** 90 kg [198 lb]

E45-75A is a missile- (SS-N-14 and -16) and aircraft-delivered weapon, an updated E45-70. -75A became operational in 1973. Maximum operating depth is about 300 m.

◆ E45-75A Mod

Dimensions: 450 × 4600 mm [17.7 × 181.1 in]
Weight: approx 840 kg [1851 lb]
Speed/Range: 38 kt/8000 m [8700 yd]
Warhead: 90 kg [198 lb]

A lengthened, modernized E45-75A, Mod is reportedly used as the payload of SS-N-14 and -16.

The 1990 U.S. release mentioned only 2 E45-series torpedoes, IOC's 1965 and 1973. Both were electric active-acoustic homers for air delivery.

◆ SET-40

Dimensions: 400 × 4500 mm [15.9 × 177 in]
Speed/Range: 28 kt/10,000 m [11,000 yd]
Warhead: 100 kg [220 lb] **Power Plant:** silver-zinc batteries

SET-40 was the first Soviet lightweight torpedo, for firing from small surface ships (light frigates and corvettes). It may also have been delivered by aircraft, though that delivery seems unlikely in view of the development of the 45-cm series. Maximum acquisition range was 585 m [640 yd: from the seeker ping rate], and maximum operating depth was about 300 m [984 ft]. This weapon used an active acoustic proximity fuze (frequency reportedly 650 kHz) similar to that of the contemporary French L 3.

This torpedo caliber first appeared in the Soviet fleet in the early 1960s on board Petya- and Mirka-class corvettes.

The 1990 U.S. release mentions E40-?, an electric dual-purpose straight-runner or acoustic homer for use by submarines and surface ships. This may be SET-40 or E40-75A.

◆ E40-75A

Dimensions: 400 × 4500 mm [15.9 × 177 in]
Speed/Range: 30 kt/14,000 yd **Warhead:** 100 kg
Power Plant: battery

The 400-mm torpedo is not nearly as ubiquitous in Soviet service as is the lightweight (324-mm) torpedo in the West. This torpedo is carried only by small corvettes (Poti and Pauk classes) and by the older light frigates (Mirka and Petya). The newer light frigates (Grisha and Parchim classes) carry 53-cm weapons. That allocation may imply that the 40-cm torpedo has never been altogether satisfactory.

◆ 40-?

Dimensions: 40 cm × 3.5 m [16 × 138 in]
Weight: 850–950 kg [1873–2093 lb]
Speed/Range: 35–40 kt/7 nm (endurance 10–12 min)
Power Plant: seawater battery

This torpedo, developed in the mid-1970s, was described by a Soviet émigré. It was intended as the SS-N-16 payload (Project Vodopod) and also as an SS-N-14 payload (Project Veter) and as an air-dropped torpedo, for bombers (presumably Bear Fs, as Project Orlan). The impetus seems to have been Project Vodopod, which the émigré stated had been inspired by the appearance of U.S. submarines capable of diving to 400 m [about 1300 ft]. The émigré understood that Vodopod was part of the initial SS-N-16 project. Tests were completed in the early 1980s, but the émigré did not know whether this torpedo, broadly equivalent to the U.S. Mk 44, entered Soviet service. Given the report that the Mk 46 and Mk 48 propulsors were compromised to the Soviets during the 1970s, it seems likely that the Soviets have developed a faster thermal, lightweight, homing torpedo, closer in concept to Mk 46.

The acoustic seeker operated at 12 kHz with a maximum range of 1200 m [1300 yd]; the acoustic proximity fuze had an effective range of 1.5–3 m. Operating patterns: loiter (circular run, using passive homing), active homing, and a straight-line run-out at assigned depth. Maximum depth was about 400 m. The émigré reported that the design of the on-board computer

incorporated LSI but that test weapons used discrete transistors. Integrated circuits were first introduced in a 1975 torpedo, Tamga, which the émigré stated had the first Soviet on-board computer guidance system. At this time a vacuum-tube torpedo, Sapfir, was still in service (although work on transistorizing its acoustics was proceeding). Neither Tamga nor Sapfir has been identified with any published Soviet torpedo designation.

The torpedo could be braked by either a conventional parachute or a rotorhute (diameter 2.5 m, with four 0.7-m blades).

The émigré reported that as of 1976, 2 experimental high-speed torpedoes were being tested. One ejected a special substance (probably a polymer) from openings near its nose. The other, undescribed, was presumably a quiet thermal engine.

◆ 40-79

Thermal torpedo for air and missile delivery, in effect the Soviet Mk 46. This is 1 of 2 current missile-torpedo payloads. Presumably, it was bought instead of the electric torpedo described above and embodies the Mk 48 propulsion technology compromised in the 1970s.

◆ RAT-52

Dimensions: 14 × 140 in (approx) **Warhead:** 200–300 lb
Range: approx 600 yd (in water)

This rocket-propelled antiship torpedo entered service in the early 1950s. It was exported to the PRC and possibly to other allied nations. RAT-52 was air-dropped from several thousand feet and guided by gyro once in the water. It had a contact fuze. RAT-52 tended to porpoise, to break up upon hitting the water at high speed, or to lose its heading. In effect it was the direct predecessor of the later antiship missiles since the bomber launching it could operate from beyond the conventional anti-aircraft range of the target. Effective range from bomber to target, most of it in the air, greatly exceeded the figure given above. RAT-52 was withdrawn from Soviet service in the mid-1960s but may survive elsewhere.

UNITED KINGDOM

◆ Mk 8**

Dimensions: 21 × 264.85 in **Weight:** 3452 lb
Speed/Range: 45.5 kt/5000 yd or 41 kt/7000 yd
Warhead: 805 lb (torpex)
Power Plant: burner-cycle (steam torpedo)

Although this straight-running antiship torpedo is no longer in British service, it was probably supplied to many other countries as the antiship torpedo to supplement a homing antisubmarine torpedo. Mk 8** was also the standard British MTB weapon. Like the U.S. Mk 14, therefore, Mk 8 may still be in service in some smaller navies. This weapon sank the Argentine cruiser *Belgrano* in the Falklands War in 1982, the guided Tigerfish not having a reliable antiship mode at that time. Current Tigerfish are dual purpose, so Mk 8** is no longer in British service. Moreover, the Royal Navy feels that Sub-Harpoon is a superior antiship weapon.

Normal depth setting is 40 ft; maximum depth is 200 ft.

Mk 8** first entered service in 1927, although the version used in the Falklands was improved. By 1927, torpedoes were fitted with magnetic proximity fuzes (compensated coil rod or CCR). After World War II the Royal Navy planned to use a modified Mk 8 propelled by hydrogen peroxide (HTP): Ferry, later called Fancy, which was issued in 1954. However, the basic torpedo design was ill-adapted to HTP, and the project was abandoned after the loss of the submarine HMS *Sidon* in 1955. The HTP documentation was sold to the Swedish navy, where the design became the basis of the Type 61 torpedo. In addition, a Trumper active-homing torpedo was begun using Mk 8's components, but work ceased at the end of World War II.

Presumably, the remaining Mk 8** (often called Mk 8 because earlier versions of this weapon are long gone) in service are carried by torpedo boats. Mk 9, the companion destroyer/cruiser weapon, is extinct. Mk 8** was the standard West Ger-

man torpedo-boat weapon before adoption of wire-guided torpedoes. Probable current torpedo-boat users are Chile (the *Gua-colda* class), Denmark (the *Soloven* class), Greece (the "Nasty" class and former German torpedo boats), Norway (the *Tjeld* class), Saudi Arabia (the German Type 141 class), and Turkey (the *Kartal* and the Type 140 class). This torpedo may also survive in Brazil and Chile on board *Oberon*-class submarines; it is being replaced by the dual-purpose version of Tigerfish.

◆ Spearfish

Dimensions: 21 in × approx 19.5 ft **Weight:** 1850 kg [4077 lb]
Speed/Range: see below **Warhead:** 300 kg [661 lb]
Power Plant: HAP-Otto fuel (pump-jet propulsor, turbine engine; HAP is hydrogen ammonium perchlorate)

Spearfish is a heavy dual-purpose wire-guided torpedo selected by the Royal Navy as the successor to the current Tigerfish, in preference to the U.S. Mk 48/ADCAP. Spearfish, being developed by Marconi Underwater Systems, reportedly incorporates some Stingray technology. Spearfish reportedly achieved a speed of 70.5 kt in a trial in a Scottish loch, but reportedly speed at depth is substantially less. Back pressure at depth substantially reduces turbine output (compared to the output of a swash-plate engine as in the U.S. Mk 48); therefore, the torpedo is designed to make its maximum speed at depth and naturally runs much faster at shallower depths. Reports suggest that the engine operates at 2 speeds, search and run-out/attack. An endurance of 21,000 m has been reported.

Reportedly, the seeker uses multiple receivers some distance from the acoustic transmitter, for better directivity. That report suggests that the receivers are arranged around the sides of the torpedo's nose. In 1981 it was reported that Spearfish accommodates 5 times the computing capacity of Stingray.

Feasibility studies were conducted in 1977–79, leading up to Naval Staff Target (later Requirement) 7525. Reported requirements were a maximum speed of 55 kt; a diving depth of 3000 ft; and significantly improved self-noise, acquisition range, and lethality compared to Tigerfish. Very broadly, the new torpedo combines Stingray's seeker technology with a new thermal power plant for high performance. As no such power plant had been developed in Britain, the U.S. firm of Sundstrand was approached to provide a monofuel turbine. Reportedly, early in 1980 Marconi decided to increase Spearfish's speed to meet the problem posed by the Soviet Alfa-class submarine. In 1981 Spearfish was competing with the U.S. Mk 48/ADCAP, which was then credited with a speed of 60+ kt; Spearfish's maximum speed is, therefore, probably somewhat higher, i.e., about 63 kt. This uprating was achieved by replacing pure Otto-II fuel with the current HAP-Otto combination, output increasing from 550 to 1000+ HP.

In 1981 it was reported that a typical Spearfish would run out at 28 kt (to avoid alerting the target) at a depth of about 50 m (launch at 200 m) under wire guidance, then would enter a low-speed glide (passive search). The torpedo might opt to attack the first target detected or to continue searching. The torpedo, once it has found a target, can switch to active mode and accelerate to high speed to attack. Marconi claimed in 1981 that in the active mode the torpedo would typically be able to measure the size and aspect of the target, and that this capability would make Spearfish very difficult to decoy, since a real target would not suddenly change size and shape. Such sonar

imaging would also, presumably, make it possible for the torpedo to choose to hit at an optimum point along the submarine's length.

In mid-1990 it was reported that a Spearfish had achieved 81 kt at shallow depth (the official figure was 75+ kt). Since the torpedo is much faster at shallow than at great depth, it may run out toward its target, under wire guidance, at such a shallow depth, then dive to acquire the target. Such operation would be the torpedo equivalent of an up-and-over shot in air defense.

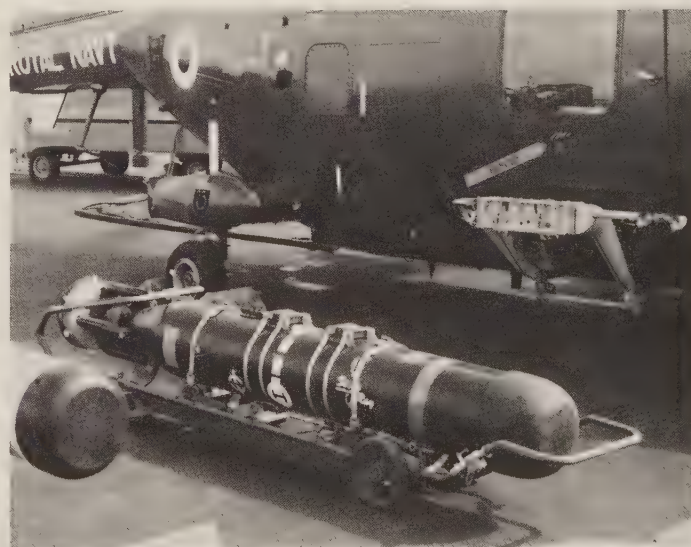
The decision in favor of Spearfish was made in 1980–81 (announced September 1981). It appears that Marconi offered a considerable savings if the Stingray and Spearfish programs were combined into a single British torpedo program. As of mid-1988, the production contract for Spearfish had been delayed because of proposals to include Dowty and British Aerospace as competitors. Tenders, which were to have been requested in mid-1989, were delayed to December 1989 to allow for competitive bids; the final bidders were Ferranti and Marconi. By the fall of 1989 the expected RN purchase was over 1000 (the earlier estimate was 770). Marconi manufactured 100 initial-production torpedoes.

As of mid-1990, the British Ministry of Defence was reportedly suspending orders (for up to 5 yr) in hopes that Spearfish would be adopted as a standard European weapon.

◆ Stingray

Dimensions: 325 mm × 2.6 m [12.75 in × 102.4 in]
Weight: 267 kg [588.5 lb] **Speed/Range:** 45 kt/8 km [8750 yd]
Warhead: 45-kg [99-lb] shaped charge
Power Plant: magnesium/silver-chloride seawater battery (pump jet)

The British replacement for license-built Mk 46s, Stingray was purchased in preference to the U.S. Mk 50. The manufacturer, Marconi, claims that Stingray is the first lightweight torpedo to incorporate a programmable general-purpose computer rather than a hard-wired special-purpose device. Stingray can,



Stingray torpedo (practice version) showing the pump jet just forward of the parachute housing. (Author)



The Marconi-Dowty Lightweight Test Vehicle (LTV), for a chemical propulsion system for a Stingray successor. Presumably, the nest of tubes near the tail of the torpedo constitutes the lithium-filled boiler, feeding the steam turbine just abaft it. The object forward of the boiler is the sulfur hexafluoride tank and pump. The front half of the torpedo is occupied by a computer, instrumentation (which replaces the warhead), and the sonar transducer in the nose. (Dowty)



Spearfish. The pump jet has a shroud. (Marconi)

therefore, be software-modified for different water environments and for different targets.

Homing is active acoustic, using dual frequency FM pulses and preformed beams. The torpedo can decide to switch between active and passive homing, using the latter mode, for example, if the target speeds up. The manufacturer, Marconi, emphasizes this ability to switch modes depending on circumstances, contrasting Stingray with a conventional torpedo that shifts between passive and active modes (if at all) using a preset homing criterion, or at a preset point. The seawater battery differs from most in recirculating its water internally, so that there is no external water scoop to make self-noise. The on-board computer selects a search mode. Target data can be compared to characteristics stored in the on-board computer, which calculates an interception path that takes into account the target's speed and maneuverability.

The seeker apparently uses preformed beams to search a considerable water depth very rapidly. Search is probably a snake pattern (rather than the helix of earlier torpedoes) at a single depth, since it is stated that the seeker can sweep the total water volume, from the surface down to maximum depth.

Stingray runs at a single speed (approximately equal to Mk 46's maximum speed), so Stingray can optimize its acoustic signature for a combination of maximum speed and maximum acquisition range. In March 1981 the torpedo was credited with depth performance equal to that of an Alfa-class submarine, presumably about 800 m. The torpedo is negatively buoyant: to avoid crashing into the bottom, Stingray must achieve substantial speed (for maneuvering) very early. The torpedo, therefore, starts up quickly upon hitting the water, and the rudders are located in the wash of the propeller for immediate effectiveness. Reportedly, Stingray can pull out of its initial (air-drop) dive in less than 4–5 sec, to avoid hitting the bottom in shallow water. There are alternative search patterns for deep and shallow water, and alternative broad- and narrow-band active ping options, presumably corresponding to long-range narrow pulses vs. shorter-range doppler.

As Stingray closes on a target, it uses highlights in the target's sonar image to measure target speed and aspect. Presumably, it employs proportional navigation (since it measures target speed). The terminal maneuver is a sharp turn into the target, to hit at right angles for maximum shaped-charged effect.

In shallow water, Stingray runs at a fixed height above the bottom.

Stingray uses a pump to recirculate hot, partly spent electrolyte; controlled amounts of cooled seawater are also run into the battery. The reaction inside is highly nonlinear and, therefore, difficult to control, but by varying the 2 factors, battery output can be varied to meet changing motor and acoustic requirements. The battery takes about 1.5 sec to fill with water and start after the torpedo enters the water. However, if the torpedo enters at too shallow an angle, the battery does not fill quickly enough, and the torpedo, which is tail-heavy when not filled, may porpoise.

When Stingray was offered in 1981, the U.S. Navy found the torpedo's speed unacceptable. Gould offered an alternative electric variable-speed power plant with a maximum speed of 62 kt. That figure may indicate the sort of performance expected of the current U.S. Mk 50.

Stingray came into service after the purchase of a long series of U.S. lightweights. The Royal Navy designed a heavy air-dropped torpedo, Mk 30 (Dealer B), but had to abandon it when the Gannet airplane was dropped in favor of ASW helicopters, which could not lift so heavy a weapon. Instead, the U.S. Mk 43 (now extinct) was bought, while a Mk 31 lightweight (proposed 1970) was developed. Mk 31 in turn was canceled in 1971, and the Royal Navy bought Mk 44 and Mk 46 Mod 2. At present the Royal Navy uses Mk 44 for shallow water and the Mk 46 for deep water.

Stingray studies began in 1964, the NSR 7511 staff requirement being issued in June 1968. It included shallow-water (presumably, for the continental shelf of the North Sea) capability.

Marconi received a contract for a seeker feasibility study in August 1969. The company apparently proposed something more, a torpedo that would modify seeker operation as it ran and that would be adaptable to a very wide range of water conditions. A design contract followed in 1977, and a production contract was expected in 1980. However, at that time the British defense budget was under pressure, and Mk 46 Mod 5 (NEAR-TIP) was suggested as an alternative. Stingray was selected instead; the stated reasons were that the U.S. torpedo had less effective homing, that its blast warhead was less effective than Stingray's shaped charge, and that Mk 46 Mod 5 could not operate in shallow water.

Production began in April 1981, with orders for 280 and then for 550. Some Stingrays were sent to the South Atlantic in 1982 (HMS *Antelope* had 4 on board when she was sunk), but they were not used. The torpedo officially entered service in 1986; the British government placed an order for 2500 Stingrays in January 1986. On 19 October 1985, in its first live-warhead test, a Stingray dropped from a Nimrod aircraft destroyed a double-hulled submarine, HMS *Porpoise*, moored at a depth of 65 m in the Mediterranean. Total running time to the target was about 3 min. The extent of damage to the submarine seems to have been surprising. The torpedo was expected to cut a small-diameter (albeit fatal) hole in both hulls, after which the submarine would have been raised for examination. Instead, it was so completely destroyed that it could not be raised. This result may indicate the power of all current lightweight torpedoes equipped with warheads made of modern explosives.

Several improved versions have been suggested. In 1981 a possible Mk 2, incorporating Spearfish's seeker technology, was mentioned. More recently a new version powered by the sort of closed-cycle engine used in the U.S. Mk 50 (Barracuda) has been proposed. There have also been suggestions that the Torpex warhead be replaced by PBX 104, a more powerful plastic-based explosive used in U.S. weapons.

About 1988 a U.S. estimate of the unit cost of this torpedo was \$440,000. Current export customers are Egypt, Norway, and Thailand.

Toward the end of Stingray's development program, Marconi analyzed a variety of alternative propulsion systems, both electric and thermal. The company proposed construction of a series of Fast Lightweight Test Vehicles (FLTVs), to be powered by the type of closed-cycle SCEPS plant employed in the U.S. Mk 50. In 1985 the British Ministry of Defence placed a contract with Dowty Fuel Systems for a land-based demonstrator, and by 1989 construction was well advanced; completion of a plant packaged for torpedo use is scheduled for 1991. The Ministry then asked Dowty and Marconi to submit a proposal for a torpedo test unit, and a development cost plan was submitted on 26 August 1988. Marconi proposes a Lightweight Test Vehicle (LTV), presumably using a modified Stingray hull.

◆ Tigerfish (Mk 24)

Dimensions: 533 × 6464 mm [21 × 254.5 in]

Weight: 3420 lb **Speed/Range:** 35 kt/23,000 yd; 24 kt

Warhead: 750 lb (magnetic proximity fuze for surface targets; impact fuze for submarine targets)

Power Plant: twin silver-zinc batteries (2-speed motor)

Tigerfish began in 1959 as Project ONGAR, for a faster and more sophisticated antisubmarine torpedo. An order for 100 was placed in 1967 with the Royal Navy Torpedo Factory (RNTF). ONGAR was a 2-speed electric torpedo with wire guidance and a passive terminal sensor. Because the torpedo was heavier than water, it used retractable wings to provide lift at low (search) speeds and also to improve roll control. Acceptance trials in 1969 were so unsuccessful that a special Torpedo Project Executive was established, and the contract transferred to GEC. The wide-beam seeker (which had large nulls in its beam pattern) was the major problem. Marconi was asked to design a new narrow-beam seeker and a more powerful on-board computer that could take over more of the guidance role. Marconi was also asked to develop a second version, Mod 1, with an



Tigerfish. This torpedo uses propellers. (Marconi)

antiship seeker. This effort also encountered problems, this time in the interfaces with the shipboard tactical-data systems and with actual torpedo control. RNTF was closed, and production passed to Plessey.

In 1973-74 a second series of trials showed that the weapon could perform as expected but that overall the system's reliability varied wildly, from 20% to 80% (40% average). The torpedo depended very heavily on data provided by the submarine but tended to dip and snap its guidance wire after being launched. In 1974 the overall production contract passed to Marconi since the major problem was not the hull of the torpedo but rather its control system (which had been Marconi's responsibility from the start). A redesigned Mod 1 passed trials in 1978, but the main version, Mod 0, was still unsatisfactory. It failed provisional fleet acceptance trials in 1979 but was issued to the fleet beginning in August 1980.

In 1982, 2 of 3 Mod 1 torpedoes fired at the burnt-out hulk of the LSL *Sir Galahad* did not hit because their batteries failed.

In 1983 the controller of the navy awarded Marconi a contract for a Mk-24 Consolidation (i.e., get-well) Program. In 1985 test shots showed a satisfactory 80% reliability. Part of the get-well program was replacement of the existing wire dispenser with a pair of dispensers, one on board the submarine. Demonstrations have shown that, with this dispenser, the submarine can evade after firing without breaking the guidance wire. Some Stingray technology has also been incorporated into the modified weapon, Mk 24 Mod 2, and all 600 war-stock Mk 24s had been modified by 1987.

This weapon replaced the earlier Mk 20E (Bidder), a dual-purpose passive-homer that entered service in the mid 1950s on board both frigates and submarines (1810 lb, 196-lb warhead, 20 kt/12,000 yd). The surface version was abandoned because its preset attack data system proved unreliable. No British surface ASW torpedo was available until 1964, when Plessey began to deliver license-built U.S. Mk 44s. Mk 20E remained in submarine service through 1970. Mk 22 was an abortive wire-guided version of Mk 20; VSEL produced a private-venture version in 1970. Mk 23 (Grog) was a modified Mk 20 with a wire-guidance section between the battery compartment and afterbody, issued from 1970 onward as an interim torpedo pending the appearance of Mk 24 (2000 lb, 28 kt/8750 yd).

Tigerfish typifies the European type of antisubmarine torpedo, operating passively at relatively low speed to avoid alerting the targeted submarine. For example, in 1981 it was reported

that Tigerfish was 15-20 dB quieter (in self-noise) than Mk 48. Passive approach died because many submarines themselves became too quiet to be detected passively. Once torpedoes approached actively, they had to be able to catch an alerted target: hence the high-speed Spearfish.

Tigerfish Mod 1 (dual-purpose) has been supplied to Brazil. Mod 2 is the improved British version currently under development.

In 1990 Cardoen of Chile obtained a license to manufacture Tigerfish, initially for the Brazilian, Chilean, and Venezuelan navies.

TORPEDO LAUNCHERS

◆ Submarines

Strachan & Henshaw has been the prime submarine torpedo-tube contractor since 1972.

Until 1945 the Royal Navy used HP air directly to fire its torpedoes. Postwar the RN began to use its submarines for ASW, and they had to be able to fire at well below periscope depth. The navy, therefore, adopted dual-pressure gear, in which lower-pressure air was used for control, and the limited supply of HP air used exclusively to eject the torpedo. This system was installed in modernized submarines and also in the new-construction *Porpoise* and *Oberon* classes.

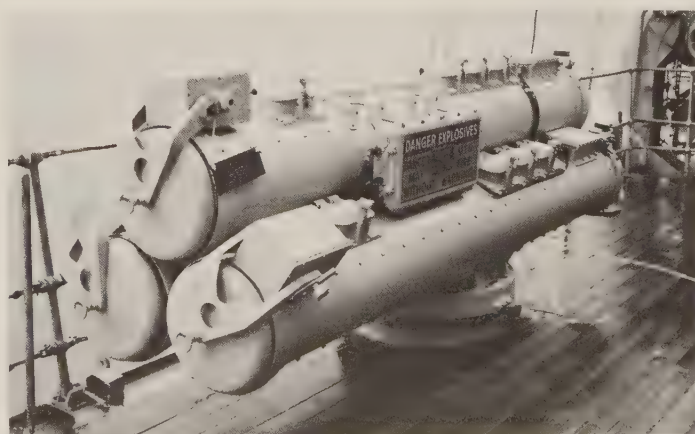
HMS *Dreadnought* introduced the U.S.-type water-ram system, which is independent of depth. HP air pushes a piston, which in turn pushes a water piston that pushes water into the torpedo tube. The next stage is to use a rotary (water) pump, driven by an air turbine, as the prime mover. This is more compact than the earlier water-ram system and has been, therefore, adopted in the new British *Upholder*-class diesel-electric submarines. This system is also used by the Dutch navy, and it has been adopted for the Australian Type 471.

SURFACE SHIP SYSTEMS

◆ STWS Series

STWS-1 is an underwater weapons system including an adapted U.S. Mk 32 torpedo tube, firing Mk 44 and Mk 46 torpedoes only. Normally, AIO target data are fed into the STWS, but it can also take sonar data directly, and data can be fed in manually in a backup mode. Operating modes: manual, aided manual, automatic. In the automatic mode STWS-1 uses sonar data to compute an FCS solution, which may take time. Hence the provision for a manual mode for snap-shots. In the aided manual or automatic modes, STWS displays the course to steer to get to the point at which a torpedo will be within acquisition range of the target, and it also shows the distance to run to the firing point. The PWO (Underwater) selects which torpedo to fire (STWS-2 carries both Stingray and US) and the torpedo search-pattern parameters (range, depth, course).

STWS-1 appeared about 1975, in effect as a replacement for the Limbo long-range mortar. It was installed on board the Type



STWS-2 on board HMS *Glamorgan*, 1985. (R. Cheung)

42 missile destroyers, the Type 21 frigates (installed after completion), and the Ikara, Exocet, and Sea Wolf *Leander* frigate conversions. It also equips the first 2 Type 22 frigates (*Broadsword* and *Battleaxe*).

STWS-2, which can fire the Stingray torpedo, appeared in 1981 on board Type 22 frigates. It incorporates the PMW49A triple torpedo launcher, which carries 4 prominent hatches and a control box (muzzle to breech) on each tube. The foremost hatch (No. 1) contains the Stingray lanyard solenoid unit. Hatch No. 2 contains the Stingray battery port cover remover. Hatch No. 3 contains the Mk 46 lanyard solenoid unit, and Hatch No. 4 contains the plug puller unit. Large boxes between Hatches 1 and 2 are distribution boxes. A pipe running along the length of the upper tube is the charging hose (torpedoes are fired pneumatically, from air flasks locked into the tube breeches). Torpedoes are fired when the tubes are trained 45 deg from ahead. There is a training handle at the breech end of the tube, although tubes are normally trained remotely. Muzzle doors are electrically operated, with a box at each muzzle.

STWS-3 is currently under contract.

◆ MTLs

Magazine Torpedo Launching System, for the new Type 23 ("Duke" class), supersedes the STWS series. MTLs is located inside the hull for better weather protection and for minimum torpedo handling. The torpedo is launched directly from the magazine space, necessary settings being fed in from the operations room via the ship's data bus. By colocating the launcher with the magazine, MTLs also serves the helicopter hangar. This arrangement was first tried in the U.S. *Knox* class, whose design was also an attempt to reduce manning. MTLs is manufactured by J&S Marine.

UNITED STATES

The current standard submarine torpedo caliber is 21 in; 19-in weapons were developed only so that they could swim out of 21-in tubes using air ejection (i.e., limited in firing depth). However, the new *Seawolf*-class will have 30-in tubes (the prototype is being installed on board the submarine *Memphis*). The increased caliber will permit silent (i.e., swim-out) firing of existing weapons, but presumably a 30-in weapon is planned. Greater diameter would make for much better acoustic performance since the area (and, therefore, presumably the gain) of the nose transducer would be about doubled. A 30-in torpedo might also enjoy a more favorable length: diameter ratio, for better hydrodynamic performance.

It was reported in mid-1989 that work had already begun on the new 30-in torpedo. The reported goal is a very quiet torpedo capable of loitering while listening, then striking, similar to Tacit Rainbow. The new weapon is intended for very long stand-off distances (equivalent to OTH-T in antiship operations).

In September 1990 Honeywell announced that it was spinning off most of its defense divisions, including the torpedo division, into a new company, Alliant.

◆ Mk 14 Series

Dimensions: 21 × 246 in **Weight:** 3209 lb
Speed/Range: 31.1 kt/9000 yd or 46 kt/4500 yd
Warhead: 643 lb **Power Plant:** steam turbine

Mk 14 was the standard U.S. submarine torpedo of World War II, remaining in use through the 1970s. Mk 14 was probably supplied to many Allied navies on board ex-U.S. submarines, and some of these torpedoes may remain in service. Although early Mk 14s had magnetic exploders, all surviving examples are contact-exploded.

About 13,000 Mk 14 torpedoes were manufactured during World War II (with others built prewar), together with 9700 of the simpler 1-speed Mk 23 version (46 kt only). Mk 14 was declared obsolete in the late 1950s or early 1960s, when U.S. submarines were all assigned to the ASW role and when the hydrogen-peroxide Mk 16 became available in quantity to provide the few antiship weapons required. However, Mk 14 was

reactivated in 1969 and was withdrawn again only as dual-purpose Mk 48s became available.

Mk 16 was never exported. Over 1700 were made postwar and remained in service until 1975. Mk 16 was the same size as Mk 14 (though it weighed 4000 lb), but hydrogen-peroxide propulsion enabled Mk 16 to achieve 11,000 yd at 46.2 kt and to carry a 746-lb warhead. The final version was Mod 8.

◆ Mk 15 Series

Dimensions: 21 × 288 in **Weight:** 3841 lb
Speed/Range: 26.5 kt/15,000 yd or 33.5 kt/10,000 yd or 45 kt/6000 yd
Warhead: 825 lb
Power Plant: steam turbine

Although no longer carried by U.S. destroyers, Mk 15 is probably the torpedo fired from surviving ex-U.S. quintuple surface tubes in ships transferred abroad.

About 9700 Mk 15 torpedoes were manufactured in 1940–44.

◆ Mk 37 and NT37 Series

Dimensions: 19 × 135 in **Weight:** 1430 lb
Speed/Range: 26 kt/10,000 yd or 17 kt/23,500 yd
Warhead: 330 lb **Power Plant:** battery

Data apply to Mk 37 Mod 0.

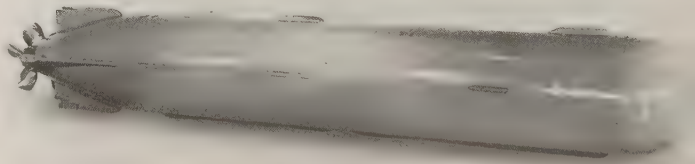
Mk 37 was the standard U.S. submarine-launched antisubmarine torpedo of the 1960s, and it survives in many other navies. For example, the Argentine submarine in the Falklands fired a Mk 37 at a supposed (and almost certainly false) British submarine contact. Design began in 1946. Evaluation of the first pilot lot (30 torpedoes, 1955–56) led to the first production order (for 90). Mk 37 was accepted into service in 1959. In U.S. service, it was superseded by Mk 48. Mk 37 was always a single-purpose torpedo because it was too slow to catch fast surface ships, and because its homing system was ill-adapted to passive operation against surface targets. It was also too slow to deal with nuclear submarines; hence the urgent development of the much faster Mk 48. In recent years Honeywell has offered kits to convert Mk 37 into various versions of NT-37 (see below). The Mod 1 version was the first major U.S. submarine wire-guided torpedo.

Operating modes are predicted-intercept, corrected-intercept (i.e., mid-course corrected run), and bearing-rider (see the discussion of the Mk 101 FCS as modified with angle solver Mk 18). Homing can be active or passive or a combination. The torpedo follows a preset horizontal search pattern to circle left or right or to snake. Vertical search can only be upward from the running-depth ordered, within preset limits. Speed is preset as high or low.

Versions:

Mod 0 Original free-running passive/active version (1957). It was carried by submarines. It was also the version carried briefly by FRAM II and *Forrest Sherman*-class destroyers, and exported for some foreign surface warships. Attempts to adapt U.S. forward-firing surface-ship tubes to fire the wire-guided version of the torpedo were unsuccessful. Hence the attempt to use stern tubes in the transoms of frigates. Dimensions: 19 × 135 in (1430 lb, 330 lb HBX-3 warhead). Range: 23,500 yd/17 kt, 10,000 yd/26 kt. The torpedo could also combine periods at both speeds. Depth limits: 4–1000 ft. Trajectory: snake or circle search under gyro control followed by helical search in depth.

Mod 1 Wire-guided version, resulting from a performance and reliability program begun 1958, followed by a development con-



Mk 37 torpedo. (U.S. Navy)

tract awarded to Vitro in June 1959. BuOrd awarded a development contract to Vitro. Final subsurface demonstration shots were fired by *Gudgeon* and *Blenny* in August and October 1960, and the above-water version was installed on board the destroyer *Robert K. Huntington* (DD 781). The internal wire reel is housed in an extender section between the afterbody and the tailcone. The effect of lengthening the torpedo to 161 in is to reduce its speed to 15.8 or 23.8 (high-speed setting) kt. There was only enough wire to guide the torpedo to 13,500-yd range. The torpedo accepts course changes in 2 deg/signal increments, and it can be command-enabled. It sends status signals (fin velocity switch activation, enable acquisition, and loss of target) back down the guidance wire. Guidance modes were bearing-rider and corrected-intercept. This version had a new helical snake search pattern for use when water depth was greater than 150 ft, allowing for a sinusoidal path both in depth and in the horizontal plane. This path varies azimuth by 2700 ft and depth by 1000 ft (the previous version had searched a 550-ft interval in depth). This version also had provision for laminar point steering; the laminar point is used in fire control computation of torpedo position, rather than body coordinates, in order to optimize acoustic acquisition. The laminar point is a point within the acoustic envelope located on an imaginary centerline, forward of the actual torpedo position, about which maximum search coverage is obtained. Enable range was 300–9500 yd. Acquisition range was 700 yd. This version was carried by many U.S. and foreign submarines. It (or Mod 2) was planned for the U.S. *Garcia*-, *Brooke*-, and *Knox*-class frigates; it would have been fired out of their transoms. This arrangement seemed necessary to allow the guidance wire to pay out properly. A few ships actually had the tubes installed, but they were soon removed. Long transom tubes for homing torpedoes (in some cases, for Mk 48) were a feature of many U.S. destroyer and frigate designs of the 1960s. Mod 1 was adopted in place of the less-flexible wire-guided Mk 39 Mod 1, a pure bearing-rider, running out at 50-ft depth (and then using its 24.5-kHz passive seeker). Mk 39 was also slower (13,000 yd/16 kt) and had a smaller warhead (130 lb of HBX-3). It was restricted to 10–100-ft depth.

Mod 2 Wire-guided version developed from Mod 1. This is the submarine-launched version that survives in foreign navies. Torpedo length is 161 in, weight 1690 lb. A 2000-torpedo 3-yr conversion program delivered the first Mod 2 in March 1967. About that time it was decided that all Mod 0 and Mod 1 torpedoes would be converted to the new configuration. The major improvements were increased acoustic acquisition range at deep depth, reduced susceptibility to surface-seeking at shallow depths, improved shallow-water performance, and better reliability and maintainability. Mod 2 used a new ceramic transducer in place of the previous magnetostrictive one; the magnetostrictive unit lost sensitivity at greater depth (Mod 2 was rated at 900+ yd at 900 ft compared with 400–500 yd at that depth for Mod 1). The shallow-water homing improvement was to discriminate against reverberation at close range, where most spurious reflections are to be found. The torpedo could be set to run at constant depth (40, 100, 150, or 200 ft) while homing (before terminal maneuvers), when above 100-ft depth in deep water, or when in shallow water. It was provided with preset operating depths of 200, 150, 100, and 40 ft for shallow water. The anticapture (anti-surface-homing) circuits were disabled when the torpedo ran below 200 ft in deep water or when it was homing passively. The anticapture feature was tested in 1966.

Mod 3 Refurbished Mod 0 (free-runner) specifically for the Spanish navy's *Baleares*-class frigates, fired out of tubes in their transoms. Each ship carries 12 torpedoes.

A Mk 37 improvement program begun at NUSC Newport in 1971 led to test runs in December 1973. This project presumably competed with the Northrop/Honeywell NT-37 program. NUSC fitted a new high-density battery, a more powerful motor, and new quieter propellers, as well as a new homing panel to improve performance against streamlined submarines (with

their reduced sonar cross sections). NUSC claimed greater active-mode sensitivity against valid targets without any increase in the false-alarm rate. The new propellers, more steeply raked than their predecessors, lengthened the torpedo by 3 in. It is not clear to what extent the NUSC program was actually implemented.

In 1968 Northrop Corporation began work on improvements to Mk 37, in cooperation with the Naval Torpedo Station at Keyport, Washington, replacing the existing silver-zinc battery with the Otto fuel engine of a Mk 46-1. Speed increased by 40%, and range by 150%. For a service modified torpedo (NT37C), the published figures are 40% greater speed, 125% more range, and about 80% more endurance.

Northrop carried the Mk 37 conversion program through about 1980, when this activity was transferred to Honeywell. The designation of the modified torpedo, NT37, still reflects the company's involvement.

The program was approved in 1968, and acoustic improvement tests began in 1969. Tests of the NT37C systems were conducted in 1970, followed by tests of the submarine systems in 1971, preproduction and production verification in 1972, and certification of readiness for service in 1973 (NT37C version). Improvements included not only the enormous increase in speed and range but also true dual-purpose capability: because NT37C was so fast, it could duplicate the straight run of, say, a Mk 14. NT37C can be set in 3 modes: (i) straight running at high speed with depth control; (ii) delayed homing, the torpedo running straight but searching if it misses (or beginning its search at a preset range); (iii) full passive homing, as in the original Mk 37. By 1977 NT37C was in service in several NATO and South American navies, and in February 1976 Norway ordered kits for conversions of its Mk 37s.

The next step was a new homing head. NT37C plus the new acoustic system is designated NT37D.

NT37D plus a new guidance system, the fully modernized torpedo, is NT37E. It incorporates a self-noise-reduction nose assembly (with baffling to protect the transducer from engine and hull noise, and with a new nose shape to reduce flow noise), a solid-state acoustic panel (to replace the vacuum tubes of the original Mk 37), and a new digital (vice analog) autopilot. In one version, the autopilot can be programmed to navigate the torpedo to specific geographical coordinates. Honeywell claims that these modifications double the active detection range and nearly double the passive detection range against fast targets, partly because with less flow noise the acoustic system can be made more sensitive (the company cites test results that showed an improvement of 50–90% in the active target-acquisition range, and of 100–200% in the passive target-acquisition range). The company also claims better performance at higher speed and in shallow water, in both cases thanks to noise reduction. On a subtler level, Mk 37 tactics are fixed; NT37 tactics are programmable and, thus, less easily predicted.

The new nose and acoustic panel were first tested in 1980, developmental and operational tests of NT37E following in 1982 and 1983. In 1980 Canadian/Norwegian/Dutch trials on the *Nanose* acoustic range showed a 71% success rate in 17 runs; an operational evaluation in the North Atlantic showed 88% success in 8 runs. Operational demonstrations in 1981 showed 100% success in 18 runs. Canadian guidance-and-control trials in 1982 (*Nanose* range) showed 100% success in 5 runs.

NT37F is the main current (1990) Mk 37 upgrade version. The principal change is some guidance improvement. Compared to Mk 37, NT37F achieves 40% higher speed, 125% longer range, and 100% longer shallow-water passive and active detection ranges (a diagram shows about 90% longer passive-detection range). Special baffling and a new nose shape protect the sonar transducer from engine and hull noise at high speed and near the surface. The fixed analog logic of the original Mk 37 is replaced by a digital programmable control system. Additional antiship run patterns are added to the control system. The manufacturer claims that major service work is reduced from an 18-

month cycle to once every 6 yr, partly through the introduction of a self-testing acoustic panel and a more reliable control system.

NT37G is a next-generation torpedo (rather than a modernized Mk 37) with a larger warhead, a proximity fuze, and increased speed (a modified engine).

Given the large number of Mk 37 produced, Honeywell (which currently has rights to NT37) has offered foreign customers a variety of modified versions in an NT37 series; these modifications could be applied to existing torpedoes. Honeywell also offered a modified Mk 37 for the abortive U.S. requirement for an inexpensive surface-only torpedo (see Surface Torpedo below). By late 1983, about 500 torpedoes in 5 navies had been upgraded to NT37C configuration.

Mk 37 was supplied to at least 16 navies. As of 1986, NT37C was in service with the navies of Canada, Israel, the Netherlands, Norway, and Peru.

Mk 37s have also been rebuilt both as Submarine-Launched Mobile Mines Mk 67 and as Standoff Weapons Mk 32. For details of Mk 67, see the Mine Warfare section. The standoff weapon is intended for use from SEAL Swimmer-Delivery vehicles Mk IX, to attack surface ships in harbors. The standoff weapon was introduced into fleet service during FY87. (The SEALs also have both limpet mines and Underwater Demolition Weapon EX-33, a 1200-lb charge that can be laid under major or nested ship targets in harbor.)

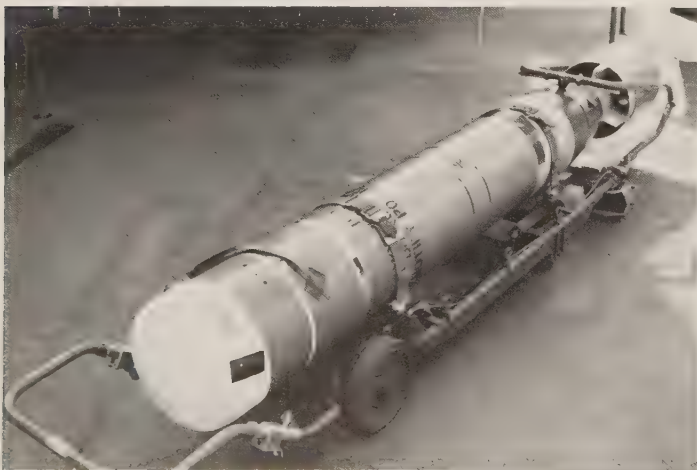
◆ Mk 44

Dimensions: 12.75 × 100 in **Weight:** 425 lb
Speed/Range: 30 kt/6000 yd **Warhead:** 75 lb
Power Plant: seawater-activated battery (30-HP motor)

Data are for Mod 0. Mod 1 is 101.3 in long, 433 lb, with a 73-lb warhead.

Mk 44 was formerly NATO's standard lightweight homing torpedo, the payload for which ASROC and Ikara were designed. Development began about 1952 and was completed in 1956. Production began in July 1958, with first delivery in FY60. Mk 44 was designed primarily to attack submarines with speeds of up to 17 kt (i.e., postwar diesel-electric types); it replaced the 15- or 21-kt Mk 43.

Mk 44 is a pure active homer, with an acquisition range of 1000 yd (max; 650 yd average). This compared to 800 yd (max) for the previous lightweight homer, Mk 43. Maximum homing range is 3000 ft. Operating depth is 50–1000 ft. Prelaunch fire-control settings: mode (surface or air/ASROC), initial search depth, search floor, and shallow or deep dive angle. The search pattern is helical, with a sink rate of 25 ft/sec and a 440-ft diameter. Initial search depth is 50, 150, 250, 450, 650, or 900 ft; search floor is preset at 150, 250, 450, 650, or 900 ft. After a runout or initial dive (at a 30-deg angle), the torpedo may execute a flat search turn at the initial search depth; it then runs



A Mk 44 torpedo on board HMS *Invincible*, 1984. The parachute pack is immediately abaft the shroud used to control the torpedo. (R. Cheung)

through the helix at a dive or climb angle of 4.5 deg, executing a flat turn at the bottom after a 6- or 7-deg dive, and then climbing back up (with an initial climb angle of 6 or 7 deg). It continues up and down along the helix until it exhausts its 6-min endurance.

Mod 0 has no run-out feature; Mods 1, 2, 3, and 4 run out about 1000 yd before beginning a helical search.

In U.S. service, Mk 44 was replaced by Mk 46 from about 1967 on, but many Mk 44s remain in service in foreign navies, and the U.S. Navy probably retains a large stockpile. A total of 10,583 Mk 44 were made in the United States under the FY59–65 programs (the last was delivered in December 1967), and this weapon was also manufactured in Canada, France, Italy, Japan, and the United Kingdom.

In 1986 Honeywell offered a modernization kit for Mk 44. The existing nose was replaced by a new one incorporating ceramic rather than magnetostrictive transducers, in a planar array (rather than using an acoustic window). The planar array incorporates a preamplifier, and the analog transmitter and receiver of the existing Mk 44 are replaced by digital devices. Claimed improvements include an increase in MTBF from 160 to 3000 hr and a 75% increase in detection range; minimum shallow-water search depth is reduced by 47%. Volume search rate is tripled. Honeywell claims that the addition of a notch filter reduces boundary-layer attacks. A new range gate reduces acoustic false alarms. A new search mode is added for intermediate water depths.

◆ Mk 45F (Freedom Torpedo)

Mk 45F has been deleted because it was never sold (a sale to Turkey was aborted because of the 1974 embargo). For details, see the last edition.

◆ Mk 46

Dimensions: 12.75 × 100 in (15.3-in fins) **Weight:** 508 lb
Speed/Range: 12,200 yd/45 kt at 50-ft depth; 10,100 yd/45 kt at 1500-ft depth
Warhead: 96 lb of H-6
Power Plant: Otto-fuel piston engine

Data apply to Mod 1 as delivered (1968). Operating depth is 20–1500 ft, and acoustic homing range is 1600 yd maximum (1300 yd average) with a 30-kHz sonar. Mod 0: 568 lb, range 9500 yd at 50 ft, 7000 yd at 1500 ft (40 kt at 1500-ft depth).

Mk 46 is now virtually the standard NATO lightweight torpedo. In U.S. service it replaced Mk 44. Mk 46 is much faster, dives deeper, has 60% greater maximum acquisition range, and can be dropped at up to 500 kt.

The final Development Characteristic was issued in June 1956 for a torpedo to attack 30-kt (i.e., nuclear) submarines, with dimensions of about 15 × 98 in, and 50–1000-ft operating depth. A feasibility study was completed in December 1956, and a development contract was awarded to Aerojet in May 1958. The Mk 46 operational requirement was issued in November 1960, and production of Mod 0 began in 1963 (it entered service in 1964). As of 1960, the design requirements for Mk 46 included an acquisition range of 1200 yd and a maximum speed of 45–50 kt. Unlike Mk 44, Mk 46 would not have to conduct a helical search. Running horizontally at a depth of 750 ft, it could sweep out all depths down to its maximum of 1500 ft. In a technical evaluation (September 1962–June 1963) Mod 0 demonstrated 70% reliability and the ability to attack submarines with speeds up to 20 kt (computer simulations showed that it could attack at target speeds of up to 33 kt, but that could not be tested). Operational evaluation (April–November 1964), involving 172 firings, showed that acquisition probability in deep water without interference sources or countermeasures was 60% and that hit probability after acquisition was 77% against submarines and 88% against mobile targets; demonstrated reliability was 75%. The first Mod 1 production contract was issued in 1965, and Mod 1 (the first main-production version) was first tested in 1966.

Mod 1 evaluation (November–December 1965) demonstrated

that, if placed within acquisition range, the torpedo had an 86% probability of acquiring, attacking, and hitting a target. Compared to Mod 0, Mod 1 was intended for better reliability and maintainability and lower production costs, largely through introduction of a high-energy, liquid, monopropellant fuel (Otto fuel); Mod 0 was powered by a solid-fuel turbine. In addition, the tilting shroud ring used to steer Mod 0 was replaced by 4 movable fins. Mod 1 and later versions (i.e., all current versions) use a 5-cylinder swash-plate engine, with 2 power strokes per revolution. Otto fuel is ignited in a combustion chamber, and the resulting gas flows into the piston engine.

Mk 46 was designed for either active or passive/active operation; in the latter mode, the torpedo listens for target-radiated noise. If it receives none during a short preset time, it shifts automatically to active search. In addition, the vertical-search beamwidth is controlled by the onboard computer or autopilot: narrow for shallow water (and during the attack phase), to avoid bottom and surface reflections, and broad in deep water.

Initial information is entered into the autopilot, which turns on the computer once the torpedo has passed its preset enable distance. The computer in turn provides control signals and a time base. It controls the active sonar and interprets its outputs, setting a range gate. Once a range gate is set, 2 valid echoes in the gate are taken to verify that a target is present, and the computer begins to send pitch commands to the autopilot. The computer also carries the tactics for search and re-attack in the event that a target is lost or an attack fails. Comparison with later torpedoes, such as Murène, shows what the computer does not do: it does not track several targets simultaneously to decide which is worth attacking (and which is a decoy), and it uses preset tactics. The difference is presumably entirely a function of the much greater power of newer computers.

Prelaunch firing information includes homing mode, initial search depth, ceiling depth, search pattern, and course heading (some versions incorporate a floor depth, to avoid hitting the bottom). At least in the current Mod 5, information can be entered up to $\frac{1}{4}$ sec before launch, and there is no warm-up prior to firing.

The 2 primary search modes, snake and circle, contrast with those of earlier torpedoes, which searched in a helix, sinking or rising as they turned. Presumably, this change reflects Mk 46's longer sonar acquisition range, which provides a wider FOV at any depth. Surface tubes are generally programmed for snake search but can select circle under urgent or close-attack conditions. Aircraft and ASROC launches are automatically set for circle. Helicopter-launched torpedoes can be set to circle or snake. Initial depth is 1 of 6 options, depending on the depth and course of the target submarine. Operating ceiling is automatically set at 50 ft for surface-tube launch (so that the torpedo cannot attack the launching ship) but is selectable for other modes. Course headings are programmed only for snake search. There are 5 headings for a surface tube but 12 for a helicopter, so the latter can attack in any direction from the hover.

Upon hitting the water, Mod 1 could run out along a gyro-set bearing, or it could conduct a circular or helical search. When dropped from an aircraft or from an ASROC missile, it immediately began to search. It, therefore, had to be dropped almost directly over a submarine contact. Mod 1 was adapted to 2-helicopter tactics, 1 helicopter using its dipping sonar to vector the other.

About 1970 existing Mod 1 torpedoes had computer logic changes to improve their performance against slow and/or periscope-depth targets.

Other versions:

Mod 1 Phase 2 had improved capability in shallow water and against countermeasures. It had all of the Mod 2 improvements except HATS (see below). It and Mod 2 became available to the fleet in the latter half of 1971. At this time work began on a proposed much-deeper-diving Phase 3, with better countermeasures resistance, which could have been launched in water as shallow as 200 ft (i.e., which pulled out of its initial dive more

quickly). Phase 3 was probably conceived as an interim approach to what became Mk 50.

Mod 2 (1970) had additional computer logic improvements and a new autopilot. It could re-attack after losing a target or chasing a decoy. Mod 2 was specially adapted to a new single-helicopter attack system (HATS, the helicopter attack tactical system), in that the helicopter FCS could preset its search mode, search depth, and run-out bearing before firing. The torpedo, therefore, had 2 search modes, AIR/ASROC (search from water entry, as in Mod 1) and HATS (in which the torpedo ran out in snake mode). The autopilot was modified so that the gyro settings previously available ($0, \pm 35, \pm 70$ deg) were supplemented by $\pm 95, 120, 150$, and 180 deg so that the helicopter could launch while hovering into the wind regardless of target bearing.

Mk 1 and 2 equip numerous foreign navies, including those of Australia, Brazil, Canada, France, Greece, Israel, Italy, New Zealand, Spain, the United Kingdom, and West Germany. These versions were manufactured from 1965 through 1981.

Mod 3 was a version with control system improvements, canceled.

Mod 4 is a torpedo built specifically as a payload for the CAPTOR (Mk 60) mine.

NEARTIP (Mod 5, the Near-Term Improvement Program) was very nearly a completely new torpedo, employing either entirely new or greatly modified seeker (sonar transducer, transmitter, and receiver), guidance, and propulsion. Sonar improvements were intended specifically to counter submarines with anechoic coverings, specifically Soviet boats. The correlation channel used to determine whether sounds detected by the sonar were in fact echoes of the pulses it sent was improved, to make up for the reduction in signal-to-noise ratio caused by the anechoic coverings. The transmitted waveform was changed to make better use of target doppler for signal processing. Signal-processing logic was improved, particularly to reject false targets. At the same time, reverberation effects in shallow water were reduced, so self-noise could better be measured and disregarded. All operation is now digital, with improved stability and precision. Mod 5 incorporates an improved digital computer whose master clock times all torpedo functions. Improved search and re-attack patterns are stored in the computer's EPROM, for better countermeasures resistance (discrimination) and target acquisition and reacquisition. A second roll pendulum improves pullout from dives and is also better for shallow-water launch.

Finally, the torpedo's motor was modified to provide a second (lower) search speed. The lower speed reduced self-noise and, thus, increased the available signal-to-noise ratio at the torpedo's sonar processor. The slower speed also increased the total torpedo endurance (in terms of time) by 30–50%. Once the torpedo has locked onto its target it still attacks at the same sort of high speed provided by the original Mk 46. The fuze was revised to function even if the torpedo struck the target at a shallow angle.

The U.S. Navy introduced the first of 2 shallow-water modifications in 1984, to improve performances against slow submarines at periscope depth in both deep and shallow water. Normally such targets are difficult to engage because they provide little doppler (which the torpedo uses to distinguish them from background noise) and because the torpedo has difficulty dealing with reflection (both of its pulses and of its self-noise) from the surface. The modification apparently consisted of a more coherent transmitter and better steering logic.

Honeywell, the manufacturer, developed a further shallow-water modification of its own. The success of the program is presumably demonstrated by a photograph, recently published, of a surfaced submarine target hit by a Mk 46 Mod 5. The target may have been fitted with some noise source, but even so it presented all the problems of a surface-ship target. The torpedo's success suggests that it can be used in an alternative anti-surface ship mode so that, for example, torpedo-carrying missiles like ASROC can be employed against surface targets. Although these missiles are generally far slower and far less efficient than their specially designed antiship counterparts,

torpedo-carrying missiles have 1 interesting potential advantage: they may be able to drop their weapons outside the effective range of close-in weapons. These points would apply more strongly to fast submarine-borne weapons such as Sea Lance.

The warhead was also improved; it was a Mk 103 with PBXN-103 explosive.

Honeywell offers a retrofit kit to convert existing Mod 1 and Mod 2 torpedoes to Mod 5 standard. Presumably, this is the kit supplied to the U.S. and foreign navies. It is a third less expensive than a new Mod 5 torpedo. The kit includes a Mod 2 transducer for increased detection range against an anechoic-coated submarine (required only if a Mod 1 is to be upgraded to Mod 5 standard); a new receiver and transmitter for increased output and sensitivity, with valid-echo logic optimized to classify and reject false contacts (for effectiveness against slow, shallow targets); a new digital-computer control system, with new attack and re-attack logic; and a 2-speed valve for 2-speed propulsion.

Mod 5 requires overhaul at 4- and 8-yr intervals (engine tear-down every 4 yr).

Mod 6 (1989) is a slightly improved Mod 5 forebody with an existing Mod 4 afterbody, for use in Captor (Mk 60) mines.

NEARTIP began in October 1972, technical evaluation being completed in November 1977 and operational evaluation in February 1978. Production release was in May 1979, the initial contract being awarded in July 1979 (and the last in February 1987). Some Mod 5s were manufactured for the Dutch and British navies, and Mitsubishi manufactures this torpedo under license in Japan (coproduction approved July 1982).

About 1986 the U.S. Navy's reported objective was a total of 5500 Mk 46-5 and 3000 Mk 46-4 torpedoes. Total production, for FY80 and previous years, was 11,646 torpedoes. Purchases in later years were: 253 in each of FY81 and FY82, 440 in FY83, 1200 in FY84, 1565 in FY85, and then 500 each in FY86 and FY87. These figures do not include the torpedoes used in CAPTOR mines and may not include some export torpedoes. In FY87 the price per torpedo was \$195,322. In 1985 the navy proposed to end production of Mk 46 in FY88 (500 torpedoes). At that time procurement of 1521 had been scheduled for FY86, and that figure was cut to 500.

In 1987 it was reported that total Mk 46 production, including export weapons, had been over 17,000. That figure included about 1252 Mod 0 of 1963-65 (by Aerojet) and about 9200 Mod 1 manufactured 1965-69 by Honeywell. As of July 1989, Honeywell had delivered 20,000 Mk 46 torpedoes for the U.S. Navy and 23 foreign navies. Honeywell became second-source supplier in July 1965 and became single-source supplier in 1969. The 5000th Mod 1 was delivered in March 1967. The first NEARTIP contract, for 2706 kits, was awarded in February 1978. Contracts for another 5140 kits were let in 1979-83, and production was continuing as of 1989.

It was announced in November 1988 that Brazil was buying Mk 46 Mod 5 torpedoes for delivery in 1988 and 1989, and kits to update existing Brazilian Mk 46 Mod 2s. Mk 46 is currently operated by 23 navies.

(Below) Mk 48 Mod 4. (Westinghouse)



Mk 46 torpedo, showing its propeller shroud and parachute pack. (U.S. Navy)

◆ Mk 48/ADCAP

Dimensions: 21 × 230 in **Weight:** 3480 lb

Speed/Range: estimated 55 kt/35,000 yd

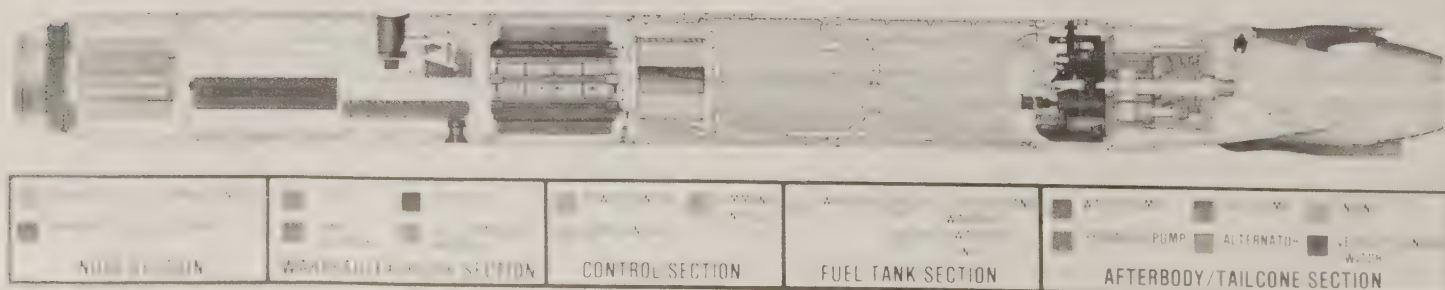
Power Plant: 500-HP Otto fuel swash-plate engine

Mk 48 began as a development of the RETORC II (Research Torpedo Re-Configuration) research program, which had been underway since 1956. Development characteristics for a new torpedo (at that time designated EX-10) were set in 1960, and tenders requested in May 1962. A project-definition contract was awarded to Westinghouse in 1964, with Sundstrand providing propulsion and Clevite (later renamed Gould) the acoustics; Clevite also received a backup contract for a separate homing system. At that time the existing Mk 37 was credited with only 10% effectiveness against a 20-kt submarine. The proposed Mk 48 was credited with 40% effectiveness against a 35-kt submarine, and work was accelerated after system tests on board the submarine *Permit* in the Pacific in 1964. In 1967-68 further contracts were awarded to modify the basic torpedo for antiship as well as antisubmarine use, the single-purpose Mk 47 antiship torpedo project having been abandoned. Mk 48 entered service in 1971.

Mk 48 is the current standard U.S. heavy torpedo. Mod 0 was a single-purpose antisubmarine torpedo, developed at high priority after 1964 tests showed very clearly that the existing Mk 37 could not successfully engage modern nuclear submarines. Mod 1 added antiship capability. Mod 1 and Mod 2 were competitive prototypes; Mod 2 (rejected) had a turbine engine, Mod 1 a swash-plate piston engine using Otto II (nitrogen ester with oxidant) fuel. Mk 48 differs from many other torpedoes in using a pump jet rather than conventional propellers for propulsion, a choice presumably made to provide very high speed without so much noise that the weapon would be unable to home, or that the target would be alerted soon enough to escape easily. Published illustrations of the new Mk 50, which is also very fast, show a similar pump jet.

The performance listed here is based on congressional testimony (in the 1970s) to the effect that Mk 48 has a range of 20 miles (presumably statute, not nautical) at "nearly twice the speed of Mk 37." Published figures more than a decade old suggest an acquisition range of 4000 yd (compared to 1000 for Mk 37) and a diving depth of 2500 ft. Mk 48 has also been described officially as the only U.S. torpedo capable of reaching the Alfa's depth, reported as 800 m [2624 ft]. It was reported in the 1980s that Mk 48's search speed was 40 kt, so presumably, the higher maximum speed given above is a run-out and attack speed.

Aside from the active and passive homing modes, there is a nonacoustic mode, presumably a straight or pattern-running



shot at a surface target, the only intelligent element of the torpedo being its fuze. Numerous published photographs showing Mk 48s blowing substantial ex-warships in half strongly suggest that the torpedo uses a standoff (proximity) fuze for under-the-keel explosion.

Mk 48's design emphasizes maintainability, with unit replacements (functional item replacements) to minimize repair time.

Mod 3 (1977) adds a 2-way (rather than 1-way) wire link (TELCOM), allowing the torpedo operator to exploit the torpedo's own sonar. TELCOM transmits 14 torpedo and target parameters once each second.

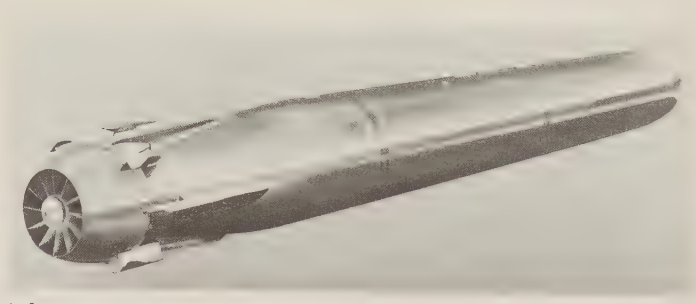
Mod 4 incorporates TELCOM as well as a fire-and-forget mode. Mod 4 was a transitional step toward ADCAP, and as of 1984 the U.S. Navy planned to buy 144 Mod 4s in both FY85 and FY86, ending procurement in FY86, and to begin production of all-up ADCAPs in FY87. Costing studies led to the decision to end Mod 4's production with 108 torpedoes in FY85 and to begin ADCAP production that year with 30 torpedoes (with 123 in FY86 and 280 in FY87). However, Congress disagreed, and ADCAP's production was actually slowed, so many conversion kits were procured instead.

Mod 5, a modification kit for existing Mk 48s, is an interim step toward the new ADCAP version.

ADCAP (Advanced Capability) is an extensively modified version capable of greater speed and endurance and incorporating a new homing device. When ADCAP was first developed, there was speculation that it should have received a new Mk number. It appears that Mk 49 was reserved for this purpose but that the Mk 48 ADCAP designator was preferred for political reasons.

The ADCAP program was inspired by tests that showed that the basic Mk 48 structure could operate at the depths achieved by the new Soviet Alfa-class submarine, and that targets could be recognized at the necessarily high torpedo speeds involved. The forward-looking sonar had adequate vertical coverage. The modifications involved were made in the Mod 4 version of the torpedo.

ADCAP provides sustained long acquisition range; it minimizes the effects of the submarine's operating envelope (speed and depth) and countermeasures; it minimizes tactical constraints imposed on the launching submarine (because of its higher speed and maneuverability); and it has increased antiship capability. Compared to the existing Mk 48, it has a new nose, including the transducer, the beam-former, and the signal processor. The new sonar is electronically steered, so the torpedo



Mk 48 torpedo, showing the pump jet. (Westinghouse)

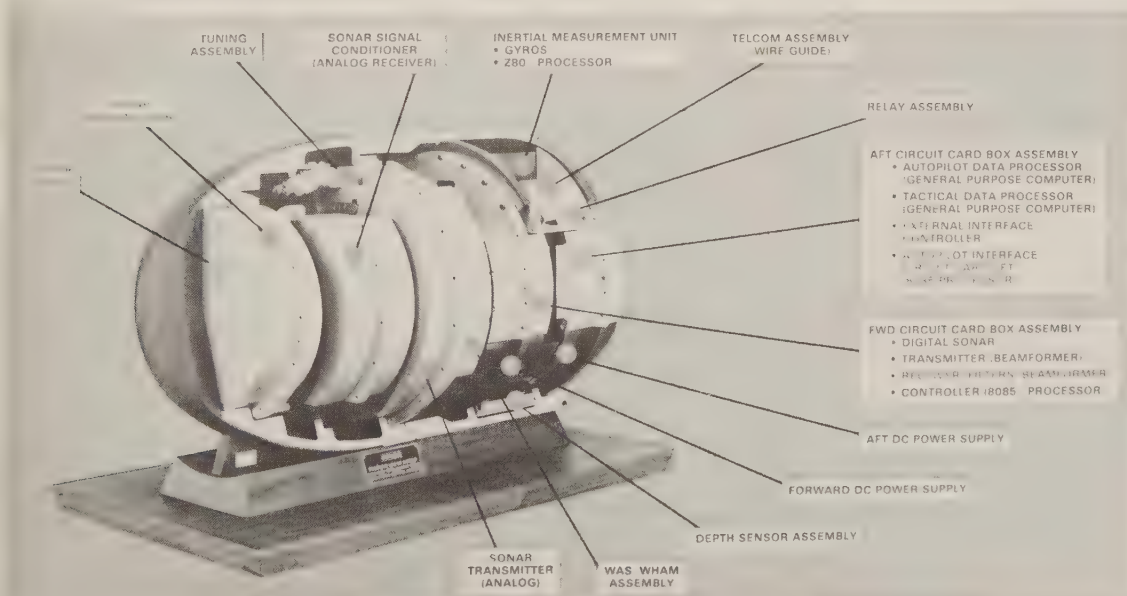
need not maneuver nor lose as much net forward speed as its predecessors as it approaches a target. Although ADCAP has the same swash-plate engine as its predecessor, the fuel rate is increased (and more allowance is made for speed variation). The torpedo carries more fuel, in space made available by a more compact computer.

The improvements were sufficiently extensive that a new designation, EX 49 (later Mk 49), was assigned in 1977. The development proposal for the new torpedo was issued in March 1975. The Mk 49 designation was formally assigned in 1984, but it was never used. Presumably, the use of the Mk 48 ADCAP designation was intended to justify a simplified development process, just as current electronic equipment often retains earlier designations despite radical improvements.

In 1981, in connection with the competition for the British heavy torpedo, ADCAP's speed was reported as 60+ kt. As a rule of thumb, a torpedo should be about 50% faster than its target. Thus the torpedo speed associated with a 42-kt Alfa-class submarine would be 63 kt (ADCAP has often been associated with the requirement to attack Alfas).

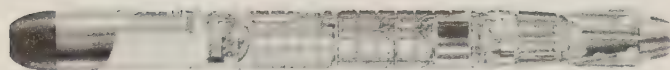
The ADCAP Operational Requirement was issued in 1975, an RFP following in November 1978. The program was accelerated in September 1979 in view of the demonstrated characteristics of the Alfa-class submarine. ADCAP went into advanced development in October 1979. Hughes received the contract to develop the torpedo's digital guidance and control electronics in August 1979. The first test run was made on the Canadian NANOSE range early in 1982, using an ADCAP inertial system. At that time it appeared that about 240 runs would be needed, continuing into 1983-84. However, development was protracted. In 1985 it was decided to accelerate production. The 1985 Five Year Defense Plan called for 1890 ADCAPs, and 123 were included in the FY86 budget. Production began in 1985. At that time the reported navy objective was 4659 Mk 48 torpedoes, of which 4000 had been funded through FY87; the cost per Mk 48 was then \$2,239,515. The

(Below) Mk 48 ADCAP's guidance section. (Hughes)





(a)



(b)

Mk 48 Mod 4 (a) and ADCAP (b). ADCAP has much greater fuel stowage, made possible by shrinking the size of the computer between the warhead and the fuel tank. (Westinghouse)

currently stated objective for ADCAP modification kits (for Mk 48 Mod 5) is 1062 (March 1988).

Production of Mk 48: 3059 were procured through 1980, then 144 in FY80, and the same number in each of FY81–84. Mk 48 procurement ended in FY85 (108 that year). Mk 48 has been exported to the Australian, Canadian, and Dutch navies; reported numbers are, respectively, 127 (1979), 48 (1985), and 100 (1980). The first near-term upgrade Mk 48 Mod 4 was delivered to the U.S. Navy in December 1980. ADCAP technical evaluation began in August 1986. ADCAP procurement: 30 in FY85, 123 FY86, 50 FY87, 100 FY88, 320 FY89, 260 (cut from 320 requested) FY90, 240 (requested) FY91 (cut from 320 planned). FY91 unit cost is estimated at \$1.46 million. The FY92–93 budget submission (in February 1991) called for 108 torpedoes in each year, at a unit cost of \$2.04 million (FY92).

The current research program includes a fiber-optically guided Mk 48 ADCAP, which is to transition to advanced development in FY91.

Westinghouse bought Gould's Mk 48 production division in January 1988. The first ADCAP warshot (which sank a decommissioned destroyer) was reported in July 1988.

The Westinghouse version was powered by a Sundstrand turbine; Gould's, by Gould's own swash-plate engine. Reportedly, the turbine was much quieter, but Gould's engine was more efficient, particularly at maximum depth, where the combustion products are ejected against considerable back pressure. Torpedo noise was not the determining factor at this time, as the United States enjoyed both the sonar and the weapons advantage, and Gould was chosen. The Sundstrand engine was adapted for the British Spearfish. The engine's power was doubled, and the thermal efficiency of the Otto fuel enhanced by 40% by mixing with an oxidant, HAP (hydroxylamine perchlorate).

In March 1990 it was reported that by 1993–94 the navy hoped to introduce a Quiet ADCAP, which would use a closed-cycle ADCAP propulsion system (CCAPS), noise damping, and machinery isolation. At the time, it was reported that a current

ADCAP running at full speed produced noise levels equivalent to a U.S. nuclear attack submarine running at full speed. Two phases were planned. The first was to increase speed (presumably, quiet search rather than noisy run-out speed) from 40 to 65 kt; the second was to increase this speed to 75 kt without any increase in radiated noise and with an increase in range from 22,000 to 30,000 yd (all of these figures are what was reported in the press at the time). Other proposed ADCAP improvements are improvements in terminal homing, in countermeasures resistance, and in guidance and control for Arctic operations.

As of 1988, there is a U.S.-U.K. MoU on cooperative development of the next-generation heavy torpedo, to replace both ADCAP and Spearfish.

◆ Mk 50 Barracuda

Dimensions: 12.75 × 111.5 in (total length may grow to 115.5 in)
Weight: 771.2 lb **Warhead:** shaped charge
Power Plant: closed-cycle thermal (SCEPS)

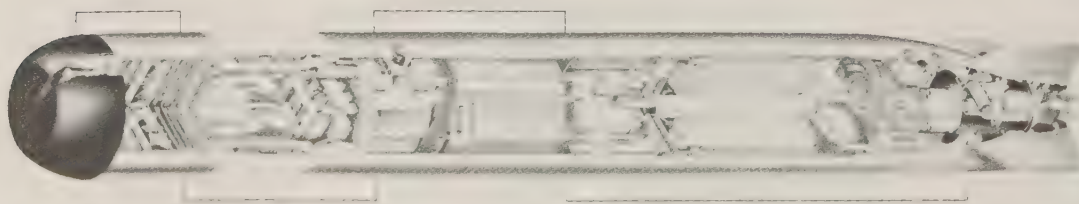
Mk 50 was developed specifically to counter Soviet Alfa-class submarines and future deep-divers, which were beyond the reach of the existing lightweight torpedoes. Mk 50 will be carried by aircraft, fired from surface ships' torpedo tubes, and fitted as the warhead of the Sea Lance and Vertically Launched ASROC missiles. The 1986 decision to develop Sea Lance primarily as a conventionally armed missile has been read as an indication of the success of the Mk 50 warhead against simulated submarine targets; proponents of the alternative nuclear version have suggested that no lightweight torpedo can reliably attack a large double-hulled submarine.

No performance or homing details have been released. However, if Alfa is credited with a speed of over 40 kt, then the usual requirement for a 50% speed margin equates to a maximum Mk 50 speed of about 60–63 kt. Homing is both passive and active (FM active), and it was officially stated in 1987 that Mk 50 homes at twice the range of Mk 46. An official ASW history written in the late 1970s but declassified in 1990 gives the design requirements (ca. 1975, before the competition) as a range of 15,000 yd at 55 kt, with an acquisition range of 3000 yd.

The unusual thermal power plant, SCEPS (Stored Chemical Energy Power System), incorporates a block of solid lithium and a tank of sulfur hexafluoride. When the torpedo is fired, electric squibs melt the lithium, and it is allowed to react with the sulfur hexafluoride, creating both heat and a solid ash. The heat in turn is used to produce the steam that propels the torpedo. This system was adopted because the combustion product, the ash, has less volume than the reactants, and so does not have to be dumped outside the torpedo during its run. The torpedo's engine, therefore, does not have to fight increasing water pressure as the weapon dives toward its target. Garrett, which developed the system, says that it is actually easier to produce than the Otto-fuel power plant of a Mk 46.

Development began with a technical-assessment phase (February 1972–September 1978). The first series of competitors (Gould/Hughes, Westinghouse, McDonnell Douglas/Raytheon, and Honeywell/Garrett) began work in 1978, following a 1975 technology assessment. Two winners were selected in 1979 for a swim-off: McDonnell Douglas/Raytheon and Honeywell/Gar-

(Below) Mk 50 Barracuda torpedo: the exercise version. (Honeywell)



rett. The Honeywell/Garrett design won in 1981, and full-scale engineering development began in 1983.

The McDonnell Douglas design, Mk 51, reportedly used Raytheon's side-looking linear or flank sonar arrays and may, therefore, have incorporated more of a passive capability. Mk 51 also had a GE silver-oxide electric battery. Published drawings of the Mk 50's nose show clearly that it has only a forward-looking sonar array.

As of 1988, the reported objective for production of Mk 50s was 7743 torpedoes plus 160 for research and testing. Estimated unit cost is \$250,000, compared to \$180,000 for Mk 46 at a high production rate.

Approval for low-rate production was granted in 1989, based on success in initial tests. Operational evaluation was to be completed by September 1990. Procurement: 39 in FY87, 16 in FY88, 140 in FY89, 200 in FY90. As of January 1990, the request for FY91 was 265 Mk 50, at a total cost estimated at \$328.3 million, or \$1.24 million each (but that figure is probably misleading). The FY92-93 budget (in February 1991) called for 246 in FY92 and 264 in FY93, at a unit cost of \$1.06 million (FY92).

In March 1990 it was reported that current plans called for a new advanced-development version of SCEPS, to increase the maximum speed from 55 to 70 kt (the range from 14 to 18 kyd). These figures are what was reported in the press in March 1990.

Two new warhead concepts are currently under consideration, one described as a trumpet (presumably a shaped charge), and the other (higher-risk) approach requiring additional torpedo volume. This is probably the follow-through warhead described officially as part of the Balanced Technology Initiative (BTI). A follow-through or tandem warhead, which has also been proposed for the army's TOW antitank missile, uses 1 charge to breach the target and then fires a second warhead through the hole. The idea is not new: early in this century the U.S. Navy (and probably other navies) experimented with a torpedo gun, a torpedo that fired a shell through the underwater hole it made in a target. Current research also includes an attempt to reduce the physical size of torpedo electronics and propulsion (while improving performance) to allow for a larger warhead; total torpedo volume is limited by factors such as the dimensions of the S-3's bomb bay.

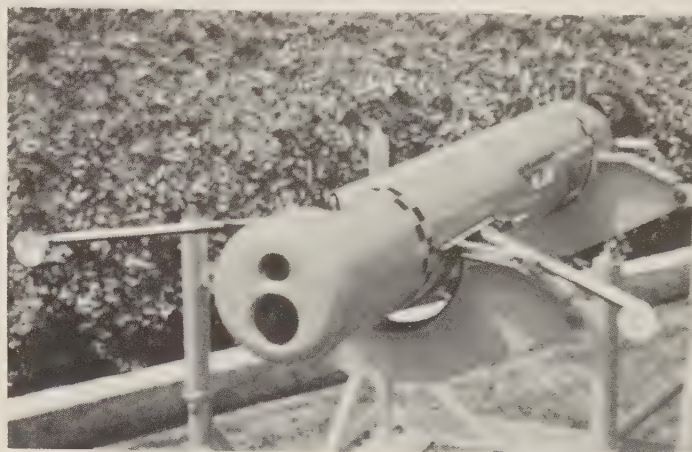
◆ Surface Torpedo

An attempt to buy a lower-cost single-purpose (antiship) torpedo ended in 1987, even though Whitehead won the competition with a modified A-184. See the previous edition for details. The designations EX-52 and EX-53 were reserved for 2 alternative heavy antisurface torpedoes, but they were not used.

◆ Lockheed Lightweight Torpedo/LENS

Since the early 1980s Lockheed has developed a range of lightweight underwater vehicles. One version was offered to Sweden to meet the Angler requirement (see the Swedish torpedo section, above); it weighed about 160 lb. It was successfully tested against tethered and bottom targets in the Baltic in 1986. The torpedo-shaped vehicle is modular, consisting of a sensor head; a basic body containing the warhead, batteries, and microprocessor control system; a motor; and a guidance section (for either free-swimming operation or for wire or fiber-optic link guidance). Lockheed offers 3 sensors: a horizontal homer (sonar), a horizontal and vertical homer (sonar), and a television with or without the sonar. The vehicle can carry either a bulk or a shaped charge. The 2 alternative power plants are 6 and 15 kt DC motors. The company designation, LENS (Lockheed Expendable Neutralization System), straddles the border between ASW and mine countermeasures. Lockheed currently offers or plans a mine-warfare LENS, a TV LENS (using fiber optics to communicate with the operator), an ASW LENS (20 kt), and a hovering surveillance LENS.

The basic vehicle is 20 cm [8 in] in diameter; the faster ASW LENS is slightly larger. Lockheed's original mine-warfare system used a 1.6-m [63.0-in], 44-kg vehicle carrying a 17-kg payload at up to 6 kt, in water depths of up to 200 m. Endurance



Lockheed LENS vehicles showing alternative sensor heads. The 2-sensor vehicle was successfully demonstrated against tethered and bottom targets in the Baltic late in 1986. It shows the folding arms that carry underwater lights. The other vehicle has a cable-catcher above its single sonar. (Lockheed)

is 30 min at 4 kt with a nickel-cadmium battery. This is essentially an antitorpedo mine, brought near the target by a guidance wire (up to 2 km long), which then uses its own active sonar (30-m range) to home onto the mine. The vehicle is tracked by the ship's minehunting sonar (it carries a sonar blip enhancer).

This is probably the vehicle tested by the Royal Swedish Navy for the Angler requirement.

The next stage was a larger vehicle (1.8 m [70.9 in] long, total weight 53 kg with a 20-kg payload), with the same speed and endurance characteristics, but carrying both a sonar and an underwater color television (range 1-20 m, depending on water conditions). The color television has a much wider FOV, and the vehicle carries a pair of high-intensity underwater lights on folding outriggers. This version is much more sophisticated: the vehicle sends back its sonar and television video via a fiber-optic link. The operator console now displays the vehicle's image of the object it is investigating. It also shows vehicle control parameters and vehicle status. The vehicle carries an altitude sonar by means of which it can fly above the bottom, and an optional nose maneuvering unit allows it to stop and point in a direction of interest. Payload weight can be traded off against an additional battery section, for greater endurance.

The undersea surveillance system is a variation on this theme. The nose of the vehicle carries the video camera, the short-range sonar, and an altitude-keeping sonar (as in the mine attacker above). The body carries a pair of high-intensity lights as well as an 80C86-based microprocessor (which deals with the 80186-based single-board computer in the operator console). As in the other versions, the vehicle carries a sonar beacon, and it sends back its video via a fiber-optic link. Length is 2 m, payload is 20 kg (weight 60 kg), and maximum speed is 7 kt (endurance, using a nickel-cadmium battery, is 20 min at 4 kt).

In this case surveillance means investigating suspicious bottom contacts (as would be the case in Sweden) rather than any wide-area mission as it would be understood elsewhere.

The ASW attack vehicle shares the shape of the other versions, but it is larger (25 × 215 cm [10 in × 84.6 in], 100 kg with a 20-kg warhead), faster (20 kt), and has greater endurance (80 min at a 4-kt search speed, 20 kt for 1 min at attack speed), because it uses a silver-zinc battery rather than the earlier nickel-cadmium. Its nose sonar is much more powerful (acquisition range in active mode, 300 m; vertical extent of sonar coverage, 30–100 m). The sonar uses a horizontal and vertical split beam for more effective homing. The weapon can function in fire-and-forget mode, or it can be wire guided (control range is 4 km), using a fiber-optic link to display its sonar picture (both raw and processed video) to an operator. Because most of the intelligence of the system is in the operator's console, the weapon itself can be relatively inexpensive.

Lockheed describes this as a mission-abort weapon, not quite large enough actually to kill a target. Presumably, it is the basis for the Lockheed contribution to 1 of the NLCAW proposals. A Lockheed sketch shows its large effective area compared to a depth bomb. Critical vehicle components were tested in the Baltic in 1986, i.e., were part of the Lockheed Angler proposal, and the homing mechanism was verified in shallow water in tests at the Nanoose range against the ex-USS *Menhaden*. This device can be dropped by an airplane or a surface ship or fired out of a conventional larger-diameter submarine torpedo tube.

TORPEDO LAUNCHERS

◆ Mk 14

These quintuple 21-in tubes survive on board a few *Fletcher*-class destroyers in foreign service. Total weight, including 5 torpedoes Mk 15, is 43,100 lb. With the tubes loaded (spoons up), working radius is 152.64 in. Torpedoes are mechanically set (the tube cannot, therefore, be used with modern homing weapons) and are mechanically started; they are ejected using black powder, at an initial velocity of 55 ft/sec. Each quintuple tube is served by a gyro setter, a trainer, and a tube captain.

◆ Mk 25

Mk 25 survives only on board the Spanish *Baleares*-class frigates and the destroyer *Marques de la Ensenada*, which use it to launch Mk 37 torpedoes. It was installed on board a few U.S. destroyers and frigates but was quickly removed. Mk 25 was designed to fire both homing torpedoes (originally Mk 35, later Mk 37) and fast straight-runners (Mk 16). Torpedoes are launched by air pressure, and the tube has provision for electrical torpedo setting. Barrel length is 247 in (overall length, with the muzzle door open, is 279 in), and total weight is 1900 lb/barrel.

◆ Mk 32

Mk 32 is the standard lightweight torpedo (12.75-in) launcher on board numerous U.S. and foreign frigates, destroyers, and cruisers. Mk 32 succeeded torpedo-launching system Mk 2, a catapult ("poor boy") for the Mk 32 torpedo, whose oversized fins precluded tube launch. Mk 2 could also be used to launch the much heavier Mk 37 torpedo. It is now extinct in the U.S. Navy, and probably also abroad.

Mk 32 is normally fired remotely (electrically), but all versions prior to Mod 15 have provision for local emergency firing. Mod 15 lacks any such provision. Torpedoes are ejected by air. Trainable tubes have interlocks that prevent firing when they are not trained outboard. In addition, Mods 9 and 15 have interlocks requiring that the muzzle doors be open before the torpedoes can be fired.

These launchers are manufactured abroad under license, e.g., by Plessey.

Versions of Mk 32:

Mod 0 Initial version, a fiberglass-barrel launcher for torpedoes Mk 44, 43 Mod 1, and 43 Mod 2. Total weight was 2280 lb.

Training circle: 70.875 in at muzzle end, 75.625 in at breech end; the tube could train through 190 deg. Overall height is 52.688 in. A Mk 44 torpedo emerged from the tube at 40–65 ft/sec. This nomenclature was assigned in May 1958. ORDALT 4342A (December 1963) modified Mods 0, 1, and 2 to permit remote presetting and firing of Mk 44 and 46 torpedoes. Mods 0 and 1 were converted to Mod 6 on ships with Mk 102, 105, or 111 FCSs. These Mods were converted to Mod 8 on ships with Mk 114 FCSs.

Mod 1 Alternative to Mod 0 with air-pressure charging line for vessels without HP-air compressor systems (1958).

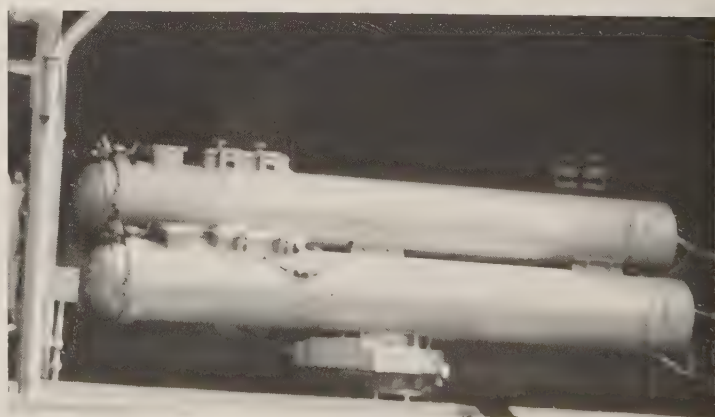
Mod 2 Value-engineered Mod 0 with new training gear, barrels, breech mechanism, and securing mechanism and a new method of storing the charging line. ORDALT 4342A (December 1963) converted Mod 2 to Mod 5 on ships with FCSs Mk 102, 105, and 111, and to Mod 7 on ships with FCS Mk 114.

Mod 3 Single-barrel fixed version for the experimental hydrofoil patrol boat *High Point* (770 lb, 1959).

Mod 4 Mod 0 or 1 modified by ORDALT 4342 to be compatible with control panel Mk 264, to permit remote changes to preset functions of Mk 44 or 46 torpedoes up to the moment of firing. Mk 264 selects and sets any 1 of 6 torpedoes in 2 tubes. The pneumatically operated torpedo-plug pullers extract the electrical plugs from the torpedoes during the firing cycle prior to ejection. The torpedo-squib fire switch automatically unlatches the torpedo's gyro during the emergency-manual-firing cycle (1961).

Mod 5 Modified Mod 2, with a second junction box to distribute electrical preset data from the Mk 264 Mod 1 panel to any of its 3 torpedoes. It has remote (by Firing Panel Mk 264) rather than local electrical firing and an air-operated plug puller. Heaters are built into the tubes. This designation dates from June 1961. This version can also be controlled by Firing Panel Mk 309. Weights: 2230 lb empty, 3110 lb with Mk 44 torpedoes, 3754 lb with Mk 46, 4450 lb with Mk 50. Some Mod 7s were converted to Mod 5 under ORDALT 6720 (September 1970) for ships with FCS Mk 105 and 111. ORDALT 7020 (November 1970) modified Mods 5–9 to indicate the type of weapon loaded without visual check. It prevented inadvertent firing of the weapon when the torpedo selected was not the same as the torpedo loaded. ORDALT 7658 (January 1971) to Mods 5–9 was interim deletion of the no-run-out presetting capability when launching a torpedo from the lower barrel. A Mk 46 launched in this mode was likely to acquire the wake of the firing ship and would probably attack it.

Mod 6 Mod 0 or 1 tube converted by ORDALT 4342 to permit remote changes to torpedo presets (analogous to Mod 4) for ships with FCSs Mk 102, 105, or 111. A second junction box is added for distribution of presetting circuitry. The associated firing



A Mk 32 triple tube on board the nuclear cruiser *Mississippi*, June 1988. (S. Terzibaschitsch)

Panel is Mk 264 Mod 1 (1961). Some Mod 8s were converted to this version (ORDALT 6720, September 1970).

Mod 7 Similar to Mk 5, but internal wiring is modified to connect to Attack Console Mk 53, so the tubes can be controlled by FCS Mk 114 or Mk 116.

Mod 8 Modified Mod 0 or Mod 1 for ships with FCS Mk 114, to permit remote setting and firing of Mk 44 and 46 torpedoes. Conversion entails installation of a second junction box, 3 pneumatic plug pullers, and 3 barrel-ready and torpedo-squib fire switches. Torpedo input-setting and tube-firing signals are transmitted from the Mk 114 system via the second junction box. The plug pullers extract the electrical plugs during the firing cycle. Barrel-ready switches signal the control center that barrel and torpedo are ready to fire. Squib-fire switches unlock the torpedo gyro during manual emergency fire (1961).

Mod 9 Twin (rather than triple) launcher, fixed in train, for *Knox*-class frigates. It is otherwise similar to Mods 7 and 8 and works with Attack Console Mk 53 of FCS Mk 114. With an insert, it can fire Mk 43 torpedoes. This is the version used in the Canadian "City"-class frigates. Weights: 2010 lb empty, 2890 lb with Mk 44 torpedoes, 3026 lb with Mk 46, 3710 lb with Mk 50.

Mod 10 Single fixed tube. Weights: 602 lb empty, 1050 lb with Mk 44, 1110 lb with Mk 46, and 1342 lb with Mk 50 torpedoes. This tube was designed for control by Control Panel Mk 264. It is similar to Mod 3 except for the remote-control features. It can fire Mk 46 Mod 1 torpedoes (1967).

Mod 11 Single fixed tube, similar to Mod 10 but with safe/ready remote features added. Weights: 650 lb empty, 1100 lb with Mk 44, 1160 lb with Mk 46, 1390 lb with Mk 50 torpedoes. This tube was designed for control by Control Panel Mk 264 or Mk 309 (1967).

Mod 12 Single fixed tube on 2 flexible (antivibration) mounts, similar to Mods 10/11 but with a power-actuated muzzle-door mechanism (1967).

Mod 13 Triple version intended for the experimental Canadian hydrofoil *Bras d'Or*, to fire Mk 46 Mod 0 and Mod 1 torpedoes (1966). It was fixed, with the 2 lower tubes splayed 34 deg outward.

Mod 14 Version for the *Spruance* class, mounted in a deckhouse. It is similar to Mod 7 but with faster response: the motorized train gear slews the launcher to a 45-deg angle for firing, and there is a remote barrel-readying feature. Torpedoes are preset and remotely fired, and the tube is trained by Torpedo Setting Panel Mk 331 (of FCS Mk 116) or Weapons-Control Panel Mk 329; there is also a local bulkhead-mounted control box. Weights: 2380 lb empty, 3260 lb with Mk 44, 3904 lb with Mk 46, 4600 lb with Mk 50 torpedoes.

Mod 15 Version for the *Arleigh Burke* class, weatherdeck-mounted. It is intended not to be manned. It is similar to Mod 7 but with remote barrel reading, a positive weapons-away indication for each barrel, and heated and remotely controlled muzzle doors.

Mod 16 Version for the SSTD program, to launch a modified lightweight torpedo as an antitorpedo weapon. Similar to Mod 15 but with different muzzle doors and modified control boxes. It can fire Mk 46 and Mk 50 torpedoes and is similar to Mod 5. This version is to be installed on board selected major combatant ships. The nomenclature was assigned in November 1989.

Mod 17 Version of Mod 5 (ORDALT 15713) modified to fire Mk 50 torpedoes (retains Mk 46 capability); for *Perry* class, WHEC 715 coast guard cutters, the *Long Beach*, and the *Bainbridge*. This nomenclature was assigned in December 1989.

Mod 18 Conversion of Mod 7 (ORDALT 15713) for *Leahy*-, *Belknap*-, and *Virginia*-class cruisers, to fire Mk 50 as well as Mk 46 torpedoes.

◆ Submarine Torpedo Tubes

Pre-World War II pneumatic tubes survive only on board former U.S. Guppy-type submarines in foreign service. These tubes (Mks 32 and 34 bow tubes, Mks 33 and 35 stern tubes) were modified postwar for electrical torpedo setting. Launching velocity varied with conditions but was typically 50–60 ft/sec. Maximum air pressure was 600 psi. Barrel lengths: bow tubes, 251 in, stern tubes 276 in. Because the tubes are pneumatic, maximum firing depth is 200 ft.

Work on a hydraulic torpedo tube began in 1944, and an experimental full-scale tube, using a motor-driven centrifugal pump, was built and tested. It achieved 15 ft/sec, and tests showed that 1900 HP would be required to achieve 40 ft/sec. In 1948 Electric Boat proposed a new design using an air-actuated piston pump instead of the centrifugal pump, and a prototype was tested on board the USS *Becuna* (SS 319). It was first operational in the *Tang* class. For each bank of 3 tubes, there is 1 ejection pump (water cylinder, air cylinder, and piston). Each stroke ejects 1 torpedo.

The initial postwar hydraulic bow tubes (Mks 43 and 45) used a 1500-psi impulse and achieved an initial velocity of 32 ft/sec. Torpedoes were all electrically set and started. Typically, a submarine had 1 hydraulic pump for the 3 tubes on each side. Barrel length was 252 in. The corresponding stern tubes (Mks 44 and 46) were swim-out tubes intended specifically for ASW torpedoes (initially Mk 27); typical swim-out speed was 10 ft/sec. Barrel length was 142 in, corresponding to the half-size adopted for such weapons.

The figures for Mks 43 and 45 are typical of later practice, although the tubes themselves have long been superseded. The main difference is somewhat greater impulse power; all current tubes are hydraulic so that they can be fired at all depths.

Current types:

Mk 63 *Permit* and *Sturgeon* classes, designed for increased depth, otherwise similar to earlier types. In contrast to previous types, these tubes were designed for operation from a control panel.

Mk 64 *Tullibee* tube, the first U.S. tube mounted abaft the bow, angled outboard.

Mk 65 Ballistic-missile-submarine tubes.

Mk 66 Experimental external 30-in tube on the deep-diving auxiliary submarine *Dolphin*.

Mk 67 *Los Angeles* class.

Mk 68 *Ohio* class.

Mk 69 30-in tube planned for the new *Seawolf* class. It will be able to fire both 21- and 30-in weapons and is a totally new design. The prototype is being tested on board the USS *Memphis*.

UNGUIDED WEAPONS (MORTARS AND DEPTH CHARGES)

CHILE

Cardoen, the Chilean explosives manufacturer, produces a fast-sinking depth charge, AS-228, externally similar to the U.S. "tear drop" of World War II. Depth of burst can be set at any of 19 figures between 100 and 1600 ft.

Cardoen also manufactures miniature antiodiver depth charges that can be set to explode between 4 and 12 m.

CHINA (PRC)

◆ 250-mm Rocket Launcher

Although similar in concept to Soviet RBUs, this weapon seems to differ in detail. As employed on board *Luta*-class destroyers, it has 12 tubes: an outer shallow horseshoe layer of 7, with 5 inside (2 on each side, 1 in the middle). The mount elevates and trains. A 5-tube version (the Soviet RBU-1200) is carried by

Jianghu-, *Jiangdong*-, and *Jiangnan*-class frigates. The tubes resemble those of the Soviet RBU-1200 (see entry below), and this weapon is probably a modification of the Chinese version of the earlier Soviet system.

This weapon became operational in 1972. The Chinese commercial designation is EDS-25A.

FRANCE

◆ 305-mm Mortar

This 4-barrel automatic-loading mount is found only on the *Commandant Rivière* class (French and Portuguese navies). Its ASW projectile weighs 230 kg and has a range of 400–2750 m [507 lb, 440–3000 yd], and there is also a 100-kg [220-lb] shore-bombardment round with a 6000-m [6600-yd] range. Usually 4 illuminating rocket rails are mounted on the sides of the mount.

The ASW round is time-delay fuzed, the fuze being set inside the launch tube. The barrels fire at the rate of 1 rnd/sec, re-loading through their muzzles (continuous firing rate is one 4-rnd salvo every 25 sec). Rounds are stowed in 4 carousels, 1 feeding each of the 4 hoists.

Typical weights are 22.2 tons (metric) for the mortar, 18.75 tons for 72 rnds of ammunition, and 4.7 tons of fittings.

Control is by a DUBA 3 attack sonar.



305-mm ASW mortar between bridge and forward gun, *Commandant Rivière*. The mortar is in the loading position. (Stefan Terzibaschitsch)

ITALY

◆ Menon Mortar (K 113)

This single-barrel automatic-loading 305-mm [12-in] mortar is fired at a fixed 45-deg elevation. Range is varied (400–900 m [440–980 yd]) by adjusting gas vent valves on 3 powder chambers. The depth charge weighs 160 kg [353 lb]. The barrel, which is 4.6 m [181 in] long, loads automatically from a 7-rnd cylinder, firing a 7-rnd pattern. An earlier 3-barrel version, Lancia Bas, is no longer in service. It fired a 21-rnd pattern in 70 sec, covering an area of about 80 × 180 yd.

There is no associated depth-determining sonar; ships carrying these mortars carry scanning sonars.



The Italian frigate *Carlo Margottini* shows a single-barrel Menon (K 113) ASW mortar between her No. 2 3-in gun and her bridge. The guns are predecessors of the OTO-Melara 76-mm/62. The fire-control radar is RTN-10X, and the air-search set is SPS-12; above it is SPQ-2 (at the masthead). (U.S. Naval Institute)

◆ MS 500

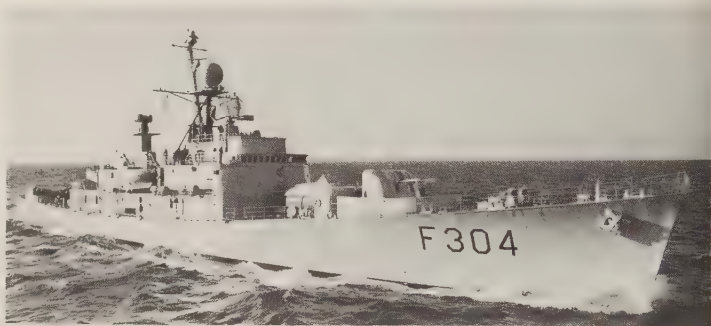
Misar's 500-lb ASW bomb/mine was designed specifically for the Atlantic maritime-patrol aircraft, which Italy operates. Although Misar describes it as a bottom mine, the company also notes that it is unusual in being equipped with an acoustic proximity fuze that detonates the bomb at the closest trajectory point to its target, so it requires no depth presetting.

NORWAY

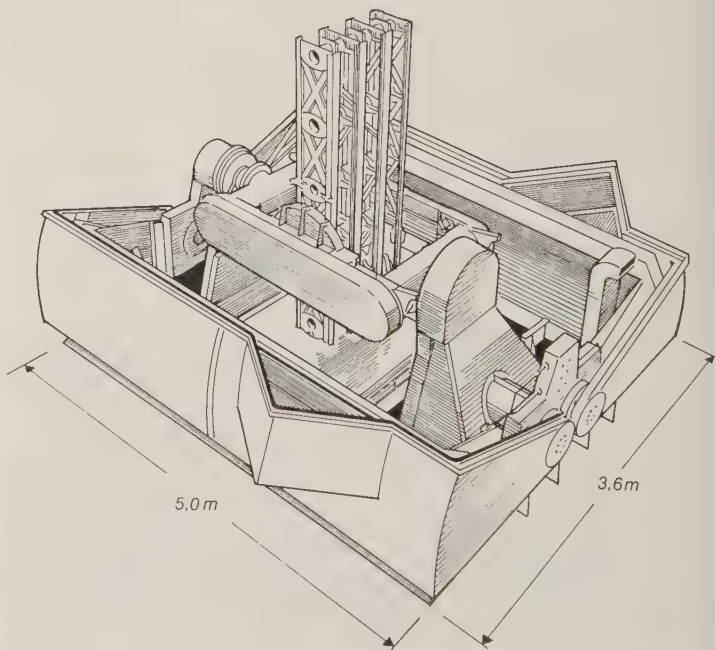
◆ Terne III

This rocket-fired depth charge was introduced about 1960 in its Mk 3 version for the *Oslo*-class frigates and the *Sleipner*-class corvettes. Terne III is now in a Mk 8/10 version.

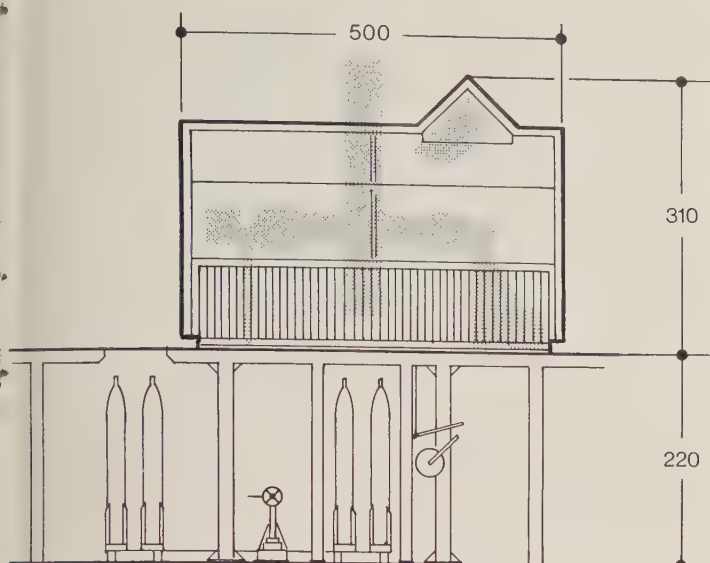
The system was developed by the Norwegian Defense Research Establishment with assistance from the United States under the Mutual Weapons Development Program. The system uses a stabilized searchlight sonar to search for, detect, and track the target in depth. As fitted to U.S. ships, Terne III was triggered by the SQS-31 or -32 search sonar. In this application the sonar had a maximum depth of 1000 ft (maximum depression angle 35 deg). The U.S. designation for the Terne rocket was Rocket Thrown Depth Charge Mk 3. The launcher was designated Mk 117 Mod 0. The typical salvo pattern consists of weapons 20 yd apart in a line perpendicular to the target's course. Fuzing modes are time and proximity, the latter using a sonic doppler signal to detonate 20 ft from the target (or upon



The Norwegian frigate *Narvik* shows her prominent enclosed Terne III launcher between her forward twin 3-in/50 gun and her bridge. The radar above her bridge is a French DRBV 22, with a Signaal WM-24 above. The radar aft is a Mk 91 controlling NATO Sea Sparrow missiles. (U.S. Naval Institute)



The Terne launcher. (Kongsberg)



Typical Terne reloading arrangement. (Kongsberg)

contact). In the time mode, the depth charge explodes 0.3 sec after water entry.

For the Mk 3 version, air range at 70 deg F is min 400 and max 920 yd. Corresponding air-flight time is, respectively, 18.2/13.3 sec. Depth limits are 50 and 700 ft. In U.S. service Terne was part of ASW Weapons System Mk 1. For Mk 8/10, range is 400–5000 m; total weight is 120 kg (explosive charge equivalent to 70 kg); dimensions are 21 cm × 2 m. The launcher has 6 barrels and elevates to 47–77 deg to fire. It can be reloaded in 30 sec, and 6 salvos are available in ready-use stowage. The deck opening, which is covered by 2 weather hoods, is 3.6 × 5.0 m.

SWEDEN

◆ Bofors 375-mm Rocket Launcher

This weapon is widely used both in the original 4-barrel and in a later 2-barrel version. However, this launcher is no longer used by the Swedish navy, that service having abandoned the use of large surface ships.

The usual installation includes a power-driven 4-barrel launcher vertically (for minimum ship impact) power-loaded from below. Initially, Bofors offered only the 4-tube weapon with either long or short hoist, but in 1967 the company added 2 types of 2-barrel launchers.

The associated ERIKA-type ASW rocket has a maximum velocity of 205 m/sec [672 ft/sec]. Range (300–3600 m [330–3900 yd]) is adjusted by selection of 1 of 4 types of rocket (for varying velocity) and by elevation. Rockets have 2 concentric (inner and outer) motors, and velocity can be further varied by firing 1 or both. Depth of burst is set either by time (STIDR) or by acoustic proximity (ZAMBO) fuze; there is also a combined impact (direct acting) and time fuze (STIDAR). The lethal radius of each round is about 15 m [16 yd]. Rockets weigh 250 kg [550 lb]; they vary in bursting charge. Types are M/50, Type E (for ERIKA), and Type F (for Flora). The mounting trains and elevates at 18 deg/sec. Elevation limits are +15 and +90 deg. Rocket characteristics are as shown below.

Bofors 375-mm Rocket Launcher

	ROCKET TYPES			
	M/50	Type E	Type F	Type N
Weight (charge)	100 kg [220 lb]	107 kg [236 lb]	107 kg ^a [236 lb]	80 kg ^b [176 lb]
Min Range	370 m [405 yd]	670 m [732 yd]	1400 m [1530 yd]	1530 m [1670 yd]
Max Range	875 m [957 yd]	1660 m [1815 yd]	2230 m [2439 yd]	3600 m [3940 yd]
Terminal Sinking Speed	10.9 m/sec [35.8 ft/sec]		10.2 m/sec [33.5 ft/sec]	9.2 m/sec [30.1 ft/sec]

^a Total weight of Type F is 242 kg [533 lb].

^b Burst weight. Total weight of Type N is 230 kg [507 lb].



The French version of the Bofors 375-mm rocket launcher. The flare-launching racks are alongside the rocket tubes. The guns are twin 57-mm/60s, also a French version of a Bofors original. (L. van Ginderen)

The long-hoist 4-rocket launcher weighs 7.3 tons exclusive of flame guard, and normally 8 rockets (2 more salvos) are carried on the rocket table below. Rockets can be fired at intervals of 1 sec, and it takes 3 min to reload all 4 tubes. The short-hoist version weighs 7.6 tons, and there is no intermediate hoist stage between magazine and launcher.

The 2-tube launcher Type A (3.2 tons, 4 rockets on rocket table) fires M/50, Type E, and Type N rockets. Elevation limits are 0 to +90 deg, but the launcher can fire only between 0 and 60 deg. Launcher Type B employed a power hoist that loaded from a rotating loading table, itself replenished by push-button operated trucks, each moving 2 rockets at a time from storage tables in a magazine. The loading table held 8 rockets, but each storage table held another 6. This version trained and elevated at 30 deg/sec.

Against a submarine at 100-m [328-ft] depth, times of flight at min/max range for M/50, Type E, Type F, and Type N are, respectively, 14.2/19.4, 16.0/25.3, 19.3/28.5, and 24/36 sec. Nonrecoverable training rockets are Types L (Lilli, for M/50) and M (Mimmi, for ERIKA) (both 80 mm). The recoverable practice rockets are M/53, Type H, Type K, and Type P for, respectively, M/50, E, F, and N.

A French version, built by Creusot, has 6 barrels and usually carries 6 rails for illumination rockets. It is Model 1964, and it can be reloaded in less than 60 sec. The French had previously used the Swedish 4-barrel launcher. Maximum rated range is 1600 m, the French navy using rounds with 100 kg of explosive. Total system weight, including remote control, is 16,000 kg. The French version weighs 7700 kg (5700 kg for the mount proper), typically with another 10,100 kg of ammunition (36 rockets).

The Bofors 375-mm system was originally developed for the Royal Netherlands Navy, which placed it in service in 1954. Current Bofors 375 users (*indicates the 2-barrel version,** the 4-barrel version; others are 6-barrel) are Belgium (4 *Wielingen* class), Brazil (6 *Niteroi* class*), Egypt (2 *Descubierta* class*), France (17 *d'Estienne d'Orves* class), Germany (4 *Hamburg* class** and 5 *Thetis* class**), Indonesia (3 *Fatahillah* class*), Japan (6 *Yamagumo* class**, 3 *Minegumo* class**, 2 *Yubari* class**, 1 *Ishikari* class**, 4 *Isuzu* class**, and 2 *Akizuki* class**), Malaysia (2 FS-1500s*), Morocco (1 *Descubierta* class*),

Nigeria (2 *Erin'mis**), Peru (6 *Friesland* class**), Spain (6 *Descubierta* class*), and Turkey (3 ex-German *Koln* class**). Bofors 375s in Japanese service are designated Type 71. Although there is some question as to the continued value of the 375 against submarines at long range (see the notes on the projected NATO low-cost ASW weapon, above), this system is probably also valued as an antitorpedo measure. At least in the Belgian navy, it is the standard counter to a torpedo, liked for its quick reaction time in a line-of-bearing shot (presumably, the hope is that the explosion will derange the torpedo's homing system).

◆ Elma

This lightweight ASW mortar is designed to attack midget submarines in Swedish coastal waters. Development began in mid-1983, and first deliveries came a year later. Elma is to arm the Swedish fast patrol craft and *Landstort*-class minesweepers.

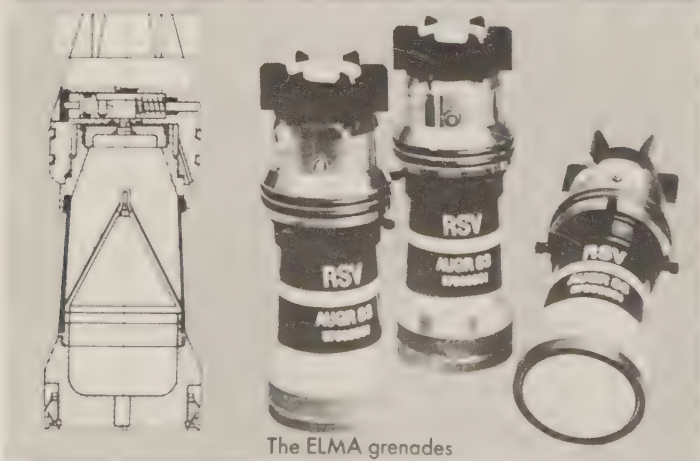
The system, produced by FFV and Saab, consists of four 9-barrel mortars firing 100 mm × 267 mm, 4.2-kg [3.9 × 10.5 in, 9.3-lb] shaped-charge contact-fuzed grenades. The grenades sink nose-first, and the shaped charge was developed from that in the Carl Gustav 84-mm antitank rocket. The barrels are mounted at a fixed 30-deg elevation, and range is about 250–300 m [267–330 yd].

In theory hits from these grenades will force a submarine to the surface without sinking it instantly, thus enforcing Swedish sovereignty in the least lethal possible way. The shaped charges should be able to penetrate the inner hull of a double-hulled submarine (at least 1 of moderate size), and thus a submarine commander choosing not to surface will have to risk the loss of the craft.

The LLS-920 launcher is nonmagnetic, and it was modified from an earlier design that had been proposed by Saab for launching of Philax chaff grenades. A hand lever adjusts the splay of the tubes, for the desired dispersion. Grenades are launched by charges fitted into the rear of the launch tubes. The firing of a 9-grenade salvo is spread over 2 sec to limit deck loads.



The ELMA ASW launcher on d



The ELMA grenades

Elma. (FFV)

In January 1985 the system was ordered modified to allow it to engage targets in water only 10 m [33 ft] deep. Later the bombs were further modified so that they armed upon hitting the water, so they could engage even shallower targets. In addition, Saab modified the system so that it could fire chaff/IR decoys.

Finland became the first foreign buyer of the Elma system, for its *Helsinki II*-class fast attack boats. Each will carry 4 LLS-920 launchers.

With the collapse of the Angler program (see above), the Swedish navy is considering (1990) 2 alternative developments of Elma. One would have increased range and would be mounted on the forward gun shield so that it could be trained. The alternative is to reduce Elma's diameter so that it can be fired from a 57-mm gun. This proposal recalls the World War II Shark projectile, which could be fired at an underwater target by a 4- or 5-in gun.

◆ Malin

This "incident weapon," announced in 1983, is a magnetic limpet mine that attaches itself to a submarine, emitting a traceable signal until removed. Malin makes tracking easy, and it is a nuisance that cannot be removed unless the submarine surfaces and sends someone out to find the mine on the hull. Malin is reminiscent of the U.S. "clicker" of the 1950s, a magnetized noisemaker that could be dropped on a submarine and that could generally be removed only if the submarine surfaced. Malin was devised to counter supposed Soviet midget submarines operating in Swedish waters.

◆ SAM 204

SA Marine's helicopter-dropped depth charge has a hydrostatic fuze (variable from 15–80 m [49–262 ft] in depth) and a variable charge (50–250 kg [110–550 lb] of high explosives). The fuze is unusual in being immune to transient pressure waves caused by other explosions, so depth charges can be dropped in salvo. Unlike the fuzes of other air-dropped depth charges, this fuze is set in the cockpit.

USSR

RBU is the Soviet designator (*Raketnaya Bombometnaya Ustanovka*, or Rocket Depth Charge). Former MBU designators reflect an earlier, erroneous Western belief that these weapons were mortars like the British Limbo.

◆ MBU-900

This weapon entered service about 1954 and may survive on board *Kronstadt*-class subchasers transferred abroad. The 25-kg solid-fuel rocket (warhead about 2 kg [55/4.4 lb]) has a range of about 900 m [980 yd]—hence the designation—and a speed of about Mach 0.5. The Soviets call this system a "jet-propelled depth-charge thrower." It is similar in configuration to the U.S. Mousetrap (Mk 20/22).

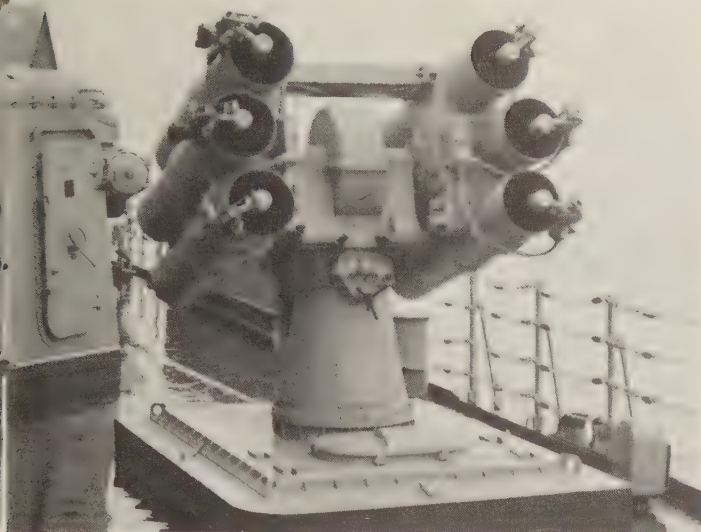
This weapon was also manufactured in China.

A Soviet equivalent of Hedgehog, MBU-600, survives on board 2 Bulgarian Rigas. The Soviets replaced this weapon in their own ships with RBU-2500s; the East Germans used RBU-1200s.

◆ RBU-1000

This launcher employs 30-cm rockets (as in RBU-600), but the barrels are longer, about 1.8 m [71 in]. Presumably, the warhead is the same but the rocket is longer, with more propellant, to achieve the greater range reflected in the new designation. The barrels are arranged in a horseshoe, and they load automatically, barrel by barrel, vertically; the barrels fire in sequence. RBU-1000 is in many modern Soviet large combatants (*Kara*, *Kresta-I/II*, *Kashin*, and *Sovremennyy*; also the large underway replenishment ship *Berezhina*). Range is 1000 m [1100 yd].

Except in the case of the *Berezhina*, RBU-1000 is mounted on a ship's quarter. In this position it is more likely an antitorpedo than an antisubmarine weapon, projecting a noisemaker decoy. The Soviets also have a towed noisemaker, but there



RBU-1000 rocket launcher on board the cruiser *Kerch*, 1989. This device is mounted on the ship's quarter, firing aft. *Kresta-II*- and *Sovremennyy*-class ships carry RBU-1000s in similar positions, which would be very reasonable if the weapon had a secondary antitorpedo (e.g., deployed noisemaker) role. The U.S. Navy experimented with a rocket-launched antitorpedo noisemaker, NAE, about 1948, ultimately discarding it because the launcher, Mk 31, presented too many hazards. Towed noisemakers were preferred. Other Soviet classes engaged in ASW lack any equivalent to RBU-1000 aft. Most carry a towed torpedo decoy. (Eric Grove)

is always the possibility that a torpedo attracted to the decoy will continue onward to the towing ship. Several navies, therefore, have investigated rocket-thrown noisemakers, which can be projected farther from a ship. The only current Western example is under development by the French navy.

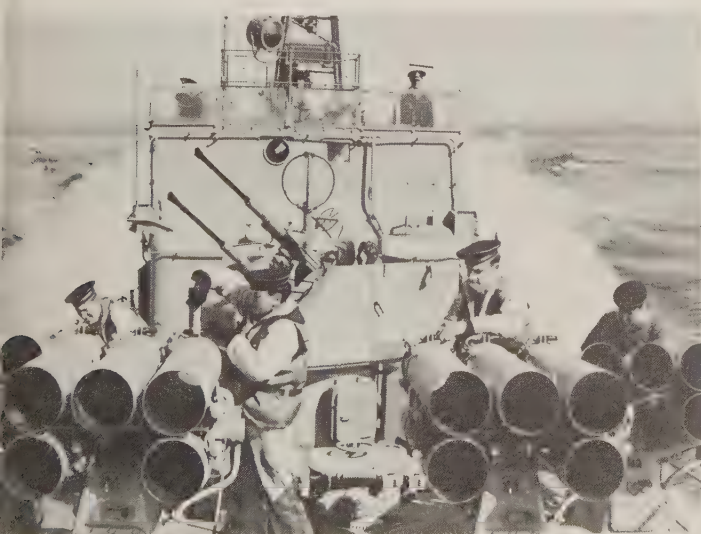
RBU-1000 may also be a barrage antitorpedo weapon, relying on concussion to destroy or disable oncoming homing torpedoes. Again, similar devices have been projected in the past by the U.S. and Royal Navies. In each case, the project has died for 2 reasons: first, the rate of false alarms was so high that excessive weights of antitorpedo charges had to be carried; second, it was never clear just how much explosive was needed to be sure of killing the oncoming weapon. These problems still beset the U.S. SSTP program (see below).

Although the first 2 *Kirov*-class cruisers lack any RBU-1000, the third ship of the class, *Kalinin*, carries 2 examples of an RBU-1000 follow-on, with 6 tubes of greater size.

The earlier NATO designation was MBU-4500A.

◆ RBU-1200

RBU-1200 has 2 horizontal rows of 25-cm [9.8-in] barrels, 3 above 2. Barrel length is 1.4 m [55 in]. The launcher elevates

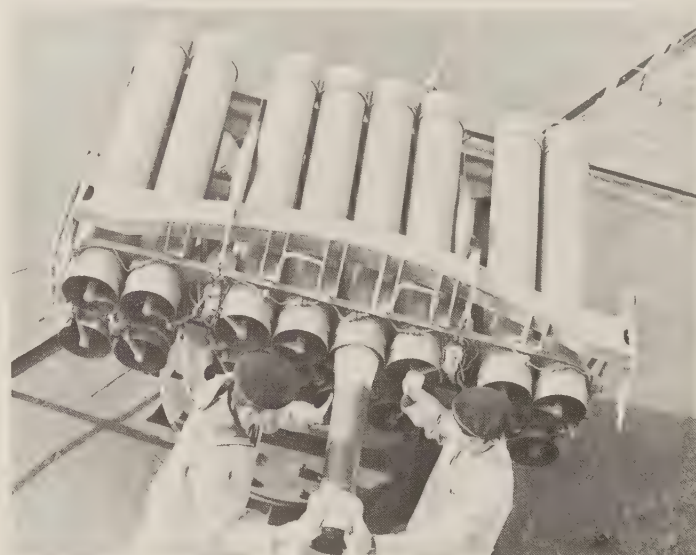


RBU-1200s on board an SO-1-class subchaser, 1968. (SOVFOTO)

for range but is fixed in train. The 70-kg [154-lb] rockets carry 34-kg [75-lb] warheads. Range is 1200 m [1300 yd]. This launcher is found on board T 58 patrol ships, *Natya*-class minesweepers, and *Pauk*-class ASW craft. The weapons in *Pauks* train for loading, but all these weapons fire dead ahead.

A PRC-manufactured equivalent uses 40-kg [88-lb] rockets with 3-kg [6.6-lb] warheads, to achieve a range of about 2000 m [2200 yd]. This version is carried on board *Jianghu*- and *Jiangdong*-class frigates, *Hainan*- and *Haiju*-class escorts, *Kronstadt*-class subchasers, and *Shanghai*-class motor gunboats. The last use suggests that there is an alternative shore-bombardment round.

◆ RBU-2500



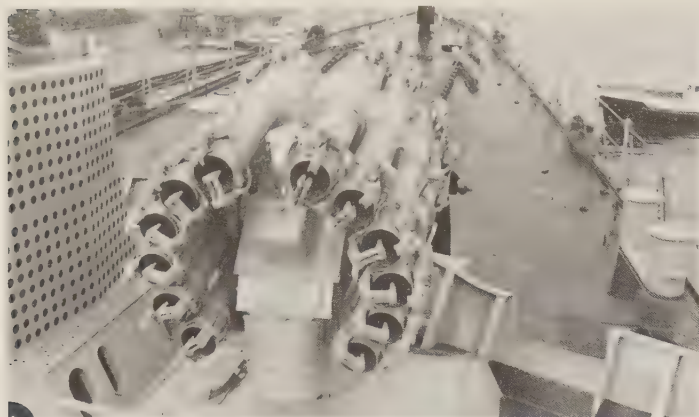
RBU-2500 being loaded. (TASS)

This standard Soviet ASW projector of the early 1960s was introduced in 1957–58. RBU-2500 has 2 horizontal rows of eight 20-cm barrels (21-kg [46-lb] warheads) each, capable of train and elevation. Maximum range is 2500 m [2730 yd].

◆ RBU-6000



The carrier *Baku* introduced a new RBU launcher, seen here. The cylindrical vertical launchers immediately abaft the breakwater are for SA-N-9, and the big tubes are for SS-N-12. (U.S. Naval Institute)



RBU-6000 forward, on board the cruiser *Kerch*, 1989. This is the standard Soviet long-range ahead-thrown ballistic weapon, supplementing missiles such as SS-N-14. (Eric Grove)

This launcher consists of twelve 1.6-m [63-in] barrels arranged in a horseshoe, automatically loaded when they are elevated into the vertical position, barrel by barrel. The barrels fire in sequence, by pairs. RBU-6000 was introduced in 1960–61 and is very widely used in the Soviet fleet. Maximum range is 6000 m [6600 yd]. The old NATO designation was MBU-2500A.

◆ RBU-10000

This is a new launcher first observed on board the carrier *Baku* in 1989; it is presumably the replacement for RBU-6000. The new launcher has 10 larger-diameter tubes in the familiar horseshoe arrangement. The same launcher appears on board the new cruiser *Kalinin*.

RBU-10000 (ten thousand) is a NATO, rather than a Soviet, designation.

◆ SUW-N-1

Dimensions: 0.55 × 9.00 m [21.7 × 354 in]

Weight: approx 2300 kg [5070 lb]

Warhead: nuclear **Range:** 70,000 m [77,000 yd]

An unguided nuclear ASW missile, SUW-N-1 is a navalized version of the FROG-7 army weapon. Unlike the U.S. ASROC, SUW-N-1 apparently has no provision for control in range. It is carried only on board the helicopter carrier/cruisers of the *Moskva* and *Kiev* classes, which presumably rely on Hormone helicopters, using dipping sonars, for final target localization. FRAS might be considered the ultimate development of the RBU idea, substituting a single massive explosion for the multiple small explosions of the RBU rounds.

This weapon was formerly called FRAS-1 (Free Rocket Over Sea) in analogy with the land-based FROG (Free Rocket Over Ground).

The details above refer to FROG-7A, which entered service in 1965. References to SUW-N-1 generally give its range as about 16 nm, but the 70 km given for FROG-7A would be more logical if the weapon was adopted to exploit possible CZ performance by the big LF hull sonar of the *Moskva* class. For the land-based weapon, reaction time to fire is typically 15 to 30 min.

FROG-7 fires to a fixed range determined by the elevation of its launcher. It is analogous to the old U.S. Honest John nuclear-armed rocket. A later version, which probably is not the one modified as SUW-N-1, has air brakes that open at a preset range.

Recently, it has been suggested that SUW-N-1 has an alternative torpedo-carrying version.

◆ Depth Charges

Many ships still carry depth charges and throwers, and similar equipment was widely exported to Soviet client states. There are 2 standard depth-charge mortars: BMB-1, now largely gone, was a spade-and-arbor type with the arbor fitting inside the barrel. In BMB-2, the entire depth charge fits within the mortar

barrel. All Soviet depth charges are cylindrical. Standard internal and external rack capacity is 10 charges per rack.

The standard types are B-1, 4VB, M-1, and 4VM. Characteristics are as follows:

	Dimensions	Weight		
		Total	HE	Settings
B-1	44 × 72 cm [17 × 28 in]	166 kg 366 lb	135 kg 298 lb	20–210 m 66–689 ft
4VB	46 × 73 cm [18 × 29 in]	163 kg 359 lb	115 kg 254 lb	15–210 m 49–689 ft
M-1	26 × 43 cm [10 × 17 in]	35 kg 77 lb	25 kg 55 lb	10–50 m 33–164 ft
4VM	19 × 63 cm [7.5 × 25 in]	22 kg 49 lb	16 kg 35 lb	10–25 m 33–82 ft

All charges are designed to be launched either by a surface ship or by an airplane.

There is probably also a nuclear depth bomb, carried by helicopters and aircraft as an alternative to a homing torpedo. It is not known whether this bomb is the same weapon used as an FRAS-1 or SSN-15/16 warhead.

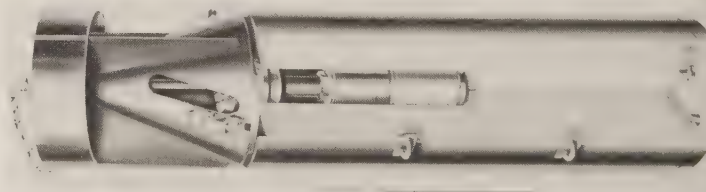
UNITED KINGDOM

◆ Air-Launched Depth Charge Mk 11

Dimensions: 11 in × 4 ft 7 in (body section is 3 ft 2 in long)

Weight: 320 lb **Warhead:** 176 lb

Mk 11 is 1 of very few surviving Western air-launched depth charges; the details describe Mod 3, a new modified version with a stronger outer case to withstand high-speed drops and helicopter vibrations. The U.S. Navy abandoned conventional depth charges on the grounds that they had only a very small chance of killing a fast submerged submarine in deep water. However, modern homing weapons are generally unable to deal with a surfaced or near-surfaced submarine. For example, in the Falklands, British helicopters attacked the surfaced Argentine submarine *Santa Fe* with Sea Skua radar-homing missiles, but the weapons passed through the submarine's sail without damaging her pressure hull. A pair of Mk 11s forced the submarine aground in a sinking state. The advantage of depth charges is that, because they are hydrostatically fuzed, they cannot home accidentally on an irrelevant portion of the submarine. On the other hand, unless the submarine is caught at the surface, the depth charges will almost inevitably miss.



Mk 11 Depth Charge. (Sperry)

◆ Nuclear Depth Bombs

The Royal Navy uses nuclear depth bombs, popularly referred to as Lulus, which is the U.S. code name for Mk 57 (see below); it is not clear whether some or all British depth bombs are of U.S. type. The U.S. weapon was designed as a dual-purpose land-attack bomb and depth bomb. The British weapon may have similar characteristics, making it suitable for dual-purpose ships: that is, the British light carriers may find themselves used either for ASW or for ground support (as in Norway).

The British official reply to those proposing abolition of this weapon is that it is the only certain counter to fast deep-diving submarines, that existing air-dropped torpedoes either lack sufficient performance or else cannot be relied upon, particularly in the presence of countermeasures.

♦ Limbo

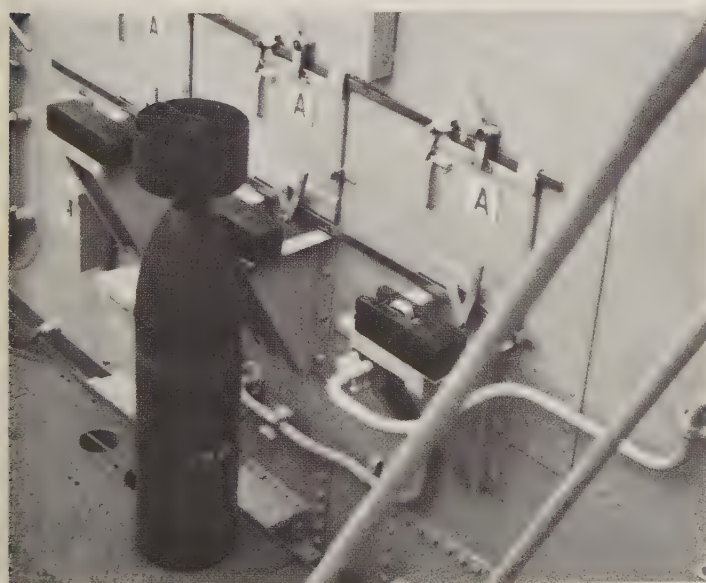
Limbo is a triple-barreled hand-loaded mortar (Mk 10). Range is varied (between 400 and 1000 yd) by opening gas vents, and the barrels are aimed by a combination of roll and pitch (which is also used to stabilize the mounting). The appropriate spacing between rounds is achieved by a short time delay in firing. The weapon is designed so that its shells always enter the water at the same angle (for any ship's speed): their underwater trajectory is easily predictable, for effective fire control. The shells are time-fuzed, to explode at a preset depth. Each projectile weighs 390 lb, including 207 lb of Minol.

The usual installation was 2 Limbos, to form a pair of triangular patterns above and below the estimated position of the submarine. In many cases, however, 1 of the 2 Limbos had to be eliminated to save weight. The total weight, for 1 Limbo mounting and a magazine holding 17 salvos (51 bombs), is about 35 tons. Lethal range is about 5 yd; however, at ranges up to 50 yd, light fittings will be shattered and pipes cracked. Serious psychological effects can be expected at even greater ranges.

Limbo was the ultimate development of World War II British ahead-thrown ASW weapons, beginning with Hedgehog. The associated sonar is Type 170. In 1988 only 4 Royal Navy ships



A Limbo mortar, 1986. (R. Cheung)



A Limbo practice round, 1986. (R. Cheung)

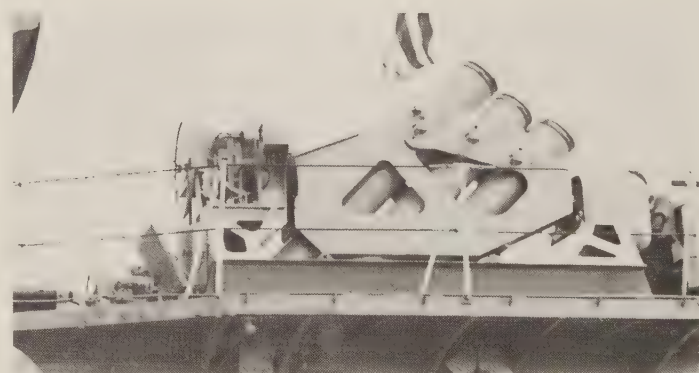
retained Limbo. Surviving Limbo installations are Canada (the *St. Laurent*, *Mackenzie*, and modified *Restigouche* classes), Chile (the ex-*Achilles*), India (the *Leanders* and *Trishul*), Indonesia (the ex-Tribal class), Iran (the Mk 5 frigates), Malaysia (the *Rahmat* and *Hang Tuah*), Pakistan (the *Leander* class), and the United Kingdom (some *Leanders*).

♦ Squid

This triple ahead-thrown mortar (Mk 6) was introduced in 1943. Unlike Hedgehog, Squid fires depth charges that explode at a preset depth. Although Hedgehog entered service first, both Hedgehog and Squid were conceived simultaneously and were developed in parallel, and Squid outlasted Hedgehog in postwar British service. Squid was the first ASW weapon to be fully integrated with a sonar, its depth pistols being set automatically by a depth-determining sonar (usually Type 147 in World War II). Each 394-lb projectile (11.93 × 56.5 in) carries 207 lb of Minol II and sinks at about 44 ft/sec. The pattern for each projector is a triangle with 120-ft sides, and the standard installation is a double Squid producing a double layer with charges about 60 ft apart vertically, the hope being that the submarine is sandwiched between them. The mountings are designed to fire dead ahead, but they can tilt about 30 deg to compensate for roll and yaw, and also for minor course errors. The middle barrel's splash range is set at 270 yd (mortar 9 ft above water; for each additional 3 ft of height, the range increases a yard). The firing interval is 0.28 sec.

There is also a shallow setting (20 ft), introduced late in World War II, that can be used against a submarine detected either on the surface or just below (e.g., by radar detection of a periscope). In such a case, radar data are fed directly into the sonar's range and bearing indicators.

Squid is still in service on board 1 Bangladeshi frigate, 2 Chilean destroyers, and 1 Iranian "Battle"-class destroyer. In these ships the projectors are well above the water line, and range is 380 yd.



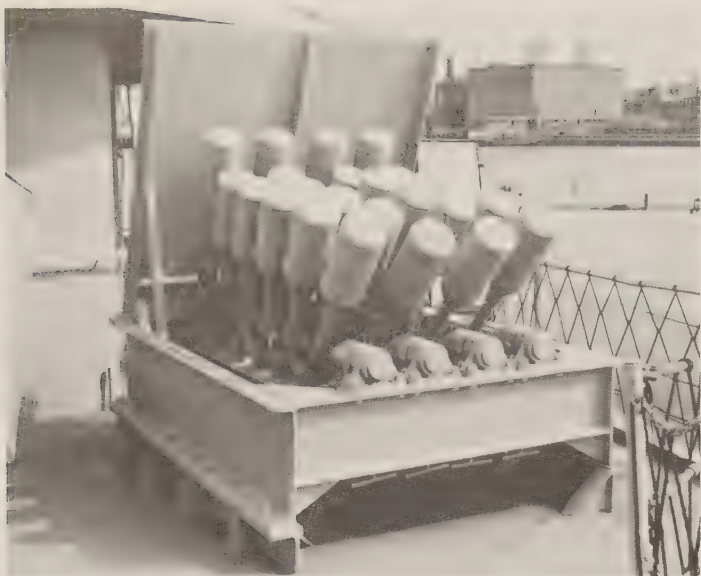
SQUID. (A. Raven)

UNITED STATES

♦ Hedgehog (Projector Mk 10/11)

This World War II standoff mortar was installed on board all U.S. World War II escorts and on board many U.S. destroyers during the 1950s, and Hedgehog survives on board some units in foreign navies. Existing units are fixed in train and elevation, although the mortar spigots can be rolled back and forth to stabilize them against the roll of the ship and to move the point of impact in train (by up to 25 deg).

Hedgehog fires 24 impact-fuzed fast-sinking rounds from spigots, the bombs forming an elliptical (Mk 10) or circular (Mk 11) pattern in the water. The standard post-World War II installation is 2 Mk 10s or Mk 11s that fire together. Typical pattern dimensions for the double Hedgehog: Mk 10, 195 ft wide and 168 ft in range at an average range of 283 yd; Mk 11, 267 ft in diameter at a range of 267 yd. Maximum bomb velocity is 175 ft/sec, and a typical flight time is 10 sec, plus 18.2 sec to sink



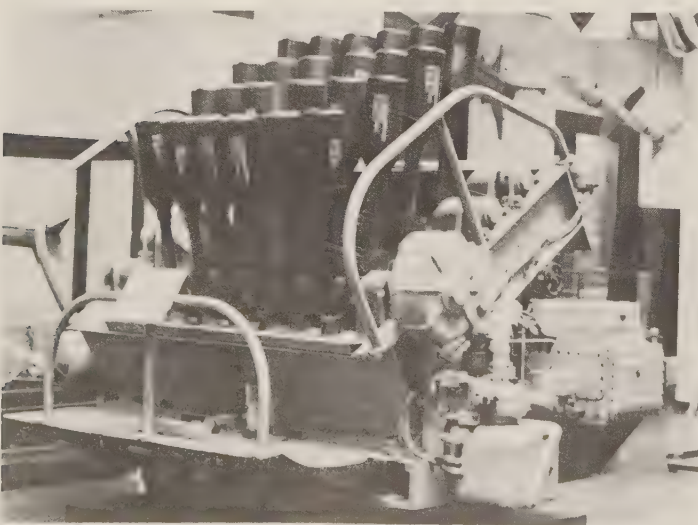
Fixed Mk 11 Hedgehog on board USS *Cassin Young* (museum ship), 1986. (A. Raven)

to 200 ft. Total installation weight, including the usual 6 reload salvos, is 28,720 lb.

Surviving fixed Hedgehog installations are in Brazil (5 FRAM II destroyers), Chile (2 FRAM IIs and 1 *Charles Lawrence* class), Greece (1 FRAM II DDR, 1 *Allen M. Sumner*, 4 *Fletchers*, and 4 *Cannon* class), Indonesia (4 *Claud Jones* class), Korea (2 FRAM II *Gearings*, 2 FRAM II *Sumners*, and 1 *Fletcher*), Myanmar (Burma) (1 PCER and 1 former minesweeper), the Philippines (2 *Cannon* class and 2 *Auk* class ex-minesweepers), Taiwan (1 *Wu-Chin II Gearing*, 2 *Wu-Chin I Sumner* FRAM IIs, 4 *Sumners*, 4 *Fletcher* class, 3 *Auk* class, and probably still some on board *Crosley*-class ex-transport), Thailand (1 *Cannon* and 2 *Tacoma* class), and Turkey (1 FRAM II *Sumner*, 1 *Smith* class destroyer minelayer, and 2 *Berk* class). The equivalent British Hedgehog is extinct.

◆ Hedgehog (Projector Mk 15)

The trainable Hedgehog spigot mortar is found on board post-war-built U.S.-designed 173-ft patrol craft in the Turkish and Chilean navies. In these cases the weapon is controlled on the basis of SQS-17A sonar data. The mortar is stabilized and power-trained; total weight is 17,425 lb (26,785 lb including the standard allowance of 6 patterns). The typical pattern was a 279-ft circle at a range of 265 yd, the bombs taking a total of 29 sec to reach a depth of 200 ft (10.4 sec in flight, 18.6 in the water). Mk 15 also survives on board the old Japanese destroyers



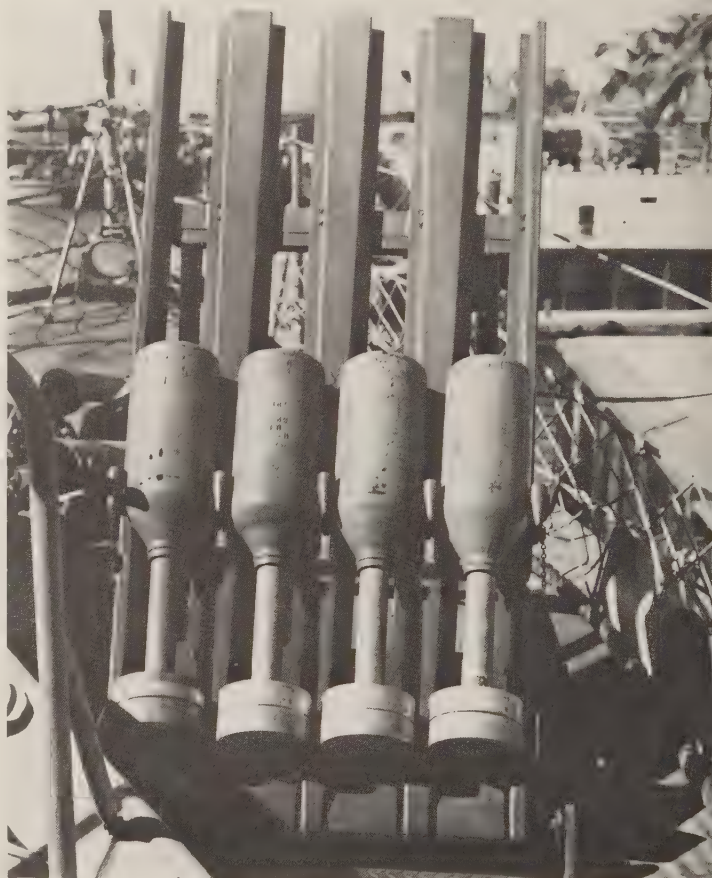
Hedgehog Mk 15. (Author)

(now auxiliaries) of the *Akizuki* and *Ayanami* classes and on board the Turkish destroyer *Kocatepe*.

◆ Mousetrap (Projector Mk 20/22)

Mousetrap is a World War II-designed rocket standoff weapon for small craft, installed on board many patrol craft supplied to U.S. allies through the early 1970s. Rocket propulsion was adopted to avoid the weight penalty (in deck strengthening) associated with Hedgehog. Mk 20 consists of 2 sets of 4 rails, which can be folded down to lie flat on deck; Mk 22 has 2 sets of 8 (4 rails on top of the original 4). The warhead was that of Hedgehog, but with a rocket motor (i.e., with a slower-burning propellant). The 16 projectiles of a Mk 22 formed a pattern about 80 yd wide at a range of 300 yd.

Surviving Mousetrap installations are in Iran (1 *Cape*-class cutter), Spain (3 U.S. 83-ft types), and Turkey (the *Girne*, 12 AB 25 class, 4 PGM 71 class, and 4 U.S. 83-ft types). Mousetrap may also be mounted on board U.S.-supplied or license-built PGM 39/71 series gunboats: Brazil (6), Dominican Republic (1), the Philippines (5), and Vietnam (10). It was originally on board the U.S. Coast Guard 95-ft patrol boats, on which the gunboats were patterned.

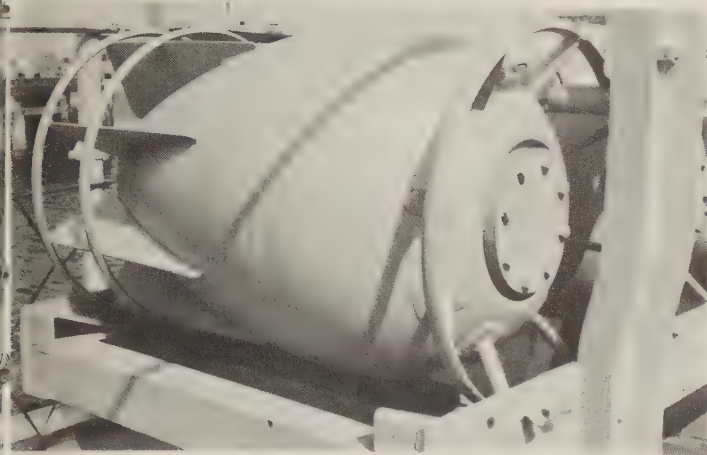


Mousetrap. (National Archives)

◆ Depth Charges

The U.S. Navy currently uses only nuclear depth bombs. The standard nuclear depth bomb is based on the B57 weapon and is designated bomb Mk 101 or "Lulu" (18 × 92.4 in, 1200 lb). B57 can be used either as a depth bomb or (in a streamlined casing) as a lay-down bomb against land targets. B57 can be delivered both by LAMPS helicopters and by fixed-wing aircraft.

One squadron each of Dutch P-3Cs (13 aircraft) and Italian Atlantics (9 aircraft) are reportedly certified to deliver U.S.-supplied B57 depth bombs. In each case, they succeed earlier aircraft that had this capability (Neptunes in the case of the Netherlands, Trackers in the case of Italy). British Nimrods are certified to deliver U.S. B57s, which presumably are backups to the British-built WE-177Cs.



U.S.-type streamlined (teardrop) depth charge, on board USS *Cassin Young* (museum ship), 1986. (A. Raven)

In June 1987 the *Bulletin of the Atomic Scientists* estimated that the U.S. stockpile contained 900 B57 depth bombs. This weapon is scheduled for retirement in the near future in favor of a new nuclear depth bomb. See the discussion of nuclear bombs in the Strike/Surface Warfare section.

Many conventional depth charges formerly used by the U.S. Navy probably survive in Allied navies and, therefore, deserve description here.

The standard air-dropped weapon was the Mk 54 depth bomb (13.8 × 52.5 in, total weight 354 lb, charge 250 lb of Torpex or HBX). Mk 54 became the standard NATO air-launched depth bomb; it is currently used by the French navy and probably by other NATO navies. A new depth bomb is being developed, in the form of a hydrostatic fuze (SAM-104) for Mk 82 bombs, to give SH-3s and other helicopters the ability to attack surfaced and near-surfaced submarines. The SAM-104 program was inspired by the successful depth-bomb attack on the *Santa Fe* in the Falklands (see the U.K.'s Mk 11, above).

The standard shipboard depth charge was the fast-sinking (teardrop-shaped) Mk 9, provided with fins that spun it to stabilize it while it sank. Mk 9 carried 200 lb of explosive and sank at 22.7 ft/sec (settings 30 to 300 or 600 ft). Overall dimensions were 17.7 × 27.6 in; total weight, 340 lb. The initial version, Mod 0, sank at 14.5 ft/sec. Mk 14 is an influence-fired version of Mk 9, using an acoustic pistol.

Some earlier cylindrical depth charges (Mk 6) may survive. Dimensions are 17.7 × 27.6 in; total weight is 420 lb, including 300 lb of explosive. Burst depth can be set at 30–1000 ft. Sinking rate is about 8.5 ft/sec.

COUNTERMEASURES

Underwater training targets are, in effect, submarine simulators and are, therefore, viable decoys, although they are not generally so described. Some of them are listed in the U.S. systems below.

FRANCE

In 1984 the French navy funded studies by Lacroix and Thomson-CSF of thrown torpedo countermeasures, with preliminary trials between December 1984 and January 1985. The grenades would be fired from SAGAIE countermeasures launchers (see the AAW section for launcher details). Three alternatives were considered: a pyro-acoustic noisemaker, a gas generator that would produce a bubble curtain to hide a ship (just like an underwater chaff cloud), and an expendable jammer. The bubble cloud would tend both to hide the noise of the ship and also to reduce the ability of an active homing torpedo to detect a ship. The expendable jammer might be used to monitor the approach of the torpedo and communicate with the ship, which in turn would order the jammer to produce noise or deception signals.

As described in 1986, the jammer would be deployable about 20 sec after alerting, 3800 m [4160 yd] from a ship, to operate for 4–8 min. As of 1988, Lacroix was designing a 130 × 780 mm [5.1 × 30.7 in] round (50 kg [110 lb]), operating in less than

3 sec, at ranges of 10–200 m [11–220 yd], carrying a 25-liter payload of bubble generators, pyro-acoustic noise sources, or an active decoy that would respond to the torpedo's sonar and emit doppler-shift-compensated false echoes. Safare-Crouzet and Thomson Sintra are developing an electro-acoustic decoy.

Reportedly, a self-propelled antitorpedo direct-kill (kinetic-energy) weapon is under consideration.

♦ SLAT

SLAT (*Système de Lutte Anti-Torpille*) is an antitorpedo system for ships not equipped with the SLASM ASW system (see above), such as carriers, AAW destroyers, and the new general-purpose frigates. Directional (presumably at least dual-line) towed arrays will provide torpedo warning, and the countermeasure will presumably be 1 of the types described above, launched by SAGAIE (see the countermeasures in the AAW section).

♦ Spartacus

Thomson Sintra, CSEE, and Lacroix jointly exhibited this surface-ship antitorpedo countermeasure at Bourget Naval in 1990. A painting of the system shows a frigate towing what appears to be an ATAS sonar and firing a rocket decoy (which floats suspended from a sonobuoy-type float) into the path of an oncoming torpedo detected by the towed sonar. Typically, the system would fire 3 decoys in sequence to seduce the torpedo far enough away from the ship so that it could not circle back to re-attack. Decoys will be launched automatically, subject only to veto by the ship's commander. They may be fired from either DAGAIE Mk 2 or SAGAIE launchers and can be deployed at ranges up to 3000 m. Both pyro-acoustic and electro-acoustic payloads are being developed: an anti-wake follower is a likely future development.

ISRAEL

♦ ATC-1

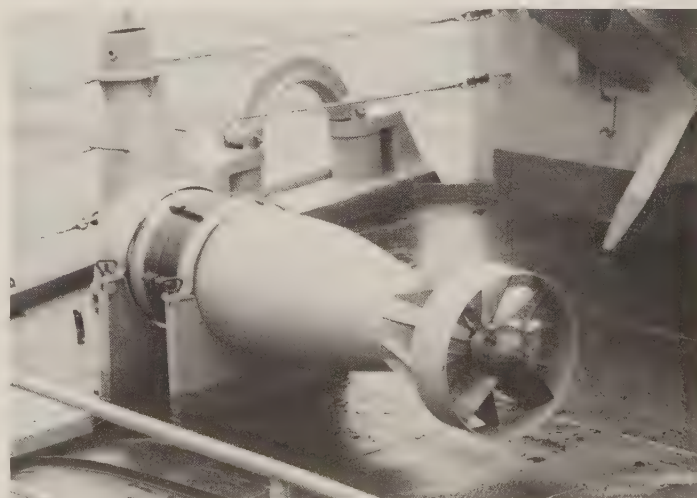
Rafael's Acoustic Torpedo Countermeasure (decoy) for the Israeli navy was announced in 1986; ATC-1 is also usable by merchant ships. Dimensions of the towed body are 30 × 120 cm [12 × 47 in], and it weighs 25 kg [55 lb]; launch and recovery gear weigh 800 kg [1760 lb], and the electronics cabinet onboard ship weighs another 190 kg [419 lb], with a 10-kg [22-lb] remote control unit.

ITALY

♦ C303

This Whitehead submarine antitorpedo countermeasure system uses an EFFECTOR expendable device, which can be configured either as a decoy or as a sonar jammer.

USSR



A noisemaker (acoustic decoy) on board a Soviet Krivak-class frigate, 1990. Most Soviet decoys are not buoyant, and they are streamed with separate floats. (H. J. Verhoeven)

UNITED KINGDOM

◆ Bandfish (Amulet)

Dowty's expendable submarine self-protection countermeasure is designed to float in the water while transmitting active pulses to confuse an oncoming active-homing torpedo. Bandfish is programmable before launch. Bandfish, which won a competition against a Marconi countermeasure, is named Amulet in British naval service. Dimensions are 102 × 995 mm [4 × 39.2 in], and weight is 12 kg [26 lb]. Shelf life is 5 yr.



A Bandfish decoy is loaded into a submarine signal ejector. (Dowty)

◆ Foxer/Unifoxer

These towed torpedo decoys were developed during and immediately after World War II. They emit broad-spectrum noise and reportedly were retained in storage because they could simulate the noise of, for example, a convoy. They were used as countermeasures by merchant ships and some auxiliaries during the Falklands War.

Derived from a wartime acoustic mine sweep, Foxer consisted of 2 steel pipes held loosely in a frame. When towed, they hit each other to produce the noise. Escorts towed a string of 2 Foxers 100 yd apart (this distance was maintained by mine-sweeping kites), on the theory that the German acoustic torpedo had only a limited FOV and might miss a single decoy. The devices were towed 200 yd astern. Foxer weighed about 3 tons

and could not be towed at speeds over 14 kt. It tended to break up under tow (average lifetime was 25 hr) and to interfere with sonar (asdic). Foxer's production began in July 1943.

It turned out that the German torpedo had a very wide FOV, so a single noisemaker, Unifoxer, could suffice. Unifoxer was issued beginning in February 1944. It was towed 350 yd astern at 10 kt (maximum tow speed was 20 kt), and it covered the 5–50-kHz band.

◆ TALISMAN

This British project for an antitorpedo project later became joint U.K.-U.S. project.

◆ Type 182/Graseby G738

This tunable narrow-band noisemaker uses a magnetostriction transducer. Wartime experience showed that the broad-band units, such as Unifoxer, jammed escort sonars. It was soon discovered that acoustic homing torpedoes themselves operated on fairly narrow bands; given sufficient intelligence, a noisemaker could be tuned to the appropriate frequency so that it could operate without jamming a sonar operating on a different one. Work began late in 1944, leading to Type 155 (Cheater), a decoy embodying a frequency-modulated (FM) noise source, to be towed 350 yd astern. Although Cheater was not ready in time for wartime use, it appears that the current standard British decoy, Type 182, was an extension of the same basic idea.

The Type 182 fish is 21 in in diameter and 79 in long and weighs 163 lb. Typically, 2 towing drums are arranged side by side at the stern, the decoy itself being handled by davit. The



A Type 182 decoy and its handling crane on board the frigate *Andromeda*, 1985. (R. Cheung)



Type 182 decoys. (R. Cheung)

decoy is designed to be streamed 400 m astern. In its present form the decoy can either simulate the noise characteristics of a ship or produce sonar-like pulses (CW) that can jam or confuse an active-homing torpedo. Both modes can be transmitted simultaneously. Shipboard signal generators are duplicated so that the system can continue to operate even in the event of 1 fails.

Type 182 was designed to protect destroyers and frigates at speeds of up to 25 kt and larger ships at speeds of up to 18 kt. To decoy passive torpedoes, it emits modulated white noise (at an intensity of 20 dB above the ship's radiated level) at 20–80 kHz. To jam (not decoy) active homers, it produces a high-intensity tone signal swept 4 times/sec over the 20–80-kHz interval, modulated (1 msec on, 1 msec off).

Graseby G738 is the export version of Type 182, and GI738 is a solid-state version. As of 1983, GI738 had been exported to both Argentina (for MEKO frigates) and India.

G738 produces 2 independent outputs: AM noise to simulate a propeller and swept CW to jam torpedo sonar.

◆ ATAAC

The DBE Technology (Ferranti subsidiary) antitorpedo acoustic countermeasure is a noisemaker designed to be fired from a standard British or U.S. chaff launcher. ATAAC was announced in 1987. Rounds are programmed immediately before launch, to produce broad-band high-power noise. ATAAC can also be produced in 3- or 4-in-diameter form, for ejection from standard submarine countermeasures tubes; and reportedly a 21-in self-propelled wire-guided version, for firing from submarine torpedo tubes, was developed in 1987–88.

DBE began work with Whitehead in 1987, and the resulting submarine-launched decoy is now (1990) in preproduction service. DBE (Ferranti) makes the sonar portion.

The Royal Navy currently uses the U.S. ADC Mk 2, and the Whitehead device was offered as an alternative. Ferranti claims that it develops more power and has longer endurance. However, ADC Mk 2 hovers better, using its small propeller to keep it between preset depth limits (ATAACS sinks on a retarding drogue). The Royal Navy also uses Bandfish; it has both 3- and 4-in signal ejectors.

Ferranti has designed additional seduction countermeasures for Whitehead (noise and real-time echo repeaters) and has built prototypes. It manufactures the analog elements of the devices but not the signal processor (which Whitehead makes under license from Gould).

ATAACS itself was designed to be compatible with the Shield

chaff rocket-launching system. It can also be manufactured in other calibers. Thus far (mid-1990) it has found no buyers. It is reminiscent of the U.S. practice, immediately after World War II, of firing noisemakers (NAE beacons) by rocket from ASW ships. This system was soon discarded because the rocket launchers had to be able to train and then to fire without warning, endangering personnel topside. Presumably, a modern fixed-train launcher could fire at such range that the ship could maneuver it into position, and the associated maneuver-advice device would cause the ship to turn appropriately.

At Comdef '90 (in November 1990) Strachan & Henshaw showed a sketch of an abortive triple torpedo-countermeasure launcher, designed for a client about 18 months earlier. It resembled a subcaliber Mk 32 tube (capable of elevating) mounted on a pedestal and was, presumably, intended to fire ATAACS or some similar decoy.

In 1987 it was reported that Graseby was developing a similar software-controlled decoy, actuated directly by a ship's sonar.

◆ Mintec Sonar Intercept System

This digital, active-sonar intercept system, incorporating transputer processors, was announced in 1990. Mintec, the manufacturer, claims that it is much simpler than earlier systems, only a single pair of wires connecting the array electronics and the main processor. The arrays themselves are smaller than existing types. Presumably, the use of a single pair of wires implies that sampled hydrophone data are transmitted sequentially, as in the SBF 256 beam-former described above.

◆ Sea Siren

This new Graseby torpedo decoy was first shown at RNEE 1989. It is microprocessor-based and user-programmable.

◆ SSDE

Submerged signal and decoy ejector, currently standard on board British submarines, is supplied by Strachan & Henshaw (which also makes the current torpedo handling-and-discharge systems). SSDE uses an air-actuated water ram adjacent to the vertical decoy launcher tube in the submarine's pressure hull. The company offers automatic store loading (from a magazine below the launcher) and a direct connection with the submarine combat system as options; it also offers a simple manually loaded version. SSDE can accommodate both standard British (4-in diameter) and U.S. (3-in diameter) decoys, up to 39 in long. Although announced in 1990, it has apparently been in service for some years.

◆ DMT

Thorn-EMI's Deep Mobile Target can be fired from submarine and surface-ship torpedo tubes. Dimensions are 12.75 × 129 in; weight is 520 lb. Speeds are 0 kt, 8 kt (for 100 min), 14 kt, and 22 kt (for 8 min). Depths are 30–1200 ft. DMT dives or climbs at 30 deg (0.84 ft/sec/kt) and has a turning radius of 250 ft (rate of turn is 0.38 deg/sec/kt). Transponders are provided for active/passive homing at 30–70 kHz and active/passive sonar at 7–11.5 kHz, and there is a miss-distance indicator at 125 kHz. DMT can be commanded to stop. It entered service in 1983 and was used in the Spearfish, Tigerfish, and Stingray programs. The cheaper towed Type 2058, which entered production in 1985, is its successor.

EMI Electronics's Deep Mobile Target can be fired from submarine and surface-ship torpedo tubes. Dimensions: 12.75 × 129 in, weight 520 lb, speed 8–22 kt, maximum depth 1200 ft.

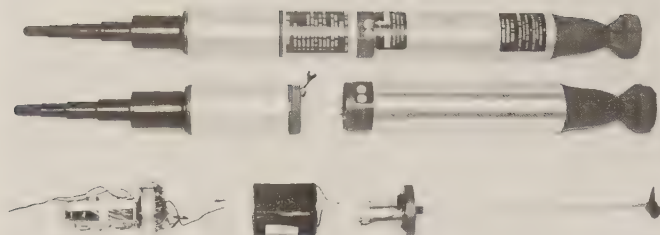
UNITED STATES

◆ ADC Mk 1

Acoustic Device, Countermeasure is a submarine-launched sonar countermeasure powered by a seawater battery. Dimensions: 5-in diameter, 72.75-in length, weight 41.3 lb. It was probably introduced about 1973.



ATAAC decoy in surface-launched form, as displayed at Farnborough. [Author]



ADC Mk 2 Mod 0. The acoustic projector is at the top. It contains the ceramic transducers and impedance-matching networks. Adjacent to it is an electronics section (the object exposed at top left) containing the signal generation and amplification circuits. Power is provided by the seawater battery (center left). At bottom left are the motor and propeller of the hovering module, which also provides the decoy's buoyancy as it hovers in the water. The hover motor is pressure-controlled to maintain nearly constant depth. Dimensions are the standard 3×39.5 in of a submarine's signal tube (weight 7.5 lb). (Hazeltime)

◆ ADC Mk 2

Emerson's electro-acoustic torpedo countermeasure was originally designated ETC-1. It is a submarine-launched torpedo decoy, hovering (by means of a small propeller) and emitting signals at a preset depth. Dimensions: 3.0×39.5 in (weight 7.6 lb). ADC Mk 2 was introduced in 1978; by 1987, when it was first shown publicly, over 2800 had been manufactured.

◆ ADC Mk 3

This torpedo countermeasure is designed for launching from CSA Mk 2. Total weight is 125 lb. Operational evaluation was completed in FY88. As of early 1989, it was expected that a production contract would be awarded in FY89. The Operational Requirements for ADCs Mk 3 and 4 (and for CSA Mk 2) were issued in December 1976.

◆ ADC Mk 4

This submarine-launched sonar jammer, complementing Mk 3, is launched by CSA Mk 2. Dimensions: 6.25×106 in (weight 100 lb). Bids for full-scale engineering development were solicited during FY88, and the FY89 program included preliminary and critical design reviews of engineering-development models (EDMs) for Mk 4.

◆ ADC Mk 5

Sonar countermeasure. Dimensions: 6×106 in (weight 110 lb).

◆ ADC Mk 6

This expendable torpedo countermeasure is intended as part of the Basic Acoustic Warfare System (AWS), for rocket launching from SRBOC surface-ship mortars. It contains 2 electronic signal generators. Diameter is 5.133 in, and weight is 30.44 lb. This nomenclature was assigned in 1977.

◆ ADC Mk 7

This mechanical sonar jammer is a motor-driven sound generator designed as a companion to Mk 6. Diameter is 5.133 in, and weight is 32.84 lb.

◆ ADC Mk 8

This mechanical torpedo countermeasure is a motor-driven sound generator similar in concept to Mk 7. Diameter is 5.133 in, and weight is 30.4 lb.

◆ ADC EX-9

The submarine mobile acoustic countermeasure, to replace the Mobile Submarine Simulator Mk 70, is a countermeasure for strategic submarines. Dimensions: 6×96 in (weight 100 lb). It is launched by CSA Mk 2.

◆ ADC EX-10

This surface-ship advanced acoustic countermeasure (AACM) was conceived as part of an early surface-ship torpedo-defense program (SSTD), about 1983. See the SSTD entry.

◆ BLR-14

Sperry's basic submarine acoustic warfare system (BSAWS) uses existing equipment to detect, evade, and counter torpedoes. It automatically alerts a submarine, rapidly classifies incoming torpedoes, tracks them, and semiautomatically releases decoys. This system uses the preformed beams of the existing submarine sonars for torpedo tracking. The detector is WLR-9A/12, and the classifier is WLR-14 (1975).

◆ BLQ Series

This decoy generation preceded the current one. These decoys may survive in foreign navies, and their characteristics, though obsolete, give some idea of what decoys are expected to achieve. At least the following were developed:

BLQ-1 Fixed jammer intended simultaneously to jam 3 ship or torpedo soars. Controlled from within the submarine, it listened for 5 sec and transmitted for 25. The first was delivered in December 1960, but it failed its operational evaluation.

BLQ-2 Mobile decoy and jammer against surface-ship sonars (submarine simulator). It carried a sonar repeater/jammer and also a beacon simulating the beat of a submarine propeller; it was launched from a submarine torpedo tube and followed a preprogrammed course (30–60 sec at 12 kt, then 19 min at 6–9 kt, at a depth of 50–300 ft). The first 5 were tested successfully in 1956, but BLQ-2 was never made in large numbers.

BLQ-3–6 A series of small-diameter (3×39 in) hovering decoys, first tested in breadboard form in 1962. They were ejected from the submarine's signal gun. BLQ-3 and -4 were jammers; BLQ-5 and -6 were sonar repeaters. These devices differed from their predecessors, the NAE series, in that they responded to sonar signals. The earlier devices were preset to emit over a given frequency range. Coverage of the full range of frequencies, in this case 7–70 kHz, required 2 separate devices.

BLQ-9 Successor to BLQ-2, and predecessor of MOSS (see below). It is a 10-in contact-breaking device with a speed of 8–10 kt, operating at 50–400 ft. BLQ-9 was initially a sonar repeater (blip enhancer) but later carried a sonar noise jammer. It also emits submarine sounds at 0.1–1 kHz. This decoy also simulated a submarine wake (which itself can be a sonar target) by passing seawater over lithium hydride. BLQ-9 and MOSS are characterized as contact-breakers. Six BLQ-9s were stowed in a modified torpedo-stowage cradle and ejected via the torpedo tube using temporary liners.

◆ CLAMS

Countermeasure launcher acoustic module set is a predecessor to the CSAs described below. It is made by Librascope, and it is carried by both strategic and attack submarines.

◆ CSA Mk 1

Countermeasures set, acoustic, is a quick-reaction countermeasures-launching system for strategic submarines. It employs launching device Mk 139. Decoys are launched by a gas generator. Dimensions are 6.5×87.54 in. This nomenclature was introduced in 1973, although the device may be older. The 5-in launcher is mounted externally.

◆ CSA Mk 2

Librascope's submarine countermeasures-launching system, for ADCs Mk 3 (torpedo) and Mk 4 (sonar), employs launcher Mk 151. Individual countermeasures devices (ADCs) are remotely selected and launched. It was conceived for ballistic-missile submarines (Mod 0), but Mod 1 will be installed on board *Sturgeon*-class attack submarines. Operational evaluation was com-

pleted during FY88. The FY89 program included the award of the CSA Mk 2 production contract and the completion of a launcher-system design for *Los Angeles*-class submarines. This has been a very protracted program; the original Operational Requirement dates from December 1976.

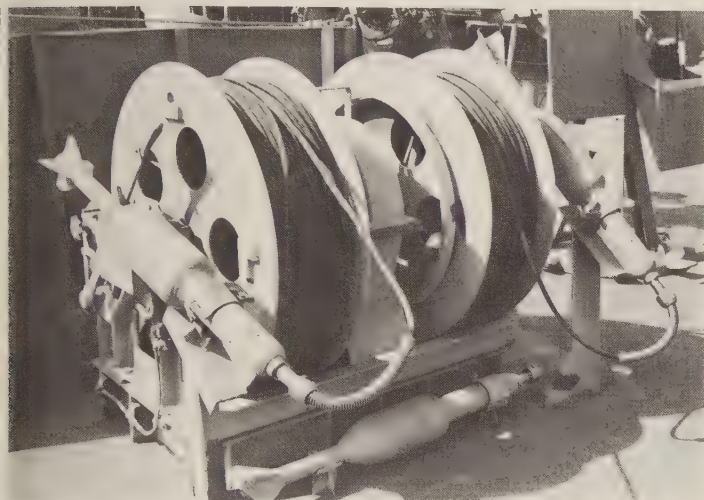
◆ CSA Mk 3

Countermeasures-launching system for the new *Seawolf*-class submarine. An unclassified 1987 data sheet shows capacity for up to 16 decoys, up to 6×106 in in size.

◆ Fanfare (T.Mk 6)

The standard U.S. towed torpedo decoy of the 1950s and 1960s is fitted on board FRAM destroyers. The characteristic installation includes a small spray shield protecting the towing winch. Two decoys are provided per installation. In U.S. service, Fanfare was replaced by Nixie, but many Fanfares probably remain in service in other navies.

Fanfare replaced the U.S. wartime FXR.



Fanfare on board the destroyer *Cassin Young*, showing the dual winches, each with its fish, and the spare fish between. (A. Raven)

◆ NAE/NAD/FTC

These World War II sonar-countermeasures designations have survived in generic form. Some of the countermeasures themselves may also have survived, at least in the smaller navies. Most of the countermeasures were intended for release from the standard U.S. 3-in signal tube, which limited them to dimensions of 3×39.5 in. The current CSAs are their lineal successors.

NAE is now the generic term for a noisemaker. The current version is NAE Mk 3.

FTC, the false-target canister, creates a false target by making bubbles, e.g., by letting seawater pour over lithium hydride. Unlike a mobile decoy, an FTC is released from a submarine to fill a volume of water with bubbles; it is the submarine equivalent of a chaff round.

◆ Nixie (SLQ-25)/SLQ-36

This towed noisemaker, made by Aerojet, was first produced in 1974. A total of 180 have been procured for the U.S. Navy, and many have been exported. The usual installation is a pair of winches with 2 Nixies, the decoys trailing through ports in the transom. They do not generally operate together; rather, 1 is available if a torpedo destroys the other. Nixie is about half the size and weight of Type 182. Towed body (TB-14) dimensions: 6 in (diameter) $\times$ 37.05 in (tail fin, 7.31-in diameter); weight is 46 lb. Nixie evaluation was completed in December 1970, and SLQ-25 was approved for service use in February 1971.

SLQ-25 is now being modified. The FY88-91 programs include 421 engineering change kits. The FY90 program includes

production of a Nixie towed-body engineering change and also of a Nixie power-amplifier engineering change.

SLQ-36 is the combined countermeasures tow (CCT), part of the new torpedo-countermeasures system. It comprises an improved Nixie, a magnetic countermeasure, a wake-homing-torpedo countermeasure, and a towed torpedo detector. The magnetic countermeasure is presumably intended to detonate torpedoes using magnetic exploders. This designation was assigned in 1983.

◆ SLQ-33

SLQ-33 is a towed acoustic simulator for escort battle groups. SLQ-33 is used for cover and deception and is van-mounted. Specifications for a product-improved version were completed in FY87. SLQ-33 is made by Honeywell. Towed body dimensions: 27.36 in (diameter) $\times$ 117 in (1950 lb).

◆ SLR-24

This passive acoustic-threat sensor (PATS) is a torpedo detector, part of the new (ca. 1985) U.S. surface-ship torpedo-defense program. The basic Operational Requirement (OR) was issued in March 1985, following a Navy Development Coordinating Paper of January 1985. SLR-24 would trigger either defensive maneuvers or an antitorpedo weapon, perhaps a converted torpedo. The SLR-24 advanced procurement program begins in FY90.

SLR-24 consists of a beam-former/signal conditioner, 1 receiver/signal processor, and 4 acoustic arrays: DT-511B/WLR-9, DT-593/WLR-12, a hull-mounted directional array, and a Martin Marietta towed torpedo detector. By 1990 it appeared that the big hull arrays had been abandoned. The inboard electronic elements are made by Norden.

◆ SSTD

Surface Ship Torpedo Defense is the current U.S.-British program. The 2 competing consortia are General Electric, Honeywell, Marconi, Plessey, and AT&T, Librascope, Dowty, Ferranti. The U.S.-British MoU on SSTD was signed 26 Oct 88. There is also a national (U.S.) SSTD program, and the connection between it and the 2 Nunn programs is not altogether clear.

An official description of the U.S. national program mentions modifications to torpedoes and acquisition of Mk 32 torpedo launchers (see also the list of versions of Mk 32, above, including 1, Mod 16, specifically for SSTD). Logos displayed at the U.S. Navy League show in 1989 showed a surface ship launching an undefined single object at an incoming threat torpedo, presumably a modified lightweight torpedo. Work is still proceeding on alternative concepts (see below).

The use of a homing kill weapon should solve a major problem of past attempts at antitorpedo defense, the excessive amount (particularly weight) of ordnance required to deal with each incoming torpedo.

The other central problem is the high false-alarm rate. It is presumably being approached via better detectors (such as the SLR-24 towed array) and better signal processing. The problem remains difficult, particularly in the face of intense sea noise in rough weather. On the other hand, beyond some particular sea-state, the sea noise will make passive homing against surface ships virtually impossible, and the roughness of the sea will probably make wake-seeking torpedoes ineffective.

This is a phased program. Phase I installations, presumably for torpedo detection (no extra torpedo tubes were fitted, so Phase I cannot have been the antitorpedo weapon), began in FY88. Presumably, too, the program initially applied only to the highest-value units (carriers), since the 1988 program description notes that, beginning in FY90, it was to be extended to surface combatants, the combat logistics force (underway replenishment ships), and to amphibious ships. That representation suggests that SSTD will employ a homing antitorpedo weapon. Such a development, which is presumably possible with modern forms of torpedo homing, would solve a major problem of earlier antitorpedo weapons, the excessive amount of ordnance needed to deal with each incoming torpedo. The

other central problem, a drastic reduction in the false-alarm rate, might be solved by better on-board signal processing. The problem remains difficult, particularly in the face of intense sea noise in rough weather. On the other hand, beyond some particular sea-state, the sea noise will make passive homing against surface ships virtually impossible, and the roughness of the sea will probably make wake-seeking torpedoes ineffective.

SSTD follows several false starts. Renewed interest in hard-kill torpedo countermeasures was inspired by the appearance of the big Soviet wake-following torpedo (Type 65), which would not respond to conventional noisemakers, no matter how sophisticated. By 1987, 2 separate programs, Antiship Torpedo Defense and Surface Ship Torpedo Defense, had both died. Under the Nunn Amendment, effort shifted to a joint U.S.-U.K. program, SSTO.

An R&D contract award is expected in 1991.

Several radical SSTO schemes, sponsored by DARPA, have been described by the press. They are outgrowths of strategic-defense research and are presumably being pursued under the BTI (balanced technology initiative) program. One approach is to use an electric (rail) gun or chemical reaction to accelerate an underwater projectile to supersonic speed; the other is to generate shock waves in the ocean to throw off or destroy a torpedo. DARPA let its first contract to the University of Texas Center of Electromechanics in 1985, to study the use of an electromagnetic launcher. Tests of projectiles made by a California company, PDA, at NSWC are said to have shown that water resistance is much reduced at very high speed because of the gas bubbles that surround the projectile on launch. EML of Hudson, Massachusetts, has reportedly developed a magnetic wave launcher, which has fired 3-in miniature torpedoes at the David Taylor Model Basin. In 1 series of tests the electromagnetic launcher fired the torpedo; in another it powered a launching piston.

At least 1 press report associated these exotic techniques with a blue-green (presumably underwater) radar. Like the more conventional antitorpedo measures, the exotic ones suffer the problem of false alarms. A blue-green radar, were it practicable, would solve that problem, but its range would be extremely limited. Presumably, a very fast projectile could make up for very short detection range. It might also be able to deal with salvo attacks, a problem that might well saturate a more conventional system based on some sort of homing torpedo.

◆ WLR-9A/9B/12/17

These acoustic intercept receivers (AIRs) for submarines are manufactured by Norden. The system typically consists of a sail-mounted sonar hydrophone, a receiver-processor, and a display group. WLR-9A provides some localization, intercepting low- and high-band signals of active sonars. The receiver-processor obtains frequency, bearing, and signal strength. WLR-9A is also used to detect enemy homing torpedoes using active seekers. Work on these systems began in the late 1960s. The current versions are automatic, presenting both CRT (raster scan) and digital readouts and identifying threats by comparison with libraries of ship, submarine, and torpedo sonars. These versions may also detect important transients such as those associated with torpedo and other weapon firings. Part of SAWS, the Submarine Acoustic Warfare System, also includes submarine-launched countermeasures.

WLR-5 was an earlier acoustic intercept receiver.

WLR-9A, which replaces WLR-9, uses DT-511B, DT-592A, and DT-593/WLR-12 HF hydrophones, all carried in 2 sonar domes. It automatically detects sonar transmissions and pulses and measures and provides digital display of sonar parameters, e.g., bearings, frequency, pulse width, pulse repetition period, and sound pressure level. It is more sensitive than WLR-9. WLR-9B has a new receiver-processor and can have a second DT-592A in place of the DT-511B. DT-592 operates at HF; it has a frequency range of more than 1 decade and provides data in 4 quadrants (1 preamp per quadrant), summing its outputs to determine signal bearing. WLR-9B encodes sonar parameters and

sends them to the submarine's BQQ-5B for further processing and display. B(V)1 has only 1 hydrophone (DT-593). B(V)2 has DT-511B and DT-592A. B(V)3 has a new receiver-processor and a DT-593 hydrophone. B(V)4 accepts serial digital data, e.g., own-ship's depth, heading, blanking, target, status, and wrap test data; it uses DT-511B and DT-592A. WLR-12 uses DT-544 and DT-593 (HF) hydrophones. DT-544 is similar to DT-512 but has an extended frequency range. It supplies data in 4 quadrants. Sonar signal parameters are displayed on a CRT and digital readouts.

These devices replace the French-supplied Velox (DUUG-1B). In the early 1960s the U.S. goal was to cover 1.1–70 kHz with frequency accurate to within 10% and bearing to within 5 deg. WLR-2 failed, and Velox (5–40 kHz, 20-deg bearing accuracy) was bought instead. A later intercept receiver, WLR-5, also failed.

◆ Mk 28

This target for warshot torpedoes is a converted torpedo body. Mod 2 was a half-length version, introduced about 1985, and presumably based on a Mk 37 torpedo body.

◆ Mk 30

Mk 30 is a torpedo-sized acoustic target used primarily to test deep-diving torpedoes, but it is also usable, in theory, as a particularly realistic decoy. Mk 30 is capable of about 30 kt. Mk 30 is the current standard U.S. submarine simulator, to be used as a target. Its characteristics suggest what sort of performance a torpedo-sized decoy can provide, although there has never been any indication that Mk 30 itself is considered a viable decoy (it would displace a torpedo, and submarines have too little torpedo stowage to afford such a decoy).

The target is 21 in in diameter and 20 ft (245 in) long, weighing 2700 lb. It can be fired from a 21-in torpedo tube or a rack, or dropped by a helicopter. Mk 30 tows a 300-ft array consisting of a hydrophone, a projector (to simulate submarine sounds), and a magnetic source (to trigger MAD gear). Speed is 7 kt (endurance 4 hr) to 30 kt (30 min); routine operating depth is 25–2000 ft (maximum depth 2500 ft). Turn rate is 0.25–8 deg/sec, depending on speed, and the target can climb at 2–20 deg. An acoustic command link controls depth, course, speed, and shutdown to a maximum range of 5000 yd.

This program began in the late 1960s but was much delayed by deep budget cuts. Westinghouse was the initial contractor, and the company delivered 2 Mod 0 to the Barking Sands Tactical Underwater Range (BARSTUR) early in 1970, for Pacific Fleet operational training. These units were 21 × 224 in (2520 lb), and speed, course, depth, and climb-dive and turn rates were controlled by an internal punched tape, rather than by an external acoustic link. In all, 11 Mod 0s were bought.

Northrop received the Mod 1 contract (11 targets) in 1972, with 7 more in FY73 and 4 in FY74. Development tests of Mk 30 Mod 1 began in FY72, the first unit being received in June 1973. Proof tests were conducted February–August 1974. Unit cost was \$895,833 in FY76, but it rose to \$2,557,143 in FY77, partly because of a Reliability Improvement Program. Between 1973 and 1976 reliability rose from 30% to 65%, against a goal of 80%. Goodyear (now Loral) is the current manufacturer. Mk 30 was approved for service use in 1978.

In 1976 the total stated requirement was 260, but this fell to 60 Mk 30 Mod 1 by 1981, the estimated unit cost then being \$2.7M (FY82). The goal of 60 units by FY86 assumes 2400 runs per year.

Mk 30 is used by the 3 main underwater ranges: Barking Sands in Hawaii, AUTEC in the Bahamas, and the Atlantic Fleet range at St. Croix in the Virgin Islands.

The next version will be Mod 3, which is part of the Advanced ASW Target program. Mk 30 Mod 3 uses the acoustic signal processor, power amplifier, and towed array previously under development for Mod 2, the guidance and control of the current Mod 1, and Mk 48 ADCAPS propulsion (selected in FY88). De-

development of the Mod 2 development target has been deferred to FY91.

The Advanced ASW Target program embraces 3 parallel programs: the Fast Deep Prototype Target (a 21-in vehicle, for Mk 48 and Mk 50 torpedoes), the Advanced ASW Target (6 Mk 30 Mod 3), and the Mk 39 EMATT.

Electro-acoustic mock-up testing of the Fast Deep Prototype was completed during FY88, and the towed array was delivered that year. In-water tests began in FY89.

◆ Mk 32

This fixed torpedo target, for Mk 37, 44, and 46 torpedoes, is suspended in the water at a preselected depth down to 500 ft (chosen in 50-ft increments). It can be used with an SQQ-18A sonar transponder, suspended at 50-ft depth; the latter provides returns for surface-ship sonars. Total weight is 95 lb.

◆ Mk 36

The towed underwater target consists of a large sonar reflector for Mk 48 torpedoes. The barge is 74 × 28 ft (95 tons), and the suspended target is 34 × 8.5 ft (22 tons). These figures explain the need for sophisticated signal processors and transmitters in much smaller torpedo-sized targets such as Mk 30 and Mk 40.

◆ Mk 38 (MMT)

The expendable mobile underwater target (mini-mobile target) is for SQS-23 and -26 sonars and for Mk 46 torpedoes. It is hand-launched, battery-powered, and free-running, with a maximum speed of 5 kt. Dimensions are 3.5 in × 4 ft (weight 20 lb); the manufacturer is Bunker-Ramo. Unit cost was \$1833 in FY81. This device is being replaced by Mk 39.

◆ EMATT (Mk 39)

Expendable Mobile ASW Training Target is an air- or ship-launched submarine simulator manufactured by Sippican for the Naval Sea Systems Command. The vehicle is the size of an A-size sonobuoy (4½ × 36 in) and weighs 21.1 lb. Run speed is 10 kt (duration 3 hr), and maximum depth is 700 ft. EMATT acts as an echo reporter for active sonars, produces signals for passive sonars, and acts as a transponder for the Mk 46 torpedo. EMATT can also deploy a 100-ft wire to produce a recognizable MAD signature.

Compared to its predecessor, the mini-mobile target (MMT, Mk 38), EMATT has increased dynamic capability, programmed run capability, acoustic compatibility with all fleet surface-ship and air platform sonars and sonobuoys, and capability for MAD simulation. EMATT provides an air-launch capability, which the current MMT Mk 38 lacks. It also provides a programmed run rather than the random course followed by Mk 38.

◆ ADMATT (EX-40)

Advanced Mobile Acoustic Torpedo Target is a modified Mk 45 torpedo hull that tows 1 of 2 acoustic arrays (100 and 380 ft long). Mod 1 has an additional 8-in section inserted between its nose and forebody, to accommodate a new processor; it has different arrays compatible with the new processor.

◆ EX-41

Advanced mobile ASW target. This program began in FY79 to replace existing Mk 30 Mod 1 and Mk 27 Mod 0 mobile underwater targets.

◆ SAWS

Submarine Acoustic Warfare System is a family of submarine systems that detect, classify, and track sonar and torpedo signals and jam or deceive those threats. Sonars are detected by WLR-9/12/17; torpedoes are detected and tracked by BLR-14/14A. There is also a special-purpose signal-tracking receiver. The system employs both a hull-mounted jammer (GNATS/NAU) and 3 families of decoys.

The decoys are 3-in devices (ADC Mk 2 Mods 0 and 1 and the NAE Beacon Mk 3 sonar countermeasure), 5-in devices

(ADC Mk 1 Mod 0), and 10-in devices (MOSS Mk 57). Of the 3, only the Mk 57 is mobile; it is a dual-purpose sonar and torpedo countermeasure, intended to simulate a full-size submarine.

Decoys were originally all of 3-in diameter, intended for launch from a modified signal ejector fed from inside the pressure hull. This ejector also fires the standard depth/temperature probes (SSXBT/SSXUI/SSXVT). CSA Mk 1, described above, is a 6-in external launcher. MOSS is fired quietly from a Mk 136 launcher, an insert in a standard 21-in tube. This device was probably introduced about 1973. It weighs about 1000 lb and can be jettisoned (through the muzzle of the tube) by water pulse.

Current efforts:

New Sonar Intercept System (NSIS) Operational Requirement (OR) was written in FY89, and that year specifications for an advanced development model (ADM) were begun. Installation and test on SSN 756 was planned for FY90. The Tentative Operational Requirement (TOR) was issued in September 1985, the Development Options Paper in September 1986, and the draft OR in September 1986.

Countermeasures Command and Control Unit (C/M CCU) This program was scheduled to begin in FY90. The Tentative Operational Requirement was issued in March 1986, followed by a Development Options Paper (DOP) in November 1987 and a draft OR in February 1988.

Sonobuoy Countermeasures This program began in FY90, and an advanced development model (ADM) is scheduled for fabrication in FY91. The TOR was issued in March 1986, followed by a DOP in November 1987 and a draft OR in February 1988.

Multi-Mode Device (MMD) An advanced development model (ADM) is to be fabricated in FY91. The TOR was issued in March 1986, followed by a DOP in November 1987 and by a draft OR in February 1988.

Submarine Torpedo Defense Weapon (SMTD) Work is to begin in FY91. Some of the exotic devices described under SSTD may be intended primarily for submarine defense. The TOR was issued in March 1986, the DOP in November 1987, and the draft OR in February 1988.

Countermeasures Torpedo Tube Launching System/Quiet Launcher (CTTLS/QLHNR) This, rather than the exotic vehicles, may be the electromagnetic launcher mentioned under SSTD. The TOR was issued in March 1986, the DOP in November 1987, and the draft OR in February 1988. The quiet electromagnetic launcher is to be fabricated in FY90, subjected to laboratory test in FY91, and passed to development in FY92.

◆ SPAT

Self-Propelled Acoustic Target is a torpedo-sized submarine simulator manufactured by Westinghouse (formerly Gould). Although normally considered a training device, SPAT might also be considered a long-lived decoy. The vehicle carries an echo repeater (4–85 kHz, pulse width 1 msec–1 sec, PRI ½ sec or more), which it tows on a 12-m coaxial cable. The echo repeater is programmable to provide a target size from 13–25 dB. The echo contains highlights, elongation, and a self-doppler. There is also a broad-band noise generator simulating a submarine (800 Hz–85 kHz). Total radiated power is at least 160 dB (re 1 micro-Pascal at 1 m). Run geometry (including snake, circular, and spiral patterns) can be programmed from the FCS launching SPAT or called up from the vehicle's preprogrammed memory. Total run time is 2 hr. Maximum speed is 11–13 kt (for up to 10 min), and cruising speed is 6–8 kt. Dimensions are 10 × 129 in; weight is 330 lb; depth limits are 16–787 ft; maximum dive/climb angle is 15 deg.

SPAT entered production about 1980. It was based in part on experience with an earlier submarine countermeasure, the BLQ-2 beacon of the 1950s.

◆ Mobile Submarine Simulator (MOSS)

MOSS is the Mk 57 10-in simulator, fired by the Mk 70 fire-control and launching system, primarily for strategic submarines. The catapult launcher is fired from a submarine torpedo tube. Each Trident submarine is to carry 2 launchers and 6 MOSSs; each Poseidon carries 1 launcher and 4 MOSSs. Attack submarines carry 1 launcher and 4 MOSSs. As of FY79, the navy inventory objective, not including Trident units, was 213 MOSSs, 134 for shipfills, 84 for the pipeline, and 7 for navy schools. These purchases covered only strategic submarines.

MOSS was in advanced development in 1973, and proof tests of 26 were completed by the end of FY76. Initial operational test and evaluation was completed in September 1976, and provisional approval for service use was granted in June 1979. Gould received an initial production contract for 36 simulators in August 1977. The FY78 program provided for 56, and the FY79 program for 65 more. The FY79 purchase was halved by Congress because the system was not yet mature, but purchases were later resumed.

MINE WARFARE

This section includes both mines (antiship and antisubmarine) and mine countermeasures. Mines in current service include some types developed as long ago as World War I, and the influence explosion mechanisms developed during World War II still seem to dominate the field. It is difficult to say which old types remain in service; for example, the United States reportedly distributed Mk 6 moored antenna mines to many allies after World War II.

The major current mine mechanisms are contact, acoustic, magnetic, and pressure, although others may exist. The simplest contact mines are set off by an electric current produced when a ship breaks open the batteries formed in the "horns" of the mine. The U.S. Mk 6 of World War I was a more sophisticated alternative: a ship touching or nearing an antenna formed 1 element of a simple battery, closing a firing circuit. The advantage of an antenna is that it greatly increased the lethal radius of the mine. In this way a submerged mine could destroy submarines passing well above or below it, at distances sufficient to block the band of depth available to World War I (but not modern) submarines.

The other major mine types are described as influence weapons, exploding at a distance from a ship. Influence mines on the seabed were the first weapons attacking ships from under the keel.

An acoustic mine listens for the characteristic signature of its target. World War II acoustic mines simply listened for an increase in broad-band sound, but it should be possible to set a modern acoustic mine for a particular characteristic frequency or set of frequencies.

Magnetic mines detect the magnetism of a ship's steel. The early magnetic mines had to rest on the sea bottom, but after World War II the U.S. Navy developed a new 3-axis magnetometer that could compensate for the tidal movement of a moored mine.

Pressure mines respond to the decrease in water pressure under a ship. Such mines necessarily lie on the bottom, and they must be protected against mistaking the change due to the turn of the tide for the change due to the passage of a ship. One solution is to combine the pressure sensor with 1 or more sensors of the target's characteristics (e.g., acoustic or magnetic), so as to eliminate the problem.

Contact mines must generally be moored. The main limitation on their design is the requirement that the combination of mine body and mooring chain be buoyant. The weight of the mooring chain limits the potential weight of explosive. For example, some have suggested that Iranian contact (moored) mines in the Persian Gulf often broke their moorings because the Iranians tried to load them too heavily and used chain that was too weak. Acoustic and magnetic mines may be moored, or they may sit on the bottom. Generally, a bottom mine can be effective in depths as great as 80 ft. Presumably, mines can lie in greater depths if they are intended to damage very large merchant ships, which may draw that much water.

There is a difference between a mine's case depth and laying depth. Case depth is the depth at which the mine itself lies or floats. A floating mine will have an anchor at a far greater depth, which will be the laying depth.

Pressure mines are inevitably bottom mines since they measure the absolute drop in pressure associated with the difference between water depth and the depth of water under a ship. Thus they are only an inshore hazard.

For very deep water, there is a further category, the rising mine. The mine case may lie close to the bottom, but when it detects a passing ship or submarine it launches a projectile or torpedo. The U.S. Captor (Mk 60) is the best known, but not the only, example. Depending upon the speed and endurance of the projectile, a rising mine may be laid in extremely deep water. Moreover, it may be able to hit a target at some distance. That capability requires a long-range sensor unlike that used in any other mine category.

The only available sensor is an acoustic one. A bottom mine must rely on passive detection of its target, recognizing the

target's signature. The mine then uses an active acoustic sensor for fire control. In principle, then, deep rising mines can generally be countered either by silencing (which denies them the initial detection) or by some form of active deception (which ruins the fire-control solution). However, the mine, even if it is quite deep, is probably functioning far closer to its target (e.g., within about a thousand feet) than any sonar (and far closer than virtually any sonobuoy), so the mine may be able to rely on an HF signature that is lost at normal ASW ranges.

As an example of such a mine, Captor relies on a long-range passive sonar for initial detection and then on a long-range active sonar for target tracking. Presumably, this mine requires the long-range initial detection for 2 reasons. First, there is a substantial time lag between the weapon's launch and the weapon's arrival near the target, so the target has to be detected early. Second, because the torpedo can maneuver as it rises, the mine can engage fairly distant targets, if it can detect them. In contrast, an unguided rocket mine (such as the abortive U.S. PRAM or, probably, the Soviet Cluster Bay/Gulf) travels straight up. Its required detection range is set by the time to rise and by the decision time required to classify the target. Such a weapon cannot rely on any kind of impact fuze because the projectile may be near, but not at, the target. Instead, the active sonar is probably used to fuze the projectile.

A rising mine's case depth is probably fixed by the crush depths of the mechanism and the projectile. In really deep water, then, the mine must be moored, and its case must be buoyant enough to support a considerable weight of cable. Consequently, the mine must be large, and the laying rate will be limited. In contrast, in shallower water, say down to a thousand feet or more, the mine case might well lie on the bottom, unsweepable by mechanical means (i.e., by any device that would cut the mooring cable). Very deep minehunting sonars, such as are now being developed, are presumably intended to detect just such bottom mines.

The effect of the existence of deep-water rising mines is to extend the mineable area of the world significantly. Countermeasures are very expensive because the mine may cover a substantial lethal area (the projectile may maneuver to 1 side or the other) and because any attempt to destroy mines or mine mooring requires very deep operations. Examples of such expensive countermeasures probably include not only the British EDATS but also the U.S. Mine Neutralization System. However, because bottom mines must use passive acoustic detectors, these mines are (at least in theory) subject to sweep by acoustic devices simulating target signatures.

There are several mine countermeasures, in 2 categories. One is self-protection, for a ship passing through an area that may be mined. The other is mine clearance, either sweeping (wholesale mine neutralization) or minehunting. In the latter, the bottom is examined foot by foot, and suspicious objects are examined and, if they are mines, destroyed individually. Sweeping means either cutting mine-mooring cables (and thus bringing the mines to the surface, where they can be destroyed by small-arms fire) or providing a false signature that causes influence mines to detonate without damaging real targets. Minehunting is necessary because some mines, such as pressure types, cannot be induced to explode by anything short of a real ship since the signatures in question cannot be duplicated.

When virtually all mines were contact weapons, the chief self-protection measure was the paravane, a towed float whose wire pushed moored mines away from the ship. Paravanes were standard in both world wars but were largely abandoned with the advent of large bow sonar domes (which paravanes could damage) and also with the advent of influence mines (which paravanes could not counter). The only modern self-protection measures are silencing (against acoustic mines) and degaussing (in effect, magnetic silencing). The only protection against pressure mines is to move so slowly that the pressure change is not quick enough to detonate the mine. In World War II, for example, tables were constructed to show appropriate speeds for ships of particular tonnages.

Most current mine-countermeasures work goes into sweeping and hunting. Moored mines may be swept by means of a cable carrying small explosive-driven cutters. Moored or bottom acoustic and magnetic mines are generally swept by towed acoustic or magnetic noisemakers. Mine designers have produced 2 counter-countermeasures. One is a ship counter, which allows several potential targets to pass before the mine is armed. The ship counter was invented by the Germans during World War II, and by 1944 many mines could let at least 15 targets pass before exploding. In theory, a counter protects the mine against sweepers accompanying a high-value target. A second counter-countermeasure is arming delay, which appears in many of the mine descriptions below. The presence of delay-armed mines forces influence sweepers to go back over a field. This idea also applies to moored mines, for which the mine's release from its anchor can be delayed.

Many current mines are described as microprocessor-controlled. They can be programmed to seek particular ship signatures, are extended in space (i.e., in time, as the ship passes over), and so will force the minesweeper to use more and more complex ship simulators. The British Sea Serpent and the French Sterne I exemplify the counters to this type of mine. Compared to earlier hard-wired mine sensors, a microprocessor can very easily be reset to any desired set of target characteristics or counter-countermeasures.

Pressure mines cannot easily be swept. If they distinguish between the turn of the tide and a ship by using a known auxiliary (acoustic or magnetic) sensor, they should be vulnerable to an appropriate towed noisemaker. However, that relatively desperate measure is much dependent on detailed knowledge of the threat mine. In any case, a pure pressure mine can be designed to avoid detonating at the turn of the tide.

Minehunting employs a high-definition (VHF) sonar to identify suspicious objects, and then some means of examining and destroying those objects. The simplest such system employs divers, but modern Western navies tend to employ remotely controlled submersibles equipped with even higher definition sonar and underwater television (such as PAP 104 or the Honeywell MNS) instead. The great problem of hunting is that most harbor bottoms are covered by the detritus of industry (cars, refrigerators, bodies in concrete, etc.), much of it vaguely resembling mines (which need not be neatly packaged as cylinders with markings like "Mine—do not handle"). The very high false-target rate explains the need to examine each suspicious object, rather than destroying it immediately from the minehunter. To the extent that friendly harbors must be protected against mining, detailed bottom surveys of the routes merchant ships are expected to take can be used for comparison, to find out which suspicious objects are new.

Even then, there is a serious problem in silty harbors, as mines dropped on the bottom tend to bury themselves. Depending on their trigger mechanisms, they may still be lethal in that state. This problem probably applies more to magnetic than to other mine mechanisms.

Mine-countermeasures vessels tend to be small because their small signatures tend not to set off influence mines and because sweepers and hunters are needed in substantial numbers and, therefore, cannot be allowed to grow too expensive. If they are built on conventional lines, then, these craft are relatively slow. They may be effective in home waters, but they cannot easily deploy with the fleet. If territorial waters are extensive, moreover, and if the sweepers are expensive (because they have to be sophisticated), then their low speed may be a problem even at home. Norway faces this problem, for example, and it explains current Norwegian interest in surface-effect minesweepers. An alternative is to develop a mine-countermeasure suite that can be fitted to extemporized craft of opportunity, but it seems less and less likely that any such craft will be quiet enough (acoustically or magnetically) to avoid setting off special antisweeper inshore weapons. One alternative, adopted by the U.S. Navy, is the helicopter sweeper or hunter. Helicopters can be carried abroad with the fleet, and they can tow special sweeps

for hunting sonars. They are clearly limited, but they make up for that limitation with extreme mobility. Experience in the Persian Gulf seems to show that conventional surface sweepers and hunters are, of course, still essential.

Small remotely controlled submersibles are commonly used by the offshore oil drilling industry. Most of these devices may be too small to carry useful mine-disposal charges (or, for that matter, useful mine-classification sensors), but these submersibles may be usable under mobilization conditions. In 1985 Gould marketed 1 such a vehicle, the Sea Rover, in the United States; it was small enough to travel as excess luggage on most airlines. The vehicle itself weighed 45–55 lb.

Many mines of pre- or World War II origin probably remain. The section that follows lists only the older Soviet and U.S. weapons, but before World War II France (Breguet and Sauter-Harle), Norway, and Sweden all produced a variety of contact mines, and, in some cases, influence mines. Some probably still exist. Vickers produced a variety of commercial mines, some of which were reported in Argentine service during the Falklands War. Some wartime German mines may have survived, as German wartime coast-defense guns have. Similarly, Japanese contact mines may have survived in the Far East. The key point is that mines, particularly contact mines, do not become obsolete. No details of which weapons are used by which navies are available. Similarly, no details of controlled mines, used for harbor defense, have appeared, apart from the data below concerning the U.S. Mk 51. It is unlikely to be unique. Finally, U.S. mine exports almost certainly included plans and production assistance, so that various countries have manufactured U.S. mines (perhaps in modified form) under local designations.

The United States supplied specially converted minelayers (and, presumably, mines) to Denmark, Greece, Norway, and Turkey during the mid-1950s, before the Mk 52 series entered full production. The principal available surface-laid mines were, then, probably Mk 6, Mk 16, and Mk 18.

MINES

Navies rarely indicate their own capacity for naval mine warfare. In 1988 the U.S. Office of Naval Intelligence stated that 21 countries could deploy mines capable of damaging major warships. In the Falklands, Argentina was credited with a serious mining capability, although it appears that she did not make use of it. In the past, the United States has provided allies near strategic straits with minelaying ships and, presumably, with U.S. mines.

CHILE

Cardoen Industries produces a clone of the British Marconi Stonefish. In August 1990 it was reported that some of these mines had been exported to Iraq.

◆ MS-L/MS-C

These are magnetic ground mines made by FAMAE (Fabricas & Maestranzas de Ejercito); MS-C is a shorter (1425- rather than 2060-mm) version of MS-L, with the same internal design and the same mechanism. Both are torpedo-tube size (534.416 mm in diameter); the smaller mine is intended for air-laying against landing craft. The fuze seeks a sufficiently large change in polarity (through zero), within a set time window, to reject fields that vary either too slowly or too rapidly (e.g., to reject a magnetic object moving too slowly or too fast). The programmable parameters are the following: magnetometer sensitivity (2, 4, 8, 16, 32 mGauss), fuze arming time (2, 4, 16, 32, 64, 128, 256, 512 hr), inhibition time (32, 256, 512 sec), lower limit window time (2 or 4 sec), upper limit window time (16, 32, 64 sec), ship counter (1–9), and sterilization time (2, 4, 8, 16, 32, 64 weeks). Inhibition time is a delay after the fuze has accepted a target as real, to protect the mine against multiple magnetic sweeps in combination.

DENMARK

◆ MTP-19

This new controlled mine, entering service with the Royal Danish Navy, was first displayed at Defendory in October 1990. It is made by NEA Lindberg. MTP-19 is launched by means of a trolley, the wheels of which fit the train rails in Danish ferries (which would be the primary minelayers in an emergency). The mine has 2 sections, the mine case proper (the 300-kg charge and a microcomputer) and the flotation unit. Because the flotation unit, carrying the mine-control cable, rises to the surface for retrieval soon after the mine is laid, connection to the control cable is relatively easy; several mines can be linked to a single distribution box. Operation is either under full control (which can be automatic, using a shore-based sensor) or auto-alarm (the mine uses its own sensors, based on criteria in its microprocessor). The normal operating depth is 20 m, and the mine can be controlled from up to 12 km away.

FRANCE

The principal prewar surface-laid mines were all contact types: the Breguet B4, B4M, and B5B, and the Sauter-Harle H5, H5P, and H6. The Breguets were relatively small horned mines, with total weights of 1168 lb (B4/B4M) and 2535 lb (B5); explosive weights were, respectively, 176 and 485 lb. B5B was an antenna ASW mine analogous to the U.S. Mk 6, with 25-m upper and 30-m lower antennae. These mines entered service in the late 1930s, the mines lying at a depth of 90 m [about 300 ft] with alternative water depths (mooring depths) of 225, 300, or 400 m [respectively, about 740, 1000, and 1310 ft]. The Sauter-Harles were antiship mines. H5 and H5P were horned mines (4 horns) with a total weight of about 2550 lb (485 lb of TNT). Some versions had antennae. These older mines were introduced in 1928. Prewar versions, which may have been experimental, were designed for greater depths (e.g., H5UM1, moored in about 3000 ft of water to float at 600 ft [1935]). H6 was a horned mine with a heavier explosive charge (about 660 lb of TNT). These mines apparently survived World War II, and some probably still exist.

Postwar, the French navy developed a wartime German project for a bottom mine triggered by cosmic radiation. In principle, the layer of water over the mine reduced the level of radiation by an amount proportional to its depth. The water under a ship would be less, so the radiation level would rise and the mine would be triggered. In theory, such operation would be analogous to that of a pressure mine. In practice, the problem was that levels of cosmic radiation fluctuated naturally, so the mine had to use an array of detectors to make instantaneous comparisons between the average radiation level and that immediately overhead. This concept was reportedly the main French mine research project of the mid-1950s; by that time the U.S. Navy had given up on the idea (which had been quite exciting about 5 yr earlier). No such mine appears to have entered service, and it seems likely that the cosmic-ray mine fell victim to the massive French research budget cuts associated with the Algerian War. The types described below were probably the only fruits of later French work.

◆ FG 29

FG 29 uses multi-influence sensors and is designed for localized laying from submarine torpedo tubes. Dimensions are 52 cm × 3 m, and weight is 1000 kg (600 kg of tritonal explosive). FG 29 can operate down to 300 m in depth. FG 29 has an arming delay, and it is an antisweep device, explosion-resistant to defeat explosion-based minesweeping. Fuzing is magnetic, acoustic, or pressure. This mine is very sensitive, so it can be used against ships with very low magnetic moments. The acoustic sensor operates on several LF channels. The main contractor is DCN; Thomson Sintra makes the sensors. The development of FG 29 began in the early 1970s, and the first batch was delivered to the French navy in 1988.

The earlier FG 18 was used on board *Daphne*-class submarines.

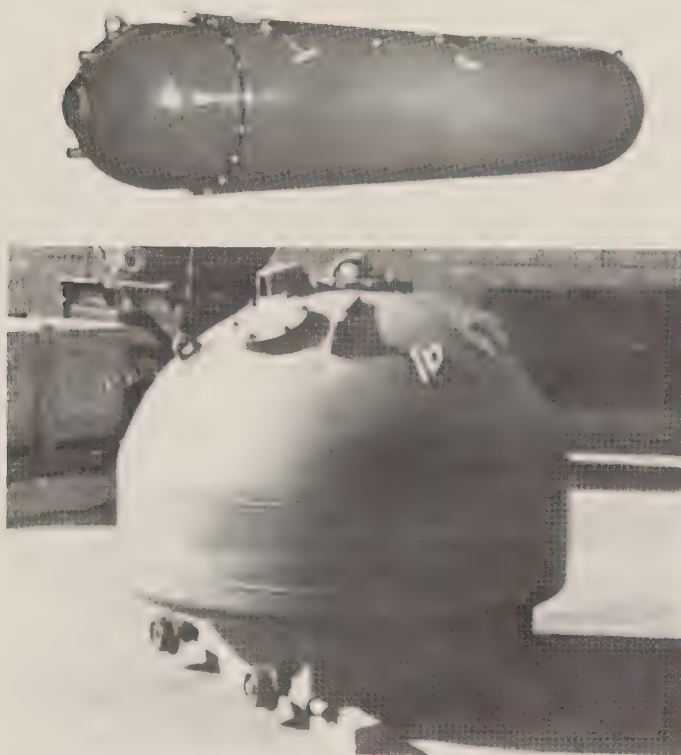
◆ TSM 3510 (MCC 23)

This magnetic/acoustic ground mine is designed to be triggered by any ship displacing over 1000 tons. TSM 3510 can be launched from a torpedo tube, so the diameter is 533.4 or 550 mm [21 or 21.7 in]; the length is 2.525 m [99.4 in]. Weight is 850 kg, including a 530-kg warhead [1873/1168 lb]. The mine can be set to wait for up to 30 days before arming, and there is a ship counter. Thomson Sintra is the manufacturer. An earlier version (ca. 1978) was 530 × 2368 mm [20.9 × 93.2 in], with a 650-kg [1432-lb] warhead.

There are also practice mines: a submarine-laid mine, EP 30C (533.4 mm × 3 m, 900 kg [21 × 118 in, 1984 lb]), which can be laid in depths of 10–50 m; and sweeper/laying training mines, ED 28B (TSM 3500) and MCED 23 (TSM 3517)/MCEM 23 (TSM 3515). The latter is intended to train minelayers, and it lacks the magnetic and acoustic detonator scoring system of the former. ED 28 is laid by surface vessels.

Thomson-CSF began work on mines in the late 1960s, beginning with exercise mines for surface ships and submarines.

◆ TSM 3530 (MCT 15)



MCC 23 (above) and MCT 15 (below). (Thomson Sintra)

TSM 3530 is an air-dropped, parachute-retarded mine. Dimensions are 1.2 (diameter) × 1.1 m [47.2 × 43.3 in]; weight is 1500 kg, including a 1000-kg warhead [3306/2204 lb]. Fuzing is acoustic/magnetic. 3530 is almost semispherical in shape. Like MCC 23, 3530 arms after a clock-set delay. Thomson Sintra is the manufacturer.

GERMANY (WEST)

The postwar German navy used stocks of wartime and postwar mines, presumably of U.S. and British origin. A new generation of ground and moored mines (and antisweep devices) was developed under a Seemine 65 program. It resulted in the FG 1 described below. Germany and Denmark collaborated in 2 more recent programs, Seegrundmine 80 (SGM 80) and Seemine Anti-Invasion (SAI).

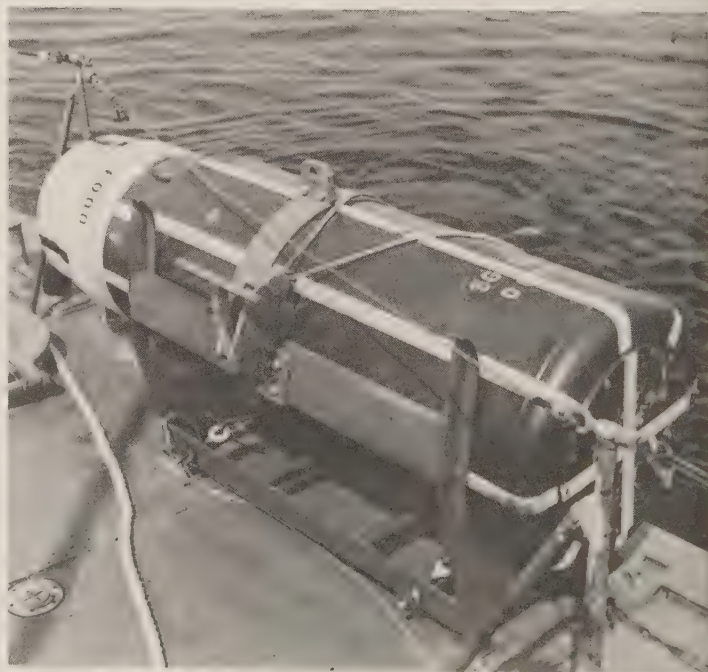
German World War II mines were all designated by letters, the first 2 indicating the function and the third the type within that category. The EM series (e.g., EMC) were horned contact mines, EMC and EMD being the most common. The KM series were anti-invasion mines, typically with a single horn protruding. RM indicated a controlled mine. UM mines were ASW contact weapons. There were also mines for torpedo-tube laying (MT and TM series) and for air laying (BM and LM series), but these are unlikely to have been suited to the requirements of current users. Likely users of German prewar and World War II mines would include Finland (which was a German ally during much of World War II, and which received little military hardware postwar), Spain (which would have received considerable aid during the civil war and afterward, and which operated some German submarines, torpedo boats, and aircraft), and Yugoslavia (which retains a few German coast-defense guns).

◆ FG 1

This submarine-launched ground mine is built of nonmagnetic material, with a 535-kg [1179-lb] warhead. Dimensions are 534 mm × 2310 mm: 710 mm for the control section, 1600 mm for the charge section [21 × 91 in: 28 in/63 in]. Total weight is 770.5 kg [1698 lb]. Maximum effective depth is 60 m [197 ft]. FG 1 is built by the Faun-Werke.

◆ G2 (SGM 80/IGM 10)

This cylindrical ground mine was developed for launch from a cradle on board a fast attack craft. The joint Danish-German program began in 1980 (hence the Seegrundmine 80, or SGM 80, designation initially applied). Development was completed in 1986, with approval for service use in July. Although Dornier had built prototypes, KAE was awarded the production contract in 1987, and tests were completed at the end of 1989. The initial requirement emphasized minimum dimensions and weight, maximum flexibility in target selection (with simplified setting), antisabotage and antisweep features, and minimum maintenance. The explosive and nonexplosive parts of the mine are separate, coupled by a clamping ring, with the safing and arming device in the explosive section. The programmable microprocessor has acoustic, magnetic, and hydrodynamic signal-processing channels, which may be used either individually or in combination. Surveillance sensors are used to filter out environmental effects, such as tides. The microprocessor program is divided into constant data (basic algorithms and signal-



SGM 80. (Dornier)

processing techniques) and mission data (preferred targets, choice of sensor combination, arming delay, ship count, etc.).

A separate data-acquisition (measurement) version of the mine can be used to obtain the signatures of potential targets, e.g., on a test range. An operational mine contains a library of such signatures, corrected for environmental conditions at the point of measurement; it arms when a received signature matches the appropriate library signature. The multiple sensors are used to estimate the range to the target, and the mine explodes when its target comes within optimum range (for that type of target, as estimated from damage curves).

There is also an exercise version.

G2 is expected to require inspection every 4 yr, at which time operational inputs are fed into the microprocessor.

IGM 10 is a G2/SGM 80 derivative, to be laid by submarines with external mine belts. It can be laid in deep water. Like G2, IGM 10 has a programmable microprocessor using acoustic (low and audio frequency), magnetic, pressure, or a combination of signatures. IGM 10 can be programmed immediately before leaving the ammunition depot.

◆ G3

This sea mine, now in the concept phase, is to neutralize new types of targets, such as surface-effect ships.

◆ SAI

Seemine Anti-Invasion, another Danish-German project, is to be laid by landing craft. It was procured in 1982–90.

IRAQ

Iraq displayed 3 mines at the Baghdad military show in 1989.

◆ Al-Muthena/35

Total weight 190 kg (84-kg mine and 105-kg sinker), with a 35-kg explosive charge. This is a contact mine to damage floating pontoons, bridges, and shallow-draft craft. It uses either electromechanical horns or an electronic timer. Total height is 980 mm, of which 610 mm is the mine proper [38.6/24.0 in], and diameter is 550 mm [21.7 in].

◆ Al-Muthena/45

95-kg mine (45-kg explosive), using electromechanical contact horns or timer. It has 6 horns, laterally spaced, like the spokes of a wheel, in 1 row. Dimensions: 555 mm dia × 660 mm high [21.9 × 26.0 in].

◆ Sigeel/400

A ship- or helicopter-laid bottom mine, in the form of a truncated cone with additional mechanism on top. Weight: 535 kg (400 kg of TNT). Dimensions: lower diameter 980 mm, upper diameter 700 mm [38.6/27.6 in] × 850 mm, of which the mine proper is 610 mm [33.5/24.0 in].

ITALY

The principal mine manufacturer, Misar, was formed in 1977 by a group of technicians who joined the Italian SEI (Società Esplosivi Industriali) and the French SAEPC (Société Anonyme d'Explosifs et des Produits Chimiques) to develop and sell both naval and land mines.

◆ EPR Series

Tecnovar's anti-invasion mines are essentially flat disks (like land antitank mines) in form. The number indicates the weight of explosive, 1.2, 3.6, or 6 kg (e.g., EPR 3.6). Fuzing is electronic.

These mines were announced about 1981.

An EPR 2.5 limpet mine advertised in 1984 weighed about 6 kg [13 lb] and carried a 2.5-kg [5.5-lb] charge. EPR 2.5 was described as an electronic underwater mine, which might be laid by aircraft or else magnetically/mechanically attached to the hull of a ship. Dimensions: 26-cm diameter × 9-cm height [10.2 × 3.5 in]. In tests, EPR 2.5 blew a 250-mm [9.8-in] diameter hole in a steel plate 30 mm [1.2 in] thick.

◆ MAL/17 and MAS/22

Tecnovar's anti-invasion mine was advertised in 1984. MAL/17 is a contact mine with 3 horns in its top and a stabilizer extending down from its spherical body. Total weight is 22 kg, and it carries a 17-kg charge [48.5/37.5 lb]. Dimensions: 38-cm diameter, 110-cm height, including stabilizer [15 in × 4.3 in]. Case depth is about 3 m [10 ft].

MAS/22 is an alternative version of the same mine, with 3 sharp stakes at its bottom so that it can be driven into a beach (just below the water line) or into a river bed. Total weight is about 22 kg, and charge weight is about 17 kg. MAS/22 is hemispherical (virtually identical to the upper hemisphere of MAL/17), with a diameter of 38 cm and a height (including spikes) of 63 cm [24.8 in].



Tecnovar mines (left to right): MAL/17, MAS/22, and EPR 2.5. (Tecnovar)

◆ MANTA

Misar's anti-invasion (shallow water) mine, for depths of 2.5–100 m [8–330 ft], has an effective lifetime of over a year. It uses magnetic and acoustic fuzes and can be laid by ships, helicopters, or frogmen. The warhead is 140 kg of TNT or 170 kg of HBX-3 [309 or 375 lb]. Dimensions: diameter 980 mm, height 470 mm [38.6 × 18.5 in]. Total weight is about 220 kg or 240 kg depending on loading [485 or 529 lb]. The form of the casing is intended both to avoid movement due to currents and to avoid visual detection. Manta's shelf life is 30 yr, and the mine will operate for 17 months when laid.



Manta, with MRP-80 in the background. (Misar)

◆ MR-80/MP-80/MRP

Misar's antiship and antisubmarine mine is usable in depths of 5–300 m [15–100 ft], with a maximum transport depth of 500 m [1640 ft] and a submerged life of up to 2 yr. There are 3

versions, A, B, and C. Characteristics are as follows:

	A	B	C
Dimensions	533 × 1650 mm [21 × 65 in]	533 × 2096 mm [21 × 83 in]	533 × 2750 mm [21 × 108 in]
Total Weight	656 kg [1446 lb]	820 kg [1807 lb]	1070 kg [2358 lb]
Explosive	460 kg [1014 lb]	630 kg [1389 lb]	870 kg [1917 lb]

Available fuzes are magnetic, pressure, and acoustic (HF or LF), and they can be used in any desired combination. Arming and neutralization delays can be set at up to 999 days, for a useful life of 500–1000 days. MR-80 can be laid by torpedo tube but also by aircraft or surface ship. The casing is made of fiberglass impregnated with epoxy resin, carrying explosives in the nose and the controls in the tail.

Reportedly, MR-80 has been sold to several Middle East countries.

MP-80/MRP is a similar mine with an updated firing mechanism and a better (digital) target recognition device. This mine has 4 microprocessors, which compare the target's signature (magnetic, pressure, and/or acoustic) with entries in a threat library: thus, mines can almost be assigned to particular targets. MP-80 is the Italian navy/NATO version; MRP, with software not subject to NATO restrictions, is the export version (Misar's Advanced General-Purpose Sea Mine).

The initial MR-80/1, announced in 1978, was the first Misar mine. It could be laid in water 10–200 m [33–660 ft] deep. In 1978 it was being evaluated by the Italian navy, probably as an alternative to the Valtec SM 600; it seems to have been the successful competitor. MRP's dimensions: 533 × 2096 mm [21 × 82.5 in]; weight: 800 kg (620-kg HBX-1 explosive). Mechanical, structural, and explosive features match those of MR-80/B.

MR-80/I and MRP/I are training and trials variants of MR-80 and MRP.

About 1986, at the request of the Italian navy, Misar conducted a feasibility study of the modernization of Italian stocks of U.S. mines (Mk 13 Mod 6, Mk 52). The conclusion, that the mines themselves were in good condition but that their firing mechanisms needed replacement, led the company to study the export market for such modernization. Presumably, this program competes with the British Aerospace modernization programs described under the United Kingdom entries below.

In mid-1985 Misar signed an agreement with Aerojet to market the U.S. Mk 65 Quickstrike mine with a Misar Target Detection Device (TDD) related to that of the MP-80/MRP.

◆ SB-33

Misar's antisaboteur mine can be used either on land or against divers (fuzed by pressure, to explode at a preset depth) or as a submarine signal. Like SB-81 (below), it can be supplied in a magazine suitable for scattering from a vehicle or a helicopter. Dimensions: 88 × 32 mm. Weight: 140 g (charge 34 g).

◆ SB-81

Misar's coastal mine/depth charge/countermining charge has a weight of 3.2 kg (2-kg charge) and can shear a 35-mm steel plate. Dimensions: 232 × 90 mm. It explodes by pressure, at a preset depth. For coast defense it is mechanically fuzed. Misar manufactures an SB-81 magazine adapted to mine scattering by helicopter (the SY-AT system).

◆ SB-MV/1

Misar's shaped-charge anti-invasion mine was displayed in 1980. It weighs 5 kg (2.6-kg charge) and can penetrate 150 mm of armor at a distance of 600 mm; Misar claims that it is 3 times as effective as a more conventional mine. It is intended to attack amphibious vehicles at the water's edge.

Misar also produces an "extended range" mine, P40, which projects a charge at a sensed target.

◆ TAR 6/TAR 16

These multicharge (string) ASW mines are made by Whitehead. TAR 6 can be used against surface targets and is intended to bar passage from the surface down to a depth as great as 820 ft. A typical barrier consists of 4 rows of mines carrying their vertical strings of charges at different depths; the numbers in TAR 6 and 16 are the number of charges. Each charge carries 3 switch (not chemical) horns. Because the detonation of any 1 charge in the string generally sets off the others, a single string cannot effectively cover the entire depth to be blocked.

TAR 6 consists of a buoy, itself carrying a charge, 5 cylindrical charges, and an anchor, the charges being spaced about 13 ft apart. Thus a buoy at a depth of 16 ft carries a string that reaches down to 92 ft. The buoy carries 110 lb of explosives, and each cylinder carries another 55 lb. TAR 16 is similar, except that it has more charges and its buoy is not explosive. TAR 16 covers a total length of 225 ft, the buoy floating 39 ft above the shallowest charge. A typical field might consist of a row of TAR 6s, their deepest charges at 92 ft, then a row of TAR 16s, with buoys at 65 ft and charges extending down to 330 ft, then another row of TAR 16s (buoys at 65 ft, but shallowest charges at 348 ft and deepest at 572 ft), and then a third row of TAR 16s (buoy at 65 ft, charges between 590 and 812 ft).

Typical assembled dimensions of TAR 6 are 6 ft 5.5 in (high) × 3 ft 6 in (wide) × 3 ft 11 in. Weight is 2435 lb. Analogous figures for TAR 16 are 7 ft 6.5 in × 3 ft 8 in × 3 ft 11 in and 3240 lb. TAR 16 can be laid in water depths as great as 1520 ft.

TAR means *Torpedine Antisom Rosario*, or antisubmarine rosary mine. It was conceived in the early 1950s, and by October 1954 test fields had been planted in depths as great as 400 ft.

◆ VS-RM-22 and -30

Valtec's anti-invasion or shallow-water mines are exploded by trip-wire. The number indicates the weight in kg.

◆ VS-SM-600

Valtec's ground mine can be laid in water 10–150 m deep [33 to 490 ft] by a surface ship, a submarine, or an airplane. The 4 sensors are magnetic, HF acoustic, LF acoustic, and pressure. There are also a ship counter, an antitamper device, and a long arming delay. The mine can be remotely controlled. Dimensions are 533 mm × 2.75 m [21 × 108 in]. Weight is 780 kg [1719 lb], with a 600-kg [1322-lb] charge.

◆ VS-SS-22 and -30

VS-SS-22, a limpet mine made by Valtec, is intended to sink ships of up to 400 tons and to disable ships up to 4 times that size. -22 carries about 12 kg of RDX/A10 explosive. The mine is attached to its target by 2 rubber suckers, by 2 pins driven in by rivet guns, or by a removable clamp. Dimensions are 200 × 650 × 360 mm [7.9 × 25.6 × 14.2 in]. Weight is 20 kg, including 10 kg of explosives [44/22 lb], and the standard arming delay is 15 min, after which antihandling devices switch on. The explosion delay can be between 1 and 10 hr.

◆ WP 900

Whitehead's modular ground influence mine is laid by submarine or surface ship. There are 3 versions, containing 1, 2, or 3 charges; and fuzing can be a combination of magnetic, acoustic, and pressure. Designed shelf life is 30 yr.

WP/E 900 is an exercise version.

◆ New Mine Projects

Three new Misar mine projects were shown at the Mostra Navale show in May 1989. Seppia is a private-venture moored multi-influence mine, using a Misar-developed programmable microprocessor. It is an 870-kg cylindrical mine (it can be laid from torpedo tubes) carrying a 200-kg (HBX-1) explosive load, and it can be laid by ships, aircraft, or submarines. It uses the Misar TDD to control its operating depth (down to 300 m), fuze

sensitivities, the moment of firing (based on target classification), arming delay, life, and ship count.

Misar is also developing a moored mine, MEB 90, in a joint venture with 2 Spanish companies, Bazan and Expal. MEB 90 uses the Misar TDD and, like Seppia, MEB 90 can be moored in depths as great as 300 m [1000 ft].

Finally, the company is developing the CSM rising continental-shelf mine in collaboration with Whitehead, for the Italian navy. The rising body is described as partially self-guided.

JAPAN

The principal wartime moored mine was Type 93, which carried an explosive charge of 220 or 243 lb. Net buoyancy (which determined how much mooring cable could be used) was 265 or 43 lb (depending on explosive load), and total weight, including anchor, was 1543 or 1565 lb. Using thin cable, a Type 93 mine could be laid in water as deep as 586 fathoms (3250 ft). These mines were provided with 4, 7, or 9 contact (Hertz) horns. Stocks in Japan in 1945 were presumably destroyed, but stocks in Japanese-occupied territory probably survived the war.

Japan currently uses mines either identical to, or externally similar to, U.S. types. Japan's current mines are designated in a K-series during their development period, after which they receive Type numbers. The types are: K-1, K-2, K-3, K-4, K-5, K-13, K-15, K-16, K-21, K-22, K-23, K-24, K-52, and K-55. K-15 is the Type 56 moored contact (antenna) mine, similar to the U.S. Mk 6. K-21, K-22, K-23, and K-24 are Type 70 bottom influence mines similar in appearance to the U.S. Mk 36. K-33 is a moored contact mine. There is also a Type 55 horned moored mine (710 kg total, including 100 kg of TNT, with total buoyancy of 60 kg to support the mooring wire; diameter is 86 cm; there are 7 Hertz horns). The K-X moored mine, an air-dropped mine, and a rising mine are under development. The new air-dropped ground mine reached the hardware stage in 1989. The current R&D program includes a study of a minelaying system to be carried on board C-130H transport aircraft.

Reportedly, Mitsubishi is modernizing some Japanese mines, presumably those manufactured under U.S. license.

SPAIN

Inisel has manufactured the French MCC 23 under license. The Spanish navy also has 1500 Vickers-designed moored mines, which have been in storage since 1945. Expal, Inisel-Bazan, and Misar are currently competing to upgrade them.

Inisel and Chaconsa (which is responsible for the mine body, mechanism, and assembly) are developing a new MOM 90 moored mine, built of a Kevlar-like composite, using a glass-fiber mooring chain. It is to have an intelligent magnetic sensor and a "3D" acoustic sensor, with a low-sensitivity filling. Thomson-CSF is also involved in this project.

SOUTH AFRICA

South Africa manufactures a bottom mine based on British stonefish technology. In March 1990 it was reported that mines of this type had been sold to Libya.

Reportedly, Armscor modernizes some existing mines.

SWEDEN

◆ Bunny

Bofors's new submarine-laid bottom mine is laid from a saddle rather than a tube. It weighs 200 kg and uses the new 9SP180 sensor, described below, which is also being offered for mine upgrade programs. The saddle was developed by the German firm of Abeking & Rasmussen; it fits over the pressure hull of the submarine, laying its mines vertically. Tests have shown that it is compatible with current Swedish submarines, but none has yet been bought by Sweden.

◆ GMI 100 Rockan

This anti-invasion ground mine, for shallow water, was announced in 1984; Rockan can also be laid in deeper water as an



Rockan (left) and MMI 80 (right). (Bofors)

ASW mine. The unusual shape causes the mine to glide through the water, typically to twice the depth of the water in which the mine is laid (5–100-m depth). The mine's low profile makes sonar detection difficult, and the irregular shape and GRP casing tend to camouflage Rockan's purpose. Dimensions are 1015 × 800 × 385 mm; weight is 190 kg (105 kg of explosive); minimum distance between mines is 25 m.

The Rockan sensor will not react to any sweep that creates a homogeneous magnetic field; this sensor is also being incorporated into the moored MMI 80.

◆ LYDIA

This rising antiship mine was placed in production about 1956. LYDIA is laid as a bottom mine and is influence (passive acoustic) actuated. When it detects a ship, the mine rises by changing its buoyancy (its hydraulic mechanism pushes water out of the lower mine chamber). LYDIA then floats at a predetermined depth and is contact fired. If the sound source recedes without contact, the mine sinks to the bottom to await another ship, when it will again rise in a new cycle. Operational life is limited only by the battery (life 3 months, or about 60–90 cycles). Operation is limited to shallow water by the small negative buoyancy of the mine, which limits its resistance to currents and also limits the speed with which it can rise to meet a potential target.

◆ MMI 80

This moored influence mine, announced in 1984, has an operational depth of 20–200 m. The buoyant body is made of plastic, and the sensors are similar to those of the Rockan mine. Dimensions are 1125 × 660 × 1125 mm; total weight is 450 kg; charge is 80-kg hexotonal; sinker weight is 240 kg. Minimum distance between mines is 25 m.

◆ Mobile Mine

In 1985 it was announced that FFV, Bofors, and Ericsson were cooperating in the development of a submarine standoff mine, probably a converted torpedo. The principal changes would be a new influence sensor and a modified propulsion system for a long/slow rather than a short/fast run.

◆ SA Marine Mines

SA Marine manufactures a wide range of mines, details of which have not been published: modular ground mines (charges of 150–2400 kg), moored mines (charges of 80–200 kg, bottom depths of 30–500 m), and rising mines (both bottom-dormant moored mines and homing mines). The company also modernizes mines. The inclusion of homing mines in the company's advertisements suggests that the United States and the Soviet Union are not alone in possessing such weapons.

◆ Type 74

This moored mine is made by SAB Industri AB. Total weight is 205 kg, and the body is cylindrical. It can be laid in depths as great as 110 m and operates over a radius of 3–70 m.

◆ Type 77

SAB's pressure mine weighs 470 kg. It is to be laid in depths from 20–200 m.

◆ 9SP 180

BEAB's (formerly PEAB) mine sensor was announced in 1988 and carries a BEAB PHCS-1 (Philips Combined Hydrosensor) hydrosensor and a 3-axis magnetometer. The hydrosensor has separate channels for depth, dynamic pressure, and sound, and all of the signals are filtered and evaluated against preprogrammed target criteria. Dimensions: 320 × 350 mm (16 kg). Maximum depth is 150 m [490 ft]. Operational lifetime (depending upon frequency of alerts) is about 12 months.

SWITZERLAND

◆ Telemine

In 1983 the Swiss company Tek Sea announced that it was developing the Telemine remotely controlled torpedo to meet an Argentine navy requirement. The mine body is 55 cm × 5 m, with a maximum weight of 650 kg (170 kg of explosives). Powered by a 4.5-kW electric motor (up to 10 km at 20 kt), Telemine would be laid on the sea floor (at depths of up to 150 m), remaining dormant for up to 2 yr, and then being activated by acoustic signals from a distance as great as 4 km. Upon being activated, the mine releases its ballast and rises to near the surface. A sensor pod on Telemine's back carries an antenna, which penetrates the surface, for radio control by airplane, ship, or submarine. The sensor pod itself surfaces 500 m from the target, to provide the controller with a television picture of the target.

Tek Sea claimed that Telemine is almost undetectable by minehunting sonars because its acoustic density is so close to that of seawater.

TAIWAN

Taiwan uses a variety of domestic and foreign-produced mines. There are still large stocks of ex-U.S. antenna and contact mines, as well as magnetic (and probably pressure) bottom influence mines. There are also air-dropped cylindrical bottom mines (designated WSM-110) and Manta-like anti-invasion mines (WSM-210). WSM-110 resembles World War II influence mines, with slight tapering at 1 end for an appropriate trajectory, and 2 holes in the side for sensors. WSM-110 may be an adapted U.S. type.

USSR

Reports of total Soviet mine reserves vary. In 1987 the U.S. DoD claimed a total of 300,000 mines, including about 100,000 moored contact mines. These figures greatly exceed World War II usage (40,000 mines for the Soviets, 44,000 for the United States). Many of these mines have been exported to Soviet client states and allies, but it is often claimed that the Soviets do not export their pressure mines. Much of the data that follows dates from the early 1950s, in many cases from mines confiscated during the Korean War. Very little information has been released on more modern types, and information given here should be taken as representative rather than complete. For example, it seems likely that there are moored acoustic and magnetic mines, but no data or designations have been published.

Many of the designations given are no more than Western applications of standard Soviet mine categories, such as AMD; it is not always clear how the Soviets designate their equipment. Moreover, the historical record, even that part the Soviets have declassified, is not particularly clear. It is entirely possible that some of the descriptions below are really somewhat different references to the same weapon, or to versions of the same weapon. Some of the weapons listed may be Western projections or estimates rather than actual mines. In some cases (1970s and 1980s) in-service dates may be projections, some of which are now obsolete.

The old Imperial Navy was an enthusiastic supporter of mine warfare, but the expertise vanished with the revolution. A special technical bureau for mine development was established in 1921 and a mine testing center in 1924. However, stocks of earlier mines remained, and their designs were repeated in new production batches. M26 was the first entirely Soviet ship-laid mine. There was also a PLT series of submarine-launched mines.

It is reported that the Soviets have submarine-launched mines, 1 with a range of about 1 km.

The following inventory estimates were published unofficially about 1988; they are probably taken from a U.S. study dating from about a decade earlier. Even if they are official in origin, these figures do not pretend to be complete, as they do not include some earlier mines.

AMD-500	18,000
AMD-1000	18,000
AMD-IV	35,000
AMD-P-V	12,000
KRAB (Improved)	10,000
MAG	10,000
MKB-3 (Standard moored contact mine)	30,000
RVM	15,000
UEP	
KB-UEP	10,000
Sectionalized	10,000
Total of these types	168,000

◆ AGSB

Development of this antenna mine began in the early 1930s; it entered combat early in World War II. AGSB had two 35-m steel antennae (above and below) and the charge of an M-26, but AGSB could be laid in water 4 times as deep as M-26 (about 560 m). AGSB uses a 2-pulse operating circuit to overcome interference problems.

◆ AMG-1

This moored, air-dropped, contact mine appeared in 1939. It is laid like a bomb by aircraft (no parachute) from low altitudes (5–25 m) and can penetrate ice; it has an ogival nose and bomb type fins. Dimensions are 37 in (dia) × 141 in; charge is 572 lb of TNT in a 1080-lb case (with a 1200-lb anchor). Laying depths are 43–327 ft; case depth is 8–28 ft. Minimum spacing is 143 ft. Planting heights and speeds are 100–160 m at 260 kt, 160–600 m at 180 kt. AMG means aviation galvanic mine (*Aviatsionnaya Mina Gal'vanycheskiy*).

◆ AMD/KMD/KMK Series/MKD

Respectively, these devices are air/surface/submarine-laid ground mines, the number (-500 or -1000, but -1000 only in the case of submarine mines) indicating the weight in kg. For 500 and 1000 kg, respectively, maximum case depths (antiship) are reportedly 24.4 and 54.9 m [80 and 180 ft]; charge weights, 300 and 699 kg [660 and 1540 lb]; and minimum distance between mines, 69 and 137 m [226 and 449 ft]. If these mines are used against submarines, they may be laid at greater depths, up to 200 m [660 ft] for a -1000. Known influence mechanisms are (i) magnetic (horizontal or vertical component of target field), (ii) acoustic (HF or LF), (iii) pressure, and (iv) combination. There may also be others; what appears to have been a Libyan-laid KMD was recovered in the Red Sea in 1984, with a new type of influence mechanism. Approximate dimensions were 21 × 12 in. KMD reportedly incorporates a ship counter (up to 11 ships) and a delayed-arming mechanism (up to 10 days). The 1984 mine may have had a modular electronic firing mechanism to replace the earlier plug-in type.

Two KMK-1000 can be carried in lieu of a torpedo.

AMD, KMD, and KMK may be no more than generic designators.

The original AMD was the air-dropped version of the MKI magnetic induction ground mine. Dimensions were 21 × 11

in. Weight was 2167 lb total with 1725 lb of modified torpex. Maximum effective depth was 120 ft. MKD could be laid by aircraft, surface ships, and submarines; and it had an arming delay clock and a ship counter. MKD was the first modern Soviet ground mine.

An MKD torpedo-tube-laid (i.e., 21-in) mine recovered in the early 1950s had a 2-look magnetic fuze (interval 4–45 sec) to ensure that the object triggering it had some substantial size. However, the fuze tended to be more sensitive for the short period, so the mine was relatively easy to sweep. The mine also had a ship counter (0–11 ships) and a clock (0–10 days), as well as a hydrostatic safety. Its detection range was limited because of the limited length of its iron-dust (Sendust) core. The warhead was 1700 lb, equivalent to 2500 lb of TNT. Overall mine length was 114 in, of which 95.5 in was taken up by the charge.

AMD, which appeared in 1942, used a new magnetic induction mechanism based on that of the British A Mk 1, some of which were provided to the Soviets early that year. Compared to the British mine, AMD was considered more rugged and also more sensitive.

AMD-II-500 and -1000 (acoustic magnetic induction ground mines) were reported in 1950, carrying 300 and 700 kg of HE, respectively; the equivalent surface-laid versions (strapped to a dolly) are KMDs. Case depth is 50 m, and the acoustic element can be HF or LF or a combination. No AMD-III was reported, but AMD-IV-500 and -1000 (pressure/acoustic/magnetic) appeared in 1954. Reported characteristics are as follows: ship count, 1–21; arming delay, 12 hr to 10 days. The firing logic takes 3 looks. These mines have anti-countermine provisions. AMD-P-V (seismic/magnetic gradiometer) was reported in 1969 (the designation suggests a mine projected by U.S. intelligence rather than actually seen). This 1000-kg HE mine, which could be laid by ships, submarines, and aircraft, was credited with a ship count to 21, with a maximum delay of 30 days, and with anti-countermine provision. A remote on-off capability was possible. In 1970 AMD-S, a remotely controlled mine, was reported. Again, this last is more likely to have been a projection than a firm report.

The AMD designations above are U.S. or NATO, not Soviet.

The Libyan-laid Soviet bottom mine found in the Gulf of Suez in August 1984 (described as "995") was presumably a recent version of the KMD series. It was large enough to accommodate a 750-kg charge (the charge cavity was apparently not filled) and had acoustic, pressure, magnetic, and seismic sensors.

AMD means aircraft-laid bottom mine (*Aviatsionnaya Mina Donnaya*); KMD means ship-laid bottom mine (*Korabelnaya Mina Donnaya*); MKD means large ship-laid mine (*Mina Korabelnaya Bol'shaya*).

The original AMD-500 appeared in 1942. It is sometimes suggested that the KMDs, which first appeared in the early 1950s, were derived from captured German mines. These mines were exported from the early 1960s on.

♦ ATM

Autonomous Torpedo Mine (a U.S. designation) is a Captor-like weapon carrying a torpedo. It was first observed in 1984 when the Northern Fleet destroyer *Otlichnyy* was seen carrying 4 exercise examples.

♦ BPM-2

This swimmer-laid limpet mine (4 kg of HE) appeared in 1950.

♦ Cluster Bay/Cluster Gulf

Cluster Bay is a rising ASW mine, reportedly for use on the continental shelf. This mine is, therefore, comparable in concept to the Anglo-U.S. Crusader/Hammerhead. The rising body is a rocket, and it is fired on the basis of passive/active acoustic sensing. The rocket is presumably unguided, probably exploding when it reaches the expected target depth (as measured by the active sonar). The Soviet term for such a mine is *Reaktivno-Vsplyvayushchaya Mm*, and it would presumably have an RVM

designation. Reportedly, the charge is 500 lb, and typical case depth is 2000 ft.

Reportedly, RVM, a passive-action acoustic rising mine, appeared in 1969. There is also an A-RVM. Reported characteristics are as follows: case depth, 300 m [approx 1000 ft]; maximum bottom depth, 750 m; charge, 220 kg of HE (200 kg in A-RVM). Passive frequency is 46 kHz. The mine measures target range in a 158-kHz active mode and is propelled upward by a rocket motor to explode at a depth set according to measured target range.

G-RVM is a reported guided version to attack both submarines and aircraft carriers. Mooring depth is 60–1000 m, and case depth is 60–400 m [1300 ft]; possible attack range to the target is 600 m [660 yd]. The firing mechanism takes 2 looks at the range before raising the mine to the target. There is no ship count. Arming delay is up to 21 days, and sterilization can be set to up to 370 days. The active frequency may be adjustable.

The advent of this mine led to U.S. and other Western interest in very deep hunting/sweeping. The name is a NATO designation.

Cluster Gulf is reportedly a similar mine for use in deep water beyond the continental shelf. Recently, a Soviet torpedo mine broadly comparable to Captor has been reported.

♦ KB-1/M-31/MAV/KB-3

These mines are improved versions of M-08. KB-1 was a special 5-horned moored contact mine for use in icy water, the mine casing releasing a protective shield after laying. KB-1 could be laid down to a mooring depth of 160 m and carried a charge of 230 kg of TNT. KB-1 probably appeared in the early 1930s, and the aircraft-laid M-31 was very similar. Some of these mines were fitted with antenna firing mechanisms. The steel antennas caused problems; they could be a source of eddy currents in seawater, and those currents could explode the mine even if no target was present. The mine could also explode when the antennas corroded and broke. Currents caused by disturbances in the sea (e.g., the explosion of a nearby mine) could also explode the mine. KB-1's case depth is 10 m; maximum bottom depth is 272 m, and minimum spacing is 42 m. There was also an aircraft-laid MAV moored mine of about this vintage.

KB-3 (MA-39) was introduced in 1941. It carried horns, a 35-m antenna, and a 250-kg explosive charge. Its relation to KB-1/M-31 is not clear.

♦ KRAB

This moored influence mine is ship-laid, has a case depth of 18.3 m and a bottom depth of 272 m, and carries 230 kg of explosive. Minimum distance between mines is 41 m. KRAB is an acoustic device inserted into a standard MKB ellipsoidal mine case. Two reported passive frequencies are 22.5 kHz and 30–40 kHz. KRAB entered service in 1949, and it may have incorporated captured German influence mechanisms. An Improved KRAB of 1960 is a moored passive/active acoustic mine with an improved case and warhead; the passive frequency is reportedly about 200–250 kHz, the active (echo ranging) 30–40 kHz. The mine uses 2-look firing logic. It carries 250 kg of HE; the case depth is 150 m (maximum bottom depth is 600 m [1970 ft]). The ship count is 1–21, the arming delay is up to 21 days, and the sterilization time can be up to 370 days.

KRAB means large ship-laid inshore acoustic mine (*Korabelnaya Reydney Akusticheskaya Bol'shaya*).

♦ M-08

This contact mine, developed before World War I (1908), is currently manufactured in North Korea; this mine is currently being used by Iran in the Persian Gulf. M-08, a spherical moored mine, carries 5 chemical horns. Diameter is 34.5 in, and explosive charge is 253 lb of TNT. Total case weight is 500 lb, and the anchor weighs about 700 lb. Laying depth is 34–360 ft, and case-depth settings are 4–20 ft. Minimum distance between mines (to avoid countermining) is 120 ft.



M-08-4 mines, of Soviet design and North Korean manufacture, seized in the Persian Gulf in 1987 on board the Iranian ship *Iran Ajr*. (U.S. Navy)

This mine was developed from the 1898 version used in the Russo-Japanese War, modified for easier stowage and laying, with the mine casing, wire cable reel, and anchor stowed as an integral unit, and with the explosive charge increased in 2 stages (M-06 and M-08). M-08 could be laid at 18 kt.

M-08 uses chemical horns, which were considered somewhat dangerous to the crew laying them. The Czarist developers, therefore, tried inertia fuzes, which were battery-powered in the M-05 (1905) version. They were rejected as too sensitive and too short-lived. M-09 used mechanical firing pins and was the basis for the M-12 mine described below.

North Korean-made M-08 mines in the Persian Gulf have sometimes broken from their moorings. That breaking may mean that the North Koreans have used a heavier explosive charge, compensating by using a lighter and flimsier mooring chain.

◆ M-12 and M-26/KB

These moored mines have inertia-impact firing devices. M-12 is spherical (34.5-in diameter, 220 lb of TNT, 1320 lb total). M-26 adds a parallel midbody between 2 spherical caps (total length 52 in, 528 lb of TNT, 1210 lb total case weight plus 990 lb anchor). M-12 can be laid in 30–432 ft of water, with a case depth of 4–20 ft; M-26 in 30–456 ft of water, with the same case depths. M-12's minimum spacing is 100 ft, 180 ft for M-26 (because of the more powerful charge). M-26 has an anti-sweep device, perhaps the first in the world. Its mine case is carried horizontally on the carriage, lowering its center of gravity and simplifying its preparation for launching; it can even be carried on board fast patrol boats.

In contrast to M-08, M-12 adjusts depth by a hydrostatic pressure brake rather than by plummet. The mine separates from its anchor case after a preset delay (5 min–4 weeks).

KB was a modified M-26, a bomb-shaped mine for aircraft delivery, dropped without a parachute. Maximum mooring depth was 270 m, and the explosive charge was 230 kg of TNT. The horns were moved into position by springs after dropping. This mine was also described as Type Geiro, and possibly as AMG.

There is also an M-16 moored contact mine suitable for a maximum bottom depth of 366 m, carrying 115 kg of explosive, with a minimum spacing of 36 m.

◆ MIRAB

This ground magnetic induction mine was shaped in the form of a half-teardrop. Dimensions were 40.5 in (long) × 27.5 ×

27.5 in. Charge was 141 lb of TNT in a 616-lb case. Minimum spacing was 200 ft. The mine was originally intended to be air-dropped; but its case was not strong enough, and it was surface-laid.

MIRAB was developed as a river mine, for depths up to 7 m, against ships of 20 tons or more running at speeds of 2 kt or more. Effective range was 5 m or less. MIRAB originally used a vertical-field single-contact circuit, but that proved unstable, and the mine could be countermined (i.e., exploded by shock). The problem was solved by providing a directional condition. The final triggering circuit used 2 looks but had no ship counter.

Work on a river mine began in 1927, leading first to a weapon called RENIN and then to B.I.D.; MIRAB entered limited service in 1939. However, Soviet histories of their sea mines state that the first Soviet influence mines entered service only in 1945. The difference in dates may mean that the histories refer to sea, rather than to river, weapons.

MIRAB means aircraft induction river mine (*Mina Induktsionnaya Rechnaya Aviatsionnaya*).

◆ MKB/MKB-3/MAG

MKB was the standard Soviet surface-laid contact mine of the 1950s. Like M-08, MKB used 5 chemical horns. Diameter matched that of M-08 (34.5 in), but the case was larger (length 52 in) and thicker. The charge was 506 lb of TNT; case weight was 984 lb, and the anchor weighed 1415 lb. Laying depths were 34–894 ft, and case depths 8–30 ft. Minimum separation was 138 ft.

MKB-3 was similar, but with a shorter parallel midsection (length 47 in); charge weight (200 rather than 229 kg) and case weight were similar to those of the MKB. Minimum spacing was 35 m [115 ft] rather than 42 m [138 ft].

The basic design was repeated in the MAG and AMG-1. There were 2 types of charge container, and the horns might be distributed irregularly over the body of the mine.

MAG was a moored ASW antenna mine, otherwise similar to MKB (diameter 34.5 in, length 52 in, case weight 984 lb, anchor 1415 lb). Maximum laying depth was 1490 ft. Case-depth settings were 8–146 ft, and minimum spacing in a field was 115 ft. The mine could be used with or without horns. The lower antenna was 35 m long (diameter 11.6 mm); the upper, 24 m (6.3-mm diameter wire).

MKB means large ship-laid mine (*Mina Korabelnaya Bol'shaya*). MAG means galvanic antenna mine (*Mina Antenna Gal'vanicheskaya*).

MKB mines were used in Korea (with AMD/KMD mines) and also in Vietnam (they were laid late in 1966 and found in January 1967 in the Long Tau Channel to Saigon). The Egyptians used MKB in 1967 to block the Straits of Tiran, and then in the Suez Canal.

◆ MYaM (YaM)

This small ellipsoidal moored contact mine had 3 chemical horns. Dimensions were 21 in (diameter) × 22.8 in. Weights were 44 lb of TNT, with a 142-lb case and a 243-lb anchor. Laying depth was 9–167 ft; case depth, 2–9 ft. Minimum distance between mines was 66 ft. MYaM was probably an anti-small-craft mine (e.g., antisweeper). It was first reported in Korea in 1952, and both Iran and Iraq used MYaM in the Gulf War.

◆ MZh-26

This sweep obstructor (against paravane sweeps) was conceived in 1926. Suspended above the main mine body is a small buoy carrying an explosive cartridge intended to break the paravane wire. After 1 detonates, another (of 4 in all) rises to replace it. This type of mine is to be distinguished from a multiple mine, in which the main body carries 3 or 5 full mines, which are released in turn as the previous mine is swept away. That type of device appeared before World War I.

MZh means obstacle mine (*Mina Zagrashdenie*).

◆ Nuclear Mines

The Soviet Union reportedly has small stocks of nuclear ASW mines (yield 5–20 kT). The virtue of a nuclear mine is that it can destroy submarines at any depth, whereas a conventional moored or ground mine has only a very limited lethal volume around itself. The other simple solution to the depth problem, the string mine, is relatively cumbersome, the only known Western example being the Italian TAR. The nonnuclear solution to this problem is the rising mine (see Cluster Bay/Cluster Gulf above).

◆ PLT/PLT-Z

This cylindrical moored contact mine (inertia-impact fired) was to be laid by special submarine minelayers; no current Soviet submarines have tubes of sufficient diameter. Dimensions were 31.5 in (diameter) × 70 in. Total weight was 1850 lb, with 506 lb of TNT. Maximum laying depth was 450 ft; case depth, 13–30 ft. Minimum spacing was 262 ft.

PLT-Z was a moored contact mine laid from a submarine torpedo tube; it was fired by 4 galvanic horns. Dimensions were 21 in (diameter) × 94 in. Total weight was 2220 lb, with 220 lb of TNT. Maximum laying depth was 470 ft; case depths, 8–30 ft.

There is a submarine-laid moored sectional influence mine, carrying 500 lb of explosive; it can be moored in depths as great as 1600 ft.

PLT means submarine tube-laid mine (*Podvodnaya Lodnochnaya Trubnaya*). PLT-Z means submarine tube minelayer mine (*Podvodnaya Lodnochnaya Trubnaya-Zagraditel'*), i.e., a mine compatible with a standard submarine torpedo tube. It was developed during World War II. PL would simply indicate a submarine-laid mine. PLT-Z is generally (incorrectly) referred to as PLT-3.

◆ PLT-G/EP-G

These moored mines were introduced early in World War II, both of them for torpedo-tube laying by K-class cruiser submarines. Designed for upright laying from special tubes, EP-G was a deep-laying version of the PLT-G, introduced by the end of 1941. There is also reference to EP-SA, a wartime submarine-laid mine with a 200- or 300-kg explosive charge and 130 m [420 ft] of mooring chain. Shell diameter was 90 cm [35 in]. Reportedly, the torpedo-tube mine was not satisfactory, at least initially.

PLT-G means submarine tube-laid deep-water mine (*Podvodnaya Lodnochnaya Trubnaya-Glubokovodnaya*). EP-G means underwater electrocontact mine, deepwater (*Elektrokontaktynaya Podvodnaya-Glubokovodnaya*).

◆ Type R

This moored ship-laid contact mine has a case depth of 1.8 m [6 ft] and a bottom depth of 35 m [115 ft]. It carries 10 kg [22 lb] of explosive, and the minimum distance between mines is 15 m [49 ft]. R was a U.S. designation; the Soviet designation was not known.

◆ R-1

This small moored contact mine for shallow water is fired by 2 chemical horns. Dimensions are 19.5 in (diameter) × 6.5 in. Weights are 88 lb of TNT, 253 lb for the case, and 352 lb for the anchor. Laying depth is 3.5–115 ft; case depth is 1.5–5 ft. Minimum spacing is 66 ft. In very shallow water the mine does not separate from its anchor.

R-1 was a U.S. designation, indicating a mine whose Soviet designation was not known [R for Russian unknown].

◆ RMZ

This antihelicopter mine (to defeat helicopter sweepers) was reported in 1980. It is reportedly 2 m long, with a total weight of about 700 kg (charge of about 350 kg).

◆ UEP

Some Soviet mines exploit the underwater electric potential (UEP) of submarines as their fuzing mechanism. UEP is caused by the electrolytic action between the dissimilar metals in a ship, such as the steel of the hull and the bronze of the propeller. It has both DC and AC components, the latter the result of propeller rotation. Both are very inherently short-ranged, and they are very difficult to silence. The Soviets probably learned about UEP from captured German records; the Germans called it the electrode effect. The British experimented extensively with UEP just after World War II, including an attempt to use a towed UEP electrode to detect a torpedo running up a ship's wake.

Reportedly, the first Soviet UEP mine was a submarine-laid bottom weapon of 1944 with a range of 30 m [about 100 ft]. It carried a 226-kg [500-lb] charge and had a maximum case depth of 487 m [1597 ft]. In 1951 a ship-laid KB-UEP moored mine (a 40-m case depth, a 450-m maximum bottom depth) with top and bottom electrodes appeared, primarily for ASW. It carried a 240-kg [529-lb] charge and used 2-random-look firing logic. In 1960 the Soviets introduced an improved KB-UEP with longer electrodes, and it was suited to deeper laying (a 150-m case depth, a 600-m bottom depth). It carried a 250-kg charge and incorporated a ship count (1–21), an arming delay (up to 21 days), and a sterilization time (up to 370 days). The next reported version is the UEP moored mine of 1969, with a case depth of 100–200 m [328–660 ft] and a bottom depth of 600 m. It uses 2 charges (150 kg each), deploying into an 80-m [262-ft] array, with float, explosive, and firing mechanism separate. There is an inhibit option to prevent countermining. Unlike earlier UEP mines, which have ellipsoidal cases, this one has a cylindrical case. It is sometimes called a sectionalized mine because the 3 case sections separate when it is laid.

◆ YaRM

This small shallow-water contact (anti-invasion) mine carries a 3-kg charge.

UNITED KINGDOM

◆ Existing Mines

In connection with mine modernization programs, it is often suggested that Britain has manufactured no mines since World War II. However, there were several postwar programs, begun about 1953. Information is somewhat fragmentary.

In the past, there were 3 mine series: moored mines with Mk numbers, air-launched mines (A numbers), and special magnetic ground mines (M series). The principal mines, at the end of World War II, were the following:

A Mk 6 was an aircraft-laid ground mine (1800 lb; 960- or 1040-lb charge; magnetic, acoustic, combination, or pressure). Minimum depth was 40 ft. Dimensions were 18.45 in × 8 ft 6 in (9 ft 4 in including parachute). In 1949, 5707 were on hand.

A Mk 7, 7*, and 7** were 1100-lb ground mines (555- or 610-lb charges). Fuzing was magnetic or acoustic. Minimum case depth was 40 ft. Dimensions were 15.8 in × 7 ft 6 in (6 ft 11 in without parachute). In 1949, 4502 were on hand.

A Mk 9 was an 1850-lb ground mine carrying a 960- or 1060-lb charge. Fuzing was magnetic, acoustic, combination, or pressure. Minimum case depth was 40 ft. Dimensions were 18.5 in × 8 ft 6 in (9 ft 4 in with parachute). In 1949, 1427 were on hand and another 400 were on order. This mine was renumbered in 1955 and is probably still in service.

M Mk 1 was the standard buoyant magnetic mine, ship-laid in up to 1000 fathoms of water. It carried a 320- or 500-lb Amatol charge. A total of 8948 were on hand in 1949.



British Mk 5 bottom mine (in Australian service). (Klein)



British Mk 17 moored mines with Mk 18 bases (in Australian service). (Klein)

M Mk 2 was a 1760-lb ground mine (1020-lb Amatol charge), laid by submarine or coastal forces in 5–20 fathoms. 1310 are on hand.

M Mk 5 was running sea trials. It was a 1930-lb ground mine (1030-lb charge, with magnetic, acoustic, or combination fuzing) laid by submarines or coastal forces in 6.5–20 fathoms.

S Mk 6 is a postwar submarine (torpedo tube)-laid mine, a successor to *M Mk 5*.

Mk 15 was a buoyant contact mine carrying 320 or 500 lb of Amatol; it could be laid in water as deep as 1000 fathoms. A total of 1972 were on hand.

Mk 17 was a similar buoyant mine, which could be laid in 500 fathoms of water; 14,933 were on hand.

A Type S and A Mk 12, developed in 1953–56, were the new air-delivered ASW ground mines. Weights were 1000 and 2000 lb, respectively. Both mines used combination acoustic-magnetic-pressure mechanisms. At the time of development, the standard air-drop requirements were 450 kt/5000 ft (Royal Navy) and 35,000 ft in altitude (RAF). Minimum water depths (which determined the shock level the mine had to survive during laying) were 12 and 40 ft.

Mk 10 was a postwar aircraft-laid buoyant ASW mine, and its development began during World War II. *Mk 10* used a contact mechanism, and the length of its mooring cable had to be adjusted before flight. *Mk 10* was intended to be as simple and as inexpensive as possible, and it was the only means of mining deep water not accessible to surface ships and submarines. Total weight was 810 lb (100 lb of Minol charge). Maximum case depth was 600 ft.

Mk 28 and Mine "H" Type "T" As of 1956, 2 new surface-laid ASW mines were under development. *Mk 28* was an antenna mine, said to be more reliable (i.e., less subject to premature detonation) than others. Mine "H" Type "T" was a small moored mine, under trial in 1956. Presumably, it was intended for laying from small fast attack craft. There were also a variety

of experimental mines, including buoyant UEP (antenna) mines tried from about 1944 on.

These programs almost certainly died in the major post-1957 British defense reorganization, so that they probably represent the high point of British mine production prior to the 1980s. In 1959 the standard British naval mines were the following: ship-laid *A Mk 9/A Mk 12*, *M Mk 1*, *Mk 17*, and *Mk 28*; submarine-laid *M Mk 5* and *S Mk 6*; and air-laid *A Mk 9* and *A Mk 12*. There were also sweep obstructors.

Unfortunately, the reported postwar Mark numbers do not correspond to the 3 reported Mark numbers of existing British service mines. Presumably, existing mines were renumbered some time after 1956, the 3 series merging into 1. The 3 current types are:

Mk 5 Submarine- and ship-laid ground mine.

Mk 12 Air-laid ground mine.

Mk 17 Moored acoustic mine.

In 1982 the Royal Ordnance Factories proposed a modernized version of *Mk 5*, *Mk 5N*, with a microprocessor-controlled fuze (target designation module) that used a BAJ Vickers mine circuit emulator (MICE). This device could also be applied to existing stocks. *Mk 12* is now being modernized by British Aerospace. Finally, it was reported in 1986 that *Mk 17* mines have been fitted with a new acoustic sensor.

◆ Dragonfish

Dragonfish is the current production Marconi 85-kg [?] (80 kg of explosive) anti-invasion mine for use in shallow water (down to 30 m). Dragonfish uses 2 types of influence sensors. It has a 200-day operational lifetime. The technology used is similar to that in the Marconi Stonefish, which is designed to be laid in deeper water.

◆ Mine Modernization Program

Britain has not manufactured naval mines for some years, probably since the mid-1950s, but she has retained large stocks of these weapons. British Aerospace has received a contract to modernize existing ground mines. The existing units required lengthy prelaunch preparation and could make little or no target selection. British Aerospace designed a new microprocessor-based sensor and processing unit (SAP) that solves both problems, while retaining as much of the original mine as possible. A new safing-and-arming system can be added if desired, and high energy batteries make for a long shelf life. The mine can be programmed before it is launched.

As described in 1982, the SAP had only magnetic and acoustic sensors, the pressure sensor being built into the software (which covers frequencies down to 0 Hz). Acoustic signals would be analyzed in 3 bands, to cover sonar, engines, and propellers themselves, and thus to provide a high degree of target identification.

The modernization program was announced in 1982. It applied to about 1500 mines, some of them reportedly dating from the 1950s (and presumably of World War II type). In 1984 it was reported that the entire program might be abandoned because at least some mines were suffering from deterioration of their TNT or RDX filling. Some of it crystallized, causing at least 2 mines to explode prematurely. Such deterioration is quite common in civilian explosives such as dynamite and may limit the shelf life of existing mines, an important consideration for a country, such as the Soviet Union, with a very large stockpile, much of which must be elderly. Modern formulations are more stable, but reportedly the existing fillings cannot safely be steamed out once they have begun to deteriorate. In 1984 the reported solution was to X-ray each mine and to discard those whose fillings showed cracks or crystallization.

Thus far mine modernization has, apparently, been applied only to surviving World War II *Mk 12* mines.

Although the SAP was developed specifically for British mines, British Aerospace claims that SAP is adaptable to many

other types. Presumably, it is either identical to, or closely related to, the SAP of the Sea Urchin mine.

◆ Stonefish

This medium-depth modular magnetic/acoustic/pressure (either single- or multiple-influence) mine replaces earlier British types. Launched by airplane, ship, or submarine, Stonefish is suitable for water depths of 30–200 m. Dimensions are 53 cm (21 in) × 2.4 m (1.9 m exercise); weight is 990 kg (600-kg warhead). The training version weighs 440 kg. Shelf life is 20 yr, and life in the water is 700 days.

The original version is being replaced by a shorter, lighter Mk 36 (500 kg of PBX in place of the original 700 kg of Torpex) with simplified firing circuitry (over 30 components eliminated). PBX is an insensitive munition, supplied by the French SNPE company. Development is now almost complete; no customers have yet been announced.

As of 1989, 5 countries, including Australia, Britain, and Finland, had adopted Stonefish.

◆ Versatile Exercise Mine System (VEMS)

VEMS is a British Aerospace system designed to evaluate the performance of mine-countermeasures forces, both for exercises and for the development of new countermeasures. Each VEMS body can be programmed to simulate any known mine firing device, and VEMS can be recovered (and on-board test tapes removed) up to 6 months after laying. The manufacturer claims a 20-yr service life.

Dimensions are 533 mm × 2.71 m, and weight is 560 kg; the body includes a buoyant section that is released for recovery.

VEMS is currently in service with the Royal Navy and has been ordered for the U.S. Navy, the Thai navy, and the Royal Australian Navy.

UNITED STATES

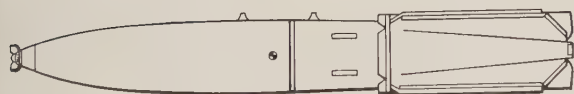
◆ Destructors

Destructors (DST) were standard streamlined bombs converted into shallow-water mines during the Vietnam War. Mk 36, 40, and 41 were, respectively, conversions of bombs Mk 82, 83, and 84. The Destructor's firing mechanism was developed very rapidly, and at the end of the war it was stockpiled. However, these mechanisms cannot have met the usual standards for reliability or shelf life: hence the development of the Quickstrike Mines (Mks 62–65, see below). It is not clear how many, if any, Destructor mechanisms remain in U.S. war stocks.

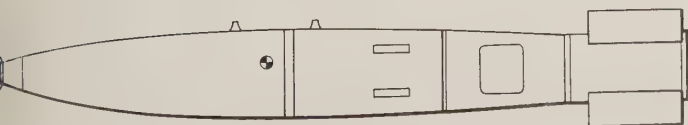
Different Mods indicate different firing mechanisms: Mod 3 is magnetic; Mod 4 is magnetic/seismic; and Mods 5, 6, and 7 are magnetic/seismic with K Tab Capability. As disclosed to the North Vietnamese in 1973 (as part of Operation End Sweep),



DESTRUCTOR (DST) MARK 36



DESTRUCTOR (DST) MARK 40



DESTRUCTOR (DST) MARK 41

Destructors (converted Mk 80-series bombs).

the DST magnetic sensor is a thin-field magnetometer with selectable sensitivity. The seismic sensor is described officially as a detection battery. Presumably, it activates the magnetic sensor, so the mine cannot be exploded by a pure magnetic field.

Destructor Mk 36 was developed beginning in August 1966, and the first deployment was in June 1967. Mods 0 and 1 require retarded delivery; Mods 2 and 3 can be delivered unretarded against land targets. Mod 0 has fixed arming delay and fixed self-destruct. Mod 1 has selectable arming delay and introduces a probability actuator. Mod 2 has selectable self-destruct as well as selectable arming delay and probability actuator, and it is suited to unretarded delivery. Mod 3 adds a sensitivity option for increased countermeasures resistance. The arming delay allows the weapon to become physically stable in the presence of water currents and wave action and hence allows its firing mechanism to become magnetically stable.

Destructor Mk 40 was developed in 1968 for greater damage effectiveness against land targets. Mods 2 and 3 may be dropped unretarded against land targets using conical fins like those of Mk 36 Mods 2 and 3.

The bomb modification kit is Destructor Modification Kit Mk 75. The original program called for 22,125 kits in FY67 and 20,250 for FY68, but in July 1967 the program was increased to 111,865 kits and in November 1967 to 148,998; by 1970, over 300,000 had been made.

Destructors Mk 36 and 40 development ended in FY70, effort switching to Mk 41 and 42 (Quickstrike) following recommendations of the NOL Minetech study, Mine Advisory Committee Nimrod study, and an Op-95 ASW R&D assessment.

There is also a Destructor M117D Mk 59-0 (1985), which uses the standard air force 750-lb bomb, with Arming Device Mk 32-1, battery, and firing mechanism Mk 42-4; the total weight is 857 lb. It is intended for minelaying by B-52s.

◆ Mk 6

This antenna mine was developed during World War I for the North Sea antisubmarine barrage and subsequently became the main U.S. surface-laid contact weapon. Mk 6 was used during World War II and was probably distributed to U.S. allies post-war. It was a 34-in sphere containing 300 lb of TNT (1400 lb total, including sinker) and could be moored in up to 3000 ft of water. Mod 3 had a 100-ft lower antenna, and Mod 4 a 50-ft lower antenna. Versions differ in type of sinker. All of these mines have Hertz horns in addition to their antennas (Mods 14 and 15, approved for service use in 1955 and 1964, respectively,



Mk 6 practice mine being launched. (U.S. Navy)

were limited to contact operation). All versions of Mk 6 were withdrawn from U.S. service in 1970.

◆ Mk 13

Mk 13 was an aircraft-laid magnetic mine, delivered without a parachute. This mine could also be used as a bomb. Total weight was 1048 lb, including 640 lb of TNT, or 1118 lb, including 710 lb of Torpex explosive. Mods 1 and 2 were redesignated Mk 26 Mods 0 and 1 (which was not produced); Mod 3 (with a parachute) was not issued; Mod 4 was designed for shallow water. Mod 5 (990 lb, including 640 lb of TNT, or 1060 lb, including 710 lb of TNT) had an acoustic exploder. Mod 6 (1020 lb, including 640 lb of TNT, or 1090 lb, including 710 lb of TPX) had an acoustic exploder and was fitted with a parachute.

Mk 36 might be considered a development of Mk 13, via Mk 26. Prior to development of the Mk 52 series, Mks 13/36 were the primary U.S. lightweight aircraft-laid bottom mines, and Mk 25 was the primary heavy equivalent. All were exported to U.S. allies postwar.

◆ Mk 16

Mk 16 is a contact (Hertz horn) mine, ovoid in shape (Mk 6 is spherical). Mk 16 carries 600 lb of HBX-1, total weight being 2040 lb. Exported postwar, Mk 16 was originally conceived as a successor to the Mk 6 antenna mine. Mod 0 was a moored induction mine. Mod 1 was a contact mine similar in operation to Mk 6. Mod 2 was a moored acoustic mine.

◆ Mk 18

Mk 18 is a surface-laid bottom magnetic mine, cylindrical in shape (with the cylinder axis vertical), with a prominent vertical post protruding from it. The mine is provided with wheels beneath the cylinder so that it can be run down a track on board the laying ship. Total weight is 2140 lb, including 1440 lb of HBX-1. Dimensions: diameter 42 in × 72 in maximum height. Mk 18 was exported to U.S. allies in the 1950s, to be used to mine shallow strategic straits. There is no other U.S. ship-laid bottom magnetic mine of the same vintage.

◆ Mk 25

The standard U.S. World War II aircraft-laid bottom mine was exported postwar, and it was used during the Vietnam War. It is no longer in U.S. service (Mod 0 withdrawn in 1970, Mod 2 withdrawn in 1974). Weight was 2000 lb total (1234 lb of TPX or 1200 lb of HBX). Dimensions: 22.4 × 87.2–93 in (depending on flight gear), i.e., roughly the size of the contemporary aerial torpedo Mk 13. In 1980 new flight gear was being issued to permit this mine to be carried at high speeds. Mod 1 was acoustic, Mod 2 pressure/magnetic.

◆ Mk 36

Mk 36 was an air-laid bottom mine with a flat slanted nose for optimum underwater trajectory. Mods 0 and 1 were magnetic (induction) mines; Mod 2 was LF acoustic, and Mod 3 was pressure/magnetic. Magnetic version weights: 940 lb (including 570 lb TNT) or 1008 lb (including 638 lb TPX). Mod 2: 1024 lb (including 570 lb TNT) or 1082 lb (including 638 lb TPX). This mine was exported postwar to allied navies. This mine is no longer in U.S. service (Mods 1 and 3 were withdrawn in 1974, and Mod 2 in 1970).

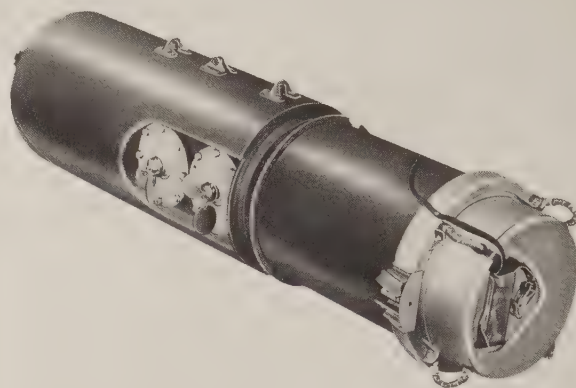
◆ Mk 49

Mk 49 is a submarine-laid ground mine designed postwar to match the operational versatility of contemporary aircraft-laid mines (particularly Mk 25) at a lower cost than the earlier Mk 27. It was first tested in 1951. Although no longer in U.S. service, Mk 49 was exported to Allied navies, some of which probably still use it. Versions: Mod 0 (magnetic induction with arming delay and ship counter), Mod 1 (LF acoustic with ship counter, arming delay, and sensitivity set automatically by sensed water depth), and Mod 2 (combination magnetic and pressure). Dimensions: 20.8 × 94.9 in (1880 lb, including 1100

lb of HBX; Mod 2 is 1840 lb, including 1100 lb of HBX). These mines were later modified, lengthened to 120 in (Mod 0, 2000 lb; Mod 1, 1890 lb, including 1180 lb of HBX-3; Mod 2, 1960 lb, including 1180 lb of HBX). Mods 0 and 1 can be planted in up to 200 ft (they can function in 16 ft). Recommended depth for Mod 2 is 30–100 ft (it can tolerate 20–150 ft). Recommended spacing: 200 ft on hard bottom, 150 on mud (Mods 0 and 1), 300 ft for Mod 2.

◆ Mk 50

This postwar (1952), lightweight, air-laid ground mine was for canals, rivers, and other shallow waterways. It used an acoustic firing mechanism that responded to hull vibrations of small vessels, a choice that contemporary sweep gear could not mimic. The Destructors were, in effect, the successor. Mk 50 was designed to fit a 500-lb bomb rack. Dimensions: 14.1 × 56.6 in (580 lb, including 238 lb of HE). When carried externally, Mk 50 was faired to a length of 89 $\frac{3}{8}$ in (603 lb). It could be launched at any altitude over 200 ft and at any air speed not over 300 kt. It armed positively in water 12 ft deep and was most efficient in 12–60-ft depths. Arming delay: 0 or 3–100 days.



Mine Mk 50. (U.S. Navy)

◆ Mk 51

This controlled mine for harbor defense is typically laid in groups of 13. Mk 51 is a vertical cylinder (62 × 37 in), carrying 3275 lb of TNT (total weight is 6200 lb). Mk 51 resembles Mk 18, but Mk 51 is substantially larger. This weapon was probably exported after World War II. Mk 51 Mod 0 was designed to counter conventional submarines, and it was modified postwar (to Mod 1) to counter midgets down to a 30-ton displacement. Mod 1 uses Acoustic System Mk 6, a line of hydrophones. The mine itself has a magnetic induction sensor. The operator ashore, who can monitor 10 hydrophone channels (13 mines group), has access to both the acoustic and magnetic sensor outputs. The operator times mine firing based in part on a judgment of the size of target. Target size is indicated in part by the number of mines responding to the target.

◆ Mk 52

The first of a postwar series of modular antisubmarine mines Mk 52 was the 1000-lb-class air-laid weapon. The World War II air-laid mines (such as Mks 25 and 36) used component plugged into the side of the mine; the Mk 50 series used an instrument rack inserted at 1 end of the mine to carry the firing mechanism, clock mechanism, sterilizer, and associated batteries. The tail cover had 3 openings for target-detecting device in contact with the sea, and there was a well for the hydrostatic arming device. When it appeared, Mk 52 offered more flexibility

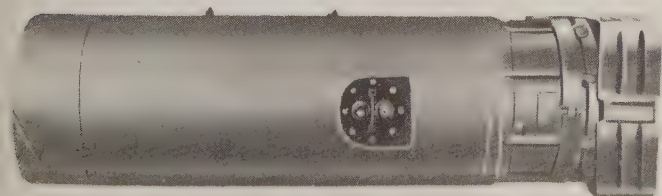


Mine Mk 51 (practice version). The vertical tube is the magnetic-induction sensor. This and Mk 18 are the only U.S. mines in the form of upright cylinders. (U.S. Navy)

in fewer different components in 1 package than ever before. The mine could be dropped either in cylindrical form with box fins (for internal carriage) or in streamlined form with a round nose and a pointed tail (with pop-out fins). It used new influence field detectors and 3 types of associated firing mechanisms: pressure, acoustic, magnetic. Versions: Mod 0 (pressure), Mod 1 (acoustic, 1130 lb), Mod 2 (magnetic, 1170 lb), Mod 3 (pressure-magnetic, 1190 lb), Mod 4 (pressure-acoustic), Mod 5 (magnetic-acoustic, 1200 lb), and Mod 6 (pressure-acoustic-magnetic, 1235 lb). Mod 7 (magnetic) and Mod 8 (pressure-magnetic) were abortive. In each case, dimensions were 18.8 × 70.2 in, and the charge was 625 lb of HBX-1. Mk 52 could deal with a submarine moving at only 3 kt and could be adjusted in sensitivity. It had a 30-count ship counter and a 1-hr to 90-day delay arming mechanism. It could be used in place of a standard unstreamlined 1000-lb AN-series GP bomb.

As disclosed to the North Vietnamese in 1973 (as part of Operation End Sweep), Mk 52 Mod 2 had a 2-look, reverse polarity, magnetic-induction fuze, with selectable magnetic sensitivities, interlock, dead periods, intership dead periods, ship counts, and preset self-sterilization/self-destruction times.

Mk 52 was part of the U.S. Long-Range Mine Program begun in 1948 and was released for production in January 1954 (operational evaluation began in October 1956). It became operational in 1961. Mod 1 was withdrawn soon after, to be superseded by the other versions, of which Mod 4 was withdrawn from service in 1978. Mk 52 was produced in West Ger-

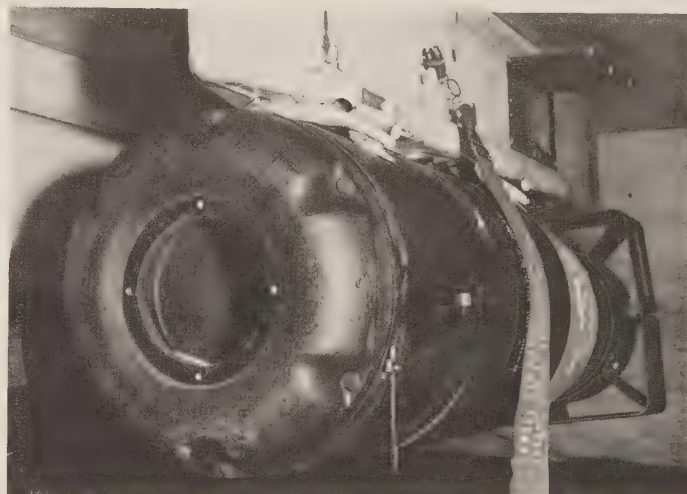


Mine Mk 52. (U.S. Navy)

many and may have been exported to other allied navies. In FY60 each of 2500 Mk 52 mines cost about \$4900.

◆ Mk 53

Mk 53 is a 500-lb air-dropped sweep-obstructor (to protect mine fields against sweepers), the first such to enter service. Reportedly, the entire U.S. stock was transferred to Turkey in 1978. Mk 53 fires when a sweep wire contacts the firing ring in the base of the mine case. Dimensions: 14.125 × 52.367 in (365 lb) in unstreamlined form (Mk 53 resembles an unstreamlined bomb with a box tail). For external carriage, it is faired at the ends, with a blunt nose and a pointed tail (which opens into stabilizing fins). Total length is 77.559 in (395 lb). Mk 53 can be planted in water as shallow as 36 ft, with a case depth of 24–300 ft.

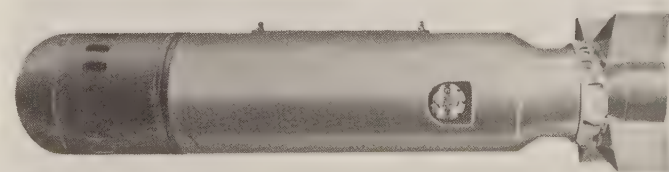


Mine Mk 53. (U.S. Navy)

◆ Mk 55

Mk 55 is the 2000-lb-class air-dropped bottom mine corresponding to the Mk 52 series; Mods 1–6 corresponded to Mk 52 Mods 1–6. Mod 0 was pressure-fired. Mod 7 used an improved dual-channel magnetic-firing mechanism. Components were interchangeable with those of Mk 52. Dimensions: 23.38 × 89.875 in (142.625 in when faired for high-speed carriage). Weights (Mods 1–6): 2039, 2110, 2120, 2119, 2128, 2118 lb. These mines could be laid by surface ships using portable rails. They were exported to some allied navies.

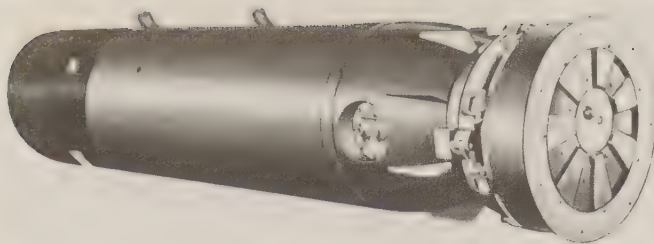
Mk 55 was released for production in November 1955 and became operational in 1961. In FY60 each of 1400 Mk 55 mines procured cost about \$5500. Of the versions, Mod 0 was withdrawn from U.S. service in 1963, and Mods 1 and 4 in 1978. The others presumably remain in service; the successor weapon is Quickstrike (Mk 65).



Mine Mk 55. (U.S. Navy)

◆ Mk 56/57

Mk 56 is a 2000-lb aircraft-laid moored mine (22.4 in × 114.3 in), with a 360-lb charge (HBX-3). Mk 57 is a similar submarine-laid magnetic moored mine (2059 lb, 340 lb of HBX-3,

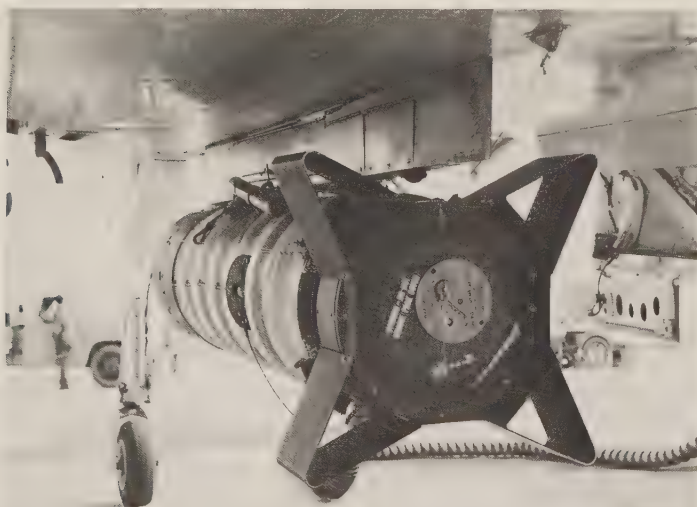


Mine Mk 56. (U.S. Navy)

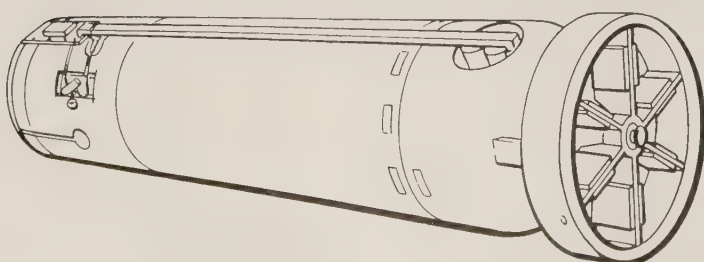
21 in $\times$ 121.1 in), for water up to 200 fathoms deep. Mk 56 uses a total-field magnetic exploder and has a stainless-steel nonmagnetic case.

Mk 56 could be set to moor at an adjustable depth (30–480 ft). Compared to earlier air-laid moored mines, it has an increased range of planting depths and a variable mine-case release timer. It enjoys greater target selectivity through the use of a new total-field magnetic-influence mechanism that can be adjusted to respond equally well to slow or fast targets. Minimum sensitivity is about 20% that of the earlier Mk 10. Like the air-laid Mk 50 series, Mk 56 is easier to assemble because it employs modular components. It has a ship counter (1–30 counts); Mk 10 has none, and Mk 36 has 1–10. Variable planting depth is 150–600 ft, compared to 100–400 ft for Mk 36. Assembly time is 2 hr, compared to 6 hr for Mk 10 and 8 hr for Mk 36. Mk 52 arms in 1 hr, compared to 65–180 min for Mk 10. When Mk 52 appeared in 1957, it was described officially as a realistic threat to submarines, whereas the earlier Mk 36 represented only a limited threat.

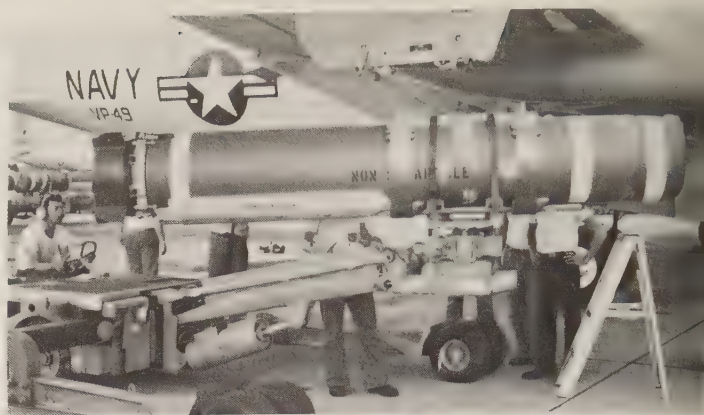
Mk 56 was released for production in 1960 and became operational in 1966; Mk 57, the submarine-laid version of Mk 56, with a fiberglass case, was released for production at the same time and became operational in 1964. In each case, the delay was caused by a lack of funding for production at the time.



Mine Mk 56 as carried on the centerline of an A-4 Skyhawk, 1965. The control unit in the tail of the mine is marked Mk 66. (U.S. Navy)



Mine Mk 57.



2000-lb-class mine being loaded onto a P-3. (U.S. Naval Institute)

◆ Mk 60 (Captor)

This deep-water ASW mine was conceived about 1960 and developed at NSWC at White Oak. A tentative specific OR was issued in November 1962, the name Captor being selected for a specific OR issued in May 1964. At that time it was hoped that Captor would reduce mine barrier costs by a factor of 100 (and barrier numbers by a factor of 400). The first production contract (for Techeval/Opeval) was awarded to Goodyear Aerospace (now a division of Loral) in 1972. Technical evaluation began in February 1974 and operational evaluation in June. Initial operational capability was achieved in September 1979 and approval for service use granted in February 1980. This very protracted development testifies to the complexity of the system. In fact, reliability problems prompted a suspension of production in 1980, procurement being resumed in FY82.

Captor (the encapsulated torpedo) is a Mk 46 Mod 4 torpedo encapsulated in a mooring/sensing body that passively detects and tracks submarines passing overhead. When a supposed track is sufficiently attractive, Captor begins active tracking and then launches the torpedo upward. This mode of operation will work in almost any depth because it utilizes reliable acoustic path (RAP) sound propagation. Determination of the target's initial bearing is by passive acoustic correlation and low-power digital processing, using techniques originally developed for the PUFFS (BQG-2/4) submarine sonar project. The mine body can be air-, surface-, or submarine- (torpedo-tube) launched, and it can moor in water at least 1000 ft deep. Lifetime is several weeks or months. Dimensions (weights) for the air/surface-launched versions are 21 $\times$ 145 in (2370 lb); for the submarine-launched version, 21 $\times$ 132 in (2056 lb).

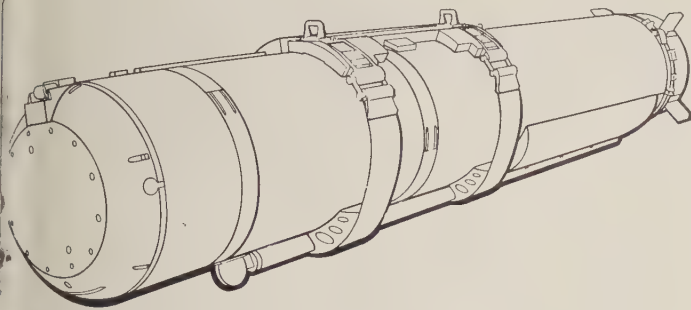
During techeval in 1974–February 1975, its detection and classification system suffered from excessive false alarms, and the system was unreliable. However, Captor had shown sufficient potential to warrant further work, and follow-on test and evaluation of initial production units was suggested. Provisional approval for service use (ASU) was granted in January 1976; at this point the production rate was limited to 10 per month. Follow-on test and evaluation, using 10 Captors, began in January 1978. Full-scale production (15/month) was approved in March 1979. At that time the ultimate objective was 5785 Captor mines.

At that time, too, the Captor project included an attempt to control it remotely (RECO) by acoustic signal. This work was still proceeding a decade later; the FY88 program included initial studies of ambient and self noise. RECO now applies to Captor, Quickstrike, and advanced mines of unspecified type. The project is being managed by NSWC White Oak; the contractors are APL and Penn State University.

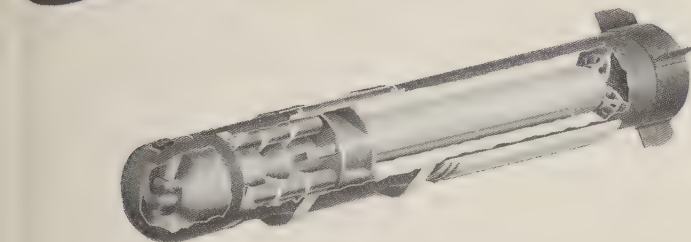
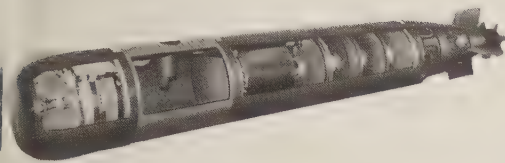
Captor is now being modified to accept a Mk 46 Mod 5 (NEARTIP) torpedo as its warhead. The hardware design for this Mod 1 version was completed under the FY88 program.

Mine Mk 66 is the practice version of Captor.

Procurement began in FY78, the FY78–80 budgets including 1810 Mk 60s. None were bought in FY81, but FY82 included a



Mine Mk 60 (Captor).



Mk 60 mine and its Mk 46 torpedo payload. (Goodyear)

request for another 400 Captors. Subsequent procurement: FY83, 300; FY84, 300; FY85, 300; FY86, 150 (unrequested). As of 1985, plans called for 475 in FY85, 600 in FY86, 493 in FY87, and none in FY88. Unit cost in FY86, the last year of procurement, was about \$377,000. In comparison, the unit cost of Captor was \$113,000 in FY78.

◆ Mk 62/64 (Quickstrike)

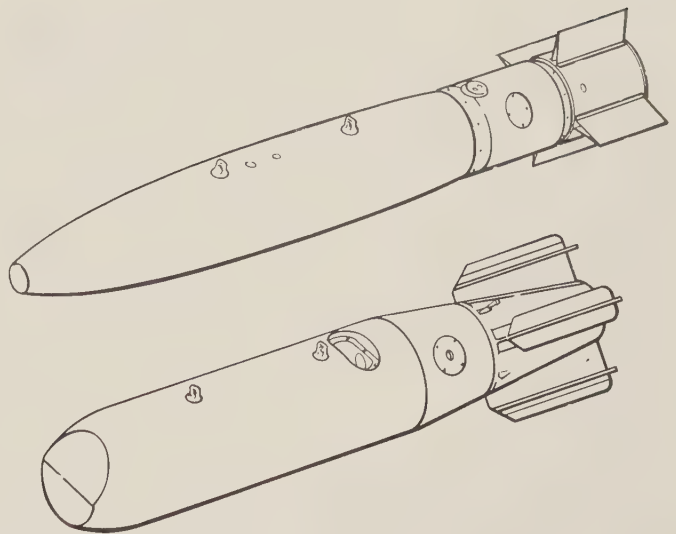
These conversions of standard streamlined bombs (Mks 82, 83, 84, respectively: 500, 1000, 2000 lb) supersede Destroyers EX-52 through -54. The Destroyers were magnetic-fuzed. These weapons can be dropped either on land (where they can be exploded by the magnetic signatures of vehicles) or in shallow water. Assembled very quickly using stored fuzes, Mk 62/64 are called Quickstrikes. All have standard thick-walled bomb casings, and their tails are adaptable to parachutes.

These weapons use 2 alternative target-detection devices (TDDs): Mk 57 (magnetic-seismic) and Mk 58 (magnetic-seismic-pressure). Presumably, seismic is, in effect, an acoustic sensor using sound as transmitted through the sea floor rather than directly through the water. These units are to be replaced by new Mk 70 and Mk 71 TDDs.

The great advantage of this program is that the United States need not stockpile large numbers of bottom mines. Instead, it can stockpile an equivalent number of specialized exploders. The logic is much the same as for the standard U.S. guided bombs, which are assembled by adding special modules to standard Mk 80-series streamlined bombs.

Mk 62 was approved for service use in 1980. As of about 1986, plans called for procurement of 39,804 Mk 70/71 TDDs, plus 3000 Mk 57 and 2500 Mk 58. Actual TDD procurement: Mk 57: 1575 in FY83 and 1753 in FY84. Mk 58: 75 in FY84, 165 in FY85, 400 in FY87, 300 each in FY88 and FY89.

Quickstrike was conceived as a new series of bottom influence mines, to enter service in 1976, to attack submarines, surface ships, and fast patrol craft. Initially the program called for 2 configurations, 500 and 2000 lb. The CNO Tactical Air Armament Study directed that the 500-lb Advanced GP Bomb (AGPB) be used for the smaller Quickstrike; the larger Quick-



Quickstrike Mines (Mks 64 above and 65 below).

strike was designed to be adaptable as a demolition bomb in the AGPB family. Both were to be air-deliverable, and the 2000-lb weapon was intended for air and submarine delivery. Quickstrike was intended to replace the earlier Mks 25, 36, 52, and 55 bottom mines and Destroyers Mk 36 and Mk 40.

The development of the Quickstrike series and its associated TDDs is justified on 2 grounds. First, the existing devices, as well as the Mk 52 series ground mines, were all compromised in Vietnam. Second, they are all becoming difficult to maintain and are no longer being manufactured. For example, their batteries must be stored under refrigeration. Quickstrike's design emphasizes ease of maintenance and also ease of mine preparation for use. All the Quickstrikes are air-delivered. The corresponding submarine-delivered bottom mine is Mk 67; there is no corresponding ship-delivered bottom mine.

◆ Mk 65

A 2390-lb modular mine (29 in across fins × 128 in), Mk 65 is the only Quickstrike not converted from a standard bomb. Unlike Mk 64, Mk 65 has a special thin-walled casing and a special



Mk 65 Quickstrike being prepared for flight. (U.S. Naval Institute)

arming device. Aerojet received the Mk 65 contract on 15 April 1982. Mod 0 uses a Mk 57 TDD; Mod 1 uses a Mk 58 TDD.

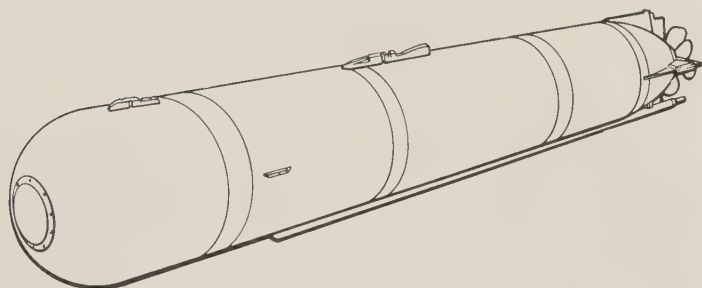
In 1985 Aerojet, the U.S. manufacturer, and Misar of Italy agreed to allow Misar to market Mk 65 in Europe. A new family of microprocessors developed by Misar will replace the U.S. Mk 58 multisensor TDD (trigger unit).

Mk 65 was approved for service use in 1983. Procurement: 307 in FY82, 579 in FY83, 600 in FY84, 524 in FY85, 1445 in FY86, 500 in FY88, and 524 in FY89, for a total of 4479 against a planned total of 4500. As of 1985, plans called for 559 in FY85, 743 in FY86, 743 in FY87, and 777 in FY88; the new schedule brought out the planned production run early. Actual procurement was 1445 in FY86; as of late 1986, plans called for 500 in FY88 and 524 in FY89 (none were bought in FY87).

◆ Mk 67 (SLMM)

The submarine-launched mobile mine was converted from a Mk-37 torpedo and was designed to be fired into a mine field from a distance. Engineering development began in FY77, and advanced development was completed in FY78. Mk 67 Mod 2 was approved for service use in FY83. A submarine successfully launched a Mk 67 mine (using fire-control panel Mk 281) during FY87; this completed development and introduced the mine into the fleet. The major contractor is the Dewey Corp. of Oakland, New Jersey, which makes the explosive section. NUWES (Naval Underwater Weapon Experimental Station) Keyport refurbishes the Mk 37 afterbody and builds up the full Mk 67. The goal, as of early 1988, was to attain the full inventory objective in FY91, using refurbishment money programmed in FY88 and FY89. In 1982, when the mine was approved for service use, the objective was 2421 mines (up from 1729). Procurement: 101 in FY82, 266 in FY83, 242 in FY84, 280 in FY85, for a total of 889. Plans for further procurement were not carried through. As of 1985, they were: 290 in FY86, 284 in FY87, and 266 in FY88, for a total of 840. However, the 1988 statement suggests that some mines have been manufactured using torpedo-refurbishment funds.

This weapon uses TDDs Mk 70 and Mk 71.



Mine Mk 67 (Submarine-Launched Mobile Mine).

◆ EX-68/IWDM/Substrike

PRAM was a proposed rocket-propelled 2000-lb weapon with a 500-lb warhead, which could be driven about 1 mile by its rocket. It was canceled in 1978 after having been conceived in the late 1960s. Engineering development would have begun in FY79, but reportedly its target sensor proved unworkable. Officially, it was dropped because of the Office of Management and Budget's regulation A-109, which required that the service no longer issue specifications describing projected weapons but instead focus on required performance. The regulation would allow for more alternative concepts. The navy, therefore, issued an RFP for what was called the intermediate-water-depth mine (IWDM). The competitors were Aerojet, Bendix, General Electric, Goodyear, Gould, and McDonnell Douglas. IWDM's dimensions were limited to 21 × 144 in (so that 2 could fit 1 torpedo skid). IWDM was to be laid by submarines, ships, and

aircraft. It would detect, classify, and localize surface ships and surfaced or submerged submarines. Demonstration-validation contracts were awarded to General Electric and McDonnell Douglas on 30 September 1980. Although IWDM was canceled it remains interesting as an indication of the nature of the projects that succeeded it. The demonstration/validation models were scheduled for delivery in June 1984, with operational evaluation in FY87. It was expected that 108 RDT&E models would be purchased, and that ultimately 6240 would be bought for \$838.5 million (about \$134,000 each). IWDM, in turn, was replaced by the new-generation mine (NGM), and then by the Anglo-American advanced sea mine (ASM) or continental-shelf mine (CSM). ASM was canceled in 1989 when Britain withdrew. There were 2 competing versions: Crusader was a rocket projectile, and Hammerhead was a torpedo. The issue was cost and capability: some have argued that any mine traveling more than about 500 m requires some degree of mid-course guidance. As of late 1989, the navy was drafting a new OR; the mine will be called Substrike.

◆ Mk 69

Training shape for California sea lions used for ordnance recovery.

◆ Mk 70

Exercise and training mine for Mine Mk 52.

◆ Mk 71

Training device to duplicate the trajectory of Destructor Mk 40

◆ Mk 72

Training device for Mine Mk 56.

◆ Mk 73

Training device for Mine Mk 55.

◆ Mk 74

U.S. designation for British VEMS (versatile exercise mine system).

◆ Universal Laying Mine

Universal laying mine is a mine development project. Procurement was 3500 in FY86, at a total cost of \$3.7 million. None were bought in FY87, but late in 1986 the navy hoped for 2400 in FY88 and 3600 in FY89. Engineering evaluation was completed during FY86, and approval for full production was expected late in FY87. Details have not been published, but presumably the universal laying mine is a new moored mine to replace Mk 56/57. The new mine is included in the same program element as the Quickstrike series of new bottom mines. No Mark number has been announced.

This mine may be associated with a new parachute flight gear Mk 16 for 500-lb mines.

◆ MOWAM

EDO's private-venture mobile mine project is designed for use principally against amphibious vehicles in shallow water. MOWAM would be deployed from helicopters or small patrol craft. MOWAM would appear to be a bottom-laid rising mine triggered acoustically, that would use a rocket motor and a magnetic proximity fuze. These data were published in 1986.

YUGOSLAVIA

In the mid-1960s Yugoslavia acquired Soviet KMD-500 and KMD-1000 influence mines (the M70 described below is presumably a locally made version of a Soviet mine). In 1975 the Yugoslav government announced that it had 2 new acoustic mines in production, *Koral* (coral) and *Biser* (pearl). However, neither appears in a catalog of Yugoslav naval weapons available for export issued in 1989. A drawing in the catalog does show a river minelayer carrying Soviet-type river mines. This is not the drifting river mine described below.

Acoustic-Induction Mine M70

This surface- and submarine-launched acoustic-magnetic bottom mine is to be used against warships of up to 5000 tons and merchant ships of up to 20,000 tons, at depths as great as 50 m against surface ships (150 m against submarines). Its electronics employs printed circuits. Dimensions: 534.4 mm × 2823 mm (21 × 111 in); weight 1000 kg (700 kg of explosive).

PLRM-1A

This drifting river mine floats upright, suspended from a float carrying a circular wire bumper. Total draft is 500 mm. Dimensions: 260 × 370 mm (mine proper); weight 14 kg (10 kg explosive). Fuzing is mechanical (clockwork).

SAG-2b

This locally produced contact mine, with a total weight of 600 kg (115 kg of explosive), can be laid in 110 m of water. This mine must date to the 1950s or before.

MINE COUNTERMEASURES/MINEHUNTING SONARS

Very precise navigational systems are essential to mine countermeasures because the sweeper must be able to identify the position of the cleared channel. Examples include the Racal Hyperfix (accuracy 5 m at 250 km) and the U.S. Precision Navigation System. Raydist, which was used to control the U.S. sweeping of Hanoi/Haiphong in 1973, was an extemporized civilian system using antennas on shore. Minesweeper navigation also requires high-definition surface-search radars, many of which are listed in the Anti-aircraft Warfare section.

AUSTRALIA

The Royal Australian Navy announced a COOP program in November 1989. Two of the craft will have a seabed-survey capability, using a commercial towed side-scan sonar, the Klein 595.

CANADA

◆ Manta

See the British FIMS, below.

◆ MCDV SOR

Several companies are currently competing to provide the minehunting and other systems of the new Canadian maritime coastal-defence vessels (MCDVs), which are part of the naval reserve mine-countermeasures project (NRMP). The MCDV is to conduct mechanical sweeping, route survey, hunting, and mine disposal. It is to employ a single integrated combat system, preferably using multifunction equipment for the different roles. The SOR (specific operational requirement) asks that the combat system's display and processing equipment be compatible with other ship's systems, that it be closely connected with the ship's command/control and integrated navigational systems, that it be located in the ship's operations room (CIC), and that it incorporate new technology.

The likely combat system alternatives are a CDC system based on SHINPADS but using the new MAGICS2 display (which is faster than that of SHINPADS and has more memory), FIMS (Ferranti's MC500), and NAUTIS-M (with an ROV-carried mirror sonar). There may also be a Canadian Litton proposal. In each case, it is expected that the standard multifunction console will provide sensor (including ROV) video as well as synthetic graphics.

The SOR calls for navigation to be accurate within 10 m.

The route survey is to be conducted with a towed sonar fish, the data from which are to be consolidated into a data base under heads such as minelike and nonminelike objects. It must cover at least 4 km²/hr, and objects 0.5 m in diameter must be detected at a depth of 200 m (300 m desirable) at a range of 200 m; they must be sorted into minelike and nonminelike categories at a range of 100 m, and their positions recorded to within an accuracy of 10 m. The survey's endurance must be at least

144 hr, and the sonar picture may be transmitted to a shore station during the survey.

The minehunting system must operate at a distance from the MCDV (which will be steel-hulled, hence vulnerable to influence mines). The SOR favors an ROV capable of largely autonomous operation (e.g., underwater-obstacle avoidance), following a programmed route while detecting objects with low magnetic and acoustic signatures. It will pass data continuously back to the parent ship, using a cable or a radio link (see the Rockwell Dolphin system described in the U.S. section), and must operate at least 600 m (1000 m desirable) ahead of the parent ship. Desired area coverage, with a high detection probability, is 2 km²/hr against moored and bottom mines ($\frac{1}{3}$ km²/hr vs. buried mines). Endurance is to be 4 hr (12 desired). Required positioning accuracy of the ROV relative to the MCDV is probably 1 or 2 m.

The ROV must also be capable of mine disposal, perhaps involving actually moving the mine out of a shipping lane.

The planned mechanical sweep is to operate down to 200 m (300 m ultimately desired), clearing a 350-m path at 10 kt on 1 side. Sweep depth-keeping and recording of deployed cable are to be automatic, and all sweep gear must be stowable between decks.

The SOR exceeds the capabilities of current systems.

◆ Model 971

Mesotech's color imaging sonar for remotely controlled underwater vehicles uses a rotary or side-scan transducer at 120–675 kHz in fan or conical beams.

Mesotech is part of the Simrad (Norwegian) group.

◆ Model 972

Mesotech's 972 side-scan sonar in a neutrally buoyant towfish, operating at 120 and 330 kHz (beam patterns 2.4 × 60 and 0.9 × 60 deg, respectively). Pulse length is 5.3 msec, corresponding to 5 m. Display ranges are 5, 10, 15, 25, 50, 75, 100, 150, 200, 300, 400, and 500 m. The video display is 1280 × 1024 pixels (128 levels of color). The towfish can also accommodate a sub-bottom profiler. Maximum working depth is 1000 m [3280 ft]; altitude sounder range is 300 m [980 ft]. Altitude sounder resolution is 0.07 m [0.23 ft]. The fish weighs 14.8 kg (165 × 1316 mm). Model 972 has a high-resolution color display and records its data on VHS tape for replay.

◆ Trail Blazer

See the British entry, below.

CHINA (PRC)

◆ Type 312

This remotely controlled magnetic and acoustic minesweeper is similar in concept to the German Troika system. Type 312 can also operate manned. Displacement is 46.95 tons fully loaded (dimensions 20.94 × 4.20 × 1.30 m), and propulsion is by a 300-BHP diesel. Radio control is effective to about 3 nm, and the craft is electrically driven at 1–5 kt. All equipment is shock-mounted, and the hull form is intended to reduce the shock effect of the mines the craft detonates. These craft have a laser precision navigation system. They are limited to coastal waters because the hull form is not suited to heavy seas.

Type 312 became operational in the early 1970s, and by 1986, 60 were in service. Reportedly, this class was inspired by successful conversion of several 400-ton *Lienyun*-class auxiliary sweepers (trawler type) to remote control.

DENMARK

A Danyard GRP torpedo-recovery vessel is to be the basis for a 2-boat drone MCM system for the StanFlex 300s. Each robot boat will tow its own TSM 2054 sonar. For classification and disposal the StanFlex will carry its own tethered underwater vehicle (which had not yet been chosen early in 1991). The robot boats are being lengthened (as compared to their prototypes)

from 16.2 to 17.7 m (the displacement increases from 23 to nearly 30 tons). Pump-jet propulsion will probably be chosen to minimize their noise signature at 12–15 kt. Trials of the drones were to begin in February 1991.

FINLAND

◆ Fiskars Sweeps

Fiskars Elesco supplies a magnetic sweep to the Finnish and Swedish navies, and in 1986 the company supplied the sweep for the 2 modified tripartite sweepers built for Indonesia. The entire system weighs 2.5 tons and is intended particularly for use against mines on a rocky seabed. The magnetic sweep can be combined with an acoustic sweep to form FIMS (Fiskars Integrated Minesweep System), in which a 16-bit microprocessor (with 1 Mbyte of memory) stores a series of up to 256 waveforms corresponding to different ships, controls both the acoustic and magnetic sweeps, and monitors mine detonation (which shows whether the applied field is sufficient).

This sweep uses a Fiskars-developed computer program to define the shape and strength of the sweep field, which varies with electrode current and spacing, the depth of water, and other conditions. The program prints out equipotential curves for the 3 field components and provides the operator with the strength of the field at the seabed. Mine detonations can be marked on the simulation curves so that the characteristics of enemy mines can be estimated in greater detail after sweeping. This system uses a special small-diameter sweep cable to minimize the reel diameter (600 mm in diameter) and to permit sharp turns by the sweeper. The manufacturer claims that its system is particularly simple to operate and can be launched by 2 people in 10 min.

FIMS is a combined sweep trailed from a single winch. Its MRK-500 magnetic component is a 500-m floating cable, from which 3 electrodes are suspended.

The Indonesian sweepers have Fiskars F82 magnetic sweeps, plus Swedish (SA Marine) AS.203 acoustic sweeps and the standard tripartite Oropesa sweep (OD 3).

◆ Kiskii Class

The Drone 17.7-ton GRP minesweepers are operated either by crews or by remote control from *Kuha*-class inshore minesweepers. They tow F82 magnetic sweeps and can also counter acoustic mines. Dimensions: 15.18 × 4.10 × 1.20 m (20 tons at full load). They are powered by 2 Valmet 611 CSMP diesels and propelled by water jets (presumably chosen for their reduced acoustic signature). Seven (1 trials unit and 6 operational, 1 per minesweeper) were delivered in 1983.

FRANCE

The Evac processor in French mine-countermeasures craft is to be modified to accept GPS satellite navigational data. This system will not replace the current Syledis but will permit overseas deployments of mine-countermeasures forces when shore stations cannot be emplaced.

◆ French Sweeps

(i) Oropesa (Wire Sweeps)

OD 1 on coastal sweepers.

OD 2 on inshore minesweepers.

(ii) Magnetic

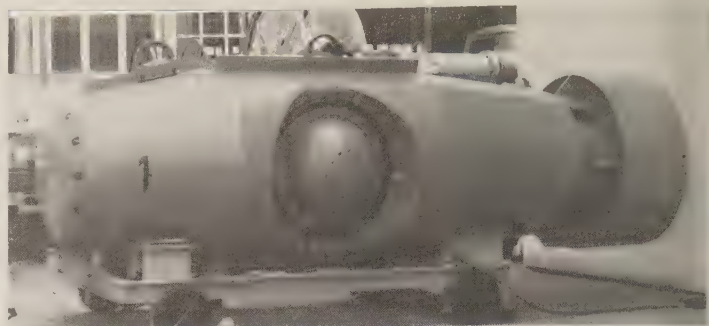
MB 1 through MB 4 symmetrical loops for coastal sweepers.

MB 5 and MB 6 asymmetrical loops for ocean and coastal sweepers. MB 5 uses a 225-kW or 364-kW sweep generator.

(iii) Acoustic

AM 1 and AM 2 hammer (*marteau*) sweeps.

AM 3 and AM 4 MF hammer sweeps for coastal sweepers. AM 3's dimensions are 856 × 520 × 340 mm; weight is 45 kg.



AP 4 acoustic sweep, covering both the low and intermediate frequency ranges. (Direction des Constructions Navales)

AP 1 and AP 2 piston sweeps for LF. AP 1's dimensions are 1130 × 558 × 380 mm; weight is 105 kg.

AP 4 acoustic sweep, announced in 1972. It combines the capability of older LF and MF towed loop systems in a single body without any surface float. Total weight is about 2 tons. This device is to equip the next-generation French minesweeper, the BAMO (*Bâtiment Anti-Mine Océanique*), and AP 4 was tested in that role in 1980–84. Compared to the British Osborn, AP 4 is said to cover a wider frequency range by using an electrodynamic (rather than hydraulic) noise generator.

AE 1 explosive sweep.

◆ Minehunting Laser

Thomson Sintra is developing a blue-green minehunting laser. The prototype is reportedly effective to a depth of 50–200 m [160–660 ft], depending on water conditions. Resolution is reportedly several centimeters at a depth of 150 m.

◆ DUBM-20 (TSM 2020)

The first French minehunting sonar incorporates both search and classification sonars. The entire dual transducer is stabilized, and the console shows both radar and sonar coordinates superimposed, for accurate mine location. Typical performance gives detection at 300 m and classification at 130 m. The detector's frequency is about 100 kHz (variable within 20 kHz, 7.5 kW), and the classification frequency is about 400 kHz (variable within 30 kHz, 4.5 kW).

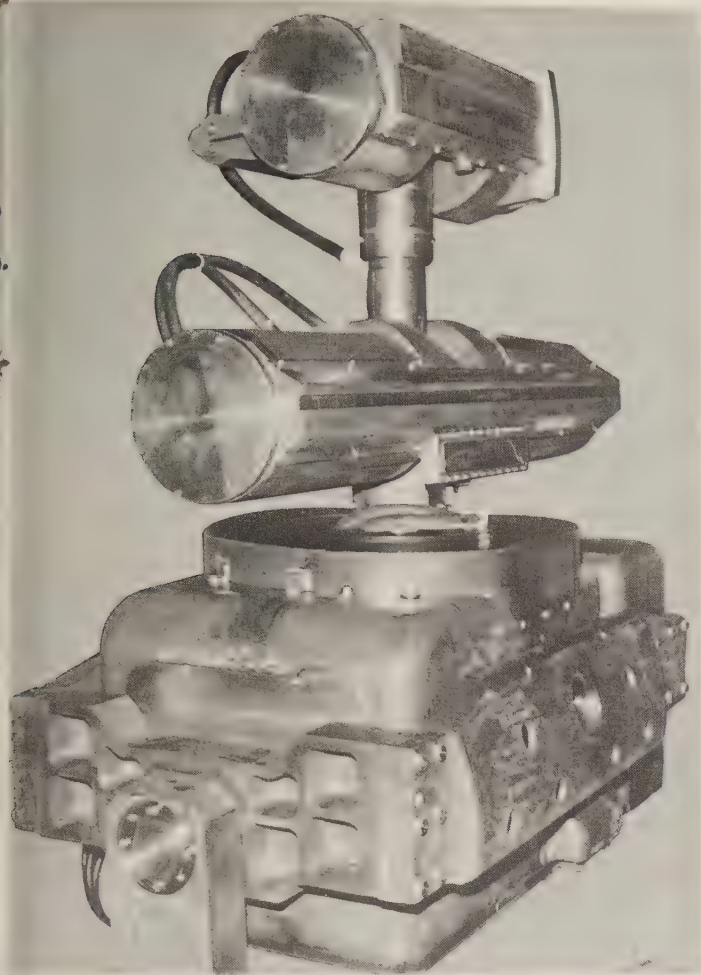
A DUBM-20A upgrade program, announced in 1984, incorporated 4 main improvements: coherent processing (for better range in noisy conditions), sweep-to-sweep integration (for a clearer display), a performance indicator (to measure bottom reverberation), and a multi-image memory (to make classification easier).

Work began in 1963, and a DUBM-20X prototype was tested on board the ocean minesweeper *Narvik* in 1967. As a result of the success of these trials, the *Circe* class was built and equipped with DUBM-20A. The first such sonar was installed in 1970 (trials 1971).

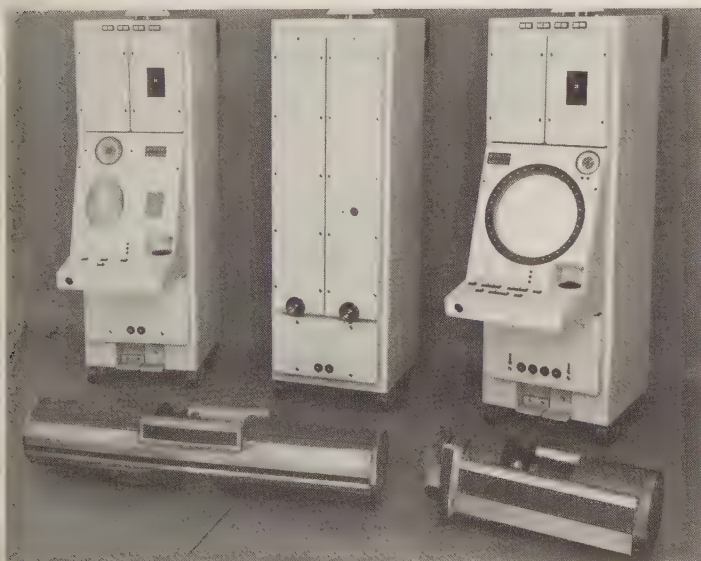
◆ DUBM-21 (TSM 2021)

Derived from DUBM-20, DUBM-21 is the successor sonar. It was first installed (as TSM 2021A) on board 5 French ocean minesweepers converted to minehunters, a program begun in 1974. Compared to DUBM-20A, DUBM-21 is much smaller and more reliable. This sonar (TSM 2021B version) plus the TSM 5730 doppler sonar log (for position keeping) are the standard sensors of the tripartite (French, Belgian, Dutch) minehunter. This sonar is also the basic element of the IBIS III minehunting system. DUBM-21 uses 2 arrays to provide simultaneous detection and classification. This technology led in turn to the U.S. SQQ-32. As of 1988, the program called for the production of 40 DUBM-21s.

Mine classification is by 2 methods, shadow and direct echo. Echo classification alone cannot be sufficient because the signatures of many mines are unknown (and the echo classifier

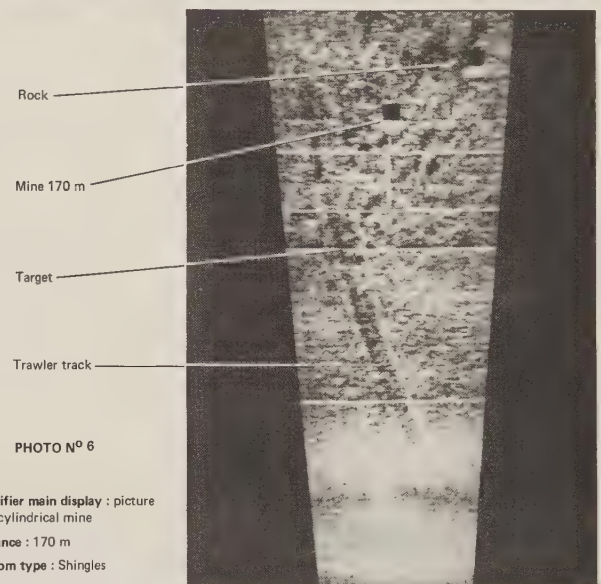
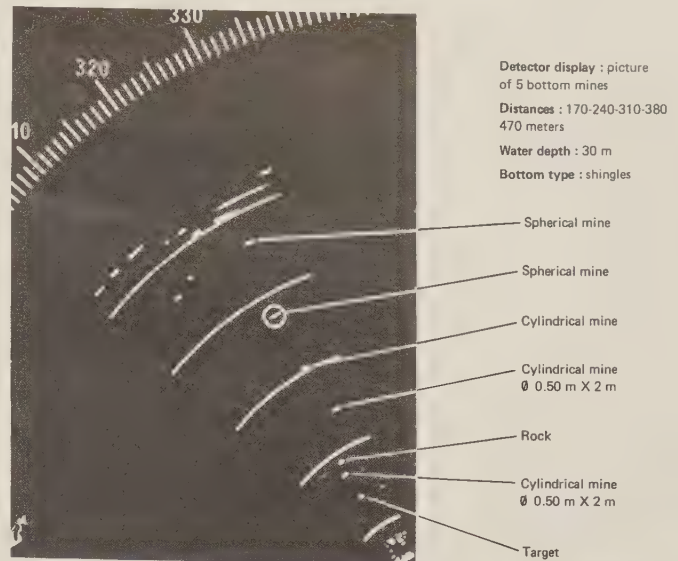


DUBM-21B (TSM 2021) array (*Eridan* or *Tripartite* class). (Thomson Sintra)



DUBM-21 arrays and consoles. (Thomson Sintra)

generally does not provide an image immediately recognizable as a mine). Moreover, an irregular seabed may mask the echoes of a small mine. Shadow classification can reveal the shape of a mine, even if it has been designed to be nonreflective. On the other hand, it is not clear whether a shadow sonar can reliably detect deep ground mines. DUBM-21 is, therefore, designed to provide both echo and shadow classification: a conventional echo detector with a range of 100–500/600 m; and a shadow classifier imaging the seabed at 100–170 m, providing images even at 200 m, and having the capability, in theory, of identi-



Detector and classifier displays (DUBM-21 sonar). (Thomson Sintra)

fying 0.2-m² objects. Both transducers are roll- and pitch-stabilized. They are not dome-housed, to avoid any distortion of the beam; at low hunting speed (4 kt), it was believed that cavitation around the transducers would have only a negligible effect.

Both transducers used preformed beams. The long-range beam (100 kHz) is 1.5 deg wide and can sweep through 30-, 60-, or 90-deg sectors. The beam uses FM pulses 0.2 or 0.5 msec long; and the range scales are 400, 600, and 900 m. Source level is 110 dB (120 dB at maximum power). The transducer has 32 staves (each of 6 elements), and it produces 20 preformed reception beams. Their output is shown on a 16-in PPI showing a 30-deg sector, with 100-m range markers.

The shadow (classifier) beam covers either a 3.5- or 10-deg arc and is 0.17 deg wide. The beam can be depressed from –5 to –30 deg. It operates at 420 kHz (± 15 kHz), using the same pulse widths as the search sonar, with 200- and 300-m range scales. Source level is 122 dB at maximum power. There are 80 preformed reception beams (from 64 staves, each of 6 transducers). Data are presented on a rectangular CRT, and the operator can mark mine images.

♦ DUBM-40A (TSM 5420)

This small towed mine-detection sonar is for use from standard naval launches and has an 80-m [262-ft] cable. DUBM-40A emits 100-microsec pulses at 735 kHz (1 kW power). Range

scales are 40, 80, and 120 m. The transducer rotates at 3, 6, or 9 deg/sec, either continuously or by 5-, 10-, or 15-deg sectors. There are 2 displays: panoramic (PPI) and rectangular. Directivity: in bearing, 22 min; in elevation, 45 deg. The standard naval launch that tows DUBM-40A is $14.87 \times 4.14 \times 1.18$ m, weighs 18 tons, and is capable of 9 kt on diesel power. The sonar fish and cable weigh 196 kg [432 lb], and the console inside the launch weighs another 185 kg [408 lb].

A modified version, DUBM-40B, was designed for use by launches, hovercraft, and hydrofoils; it can also be used for wreck surveys. Total weight is 2055 kg, which compares to 4500 kg for DUBM-21A.

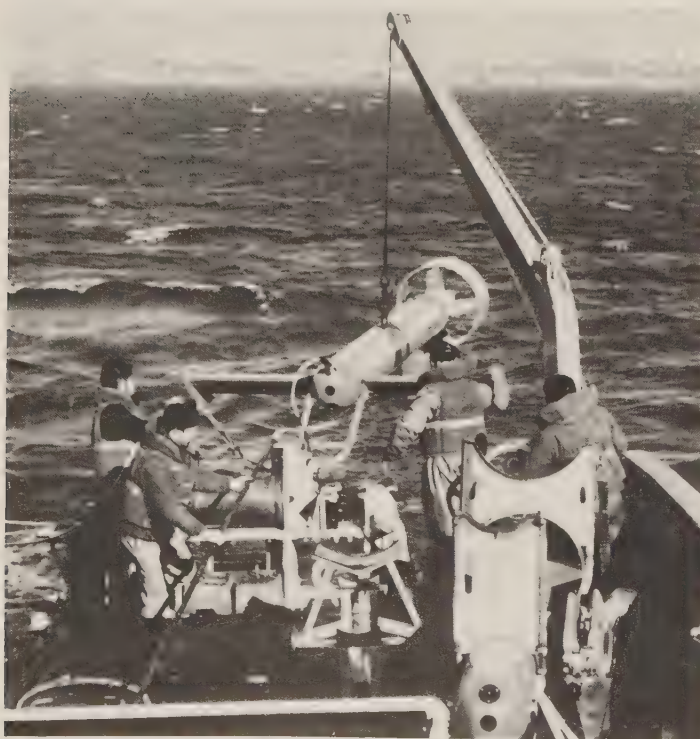
◆ DUBM-41

This towed side-scan sonar displays its data in real time on board the ship. The French navy towed this sonar from U.S.-supplied MSO-class minesweepers equipped with the UQS-1D search sonar; DUBM-41 functioned as a classification sonar. The French view was that such a combination was much inferior to a single integrated sonar such as SQQ-14 or DUBM-20.

The sonar fish is 3.7 m [146 in] long and weighs 350 kg [771 lb]. It emits 200-microsec pulses at 735 and 785 kHz (750 W), and range is 45 or 75 m to each side. If 2 fish are used (50 m [164 ft] apart), a total sweep width of 200 m [220 yd] can be achieved. The fish is held at a depth of 5–60 m [16–197 ft], and speed is 5 kt. The towing cable is 115 or 120 m [377 or 394 ft] long, each fish being held down by a kite. The height of an object can be determined within 0.5 m. Directivity of the beam is 35 deg vertically, 15 deg horizontally.

The display is either a persistent-image CRT (TEI) or a pen-marked paper (ALDEN). Typical mine classification range is 60 m.

This sonar is very similar to the U.S. Shadowgraph of the 1960s, except that DUBM-41 has 3 bottom-looking sonars to keep it clear of underwater obstacles.



The DUBM-41B fish. (Direction des Constructions Navales)

◆ DUBM-42/IBIS 42

This side-looking sweep replaces DUBM-41, for future French minesweepers (BAMO). Tow speed is greater (10 vs. 4 kt), maximum depth is greater (300 vs. 100 m), and maximum detection range is increased (150 vs. 50 m). Unlike DUBM-41, DUBM-42

uses multiple preformed beams, and 1 rather than 2 vehicles are required. DUBM-42 can cover almost 10 times the area in a given time.

The system built around DUBM-42 is IBIS 42. IBIS 42 is described as a surveillance system, mapping Q-routes in peacetime so that any changes (i.e., bottom-laid mines) can be detected rapidly in an emergency. The fish carries a TSM 2051 sonar, for shadow classification of objects in its path, and a multibeam side-looking sonar (TSM 2054). The latter can cover a 200-m track at 12 kt, providing a high-resolution (20 cm $\times$ 10 cm) picture of the sea bottom. An associated hull sonar, TSM 5421, is used to detect moored mines so that the hunter can avoid them. IBIS 42 feeds its Q-route data into a land-based processing center, which compares each survey with previously held data. A minehunting map is created in 2 steps. First the sonar image is updated, then the image is used to generate a synthetic map. Processing consists of bottom-image processing, extraction of any new echoes, location, correlation, and updating of the reference picture.

◆ DUPM-1

This hand-held minehunting sonar for divers operates in both active and passive modes and enables a clearance diver to find a mine in disturbed or muddy water. DUPM-1 uses a conical reflector with the controls on its back. Power is provided by nickel-cadmium batteries (good for 50 hr), and range is about 200 m. Overall diameter is about 12 in, for a 9-deg beam (FM slides at 50–90 kHz). The operator listens to beats between the transmitted and received beams; the beat frequency is proportional to the time difference and, therefore, to the range, since the returning signal comes from a different portion of the FM slide. Range scales are 2–22 m, 20–90 m, and 60–200 m. In each case the audio frequency range is 250–2500 Hz. This sonar can also listen for a sonar beacon that is laid to mark either an area to be cleared or a suspicious object (37–41 kHz, tuned manually). The beacon, operating at 38 kHz, lasts for 500 hr and can be detected at 500–1000 m [550–1090 yd].

◆ Buried-Mine Hunting

Two alternative sonars to detect buried mines were shown at Bourget Navale in October 1986. They are the fruit of discussions among British, French, and Dutch companies begun about 1982; and at the time of the show a trilateral MoU was expected.

British Aerospace and Thomson Sintra proposed an LF towed sonar, which might be accommodated in a DUBM-41 body, and which would use a flexensional transducer. To some extent this approach was proven during the hunt for the *Titanic*, an LF sonar on board the SAR vehicle giving an image of the composition of the ocean's floor down to 1000 ft.

DRET (*Direction des Recherches, Études, et Techniques d'Armement*) is supporting a project using a 10–50-kHz sonar, which is suggested as a compromise between LF (which penetrates deeply but has poor definition) and HF (no penetration, high definition for mine classification). The array shown consisted of 8 staves in star formation, each carrying 3 spot transducers, and the electronics would concentrate the beam on the bottom. Maximum penetration would be about 3 m.

◆ Petrel (TSM 5424)

This Thomson Sintra surface-ship mine-avoidance system was announced at Bourget Naval in October 1990. It uses the TSM 5424 preformed-beam mine-avoidance sonar. Petrel is designed for both major combatants, which may have to transit mine fields, and mine-countermeasures/surveillance units employing towed sidescan sonars, which have no way of detecting mines in their path. Petrel can also be used to evaluate mine density and risk, to mark safe channels, and to conduct preliminary operations prior to minehunting.

◆ SAR

Thomson Sintra's advanced towed imaging sonar is effective down to 6000 m. This sonar was used to locate the *Titanic*. SAR

would have naval applications in deep minehunting, and its characteristics give some idea of what really deep sonar imaging requires. The sonar, which is positively buoyant, is towed by a heavy (2.5-ton) depressor. In survey configuration, the towed body (1 × 5 m [39.4 × 197 in], 2.3 tons) carries a pair of side-scanning sonars (range 600 m to either side) and a bottom-penetrating echo sounder. The sonar operates at HF (190 kHz port, 170 kHz starboard) with a 0.5 × 80-deg beam; the transducer is 914 × 63 × 43 mm [36.0 × 2.4 × 1.7 in].

◆ TSM 2022

Thomson Sintra's single-array hull-mounted commercial minehunting sonar is designed to detect mines at ranges of 500–600 m and to classify them at up to 250 m; this performance is achieved at water depths of 10–90 m. The sonar can also measure the depth of moored mines and can conduct channel searches in the side-scan mode. For minehunting, TSM 2022 is part of the IBIS V system with the TSM 2060 automatic plotter.

The single array, which is stabilized in roll and pitch (15 deg in pitch, 5 deg in roll), feeds 1 console; detection and classification must, therefore, be carried out consecutively. For detection, the sonar covers sectors of 14, 28, or 60 deg, the last requiring mechanical rather than electronic scanning. These sectors can be steered ±175 deg from the bow. Range scales are 50–500 or 50–1000 m. For classification, the range scales are 50–150 or 50–250 m, and a 7-deg sector is covered, steerable ±175 deg from the bow. Classification is either by shadow or by direct echo.

The transducers are arranged in a horizontal linear array, which can be tilted into the vertical position for depth-finding (e.g., of moored mines). The array has 2 beamwidths, 0.37 deg for search and 0.17 deg for classification. Either the search or the classification mode can be used for depth finding. The array can be turned broadside to an expected mine position, or turned to look down, the array can be used to profile the bottom over a 14- or 28-deg arc.

Minehunting is possible at up to 6 kt; mine avoidance, at 10 kt; and side-scanning, at 10 kt. The sonar is credited with a mine-position accuracy of 1 m [3.28 ft]. In the classification mode, resolution is 0.16 deg, and range resolution is 0.15 m. Thomson Sintra claims a 90% probability of detection of a 1 m² target (ground or moored mine) at ranges from 100 to 500 m. With the array vertical, a moored mine 5 m [16.4 ft] below

the surface can be detected at 300 m [about 330 yd]. Objects as small as 0.5 m² [1.6 ft²] can be classified at up to 170 m [about 186 yd].

TSM 2022 was designed for smaller ships (hence the reversion to a single array). In all, 21 have been sold to 6 navies; this is the minehunting sonar of the Swedish *Landsort* class. TSM 2022 is the 4th generation of Thomson Sintra minehunting sonars, counting from the DUBM 20 of about 1970 and including DUBM 21A and 21B (IBIS 41A and 41B).

◆ TSM 2023

This multiple-frequency multifunction sonar is the core of the new IBIS VII system, which is intended to hunt deep (rising) mines. TSM 2023 is based on R&D work done for the classification element of the U.S. SQQ-32. It is intended to provide simultaneous detection to a range of 1200 m (at 35 kHz) and classification (at 300 m, at 250–525 kHz), and it will also be used to guide a mine-disposal device. The displays are Colibri consoles.

◆ TSM 2060 (NAVILOT)

Thomson Sintra's minesweeping tactical system is the basis of the IBIS III and IBIS V systems. TSM 2060 is a tactical plotter based on the 15M05 computer. The display is a 22-in, 4-color, circular CRT showing both symbology and raw video (for navigation among land areas). Planned and actual ship track are shown, together with up to 256 contacts. All data are recorded for later comparison with previously recorded data.

◆ TSM 2061

Thomson Sintra's tactical display (navigation/plotting system) for the IBIS 43 minehunting system (in which it is combined with a TSM 2054 towed fish) contains 2 × 19-in, high-resolution, color, raster-scan screens; a computer using 68020 chips; a removable hard disk; a keyboard with a trackball; a printer; and an X-Y plotter. TSM 2061 can also replace TSM 2060 in IBIS V.

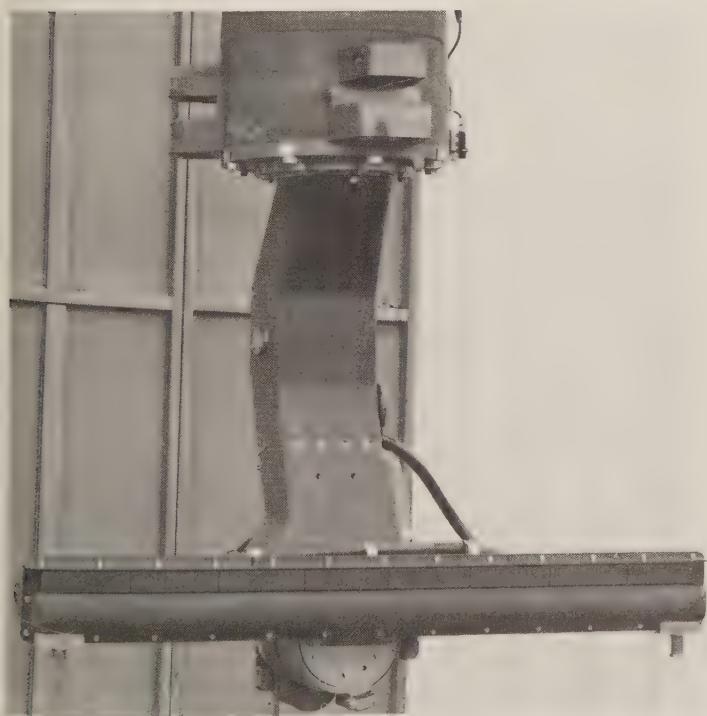
◆ TSM 5420

Thomson Sintra's small-craft dipping search sonar is capable of displaying and classifying small seabed objects at depths as great as 300 m [984 ft].

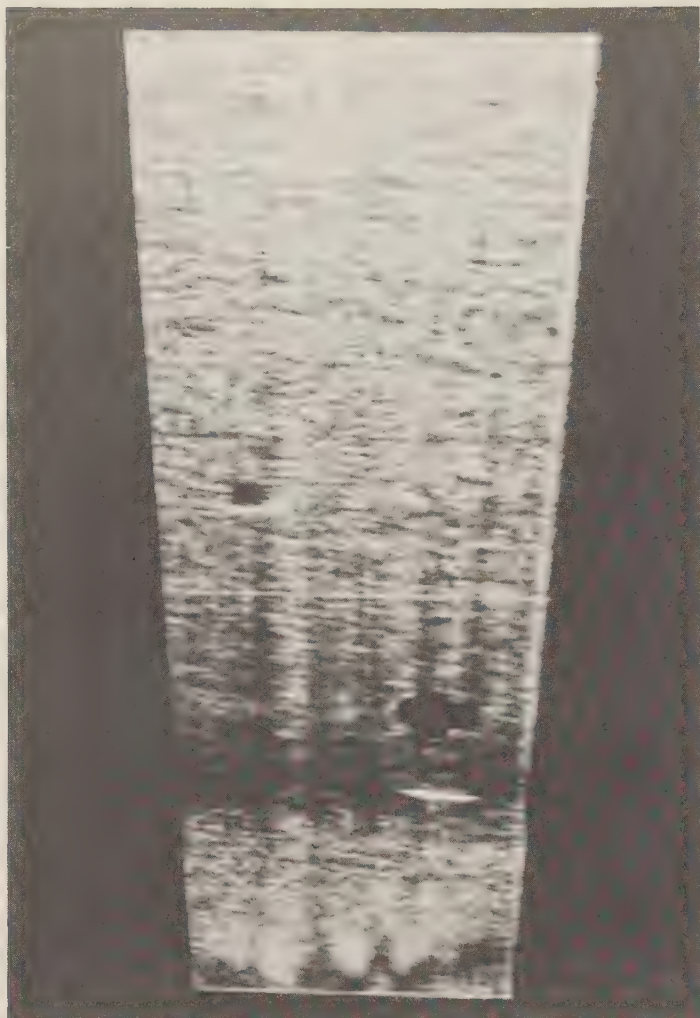
◆ PAP 104

PAP 104 (*poisson auto-propulsé*) was the first of the modern series of unmanned minehunting/minekilling submersibles. PAP was developed by ECA for the French navy, to a requirement set by GESMA (*Groupe d'Études Sous-Marines de l'Atlantique*). GESMA wanted a mine-disposal device that could operate up to 500 m from a ship, in water between 10 and 100 m deep, for up to 20 min on station. The device had to be silent and almost entirely nonmagnetic to avoid setting off influence mines, and it had to be small and inexpensive so that it could be used in large numbers by small minesweepers. Because PAP 104 replaced the usual mine-clearance divers, it had to be able to operate in conditions too severe for them, particularly in water with 4-kt current and in a force-4 wind. Finally, because the device was unmanned, it had to transmit to the controller on board ship sufficient information to make the identification of a supposed mine reasonably certain, by means of some type of image.

The fish was, therefore, designed to carry an underwater television camera and an associated floodlight. Propelled by on-board batteries, the fish had sufficient energy for five 20-min operations before recharging. The fish's speed, about 5 kt, was set by the requirement to operate despite a 4-kt current, and propulsion was by 2 podded electric motors. Because they could be controlled independently, the fish could turn sharply. There was no depth control as such. However, the fish, which was slightly heavier than water, had a guide rope hanging from it. When the rope hit bottom and began to drag, the weight that must be supported by the buoyancy of the fish was reduced



TSM 2022 array. (Thomson Sintra)



A mine and the PAP 104 vehicle on the main minehunting sonar (classifier) display of a French minehunter. (Thomson Sintra)



PAP 104. (Direction des Constructions Navales)

enough to allow it to hover. Similarly, when the operation was over, the guide rope was dropped and the fish, which was now positively buoyant, surfaced. An on-board gyroscope kept the fish on course.

PAP was tracked by the shipboard minehunting sonar, using an on-board transponder in the sail atop the hull. Once PAP had been guided into position, the operator on board the minesweeper could fly the device into place, examine the supposed mine, and set a 100-kg demolition charge. In very poor visibility the destruction charge could be dropped by sonar alone; the

sweeper's sonar would probably give an accuracy within 2 m [6.6 ft]. After all, the purpose of the fish was not so much to ensure accuracy as to identify the object to be destroyed, so that ammunition (and time) was not expended wiping out bottom junk. The demolition charge was fired from deck, by acoustic signal (a small grenade), after the fish had been retrieved (typically 15–30 min after the charge had been laid).

Launching took about 5 min, and refitting between operations (replacement of guide rope, new guidance wire, new charge, battery replacement) took about 15.

The original version had a radius of action of 500 m [550 yd] and could run at either 80 m ("GESMA," i.e., French navy, version: 262 ft) or 300 m ("civil" version: 984 ft). Speed was 2, 4, or 6 kt; and weight was 700 kg. Endurance was 3 hr at 2 kt. This version was intended solely to attack ground mines; it had no cutters to deal with mine mooring cables.

The first production version, for the French navy, was Mk 2 (1975), made of formed aluminum rather than the sheet metal of the Mk 1 prototypes. Production cost was reduced by using standard car-type batteries and a commercial television camera.

Mk 3 was designed for reduced magnetic and acoustic signatures, as well as reduced corrosion. Mk 3 was the first export model. Mk 3s for the Royal Navy were built of nonmagnetic materials (other Mk 3s are degaussed).

PAP Mk 4 (1983) could operate at depths of 300 m rather than the 120 m of earlier models. Although the Mk 3's hull could withstand the greater pressure, the earlier motors could not; Mk 4 has new motors (which can operate at a greater depth, using electronic commutation rather than brushes) for a speed of 5 kt. The principal sensor is either a high-resolution short-range sonar or a low-light television. Mk 4 was developed specifically for the Malaysian navy, which wanted to be able to hunt mines at a greater depth.

Mk 4 has a high-data-rate cable developed for the German navy, which wanted to use a Krupp-Atlas AIS 11-104 high-resolution short-range sonar instead of the usual television camera (for poor visibility). The sonar can acquire targets at up to 20 m, beyond television range. Although the Royal Navy also operates under conditions of low visibility in the water, the RN has preferred the low-light-television version of PAP 104.

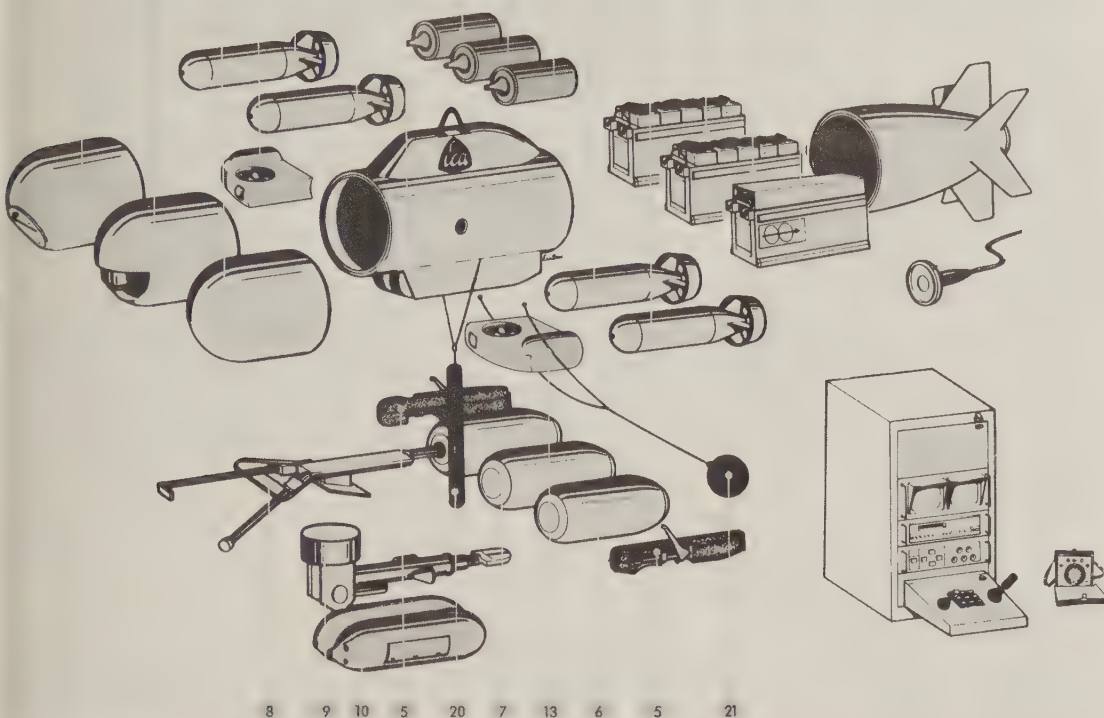
Finally, Mk 4 introduced a cable-cutter, to attack deep-moored mines.

PAP Mk 5 is the current version. Maximum speed is 6 kt, and maximum depth is 300 m. Maximum distance from the launching ship is 600 m, and endurance is five 20-min missions. The fish is modular, carrying alternative heads (user's sensors; a long-range relocation sonar; or a short-range classification sonar, the Krupp-Atlas AIS 11); alternative payloads (2 moored mine cutters, 1 on either side; the 100-kg mine-disposal charge; a manipulator with a TV; a high-capacity cutter; or ballast for mid-water navigation); alternative forms of propulsion (standard variable-pitch propellers or MG motors with electronic commutation, for increased power and depth and reduced acoustic/magnetic signature; or vertical thrusters); alternative control cables (standard 1000-m [1090-yd] blue wire; a wider-band 1000-m green wire; or a 2000-m [2200-yd] red fiber-optic wire); alternative energy source (sealed battery; high-capacity storage battery; or power drawn through the control cable); and alternative means of depth control (guide cable with variable-length control or manipulator guide cable with variable-length control). Dimensions are 120 cm in diameter $\times$ 2.7 $\times$ 1.3 m; total weight including charge is 700 kg (800 kg for Mk 5) [47.2 $\times$ 106 $\times$ 51.2 in; 1542/1763 lb].

This system, developed and built by ECA, is currently in service in the Australian, Belgian, British, Dutch, French, German, Indonesian, Malaysian, Norwegian, and Yugoslavian navies; over 325 PAP vehicles have been sold. PAP-104 has been used operationally in the Falklands War, in the Red Sea (1984), and in the Persian Gulf.

In Royal Navy service, PAP 104 Mk 5 is designated RCMDS (remote-controlled mine-disposal system) Mk 2 (Mk 1 was an earlier PAP version).

4 3 2 13 12 11 16 15 14 11 12 17 18 19



8 9 10 5 20 7 13 6 5 21

(Above) PAP 104 Mk 5 modular design alternatives. Key: (1) central body; (2) standard or user-chosen head; (3) reacquisition sonar heads; (4) near-field identification sonar head (KAE AIS 11 sonar); (5) 2 moored mine cutters, 1 each side; (6) standard destruction charge (100 kg); (7) exercise charge; (8) high-capacity cutter; (9) manipulator with TV/searchlight; (10) ballast; (11) standard variable-pitch propellers; (12) MG motors (electronic commutation); (13) vertical thrusters; (14) standard blue wire; (15) new green wire (1000 m); (16) alternative red (fiber optics) wire; (17) sealed battery; (18) high-capacity battery; (19) power down the cable; (20) standard guide rope with variable-length control; (21) manipulator guide rope with variable-length control. (ECA)

◆ IBIS III

The minehunting combat system of the tripartite minehunters (a version of Skubermor II, see below) has also been adopted by the Royal Norwegian Navy. It uses the DUBM-21 sonar and the TSM 2060 TDS.

◆ IBIS V

Thomson-CSF's minesweeper combat system was announced in 1980. IBIS V incorporates the TSM 2022 sonar and the TSM 2060 22-in 4-color tactical display. The action display shows the ship's track and the contact's location; the operator can record and display positions of minelike objects such as obstructions on the bottom. Similarly, the operator can compare the current situation with previously recorded runs. The display shows a 100-m safety circle around the minesweeper/hunter, so that it does not come too close to a suspected mine while investigating it. Ten previous contacts can be recorded and displayed.

Typically IBIS V includes a Thomson Sintra doppler bottom log (TSM 5721 or 5730).

Compared to IBIS III, IBIS V weighs 1.4 rather than 6 tons.

The Mk 2 version incorporates the new Colibri console, used by both the sonar operator (one 19-in display) and the tactical officer (who has 2 screens). It provides computer-aided detection and classification and includes a sonar-performance indicator.

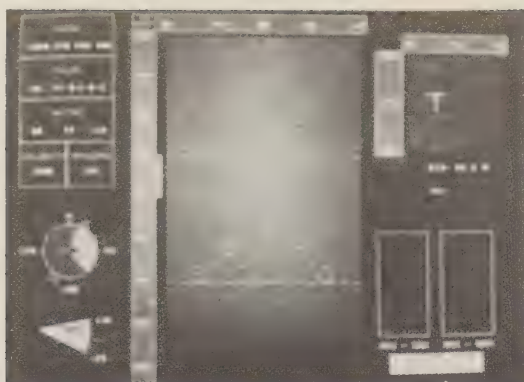
This system is on board modified Indonesian Tripartite and Malaysian and Nigerian *Lerici*-class minehunters.



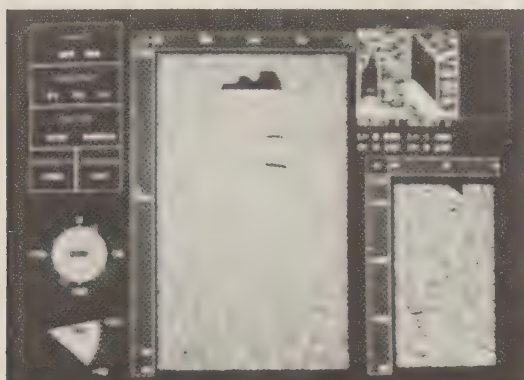
IBIS V minehunting system shows the shadowing effect of mines illuminated by an overhead sonar. (Thomson Sintra)

◆ IBIS VII

IBIS VII is a self-propelled sonar fish for the *Narvik*-class ocean minehunter (BAMO). Under development by DCN, the fish is fitted with TSM 2023. Alternatively, the sonar could be fitted in towed form, to function either as a VDS or (housed) as a hull sonar. When towed, the sonar can operate down to a depth of 200 m [about 660 ft] but at a trailing distance of less than 150



IBIS VII mine-detection display, showing synthetic video to indicate mine positions. (Thomson Sintra)



IBIS VII mine-classification (shadow image) display. (Thomson Sintra)

m abaft the ship. The sonar can operate at ship speeds of up to 5 kt, and its depth is automatically controlled. In self-propelled form, the fish can operate up to 600 m ahead of the using ship, down to 300 m in depth [about 1000 ft], and at up to 6 kt. The fish's course is automatically controlled. In either form, TSM 2023 can operate in sea-states up to 5. The sonar is designed to detect and classify targets simultaneously, at long range, operating at several frequencies. Classification is either by echo (image) or by shadow, and both detection and classification are computer-aided. Operating mode is selected with the assistance of a performance-prediction system.

(Below) A Sterne I integrated mine-countermeasures tow, consisting of a noisemaker flanked by 2 solenoid fish. (Thomson Sintra).

Thomson Sintra describes this sonar as suitable, then, both for escort missions in moored fields, where it functions as an evasion aid, and for transit and operations in shallow waters, where it would be faced with bottom mines. DCN-Thomson Sintra-Bertin are the manufacturers, and IBIS VII is to replace DUBM-42. IBIS VII is in the early development stage.

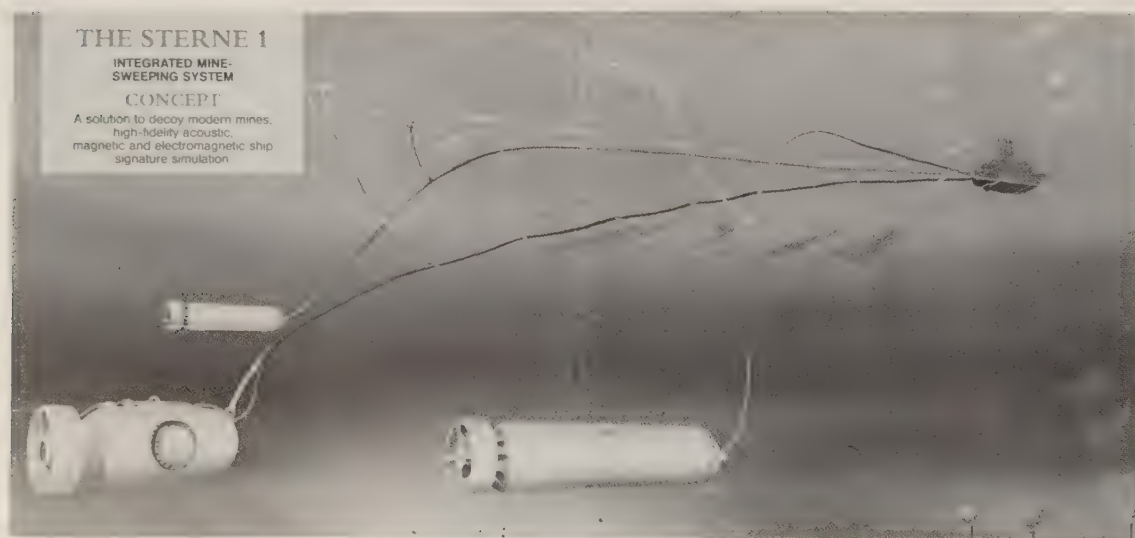
◆ IBIS 43

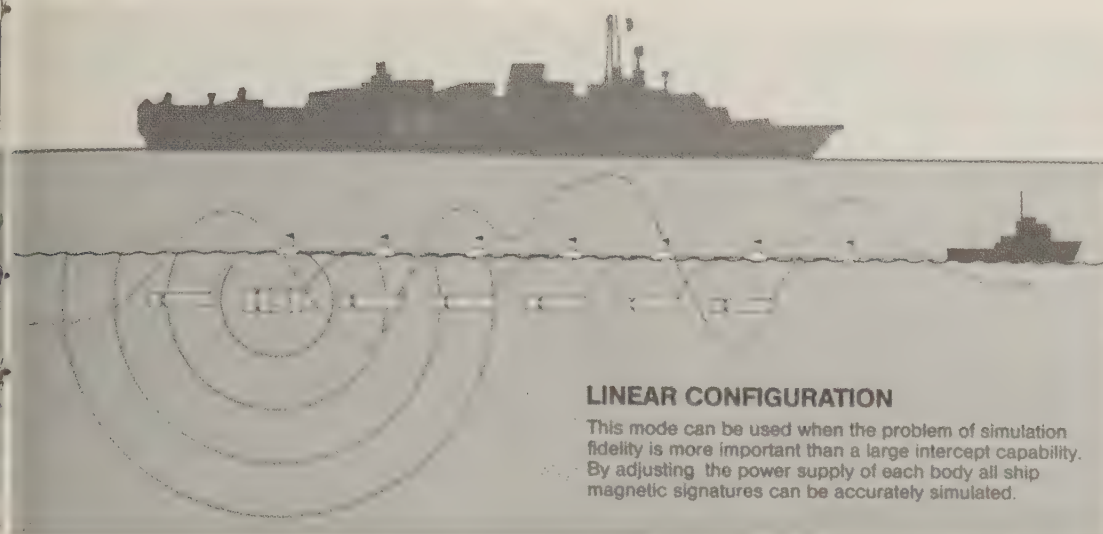
In 1989 Thomson Sintra announced the IBIS 43 minehunting system, developed from the earlier DUBM 41 and IBIS 42 (DUBM 42). The sensor is the TSM 2054 high-resolution multibeam side-scan sonar, mounted in a fish towed at 4–15 kt, covering 5.4 km²/hr. The fish operates down to a depth of 200 m [660 ft], sweeping a 50- or 100-m-wide [55 or 110 yd] swath (resolution cells are 20 × 10 cm or 20 × 20 cm, depending on range). The operator programs the fish to fly at a fixed height above the seabed, using its on-board echo sounder. The fish also carries an obstacle-avoidance sonar, which enables the fish to fly over 10-m [33 ft]-high obstacles. It carries a doppler sonar for precise speed measurement. The system automatically corrects the fish's speed, yaw, and pitch and computes the precise position of the towed body to an accuracy of better than 9 m. The system has 2 Colibri consoles, for sonar display and tactical control.

IBIS 43 has been chosen to equip the Danish StanFlex 300 corvettes in their Q-route (600 yd wide) surveillance role, using 2 remote-controlled 15-m craft, each towing a fish at up to 15 kt. Each craft covers the channel of interest with 3 overlapping runs to maximize mine-detection probability, each operator seeing the same object 2 or 3 times from different angles. The corvette carries a remote-controlled fish for mine disposal. The Danish IBIS 43 includes the TSM-2061 tactical data-handling system.

◆ Sterne I

Sterne I is a complex acoustic/magnetic sweep designed to mimic some of the detailed structure of a target's signature. Sterne I is analogous to the British Sea Serpent. The sweep employs 2 magnetic bodies (solenoids) and 1 acoustic body (the standard French navy AP 4), the 2 solenoids lying to either side of, and slightly ahead of, the AP 4. Alternatively, a linear configuration, e.g., of 6 solenoids and 1 AP 4, can be used against mines so sophisticated that fidelity to the ship's signature is more important than swept width. Solenoid power is supplied by an electronic amplifier that can adjust power to the level and shape of the desired signature. The manufacturer, Thomson Sintra, claims that it can achieve a large magnetic sweepwidth even using low electrical-power levels.





(Above) The linear Sterne I tow, intended to mimic a ship's detailed magnetic signature. (Thomson Sintra)

◆ Skubermor

Skubermor is the French series of minesweeping systems; the Breton name means sweeper of the sea. All versions consist of a detection/classification sonar, a means of identification and neutralization, and a means of precise navigation. Skubermor I, in the minehunter *Circe*, uses the DUBM-20 sonar, an EVEC 10 plotting table, radar and Ragep-Toran for navigation, and PAP 104 and divers for mine classification and destruction. Skubermor II, in the converted ocean sweeper *Dompair* (now discarded), used the DUBM-21 sonar, an EVEC 11 plotting table, and the same means of navigation and mine destruction (plus the American wire sweep originally supplied with the ship). Skubermor III, in the tripartite minehunters, uses an EVEC 20 plotting table, radar, Syledis-Toran or Decca (in Dutch and Belgian ships) for navigation, PAP 104, divers, and the lightweight wire sweep OD 3.

The EVEC (*Ensemble de Visualisation et d'Enregistrement de la Chasse Aux Mines*) automated plotting table is installed in the minehunter's CIC. EVEC 20 includes automatic navigational radar input. Toran and Syledis are radio navigation systems using the HF and VHF bands, respectively; the Decca system is Hi-Fix.

GERMANY (WEST)

◆ DSQS-11

The current standard German minehunting sonar is also found in the new Australian *Rushcutter* class and on the last 4 Swedish *Landsort*-class minehunters (replacing the Thomson-CSF TSM 2022). DSQS-11 uses a 90-deg horizontal beam with overlapping sweep sectors to port, starboard, and straight ahead, all 90 deg wide. The sonar can be depressed to measure a target's depth. DSQS-11 has a variable pulse rate and uses a PPI display whose video is processed to suppress noise returns.

DSQS-11H is a hull sonar in a retractable dome. This version consists of a cylindrical detection array and a flat classification array trainable through 130 deg in azimuth. Simultaneous coverage of a 90-deg sector (in azimuth) is provided by RDT of 45 pulses, with 45 preformed receiving beams, each 2 deg wide. The detection sector can be switched to any 1 of 5 preset center bearings 72 deg apart, the sectors overlapping by 18 deg. Classification is in 2 stages: first depth, then shape; up to 5 classification images can be stored. Operating frequency is 103 kHz, using 1-msec FM pulses for detection and 0.1-msec CW pulses for classification. The flat array is square, for a narrow beam; the cylinder is relatively shallow, presumably to form a fan

beam. The full array projects 0.9 m below the keel, and the assembly above it is 2.5 m high. The cylindrical array transmits 45 preformed fan beams for detection (search); the flat array transmits 20 vertically stacked beams within a 2-deg horizontal width. This sonar equips the RAN *Bay*-class minehunters, the Thai navy M48s, and the West German Type 332s.

Experience with the original DSQS-11H has apparently been less than happy. The Royal Thai Navy has had to use its new minehunters as patrol craft, retaining older U.S.-built "Bird"-class sweepers with UQS-1 sonars for mine countermeasures. Reportedly, it is planning to buy a new minehunting sonar, probably a Thomson-CSF type. The Royal Australian Navy, too, has been unable to use DSQS-11H effectively. Reportedly, as of mid-1989 it had not yet accepted the first of the new minehunters because of the unsatisfactory performance of the detection element of the DSQS-11H sonar. The RAN will probably seek trials of alternative systems by 1991. The German navy is replacing DSQS-11H with a new version, DSQS-11M. Reportedly, the problem was undue reliance on electronic scanning, a technology with which KAE had been very successful in lower-frequency submarine sonars.

◆ Penguin A1

Penguin A1 was the vehicle from which B3 was developed. A1 is now being used as the basis for a mine search/classification vehicle without mine-destruction capability. At present this phase of minehunting takes much longer than actual disposal. The search/classification vehicle can be lighter than a full minehunting device and can operate in tandem with a mine destroyer. Dimensions are 1.0 m (diameter) $\times$ 3.7 m $\times$ 2.0 m (span) [39.4 $\times$ 145.7 $\times$ 78.7 in]; weight is about 2 tons; and diving depth (hull strength) is 200 m [656 ft]. Propulsion is by a shrouded propeller at the tail, for a speed of up to 7 kt. The vehicle maneuvers with flaps set into the trailing edges of the 2 delta wings and with a vertical flap in the fin.

Normally, Penguin is powered through a cable run from the minehunter. However, the vehicle can also operate from a catamaran buoy carrying a small motor/generator unit. The fish tows the buoy, and in this form Penguin can operate for up to 10 hr. The buoy is used as 1 terminal of a radio data link with the minehunter, the vehicle operating much farther away than is common in other underwater vehicle systems.

Penguin A1 is expected to become operational in its role in the 1990s. A1 will probably carry a side-scanning sonar that will replace a similar sonar streamed by a minehunter.

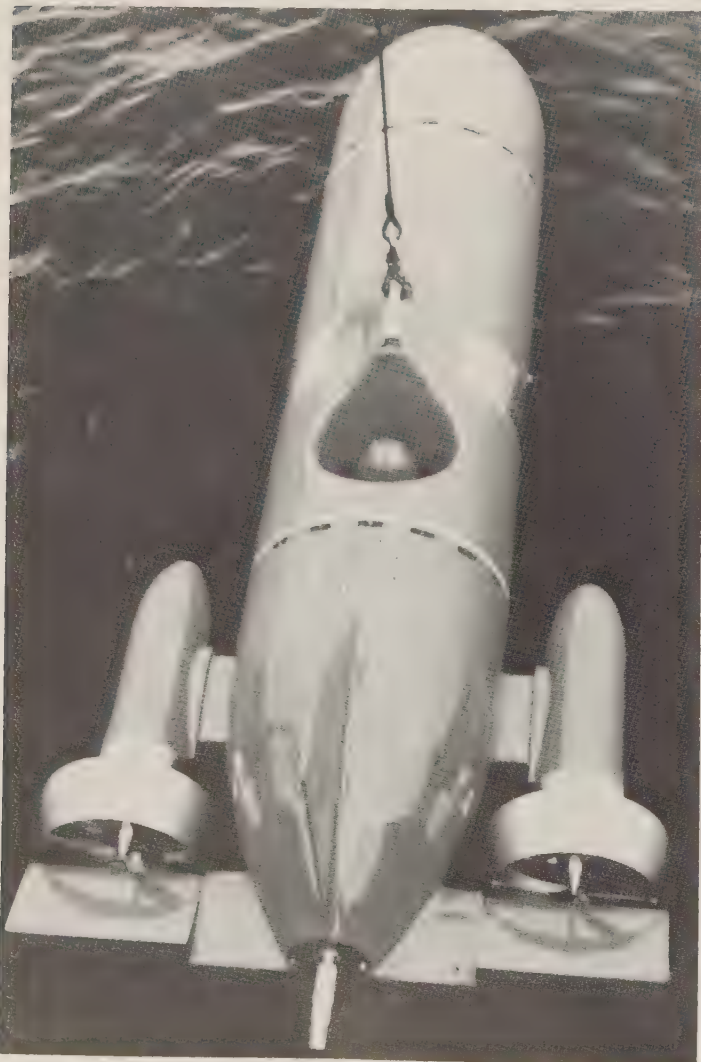
Work on the Penguin series began in the early 1970s, and at that time layouts for B3 and for B6, for offshore work, were developed. Design of a model of B3 for engineering development began in 1979, based on experience already gained in the Type 331 minehunter program.

◆ Penguin B3

This mine identification-and-disposal vehicle was part of the Type 343 minehunter program. Like PAP 104, B3 is powered by motors fed by on-board batteries, in this case silver-zinc units giving 150 min of endurance at 6–8 kt. Propulsion is by twin podded units. The high speed was chosen because of the strong currents in German coastal waters; the vehicle can also hover. It turns by controlling the thrust of the 2 motors, and it climbs and dives by manipulating elevons in the wash and by using a vertical propeller in a tunnel. The gyro-stabilized vehicle is launched along a preprogrammed path to a point selected by the minehunter's combat system, and this degree of self-control reduces the operator's workload. Penguin is brought into a hover over the location of the presumed mine, then uses television (which looks both ahead and down) or high-definition (2 MHz) sonar. The sonar's range is about 10 m, and the beam is focused using an acoustic lens. Alternatively, Penguin can be fitted with a Krupp-Atlas high-definition (but lower frequency) sonar. The cable link with the controlling ship carries 3 sets of signals: a 2-way digital data link for commands and feedback, a sonar link, and a television link.

The B3 body is slightly positively buoyant, to facilitate recovery. However, this buoyancy is small enough so that B3 can fly using relatively small control forces. Thus with 30-deg-down elevon angle, B3 can reach maximum depth (from the surface) in less than 1 min.

The manufacturer is MBB-VFW. The first test vehicle was completed in 1979, a second following in 1982, with sea trials in September–October 1982, followed by trials with the minehunter *Minden* in August 1983, and trials with alternative sensors in October–November 1983.



Penguin B3. (Messerschmitt-Bölkow-Blohm)

Dimensions are 70 cm (diameter) $\times$ 3.5 m $\times$ 1.5 m (span) $\times$ 1.45 m (height) [29.9 $\times$ 137.8 $\times$ 59.1 $\times$ 57.1 in]; weight is 1350 kg [2975 lb]. Penguin B3 carries two 120-kg [264-lb] charges in tandem so that it can destroy 2 mines during a single mission. Range from the operating ship is 600–1000 m [660–1090 yd]. Diving depth is 100 m [328 ft].

◆ Troika

Troika consists of a control ship (which tows a moored sweep) and 3 drone sweepers that provide acoustic and magnetic signatures to trigger influence mines. The drones are tracked by stabilized X/C-band radar (the 3 boats are fitted with Luneberg Lens radar reflectors atop their masts), and the data link is UHF. Courses for both drones and control ship are corrected automatically. Control range is several miles. Typically, the control ship carries her own mine-detection/avoidance sonar (DSQS-11A) to detect moored mines not swept by the drones.

Each Troika sweeper is 24 m [79 ft] long and displaces about 95 tons; draft is less than 2 m [6.6 ft]. The boat has a blast-resistant steel hull (around which a wooden hull has been built), in which diesel engine, control, power supply, and remote controls are all shock-mounted. The diesel uses a hydraulic drive for shock resistance. Two coils, 1 at each end, generate a strong magnetic field to explode magnetic mines. For acoustic mines, each Troika carries 2 MF sound sources in its bow and tows an LF source.

Krauss MaK is the prime contractor.

Experiments in 1959–60 led to the construction of 2 remotely controlled sweepers, *Walross* and *Seekuh* I (Manatee), followed in 1965 by 2 more *Seekuh*, the 3 constituting the first German Troika. The coastal minesweeper *Niobe* served as control ship. In 1969, under remote control, *Walross* swept a field of World War II mines in the Tegeler Platte shallows so that a lighthouse could be built. Six Troikas (18 remotely controlled craft and 6 controllers) were ordered in the mid-1970s (the controllers were converted in 1979–81).

Krupp MAK has announced a new version of Troika, MCM-SDS (surface drone system), which is more flexible than the original and can hunt and lay mines. The drones are self-guided through a series of preset navigational waypoints (using the new very accurate navigational aids), and thus up to 4 can be controlled by a single operator. This contrasts with the previous method, in which the operator controlled a drone by steering it along a track line visible on the radar. The drones can be controlled from a ship or from shore. They are also faster than their predecessors, with greater range and survivability. Each 25-m (90-ton) drone can carry 4 alternative mission kits: for route surveillance (towing a fish with side-looking sonar), for wire or magnetic sweeping, and for minelaying. Missions are varied by embarking alternative kits; the control station does not change. An alternative single-mission drone would displace 50 tons.



A Troika boat, *Seehund* 1. (L. van Ginderen)

◆ MWS 80

Krupp-Atlas's minehunter weapons system uses the DQS-11H sonar and the PAP 104 vehicle. As applied to the Australian catamaran minehunters, the operations room itself is containerized so that it can be removed for maintenance without withdrawing the hunter herself, a second operations room being substituted.

INTERNATIONAL

◆ EPMDS

Experimental Parametric Mine-Detection System is a French-British-Dutch program to find buried and disguised mines. EPMDS uses a very stable towed fish carrying sonars, beamformers, some of the processors of the French DUBM-41, and new receiver arrays (with on-board processors) developed by British Aerospace. Trials were scheduled for 1990, on board the Dutch research ship *Tydeman*.

◆ NATO MCM Studies

NATO Project Group 22 is studying technologies for mechanical and influence sweeping in the mid-1990s and beyond, both for the deep sweeps wanted by the U.S. Navy and for coastal waters. The study of mechanical sweeping was conducted between September 1987 and May 1988; the issue was whether the full water column (2 km) could be swept by 1 system. The conclusion was that no single system could easily handle this volume because the sweep would be so heavy that a ship of destroyer size would be needed to tow it. Instead, 2 types of sweep would be required: a flying sweep using existing types of cutters, and a rolling or sliding sweep to clear bottom mines. Even so, large sweepers would be required, and the group considered using decommissioned bulk carriers and other merchant ships.

◆ ERMIS

Explosion Resistant Multi-Influence Sweep System is under development by a 5-nation consortium within NATO (France, Germany, the Netherlands, the United Kingdom, and the United States) to deal with pressure as well as acoustic and magnetic mines. The first underwater explosion trials were conducted in 1983. The idea of an unsinkable craft that would simulate the usual target dates back to World War II, and in the early postwar era the idea led to the construction of the U.S. XMAP cylindrical countermeasure and to British experiments with strings of Thames barges. In the 1950s and 1960s the United States experimented with explosion-resistant modified Liberty ships, powered either by deck-mounted turboprops or by what amounted to outboard motors.

ERMIS is conceived as an inflated fabric tube surrounding an explosion-resistant body consisting of ballast tanks open at the top and sealed at the bottom by flexible rubber diaphragms. The inflated portion of the hull carries the diaphragms above the water, to form an air space that reduces shock effects. This concept is similar to the abortive U.S. surface-effect minehunter (MSH), and the air cushion also explains why air cushion minesweeping experiments have been so successful. In the case of ERMIS, the problem is to provide a sufficient pressure signature to detonate a pressure mine without coupling the hull so strongly to the water as to destroy it.

Germany, Britain, the Netherlands, and the United States signed an MoU covering the first 2-3 yr of ERMIS development in 1978.

ITALY

The standard wire sweep is designated MIS.4.

◆ P2072

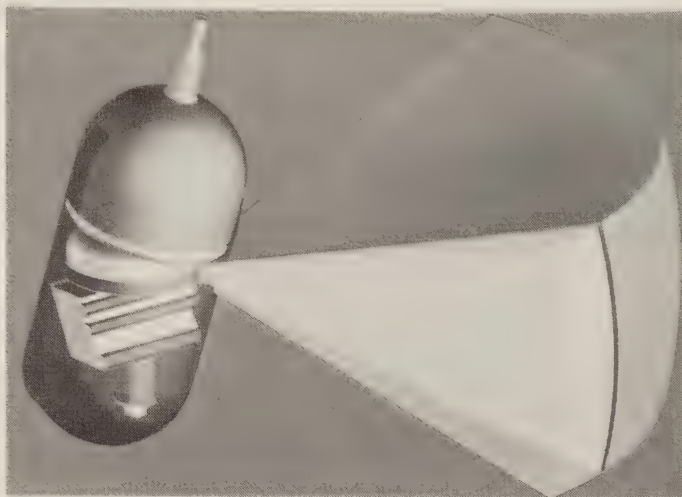
P2072 is FIAR's sonar for *Lerici*-class minehunters: see the U.S. SQQ-14 entry. This sonar is also used by the Belgian navy. The Plessey Speedscan (see the British Type 2048 in the ASW section) has been integrated with P2072 for route surveillance. A

memory has been added to the classification sonar so that up to 4 pictures can be recalled at will, either singly or together, to assist in classification. Signal processing is largely digital.

This sonar is considered effective down to 350 m (i.e., down to the continental shelf).

◆ P2095

The successor to P2072 (SQQ-14/IT) is for use at greater depths (for oceanic mine hunting). P2095 is a development of the Plessey/GE Type 2093 by FIAR, GE, and Plessey to meet Italian requirements. P2095 should enter service on board a new class of ocean minehunters planned for construction from 1993 on.



The Plessey-FIAR P2095 minehunting sonar (the towed body is shown). Operational testing is expected in 1992, with installation on board an Italian minehunter by the end of 1993. (FIAR)

◆ IMICS

The Integrated Minehunting Combat System for the *Lerici* class consists of the SQQ-14/IT sonar, SSN-714 MACTIS (Minehunting Action Information System), SPN-703 navigational radar, SSN-715 navigation and tracking system, and a precision navigation system. There are 2 IMICS displays, 1 on the bridge and 1 in CIC.

◆ MACTIS/SSN-714

Datamat's digital navigation (tactical-situation compilation and display) and plotting system is for the *Lerici*-class minehunters. The display uses a 16-in circular CRT with a keyboard and tracker ball, and the associated computer is the same Rolm MSE 14 used in the SACTIS submarine combat-data system. MACTIS is the main subsystem of IMICS, described above.

◆ MIN 77

This mine-disposal vehicle is designed for the *Lerici* class. Smaller than PAP 104 or Pinguin, MIN is powered, at up to 5 kt, by a single ducted propeller, which can be oriented in 2 planes for steering. Paired (fore and aft) vertical and horizontal thrusters work in tunnels in the body of the vehicle. For minimum magnetic signature, the body is GRP over an aluminum frame, and the use of pneumatic (actually compressed nitrogen rather than compressed air) motors eliminates the usual magnetic signature of an electric motor. The motors are fed by 5 oil-nitrogen pressure tanks, which can be topped up by an electric pump in the vehicle. Because the motors can operate at variable speed, the propellers can be fixed pitch, to minimize the acoustic signature. The vehicle can be recharged in 15 min and turned around for a second mission in 20 min.

MIN carries either an LLLTV (with underwater light) or a sonar and is powered, in either case, by on-board batteries. The sonar operates at 400 kHz with 0.05- or 0.70-msec (for, respectively, seabed or moored mines) pulses, scanning a 60-deg sector in about 2 sec. Maximum range is 20 m or 40 m (bottom or moored target). Display modes are raw video (bottom mines),



MIN 77. (Selenia)

synthetic video (moored mines), or raw video with digital range (moored mines).

The vehicle floats to the surface after it drops its acoustically fired charge.

Dimensions are 105 cm (diameter) $\times$ 3.5 m $\times$ 1.4 m [41.3 $\times$ 138 $\times$ 55.1 in]; weight is 1300 kg [2865 lb]. Maximum depth is 200 m [656 ft], and maximum operational range is 400 m [440 yd] (the umbilical cable's length is 1000 m [1090 yd]). Endurance is 40 min at 3 kt. Hovering control is better than ± 0.5 m, and the depth of the bottom can be measured more accurately than ± 0.25 m. The vehicle can operate in sea-states up to 4 and in currents up to 3 kt (along the hunting line).

The vehicle is built by a consortium, SMIN, formed in February 1978 by Elsag and Riva Calzoni. SMIN received a contract for 4 vehicles in June 1979. Tests began in 1983.

◆ Pluto

This private-venture minehunting vehicle, designed by Gaymarine, is based on the FILIPPO underwater inspection device. The fiberglass body is mounted on a steel sled frame (for ease of handling). The body in turn consists of a fixed rear section (containing batteries and electronics) and a forward section that can tilt up to 240 deg, carrying the sensors (200-kHz sonar, with a range of 30 m [98 ft] and 10-deg beamwidth, and television). Propulsion and control are by 5 electric motors: 2, inclined at about 45 deg, behind the head; 2 horizontal at the stern, for motion forward or in reverse; and 1 horizontal at the stern, to turn the vehicle. The operator uses 2 joysticks. The vehicle carries either explosive cutters or a 15-kg mine-destruction charge. Dimensions are 0.6 $\times$ 1.6 $\times$ 0.6 m [23.6 $\times$ 63.0 $\times$ 23.6 in]; weight is 160 kg, including a 40-kg charge [353/88 lb]; maximum range is 500 m [550 yd]; maximum diving depth is 400 m [1312 ft]; speed is 6 kt; endurance is 1–2 hr.

As of 1986, reported purchasers were the Nigerian navy (for 4 *Lericis*), the South Korean navy, the Thai navy, and the Italian navy (which had conducted trials with the prototype in 1982–83). The U.S. Navy has bought at least 2 units. The Spanish navy has chosen Pluto for its new minehunters (modified *Sandown* class).

Gaymarine exhibited a new mine-countermeasures submersible, Pluto Plus, at Mostra Navale in Genoa in May 1989. Compared to the existing Pluto, Pluto Plus is longer (1.95 vs. 1.6 m) and heavier (250 vs. 160 kg); Pluto Plus can operate to a depth of 400 m and at a speed of up to 7 kt (with an endurance of 10 hr). Sensors are a color television camera and 3 sonars (for search at medium range, navigation, and target identification).

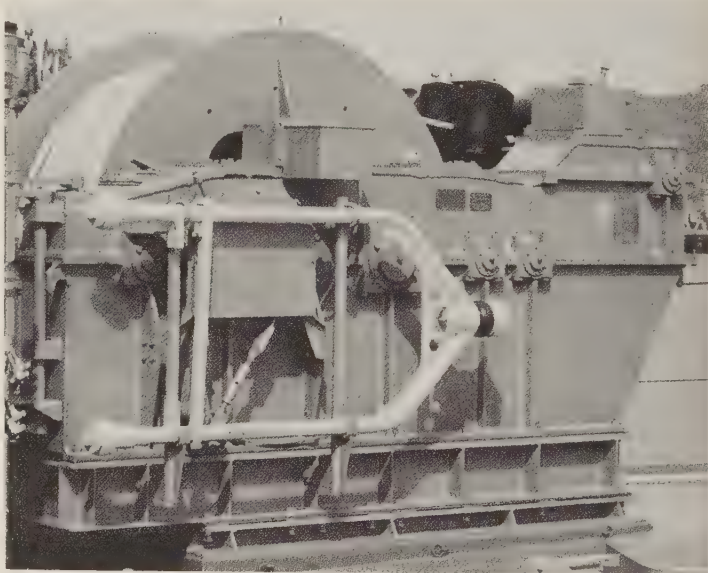
◆ SSM

Gaymarine's semisubmersible minehunting vehicle operates at periscope depth under remote control (UHF data link), in up to sea-state 4 or 5. SSM carries both search (forty 3-deg preformed beams in a tiltable head, range about 200 m [656 ft]) and classification (mechanically scanned, 2 scans/sec, over a 45-deg sector, at 1.2 MHz, with a 7.5-m [24.6-ft] range) sonars. SSM can release a Pluto mine-disposal vehicle (released and recovered via a stern hatch). The Pluto can be automatically reloaded with mine-disposal charges (SSM carries 6). The vehicle is powered by 2 diesel generators, amidships, and it has 2 stern propellers (for speeds up to 6 kt) and 2 vertical and 2 lateral thrusters (1 each at bow and stern) for maneuvering.

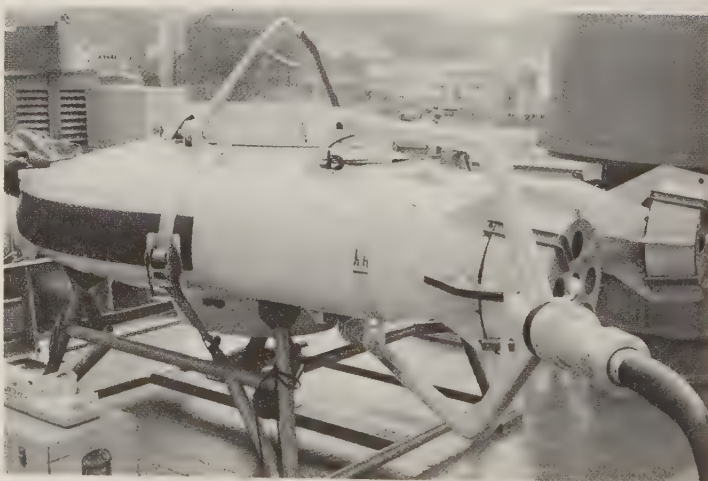
SSM was announced in 1986, and construction of a prototype began in the fall of that year. SSM was conceived as a minehunting system for a craft of opportunity, the mother ship having no sonar.

JAPAN

The standard Japanese minehunting sonar is ZQS-2, a license-built version of the British Type 193. The -2B version is in the *Hatsushima* class. The earlier ZQS-1 was a modified U.S. UQS-1 on board 4 former minesweepers (*Kasado* class). A ZQS-3 is planned, presumably for the new minesweepers. All are hull sonars rather than VDS. The JMSDF also uses a hand-held diver sonar, RQS-1 (comparable to the U.S. PQS-1), and divers' magnetic-mine detectors (RSX-1 and -2). RSX-2 is analogous to the



S-2 (Type 71) acoustic sweep gear. (Ships of the World)



S-4 (Type 75) mine-destruction vehicle. (Ships of the World)

U.S. EOD Mk 4. The standard acoustic sweep is designated S-2. Japan also uses the U.S. A Mk 4(v) and A Mk 6(b) and the U.S. magnetic sweeps M Mk 5(a), M Mk 6(a), and M Mk 6(h). Japan uses a distinctive Type S-4 remotely controlled underwater vehicle that lays its own mine-disposal charges. S-4 has 2 thrusters with prominent motor housings, 1 at each side at the rear end, and a saucer-shaped nose with a flat dome on top. S-4 is carried by the *Hatsushima* class; the earlier *Takami* class carries 4 divers.

The Japanese FY89 budget included the first of a new class of deep-water minehunters, to employ the S-7 deep-water minehunting system and the S-8 deep-water moored sweep.

Japan also employs a helicopter minesweeping system, using KV-107s. They are now being replaced by Sikorsky MH-53Es.

NETHERLANDS

The standard sweeps (in the tripartite minehunter) are the French MDV/OD.3 wire sweep, the Finnish F.82 magnetic sweep, and the Swedish AS.203 acoustic sweep.

NORWAY

◆ Albatross

Simrad's distributed tactical system for Norwegian *Orsoy*-class minehunters and *Alta*-class minesweepers uses 6 standard multipurpose consoles. Four of them are linked by a dual Ethernet data bus: the navigational console alongside the officer-of-the-watch (OOW) console, and the mine-avoidance sonar or minehunting sonar console alongside the tactical console. A separate console for the commanding officer is linked to the sonar, tactical console, and OOW console. There is also a mine-warfare-officer console separate from the tactical console. The navigational radar or radars (3-cm, plus an optional 10-cm set) feed into the OOW and mine-warfare-officer consoles. Sources of navigational data are a GPS receiver, an inertial navigator, and the usual combination of log and gyros. Wind sensors feed directly into the navigational console. A mobile positioning system and an electromagnetic log can be available as options. The navigational console directly controls the thrusters and waterjets that position the craft. The minehunting sonar is the French TSM 2023N; the mine-avoidance sonar (in the minesweeper version) is the Simrad SA950. An unusual feature of the system is the peripheral computer connected not only to a printer and plotter but also to a digitizing board, which can insert charts into the system. It connects both to the Ethernet and to separate displays on the bridge and in CIC (Operations Room).

◆ SA950

Simrad's mine-detection and -avoidance sonar uses a retractable hull transducer. The transducer consists of 64 vertical staves, individually driven. Operating frequency is 95 kHz. It transmits in a wide (sectoral) beam and receives in digitally preformed multiple beams, over a 45-deg sector (1.7×10 -deg beams); the sector is trainable (± 190 deg) and tilts (limits $+10/-90$ deg). Train rate is 30 deg/sec; tilt rate is 150 deg/sec. Typical CW pulse lengths are 0.2–12.8 msec, selected according to search range. FM pulse lengths: 0.8, 3.2, 12.8 msec (bandwidth 5 kHz). Pulse forms: CW short, normal, and long; FM-0 (1 pulse), -1 (2 subpulses), -2 (4 subpulses), -3 (8 subpulses), and auto. Each FM subpulse is on a different frequency. For example, FM-3 produces 8 subpulses, each 1.6 msec long, each with a frequency bandwidth of 625 Hz, $\frac{1}{8}$ the total. Range scales: 75, 150, 300, 600, 1200 m. The sonar can track targets. The display is a 20-in color CRT (680×512 pixels in 8 bitplanes). The echo field is contained in a 512×512 left square coded in 6 bits (64 colors), with the right 2 bitplanes for overlay and menu. There are 3 display modes, in each of which the sonar sector is shown in a plane that tilts with the transducer: true motion, sector, and zoomed sector. True motion is north-stabilized. The current 45-deg sector is updated, while data from sectors examined ear-

lier remain on the screen. Ship's motion is taken from the speed log and gyro, and a track history is shown. Up to 8 markers can be placed on the screen. In the sector mode, the full 45-deg sector is shown (512 range arcs and the 32 beams interpolated to 64 beams). The rest of the echo field is filled with range-time data, scrolled to the right after each sweep. This mode shows the direction of the sector with respect to the ship. The zoomed sector mode is a sector with only the outer half shown, e.g., echoes from 600 to 1200 m only. Maximum ship's speed while operating the sonar is 12 kt.

SA950 has been under test on board the Norwegian "Bird"-class minesweeper *Kvina* since February 1988. Targets included both mines and submarines.

◆ SH100

This Simrad mine-detection and -classification sonar entered production in 1989. It normally operates at LF (95 kHz) for wide-sector search and target acquisition and at HF (335 kHz) for classification/localization, but the 2 modes can be interleaved. The transducer can also be set in the vertical position to classify moored mines. There are two 20-in raster-scan color CRTs. Both transmitting modes use sector transmission and form beams for reception: 32 beams, each 1.7×10 deg (total 45 deg), for search; and 64 beams, each 0.25×10 deg, for classification (total 16 deg). The HF and LF transducers are aligned together, and train within ± 200 deg; they tilt within $+10/-90$ deg. In effect, SH100 is SA950 plus two 64-element HF receiving arrays. The HF sonar uses a curved array for transmission (the LF sonar uses the same staves for transmission and reception). There are two 680×512 -pixel color CRTs, 1 (normally the top 1) for the tactical display, the other for the echo presentation. Echo data can be presented in detection, classification, or combined mode, as B-scans or echograms. Typically, the screen is split horizontally between the 2, e.g., HF echogram on the left and HF B-scan on the right (but it can also mix, e.g., LF B-scan on the left and HF echogram on the right). Each presentation can be zoomed.

SWEDEN

The Swedish Defense Research Establishment is working on underwater lasers, presumably for minehunting.

◆ 9TS700

The standard Swedish navy acoustic sweep, this BEAB acoustic projector incorporates 2 magnetostrictive and 5 ceramic transducers covering 4 acoustic bands, the intensity of which can be controlled by sweeper. Propeller modulation can be superimposed on transmitted signature. A single unit controls both 9TS700 and a magnetic sweep. The projector is 2 m long (835 kg in air, 438 in water).

◆ 9MJ400

The BEAB-Racal-Decca minesweeping direction system of the Swedish *Landsort* class is related to the 9LV series. It can control up to 3 SAM vehicles. The main sensor is the French TSM 2022 sonar, and 9MJ400 is integrated with a 9LV100 optronic FCS (which uses the electronic plot of the 9MJ400 system for target detection). This is a centralized system built around 2 computers, a main processor and a minehunting computer. The main processor feeds the displays (1 horizontal tactical console and 2 navigational PPIs). It is fed by the optronic director, target designators (pointers), the navigational radar, the wind sensor, and radio data links. It in turn is connected to the separate minehunting computer. The latter is connected to the minehunting sonar, automatic chart table, helm indicators, printer, and gyro compass. The integrated navigation and minehunting functions are based on the British Decca MAINS/CANE systems. During mine search the ship is controlled by an integrated autopilot for maximum track accuracy. The autopilot hovers it in the optimum position during mine disposal.

◆ SAM

A remotely controlled vehicle for preliminary sweep, SAM uses an integral magnetic sweep and a towed acoustic sweep and carries 8 Dan buoys to mark a cleared channel. The hull is a pair of foam-filled GRP pontoons covered by an 18×6.1 -m platform of aluminum girders, on which sits the engine casing (one 150-kW Volvo Penta TAMD 70D engine and Schottel propulsion unit). Speed is up to 8 kt, and endurance is up to 330 nm. Draft is 0.7 m (1.6 m over propeller).

The SAMs were delivered by Karlskronavarvet in 1983–86.



SAM unmanned craft. (SUTEC)

◆ Sea Eagle/Double Eagle

This vehicle, used on board Swedish M80 (*Landsort*) -type minehunters, was developed by the Scandinavian Underwater Technology Group (SUTEC) from the earlier commercial Sea Owl. The Swedish navy used Sea Owl and underwrote half the development cost of Sea Eagle.

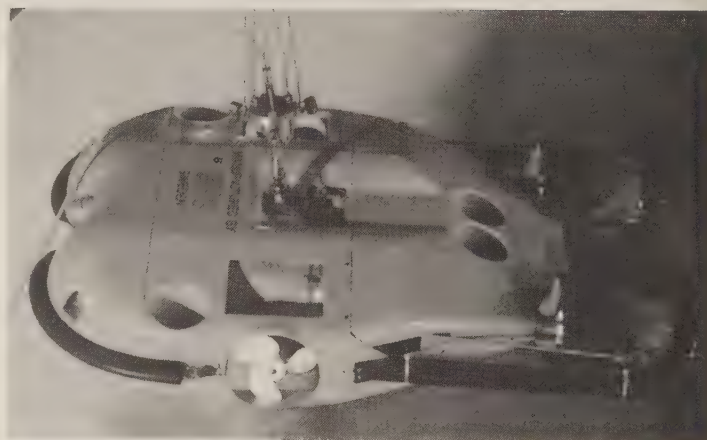
The vehicle is built of aluminum inside a steel frame and is powered by 4 horizontal (2 athwartships, 2 lengthwise) and 3 vertical electric thrusters; power is fed through the umbilical, which also passes control instructions and data. The 350-m main sensor is a television camera. Sea Eagle is launched into the beam of the minehunting sonar and tracked as it swims to the mine. The telescopic arm carries a miniature television camera and a mine-destruction charge the last 5 or 10 m to the mine; using the camera, the operator inspects the mine to ensure that the destruction charge is in the optimum position. The charge is detonated by acoustic signal at a range of 350–1000 m.

Dimensions are 76 cm (diameter) $\times$ 1.45 $\times$ 0.58 m [29.9 $\times$ 57.1 $\times$ 22.8 in]; weight is 90 kg [198 lb] total; range is 350 m [380 yd] from ship; maximum depth is 250 m [820 ft]; speed is 2.5 kt.

The new Double Eagle was conceived to extend Sea Eagle's capabilities. It can operate in strong currents (up to 3 kt). Where Sea Eagle could take any attitude within ± 40 deg, Double Eagle can be made stable in any attitude at all (± 180 deg). Power consumption is almost 5 times that of Sea Eagle, but weight is only doubled. Payload capacity has been increased. Double Eagle can achieve more than 5 kt forward speed (3 kt backward, 2 kt laterally, 1 kt vertically; but it ascends and descends at over 5 kt). Payload is normally 30 kg, but additional buoyancy modules can increase that weight. Telemetry is provided by 4 fiber-optic links, each of which can carry 2 video/sonar channels and spare serial data channels. The standard system includes 1 external tiltable color CCD camera with remote focus and connector for an additional color or black-and-white camera; the vehicle carries drivers and power supplies for 2 video cameras. The typical sonars are the UDI and Mesotech types described in this section and in the ASW section. Dimensions: 2.05 (length) $\times$ 1.3 (width) $\times$ 0.45 (height) m; weight is approx 300 kg, with slightly positive buoyancy. Control is by 2 joysticks (forward/back, lateral, yaw; and up/down, roll, pitch) and 3 mode-control switches (power, selection of axis along which



Sea Eagle. (SUTEC)



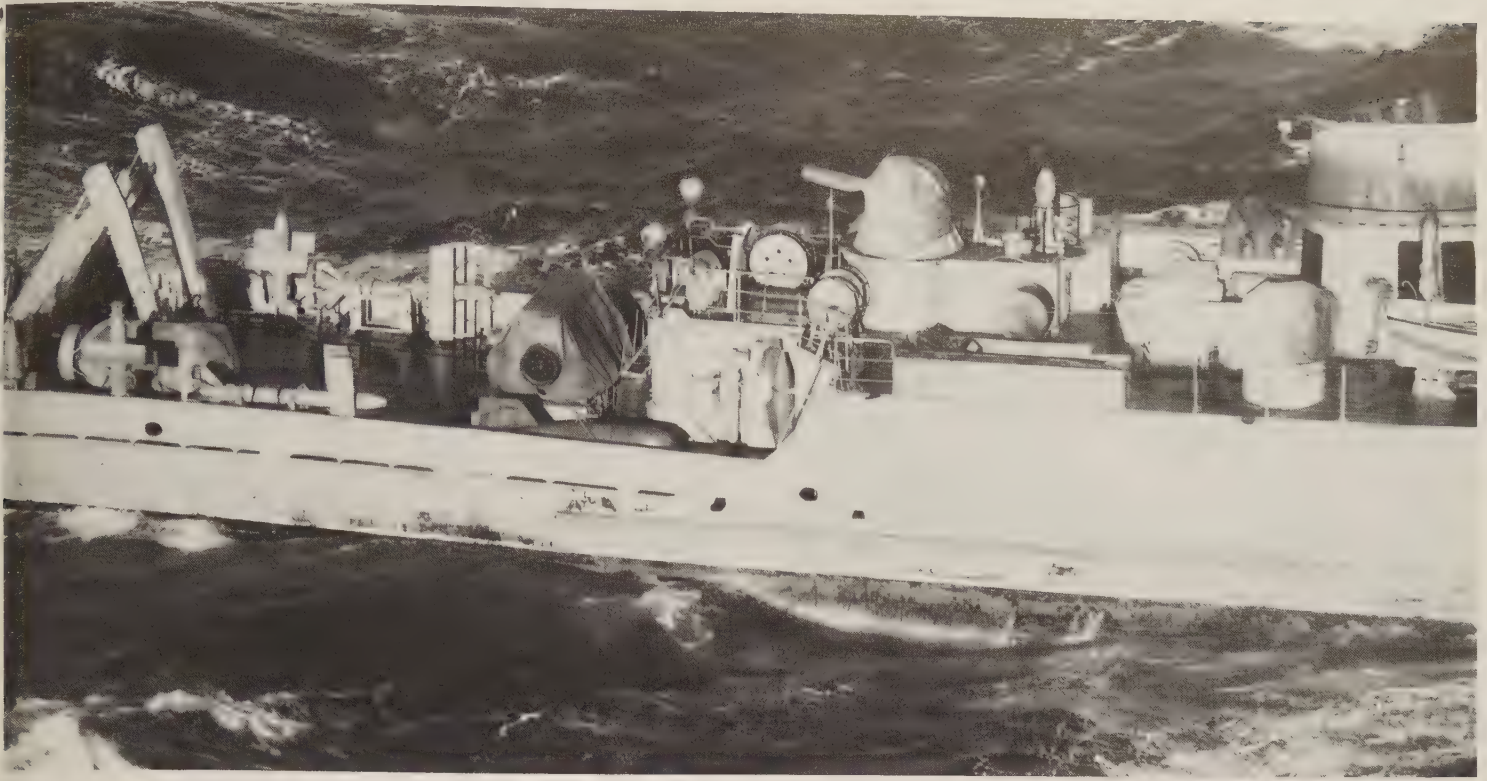
Double Eagle. (SUTEC)

joysticks operate, and reference adjustment, to balance current or cable drag). Maximum operating depth is 300 m [about 1000 ft], and the vehicle is gyro-stabilized to within ± 2 deg. The tether (control) cable is 600 m long (a greater length can, however, be supplied).

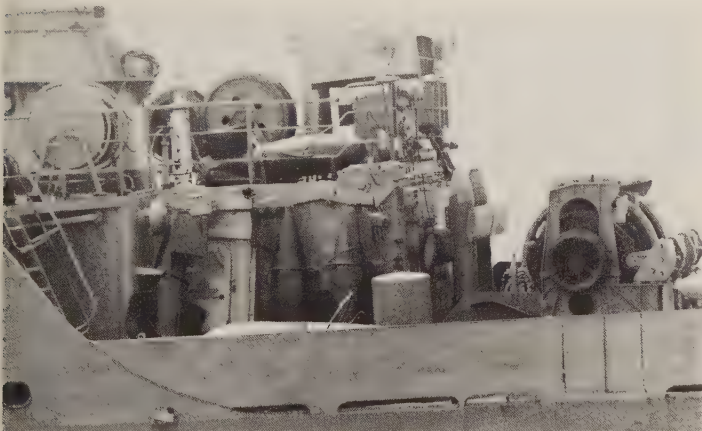
As of early 1990, the prototype Double Eagle had been completed, and SUTEC was beginning a 1-yr feasibility study of a fully autonomous underwater vehicle.

USSR

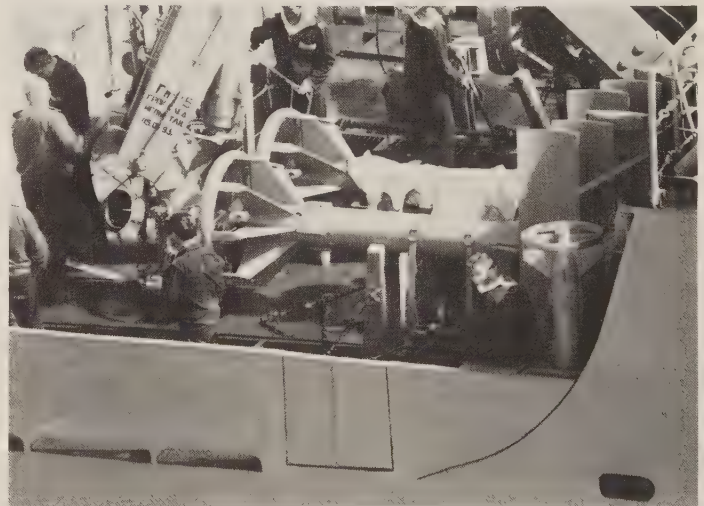
Four or more Soviet Polnocny-A and -B-class medium landing ships are line-charge layers to clear beach defenses. These ships carry line charges in side troughs, with stern chutes to launch the 2 small remotely controlled motor boats that tow the charges into place.



The fantail of a Natya-I-class minesweeper shows, aft, biplane and triplane paravanes and an LF acoustic source. (U.S. Navy)



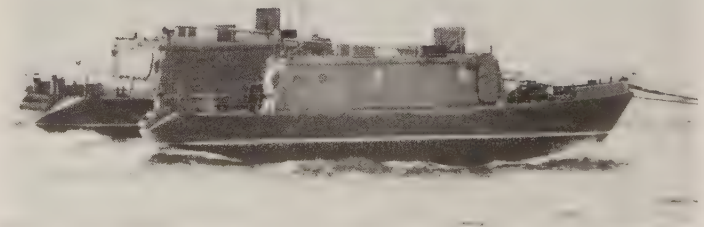
A Natya-I-class minesweeper displays standard Soviet medium sweep floats and biplane paravanes (vertical). The winch is used for magnetic, mechanical, and acoustic sweeping. (U.S. Navy)



The new Gorya-class ship shows standard Soviet triplane paravanes. In the background, largely hidden by the crane, is the acoustic sweep device. (U.S. Navy)



The new Gorya-class minehunter/sweeper displays an acoustic sweep device on her fantail (under the standard articulated crane). The sliding doors visible on the left may cover RBU-1200s, which are standard aboard Natya-class sweepers. They are used for countermining and for ASW. (U.S. Navy)



Soviet towed-sweep craft under tow. Each can deploy magnetic sweep cables or explosive line arrays over its stern (a tow cable is visible on board the near unit). The Soviets have several dozen of these craft.

As of 1988, the Soviets do not appear to have a mine-disposal submersible in service; their 2 *Vanya*-class minehunters carry boats, presumably for diver support. The Soviets do use a television minehunting system that lays marker buoys for later investigation of supposed mines. Published reports of a Soviet mine-disposal vehicle (SPA) seem to reflect the inclusion of such vehicles in encyclopedia articles (which describe the general state of the art, not necessarily the state of Soviet mine countermeasures).

The Soviets do have drone minesweepers (analogous to the German "Troikas"), the Ilyusha class. There are also several dozen towed sweep craft, and there is a helicopter-towed version of the Volga-class sports hydrofoil, carrying acoustic and magnetic countermeasures.

UNITED KINGDOM

Current British thinking on mine countermeasures is typified by the decision to build the steel-hull "River" class primarily to clear submarine sortie routes by disposing of mines at depths between 55 and 200 m [180 and 660 ft] because 55 m is the effective limit to deploy ground mines. The theory is that moored mines cannot have very sensitive magnetic sensors because they are subject to considerable tidal movement, so a degaussed steel hull suffices to protect against them. For shallower water, the Royal Navy relies on hunting and sweeping.

◆ Towed Sweeps

Type "O" is Oropesa, the sweep to cut mine moorings; Type "A" is acoustic; and Type "M" is magnetic. The current standard British sweeps are the Oropesa Mk 3 Mod 2 (plus a later version with GRP floats, kites, and otters, for reduced weight); the MM Mk 11 magnetic loop sweep; and the Osborn acoustic sweep (see separate entry below). In the mid-1950s the wartime electrode (magnetic) sweeps were supplanted by loop sweeps, which could be towed at relatively high speed and were easier to stream and recover. However, because the loops swept out to both sides of the sweeper, they tended to place a higher magnetic field under the sweeper. Moreover, it was relatively difficult to place an LF acoustic sweep inside a loop to trigger combined magnetic/acoustic mines.

Typically, a double "O" sweep (towed by 1 sweeper, double because 1 wire is streamed to each side) has a depth of 30 m and a swept path 265 m [290 yd] wide. Team sweep by 2 ships is with an "A" sweep, with a depth of 90 m [300 ft] and a swept path 350 m [380 yd] wide. A typical magnetic loop sweep clears a path 75 m [80 yd] wide, 400 m [about 1300 ft] abaft the sweeper.

Standard acoustic sweeps use a broad-band noisemaker covering the usual ship frequencies. More recent systems, such as Osborn, can be tuned more precisely to the expected mine-triggering frequencies.

Below are listed the wire and magnetic sweeps in service just after World War II. Although much has changed since then, the figures listed should be typical of modern sweeps. Wire lengths are in fathoms (6 ft each), and other distances are in cables (120 fathoms). Since the wires are not straight, swept paths are much narrower than the lengths of the streamed wires.

(i) Oropesa Sweeps

Mk 1 ocean sweepers. "O" sweep 300 fathoms (kite to otter), 8/8.5 kt; "A" sweep (2 sweepers, 2½ cables apart), 400–450 fathoms between kite blocks, 8/8.5 kt.

Mk 2* coastal sweepers. "O" sweep 300 fathoms, 6–9 kt; "A" sweep, 300 fathoms, 5–7 kt.

Mk 3* coastal sweepers. "O" sweep 250 fathoms, 7–8 kt; "A" sweep, 300 fathoms, 5–6 kt. Mk 3*, rather than Mk 1, is the standard "Hunt"-class sweep.

Mk 7 inshore sweepers. "O" sweep only 60 fathoms, 9–10 kt. This sweep was used by postwar inshore craft ("Ham" class).

Mk 9 deep wire sweep (EDATS) introduced 1981; see EDATS, below.

These sweeps may be prefixed W, as in W Mk 2 for coastal sweepers.

(ii) Magnetic Sweeps

LL means double longitudinal.

LL Mk 3 for coastal sweeper. Long leg 525 yd, short leg 200 yd, maximum sweep speed 7 kt, 300 yd wide in P formation (108-kW sweep current). Cycle 4.5 sec, double cycle 60 sec.

LL Mk 6* for ocean sweeper. Long leg 575 yd, short leg 225 yd, maximum sweep speed 12 kt, path 300 yd wide in P formation (220-kW sweep power). Cycle normally 3.5–7 sec, special 10 sec, double cycle 28–60 sec.

LL Mk 8 for inshore sweeper. Long leg 500 yd, short leg 175 yd, 7 kt, 200 yd wide (sweep power 35 kW using batteries).

Mod L modified Loop sweep. Three legs (575, 325, 185 yd), maximum speed 12 kt for ocean sweepers, 10 kt for coastal sweepers, 8 kt for trawlers; 125-yd-wide path.

ME means electrode sweep (this series probably superseded the earlier LL designations).

ME Mk 103 for motor minesweepers (MMS), using a 108-kW generator/battery outfit. Maximum pulse current is 1500 amps, maximum sweep speed is 10 kt.

ME Mk 106 for *Algerine*-class steel ocean sweepers, using a 220-kW diesel generator to provide the sweep impulse, with a maximum pulse current of 1500 amps and a maximum sweep speed of 12 kt.

ME Mk 107 alternative for *Coniston*-class coastal sweepers, using a 375-kW diesel generator; maximum sweep current is 2500 amps; maximum sweep speed is 12 kt.

ME Mk 108 for minesweeping motor launches, alternative for inshore sweepers ("Ham" class), using a 35-kW generator (340-kW inshore sweepers); maximum sweep current is 1200 amps; maximum sweep speed is 12 kt.

ML means loop sweep. As of 1959, the loop sweeps were standard, but some sweepers retained electrode sweeps, pending development of a convertible sweep.

ML Mk 3 for inshore sweepers ("Ham" class), using a 340-kW generator; maximum sweep current is 1500 amps, and maximum sweep speed is 6 kt.

ML Mk 4 for *Algerine*-class steel ocean sweepers, using a 220-kW generator; maximum sweep current is 2500 amps, and maximum sweep speed is 10 kt.

ML Mk 4-1 for coastal sweepers ("Ton" class), using a 375-kW generator; maximum sweep current is 2500 amps, and maximum sweep speed is 10 kt.

The current standard magnetic sweep is MM Mk 2.

(iii) Acoustic Sweeps

There were also acoustic sweeps, using both noisemakers and explosives. The latter, which may still be in use, were intended to deal with mines that could distinguish between the steady build-up of noise from a noise-making sweep and the relatively sharp build-up of the noise of a real ship.

AD (Acoustic Displacer) uses ship's 220-volt DC current to produce LF noise (10–30 Hz) in 2 ranges, depending on the size of the crank (1 in gives 10–16, ¼ in gives 16–30). This device was used on board ocean, coastal, and inshore sweepers.

AH Mk 4 (Hammer) uses ship's power (220 V) to drive 2 alternative diaphragms, either 19 in (150–1000) vs. RN mines or 27 in (60–1000) vs. German mines (during postwar mine clearance in European waters; but the Soviet KRAB was probably based on German practice).

AO Mk 4 (Acoustic Oscillator) uses a 5-kVA motor alternator to provide high-intensity narrow-band noise (235–245 Hz) against coarse mines.

AX Mk 3 (Explosive Sweep) produces broad-band noise from 100 Hz up, suitable for all sweepers, including small craft.

See also EDATS, below.

◆ Type 193/193M

Type 193 is the current standard British minehunting sonar. It operates at 2 frequencies: a lower frequency for search and a higher frequency for better resolution for mine classification. The sonar transducer, which is stabilized, is hull-mounted, and it is steerable both in train (270 deg to either side) and in elevation.

The modernized Type 193M entered production in 1976. Improvements include greater reliability and much reduced weight and volume, all consequences of adopting solid-state electronics. The most significant performance improvements were the introduction of a long (600-yd) range scale and a better beam pattern.

Because the variety of objects on the sea floor is immense, the sonar needs an unusually wide dynamic range, in this case 120 dB. However, conventional displays are limited to 20 dB, so that the sonar must be set to operate in a variety of modes: shadow, target shape, or echo structure classification. A very short pulse mode (50 microsec) shows target highlights without distorting them by overlapping.

In the shadow mode, the sonar illuminates the area behind the mine and then picks up the reflections. This technique is used in Type 162 and in the U.S. Shadowgraph. The shape of the shadow does provide evidence of the shape of the object, but in many cases no shadow can be formed (the seabed is not sufficiently reflective), or there may not be a useful shadow (as in the case of ground mines in deep water). In the target-shape mode the sonar senses the detailed structure of the returning echo. This mode is expected to be particularly effective when the mine has a rough surface, echoes coming from many points on its surface. However, modern mines are unlikely to become very rough even after lengthy immersion. A smooth mine is a poor reflector, and its shape may not show up clearly. The third mode, echo structure, works on discontinuities in the mine's projected surface. The result is only rarely an image resembling a mine, but it does make classification more accurate.

Type 193M searches at 100 kHz (16×1 -deg beam, range 600 yd) and classifies at 300 kHz (6×0.3 -deg beam, range 300 yd).

Type 193 is used by the Royal Navy (193M Mod 1 is on board the "Hunt" class), by Argentina (on board 2 "Ton"-class minehunters), by Australia (1 "Ton" class), by Germany (on board the Type 331 class), by Korea (on board the minehunters now being built), by Norway (*Tana*), by South Africa (*Kimberley*), and by Yugoslavia; it is manufactured under license in Japan. As of late 1989, 50 had been made. It will be succeeded by the AMMS mirror system, which uses Type 2093 inboard electronics.

Current improvements include the addition of a Mills Cross, which improves long-range performance against small contact (moored) mines. Up to 4 views of a target can be stored and compared for classification.

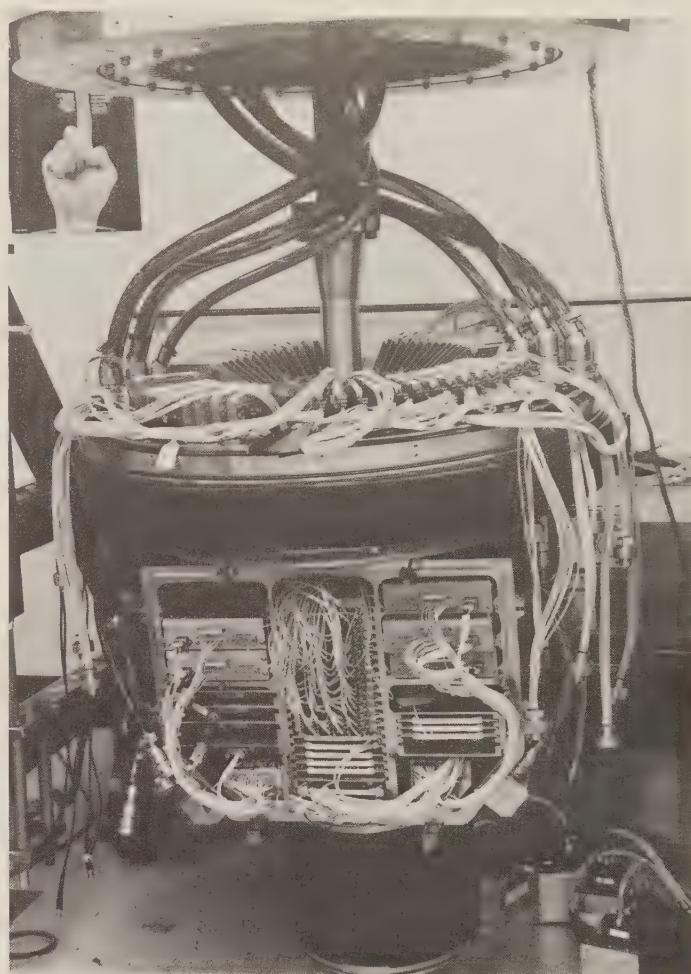
◆ Type 2034/2053

See the ASW section and Waverley 3010, below.

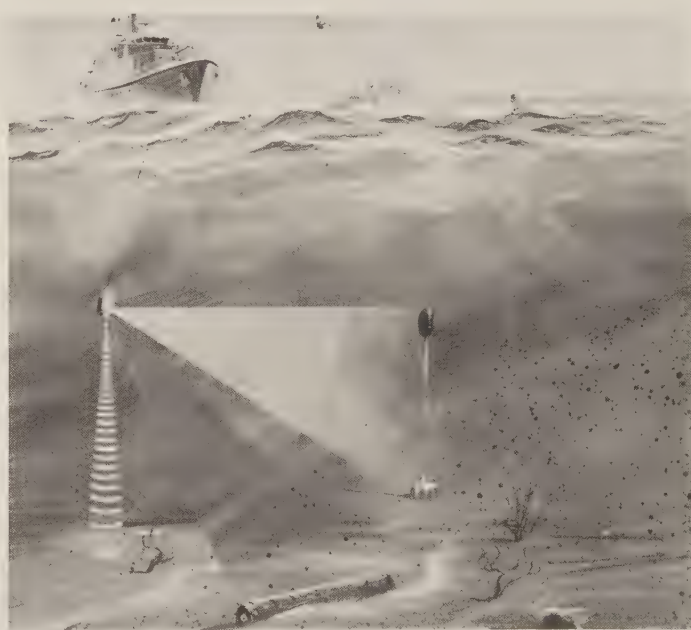
◆ Type 2093

Type 2093 is the Plessey/General Electric replacement for the existing hull-borne Type 193, the first of which will be fitted to the new British *Sandown*-class Single Role Minehunter. The manufacturer describes 2093 as the first variable-depth multi-mode minehunting sonar. It can operate as either a hull sonar or a VDS and has different frequencies for search and classification. The manufacturer claims a range at least twice that of a conventional hull-mounted minehunting sonar and 3 times the detection depth. Maximum speed of advance is 12 kt, compared to 3–4 kt for Type 193M.

The towed body, 1.054 m in diameter (not including vanes) and 2.521 m high; weighs 2900 kg in all. It accommodates an



Type 2093 transducers. (Plessey)



Type 2093 operation, showing the multiple sonar beams. (Plessey)

LF ring array, a VLF ring array, a VHF projector, an HF projector, a VLF projector, and an HF/VHF hydrophone, as well as a depth sounder on the underside. The manufacturer does not define these frequency bands, but even the VLF band is likely to be on the order of 100 kHz. The HF and VHF sonars are used for classification, and they share a common broad-band receiver. They use separate transmitter arrays, generating either wide or narrow beams according to the selected sonar function. The LF

height-finder uses a separate fixed-beamwidth array. The VLF transmitter uses its own array of 6 circular transducer layers, for vertical beamwidth control. The depth sounder operates at VLF.

Alternative operating modes are VLF search and moored mine classification; LF search and moored mine classification; VLF and LF search; search and ground mine classification; and search and route survey. A special height-finding sonar in the system can find moored mines, concurrently with the search for bottom mines. Two classification frequencies are available, to deal with different bottom and sea conditions.

There are 2 identical shipboard displays, each fed by a telemetry link and each capable of any of the sonar processing functions (for dual operation). Computer-aided classification circuits take expanded HF or VHF range data and provide images directly to the display consoles.

Reportedly, 2093 searches at 80 kHz (90×1.5 -deg beam, range 1200 m) and classifies at 350 kHz (20×0.3 -deg beam, range 300 m).

2093 is credited with twice the range and 3 times the depth performance of 193, down to the continental shelf. 2093 costs 3 times as much as the hull-mounted 193. The RN has ordered 13 units, and the first are now on trials.

Type 2093 was developed under a fixed-price contract at a total cost of £83 million, including delivery of 2 preprototypes and 10 production units.

◆ EDATS

Extra-Deep Armed Team Sweep is found in the current "River"-class steel ocean minesweepers. EDATS, deployed by paired sweepers, is a wire catenary stretched between them. Each sweeper tows a kite to depress its end of the sweep wire, and a sweep monitor pod hangs from the sweep wire just outboard of the kite, to provide an acoustic telemetry link back to the sweeper.

This system is also referred to as BAJ-Vickers Wire Sweep Mk 9 Team Sweep System; the word "armed" presumably refers to the use of explosive wire cutters rather than a serrated wire. The original EDATS used a kite to depress both the sweep wire and the kite wire. WS Mk 9 has only 1 kite, since the sweep wire is attached to the end of the kite wire, to give a deeper sweep with a given length of kite wire.

Typically, the sweep depth is 200 m and the sweep path is 350 m wide. The ends of the sweep wire are about 1000 m astern of the sweepers, and ideally the wire is towed at 8–9 kt about 2–3 m (in practice, about 10 m) above the seabed, to cut wires of mines with very short tethers. These conditions are difficult to ensure because of the current and the irregular shape of the bottom. The sweep, therefore, incorporates tension meters

measuring the pull of the wire and kites (to maintain a constant sweep speed). The pair of acoustic monitor pods are intended to maintain depth above the bottom.

The current WSME (Wire-Sweep Monitoring Equipment) can maintain the sweep 10, 20, or 35 m above the seabed by paying out or pulling in wire. BAJ is working on actively controlled depressors and diverters, which would make a single-ship deep sweep practicable. The company has completed wind-tunnel tests of a diverter with a wingspan of 2.5 m as well as a 1.6-m delta.

The first "River"-class sweepers were ordered in September 1982, after EDATS trials using the commercial stern trawlers *St. David* and *Venturer*. The British naval requirement is to sweep mines out to the edge of the continental shelf. The sweepers are steel, and in wartime they would approach from the sea to avoid influence-mine fields closer inshore.

EDATS has been ordered for the new Canadian MCDVs.

◆ Osborn (MSSA Mk 1)

Osborn is an acoustic sweep developed and manufactured by British Aerospace. In contrast to earlier broad-band noise sources, Osborn can simulate specific ship signatures and, thus, can deal with a relatively intelligent acoustic mine. Osborn combines an acoustic generator near the surface with an acoustic monitor towed at greater depth, to ensure that the required degree of signature is supplied near the mine, despite surface layering.

As of 1988, Osborn was in service in the Royal Navy and was being evaluated by the U.S. Navy.

◆ Pilotfish

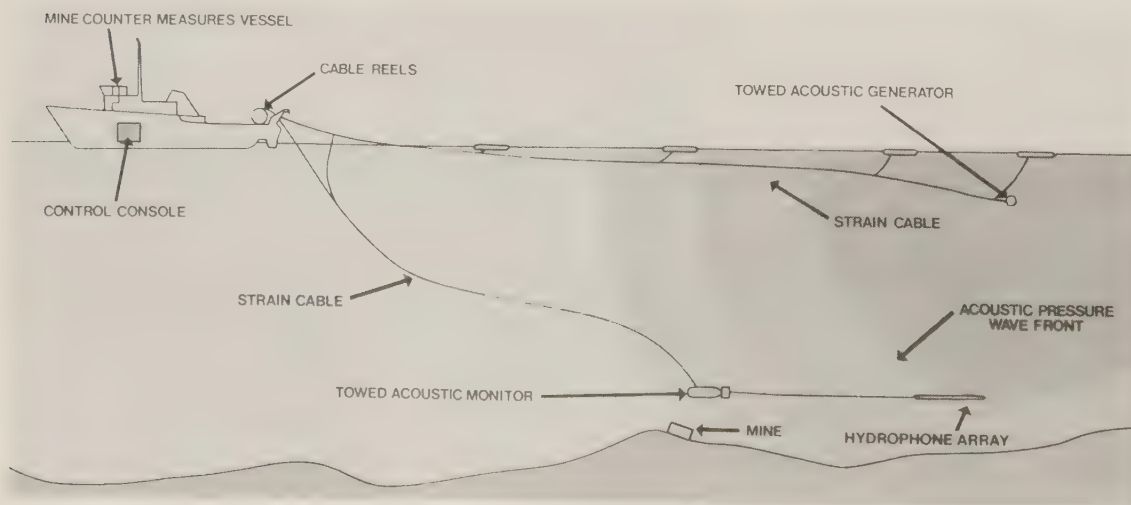
This agile towed body was developed by ARE as the basis of a future deep single-ship sweep. The sweep would be positioned between 2 Pilotfish, which would control its depth. Pilotfish could also be used as a maneuverable acoustic decoy. Control is exerted by ailerons (in an X-shaped wing, for roll) and by elevators (in a cruciform tail).

◆ Scarab

This floating mine countermeasure was developed on an urgent basis by ARE, for the Persian Gulf. Scarab was intended to replace the usual technique, shooting at the mines with rifles, since some mines sank instead of exploding and thus remained dangerous. Scarab is a pair of pontoons driven by a BMW yacht engine. Guided visually to within 50 m of the mine, at a speed of about 5 kt, Scarab is then guided closer by closed-circuit television. Scarab carries a hydraulic grab. Once the mine has been secured, Scarab reverses, reeling out a cable by means of which the mine can be either towed away or detonated at a safe distance. Scarab is thus, in effect, a sea-going equivalent of the remotely controlled mine-disposal vehicles that have existed for some years.

Endurance is 10 hr at 5 kt.

Osborn. (British Aerospace)





TOWED ACOUSTIC GENERATOR



TOWED ACOUSTIC MONITOR

(Above) Osborn. (British Aerospace)

Scarab is now designated FMDS (Floating Mine-Disposal System) 1.

◆ Towtaxi

This stable actively controlled towed body was built by BAe for ARE. Maximum operating depth is 250 m (normal depth is 100 m). The body can carry payloads internally, and an external load, such as a transducer, can be slung beneath it. Presumably, Towtaxi is being used to evaluate future deep-water minehunting sonars.

◆ Invasion Sweep

During the Falklands War, AUWE designed, delivered, and shipped (via Hercules) both magnetic and acoustic influence sweeps intended to protect landing ships in the islands' inshore waters (such as Teal Inlet). The sweeps, which simulated an LSL signature, were towed ahead by smaller landing craft (LCVPs). LCVPs were considered preferable to helicopters because the craft were less easily detected from shore and, thus, did not tend to reveal the fact of a planned landing.

The magnetic assault sweep was a towed bar electromagnet in a cushioned wooden box, fed by electronics on board the towing craft. The acoustic sweep (Go-Kan) was a commercial hydrosonder (a Kango Type 637 hammer, later replaced by a Type 2500 for greater power and more output at LF) in an industrial waste-cotton bin. In fact, this sweep was used only once, for an exploratory trip on the north side of East Falkland; no amphibious craft followed on that occasion.

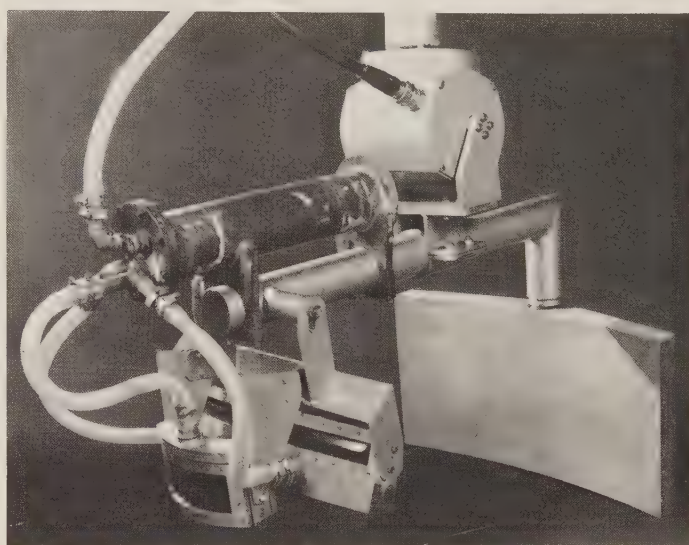
These improvised sweeps worked well enough to encourage postwar work on something more satisfactory. By 1983 AUWE had developed a variable-moment magnet (VMM) that could be air-shipped in a no-field condition, then set at different strengths for different conditions.

In a larger sense, the Falklands demonstrated a need for a covert sweeping capability: otherwise, the sweepers preparing the beach alert the defenders. In 1983 it was reported that AUWE was working on a torpedolike device, carrying a side-scanning sonar, for covert minehunting.

◆ AMMS

Plessey's Advanced Mirror Minehunting System employs a trainable reflector instead of a beam-preformer. The projector produces a broad beam; the reflector focuses the reflected beam. This type of system is usable for minehunting because the target, the mine, does not move and because distances are quite short: there is enough time to send and receive many narrow beams in succession. In ASW, an equivalent system would fail because a sonar waiting to receive on 1 beam before listening to the next would miss distant, fast-moving targets. In AMMS, returns from each sector scanned are stored and then displayed simultaneously.

Under Project Kingfisher, Plessey packaged several minehunting mirror sonars into hull domes for use on board U.S. frigates for mine evasion in the Persian Gulf.



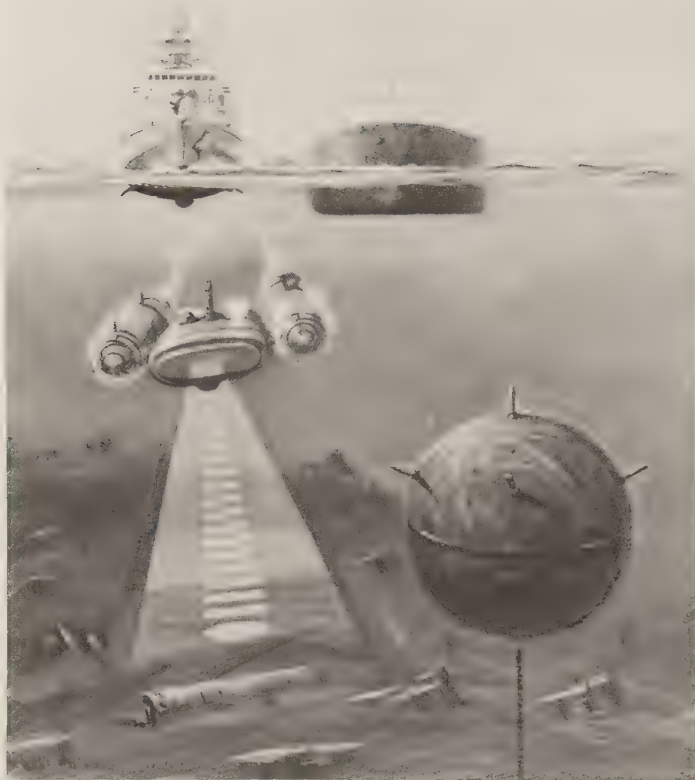
The Plessey mirror minehunting sonar. The object in the foreground is the broad-beam transducer, with a narrow-beam transducer behind it, and the mirror itself in the background. (Plessey)

◆ ARMS

Plessey's Advanced Remote Minehunting System is designed to be carried by ships not intended for minehunting. A remotely operated vehicle (ROV) would swim up to 1000 m ahead of the ship and down to 300 m below it, at a speed of up to 6 kt, clearing a safe channel. The vehicle is fully stabilized, and its automatic operation can be overridden by its operator, who can make ARMS hover. The vehicle itself provides a sonar or underwater television picture on a display screen on board the operating vessel. When ARMS identifies a mine, the ROV can lower a mine-destruction charge, which is detonated from the ROV by acoustic link. There is also a cable cutter for use against moored mines.

The ROV is lowered over the side by crane, then swims out 20 m and submerges to an ordered depth and heading. The ROV is controlled via a cable tether and has a unique tandem propeller drive that should make for very accurate positioning even in high currents and turbulence. Because the ROV is positively buoyant, it will rise to the surface in the event of failure. The entire system is containerized for rapid deployment, 1 of 3 containers carrying the vehicle and its spares.

ARMS was announced in 1987, as a private venture. It may have been inspired by British fears of Argentine influence mines in the Falklands landing areas; there were no British mine-sweepers fast enough to accompany the invasion fleet, and the



ARMS vehicle hunting for mines. (Plessey)

British had no minesweeping helicopters. Plessey's claim that the 3 ARMS containers can fit a standard DC-9 would apply to the Persian Gulf problem: if ARMS had been on the shelf, it could presumably have been deployed very fast. More generally, ARMS can be seen as 1 ultimate development of the mine-hunting vehicle idea typified by the French PAP 104 or the U.S. MNS.

Total vehicle weight is about 365 kg, including a 90-kg payload (70-kg mine-disposal charge, cutters, etc.). Operating depth is 300 m. The mirror sonar detects mines beyond 600 m at 100 kHz using microsecond pulses; it switches to 300 kHz for classification.

◆ Dragonfly

The GEC Avionics/OSEL (Offshore Systems Engineering, Ltd.) modular underwater vehicle was entered in the Royal Navy's competition for an underwater remotely controlled inspection and mine-disposal vehicle (RCIV and RCMDS II). The basic vehicle (hydraulic thruster, electrical power system, control telemetry, navigation equipment, and cameras) carries a variable payload, such as a pair of manipulator arms or cutters.

The umbilical carries both power and a fiber-optic data link with 3 digital video channels (allowing for both television and sonar) and a high-speed 2-way control (and feedback) data link. Up to 6 cameras can be accommodated. There is a second fiber-optic link for redundancy, and the umbilical carries 2 additional cables so that sonar or other payload data can be carried outside the fiber-optics.

The combination of RCIV and RCMDS is to replace the single PAP 104; this combination shows much the same logic as the German choice of Pinguin A1/B3 (see West Germany above).

Two separate requirements for remotely controlled vehicles were formulated late in 1984, with an initial purchase of 20 vehicles planned (and a total of as many as 100 possible). Formal invitations to tender were issued in the summer of 1985, with bids for the inspection vehicle due by 14 November 1985 and those for the mine-disposal vehicle due by 28 November 1985.

The inspection requirement, NSR MER(S) 19/85, calls for a fast inexpensive vehicle, the RCIV, to classify a sonar contact.

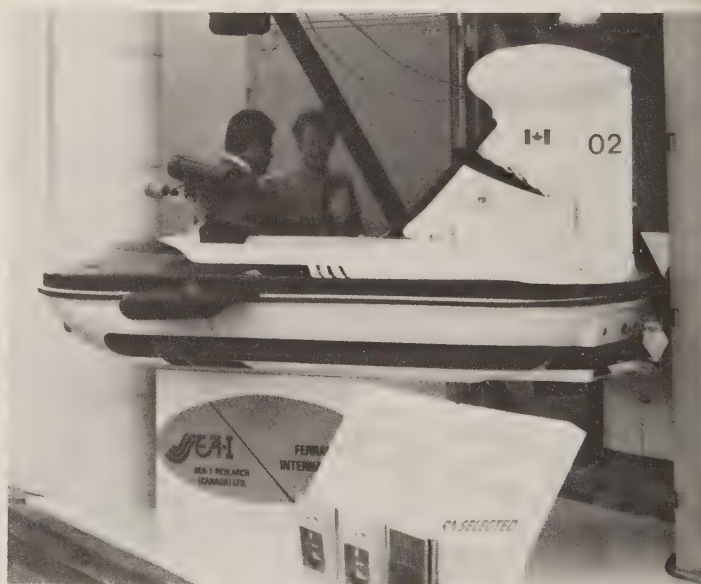
The RCMDS will actually place the charges. Reportedly, both vehicles will have to be able to navigate very precisely to benefit from route surveys so that only objects not previously identified will be investigated. ECA and Honeywell offered PAP 104 Mk 5 for the RCIV, with an enhanced version for the RCMDS; Plessey/Ametek Straza offered a derivative of the Scorpio remotely operated vehicle; Ferranti offered a modified version of the existing Spring 104 designed by Robertson Tritech of Norway; Smiths Industries/OSEL offered a new vehicle; Sutec of Sweden offered a version of its Sea Eagle; Fairey offered Trail Blazer; GEC offered Microv; BAJ and MBB offered Pinguin; Marconi offered Minnow; and British Aerospace also offered a system. High-definition sonars were the subject of a parallel competition.

◆ FIMS/Manta II

Ferranti's Integrated Mine-Countermeasures System will probably equip the Canadian MCDVs. The associated Manta ROV completed Canadian trials in mid-1989, having been delivered late in 1988 to train naval reservists in mine-countermeasures techniques. The Manta II ROV is controlled by the Ferranti MC500 system (a version of the company's System 500 described in the Surveillance and Control section). Manta itself is built by SEA-Industries of British Columbia, Canada.

Manta is described as already in service (as of 1989) "with a major NATO navy." It is made of GRP, is controlled by means of a single-strand fiber-optic cable, and is fitted with 2 external mounting points. Manta can carry a side-scan sonar, a video camera, and a 250-frame still camera. Manta II will carry a high-resolution, scanning, target-classification sonar (which will retract into its belly) and will hunt ahead of the ship controlling it. The MCM version will carry a mine-disposal charge under its body.

Unlike most current ROVs, Manta depends on hydrodynamic control surfaces for rapid and precise maneuvering; it has only 2 thrusters (total 6 HP, endurance 2-4 hr on 1 battery pack). Its umbilical is paid out of the top of its tail fin.



Ferranti's FIMS vehicle, as displayed at RNEE 1989. (Author)

◆ Microv

This vehicle, developed by GEC/OSEL, is teamed with Dragonfly for the Royal Navy RCIV/RCMDS II requirement. Microv is derived from the earlier UFO and ROV oil-field support vehicles, the principal change being a low-drag frame. Power is supplied by an internal battery, and propulsion is by 3 thrusters.

Dimensions are 1 m (diameter) × 2.1 × 0.6 m; total weight is 150 kg; maximum range is 800 m; depth is 200 m; speed is 8+ kt.

◆ Minnow

The Marconi Underwater Systems, Ltd. (MUSL) mine-disposal vehicle is driven by 4 thrusters. Power is taken from an umbilical, and Minnow carries both a sonar and a television.

◆ PMS 58

This Plessey minehunting sonar is part of a larger modular family, the other members of which are described under antisubmarine warfare. PMS 58 is, in effect, a modernized Type 193 whose inboard electronics have been redesigned to take advantage of experience gained with Type 2093. As of late 1989, Plessey hoped to offer it for 30% less than other hull-mounted minehunting sonars, and for 70% less than other sonars with similar performance.

PMS 58 can be arranged for single or dual operator use; it employs identical color consoles in each case. It detects and classifies moored, surface, and near-surface mines. The sonar has a flexible architecture for alternative roles: mine avoidance sonar for sweepers or non-MCMs, standard single- or dual-operator minehunting. All versions have a special array and processing to detect and classify moored, surface, and near-surface mines. Drawings in Plessey's brochure show alternative beam patterns. The near-surface mine seems to be detected using a narrow fan beam scanning horizontally. A moored mine is detected by a similar scan repeated in vertical slices to achieve a 3D effect.

Search mode: 90-deg FoV, which can be reduced in areas of high clutter to optimize operator performance. Beams are formed for both transmission and reception. Displays: full-range PPI and B-scans, and 32-m expanded range A-scan for maximum resolution. Plessey claims that the special array configuration gives exceptional range performance against surface and near-surface mines, which is especially important for mine avoidance.

PMS 58 simultaneously searches and classifies (a minehunting equivalent of TWS). It uses both image and shadow classification; it can store up to 4 targets for recall and display. The minehunting version automatically measures target size and principal physical features; its computer compares these figures to standard preset parameters, advising the operator as to whether the target is a possible mine. The separate classification array and processor determines the height of a moored mine and can classify it at great range. The minehunting version can enhance its imagery for better classification.

Full-route survey capacity (high-definition, side-scan bottom mapping) is standard. The sonar converts slant to plan range, fully stabilized geographically; it annotates this record with range and track data.

Options:

Computer-aided detection: the sonar automatically tracks potential mine targets. It alerts the operator that targets are approaching classification range.

Multiping processing allows the alignment of sonar bearing cells on a ping-to-ping basis. Special processing enhances sonar echo points to increase recognition probability. This feature extends the range over which the sonar can detect mines with acceptably high probability.

◆ RCV225

A competitor with Dragonfly and Microv for RCIV/RCMDS II, RCV225 was developed by Honeywell Leaffield, the British contractor for PAP 104. The company developed new modules for PAP 104s on board "Hunt"- and *Sandown*-class countermeasures ships. RCV225 itself was developed for North Sea oil-field support and was first used in 1974. RCV225 is powered by 4 thrusters.

A larger RCV150 has manipulators and/or cable cutters.

◆ Sea Pup

British Aerospace Naval Division's mine-disposal vehicle was tested in October 1983.

◆ Sea Serpent

Vosper Thorneycroft's sweep was announced in 1987, to counter sophisticated mines. Two or more bodies, each containing 19 variable-moment magnets, can simulate a real ship, whose magnetic field varies along its length. The usual magnetic countermeasure, whose field is more or less uniform along its length, can be recognized as a decoy by a sophisticated signal processor. Conversely, if Sea Serpent is towed by a potential target, a sophisticated mine will detect and interpret the extended field as a magnetic sweep. The magnets are all permanent; the system requires electric power only for resetting. In effect, Sea Serpent is a huge (and sophisticated) equivalent of the U.S. Magnetic Orange Pipe (see below).

Osborn is the acoustic complement to this system.

◆ Trail Blazer

This joint-venture underwater vehicle is made by Fairey Hydraulics and ISE of Canada. Trail Blazer was designed to fit a standard 747 cargo container and can be deployed from small fishing craft. The vehicle is designed for slight positive buoyancy, using high-density foam (and more foam can be added to balance heavier loads). Propulsion is by 5 hydraulic thrusters (2 at the after end for ahead and reverse, 2 amidships for lateral movement, and 1 vertical), the electrical power for the hydraulic pump coming from the controlling vessel through the umbilical. Control is exercised through a single joystick for the 4 thrusters in the horizontal plane, with a separate control for the vertical thruster. The standard sensor is a television, and the vehicle can carry either four 50-kg (U.S. Navy standard) or one 127-kg (NATO standard) mine-disposal charge.

Dimensions are 64 cm (diameter) $\times$ 2.63 $\times$ 0.86 m; weight is 772 kg, including a 130-kg charge. Maximum range is 1+ km; diving depth is 500 m; speed is 5.75 kt.

Trail Blazer uses a 675-kHz Mesotech scanning sonar and LLLTV. It has been demonstrated during NATO breakout exercises. Trail Blazer has successfully cut moored mine cables in 120 m on the edge of the Gulf Stream (2.5-kt current) in U.S. Navy trials.

◆ Waverley 3010

This side-scan sonar is for route surveillance (100 kHz) and mine detection (300 kHz). It has been ordered by the U.S. Navy in its 3010/T version (which includes a Ferranti towfish tracker) for COOP ships (10 are on order, and there are options for 47 more). The console includes a high-resolution CRT and a thermal printer; on board the COOPs it will interface with the Integrated Shipboard Navigation System developed by the Naval Coastal Systems Center. Two Integrated Route Surveillance Systems (IRSS) based on 3010 have been delivered to the Singapore navy for COOP.

See Type 2034/2053 under ASW.

◆ DBA 4

Ferranti's CAAIS version for the "Hunt" class is the first digital minehunting-control system. It dates from the late 1970s. Capacity was originally 64 contracts, updated continuously; it has now been increased to 5000.

◆ MAINS

Racal's minehunting version of its CANE command/control system (Minehunting Action Information and Navigation System) is integrated with 9MJ400 on board Swedish *Landsort*-class minehunters. The PPI shows the current radar plot as well as the sonar search plan and current underwater contacts.

◆ MC500/SATAM

MC500 is Ferranti's minehunting version of System 500 (see the Surveillance and Control section). SATAM is MC500 adopted for the German Type 332 minehunter.

◆ NAUTIS-M

The minehunting version of the Plessey NAUTIS command/control system (see the Surveillance and Control section) is on board the *Sandown*-class single-role minehunters. A version of this system will probably be adopted for the U.S. *Avenger* class.

NAUTIS-M is a 3-console system (minehunting, operations, bridge, linked by a dual-redundant 1553 bus). As in other versions of NAUTIS, each console is modular, built up from 5 module types: a radar plot extractor, radar video module, graphics module, controller module, and power module. The display is a 16-in circular CRT (which can be provided either in analog or in raster-scan format). The keyboard and tracker ball are a separate module. The controller is the computer for CIC functions. Each console is built around an Intel Minibus, which can support 2 or more processors per bus. Each carries the full system software in its bubble memory, so the system can continue to function after a console fails. Memory is dual-ported, so each processor can work independently.

As installed on board HMS *Sandown*, NAUTIS-M is combined with paired ROV (PAP 104) control consoles, the two 1-operator NAUTIS consoles alternating with 2-operator sonar and ROV-control consoles (each with 2 operators and square CRTs). The mine warfare officer and the minehunt director each have their own NAUTIS consoles, and the sonar operators use 2 consoles for search and classification. The search operator and minehunt director have access to the ROV joystick and the ROV control display. The third NAUTIS console is on the bridge.

◆ QX3/System 880

Racal MCM's Action Information System, the third-generation, consists of a Racal Integrated Navigation System (RINS) and a Racal Action Display System (RADS). RINS suffices for mine-sweepers, which need only to know precisely which channel they have swept. RADS is required for minehunters and sweeper/hunters. A typical RADS display shows the known bottom features, the vessel's track, a safety circle around the vessel, the location of a suspected mine (with its danger circle), and the locations of other suspected mines.

In the complete system, RINS and RADS share a common central computer. The RINS inputs are various positioning systems, including the log and gyro; RINS exchanges data with the autopilot. RADS inputs are from sonar and radar; RADS exchanges data with the minehunting vehicle proper and provides data to the chart table and to tactical displays. RINS can be used to guide the helmsman, or it can control the ship automatically for great track precision.

In theory, the minehunter can make an initial route survey using a side-scanning sonar; RADS/RINS can locate any contacts precisely so that the hunter can revisit them later. The system also incorporates a track plotter, so the results of mine-sweeping or -hunting can be charted for use by other vessels. These charts also show whether coverage of an area is sufficiently complete.

QX3 can store up to 80 km of route, with 60 contacts/km. The QX3 tactical display shows a real-time ground-referenced plot, with land masses, navigational markers, underwater pipelines, and wrecks. The centerline of the task route, annotated with waypoints and the location and classification of sonar contacts, is superimposed over this background.

QX3 is in service on board British "River"-class (QX3/1) and "Ton"-class (QX3/3) minesweepers (the latter has an interface with the Type 193M sonar); it is also on board the U.S. *Avenger* class. System 880 is the export version.

UNITED STATES

◆ U.S. Towed Sweeps

There are 3 types: A, acoustic; M, magnetic; and O, Oropesa (wire sweep). All date from World War II. The principal versions are:

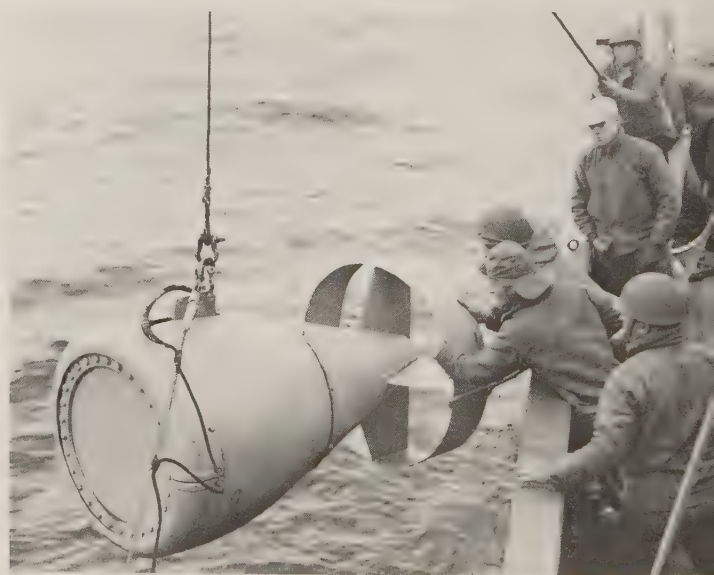
(i) Acoustic Sweeps

A Mk 2 parallel pipes or bars, towed broadside-on, in different versions for different frequencies and different towing speeds (4–20 kt). A Mk 2(g) was used by helicopter minesweepers in North Vietnam in 1973. Suspended from a Size 5 O-float, A Mk 2(g) weighs 130 lb and consists of 2 parallel triangular plates connected by 3 pipes, each of which is welded at each end to the vertices of the triangles. Two other pipes are pivoted from 1 of these plates; as the device moves through the water, the 2 pivoting pipes strike each other and the other pipes. Water passing between the pipes creates a venturi effect, reducing the pressure between them and thus causing them to collide. The faster the tow, the greater the intensity of the collisions.

A Mk 4 (TB-25) towed hammer box, conceived for small craft in restricted areas but later extended to all types. A Mk 4 consists of a hydraulically driven hammer in a streamlined box, driven by a gasoline engine on board the sweeper. A Mk 4(v) weighs about 1300 lb. Dimensions are 40 × 70 in. Output is 60–600 Hz. TB-27 (part of SLQ-37) is Towed Body 4(V). Dimen-



A U.S. acoustic sweep, photographed in 1987. It resembles, but is not identical to, the old A Mk 2. It is streamed suspended from an O-type float. (U.S. Navy)



A Mk 4(v) acoustic sweep. (U.S. Navy)

sions are 40 in (dia) $\times$ 70 in (1300 lb). It produces pulsed (duty cycle 0–100%) HF noise (40–600 Hz).

A Mk 6 VLF acoustic sweep, the towed eccentric mechanism, usually towed about 1200 yd astern of a coastal sweeper. A Mk 6(b) uses a diaphragm driven by pistons connected to an eccentric driven by an electric motor. Weight is about 3500 lb. During Operation End Sweep, the clearance of North Vietnamese waters, A Mk 2(g) was recommended as a replacement for the A Mk 6(b) then in use by the surface sweepers. A Mk 6(B) Mod 5 is TB-24 (used in SLQ-37); it is a motor-driven mechanical oscillator made by the John Bean Food Machinery & Chemical Co. Dimensions are 37.75 in (dia) $\times$ 69 in, and weight is 3500 lb. It operates at 10–35 or 10–22 Hz. TB-26 is Towed Body 6(B), also part of SLQ-37. Dimensions are 23 in wide $\times$ 45 in high $\times$ 65 in long (2800 lb). It produces pulsed (20–100% duty cycle) LF signals at 6–40 Hz.

There was also an explosive sweep (A Mk 5).

(ii) Magnetic Sweeps

M Mk 1 magnetized iron rail, which could be extemporized. It was not standard after World War II, but a device of this type was used in Vietnam (in the Cua Viet River, after magnetic/acoustic mines were found there). The MOP (see below) is reminiscent of this device.

M Mk 4(m) small 2-ship closed loop.

M Mk 4(i) 2-ship single-catenary small-craft sweep, using special tails, the short legs of which are connected by an insulated cable forming the catenary; the long legs stream aft.

M Mk 4(v) postwar variation on M Mk 4.

M Mk 5(c) standard large-sweeper sweep, consisting of 2 legs (buoyant conducting cables) married together through the 675-ft length of the shorter leg, with the longer leg streaming aft another 900 ft. In some arrangements 2 or more ships could sweep together, pulsing their tails synchronously.

M Mk 5(a) straight-tail electrode sweep (I-sweep).

M Mk 6(a) J-sweep: the long leg curves around to meet a diverted line towed by the ship and connected to an Oropesa and a kite.

M Mk 6(b) single-ship closed-loop sweep, using Oropesa floats to keep the legs apart.

M Mk 6(h) closed-loop sweep, the 2 legs meeting at a diverter line streamed from an Oropesa.

(iii) Oropesa (Wire) Sweeps

O Size 1 largest, for ocean sweepers (MSO and MCM). When streamed with 300-fathom wires, the swept path is 500 yd wide (double sweep) at maximum sweep speed, about 8.5 kt for an MSO. A single-side sweep can clear a 250-yd path at 10 kt. Sweep depth is 5–35 fathoms (maximum 40 fathoms).

O Size 4 modified, for coastal sweepers (MSC). With 300 fathoms of wire streamed on each side, the swept path is 420 yd at 8 kt; wire depth is 2–30 fathoms.

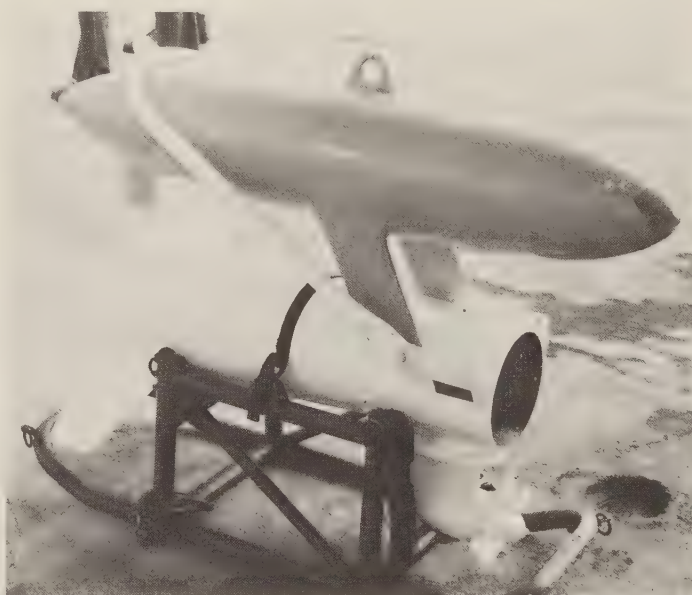
O Size 5 small, for minesweeping launches (MSL), etc. This type uses explosive cutters because the craft are too slow for the saw action of the wire to cut mine moorings. Sweep speed can be up to 7 kt. With 250 fathoms of wire streamed on 1 side, the swept path is 176 yd wide. This sweep could be used as an emergency or shallow-depth sweep, with a wire depth of 2 or 3 fathoms. Size 5-G is used for adapted landing craft, etc., and was modified for helicopters and MSBs. 5-G uses a different otter and depressor and can be streamed at relatively high speed in shallow water, e.g., for assault purposes. Depth control is more precise than in Size 5, so 5-G can operate in 1–7 fathoms, at 6–14 kt. With 150 fathoms of wire streamed on 1 side, the swept path is 70 yd wide.

S Type C a 2-speed high-speed sweep for converted destroyers, but such ships no longer exist. The 2-speed feature referred to the ability of the special paravanes to stabilize the sweep in 2 quite different speed ranges, around 12 and 20 kt.

All the standard sweeps are designed to deal with mines floating close to the surface. When the sweeps were designed, the only exceptions were ground mines (which cannot be wire-swept) and antenna mines, the cases of which might be well below the surface. However, the sweep wire could brush the vertical antenna, causing the antenna mine to explode. At present the United States, like her allies, is developing a deep sweep to cut loose the cases of rising mines, which may be over a thousand feet below the surface.

◆ ALQ-141/SLQ-35

ALQ-141 is called DOUBLE ALFA; SLQ-35, a ship-towed version, is ALFA TWO. The designation suggests an acoustic sweep, presumably covering a different portion of the spectrum than ALQ-160. ALQ-141 was described about 1979 as an electronic counter to deep-water rising mines. This sweep is manufactured by Westinghouse. There was also an EDO ALQ-138, probably an unsuccessful competitor.



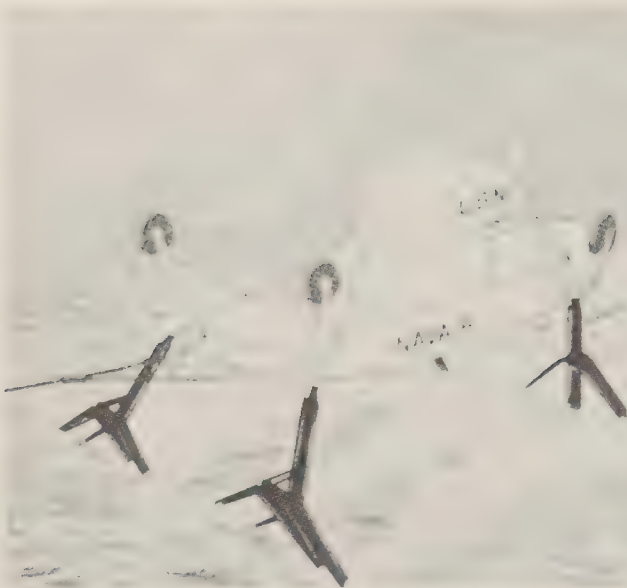
A helicopter-towed acoustic countermeasure used during the clearance of the Red Sea in 1984. Although labeled Mk 104, it is far more sophisticated than the simple bars used in Vietnam and is presumably ALQ-141 or -160. (U.S. Navy)

◆ ALQ-160

ALQ-160 is a helicopter-towed acoustic sweep using a stable towed body.

◆ ALQ-166

EDO's magnetic minesweeping hydrofoil sled is the successor to Mk 105. ALQ-106 exploits the greater pulling capacity of the new MH-53E helicopter, which replaces the original RH-53D. Unlike the earlier catamaran, ALQ-166 is a monohull and, thus, can carry a heavier load in the same dimensions. The new 1200-HP Avco Lycoming engine is about 3 times as powerful as the engine of the Mk 105, to drive a more powerful sweep generator. Reportedly, 166 quadruples the net sweep rate of the earlier device and can operate at 6–30 kt. A sled-mounted ASQ-182 measures the magnetic environment so that sweep track spacing can be optimized. The second production ALQ-166 was delivered in FY83. EDO began the development of this Light-weight Magnetic Sweep (LMS) with internal R&D funds, to counter the next-generation mine threat; this LMS was then



ALQ-166 (EDO)

successful against existing advanced projects in a navy trade-off study.

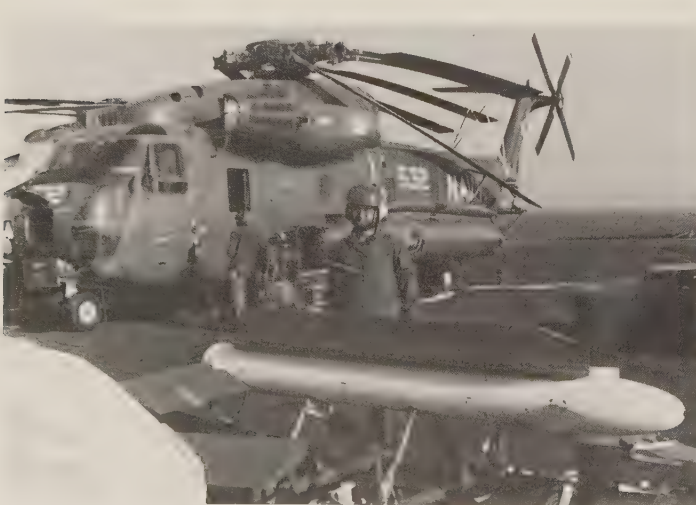
TF-40 engines were installed in an ALQ-166 in FY88, and operational evaluation began in FY89.

Reportedly, it is possible to use a magnetic sweep of this type in conjunction with a water-pressure monitor, so that pressure/magnetic mines can be swept at the turn of the tide. Such mines avoid detonation at the turn of the tide by seeking an accompanying magnetic signature. Similarly, it would be possible to sweep pressure-acoustic mines using a pressure monitor and an acoustic sweep. However, at least some pressure mines avoid this problem by monitoring the rate of pressure change, which is much faster for a ship than for the tide.

◆ AQS-14

AQS-14 is Westinghouse's high-speed helicopter-towed minehunting sonar. It is actively controlled for platform stability; the stabilized towed body carries a high-resolution side-scanning sonar. AQS-14 is said to allow sweeping at a rate about 40% faster than can be achieved by conventional methods.

The sonar is a Westinghouse-patented multibeam all-range focusing type, providing an operator with a continuous high-resolution television image of objects to either side. The system employs active controls to keep itself clear of both the bottom and the surface and can even right itself if launched upside



AQS-14 helicopter-towed fish, with the towing helicopter in the background. (U.S. Naval Institute)

down. Objects detected by the sonar are marked by the towing helicopter for further investigation.

Westinghouse describes AQS-14 as suitable for installation on board hovercraft and other surface-effect ships.

Production was approved in March 1980, operational evaluation having been completed in September 1979 (and having proceeded since FY76). As of March 1988, 29 units had been made. This sonar operates with ALQ-141. AQS-14 was first used operationally during the Red Sea operation in 1984, marking minelike objects with sonar beacons for subsequent inspection either by remotely operated vehicles or by divers.

◆ AQS-17(V)

This experimental, helicopter, minehunting sonar was developed by Allied-Signal (Bendix Oceanics). Although not adopted, it is interesting as an example of current technology. The 200-kHz sonar operates in search and classification modes, over 90- and 60-deg sectors; it is trainable at 10 deg/sec. In each case, it produces 128 narrow beams, 18×0.90 deg for search and 18×0.45 deg for classification. Beams are formed electronically and processed digitally. The beams can be trained between $+10/-45$ deg. Maximum search range is 600 m; classification range is 300 m. The 25-cm [10-in] CRT operates in PPI format, with 150-, 300-, and 600-m range scales and a 30-m expanded classification display. There are 16 shades of gray (presumably the CRT is digital). The towed body is 100 (dia) $\times$ 230 cm (320 kg in air). Maximum operational depth is 100 m.

Allied-Signal offered this sonar in shipboard as well as airborne form.

AQS-17 was conceived as part of a system employing mine-killing miniature torpedoes. Although AQS-17 itself has been abandoned (probably in favor of AQS-20), the expendable-mine-destroyer (EMD) concept survives (see below). Compared to AQS-14, AQS-17 provided mine classification as well as search.

◆ AQS-20

AQS-20 is a sonar mine detector, formerly the Advanced Minehunting Reconnaissance System. Fabrication of the engineering development model is to begin during FY91 (having slipped a year because of a reduction in FY88/89 funds). An associated mine neutralizer also slipped a year.

◆ Mk 24 Underwater Ordnance Locator/Klein 595

This lightweight side-scanning sonar for minehunting and channel conditioning was developed by Klein Hydroscan. Earlier UOLs were magnetic detectors. Mk 24 can be used on board virtually unmodified commercial helicopters and small craft, and it has been adopted for the U.S. Craft of Opportunity Program. Mk 24 has also been adopted for the 7 surviving U.S. minesweeping boats (MSBs), 4 of which were sent to clear the Persian Gulf in 1987. Mk 24 was used during the clearance of the Suez Canal after the 1973 Mid-East War and has been used extensively since then by U.S. Navy explosive-ordnance-disposal teams and similar organizations. Foreign naval users include Sweden, Greece, Colombia, South Korea, New Zealand, Norway, Pakistan, Portugal, West Germany, the Netherlands, Indonesia, Thailand, and Canada.

Small size and light weight are achieved by using VHF: Mk 24 operates at 100 kHz (beamwidth $\frac{3}{4}$ deg), but Klein offers an optional very high resolution 500-kHz sonar. In the past, this sort of frequency has generally been associated with very short range, perhaps a swath width of 100 m. However, Klein claims a swath width twice that. There is also an optional 50-kHz fish for large-area sonar sweeps, e.g., for channel surveys. It covers a 1.2-km-wide swath. An optional 3.5-kHz sub-bottom profiler can indicate bottom hardness and, thus, can indicate whether buried mines are likely to be a problem.

Total weight, for both recorder and fish, is about 150 lb, and range is selectable in 13 increments between 25 and 600 m. The fish can be operated down to 2300 m or, as an option, 12,000 m.

The Klein 595 100/500-kHz system was supplied in 1988 to



Klein 500-kHz (extended-range) side-scan sonar records a Mk 18 base with a Mk 17 moored mine (both British types) moored about 6 ft above the bottom, and a simulated Destructor (Mk 82 bomb with mine fuze) bottom mine at the bottom. The fish was towed at 2.5 kt, and water depth was 22 m. (Klein)

the Royal Australian Navy for its COOP program. In 1984 the Royal Swedish Navy bought 7 Klein side-scan sonars, with a reported range of about 900 m (which seems too great) for in-shore ASW.

◆ Shadowgraph (C. Mk 1)

This side-looking mine-detection sonar was built by Gould; the designation refers to a sweep to deal with combination (as opposed to acoustic or magnetic) mines. Shadowgraph was originally designed during the 1960s for U.S. minehunters operating in shallow water, but the system did not become operational. However, over 100 units were manufactured for the U.S. and French navies. Stored U.S. units were proposed as COOP sensors, but the Klein Mk 24 was adopted instead because of its lower cost (modification of Shadowgraphs would have cost more than new Kleins) and greater capability and reliability. Shadowgraph's fish was very heavy, so it would be awkward to handle from small COOP craft.

Total weight (recorder and fish) is about 1500 lb, and range is fixed at 82 ft. Frequency is 1.4 MHz to port, 1.3 MHz to starboard. Operating depth is 3–30 fathoms. The towed fish, which maintains itself at a preset height above the seafloor, carries 2 markers that it can drop.

Shadowgraph provided so detailed a picture of the bottom that, in theory, it could be relied upon to classify the objects it saw. It was then practical to use guided weapons to destroy mines, since the rate of false alarms would (in theory) be relatively low. The destruction vehicle was Sea Nettle, a wire-guided torpedo carrying 75 lb of HBX. Shadowgraph was successfully evaluated in 1962–63, and it and Sea Nettle were included in the new minesweeper designed in 1965–66, but the project died because of the demands of the Vietnam War.

C. Mk 1 was displayed publicly for the first time in 1980, when Gould was hoping to find new customers for a solid-state version. The French DUBM-41 is derived from Shadowgraph.

◆ PQS-1/SQS-37

PQS-1 is a hand-held mine-clearance sonar for divers. It uses continuous FM transmission or passive detection of a sonar beacon. PQS-1 employs a 12-in conical reflector, which forms a 9-deg beam at 70 kHz. In search mode, frequency is swept over 30 kHz (between 50 and 90 kHz); there are 3 range scales (20, 60, and 120 yd). Source level is 72 dB. The reflected beam is combined with a sample of the transmitted beam to form a difference frequency in the audio range; the minimum and maximum frequencies in this range correspond to the minimum and maximum ranges of the range scale selected. The lower the tone, the closer the object. The set can also be used to detect 40-kHz marker beacons; the sonar indicates direction but not range.

SQS-37 was PQS-1B modified for riverine use in Vietnam. SQS-37 could easily be transferred from craft to craft. This sonar was also used for helicopter-minehunting trials in the mid-1960s. A towed body (Turtle) carried a modified PQS-1 for detection, a television for classification, and a destruction charge. The system was rejected because water was often too turbid for the television.



PQS-1B in use. (U.S. Naval Institute)

◆ PQS-2A

This nonmagnetic portable sonar was announced in 1986 by General Instruments Corp. Modes are active (continuous transmission) and passive (beacon reception, in the 24–45-kHz range). Active range scales are 20, 60, and 120 yd; like PQS-1, this sonar uses an FM slide, so the tone of the echo indicates the range. Beamwidth is 6 deg, and a 12-in object can be detected at 120 yd. In the passive mode, a 39-kHz beacon can be detected at up to 2000 yd. The sonar can operate down to 300 ft. Dimensions are 4.5 × 12.5 in (height, with handle, 9 in); total weight is 8 lb.

◆ SLQ-35

See ALQ-141 above.

◆ SLQ-37

This modular magnetic/acoustic combined sweep is found in the new U.S. *Avenger* class. Three were procured under the U.S. FY89 budget.

◆ SLQ-48

See Mine Neutralization System, below.

◆ SQQ-14/P2072

The standard U.S. minesweeper/minehunter sonar of the 1960s is also built under license in Italy in a modified version. SQQ-14 equips many minesweepers transferred by the United States to foreign navies. In a license-built form (P2072), SQQ-14 equips Italian *Lerici*-class minehunters. SQQ-14 is basically UQS-1 fitted with CXRP, a copy of the British Type 193 high-resolution sonar, for classification.

SQQ-14 is unusual among VDSs in that it is carried on a rigid retractable boom rather than at 1 end of a flexible cable. The reason seems to have been an inherent instability in variable-depth bodies, which tend to swing back and forth at speeds above 5 kt, ruining the accuracy of their narrow beams. In later systems, such as SQQ-30 and the British Type 2093, considerable attention has, therefore, gone into stabilizing the variable-depth body using fins.

SQQ-14 was standardized in 1960. The data that follow are for the Italian-built P2072 version; they are probably also accurate for the U.S. SQQ-14. Maximum depth is 45 m beneath the keel. SQQ-14 consists of an 80-kHz search sonar (which is also used for route surveys) and a 350-kHz classification sonar. The search sonar has a 1.5-deg-wide beam (100-deg FOV); azimuth resolution is 1.5 deg, and range resolution is 1 m (1.0-msec pulses, 15 kW, 126-dB source level). The classification sonar has a 0.3-deg beam (18-deg FOV); azimuth and range resolutions are 0.3 deg and 8 cm, respectively (0.1-msec pulses, 15 kW, 125-dB source level). In search mode the sonar scans a sector at least 82 deg wide at a speed of at least 15 deg/sec. Once a target has been detected, it is transferred to the classification sonar. Both the search and classification sonars can be tilted between +10 and -30 deg (elevation). There is also a side-scan mode.

The FIAR version has been completely redesigned for the Italian *Lerici*s. Only the mechanical hoist has been retained; the transmitter electronics have been relocated into the towed body, and there are new consoles.

SQQ-14 users are Belgium (6 *Dash* class), Italy (SQQ-14/IT in 6 new *Lericis*, SQQ-14A in 4 original *Lericis*, 7 converted *Adjutant* class), Saudi Arabia (4 MSC 322 class), Spain (4 *Aggressive* class), and the United States (2 *Acme* class, 19 *Aggressive* class).

◆ SQQ-30

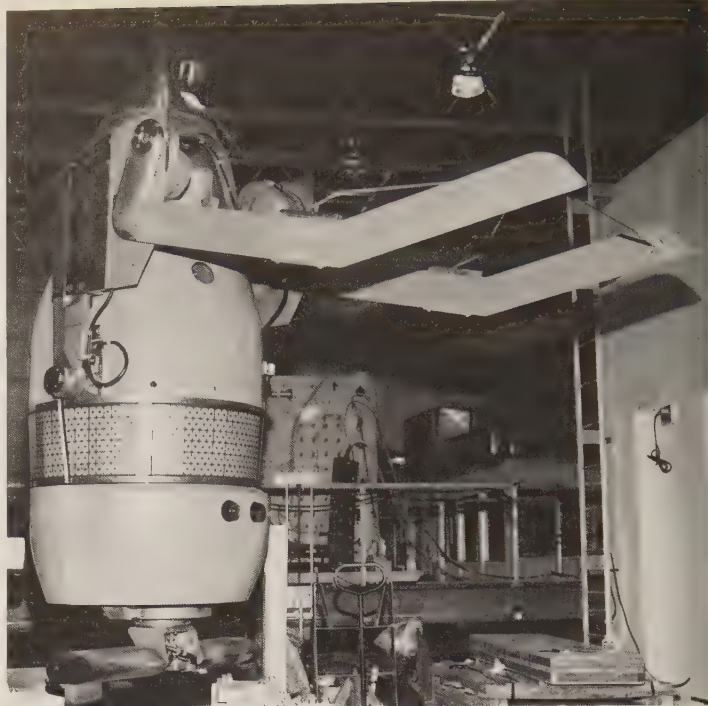
Replacement for SQQ-14, SQQ-30 is a much modified solid-state version of the earlier sonar. Unlike the earlier sonar, SQQ-30 is towed by a conventional cable/umbilical rather than articulated links. It can, therefore, operate at greater depths and can be handled more easily. The towed body is self-stabilizing and reportedly houses 3 sonars. SQQ-30 searches at 80 kHz (90 × 1.5-deg beam, range 600 m) and classifies at 350 kHz (20 × 0.3-deg beam, range 200 m).

SQQ-30 will equip the new generation of U.S. mine-countermeasures vessels until SQQ-32 becomes available.

◆ SQQ-32

Raytheon/Thomson Sintra's minehunting sonar is for later U.S. MCM- and MHC-type countermeasures ships. SQQ-32 was originally designated AMSS (Advanced Minehunting Sonar System). This sonar uses DUBM-21 and TSM 2022 technology for its high-resolution classification sonar, and Raytheon technology for its search component.

SQQ-32 displays search and classification data simultaneously, using separate search and classification transducers in a stable variable-depth towed body. There are 2 identical display consoles, each of which can display either set of data. Although SQQ-32 normally uses 2 operators, it can be located in 1 mode by only 1. The search display shows the location of objects of potential interest; the classification display provides images, either of the object itself or of its sonar shadow. Both methods are complementary: the echo mode is most useful for objects clear of the bottom (and for rejecting objects clearly not mines



SQQ-32 towed body, showing the separate detection (belt of transducers) and classification (bar transducer at bottom) arrays. (Raytheon)

by their apparent shape); the shadow mode, for objects on the bottom (where reverberation is a major problem). A computer is used to help classify the objects detected, so as to reduce the operator's workload. Multibeam operation increases the sonar's search rate. SQQ-32 searches at 35 kHz (60 × 3.1-deg beam) and classifies at 445–650 kHz (14 × 0.13-deg beam).

SQQ-32 can also be used from the hull in shallow water.

The *Osprey* will be fitted with 1 of the refurbished test sets. Operational SQQ-32s will be delivered from mid-1991 on, the first on board the *Warrior* (MCM 10). The first export sale, to Japan, was approved in the fall of 1989.

◆ SQQ-35

Dowty (Waverley) Type 3010T (British Type 2034/2053) side-scan sonar for craft-of-opportunity, a designation assigned in 1990.

◆ UQS-1

This minehunting sonar of the 1950s remains in service on board most ex-U.S. minesweepers. UQS-1 is a short-pulse, electronically scanned sonar. UQS-1 has been superseded in the U.S. Navy by SQQ-14. UQS-1D has a total weight of 2126 kg and a frequency of 100 kHz (10-kW pulses). Range scales are 200, 500, and 1000 yd; precision is 5 yd at 200, 25 yd at 500, and 50 yd at 1000. Resolution is 2 deg in azimuth and 10 deg in elevation (2 m in range). The beam is 20 × 10 (vertical) deg; but it rotates, and it can scan up and down to cover angles between +5 and -50 deg. Bearing precision is 30 min. The sonar can scan over a 90-deg sector or over all 360 deg, or it can be trained manually. UQS-1 is not stabilized, and it cannot provide the mine image required for classification.

UQS-1 was derived from the World War II Underwater Object Locator Mk 4 (most UOLs were magnetic); about 150 UQS-1s were built in 1951–54. SQS-15 was a variable-depth version. SQQ-14 was derived from this sonar.

UQS-1 users are Belgium (4 *Adjutant* class), Denmark (3 *Adjutant* class), Greece (9 *Falcon* class, 5 *Adjutant* class), Iran (1 *Falcon*), Italy (9 *Adjutant* class, 4 *Agile* class), Korea (probably 5 MSC-289 class, 3 MSC 268 class), Norway (7 *Falcon* class), Spain (8 *Adjutant* class), Taiwan (13 *Adjutant* class), Thailand (4 MSC 289 class), and Turkey (12 *Adjutant* class, probably 5 ex-Canadian Bay class and 1 ex-U.S. Cape class).

◆ Airborne Mine-countermeasures System Mk 103 and A/N37U

This helicopter-towed moored-mine sweeping system is manufactured by Boeing Vertol. Mk 103 consists of a tow wire, sweep wires (with explosive cutters), floats, a depressor, otters, and float pendants. In operation, the helicopter sits at the extreme end of the flight deck, streams the gear into the water, and then takes off. Total weight is 1178 lb.

The earlier Mk 101 was a mechanical sweep (1964). Mk 102 was a contemporary high-speed mechanical sweep (VERMOOR-AMCM), which could be towed by a helicopter in an assault at a 12–25-ft depth at up to 25 kt, or at a 25–60-ft depth at a slow speed to sweep a path at least 300 ft wide. Maximum drag was 5500 lb regardless of load, and the sweep could be used to port or starboard or as a double sweep. It used one lead float, one depressor, and 2 otter markers; total weight was 3050 lb, not including the tow cable and cutters.

The main recent development is A/N37U, a controlled-depth, rapidly deployable sweep for use at greater depths. This deep sweep is now being adapted to surface ships as the single-ship deep sweep (modular). Four engineering-development models were scheduled for procurement in FY88. As of early 1989, limited production was scheduled to begin in FY90, with technical and operational evaluation in FY91.

◆ Airborne Mine-countermeasures System Mk 104

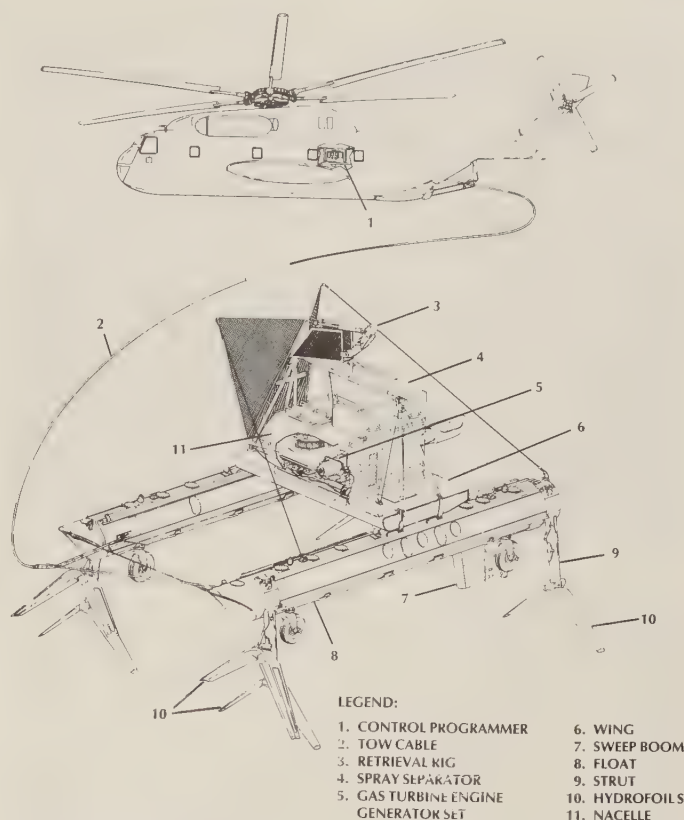
This helicopter-towed acoustic-mine countermeasure consists of a cavitating disk within a venturi tube, driven by a water turbine. Mk 104 was originally developed by American General. For this system the helicopter supplies sweep power. Minimum sweep water depth is 30 ft, compared to 15 ft for an MSL or MSB and 30 ft for an MSO or MSC. Total weight is 180 lb. Dimensions of the towed body are 26 in wide × 35 in high × 49 in long (87 lb).

Mk 104 and the other major helicopter-towed mine countermeasures were bought in quantity in response to Project SIXTY Decision 5 (1970, under Admiral Zumwalt), which ordered the mine-countermeasures forces reorganized to emphasize helicopters. In 1971 the navy borrowed 15 Marine Corps CH-53A helicopters to equip the first squadron, HM-12. This squadron swept North Vietnamese waters in 1972–73 and the Suez Canal in 1974–75.

◆ Airborne Mine-countermeasures System Mk 105

Mk 105 is the EDO helicopter-towed minesweeping hydrofoil sled. It carries a power pack (gas-turbine generator) for magnetic sweeping. Mk 105 is being succeeded by ALQ-166. Mk 105 was approved for service use in 1970. The first production models were delivered on 1 July 1972. Mk 105 was first used operationally during the Hanoi-Haiphong sweep at the end of the Vietnam War and was also used for the Suez Canal sweep the following year. Initially the sweep had to be streamed from the helicopter-carrying ship (e.g., an LPH); the sweep was then attached to the sled after having been streamed, and only then did the helicopter lift the sled into the water. The helicopter pilot had to thread the tow ball through the throat of the lifting device of the sled, a very difficult operation. It was discovered during training that the sled could be launched much more safely from the well deck of an LPD. The sled (with its foils up) was positioned at the after end of the well deck, ready for streaming, with the ship ballasted so that the ramp was about 18 in above water. The helicopter then picked up the tow cable from a small landing craft (LCVP) and carefully pulled the sled down the ramp.

The sled is typically towed at 25 kt, about 450 ft behind the helicopter, the on-board gas turbine powering twin magnetic tails. The sled becomes foilborne at 13 kt, and minimum sweep water depth is 12 ft. The sled trails a conventional open-electrode magnetic sweep 600 ft long. The total weight is 5200 lb.



Mk 105 sled. (EDO)

Six Mk 105 sleds were purchased by the Shah of Iran, and reportedly they were delivered before his fall.

See also EDO Model 819 (MIMS), below.

◆ Airborne Mine-countermeasures System Mk 106

Mk 106 is a combined Mk 104 and Mk 105 for acoustic/magnetic sweeping, the Mk 104 being attached to 1 of the Mk 105 tails. This device was used extensively during the 1984 Red Sea sweep.

◆ Buried-Mine Hunting System

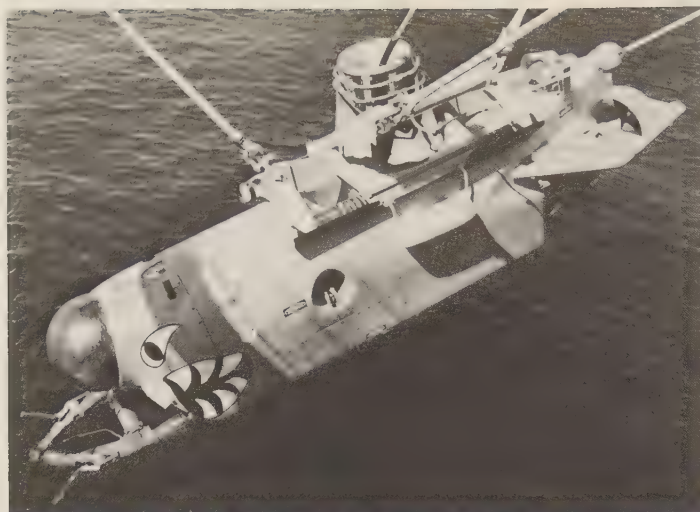
This system is an FY88 new start, in collaboration with Britain and Germany. It is to use both magnetic and acoustic sensors. The ASQ-81 MAD (on a catamaran) was used to locate buried mines at the end of the Vietnam War, in Operation End Sweep.

◆ Mine Neutralization System (SLQ-48)

SLQ-48 is the current U.S. unmanned minehunting submersible, equivalent in principle to the French PAP 104. The vehicle takes its power from the launching ship, proceeding at a speed of 6 kt. Weight in air is 2500 lb; the vehicle has 20 lb of positive buoyancy and rises to the surface in the event of failure. Dimensions are 12.5 × 3 ft, and power is provided by two 12-HP electric motors. There are also 2 side thrusters. The umbilical cable is 3500 ft long. Including its shipboard components, the mine neutralization system weighs 26,000 lb and requires a 60-kW power source. Honeywell, the manufacturer, claims that MTBF is 120 hr, with a 4-hr MTTR.

The vehicle itself carries a small high-definition sonar and an acoustic transponder that enables the vehicle to be tracked by the shipboard minehunting sonar. There is also an LLLTV for examining a mine or minelike object. The vehicle carries MP-1 (Mk 26-0) cable cutters and an explosive mine-destruction charge (MP-2, Mk 57-0).

Prototypes were tested in 1971–77, with a decision to begin engineering development made in 1977. In 1978 Honeywell was awarded a contract for 2 prototypes, and operational evaluation of the engineering-development model was completed in September 1982. It was tested on board the *Fidelity*.



The Honeywell Mine Neutralization System vehicle. (Honeywell)

It was announced in 1985 that the mine neutralization system would be supplemented by an advanced remotely operated underwater vehicle (ARDROV) that will help locate and identify objects, perhaps like the projected German Penguin A3.

◆ Special Acoustic Sweeps

Several special noisemakers were manufactured by the Naval Coastal Systems Laboratory (Panama City) specifically for shallow-water mine clearance as part of Operation End Sweep (1973). They had to be simple and were turned over to the North Vietnamese. Although these noisemakers probably would not be precisely duplicated in future, they are interesting examples of extemporized devices:

Drum Sweep a device to sweep magnetic-acoustic mines (DST Mod 4) in canals and rivers too narrow for helicopters or boats. Drum Sweep was a cut-down 55-gallon drum with a 3-HP lawnmower engine inside, and with permanent magnets and a small paddle wheel outside. The paddle rotated the drum about its vertical axis. This rotation changed the drum's magnetic field and helped free the drum from snags so that it could ride the current down river. The drum's acoustic signature was provided by the engine and by the exhaust, which was vented into the water. Five drums were provided to the North Vietnamese.

Rotating Acoustic Pipe (RAP) a 4-ft section of 10-in steel pipe with a towing swivel, nose cone, and external vanes causing RAP to tumble when towed. Scrap iron bars inside tumbled to produce noise. When towed with an MOP (see below), the RAP could detonate a U.S. seismic/magnetic destructor (DST Mod 4, at its most sensitive setting). Twenty were manufactured for the North Vietnamese.

Big Noisy Orange Barrel (BNOB) a towed barrel noisemaker developed in part by the mine force in Vietnamese waters. BNOB was a 55-gallon drum containing scrap iron and fitted with vanes on its outside; it worked much like the RAP. One was built.

Magnetic Orange Barrel (MOB) a horizontal coil of about 400 ampere turns, 7 ft in diameter, with a battery at its center to supply current. MOB was towed on a styrofoam float by a boat. This device was experimental only.

Sophisticated Orange Barrel (SOB) (acoustic solenoid barrel) a solenoid inside a 55-gallon drum, energized by a battery inside. As the solenoid was pulsed, it struck the inside of the barrel. The SOB designation differentiated it from BNOB; SOB was not built.

Static Loops static coils used for inland sweeping. Dropped on the bottom or placed on a raft (or suspended from floats), these coils could be pulsed to simulate the signature of a passing boat;

they were repositioned after sweeping. Power could be provided either by a battery or by a welding generator. Two such loops were lent to the North Vietnamese.

There was also a drone minesweeping boat developed specifically for End Sweep (and not, therefore, identical to the drone sweepers developed during the Vietnam War). This boat was commercial fiberglass (14 ft 6 in × 5 ft) and could tow RAP, MOP, and the A Mk 2(g) sweep. One problem was that the existing drone sweepers (MSD) had magnetic signatures that would have detonated destructors under them. Ten remotely controlled boats, which could be operated from a range of 2 miles, were provided to the North Vietnamese.

◆ SPU-1/W (MOP)

SPU-1/W is a magnetized pipe filled with styrofoam; MOP means Magnetized Orange Pipe. It was employed during the sweep of Haiphong harbor at the end of the Vietnam War. At that time, it turned out that some of the mines laid in Vietnamese waters were so sensitive that they would have destroyed the sweep sleds. A precursor sweep was needed: the MOP. This procedure was interpreted by some as demonstrating shortcomings in helicopter sweeping, but in fact precursor sweeping was more a commentary on the design of mines sensitive enough to destroy small wooden craft held together by metal fasteners. The MOP was also needed to sweep water too shallow for a Mk 105.

A modern version of the 1940 iron-rail sweep (M Mk 1(m)), MOP was a pipe long enough to provide the magnetic mass of the rail and wide enough to be buoyant (30 ft × 10 in diameter). MOP was sealed at each end, filled with styrofoam, fitted with towing lugs, and magnetized. A helicopter could tow as many as 3 MOPs in tandem. A total of 150 were manufactured by the Naval Coastal Systems Laboratory (Panama City).

In 1972, when Operation End Sweep was being planned, there was some fear that not enough Mk 105 sleds would be available in time. One proposed solution was to wrap a MOP in coils energized by a generator in the helicopter, increasing the sweep path's width by a factor of 5.

◆ ALARMS

Northrop's Airborne Laser Radar Mine Sensor employs a downward-looking blue-green laser pulsed at 10 kHz. Prompted by reports of moored mines in the Persian Gulf, Northrop proposed the system to DARPA in the summer of 1987 and was awarded a development contract late in November 1987. The first tests were run early in August 1988, at San Clemente Island. Northrop claimed that these tests showed a search rate at least 10 times the current visual rate.

ALARMS used a blue-green pulsed copper-vapor laser (510 nm, near the blue end of the spectrum) for good water penetration, scanning in a 682-shot oval pattern (circular with respect to the helicopter). The pattern hits the mine with both its forward and trailing edges; backscatter indicates shape and position in 3D. Trials showed that the shadow cast on the seabed by the laser provided the most informative data. Mines are displayed as squares, the color of the square showing the depth. The system shows only moored mines; it is range-gated to reject the reflections of the surface and the bottom. Gain is adjusted for sea-state.

The Northrop system is built around a Larson 500 ladar (laser radar) built by Optech Systems of Downsview, Ontario, Canada. Reports of operating depth vary. DARPA required 100 ft, but it was also reported that the system could reach down to 300–600 ft.

ALARMS was never actually deployed to the Persian Gulf. It is still a developmental system, housed in a 35-ft container and carried by a big MH-53 helicopter. Northrop is seeking funds for a more compact version. ALARMS has not received any funding since FY88; it is included here because it is probably typical of an important class of minehunting laser systems. As tested late in the fall of 1988, it was beaten out by the Kaman

Magic Lantern: it achieved only about half the depth of the Kaman system and showed poor resolution.

ALARMS is not the only laser minehunting system proposed; see also the description of the Australian laser system in the ASW section. See Magic Lantern, below.

◆ AMDAS

The Marine Corps's Airborne Mine Detector and Survey system is intended to find mines 6 in in diameter in surf and turbid water. The concept was successfully tested in FY89. This device would be carried on board a UAV, its data transmitted back to commanders via a new Airborne Imagery Transmission (AIT) data link. In December 1990 an exhibit prepared by the Naval Coastal Systems Center, the system sponsor, showed how AMDAS works. The laser scans about 500 ft on either side of an airplane or helicopter to a depth of 10 ft in surf or muddy water. Search rate is 16–80 nm²/hr. The system produces a 50 × 50-pixel image per cell. It is expected to transition to development in FY91.

Late in October 1990 Senate and House appropriations committees recommended that DoD choose between AMDAS and the Navy Magic Lantern because both systems use the same basic technologies.

◆ CLG

Closed-loop degaussing, under development to meet an OR issued 19 December 1985. Strictly speaking, this is a means of protecting mine-countermeasures craft rather than a direct mine countermeasure. Here closed-loop means self-correcting: the ship's degaussing circuits are controlled by sensors outside the hull, which measure the actual magnetic field. The better the degaussing, the more easily the sweeper or hunter can operate near magnetic mines.

◆ Commercial ROVs

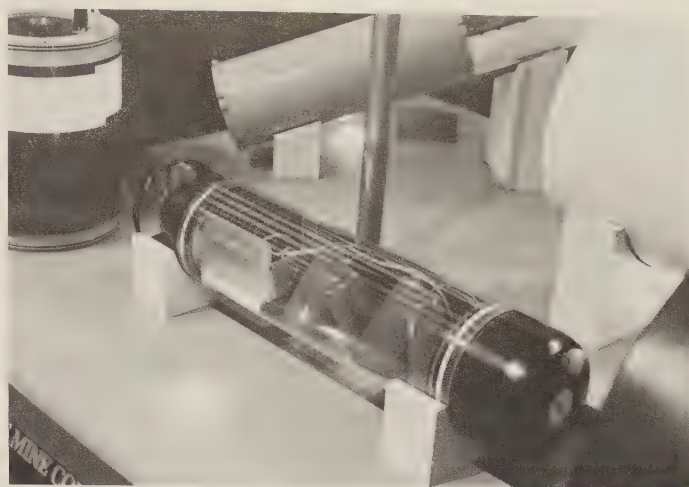
Commercial ROVs were ordered in December 1987 for use on board ocean minesweepers (MSOs), to identify mines. Deliveries began in the fall of 1989. Several are described below.

◆ EMD

Expendable Mine Destructor, a mine-killing miniature torpedo, was originally conceived to work in tandem with the AQS-17 helicopter minehunting sonar. EMD is preprogrammed by its operator's observing it on sonar, and the operator can override the program (i.e., provide mid-course guidance) via an acoustic link (range 800 m). There are 32 commands. EMD has its own high-definition HF sonar array, and it can operate independently, homing on a bottom transponder. Acoustic homing range (for final kill) is typically 30 m. The sonar guides EMD over the target mine at a height of 0.5–1 m, and the weapon fires its 4 shaped-charge downward-looking warheads. The manufacturer, Allied-Signal (Bendix Oceanics), claims that it is effective even against a buried mine. The company claims probability of a hard kill (detonation of mine explosive) is 0.90; that of a soft or hard kill (at least disablement of the mine trigger)



The EMD concept, according to Bendix (drawing displayed at RNEE 1989). (Author)



A model EMD displayed at RNEE 1989, showing its 4 downward-looking shaped charges. (Author)

is 0.95. Propulsion is by a lithium or thermal battery (maximum speed 12 kt, endurance 15 min, i.e., 4000 yd at 8 kt). EMD can operate in currents of up to 5 kt. Maximum operational depth is 300 m [1000 ft]. Dimensions: 20 × 100 cm [8 × 39 in]; weight, including warheads, is 25 kg [55 lb].

EMD has been under development since 1986, Royal Ordnance (of Britain) being responsible for the warhead. As of 1989, estimated unit cost was \$12,000.

◆ Magic Lantern/DEMON

In September 1989 it was reported that, at strong congressional urging, the navy was about to begin a crash program to deploy a laser mine detector on all LAMPS helicopters. It is a blue-green laser, reportedly effective down to 200 ft, and its success has inspired interest in ASW applications. In 1989 it appeared that with adequate funding Magic Lantern could be deployed by 1991.

Magic Lantern is a mine-detection LIDAR (laser radar) that images underwater objects. All of the other surface-piercing LIDARS use a very small spot and require computer processing (which cannot be done in real time) to reconstitute an image. Magic Lantern produces a spot of light, range-gates it to remove surface reflection, and puts the remaining light through a television camera to produce a direct image. In the future it will be possible to combine several such images to achieve a greater search width (range gating limits the width per image because a greater width corresponds to a greater variety of slant ranges to the water surface).

Magic Lantern began in the fall of 1987 as a Kaman private venture. It received some U.S. Navy funding under Project Kingfisher (see below) and underwent a very successful 6-week demonstration. More funds were provided for further scientific work, which was completed in May 1990. A second system was assembled for a helicopter. As of early 1991, Congress wanted Magic Lantern in all MH-53E mine-countermeasures helicopters for rapid mine search during exploratory sweeps and minehunting. The naval reserves wanted it in their helicopters and had adopted this requirement as an official position.

DEMON is another navy laser detection program (no other details are available).

◆ Magnetic-Acoustic Detector

Work began in FY89 on magnetic-acoustic mine detection, to transition to development in FY92. As of early 1989, system integration and sea trials were scheduled for FY91. In theory, the use of 2 detection methods should greatly reduce the false-alarm rate in minehunting. It is also possible that the plan is to use some form of magnetic resonance to detect particular explosive compounds, even if the mine casing is nonmetallic.

This project is distinct from efforts to develop countermeasures to buried mines.

◆ MIDS

Modular Influence Minesweeping System was a new start planned for FY90. It was begun in accordance with a CNO memorandum of 14 February 1986.

◆ MTDS

Mine Countermeasures Tactical Environment Data System is a current project begun in accordance with a CNO memorandum of 7 April 1986. In this case the tactical environment includes background magnetic fields and tides.

◆ Project Kingfisher

Kingfisher was a 1988 emergency project for mine detection and evasion, begun after the mining of the frigate *Roberts* and funded out of the JCS War Chest (\$30 million). Projects funded by Kingfisher were the use of the Plessey Mirror Sonar, the test of Magic Lantern, the Hughes MMS (described in the Antiaircraft Warfare section), and Project Midnight. Project Midnight was a Diagnostic Retrieval Systems (DRS) attempt to use fields of active sonobuoys plus a processor. The MMS was intended primarily to detect floating mines. Of these prototype systems, the MMS and the Mirror Sonar were actually deployed to the Persian Gulf.

◆ Remote Minehunting

The current mine-countermeasures program includes development of a system employing multiple remotely controlled vehicles operated from a single platform in amphibious objective areas and in other areas where conventional forces are not available. As of early 1989, FSED was scheduled for FY92.

◆ SISS (SYQ-12 and -13)

UNISYS's Shipboard Integrated Route Survey System is a software package hosted on various computers. The existing old MSOs use the SYQ-12 Integrated Shipboard System (ISS), running on a DTC I computer (HP 9020). SYQ-12 was installed on board the first MSO in 1985 and was used in the Persian Gulf. There it operated with Sea Rover ROVs (which were bought specifically to operate with this system). It also has a Route Survey Data Management System. A DTC II version of SYQ-12 is under development but had not yet been delivered as of mid-1990. All U.S. COOP minehunters also have the ISS (SYQ-12). SYQ-12 has also been sold (FMS) to Egypt for use on COOPs, with the EG&G 260 towfish and the Super Sea Rover vehicle.

The new *Osprey* class has the Navigational Command and Control System (SYQ-13), which is basically the SYQ-12 software hosted by a fully militarized 68020-based computer with a mass memory (which has no separate AN designation), a high-resolution color display, a tape driver, a printer/plotter, up to 8 navigational aids, and MCM sensors (which can include side-scan and hull sonars).

◆ SSDS

Single Ship Deep Sweep was a new start in FY90 to meet an OR issued 8 March 1983. Presumably, it is a U.S. equivalent of the single-ship version of the British EDATS.

◆ Surf-Mine Detection and Destruction/RSWMCS

In 1989 the navy reported that in FY88 it had completed laboratory tests of a system for laser mine imaging to detect mines in the surf zone, which would impede an amphibious assault. At the same time, linked miniature shaped charges had been demonstrated as a means of neutralizing these mines. The laser surf-mine work continued through FY89, and the miniature shaped charges were incorporated in a new mine-destruction system (not named). This work may refer to a new program, RSWMCS (rapid shallow-water-mine countermeasures system), for which formal requirements were prepared in FY90, looking toward an initial contract award in FY91.

This is a Marine Corps system. The ultimate goal is to reduce

size to the point where the laser detector can be carried by a UAV.

The FY89 program also included exploratory tests of high-powered microwave technology for mine destruction (presumably through EMP-like attacks on mine electronics). The announced FY90 program included completion of development of the airborne mine-detection-system image processing, with testing scheduled for completion during FY91 (this is not the Northrop ALARMS system).

◆ EDO Model 819

A shipboard derivative of the EDO Mk 105 airborne mine-countermeasures system, 819 is called MIMS (Modular Influence Minesweeping System) by the company. 819 employs a gas-turbine generator and a tow cable for both acoustic and magnetic sweeps, the cable carrying magnetic electrodes and towing an acoustic fish. MIMS is intended to equip craft of opportunity; the towing reel and winch weigh, together, only 5000 lb (it takes up only about 10 ft² on the ship's deck).

◆ EDO Model 910

See the ASW section (Model 900/910).

◆ Model 260

EG&G Environmental Equipment's Image-Correcting side-scan sonar fish can be towed at up to 12.7 kt, covering a 600-m swath on each side, with a resolution equal to 0.25% of range.

◆ Phantom

Deep Ocean Engineering's modular ROVs are used for tasks such as ship inspection, bottom survey, harbor patrol, and mine countermeasures (for which the HVS4 version was specifically designed). HVS4 weighs 82 kg, develops more than 68 kg of thrust, and sustains a speed of more than 4 kt at depth. It has been used with the Canadian Mesotech 971 sonar and with a 20-kg payload release. The vehicle has 2 thrusters aft and can sit on the bottom using a sledlike frame. As of late 1989, nearly 150 had been sold, including 2 HVS2s for the U.S. Navy Coastal Systems Center (for airborne mine countermeasures), 2 HVS4s for the EOD (explosive-ordnance disposal) Technical Center, HVS2 for AMCM, and Phantom Supers for the Royal Navy and Royal New Zealand Navy.

◆ RCV-425

Hydro Products' ROV is controlled and propelled by 4 thrusters (2 axial, 1 vertical, 1 lateral), all driven by a 10-HP hydraulic system. It typically carries an LLLTV camera and 4 high-intensity lights; a sonar is optional. The tether cable is 1200 ft long and 0.46 in in diameter. Maximum depth is 1000 ft. Dimensions: 47 (long) × 39 (wide) × 23 (high) in; weight is 200 lb.

◆ Recon IV-S

Perry Offshore Inc.'s ROV has 4 thrusters and automatic depth control, and all components are separately controlled from the surface. The ROV has 160 kg [353 lb] of positive buoyancy, available for payload, and it also has 38 spare connections for additional equipment. It can accommodate sonar, cameras, and spotlights in its open frame. Speed: 3 kt forward, 1 kt vertical or lateral. Maximum depth is 457 m [1500 ft]. Dimensions: 2.06 (long) × 0.9 (wide) × 0.85 (high) m; weight is 457 kg [1007 lb].

◆ Team Rockwell MCM System

This system has been proposed by Rockwell Autonetics Marine Systems division with 2 Canadian companies, ISE (International Submarine Engineering) and OSL (Offshore Systems Ltd.). Rockwell will provide its Mil-Spec console and, presumably, system integration; ISE provides the remotely operated vehicle, and OSL the navigation. The initial proposed application is on board the projected Canadian mine-countermeasures craft (MCDVs).

The ISE Dolphin semisubmersible vehicle cruises at 12 kt (26 hr endurance) with a maximum speed of 16 kt (endurance

325 nm). Dolphin carries a side-scan sonar, data from which are transmitted back via VHF radio link. The single-beam side-scan sonar has detected targets at 500 m at up to 6 kt. Two Dolphin vehicles have been supplied to DARPA to aid in the development of an autonomous minehunting vehicle for future COOPS and minehunting helicopters. In theory, Dolphin could find targets for later investigation by British Trail Blazers, smaller ROVs made by ISE (see above).

◆ TP Scout

Katema Aerospace's ROV uses propellers at either end, operating at various combinations of cyclic and collective pitch, for propulsion and control (presumably, this is equivalent to the operation of a coaxial helicopter, turned on its side). Maximum speed is 8 kt, and maximum depth is 300 m [about 1000 ft]. Dimensions: 0.51 m (diameter) $\times$ 2.18 m.

◆ Viper Mk 1

Allen Osborne Associates' ROV is powered either by batteries or by a fuel cell driving 4 thrusters. It is controlled by a fiberoptic umbilical out to 2000-m range; the pilot uses a joystick and a mouse. The sensors are a high-resolution sonar (200-m range) and an LLLTV (CCD camera). Maximum speed is more than 8 kt (the ROV dives or ascends at 1.5 m/sec); maximum depth is 200 m. Dimensions: 0.5 (wide) $\times$ 0.53 (high) $\times$ 1.88 (long) m; weight is 46 kg.

YUGOSLAVIA

Yugoslavia has the following river sweeps: Type PEAM magnetic and acoustic; Type AEL-1 explosive; Types MDL-1 and -2 mechanical.

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ADDENDUM

In December 1990 Aeritalia and Selenia merged to become Alenia. Consorzio Sistemi Navali Selenia-Elsag will continue under its present name, taking over the Elsag holdings in Welse, USEA, SEPA, and the French CSEE (40% control). However, a proposed joint venture among Matra, OTO Melara, Breda, SMA, and Officine Galileo, to have been called OTO-Breda *Missile e Sistemi*, apparently will not go ahead.

As of 1 January 1991, Bofors and FFV had merged most of their defense (ordnance, as opposed to electronics) activities in a new joint company, Swedish Ordnance-FFV/Bofors. Bofors had already absorbed the former Philips military electronics arm, PEAB (which is now trading as BEAB).

As of January 1991, the name MEL ceased to exist; the company became part of Thorn-EMI Sensors (the headquarters of the Thorn-EMI Sensors division was moved into the former MEL headquarters).

A project to combine BAe missiles and Thomson-CSF missiles divisions under the name Euromissile was canceled in mid-March 1991.

The U.S. FY92/93 budget issued in February 1991 terminated the following weapons programs: RAM (later reinstated), ASRAAM support, 16-in gun ammunition improvement, high explosive antiarmor, 16-in gun ammunition, Excalibur (LRCSW) missile, Bigeye chemical weapon, B-90 nuclear depth bomb, low-cost seeker, 3-in/50 gun ammunition, and 5-in/38 gun ammunition. Other announced terminations included an electro-optical sensor, RECO (remote minefield control), the new CAINS, NCCS shore systems, directed-energy countermeasures, cooperative engagement, C3 countermeasures, SAR-8, NAAWS, CORT (Mk 92 Mod 6), ROTHr procurement, and SQR-18 backfits. Some of these programs may survive under other designations, to be financed as parts of other programs, and others may be restored by Congress or by supplementals. Both remaining battleships are to be retired, hence the elimination of 16-in gun improvement programs. There is good reason to expect other programs to be revived.

A supplemental program presented to Congress after the cease-fire in Kuwait called for procurement of 290 Tomahawks, 8 SLAMs, 2033 HARMs, and 5000 Mavericks (air force version).

Readers are cautioned that the FY92-93 U.S. budget figures in this addendum are those proposed by the administration; they often change radically between proposal and final enactment (for example, Congress rejected the cancellation of Sea Lance and V-22 during 1990).

SURVEILLANCE AND CONTROL

CANADA

In August 1990 the underway replenishment ship *Protecteur* was fitted with ADLIPS specifically so that she could receive Link 11 data and so carry the same air picture as her 2 consort destroyers in the Persian Gulf.

◆ SHINPADS

This system equips the new Canadian *Halifax*-class patrol frigates. It uses much of the architecture originally developed in the 1970s, which is broadly similar to that implemented by Honeywell/Hughes in the H930 series. The system operates in 3 modes: automatic, semiautomatic, and manual. The normal mode is semiautomatic; the tactical situation builds relatively slowly. The automatic mode is for very fast engagements (the command can control engagements by veto). In the fall-back manual mode, the operator assigns weapons, begins engagements, and reconfigures the system to account for failures or damage to its components.

The 32 computers (UYK-502s, UYQ-504s, UYK-505s) of a SHINPADS system are linked by 4 triaxial cables, only 2 of which need be active for 100% capability. Each cable can carry either system data or electrical control messages. The 10-Mbit/sec UYC-501(V) serial bus, equivalent to ten 1553B buses, was developed especially for SHINPADS. It uses only about 10% of its 10-MHz bandwidth. Similarly, 60% of total computer power

could be lost without the loss of full system capability. All of the display consoles are interchangeable. SHINPADS is unique in its direct integration of EW (including chaff launching) into the combat system's data bus. The current word length is 16 bits (sometimes ganged to 32). All the computers are to be upgraded to UYK-507s (SHINPADS currently uses a mix of UYK-502s and -505s).

In a Canadian patrol frigate, there are 13 SHINPADS standard display consoles (UYQ-501s) in the operations room and another on the bridge, plus a U2049 display used to monitor and reconfigure the system after damage or when changing modes, and 2 STIR (FCS) consoles. The operations room (CIC) is divided into 2 teams, AAW/Surface (led by a sensor weapons controller) and ASW (led by the assistant sensor weapons controller). The AAW/Surface group includes the 2 STIR operators, the track supervisor (with 2 radar tracker operators), and the EW supervisor (with an ESM operator and a communications-intercept operator). The ASW group includes a sonar-control supervisor (to supervise the operators of the hull sonar, towed array, and sonobuoy processor [Jezebel]) and the ASW-aircraft controller. The teams in the operations room are supervised by the operations room officer, who stands at an additional standard console, and there is also a standard console in the operations room for the commanding officer (but the communications-intercept console is not a standard console).

The separate, integrated, machinery-control system (SHIN-MAX) has its own SHINPADS data bus. Very early on (late 1970s, certainly before 1983) there was some interest in integrating the operations room with machinery control, but that idea was dropped, and a different (CAE) system monitors the machinery and ship's condition.

The Link 11 data terminal set in this system is USQ-76.

◆ HINPADS/MSDHS

HINPADS was formally dropped in mid-March 1991 in favor of a UNISYS (Paramax) Mission System Data-Handling System. MSDHS will conduct the back-seat functions, using a 68000-based computer, IPDS (integrated processor and display system), based on the UYK-507. It will incorporate the operator-machine interface work originally done for HINPADS and will have real-time software. Final negotiations were conducted in March 1991. Four consoles in the back of a helicopter, a 1553B bus, and 6 computer cards in the cabinet will be integrated with the front seat and tied to a European front end. Paramax is the integrator of the avionics systems. Paramax has also developed an alternative scaled-down (2-seat) version with color, windowing, and multipurpose consoles. This version will have both joystick and keyboard data entry. There is still some question as to whether this helicopter will have FLIR (PAV) and MAD, but it will have a dipper and buoys.

FRANCE

◆ Super-Étendard Tactical Data System

Here is some additional information on the Super-Étendard system. The prototype upgraded Super-Étendard began flight tests on 5 October 1990. A total of 48 aircraft are being upgraded (3 prototypes, plus 15 per year from 1992 to 1995). The airframe modification is to extend the aircraft's service life to 2005. Improvements include installation of an Anemone TWS radar (in place of the current Agave), a new inertial platform, a new wide-angle HUD (which can also display TV and FLIR images), the Sherlock RWR, extra stores attachment points, a provision for night-vision goggles, a HOTAS control, and a new central computer (SAGEM UAT 90 in place of the earlier UAT 40).

◆ TAVITAC 2000

A 1991 Thomson-CSF brochure shows that the system is built around a duplicated Ethernet LAN carrying up to 15 high-resolution Vista consoles, with separate interfaces to the tactical computers (including redundant computers) and redundant interfaces and through computers to specific sensors, weapons,

and data links. These devices are also connected directly to the main Ethernet for full redundancy. All the computers use 68030/68040 processors with 1–4 CPUs and up to 4 Mbytes per computer. Each Vista console has a 1280 × 1024-pixel, high-resolution, color screen, 2 software-defined touch-sensitive keyboards, and a 32-bit processor (which can process up to 800 tracks). It is programmed in ADA. The console can display up to 300 tracks (256 in color) and has windowing and zoom capability.

◆ Vega

Vega was never a full CDS; it was a partial system grown from a GFCS. The original analog gun computer, BCH, could manage fire control and also make ballistic calculations. All examples in service are being replaced by digital (16-bit) CDE computers developed and manufactured by Thomson-CSF. CDE is especially adapted to gunnery calculations; it is not fully reprogrammable. It is the current standard French navy fire-control computer.

GERMANY

Here is some additional information on German tactical data systems:

◆ AGIS

There are 2 versions, S143 and S143A. In each, the Signaal WM27 radar feeds a horizontal tactical table (*Taktischer Bildschirm horizontal* or TBh) with tactical data (*Taktischer Datenanzeige* or TDA), as well as feeding the fire-control computer (*Feuer Leit Rechner* or FLR). The FLR is connected to the command/control computer (FUR), which is connected to the tactical table (TBh). In the S143 version, besides controlling weapons, the FLR also drives a series of vertical consoles (2 TKG and 1 output console, *Ausgabekonsol* or AKG). The FUR is connected directly to the console of the Norwegian-supplied SR-1A ESM system. In the S143A version of the system, the FLR drives a single vertical output console (AKG). The FUR is connected to a vertical display console (multipurpose display console, *Mierzweckdarstellungskonsol* or MDK) and to the FL1800 ESM system.

The S143 version uses a UYK-7 computer with USC-27 as its data terminal set; the S143A version uses a TE-905 as its data terminal set. The S143 version can operate simultaneously in HF and UHF.

AGIS means *Automatisiertes Gefechts- und Informationssystem* (automatic combat evaluation and weapons-control system). It was the second generation of German CDSs, after SATIR I.

◆ PALIS

PALIS (*Passiv-Aktiv-Link-Lage-Informationssystem*) is a lightweight tactical data system for fast attack boats (S148 class), for the Hamburg-class destroyers (Z101A class as modernized), and for the new fast minehunters (M343 class). In each case PALIS is built around a UYK-20A computer. S148 and Z101A use the same version, with Sanders Mk 95 and Mk 95 Mod 1 consoles and with TE 905 and TE 237 data terminal sets. The minehunter version uses the new KAE BM 802-61 console and the TE 237 data terminal set. PALIS's functions are navigation, tactical navigation, target tracking, identification, indication of special (fixed) points, tactical bearing indication, ESM integration, weapons designation, Link 11, alerts, and data extraction.

PALIS appeared in the mid-1970s.

◆ SATIR

There are 3 versions:

SATIR I for *Lutjens* (modified *Adams*)-class (Z103-type) destroyers, which have now been modernized (Z103B class). Although SATIR originally used a USQ-20B computer, the current (modernized) version uses a UYK-7. It incorporates a version of the SYS-1 integrated ADT (IADT). SATIR I incorporates 3 OJ-194(V)/3/UYA-4 PPI consoles (2 for SYS-1, 1 for the FL1800S

ECM system), 11 OJ-7979(V)/UYA-4 multipurpose consoles (each with an associated digital indicator), a disk memory unit (U 1647/1, with 500k 32-bit words; data rate is about 127 kwords/sec), and a USQ-69 data terminal set. SYS-1 includes a range-height indicator (IP-1117/UYA-4). This equipment is typical of contemporary U.S. NTDS practice. The Z103B combat system includes an SPS-67(V)1 surface-search radar in place of the earlier SPS-10F and a DSQS-21B sonar in place of the earlier SQS-23L. The MFCS is Mk 74 Mod 6, and the GFCS is Mk 86 Mod 8. This version controls 2 RAM missile launchers.

The SATIR I operational program was written by German officers at the U.S. naval programming center at San Diego. SATIR originally corresponded to the U.S. NTDS. It tracked the ship's position automatically and conducted navigational calculations (such as collision points and CPAs). It kept track of (and provided rate-aided projection of) radar-target data entered manually. It provided computer assistance to maintain a radar and sonar plot and could pass target data to the weapons-control system (and calculate whether particular targets were engageable). It also exchanged data with other units via Link 11. It was not integrated with the ship's ESM system nor with the ship's underwater FCS. The Z103B system enjoys improved AAW performance through automatic radar-target detection and tracking (SYS-1), incorporates a new GFCS (Mk 86), can control a long-range antiship missile (Harpoon) and a new AAW weapon (RAM), and is integrated with the ship's ASW FCS (it mediates between the ship's sonar and her Mk 114 underwater FCS) and with her ECM system (FL1800S; it mediates between the FL1800S sensor and its transmitter).

SATIR II for the *Bremen* (F122) class is built around a UYK-7 computer, which is powerful enough to handle all shipboard sensors and weapons (Z103 had a separate Mk 114 underwater FCS and separate missile and gun FCSs). All weapons and sensors operate through multifunction consoles (MZKs). This version incorporates automatic radar-target detection and tracking and can engage air targets automatically (it chooses the weapon most appropriate to a given target). It supports ASW using both shipboard weapons and the embarked helicopters. Like the Z103B system developed somewhat later, SATIR II integrates ESM with other shipboard sensors.

SATIR III for the new F123 class is built around a UYK-43 computer. This system has 12 display consoles and 2 Link 11 data terminal sets.

INTERNATIONAL

Here is further information on Western data links:

Link 1 This ground-to-ground link is between sector observation centers in an air-defense environment such as UKADGE. TADIL-B is similar but uses the Link 11 (TADIL-A) format and a different speed of transmission.

Link 4 This interceptor-air-control link was used by both France and the United States. It has been replaced in U.S. service by Link 4A, which is used for carrier-controlled (all-weather) approach as well as for air defense. Link 4B is a ground-to-ground land-line link. At least the original Link 4 used 70-bit messages (each bit being 200 microsec in duration, for a total of 14 msec), each of which included a synchronizing pattern, a start pulse, an aircraft address, a message number or label, 2 information groups, and parity-checking bits. The link operates at a fixed frequency within the 300–325-MHz band by frequency-shift keying. There is no overall net-control clock; an airplane receiving a message uses the synchronizing pattern to set its own clock to receive. Even so, the finite length of each message sets a practical limit on the number of aircraft that can share a single net. A controlling transmitter must be able to send messages to all its aircraft in sequence, and there must be some allowance for message feedback. There must also be some short time between messages. Practical net size is limited by allowable time-lateness of messages. For example, 20 messages would take something more than 0.28 sec, so 1 of 20 aircraft would have to wait at least that long for an updated enemy aircraft position.

Link 5 This ship-to-shore link was to be used with Link 11 but was abandoned.

Link 7 France uses this air-traffic-control (point-to-point) link. Because only France used this link, the Link number was not adopted by NATO.

Link 11 These are the export versions for E-2C aircraft:

Link Delta for Egypt (reportedly because Delta resembles a pyramid)

Link Pi for Israel (eleven with a line above it)

Link Sigma for Singapore

Link 13 This smaller version of Link 11 was developed by France, Belgium, and Germany in 1962–64 but was ultimately dropped.

Link 15 This projected (abandoned) link was to have allowed noncomputer ships to send teletype data to Link 11 ships.

Link G This air-ground link by Ferranti was presumably equivalent to Link 4.

Link W This is an unlicensed derivative of Link 11 (but is not compatible with Link 11) developed specifically for the Saudi frigates. Its name comes from the "W" in Sawari, the code name for the French-Saudi naval arms project.

Link Y This current Ferranti version can transmit up to 4800 bits/sec, using a TDMA network with up to 30 subscribers. As of 1985, Link Y had been sold to Brazil and Egypt. Link Y was offered for export on board Tornados, so it may be in service in Saudi Arabia.

Link Z This link typically transmits at 75 bits/sec. It is a broadcast system, so 1 terminal can transmit to any number of subscribers.

JAPAN

◆ Bottom Surveillance Arrays

Japan maintains 2 surveillance centers at the southern and northern entrances to the Sea of Japan (Tsushima Straits and Straits of La Pérouse), using a combination of bottom arrays, shore radars, and optical observation. Because they are barrier arrays, the bottom arrays used would not have been long-range SOSUS-type installations; initially, they were probably upward-looking devices. In the late 1960s they were replaced by a total of 19 LQO-3 arrays; the first 2 of 5 sets in the Tsushima Straits were installed in 1968. In the 1980s these devices were upgraded to LQO-3As. At that time an official report suggested that a diesel submarine operating at less than 6 kt had a 70% chance of being detected at a range of 1000 yd and a 15% chance of detection at 3000 yd. Such figures would be entirely acceptable in a barrier, as opposed to an open-ocean, tracking system. In the 1970s development of the lower-frequency LQO-4 began. It is a longer-range system and initially coordinated operations of P-2J patrol aircraft.

Japan is currently deploying SURTASS-type surveillance towed-array ships with U.S. technical crews; Japan and the United States share their surveillance data.

NETHERLANDS

◆ SMCS

The Signaal Modular Combat System is the fully distributed successor to the centralized SEWACOs. It will probably be renamed in view of the merger with Thomson. The fire-control module is STING (similar to the earlier STIR but with hydraulic rather than electric drive, using the 1.2-m dish), and the radar will probably be SMART/MW-08. The Signaal approach has been to link separate building blocks by bus interface modules to a fiber-optic bus (which has greater capacity than the Ethernet bus of the M-class frigates). This type of architecture can be fully open, but it is not entirely clear yet whether Signaal will go all the way in that direction.

At this writing the standard SMCS console is still SIGHT (Signaal General-Purpose High-Resolution Tactical Display), incorporating a 19-in, high-resolution, raster-scan, color screen, a 12-in monochrome or 15-in color television screen (either atop the main display or to its left), a keyboard with trackball, a display processor, and a bus interface. Each console can be linked directly with up to 4 subsystems.

◆ STACOS

The Turkish and Portuguese MEKO 200 frigates have the original STACOS CDS. Mod 2 is in the Greek frigates. A Blohm & Voss report dated March 1991 shows Mod 3, rather than CoSys 200, in the Turkish Track II frigates. However, these ships are still listed as using Plessey-Contraves sensors and fire controls rather than Signaal's: forward, the AWS-9/996 air-search radar and the Contraves TMX and TMKu rather than DA-08 and WM25; and aft, STIR and TMKu rather than STIR. Both versions use the Dolphin target-indication radar (the Portuguese and Greek units use MW-08 instead).

UNITED KINGDOM

◆ System 500

As of March 1991, this system was being offered to Brunei, Malaysia, and another potential Far East customer. Ferranti's bid to Korea was a version of CAAIS.

USSR

◆ "Second Captain"

In the *Moskva* class the Soviets introduced a new command-assistance computer, sometimes called the "Second Captain." Given tactical data, such as the designation of an approaching attack airplane, the computer provided an optimum course of action. This is not too different from the initial Soviet tactical computer application on land, in which a computer chose among several precanned courses of action. This sort of application derives from the Soviet view that war is a scientific endeavor, in which the optimum course of action in any situation can be determined mathematically (a concept that radically reduces any need for individual initiative). Because of the state of Soviet computer development in the late 1960s, the inputs describing the tactical situation cannot have been very elaborate. On board the *Moskva*, for example, the "Second Captain" did not (reportedly) maintain any sort of current plot. Instead, it provided a series of textual recommendations, with calculated data (e.g., "You have 45 seconds within which to react to the approaching A-7 aircraft"). The computer display, moreover, was not in the CIC (which the Soviets designate BIP, battle information post) but in a separate guarded space. Although there was apparently provision for automatic input, actual input seems to have been by voice and written message.

In the early 1970s this system also appeared on board the other Soviet flagships: the converted *Sverdlov*-class cruisers and the big submarine tenders. It was not on board Kashin-class destroyers.

SOVIET NAVAL COMMUNICATIONS ANTENNAS

◆ Data Links for Missile Targeting

Band Stand This is probably an air-to-ship data link for SS-N-9 and SS-N-22 targeting, first installed on board Nanuchka-class missile corvettes. It is also carried by *Sovremennyy*-class destroyers, Tarantul-II (SS-N-2C) and -III class missile corvettes, and the Sarancha hydrofoil.

Fish Bowl This predecessor to Light Bulb was on board some Nanuchka-III-class missile corvettes (mounted 1 on each side of the mast, above the ESM radomes). This receiver is also on board the Sarancha and some Nanuchka-Is.

Light Bulb This satellite- (or air?) to-ship data link is associated with the SS-N-25 missile on board *Sovremennyy*-class destroyers, Tarantul-II and -III class missile corvettes (associated with

SS-N-2C in Tarantul-II), and some Nanuchka-III-class missile corvettes (1 on each side of the mast, above the ESM radomes).

Plinth Net This is probably a transponder for use with SS-N-3 missiles, on board some (but not all) Kynda and Kresta-I class cruisers (exceptions are the Kresta-class *Vladivostok* and Kynda-class *Admiral Golovko* and *Varyag*). Plinth Net is a large parabolic antenna resembling an air-search radar, but it is located relatively low in the ship's superstructure on each side and is thus ill-suited to any air-search role. It may provide missile-guidance channels additional to those of the Scoop Pair antenna that usually controls SS-N-3.

Punch Bowl This satellite-to-ship data link is associated with the SS-N-19 missile and is carried on board carriers, cruisers, and Oscar-class submarines.

◆ Communications Antennas

The great variety of antennas on board a single ship suggests that many are special-purpose. Most are omnidirectional; presumably, those in radomes (Bell series and Fig Jar) are directional. Much of the information below is derived from a published list associating particular classes with particular antennas; it is probably incomplete and should be treated with some caution as a guide to patterns of antenna employment. However, if the pattern given below is correct, it seems likely that Bell Crown is a directional system superseding Fig Jar; Bell Crown is limited to modern large-ship classes with ASW capability, ships that might be expected to operate together. Some of the designations given in the accompanying photos do not jibe with the list below (they may be unofficial).

In addition to the designated antennas, modern cruisers and destroyers are equipped with HF and HF-MF whips (varying in length from 10 to 50 ft) and with MF cage antennas strung between their masts (e.g., with 4 wires and circular spreaders every 20 ft). Submarines have telescopic HF antennas, and Park Lamp can reportedly receive VLF signals down to 30 ft below the surface.

Bell Crown Kiev, Moskva, Kirov, Slava, Kara, Kresta-II, and Udaloy classes.

Bell Nest Tarantul-II-class missile corvettes only.

Big Ball Satellite communications, superseded by Low Ball. Associated with Molniya and Raduga satellite systems.

Bike Pump Broad-band end-fed UHF dipole, recognizable because it has two thick tubular segments joined by a thin tube. Kara, Kresta-II, Kresta, Mod Kashin, Krivak, Grisha, Mirka, Petya, and Poti classes.

Bird Dipole/yagi UHF antenna. It consists of yagis at the top and bottom of a vertical mast (with 4 dipoles on the upper yagi and 3 on the lower), and it has a single horizontal dipole at roughly the midpoint of the mast. A monopole antenna extends vertically above the upper yagi.

Bow Split On board some Grishas.

Box Yoke UHF communications antenna, on board Kirov, Kashin, Krivak, Grisha, Petya, and Natya.

Bread Knife Kresta, Mod Kashin, Riga, Grisha, and Petya classes.

Brick Spring High-gain horizontal UHF helix antenna (tube) with circular ground plane (with circular holes cut in it).

Cage Bare VHF dipole antenna, on board all combatant ships; standard VHF antenna down to missile and gun boats.

Cage Cone VHF antenna, on Kiev, Moskva, Kirov, Slava, Kara, Kresta-II, Kresta-I, and Kynda classes.

Cage Stalk VHF (broad-band dipole) consisting of 2 vertical tubes (cages) tapered down to join at the middle with a yardarm. On Kiev, Moskva, Kirov, Kara, Kresta-II, Kresta-I, Kynda, *Sovremennyy*, Udaloy, and Mod Kashin classes.

Cat Cage Mirka class.

Chuck Tube Dipole antenna, supported at its center.

Coin Grass Alligator class.

Cross Fold Polnocny class.

Cross Wedge Kashin, Nanuchka, Poti, Andryusha, Vanya, and Alligator classes.

Cuff Pair Petya class.

Farm Loaf On board Kashin, Koni, Riga, Grisha, and Mirka classes; formerly on Kotlins and Kildins. It is carried at the end of a yard and is a rectangular (rather than cylindrical) radome, tapered at its top.

Fig Jar Squat cylindrical radome pointing up at the end of a yardarm. On board Kresta-I, Kynda, Kashin-II, Mirka, Petya, and Poti classes, hence presumably associated with an ASW data link. Bell Crown may have been the successor device.

Fish Spine On board most modern combatants, from Krivak-class frigates up. A long yagi, it looks like a directional television antenna. Presumably, this is a directional UHF antenna.

Grid Bow Unidirectional, vertically polarized, broad-band UHF antenna. It consists of a vertical Bow Tie dipole (2 squares with their sides at 45 deg to the vertical) in front of a vertical screen.

Grid Quad Mirka class.

Half Key Moskva and Sovremennyy classes.

Hat Box Kiev, Moskva, Kara, and Kresta-II classes.

Long Fold Standard antenna, on board most combatants from the Pauk class up. May not be on board *Slava*, *Sovremennyy*, and Kashin as built.

Long Wire MF/LF dipole, on destroyers and similar ships.

Low Ball Satellite communications, e.g., on board carriers.

Pole Star Moskva, Kynda, *Udaloy*, *Zhenya*, *Ivan Rogov*, *Ropucha*, and Alligator classes.

Pop Art Standard VHF antenna on corvettes and larger warships from Kashin class onward. It consists of dipoles bent into a pair of rhomboid shapes at angles to each other. Variants A through D are in service.

Quad Rods *Slava*.

Rib Cone Vertically polarized, omnidirectional, broad-band VHF antenna, with 10 horizontal dipoles at its upper end forming a ground-plane reflector. There are 2 cones, 1 at the top (under the dipoles) and 1 lower down consisting of stays to the deck. This antenna is somewhat similar in appearance to the U.S. broad-band antenna used with NTDS. Kashin, Krivak, Petya, and Alligator classes.

Ring Web Krivak, Mirka, and Polnocny classes.

Round Web Kashin, Krivak, Mirka, Poti, SO 1, Osa, Yurka, Alligator, and Polnocny classes.

Slant Blade Polarized array of broad-band VHF blade antennas at a 45-deg angle, typically pointing up from under a yard.

Soup Cup Mirka class.

Shot Dome/Shot Rock Small antennas in vertical radomes, carried on board most combatants.

Sprage Star Horizontally polarized VHF dipoles at different angles to the horizontal. Mirka class.

Sprat Star Dipole array, listed here as an ESM antenna but sometimes considered a communications antenna.

Straight Key VHF dipole antenna, on Kashin, Mirka, Petya, SO 1, Osa, Shershen, Natya, T.43, Sonya, Zhenya, *Ivan Rogov*, and Polnocny classes.

Straight Pole Kara, Kresta-II, Krivak, Yurka, and Polnocny classes.

Straight Rail Moskva class.

Straight Tee Kashin and Vanya classes.

Stub Brace Broad-band, horizontal crossed dipoles, passing one above the other through a vertical circular sleeve (horizontally polarized).

Top Star Mirka class.

Vee Bars Two cones at 90 deg with additional crossed dipoles at their ends. The Vee series are long-range, directional HF antennas associated with flagship operation, especially the *Kiev* class. They are also on board some scientific auxiliaries operating far from home waters.

Vee Cones HF: 9-m cones at 70-deg angle. On board 1 Don- and 1 Ugra-class auxiliary (flagship). This was the first in the series, originally on board 2 *Sverdlov*-class cruisers modified as flagships.

Vee Tubes HF: 8.60-m cones at 90 deg. *Kirov* class.

Wedge Pair Mirka and SO 1 classes.

UNITED KINGDOM

◆ CANE I/II

CANE I/II use the Kongsberg KS500 computer and provide a 40-character × 12-line interactive display. They can indicate targets to an associated FCS. Capabilities are autotrack and semi-autotrack, CPA calculation, intercept and relative velocity calculation, autopositioning on charts, autopositioning print-out, and creation of a labeled plan display (LPD), i.e., of a synthetic-video PPI picture.

◆ Captain's Combat Aid

In December 1990 Thorn-EMI received a contract to develop a version of the Captain's Combat Aid for the ADIMP (ADAWS upgrade) program.

◆ DLPP

In 1986 Ferranti received a contract for 17 data link preprocessors built around Argus processors, for Type 22 frigates with CACS combat data systems. DLPP constructs and maintains a track file (up to 100 tracks) based on Link 11 data; it acts as a buffer. Because DLPP is external to the ship's main CDS, it can be modified relatively easily to accept data from other links, such as Link 16. Presumably, CACS originally accepted only Link 10 data.

A DLPP is also part of the ADIMP upgrade for Type 42 destroyers.

◆ KDX Combat System

As of early 1991, the Korean navy had reportedly decided to choose between the Sema-Dowty SSCS and the Swiss-German CoSys 200 for the combat system of its next-generation destroyer (KDX). The main sonar alternatives were reportedly the KAE DSQS-23 and Spherion. The program called for 8 destroyers optimized for antiship warfare, to be followed by 8 for AAW and 8 for ASW. At this writing it is by no means certain that the program will proceed as projected.

UNITED STATES

◆ SOSUS

The information that follows comes from an official history written about 1977 and declassified at the end of 1990. Although a great deal has happened since 1977, this account gives the first declassified picture of the logic and direction of SOSUS's development.

The contract for a LOFAR system was let to Western Electric in the fall of 1950. The prototype shallow-water array at Sandy

Hook was in place by the beginning of May 1951, and the first 40-hydrophone array at Eleuthra had been installed by January 1952 for tests beginning in April 1952. After their success, the CNO directed in June 1952 that 6 deep-water (1000-fathom-deep) arrays be installed in the Atlantic, the first at Bermuda, as the initial portion of Project Caesar, which was the original name for SOSUS. The first system test, using the Eleuthra and Bermuda arrays and the ASW submarine K-1, was conducted between 26 April and 7 June 1954. Sound data were all relayed to an analysis center at Norfolk, and sonobuoy-equipped aircraft were able to acquire the targets 90% of the time. The experimental sites detected submarines as far away as 600 nm, although average ranges were 300–400 nm. The full Caesar system consisted of Atlantic and Pacific barriers. The Atlantic sites (8 of which were operational by early 1956) were relatively far offshore because the continental shelf extends well out to the east; the Pacific sites were close to the steeply shelving coastline. By January 1956 the Atlantic sites were reporting 3400 contacts/month, of which 64 were classified as non-U.S. submarines. Most contacts were not submarines.

At this time, SOSUS was supplemented by submarine patrols (largely for electronic reconnaissance) in the North Atlantic and North Pacific, by electronic intercepts (from Norway) covering the operating area of the Soviet Northern Fleet, and by surveillance of the Northern Pacific mounted from the Aleutians and Japan. Sound surveillance was supplemented by 3 HF/DF networks (2 Pacific, 1 Atlantic), which were being modernized to deal with very short, time-compressed transmissions (the goal in 1960 was an ability to deal with a 1-msec signal). The new systems were installed during FY61–64. In an emergency, submarine barriers would be deployed in sensitive areas and strategic choke points. The Caesar system itself was very largely an extended form of coastal cover. Work was proceeding on a shallow-water extension (to protect the shoreward terminals of the offshore arrays) and a deeper-water extension.

Caesar was based in U.S. waters. In the Atlantic, the system's effectiveness was inherently limited by the Mid-Atlantic Ridge, which blocked sound transmissions from the Eastern Atlantic. In the Pacific, U.S. territory (in the Aleutians) extended toward the main base of the Soviet Pacific Fleet, Petropavlovsk. The OBOE array at Adak (1962) was successful in covering Petropavlovsk as well as the transit area running toward the mid-Pacific. Its success led to the cancellation of the then-current SOSUS-expansion scheme in favor of a new emphasis on forward-area listening. One advantage of listening in the areas through which Soviet submarines had to transit (rather than in their likely patrol areas) was that transmitters were generally louder (since they had to make a substantial speed to reach their patrol areas within a useful time). New arrays in North American and Western European waters extended coverage into the Norwegian Sea and also into the Eastern Atlantic (Project Backscratcher) early in the 1970s. At about the same time, arrays were installed to cover areas of the Western Pacific and mid-Pacific. In many places, the SOSUS coverage was precise enough to cue ASW aircraft directly, but Pacific arrays were sometimes too far from the submarines they were detecting. In the Pacific, therefore, an intermediate form of surveillance, HILAST, was developed about 1965. A P-3 flying at 20,000 ft monitored a square field of 9 LOFAR buoys spaced 75 nm apart; this combination was expected to detect any transiter at least once.

Longer effective ranges greatly increased the number of contacts with which the system had to deal. In 1968, in the Atlantic, SOSUS made 467,677 contacts, of which only 4755 were evaluated as submarines: 1716 U.S. nuclear, 2451 U.S. diesel, 303 Soviet nuclear, and 285 Soviet diesel.

By the early 1970s there was increased interest in using all-source intelligence, properly sanitized, to cue SOSUS arrays. The arrays achieved their maximum range in alerted searchlight mode because in that mode they could accept a higher theoretical false-alarm rate. In 1973 DoD issued a classified Area Coordinating Paper on Undersea Surveillance that seems to have shaped subsequent policy. The paper noted that SOSUS was

vulnerable to countermeasures and inflexible in its inability to deal with future very quiet submarines and third-party basing (i.e., basing out of Soviet base areas covered by the forward-area extension). The solutions were the following: better signal processing (including interarray correlation for lower overall system noise), which the 1973 paper suggested could deal with problems arising over the next 10–15 yr; possible alternative array concepts; and mobility (flexibility) based on towed arrays and deployable moored buoys. The towed-array solution was presumably encouraged by the success of the interim array (SQR-14) in the Mediterranean. The deployable buoys were the abortive RDSS (rapidly deployable surveillance system). The future possibilities were the fixed distributed system (FDS), which has actually been used; suspended arrays (as opposed to seabed arrays on the continental shelf, for deeper-water deployment); and coherent signal processing. As of about 1976, the improved signal-processing system was scheduled for operational evaluation in the winter of 1977–78.

◆ APS

Hardware characteristics of the McDonnell Douglas APS interactive TLAM planning system are as follows: 20–234 MIPS, 256 Mbytes of storage, 7.2 Gbytes on the hard disk within the equipment rack; 3D graphics, up to 1 million polygons/sec. The system is implemented on a Silicon Graphics 240GX workstation. The ashore version (TMPC Upgrade) has far more mass storage and higher performance (hence the range of speeds listed above). It uses a Loral ruggedized workstation.

The first APS engineering-development model (EDM) is scheduled for delivery in 1992. It was originally to have been aboard the *Wisconsin* but will now be on board the *Mount Whitney*.

◆ DSS

The DTC II-hosted data server system is the basis of the OSS (operational support system) that runs in the major fleet headquarters. During 1991 it was being installed in the OPNAV command center and in the headquarters of CINCLANT, CINCPAC, CINCLANTFLT, CINCPACFLT, and CINCUSNAVEUR (London and Naples). DSS runs JOTS II, Map Server, and Tactical Display Manager software, the Oracle relational data base management, and a series of tactical decision aids including CASES (capabilities assessment, simulation, and evaluation system) and FRESH (force requirements expert systems).

CASES analyzes combinations of different warfare areas and controls simulations and warfare models running simultaneously on other dedicated computers. Its models are Ray Mode Acoustic Propagation, Sweep Width/Search Rate Acoustic Search, ASW Barrier, ASW Area Search, IUSS (Integrated Undersea Surveillance System), OPTAMAS (Optimization of the Performance of Theater ASW Mobile Acoustic Sensors), Acoustic Detection, Battle-Group Defense, and Carrier- and Land-Based Air Strike. It also includes 2 expert systems, OPERA (ASW water management) and ASSESS (to derive conclusions from CASES studies, including generation of summary reports). OPERA bases its recommendations on the expected detection and attack potential and expected survivability of the various available ASW platforms (air, surface, submarine). CASES was developed under DARPA sponsorship (under the Strategic Computing Program) and is now operational at CINCPACFLT at Pearl Harbor. It is currently running on a Macintosh and has to be revised for DTC II operation.

FRESH is used for resource allocation (logistics) and provides daily information on force alert and readiness, fuel consumption, and personnel. It originally (1986) used a VAX to carry its large data base. FRESH is currently running at CINCPACFLT and NOSC San Diego.

◆ EWCM

EW coordination module, developed by NRL, is intended to allow force commanders to evaluate alternative EW tactics on a

large scale quickly enough for them to be implemented. Decision aids include selection of optimum power and frequency of communications equipment (to minimize the probability of intercept) and optimum decoy location. The prototype first went to sea on board the *Eisenhower* in October 1989. EWCM is now to be merged with the NOSC ECM (electronic combat module).

EWCM is currently a stand-alone system, but it is being rewritten as an applications program for JOTS II.

◆ ISPS

An ISPS assists a force planner by giving an M (friendly) vs. N (enemy) simulation using Monte Carlo techniques. It can maximize strike effectiveness by changing the force mix (e.g., Tomahawk-airplane combinations). An ISPS should task mission planning systems such as TAMPs and the Tomahawk planner (TMPCU or APS). General Dynamics displayed its ISPS package at the March 1991 U.S. Navy League show (running on a DTC II); presumably, McDonnell Douglas (which developed TAMPs and APS) is also a potential supplier. ISPS is also a force allocator, choosing among mission profiles.

◆ JOTS II (USQ-112A)/VIDS

Despite its nonstandard hardware, JOTS II has been assigned the AN-designation above. USQ-112 is JOTS I (DTC I version), deliveries of which began in 1984. JOTS II was operationally evaluated on board the *Independence* and *Jouett* in June 1990; more than 200 systems were then hurriedly produced to support Desert Shield. They included JOTS installations on board the Australian and Canadian ships in the Persian Gulf. As of early 1991, Japan was considering a version for its P-3 Orions. Rapid production was possible because JOTS II is little more than a standard commercial workstation running software that can easily be reproduced.

VIDS (visually integrated display system), introduced in 1988, is used by the Joint Chiefs of Staff and the U.S. Customs Service. VIDS's software is written in the C language (using the Unix operating system) rather than in Rocky Mountain Basic, as in JOTS I. VIDS adds tactical decision aids to JOTS I, which was conceived as a stand-alone mission-planning tool. VIDS was designed to run on a more powerful workstation suitable for multitasking, with windows.

JOTS II is essentially VIDS adapted to networking, with more tactical interfaces, distributed graphics (X-windows), and the Wizard X software "tool kit," by means of which the user can quickly assemble application programs. The basic program consists of 300,000 lines of code, and it can run on any Unix-based computer with 32 Mbytes of memory, a 500-Mbyte hard disk, and a speed of 7 MIPS or more. The associated bus is Ethernet (generally a fiber-optic bus in U.S. applications). DTC II is the usual host computer, but JOTS II can also run on some Hewlett-Packard machines and on Silicon Graphics and Sun workstations.

The JOTS software comprises an operator-machine interface and 4 main programs: a tactical data base manager (Tdbm), a geographic data base (The Chart), communications, and the Wizard X "tool kit." Tdbm fuses available information to form a correlated track data base. Typically, 1 workstation in a ship's system is designated master track keeper, and its changes are automatically passed around the shipboard network. The ship designated FOTC (force over-the-horizon track coordinator) passes its track data base to other ships of its battle group via OTCIXS. With several battle groups (and several different countries' ships) operating together, it becomes necessary to designate a theater-wide FOTC (super-FOTC). This minor enhancement was added late in 1990 and tested early in 1991. The Chart automatically plots Tdbm data for display, and it also provides such navigational graphics as projected tracks. The communications software configures the system to accept various external inputs, such as OTCIXS messages (primarily OTH-Gold format). The "tool kit" defines such features as buttons, scrolling windows, and pop-up menus, by means of which applications can easily be built.

Version 1.1 (February 1991) is to include the following tactical decision aids:

- ASW: barrier search, area search, ray trace, propagation loss
- ASUW: 2-track analysis, maneuvering board, closest point of approach (CPA), range/bearing table
- ASUW/ASW: moving-target statistical tracker (MTST) analysis, transit search
- AAW: CAP engagement
- EW: satellite vulnerability prediction, integrated radar environment prediction (IREPS)
- Weather: prediction using the GOES satellite

The Chart is to be revised to include terrain elevation and other features (to support amphibious operations) and also to support more projections (a total of 15).

Ultimately, enhanced versions of JOTS II are to be used by the Joint Chiefs of Staff as their main command/control tool, by the ASWOCs, and by the major fleet headquarters (OSS, operational support system).

The current software contractor is INRI (Inter-National Research Institute), which is trying to rewrite the system in ADA.

◆ Maritime Mission Support System

PRB Associates (which makes TEAMS) is developing this ASWOC equivalent for the Pakistani navy, to support that service's P-3C UPDATE 2.5 aircraft. It runs on a VAX computer and incorporates Link 11; it does not include a fast spectrum analyzer. The first such system is due for delivery to the U.S. Navy in August 1991 (for transfer to Pakistan under Foreign Military Sales).

◆ MDS

The Tomahawk Mission Display System is used for shipboard planning of Tomahawk and combined Tomahawk-TacAir attacks. An MDS can electronically sort the missions available (via DTD) to select a strike package. Analogous sorting by hand would be totally impracticable because each mission is so complex, and because so many missions are available to any force commander. The MDS can automatically retrieve and display TCI data (target data, route data, launch data, and TLAM route graphics); it can generate strike packages (multiple mission/target combinations and specific times on target); it can input TacAir routes manually; it can prepare a digital map with TLAM and TacAir routes overlaid; it can recall and display TCI target images; and it can display the AAW threat against which the missiles are likely to fly (which affects tactical aircraft routing). The MDS terminal automatically receives TCI updates (called Mission Folder Updates, MFUs) from the TMPC (Tomahawk Mission Planning Center) via its communications processor (the GFPC).

Typically, then, MDS inputs are the TCI updates received via OTCIXS or TADIXS, the TCI data base received in cartridge form from the TMPC, and TacAir routes. The MDS searches to display/print target, geographic area, launch area, and mission constraints. It produces displays and paper folders of TCI data and displays and paper charts of digitized map data with TLAM and TacAir routes overlaid, and it generates and receives on-line Opnotes.

TLAM command/control information for tailored strikes (such as those made repeatedly in the Gulf area) can be collected into a single Tomahawk strike package to support the preparation of an Operations Plan (OPPLAN).

The MDS was proposed as a concept demonstration program by the 12th Cruise Missile Steering Committee (6 October 1983) and approved by the CNO in 1984; it was described as a means of preparing automated mission folders. It became a rapid-prototyping fleet demonstration system. The first engineering-development models (EDMs) were installed on board several ships and at shore stations beginning in May 1987; they run on HP-9350 computers with Zenith 386 or HP displays. The XMDS/DMIF version was installed on board the *America* in May 1989; it is compatible with the TMPC Block Upgrade pro-

gram. It runs on the same hardware (but with a floppy disk drive for DOS file access), but the CPU is upgraded to HP-9370, and an HP high-resolution (1280 × 1024-pixel) color monitor is required. The system also contains a laser printer and a color copier.

The software, developed by Tiburon Systems, is an outgrowth of the MDF function of the shore-based MDDS (Mission Data Distribution System, see separate entry). The current version, X-MDS, adds X-Windows (multiple windows operating concurrently), as well as a security log-on, OPNOTE receive and transmit, Tomahawk strike planning, and compatibility with TMPCs to support the BGM-109D (bomblet) version of the missile. X-MDS was informally released in March 1989. It consists of 3 main software packages: XMDs (X-Windows applied to Tomahawk C2), a digital map interface (DMIF), and a Tomahawk Command Information data base-generation package (used by the Cruise Missile Support Agencies of the CINCs to produce MDS data base cartridges). A multisensor processor system (MSPS) is being developed to provide near-real-time threat correlation and display updates. Further developments will include decision aids for Tomahawk strike planning and on/off-line training aids.

◆ MDDS

The Tomahawk Mission Data Distribution System is the heart of the ashore Tomahawk Mission Planning System. MDDS prepares both the digital data that actually guide the missile and a data package (TCI, Tomahawk Command Information) that describes the mission and can be turned into a computer display or a paper mission folder. The display portion of the system, the Mission Display Function (MDF), ultimately became the MDS, described above.

Mission data are entered into a large (about 80-lb) transportable hard disk drive, the DTD (Data Transport Device), which must be moved physically to C2 nodes such as carriers and then off-loaded to Tomahawk shooters. The DTD is 1960s technology and is now to be downsized. A single DTD (ships carry several) will contain digital data for numerous missions. The mission planner on board the ship will use the MDS to select the appropriate missions from among those available.

The MDDS, then, produces mission DTDs, electronically updates mission data, prepares the corresponding TCIs, and is responsible for mission accountability (i.e., it provides a facility for reviewing just what missions have been designed). The TCIs are transmitted in data-cartridge form to the MDS for mission selection.

This process is broadly analogous to that originally used for Polaris targeting. It is necessary because the missiles' flight paths must be specified in enormous detail, far too much to have been generated on board ship until quite recently. Moreover, it is far too much to be transmitted electronically. Mission upgrades are typically transmitted directly to the shooters (the corresponding TCI upgrades go to the tactical commanders).

Nuclear Tomahawk missions require an additional degree of validation. Tiburon makes DCP, the Data Transport Device Certification Processor, which certifies that mission data satisfy nuclear safety requirements.

MDDS currently uses a Rolm 1666 and a Data General computer. The workstation is a DTC. The system is being upgraded to use a Silicon Graphics workstation compatible with that planned for the APS.

◆ MTST

The standard navy Maneuvering Target Statistical Tracker is a software package used for OTH tracking in the TWCS, CCS Mk 1 and 2, JOTS II (MTST variant), and ATW/Outlaw Hunter/OASIS. The basic algorithm, developed by Tiburon Systems, has been written in Fortran, Turbo-Pascal, and ADA for various applications. It can run on a standard 80386 desktop computer. MTST processes contact and line-of-bearing reports and statistically projects ahead target position and area of uncertainty for any requested time. This is the basis for Tomahawk targeting.

Since Tomahawk is relatively slow, it arrives long after the initial target position report (e.g., as much as half an hour after firing). Without any statistical estimation of target position, all that can be said is that the target is somewhere within a circle whose radius is defined by the target's maximum speed. A much better estimate can be made using a series of earlier target positions and some knowledge of what the target is likely to be doing. The missile is not updated in flight, so it cannot make use of later data. If it were merely fired at the reported target position, the missile would spend considerable time searching, quite possibly within range of target defenses. It may also acquire and attack ships other than the target of interest since they may come closer to the original target position. The simplest solution would be to track the target continuously using some dedicated sensor, such as a space-based radar. However, the central U.S. decision was to avoid exactly that solution, on the ground that it would be costly and inflexible. Instead, Tomahawk antiship targeting relies on data from a large number of dissimilar sensors, most of which were never intended for this specific purpose.

Hence MTST, which was developed by those who originally developed Outlaw Shark. See also ATW.

◆ Outlaw Hunter/OASIS

Outlaw Hunter was conceived as a means of binding the P-3 with its ISAR radar into the overall fleet OTH-T system. It applied accurate target-location data and an area of uncertainty to the target identified by the ISAR imaging radar. Aircraft position was obtained from GPS, and the data thus developed were correlated with the JOTS data base (received via OTCIXS) and then transmitted to other platforms (e.g., those using the Tomahawk Weapons Control System, TWCS) via the OTCIXS link (OTH-T Gold message format).

The new ISAR radar made the P-3 effective (for target identification) against Soviet warships equipped with long-range defensive missiles, particularly SAN-6. The problem was that their inertial navigation systems (2 LTN-72s) were not accurate enough to fix those targets within Tomahawk launch criteria (the missile cannot be allowed to spend much time searching for its target at low speed within the target's self-defense zone; position errors translate into search time). The solution was to use the new GPS navigational satellite system. In Outlaw Hunter, GPS data are assigned a figure of merit for purposes of comparison with inertial navigation fix data; the inertial navigation system takes over when the figure of merit falls below a fixed value. The radar and the navigator are combined with a communications system that can pass targeting information to a Tomahawk platform with the necessary speed and reliability (via OTCIXS).

The fallback to the inertial navigator is necessary because the GPS satellite constellation is still incomplete (ultimately, an airplane receiving 4 satellites will be able to fix its position within 75 ft). For example, as of early 1991, gaps in full coverage in the Eastern Pacific amount to 12–16 hr/day, and in the Western Pacific they amount to 8 hr/day.

The on-board data processor is the Tiburon ATW (see separate entry, below). As used in Outlaw Hunter, the ATW can display tracks, labels, and areas of uncertainty. The workstation can also play back or fast forward the tracks it carries, so the operator can analyze target motion and detect trends to predict future actions. The operator can list displayed tracks, read incoming Opnotes, create outgoing Opnotes, control the list of addressees, view the incoming-message log, and select output filters. The operator can designate an area from which all of the updated positions for the contacts, which are being automatically tracked by the aircraft's ISAR radar, can be transmitted either manually or automatically at set intervals. This feature is valuable because it provides a distant commander with a full picture of all shipping in an area, besides the target of interest. Opnotes can indicate the confidence of the ISAR operator in target classification, and they can also send environmental data

such as wind speed, direction, and air temperature, all of which are important in Tomahawk launch planning.

The system was first installed on board a VP-9 P-3C in August 1989, and about a year later this airplane was turned over to VP-19 at Misawa. In tests in 1989-90, tracks or Opnotes transmitted via OTCIXS to ships or to shore sites typically took about 3 min from transmission to verification of receipt. To reach a submarine, data must be routed through a Shore Targeting Terminal (STT), which imposes a 5-8-min delay. In the 1989 exercises, Outlaw Hawk successfully cued the submarines *Salt Lake City* and *Omaha*. The system was also used to provide targeting and prestrike surface pictures to a carrier, both to the combined strike warfare commander (Alfa Sierra) and to the aircraft themselves (via voice SURPICS [secure voice]). Outlaw Hunter has also transmitted targeting data over Link 11 and over plain-voice channels, sometimes simultaneously with the OTCIXS and SURPICS channels.

On board the Orion, a single equipment rack, just aft of the sonobuoy storage rack, accommodates a communications/radar processor (CARP), a generic front-end communications processor (GFCP), a satellite communications controller (ON-143(V)6) with an encrypting unit (KG-84), and the modem and other equipment linking the communications processor to a small satellite antenna (DMC-34) atop the airplane amidships. A second antenna serves GPS. The ATW itself is just forward of the aft observer's station. Besides its high-resolution display, it has a laptop computer to monitor overall hardware performance and to display raw teletype information.

The Outlaw Hunter P-3C proved very successful in Desert Shield; presumably, it supported maritime interdiction (the embargo) by detecting, identifying, and tracking the very numerous merchant ships in the area around Iraq.

OASIS (OTH-T Airborne Sensor Information System) is the successor to the 1989 Outlaw Hunter prototype system. OASIS I was assembled quickly to equip an Atlantic Fleet P-3 for Desert Shield. It is Outlaw Hunter with more reliable components and upgraded tactical software. In this version, the OTCIXS channel is the satellite communications system designed for UPDATE IV. The tactical data processor uses a VME system bus to connect the CARP (which receives both GPS and ISAR radar data) with the ATW and also with a scan converter. The scan converter provides ATW video output to a channel selector, which the TACCO can use to display ATW outputs or APS-137 radar video or data from the aircraft's mission computer (CP-901); thus, the main system display has moved to the TACCO station, where it belongs. The TACCO controls the system via trackball and keyboard.

OASIS II is a repackaged (230 vice 550 kg, smaller volume) Outlaw Hunter occupying 2 racks at the ordnanceman's station of the P-3C. The correlator uses 80486 chips. At present, OASIS II can use its ELINT correlator to cue the ISAR radar operator, and it can project ahead radar tracks to regain false contacts. The combination of active radar and correlated passive (ELINT) data makes an OASIS airplane a source of independent, fully correlated OTH-T data; alternatively, it can feed a larger network of FOTCs. Current plans call for installations on board P-3Cs (possibly as part of UPDATE IV) and probably 3 S-3s (during 1991). OASIS is later to be extended to use ALR-66 inputs and satellite data.

See also the separate entry for the ATW workstation used in Outlaw Hunter.

◆ POST

POST (Prototype Ocean Surveillance Terminal) accepts and automatically processes, correlates, and displays data from a wide variety of sensors. Correlation is by a statistical/heuristic algorithm using such factors as radar emissions (for identification), feasibility of different possible motions between detections, and likelihood of movements. For example, 2 detections of a ship's air-search radar 30 nm and 15 min apart would have to be taken as separate ships, whereas the system might determine that 2 such detections 30 nm and 70 min apart came from

the same ship. The result of correlation is a picture of the likely positions of ships, a data base that can be used, e.g., for OTH-T.

POST is thus the expression of the U.S. decision to try to fuse data from the great variety of existing sensors, many of them national, rather than develop a single dedicated ship-detection and -tracking system (which would not need much in the way of data-fusion capability).

As its name implies, POST was conceived as a hardware unit but ended up as software running on the standard DTC II computer.

◆ TAMPS

McDonnell Douglas's Tactical Aircraft Mission Planning System is the standard aircraft planning system for the U.S. Navy and Marine Corps, developed in 1985. The first delivery was for the *Carl Vinson* in August 1986. As of March 1991, McDonnell Douglas offered a modified version to foreign customers. At this time TAMPS is installed on board 11 carriers and at numerous land sites. A further development (a rapid advanced prototype system) was produced in 1989-90.

◆ TEAMS (TSQ-142)

The Tactical EA-6B Mission Support system provides an EA-6B squadron either on board a carrier or ashore with full mission data (as assembled from the vast amount of intelligence available before flight), and assimilates data collected in flight. TEAMS is unusual in that it actually reprograms 3 sets of EA-6B mission computers (navigation, ALQ-99, and HARM) on board the airplane by means of a data cartridge inserted at flight time. TEAMS also produces flight plans, kneeboard charts, and 30-min strip maps. One cartridge can carry several missions' worth of data, so a mission can be changed even after the EA-6B has taken off. In flight, the airplane's ECM receivers feed their data into the cartridge, whose contents are read back into the TEAMS data base after the EA-6B lands. To serve the new ADVCAP version of the EA-6B, TEAMS will program a total of 9 aircraft computers (including ALR-67ASR, ALQ-149, and the ALE-47 chaff launcher). TEAMS's data bases include the Defense Mapping Agency's computerized maps (including terrain) and several intelligence data bases; the system receives tactical intelligence (TENCAP) data directly via OTCIXS nets. TEAMS also includes performance predictions for the airplane, for its ALQ-99 system and for the HARM missile, so it can predict the effect of a particular mission profile or tactic in a specific situation. On a carrier, it runs on paired VAX 3800 workstations (each with 32 Mbytes of RAM and about 2 Gbytes of storage). There is also a transportable version for the Marine Corps, and a portable version is currently under contract. The system is being developed into an open architecture that will be suitable to a variety of workstations, such as Sun (DTC II series) or the new IBM RISC stations.

TEAMS was developed by PRB Associates. It entered service in 1984 and at the time was probably the first such mission planner to program the airplane for a particular mission (by reprogramming its computer). The current version carries a data base covering 6-7 million square miles, with very large lists of friendly and enemy orders of battle. It keeps track of these orders of battle and also of theater assets (such as weapons and expendables). The post-flight readouts are used both to update the data bases and to reconstruct missions to extract lessons learned and tactically significant intelligence and EW data; the system helps produce post-action messages and reports.

A TEAMS derivative is now being developed to support EW reprogramming for radar-warning receivers and jammers on board other carrier-battle-group aircraft.

◆ TIPS

TIPS (tactical information processing system) is the current tactical/administrative system on board LHAs and LHDs. It uses a single UYK-7 (LHA) or UYK-44 (LHD).

◆ TMPS/TMPCU

McDonnell Douglas's Tomahawk Mission Planning System was developed in 1978 and is now deployed in 9 locations worldwide. This is a shore system to develop attack flight plans for land-attack Tomahawks. Mission tapes must be physically brought aboard attack platforms (the amount of data is too great for radio transmission). The new APS is to provide this capability aboard ships.

TMPCU, the Tomahawk Mission Planning Center Upgrade (both ashore and afloat), was first delivered in 1988.

Tomahawk missions represented by TMPS tapes are displayed aboard carriers using a Tiburon Systems Mission Display System (MDS). MDS will also be used to display the output of the APS. It currently runs on a DTC I computer and is being rewritten for DTC II.

◆ TMS/ATMS

Track Management System was developed by Lockheed Missiles & Space Company under a DARPA contract as part of the company's Advanced Navy Battle Management (ANBM) program. TMS, which was tested on board the *Vinson* and *Belknap*, was the first U.S. Navy Unix-based, Sun workstation, command/control system and the first to use windowing. It is probably the *Vinson* experimental system (SDMS) described under JOTS in the main text. TMS provided tracking and decision-making algorithms to complement display and communications-management functions from JOTS. TMS, which is written in C and Fortran, is now being rewritten as JOTS II applications software.

TMS uses the position-fixing algorithm written for the Tomahawk Weapon Control System (TWCS) Block II, extended to add acoustic correlation data. Inputs are OTH-T Gold, Rainform, JINTACCS, Link 11, and Link 14 messages. TMS filters contacts by category, threat class, area of interest, and ELINT category of interest (i.e., identity category). It can develop target positions and tracks based on single or multiple hypotheses. The system incorporates 3 major data bases: contacts (50,000 per 100 Mbytes of disk storage), tracks (more than 10,000, each with attributes such as emitter characteristics, and a list of up to 100 contacts), and a technical library.

ATMS, the ASW Track Management System, is a Lockheed private-venture development of TMS. It and an associated oceanographic package (Nautilus) have been developed as part of Lockheed's bid for the Surveillance Direction System (SDS). Lockheed is associated with Raytheon (Submarine Signal Division), SAIC, and Planning System Inc. (PSI) in its SDS bid.

◆ TWCS

TWCS (Tomahawk Weapon Control System) is SWG-2 (ships with armored box launchers)/SWG-3 (ships with vertical launchers). It consists of a track-control group (TCG) and a launch-control group (LCG). The TCG receives target information from own-ship, battle group, and external systems via data links and maintains a surface-track data base over the launching ship's area of responsibility; the data base in turn is used to develop missile-engagement plans. The LCG maintains a missile inventory (monitoring numbers and types), selects and programs missiles, and monitors launching. SWG-2 was evaluated and then brought into service in 1984. The current upgrade replaces the original UYK-19 computer with the more capable UYK-64. It also incorporates the capability to program and control the RGM-109D (bomblet) version of the missile. Further upgrades allow more flexible targeting, incorporate tactical decision aids, and accept more external data, such as that derived from electronic intelligence. The SWGs are designed primarily to support antiship attack. The overland flight of land-attack Tomahawks is currently planned ashore (hence the importance of the APS) at a theater mission-planning center (TMPC); flight plans are provided to ships in the form of data-transfer devices (DTDs).

◆ USQ-64

USQ-64 is the special tactical intelligence link, using FLTSATCOM, that exchanges data among systems such as Outboard and Combat DF. A single net can carry up to 23 subscribers.

◆ USQ-83

At the end of December 1990 GTE was awarded a full-scale production contract for the new USQ-83 data terminal set, to be delivered in 1992. USQ-83 replaces not only the current USQ-74 Link 11 data terminal but also the current HF fleet broadcast terminal (UCC-1) and the advanced narrow-band digital voice terminal (ANDVT). Work on USQ-83 began in 1985, and the first 4 production units were delivered for tests in 1989.

◆ Link 14

A plan to replace all Link 14 terminals with receive-only Link 11 was canceled early in 1990. A stand-alone, 2-way Link 11 proved less expensive. The latter uses a Link Eleven Display System, part of which is USQ-69.

◆ Copernicus

Copernicus is the new U.S. fleet-level command and control architecture, using very powerful workstation terminals derived from the JOTS program. The object is to reorient naval communications so that the communications links revolve around the users rather than the other way around. Hence the name. In this system, the total available communications capacity is split by software into the required set of satellite links (GLOBIXS and TADIXS). The links are virtual, i.e., software-defined, rather than hardware-defined, and their boundaries (capacities) can shift to accord with tactical needs. The lesson drawn from JOTS is that by using commercial or commercial-type hardware, the system can be built up very rapidly, its developers concentrating on creating the required software.

Copernicus is currently described as the navy's C4I (command/control/communications/computer/intelligence) post-Cold War architecture, with special emphasis on the ability to shift focus among geographical areas. That is possible because it relies on space-based rather than fixed surface assets.

The responsible OPNAV agency is OP-094 (space and electronic warfare, or SEW). Without SEW, the battle space of a carrier battle group is about 500 nm in radius. With SEW added, the radius increases about tenfold. Here SEW includes both space-based surveillance and passive (ESM as part of EW) surveillance beyond the battle group horizon. Effective use of ESM data requires data fusion on a very large scale, ultimately on a global scale. The OP-094 view goes so far as to suggest that the composite warfare commander (CWC) of a battle group should add a composite SEW commander to the traditional quartet of AAWC, ASUWC (antisurface), STWC (strike), and ASWC.

Copernicus, then, is the latest attempt to solve the problem of effectively using nonorganic sensors. Such sensors, and OTH weapons, first appeared in the 1960s, together with the earliest satellite communications that would ultimately tie them all together. The nonorganic sensors (largely ESM/ELINT) matured in the 1970s, when UHF (i.e., high capacity) communications satellites appeared. In the 1980s the introduction of Tomahawk antiship missiles made it vital to find some means of doing OTH-T; the U.S. choice was to do so by data fusion rather than by introducing some new dedicated system. Multifrequency satellite communications and C4I should mark the 1990s.

The new architecture must merge organic and offboard sensor data, providing the same picture to all commanders, ashore and afloat. In the past, the issue has been whether to concentrate command in a flagship afloat or in a center ashore with better access to data (particularly from "national" sources such as satellites). The choice in Copernicus is "distributive fusion," in which information is freely passed through a network, and each node in the network contributes to the same overall tactical picture. This is much the same idea as a fully distributed combat system but on a much larger scale. Just as the distributed

combat system is practicable only because shipboard data buses now have sufficient capacity, distributive fusion is possible only because the satellite links now have enormous capacity. In the past, too, the communications system was easily overloaded because channels could not interchange capacity and, thus, there was very limited surge capacity in a crisis. Moreover, most messages were of the wrong type (narrative) and had to be produced on paper. In addition, in the past much ESM data has been so closely held that commanders have not realized just how valuable such assets could be.

The messages themselves are of little moment. What matters is the fused tactical picture built out of them. To produce that picture, the messages have to be recast into a computer-to-computer, essentially graphic, form.

Copernicus is to use a special intelligent terminal, FASTT (Fleet All-Source Tactical Terminal), to streamline the mass of special messages currently in use and also to sanitize them. For example, an OTH-T message (which would contain information limited to special U.S. users) could be searched to eliminate information limited to NATO users in the Mediterranean. It can also be reformatted to eliminate references to specially classified U.S. sensors, and specially sensitive information can automatically be removed. This sort of reformatting is necessary if messages are to be used directly to build the data bases (i.e., tactical pictures) in numerous locations.

Beyond the communication server (FASTT), there are 3 other main computer building blocks: a desktop series (equivalent to personal computers, not to the DTCs), a tactical workstation series (TAC III), and file servers to handle large data bases. One objective of the system is to develop a common (across warfare areas) method of handling and denoting tracks. One reason is that the warfare areas are not really altogether separate: for example, a submarine (ASW) can and often will fire antiship missiles (AAW).

The Copernicus project office was established on 1 October 1990, and the first industrial symposium held to announce system architecture was held on 28 January 1991. As of that time, the Copernicus hardware and software program, leading to a 6-yr procurement plan, was to have been completed during 1991.

◆ GLOBIXS and TADIXS

New high-capacity command links (GLOBIXS and TADIXS) have been developed since 1985 to work with FCC ashore and TFCC at sea. TADIXS will replace the current OTCIXS. The new system replaces a current series of formatted OTC messages, each of which requires its own dedicated communication net. Because each formatted net is concerned with only one type of sensor, this system does not encourage consolidation of sensor data. The specific combination represented by the OTCIXS nets reflects the requirements of war against the Soviets. The many separate nets also exhaust finite UHF communication capacity. The new philosophy, of which JOTS is a part, is to structure the nets functionally rather than by data source. All subscribers to the tactical nets have access to the tactical data, which they may need to be able to operate in large (over-the-horizon) battle spaces. The new official view is that it is literally easier for all tactical subscribers to have full access than to choose which data each subscriber really needs. Subscribers filter data themselves, e.g., geographically.

This type of exchange requires that data from numerous sources be concentrated ashore for transmission by functional channels; the ashore centers (the FCCs) communicate among themselves and receive data via the GLOBIXS net. The TADIXS net operates in both directions so that commanders afloat can fuse FCC-provided data with their own data and then send the results back for comparison. The afloat terminals of the system are the TFCCs and the JOTS terminals.

GLOBIXS data are transmitted over the Defense Data Network (DDN) and the Defense Satellite Communications System (DSCS). The GLOBIXS constitute a data network among the FCCs (with input from some other sources, such as the DoD

and naval intelligence systems). Some of the GLOBIXS nets will cross connect. FCCs ashore take GLOBIXS data and consolidate them into TADIXS broadcasts to the TFCCs afloat.

The TADIXS/GLOBIXS combination is intended to replace a current system, based on Naval Communications Area Master Stations (NavCAMs), with one controlled more directly by the FCCs and TFCCs. The current fleet broadcast mixes operational and administrative signals, which are difficult to disentangle and which fill a limited jam-resistant channel capacity (sixteen 75-baud channels). The choice in TADIXS is to split up the broadcast, relegating administrative signals to the NAVIXS channel. The different TADIXS channels compete with one another for channel space, which will ultimately be allocated among the EHF, SHF, UHF, and HF satellite capacity.

Current satellite capacity limits are:

Comsat	1.544 Mbits/sec
EHF	2.4 kbits/sec
SHF	19.2 kbits/sec
UHF	9.6 kbits/sec
HF	1.2 kbits/sec

As an example of communication-load requirements, each tactical report (HIT) of the current type consists of 10 lines (65 characters, each 8 bits), or 5.2 kbits. In a typical 18-hr period, a carrier battle group in the Mediterranean might receive 500 such reports (2.6 Mbits) coming from a series of organic and nonorganic sensors. These reports would include indications and warning, queuing, tracking, targeting, engagement, BDA, and retargeting. Current message capacity in the Mediterranean, in terms of retransmission from the major shore stations, for the battle group is 155.5 Mbits/18 hr, so the overall system has sufficient link capacity (i.e., satellites and radios) if that capacity is properly used, i.e., if it can be spread across channels. However, the capacity is currently spread among several channels.

Global Information Exchange Systems (GLOBIXS):

GLOBIXS A	SIGINT Management
GLOBIXS B	ASW Management
GLOBIXS C	SEW Management
GLOBIXS D	Command
GLOBIXS E	Imagery Management
GLOBIXS F	Data Base Management
GLOBIXS G	RDT&E Coordination (new secure telephone net)
GLOBIXS H	Navy-wide Administration

Tactical Data Exchange Systems (TADIXS):

TADIXS A	OTC Battle Management
TADIXS B	ELINT
TADIXS C	SEW Management
TADIXS D	ASW Management
TADIXS E	AAW (JTIDS)
TADIXS F	Tacintel (Tactical Intelligence)
TADIXS G	Cruise Missile Targeting
TADIXS H	High Command
TADIXS I	INTELCAST (Intelligence Broadcast)
TADIXS J	NAVIXS
TADIXS K	Common High-Band Data Link
TADIXS L	INTELNET (Intelligence Net)
TADIXS M	Combined Broadcast
TADIXS N	Single Integrated Satellite BCAST (Broadcast)

Here SEW is space and electronic warfare, a term that replaces radio-electronic battle management and expresses the key role of space assets in intelligence and battle management.

◆ Cardion MCDS

Modular Combat Display System is a new small-combatant CDS announced at the 1990 U.S. Navy League show. It had already been in production for some time for a friendly navy. MCDS is based on the video processors Cardion developed for SPA-25G and SPA-50G; as the main text suggests, the gap between such displays and a full-fledged CDS is narrow indeed. A

full MCDS would use a 1553B bus to carry sensor data, which would be picked off by a series of operator consoles and a horizontal command console. The latter is the only real new display unit; it is a 23-in monochrome (20-in-diameter viewable area). It is viewed by 3 operators, each of whom has a keyboard and trackball. The system can accept radar scan rates of up to 60 rpm and pulse widths of 0.06–600 microsec. Each console can handle up to 6 radar inputs plus 2 TV inputs (TV and IR).

The brochure concentrates on the details of the consoles. The operator console contains a microprocessor that feeds both a video processor and a graphics processor (3 or 4 memory planes, 8 or 16 colors/region, allowing for write-protect areas). The sensor video processor provides 3–5 memory planes (i.e., it can display 3–5 sensor pictures simultaneously), up to 16 radar gray shades, and up to 32 TV video levels. It can control the apparent decay of radar traces. The display for both is a high-resolution, raster-scan, 19-in color or 23-in monochrome monitor (1365 × 1024 pixels). Frame rate is 60/30 frames/sec (80/40 is also available). The radar picture can be offset, and the system carries 256 programmable symbols. There are 8 range settings (2.5–320 nm). The console processors are dual 68000-based units, and the console processor's memory is 32 kwords of 16-bit RAM plus 32 kwords of 16-bit EPROM.

The command display is 1024 × 1024 pixels; the vertical line frequency is 60 Hz (interlaced).

The system can also incorporate separate applications processors, e.g., a sonar signal processor. As described by Cardion, it does not include weapons control directly, although clearly that can be accomplished through the system bus (MCDS is described as a means of compiling and maintaining a full current tactical picture). For example, the typical screen layout shown in the brochure includes weapons' firing status ("ready to fire") and other engagement data alongside a synthetic-video PPI picture. In the project already underway, Cardion is a subcontractor to the system integrator, which provides the weapons-control console(s).

◆ Raytheon ICS

Raytheon announced a new Integrated Combat System at the March 1991 U.S. Navy League show. The company hopes to use the CDS design and integration expertise built up during the NAAWS effort to develop and sell core systems of its own. Its work includes the track management and TEWA software required for combat direction, and also a series of new consoles that can be adapted to an advanced bus to form a distributed and reconfigurable combat system. The question then will be which element, the core or the missile, is the limiting factor in overall system reaction time or defensive capability. At present the kinematics of the Sea Sparrow missile limit existing systems much more than their core architecture. The solution would be to use the tail-controlled version with a new motor. Once the missile is fixed, then it becomes more important to provide the new core.

ICS is a fully distributed combat system using a pair of buses (port and starboard) that communicate with sensors, weapons, and support systems via a series of system interface subsystems (SIUs). The command and display subsystem will have 4–10 consoles, 1–2 plotters, and 1–2 hard-copy terminals. Processing will be done by a series of computers tied to the same bus, with 2 mass storage units and 1–2 tape units. The baseline system processor is a MIPS RISC machine running a POSIX-compliant operating system and incorporating a VME-type backplane. It can be upgraded to the next-generation Futurebus+ backplane. Each multifunction display console carries 1 or 2 screens and a single keyboard; it is driven by a MIPS R2000 display processor. The displays are militarized versions of the Silicon Graphics (SGI) Personal IRIS workstations and, thus, are related to the CCS Mk 2 consoles that Raytheon has already developed for submarine use. The system bus is either Ethernet or the fiber-optic standard (FDDI) in its militarized form (Safenet II).

At this writing Raytheon was still competing with GE for the Taiwanese frigate project (now for the 8th rather than the 7th

unit). Raytheon's CMAR competes with GE's ADAR-N; a preliminary decision was expected in the summer of 1991. Even though only a single frigate is involved, the winner will have a good chance of being selected for the corvettes to follow.

◆ ATW

Tiburon Systems's Advanced Tactical Workstation incorporates a dedicated correlation "engine." It is used in several OTH-T systems, including Outlaw Hunter and its successor, OASIS. ATW uses the navy-standard Maneuvering Target Statistical Tracker (MTST), combined with ELINT and attribute correlation, to associate reports with tracks and also to associate dissimilar tracks. The ATW software runs on a standard AT-compatible personal computer (such as a CP-1933/UYK) with a high-resolution color (VGA) monitor driven by an 80386 chip (with an 80387 coprocessor), with 4–16 Mbytes of RAM, a Video 7 VRAM graphics card (with 512 kbytes of RAM), a hard disk with at least 40 Mbytes of storage, and a Microsoft mouse or trackball. The current software is written in Turbo Pascal, and a translation into ADA is under evaluation. It is also being modified to work with the X-Windows graphics package used in JOTS and JOTS-related systems.

The ATW executive system controls 5 program packages: Communications Processing (data reception from OTH Gold, TACELINT, Bullseye [HF/DF], ATARF, ISAR), Correlation Processing, Track-File Management, Tracker Processing, and Tactical-Display Processing. The correlation processor correlates received track numbers, unique attributes, ELINT data, hull-to-emitter data, and TIB files and associates tracks. The track-file manager updates, deletes, merges, disassociates, and reprocesses tracks, and conducts periodic track maintenance. The tracker processor updates track parameters, generates track solutions, and assesses whether the generated positions are in fact feasible (i.e., whether a ship of known capabilities can get from a past known position to a projected position in the time available). The display processor includes tactical decision aids.

Here ATARF is Automated Tracking and Reporting Format, a message format used with IUSS messages. TIB is the Tactical Information Broadcast, a U.S. Air Force intelligence broadcast associated with the RC-135 (Rivet Joint) program. OTH Gold is the message format, formerly JINTACCS, used by a battle group's FOTC; it is a machine-readable format that gives a ship's name, location, and time. This is the format read by JOTS.

The major advantage claimed for ATW is that its data base is flexible enough to handle a wide variety of data, from both on-board and external sensors. It can form multisource track files, support bearings-only tracking, and allow track merging and unmerging (when a track merge proves erroneous). It can also generate free-text TACNOTES to provide a distant commander with some feeling for the confidence in which track or location data are held. ATW supports both FOTC participant and non-participant modes of operation. ATW also logs incoming and outgoing messages.

ATW is both similar to and competitive with many aspects of JOTS. See also Outlaw Hunter/OASIS above.

The connection with Outlaw Hawk/Outlaw Shark is not coincidental: Jere Patterson, the founder and president of Tiburon, managed both programs while at Lockheed Missiles and Space Company (Tiburon, Spanish for Shark, recalls the earlier association).

◆ DGU

DRS's Display Generator Unit is for the IPADS upgrade proposed for Naval Reserve P-3As and -3Bs. DGU feeds a high-resolution (1664 × 1024-pixel), monochrome, raster-scan display and can handle graphics processing as well as tactical and acoustic displays. The DGU hardware also supports windows (960 can be formed to display waterfalls and multiple I/O pairs). The video output provides 6 planes of memory (including alphanumeric and cursor planes), 8 or 16 shades of gray, and a graphics overlay. Display formats are fully programmable.

DGU uses 68000-series processors, with dual parallel, bi-directional SCSI buses and 2 RS-343 outputs. It has high-speed memory and acoustic-data storage for 16 channels of LOFAR, 16 of ALI (automatic line integration), 16 of BVF, 2 of active, 4 of Beta band, and 2 of BT (bathymograph). Display formats are ALI, LOFAR, BVF, DICASS, Beta Band, and BT.

◆ DTC II

The total DTC II contract is for 3000 computers (total cost \$115 million), of which more than 1800 had been delivered by the beginning of 1991. There are currently several alternatives based on different Sun workstations: Sun 4/110 (7.5 MIPS), Sun 4/300 (16 MIPS), and Sun 4/470 (22 MIPS—may be used for the NIPS program; it is a powerful file server, with up to 6 Gbytes of storage). These machines can also accept special graphics and applications processors on internal boards, e.g., the CSPI Supercard 2 array processor (a 6U VME board using the 40-MHz i860 RISC microprocessor, with total throughput of 80 MFLOPS) used in the SURTASS and LFA programs.

At least partly because of cost, DTC II (\$80,000) superseded the Raytheon CWS (\$250,000). However, there were also claims that CWS was not ready in time for the initial deployment of FDDS on board the *Saratoga* in 1989.

◆ DTC III (TAC III)

DTC III has been renamed TAC (Tactical Advanced Computer) III. As of March 1991, the TAC III RFP had not yet been issued.

◆ FASTT

The Fleet All-Source Tactical Terminal is a basic element of the new Copernicus architecture (see above). TRW displayed its version, which it called FAST (Fleet All-Source Terminal), at the March 1991 U.S. Navy League show, but it gave few details. The only statistic given was that FAST could perform high-speed character matching at up to 9.5 million characters/sec.

◆ GFCP

Tiburon's VME-based, generic front-end, communications processor is currently deployed on board ships and at shore stations to support Tomahawk targeting. It is an interface between tactical data processors or a Tomahawk mission display system (MDS) and the ON-143(V)6 satellite interface used for the OTCIXS net during Tomahawk targeting; for example, GFCP is part of Outlaw Hunter/OASIS. It formats and reformats messages, determines and controls data routing to appropriate systems, allows tactical data processors and communications systems with different interface protocols to exchange data, and provides message buffering. Applicable tactical data processors are the USQ-81(V) OTH-T system (formerly Outlaw Shark/Outlaw Hawk), JOTS, the Fleet Data Distribution System (FDDS), the Tomahawk command/control network (CCN), the Tomahawk Mission Data Distribution System (MDDS 1.X and 2.X), the Tomahawk Mission Display System (MDS), TWCS, and OSIS baseline and upgrades (OBS/OBU). Planned applications are to TEPEE, VIDS (visually integrated display system), and TAMPSS.

◆ OJ-663/UYQ-21

This is the latest UYQ-21-series console. The prototype exists, and the console was already under contract as of late March 1991. It carries a touch pad, a keyboard, and a trackball. The console carries a 19-in color monitor (1280 × 1024 pixels). This console uses X-windows software with real-time tactical extensions (e.g., it can show real-time radar video and NTDS synthetic video simultaneously).

◆ UYQ-31

Raytheon's standard polar situation displays are used in the SLQ-32 and SQS-56 systems. UYQ-31 is a modular device that can fit through a standard submarine (25-in) hatchway when its keyboard shelf is removed. It is an intelligent programmable

console that can be used either with a host computer or on a stand-alone basis, and it can also be backfitted to existing devices. The 15-in raster-scan CRT (1024 × 1024 pixels) has a 50-Hz refresh rate and is fed via a programmable display processor. Operator controls are a keyboard and a stiff stick.

◆ ASQ-212

This is the designation of the UNISYS computer system now replacing ASQ-114 in the P-3C UPDATE III, incorporating a CP-901A computer in place of the earlier CP-901. At the March 1991 U.S. Navy League show, UNISYS distributed a brochure on its proposed airborne ASW open architecture, which will use the next-generation computer and will presumably be offered to the navy in the event that the Boeing UPDATE IV is abandoned.

◆ UYK-83A

C3 Inc.'s ruggedized 80386-based PC.

◆ UYK-85A

C3 Inc.'s ruggedized 80486-based PC.

◆ ASPRO-VME

In 1991 Loral announced a version of ASPRO suitable for mounting within a larger 6U VME-backplane computer. The upgradable family of parallel processors offers from 150 MFLOPS (with 512 processing elements) to 2.4 GFLOPS (8192 processing elements). The basic processor resides on 3 boards (1 array memory with 512 processing elements, 1 array control, and 1 control processor). The control processor is a MIPS R3000. Each custom VLSI processor chip contains 32 processing elements; each element contains a high-speed, word-parallel arithmetic unit and a bit-serial logic unit. The associated scalar processor is a MIPS R3000/R3010 RISC processor. Memory is 128 kbits/processing element (8 Mbytes/array memory board) expandable to 1 Mbit/element. Scalar memory is 2 Mbytes on the control processor board, expandable to 32 Mbytes. Array memory to processing element sustained transfer rate is 640 Mbytes/sec (512 processing elements) to 10.2 Gbytes/sec (8192 processing elements).

STRATEGIC WARFARE

USSR

◆ SS-N-23

The Soviet designation for SS-N-23 is RSM-24.

UNITED KINGDOM

The British WE 177, which is the only current British free-fall nuclear weapon, entered RAF service in 1966 and RN service in 1971.

UNITED STATES

The FY92/93 program (announced in February 1991) calls for the following purchases (FY92 unit cost is given):

	FY91	FY92	FY93	Unit cost
Trident D-5	52	28	31	\$39.3 million
Tomahawk	400	236	200	\$ 1.92 million

The FY91 *Ohio*-class submarine (the 18th) is to be the last. The first 10 *Ohio*-class submarines are not to be reequipped with Trident-II missiles. Of earlier strategic submarines still in service, 4 are to be retired during FY92 and 6 during FY93. Thus Poseidon C-4 should be out of service by the end of FY93.

◆ Tomahawk

As used in the Gulf War (January 1991), Tomahawk was reportedly extremely successful, 51 of the first 52 fired hitting their targets. Hits included several within Baghdad, including 1 that clipped a television tower in half. Reportedly, about 100

Tomahawks were fired as precursors to the manned air strike on the first night of the war.

Reportedly, the chief limitation in Tomahawk's operation is the cumbersome mission planning, including the difficulty of estimating the missile's time of arrival over a target. See the APS (Afloat Planning System) entry in the Surveillance and Control section.

The FY91 supplemental program includes an additional 400 Tomahawks, and early in 1991 the production of missiles ordered in FY89 was accelerated. About 300 Tomahawks were fired during the war with Iraq. It was reported that at the outbreak of war on 16 January the total inventory of land-attack conventional Tomahawks was about 900 BGM-109Cs and 100 BGM-109Ds (bomblet version). By mid-February missiles had been fired by both of the battleships in the area (*Missouri* and *Wisconsin*), by 11 other surface ships, and by at least 2 attack submarines.

Overall, about 85% of all Tomahawks reportedly hit and damaged their targets (95% launched successfully). Tomahawks were used against Baghdad, particularly when the weather was too bad to permit manned attacks with visually guided bombs. Often the Tomahawk attacks were timed so that the missiles would impact about one hour before a satellite passed over the target and assessed the damage. During the war, Tomahawks were fired from the Persian Gulf, the Red Sea, and the Mediterranean. The war included several submarine launches.

The next version will be Block III. Weapons are now (1991) in development and flight test, and Block III should become operational late in 1992. Its main features are

- (i) a GPS guidance capability to supplement or replace TERCOM. This is particularly important in attacks on coastal targets; otherwise, the missile has to come ashore to orient itself by terrain matching.
- (ii) an improved DSMAC (DSMAC 2A) for terminal guidance, better able to compensate for diurnal and seasonal changes in landscape appearance.
- (iii) a new 750-lb (rather than 1000-lb) unitary warhead using insensitive explosives and a programmable-delay fuze. It will leave extra weight for fuel (for about 30% greater range).

Later Tomahawks should incorporate a more efficient engine (F107-WR-402) with 10% more thrust (660 lb; 20% more under hot conditions) and about 3% lower specific fuel consumption, and a more powerful Mk 111 booster. The booster will permit submarine-launched weapons to carry the same fuel load as current surface ship-launched missiles, hence to achieve the same ranges. The new engine is more reliable (it doubles the engine recertification time to 6 yr), and with the extra fuel capacity it should increase TLAM-C's range to about 900 nm. The corresponding change in TLAM-D would be to replace the aft payload bay with fuel, adding about 100 nm of range.

The first successful Block III test occurred on 13 February 1991. Current plans call for 1795 Tomahawks to be remanufactured to Block III configuration: 401 in FY92, 301 in FY93, 267 in FY94, 349 in FY95, 421 in FY96, and 56 in FY97. Reported plans for the production of new Tomahawk Block III missiles, as of February 1991, follow: FY92, 326; FY93, 290; FY94, 282; FY95, 282. An FY91 contract for 400 Tomahawks, including 287 BGM-109Ds (\$422 million, \$1.06 million per missile) was awarded late in January 1991.

Tomahawk flies to a preset point in space. Autonomous terminal guidance (several approaches to which were shown at the 1990 Navy League show) would allow it to decide to attack a specific target in the target area, e.g., an airplane whose position was not definitely known when the missile was launched. Possible approaches include mm-wave radar, laser radar, SAR, and IIR.

As of January 1991, LRCSW has been reduced to R&D status (concentrating on guidance) because of budget cuts. General Dynamics and McDonnell Douglas have proposed a Tomahawk Block IV to replace it. Block IV is to have better mission-plan-

ning capability using different sensors, including the fully autonomous attack sensors that had been proposed for LRCSW (now dead). There seems little chance of adopting the LRCSW unducted-fan power plant because the current range of Tomahawk seems sufficient for nearly all contingencies.

STRIKE/SURFACE WARFARE

Although they received the greatest publicity, guided bombs and stand-off missiles accounted for only a small percentage of the total bomb tonnage used during the Gulf War against Iraq. Total figures on bomb numbers have not been released. The U.S. total bomb *tonnage* was 88,500, of which 6520 tons (7.4%) were precision weapons. General Merrill McPeak, the U.S. Air Force Chief of Staff, immediately after the war claimed a 90% success rate for the air force's laser-guided bombs, but that figure was probably somewhat exaggerated. The weapons in question were mainly laser-guided (Paveways: GBU-24s and a few GBU-27s and -28s), but a few electro-optically guided bombs were also used (e.g., the GBU-15s against the oil terminal pumping the great oil slick into the Gulf). The U.S. Navy used a small number of Walleyes and a very few Skippers.

The Royal Air Force dropped a total of 6000 bombs, and about 10% of them were laser-guided 2000 pounders. This figure may not include the 100 JP-233 runway-attack munitions dropped by Tornados. The typical load-outs were three heavy laser-guided bombs by a Tornado (designated either by the Tornado, using a TIALD pod, or by an accompanying Buccaneer) and four or six 500-lb unguided bombs by a Jaguar (6 for targets in Iraq, where the air defenses had been thoroughly destroyed, 4 plus an ALQ-101(V)10 jamming pod and a Sidewinder [later, 2 Sidewinders overwing]) in sorties over Kuwait, where air defenses were not destroyed until late in the war.

French aircraft were used mainly in airfield attack and for close air support in Kuwait. They fired AS 30L missiles but apparently did not drop laser-guided bombs. These aircraft also used the BAP 100 runway-busting munitions (Durandal is an export weapon only). Reportedly, they soon ran out of French weapons and had to be rewired to take U.S. cluster and iron bombs. Presumably, rewiring was necessary because France did not accept the NATO weapons standards.

It seems unlikely that other coalition air forces used guided air-to-ground weapons.

FRANCE

◆ AS 12

This lightweight air-to-surface missile is carried by Alouette III, AB 212/204, Gazelle, Lynx, and Wasp helicopters. One AS 12 is equivalent to 1 Mk 44/46 torpedo. Not all such aircraft are necessarily so equipped. A Lynx can accommodate 4 AS 12s, a lighter helicopter 2. Reported users of such aircraft (as of 1990) were Argentina (2 Lynxes, 8 Alouette-IIIs), Belgium (3 Alouette-IIIs), Brazil (9 Lynxes and 8 on order), Denmark (7 Lynxes), Egypt (12 Gazelles and 12 on order)*, France (38 Lynxes*, 13 Alouette-IIIs), Germany (14 Lynxes), Greece (4 Alouette-IIIs* and 16 AB 212s), India (18 Chetaks, the domestically built Alouette-IIIs), Indonesia (1 Alouette-III, 14 Wasps), Iran (7 AB 212s), Iraq (5 AB 212s on order), Italy (12 AB 204Bs and 27 AB 212s), Korea (10 or more Alouette-IIIs, 12 Lynxes), Libya (12 Alouette-IIIs), Malaysia (6 Wasps), Mexico (4 Alouette-IIIs), Netherlands (22 Lynxes), New Zealand (9 Wasps), Nigeria (3 Lynxes), Peru (6 AB 212s), Pakistan (4 Alouette-IIIs), Peru (6 AB 212s, 2 Alouette-IIIs), Portugal (5 Lynxes), Seychelles (2 Chetaks/Alouette-IIIs), Spain (11 AB 212s*, 10 Sea Kings*), Thailand (10 Bell 212s), Turkey (3 AB 204s and 9 AB 212s), United Kingdom (78 Lynxes), and Venezuela (6 AB 212s). Asterisks indicate aircraft definitely carrying AS 12 missiles. British, Brazilian, German, and Korean Lynxes carry Sea Skuas instead. Italian AB 212s carry Sea Killer (2 per helicopter). AS 12 can also be carried on board a Sea King (which usually carries a heavier missile, Marte or Exocet), 4 per helicopter.

◆ AS 15TT

During the war against Iraq, the Royal Saudi Navy reported firing AS 15TTs from its Dauphin helicopters against 5 Iraqi patrol boats.

◆ Excalibur (MP 22)

SAMP, which manufactures the standard French bombs, is developing an inertially aided version of the standard 250-kg bomb. It incorporates a slow-burning (15-sec), low-thrust rocket motor for positive flight control. Target coordinates are entered by the attacking airplane 10 msec before launch, and the estimated CEP is 30 m [100 ft] at a range of 10 km. Dimensions are 273 mm × 2.25 m (tail span is 546 mm).

GERMANY

Because of changing German priorities, Kormoran 2 will probably enter service in 1993 rather than in 1991. The German HARM program, begun in 1987, will be completed in 1992.

ISRAEL

◆ CR-2800

Reportedly, only 3 CR-2800s were made, 2 of which were installed on board Westwinds for maritime surveillance (the third was a ground-system prototype). As of early 1991, 1 of the 2 Westwinds had reportedly been destroyed.

◆ Owl ESM System

The known users of this system are Israel (4 or 5 on Aravas) and Thailand (3 on Aravas, 1 in a ground station). Likely users are Argentina (possibly on board the modernized S-2Es) and South Africa.

ITALY

◆ Otomat

A 1989 Matra proposal for an air-launched Otomat seems to be proceeding to development. The Italian navy's Harriers are the most likely initial platform.

NORWAY

◆ Penguin

In addition to the 64 missiles already under contract, the U.S. Navy plans to buy 193 more during FY90-93, with authorization for full production expected in 1991 (but note the lower figures, totaling 106, given in the FY92-93 program, below).

USSR

◆ Air-to-Surface Missiles

Here is further information on Soviet air-to-surface missiles:

AS-2 This is probably the missile the Soviets call Burya. The service designation is K-10; the design-bureau designation is RSL-1 (*Raketniye Sniard Lavochkina*, or Rocket Weapon developed by the Lavochkin design bureau).

AS-3 A strategic weapon developed by the MiG bureau, this is K-20. The MiG bureau absorbed many missile designers in 1950-51, and its missile-design group broke away as a separate bureau about 1956-57.

AS-6 Its Soviet designation is RSR-5, presumably indicating a different design bureau (R).

AS-10 The Soviet designation is Izd (*Izdeliye*, or Object) 69. This weapon is also designated Kh-25L. The antiradar version of the same missile, AS-12, is Kh-25MR. There is also another version, apparently lacking any NATO designator, that the Soviets designate Kh-25P. It is radio command guided.

AS-11 The dimensions of this missile are also given as 32 cm × 4.3 m (span is 1.2 m); weight is 420 kg (warhead is 130 kg). Range is 50 km. AS-11 entered service about 1978.

AS-12 Its dimensions are also given as 30 cm × 3.85 m (span is 90 cm); weight is 300 kg, and range is 35 km. AS-12 entered service about 1978. AS-12 is the antiradar version of AS-10.

AS-14 The Soviet designation is Izd 64/Kh-29L (L for laser; Kh is the English equivalent to the Cyrillic X). Dimensions are also given as 34 cm × 3.84 m (span is 1.28 m); weight is 625 kg, and the warhead is an adapted 250-kg GP bomb. AS-14 entered service about 1980. A striking feature of the missile is the small-diameter laser seeker on the nose of the larger-diameter missile body.

AS-17 This is reportedly the air-launched version of the new small naval missile, SS-N-25. This weapon was in March 1991 described unofficially as turbojet powered, like Harpoon; it may be based on the Harpoons compromised after the Iranian revolution of 1979. Reported characteristics are as follows: length, 4.5 m; weight, 700 kg (warhead, 250 kg); range, 100 km [55 nm].

Kh-66 This missile is a version of Kh-23 (AS-7). The only obvious difference between the two is that only AS-7 has a prominent fairing above its tail, between the 2 upper tail fins. A history of the MiG design by Piotr Butkowski (who had some contacts both in Poland and in the Soviet Union), recently published in the United States by Specialty Press, lists Kh-66 as guided by a radio beam and as shorter-range than AS-7 (2-6 rather than 9.3 miles), with a slightly heavier warhead (105 vice 100 kg) and much higher speed (Mach 2.0 vice Mach 1.0). Total weight was given as 287 kg [631 lb] rather than 350 kg [772 lb] and length as 3.631 m [11.6 ft] rather than 3.5 m [11.2 ft]. Photographs of both missiles in Butkowski's book show much the same fin configuration and size (both have small canard steering fins and large fixed tail fins, with rockets exhausting out to the side rather than straight back so as not to interfere with the reception of the guidance signal). The same photographs show what appears to be a prominent nose radome on AS-7 (i.e., a darkened area that looks like dielectric), a feature that cannot be consistent with the use of radio command guidance. The combination of steering canards and side-exhaust rockets is similar to that in the first Soviet air-to-air missile, AA-1 (RS-2U).

◆ Su-27

A new version of the Su-27 carrier-based fighter has appeared, with side-by-side seating, with what appears to be a laser designator, and with what seem to be stronger underwing hard points for weapons. The nose is reshaped, with chines on its sides (the plane thus may lack a conventional radar); an underbody pod may accommodate a FLIR. This version has landed on the Soviet carrier, and it may be the prototype of a future Soviet carrier strike bomber. However, there is also evidence that it is a carrier trainer, the conventional tandem layout not providing enough visibility from the rear cockpit.

UNITED KINGDOM

◆ ALARM

ALARM antiradar missiles intended for tactical trials were used tactically (and successfully) in the Gulf War instead (January 1991). In all, 100 were fired.

UNITED STATES

The FY92-93 program (as announced in February 1991) calls for (unit cost is for FY92)

	FY91	FY92	FY93	Unit Cost
Harpoon	160	—	—	N/A
HARM	1320	749	215	\$281 thousand
Hellfire	1198	—	1000	N/A
Penguin	40	42	—	\$1.14 million

Tacit Rainbow has been canceled. No further purchases of Maverick are expected. No unit cost was given for Harpoon

(since no more are being bought), but funding is provided in both FY91 and FY92, presumably largely for modifications and support equipment. The Penguin purchase follows 24 in FY90.

The new budget includes funds (\$7.5 million in FY92 and \$7.3 million in FY93) for a new air-launched saturation system.

One surprise of the Kuwait war was that unguided bombs made little impact on dug-in Iraqi armor, whereas the enemy tanks could quite easily be destroyed one by one using laser-guided 500-lb (Mk 82) bombs. This was such a surprise that stocks of the light laser-guided bomb kits ran short, whereas there was no shortage of kits for Mk 83 and Mk 84 bombs. There was also some unhappiness that Walleye, Mk 83, and Mk 84 could not penetrate bunkers and were not effective against bridges. I-2000 was quite effective in these roles. The approximate total of U.S. Navy and Marine Corps expenditures of short-range guided weapons was as follows: Walleye, 130; Skipper, 5; HARM, 900; Shrike, 25; Mk 84 LGB, 260; Mk 83, 210; Mk 82, 420; Maverick, 40; and laser-guided cluster bombs, at least 550 (this figure was accurate only until the ground campaign began, and it does not include the marines' expenditures). Several SLAMs were fired after the first success.

About 6000 Rockeyes and APAMs were dropped (so the guided bombs amounted to just under 10% of the total). Available figures suggest that for the navy alone, laser-guided bombs dropped prior to the ground campaign amounted to 22.6% of all Mk 84s, but to only about 2.5% of all Mk 83s and Mk 82s (i.e., of lighter weapons). Such figures would correspond to a prewar doctrine stressing the precise destruction of important fixed targets but calling for the area bombardment of troop concentrations.

◆ Hellfire

The Israeli navy is buying a version of Hellfire for its fast patrol boats (*Dvora* and successors). This version will use an electro-optical FCS with an associated laser designator. This choice follows a bad experience in which a *Dvora* was not fast enough to run down a boat filled with terrorists and thus could not bring her 20-mm gun into range. The Israelis were apparently impressed with the Swedish coast-defense version of Hellfire. The new FCS will be installed on larger Israeli craft as a backup to their radar FCS (for Barak and Phalanx). The Swedish navy, which uses Hellfire for coast defense, also carries it (on its tripod) on board the new Stridsbat 90 anti-invasion landing boat. Hellfires so carried can be dismounted for use ashore after the boat grounds.

◆ HARM

The low-cost seeker version was first fired on 20 December 1990; it will compete against Texas Instruments's seeker for Block IV missiles.

◆ Senior Pennant

The stealthy U.S. successor to MSOW may be a Northrop program conducted for the air force, Senior Pennant. It was scheduled to complete full-scale engineering development at the end of 1990, at a program cost of \$1 billion.

◆ Harpoon

SLAM (AGM-84E) was used in combat early in the Gulf War (January 1991) when a pair of missiles launched by an A-6E from the *Kennedy* (and guided by an A-7E) hit a hydroelectric power plant; the second missile flew through the hole made by the first. These were prototype missiles; the full-scale production order is not expected until late in FY91. SLAM is programmed before launch, using GPS to achieve a 16-m accuracy in mid-course flight. Like Tomahawk, it flies several legs to avoid enemy air defenses. The data link is used only for the last 60 sec before impact. Complex flight paths are difficult to design; reportedly, preflight planning requires $\frac{1}{2}$ –2 hr, then 30 min for typing into a prelaunch computer (to translate into mission data for the missile), 5 min to load those data into a prelaunch data memory loader, and 5 min to load data into the missile

itself. The prelaunch loader can hold up to 64 missions (in groups of 4, presumably corresponding to the capacity of an A-6E). Presumably, the Tomahawk APS will also be able to plan SLAM missions, and it should be able to generate mission data directly and much more quickly. Reportedly, production SLAM missiles will be redesigned for better performance and lower unit cost. The current version incorporates existing components (such as the Maverick seeker and the Walleye data link) to cut development time and cost, but they add length and weight and therefore cut the missile's performance (for example, the missile has to cruise in an inefficient nose-up attitude). Better component integration would increase the missile's fuel capacity. The production missile may also incorporate a more efficient engine or relocated (or larger) wings. A better concrete-penetrating warhead is also under consideration.

AGM/RGM-84D, the dogleg (waypoint) version, requires SWG-1A rather than SWG-1 for mission planning.

The launchers are (i) Mk 140, a lightweight version (17,472 lb loaded) on board the PHMs; and (ii) Mk 141, the shock-hardened version (27,126 lb loaded) on other ships. Missiles are fired at a fixed elevation of 35 deg.

◆ GBU-27

This is the laser-guided (Paveway III) version of the I-2000 concrete-penetrating bomb, used extensively against Iraq by the U.S. Air Force during the Gulf War. There is also an I-2000 version of GBU-15 designated GBU-15-I. An I-750 or I-800 warhead is in development for use with the Israeli Popeye (Have Nap) guided bomb, to replace the current 750-lb general-purpose bomb.

◆ GBU-28

Lockheed developed this heavy bunker-buster within 22 days (from request to attack). The sled-test and safe-escape drops were conducted on the 21st day; on the 22nd, the final day of the war, 2 GBU-28s penetrated a deep command bunker in Baghdad. These bunkers had been immune to attack by other U.S. weapons, and the effect of the attack was to demonstrate clearly that Saddam Hussein and his associates enjoyed no sanctuary whatever. Such a demonstration will probably be very important in any future operation analogous to Desert Storm. The very long, slender bomb (150.75 in for the bomb proper, excluding fins and homing head; 225.0 in overall; 4414 lb plus 258 lb for the guidance kit) had to be carried externally by an F-111 (the internal bay was too short). The bomb was made from a surplus 8-in/55 naval gun barrel filled with explosive.

◆ Antiradar Missiles

The U.S. Air Force used small numbers of Shrikes and Standard ARMs during the Gulf War, clearing out inventories of these obsolescent weapons before standardizing with HARM. The navy and marines also fired fewer than 25 Shrikes. Presumably, this weapon is no longer being carried in the active inventory.

UNGUIDED MUNITIONS

Further details of 2 major U.S. types extensively used in the war against Iraq follow.

◆ CEM (CBU-87/B)

The combined effects munition, which entered service in FY86, was intended to overcome the limitations inherent in earlier CBUs. CBU-52 was effective against people and light vehicles (or helicopters) but not armor; Rockeye could defeat armor but did not produce enough fragments to kill people or destroy large numbers of light structures, nor was it considered incendiary enough. The existing CBUs also required the delivering airplane to fly relatively high (i.e., into enemy fire) to ensure that the bomblets dispersed properly, and all but Rockeye produced doughnut-shaped patterns.

CBU-87 is a 1000-lb-class bomb consisting of a dispenser (SUU-65/B) with a time fuze (delays of 0.63–4.1 sec; the dis-

penser can also carry an optional proximity fuze for a height of burst of 300–3000 ft, carrying 202 BLU-97/B bomblets. Unlike the earlier SUU-30, which released its bomblets into the airstream for self-dispersal, SUU-65 uses its tail fins to spin itself up (to 1 of 6 preselected settings, 0–2500 rpm in 500-rpm steps) for a preselected pattern (70 × 70 to 450 × 150 ft). SUU-65 can be dropped from altitudes of 200–40,000 ft and at speeds of 200–700 kt; it can be lofted (at up to +30 deg) or dropped in a dive (at down to -60 deg). All of these figures are much less restrictive than those for SUU-30. BLU-97/B itself (2.5 × 6.65 in, 3.41 lb) has a scored-steel body (for fragmentation), a zirconium sponge ring (to start fires), and a downward-firing shaped charge (similar to that in a Rockeye Mk 114 bomblet, to kill armor). It is decelerated (to 125 ft/sec) and stabilized (to point down) by a miniature ballute.

CEM benefitted from a marked change in shaped-charge technology since the development of Rockeye: the ratio of charge diameter to thickness penetrated rose from 3:1 in the Rockeye generation to 5:1 to 7:1 in the next generation of air-dropped munitions. In each case, the requirement was to penetrate about 60 mm of tank roof armor, so the result is that much smaller bomblets could be used. Third-generation shaped charges enjoy ratios as high as 14:1. They are now used mainly in antitank rockets, where the requirement is to penetrate increasingly thick armor using a constant-diameter (i.e., constant-weight) round; however, they should ultimately also yield much smaller bomblets. The improvements come from a better understanding of shaped-charge dynamics, from better explosives, and from better machining of the metal cone of the shaped charge. There is also increased interest in lining materials other than copper (e.g., uranium) for their effects in metal-to-metal reactions. The effect of a better ratio is much smaller submunitions, hence more submunitions per unit volume, i.e., greater efficiency.

◆ I-2000 (BLU-109)

This hard-structure penetrator was used successfully, in a laser-guided version, against Iraqi aircraft shelters and also against Iraqi bridges over the Tigris River. I-2000 was designed specifically to attack hard concrete structures such as the Warsaw Pact hangarages in Eastern Europe; it was intended for use in electro-optical and laser-guided bomb systems. It was shaped specifically to mate with the GBU series but can also be dropped unguided. The existing Mk 84 GP bomb was not considered hard enough to penetrate (it had, after all, a lighter case so that it could produce a balance of fragmentation, blast, and penetration). Even attacking nose-on, a Mk 84 could not penetrate more than about 3.5 ft of concrete, and it could not penetrate at all at an angle greater than about 55 deg to the target's surface. Nor could the existing Mk 84 fuze survive the shock of penetration. The goal of I-2000 was to penetrate 6 ft of concrete at 0 deg and to survive (without ricochet) out to an angle of 30 deg to the target's surface (where it could penetrate about 2 ft). The thicker casing cost 340 lb in explosive content. The fuze problem was cured partly by eliminating the nose fuze in favor of a tail fuze. I-2000's characteristics (Mk 84 in parentheses) are as follows: dimensions, 14.5 × 95.0 (18.0 × 97.7) in; weight, 1925.5 (1902.1) lb; case thickness, 1.062 (0.562) in; and case-material yield strength, 170 (70) ksi. Fuze delays for I-2000 are 0, 10, 25, or 60 msec. Because the casing is so much heavier than that of Mk 84, I-2000 produces larger fragments, so an airplane dropping it unguided needs much greater altitude to escape them. Because its ballistics differ from those of Mk 84, in some cases it cannot be dropped accurately unless FCSs are modified. For example, as of early 1990, an F-16 could drop I-2000 accurately at low angles below 5000 ft or at high angles (dive/glide) above 5000 ft (giving a 37.7-ft estimated average miss distance) but not in a loft (which gave a 1200-ft average miss distance). Presumably, similar figures apply to naval attack aircraft.

I-2000 was developed by the U.S. Air Force Armament Laboratory and completed initial tests in FY83. It was then tested (in a program called Have Void) with GBU-10, -15, and -24 guidance packages.

◆ Advanced Bomb Family (ABF)

Three competitors for the ABF contract (500- and 1000-lb bombs) were displayed at the March 1991 U.S. Navy League show: the Lockheed concept displayed earlier, a Martin Marietta design, and a McDonnell Douglas design. Raytheon/Chamberlain is also a competitor, but its design was not shown. Among those shown, Lockheed's is unique in using folding fins. The 500-lb version is intended to maximize blast/fragmentation, while the 1000-lb version is a semi-hard-target penetrator. Dimensions of the Lockheed ABFs are 500 lb, 10.70 × 82 in; and 1000 lb, 10.70 × 102.35 in (diameter does not include the fixed fins). Dimensions of the Martin Marietta version are 500 lb, 11.75 × 74.38 in (fin span 16.0 in); 1000 lb, 11.75 × 100.88 in (fin span 16.0 in). Martin Marietta claims 15% better Pk than the Mk 80 series bombs, and a 20% improvement in dispersion through better aerodynamic design. All of these bombs include provision for inertial guidance.

◆ ALR-67 ASR

The ASR differs in architecture from other U.S. airborne RWRs in that its RF receiver is channelized (a technique more normally used in ELINT). Hughes claims that a channelized receiver can distinguish weak threat signals even in the presence of strong radar or jamming signals from a nearby wingman. The first 10 units should be produced in 1992, with operational evaluation in 1993, and low-rate production approval sometime in FY93.

◆ ALQ-167A(V)1

Compared with ALQ-167, this version adds a range gate stealer and aft radiation capability. Frequency range is 4–11 GHz in 2 bands (G: 4–8, I: 8–11). Output in G-band is 2 kW ERP, in I-band is 4 kW ERP. Dimensions are 10 in (dia) × 138 in. The pod contains 2 oscillators, an amplifier, and a transmitter. All of these components are types associated with DLQ-3 (presumably, the two systems are nearly identical). Weight varies with configuration (236–320 lb).

◆ AVR-3

AVR-3 is the U.S. designation of the Israeli Elisra SPS-65 helicopter radar/laser-warning receiver, consisting of SPS-20 integrated with the company's LWS-20 laser-warning receiver. The U.S. Army and the U.S. Navy are now jointly evaluating AVR-3. Frequency range (RWR) is 0.7–18 GHz for pulsed radar and 6.5–18 GHz for CW radar. SPS-20 uses a superheterodyne receiver. Information is presented on a 3-in alphanumeric display, which shows emitter type, relative bearing, and relative (assumed) lethality for up to 16 threats. There is also an audio alarm for the pilot. The receiver can be integrated with a decoy dispenser. Information is automatically recorded for later analysis.

◆ DLQ-3

This active airborne ECM system ("Hooter") is used primarily for training. It consists of broad-band multimode equipment remotely programmed to simulate threat radars and threat power levels, both radars and jammers. DLQ-3A introduced remote tuning of spot noise, a dual-mode dwell/walk function, and carrier blanking in the dwell mode. The current operational version is DLQ-3B. This set covers 4–12 GHz.

◆ TALD/ITALD

In a brochure distributed at the Navy League show in March 1991, Brunswick claimed that, launched at 10,000 ft, ITALD would achieve a range of about 150 nm, most of that at 20,000 ft and at Mach 0.8. Alternatively, it could fly in at very low level at Mach 0.73 and then pop up to 10,000 ft about 100 nm from its launch point. These figures compare with a range of 68 nm when released at 40,000 ft at 250 kt, or 14 nm when released at 2,000 ft at 250 kt. This brochure also stated that the chaff version of TALD carries 80 lb of chaff, which it releases in 40 increments. The total weight is 400 lb.

ANTIAIRCRAFT WARFARE

CHINA

◆ ERC-1

This Chinese decoy-launching system was announced in 1988 by the China Shipbuilding Trading Co. ERC-1 consists of 15 tubes and a fire-control unit and fires IR or chaff decoys singly or in salvos. Decoy modes are attraction (persists in the air for 2 min), distraction (6 min), and dump (4 min).

FRANCE

EXPENDABLES

As of early 1990, no MAGAIE decoy systems had been sold. This system is presumably dead. A French article published in 1990 claimed that 18 navies had bought DAGAIE (the published figure 2 years earlier was 15).

◆ DAGAIE

To date, known sales have been to Argentina (11 ship sets, plus 2 being installed, for the MEKO ships and A69s, sold in 1980), Bahrain (6, plus 2 being installed, for the FPB 62- and TNC 45-class boats, sold in 1979 and 1984), Colombia (4 for the FS 1500-class frigates, sold in 1980), France (31, plus 14 being installed, the most recent orders being for the *Floreal* class), Indonesia (2, plus 2 being installed for the Lurssen PB 57 boats, sold in 1982), Italy (for 12 ships, delivered in 1987; presumably, for operations in the Persian Gulf), Kuwait (8 installed on the FPB 57- and TNC 45-class boats, sold in 1980), Malaysia (4 sold in 1981 for FS 1500-class frigates), Peru (ordered for the 2 ex-Dutch cruisers, but never paid for and therefore not delivered), Morocco (2 sold for the *Descubierta*-class frigate in 1979), Qatar (3 double sets for the Combattante-III-class boats, sold in 1981-83), Saudi Arabia (8 sold in 1980 for the *Al Madinah*-class frigates), Thailand (2 sold for the PFMM Mk 16-class corvettes in 1983), Tunisia (3 sold for the Combattante-III-class boats in 1981), and the UAE (10 for the Type 62-, FPB 38-, and TNC 45-class boats). The other 3 users are unknown; Italy was the 16th, and the first to order DAGAIE Mk 2. China may have bought DAGAIE as part of its large-scale purchase of French equipment, much of which appeared on board the 2 Jianghu-IV-class frigates. It seems likely that the last 2 purchases were emergency procurements for the Gulf operations; the likely candidates include Belgium and the Netherlands, for mincraft or mine-support units. The other *Descubierta*-class corvettes (for Egypt and Spain) use the U.S. Hycor/Mk 137 system.

◆ SAGAIE

Purchasers include Italy (the *Animoso* class), France (8 systems for the *Clemenceau*-class carriers and air-defense frigates; on order for the carrier *Charles de Gaulle*), and Saudi Arabia (for the 3 new FL 3000-class frigates). The Italian sales may be DAGAIE Mk 2, which fires both DAGAIE and SAGAIE rounds.

◆ French Naval Radars

Arabel is to be carried on board the new French-built Saudi frigates (Sawari 2 program). The corresponding *Lafayette*-class ships of the French navy will have simpler Sea Tiger Mk 2 radars. The *Lafayettes* will have no sonar at all because they are intended for the Persian Gulf and the Indian Ocean. The Sawari 2s will have sonars, like the Sawaris.

Mars is being offered with the MR-05 antenna under the designation Mars 05; in the *Floreal*s it will still have a reconditioned DRBV 22 antenna. In this form it should be able to detect aircraft at 60 nm, and the optional automatic tracker can accommodate up to 100 tracks.

Reportedly, there is also to be a Jupiter 08 (Jupiter electronics and the LW-08 antenna).

MRR is in fact a 2½D type, as suggested in the main text (search with synthesized fan beam, tracking with a pencil beam). It replaces the earlier Triton in the Thomson-CSF radar series, and a corresponding Vega successor is being developed.

MRR and MW-08 compete within the Thomson-Signaal group, and one will probably be dropped. MRR is the likely victim since MW 08 has already been sold to Greece and Portugal for MEKO 200 frigates.

DRBJ 11 scans electronically in both elevation and bearing to detect and confirm a target on a single scan, then begins tracking on the second scan. That is, once a target has been detected, the beam skips back to redetect it before the array has fully turned away. In all, 4 sets have been manufactured, for 2 AAW destroyers and for the nuclear carrier. Thomson-CSF has suggested that the same radar, fixed in bearing, could be used to support an anti-ballistic-missile system ashore.

SCORE replaces TRS 3410 as a coastal radar. SCORE has a very similar antenna. The first sale, concluded in March 1991, was to Cyprus for control of Exocet missiles. SCORE operates in X-band and can have either a 4.8-m foldable or a 2-m one-piece antenna. It can be fixed or mobile. With the larger antenna, it can detect a 10-m² fast patrol boat at 124 km, and a 2-m² fighter at 72 km. The corresponding figures for the 2-m antenna are 83 and 48 km. SCORE is a pulse-compression radar (very short effective pulse to overcome sea clutter) with circular polarization (to overcome rain), high transmission power, and pulse-to-pulse frequency agility. The associated processor is a 32-bit machine programmed in ADA.

CTM (*conduit de tir multisensor*) is the Crotale NG fire-control system, but it has wider application. The *Lafayettes* carry 2 for GFCS and MFCS. This system replaces Castor III and perhaps should be called Castor IIJC (C for compact or Crotale). Castor III itself has died with the Satan CIWS. Castor IIC is the latest and last improvement of Vega. It is particularly effective for GFCS because it incorporates an internal gyro for high accuracy. The associated Ku-band, Doppler, monopulse radar has a TWT transmitter for frequency agility and pulse compression (processing includes FFT Doppler filtering). It automatically acquires a fighter at 30 km and an antiship missile at 18 km. The other sensors on the mount are an IR camera and a TV camera.

GERMANY

EXPENDABLES

Hot Dog/Silver Dog are simple adaptations of standard armored-fighting-vehicle devices. The other land-combat rounds are smoke, thermal smoke, and fragmentation grenades.

INDIA

Besides RAWL and RAWS, Bharat Electronics currently markets a second S-band naval radar, RAWS-3, and a pair of surface-search or navigational radars, Rani and Rashmi. RAWS-3 is a pulse-compression radar with variable pulse width, described as similar to RAWS. Rani/Rashmi are similar to the Signaal ZW-06; each uses a 24-in raster display. Rani uses a 6-ft slotted array; Rashmi uses a parabolic antenna. Both operate at X-band (peak power, 40 kW; range discrimination, 20 m; maximum range, 20 nm on a small vessel and 12 nm on a helicopter).

There are also RAWL-2, a copy of Signaal's LW-08, and Indra (Thomson-CSF's Tiger). Indra exists in naval (Indra 1) and land (Indra 2) versions. Bharat also manufactures the Signaal Flycatcher land FCS radar and a Contraves Seaguard tracker module (probably TMX/KA) under license, the latter as Shikari.

Bharat Electronics was largely established by Signaal, which is why it manufactures Signaal products under license.

The new *Delhi* (Type 15) destroyer is to be armed with the new Trishul missile, on a twin launcher, plus Soviet surface-to-surface missiles (Styx variants), a single Soviet 76-mm gun, and 4 twin 30-mm close-in defense guns (2 mounts on each side). The main air-search radar will probably be RAWL-2, with target acquisition/missile detection by Indra. Contraves is largely responsible for the FCS, which employs 3 Shikaris on a data bus (as in Seaguard). Trishul itself is, in effect, an Indian interpretation of the British Sea Wolf system (which BAe long tried to sell to them), using an airframe adapted from that of

the Soviet SA-6. Trishul is now flying, using a Flycatcher for control (the production version will be controlled by Shikari).

The ship would have initially had 1 tracker for each of the port and starboard 30-mm batteries and a third for the 76-mm gun and the Trishul missiles, all with NTDS links to a central computer system (the Indian-built IPN-10, which is now standard in that navy). Contraves convinced the designers to opt for a bus so that directors can shift between weapons. Trishul's range is about 20 km. The requirement was to acquire at 20 km and fire and intercept at 14 km. The Indians rejected a Contraves suggestion that C-band would be better than S-band against sea-skimmers (they specifically rejected AWS-6).

INTERNATIONAL

◆ ASRAAM

As of February 1991, the ASRAAM program was still alive, though badly weakened by the loss of the German partner. The British government was considering the proposed MICA-SRAAM as a lower-performance but less-expensive alternative. It rejected a U.S. proposal to use the new version of Sidewinder because such a choice would violate the MoU on the basis of which the Europeans were to buy the U.S.-developed Sparrow replacement (AMRAAM) while developing the Sidewinder replacement (ASRAAM); the United States has already dropped its end of the agreement by abandoning ASRAAM.

◆ PILOT

Under the Signaal-Thomson contract, this name can no longer be used. The Signaal version of the basic technology, Scout, uses a different antenna and is dramatically less expensive (reportedly, by a factor of 5 or 6 in price).

JAPAN

The following is additional information on Japanese naval radars. In the designations, some first letters are O for on board (i.e., ship), H for *Hiko-ki* (airplane), and R for portable (*Raku ni Moteru*, literally, easy-to-carry). The prefix N means system; it is currently used mainly in ECM. In the following notes, frequency bands are generally identified in the ECM system, not the conventional radar-design system.

OPS-9 is an I-band radar for medium minesweepers. Versions are OPS-9B and -9C. The original OPS-9 had 2 separate displays, 1 for true and 1 for relative position. Both are combined in OPS-9B and are transistorized. This radar has a very narrow beam for accurate position finding and for picking up buoys that are marking a swept channel.

OPS-11 operates in B-band. OPS-11B is a retrofit with an improved amplifier. OPS-11C incorporates MTI. These radars have much greater range than the 3D sets with which they are used. The array on top is an IFF.

OPS-12 is a naval version of a land-mobile 3D radar, operating in E/F (S)-band.

OPS-14 operates in D-band. Versions are -14B and -14C. OPS-14B has MTI. OPS-14C has its magnetron replaced by a klystron for coherent (pulse-compressed) operation.

OPS-16 is a G-band surface-search radar for major units. Versions are -16C and -16D (a solid-state version of -16C with different PRF).

OPS-17 and -18 are surface-search radars for frigates and large auxiliaries. OPS-17 uses medium PRF. The OPS-18 transmitter is frequency-agile. It is an ARPA radar capable of displaying 10 targets simultaneously. OPS-18-1 is similar but more sensitive.

OPS-22 is a J-band, high-sensitivity radar with high data-processing capability. Used on icebreakers, it is designed for great resolution.

OPS-24 is a D-band, 3D, long-pulse (pulse-compression) radar using active array elements. Heat is dissipated in a pair of heat exchangers flanking the array, and the IFF array is carried below the main array. Coverage is from the zenith to below the horizon. This is the first active array radar to enter service. It may

be related to the higher-frequency (C-band, in conventional nomenclature, i.e., 5 cm) FCS 3.

OPS-28 is a G-band set to detect low-fliers. It uses a TWT transmitter and a crossed-field amplifier (CFA). The antenna is stabilized (roll up to 15 deg, pitch up to 7 deg).

FCS 1 is an I/J-band set comparable in performance to the U.S. Mk 57 or Mk 63. FCS 1 can deal with subsonic aircraft at medium range. It sets fuzes and computes lead angles and ranges.

FCS 2 has limited ECCM features. The dome protecting FCS 2-12 covers separate search and track antennas, as in the Signaal WM20 series "egg." During search, all radar energy goes to the search antenna. Once a target has been detected, 40% of the total energy goes to the tracking antenna. A 1-m² target can be detected at a range of 30 km and at an altitude of 10-15 km. An 0.5-m² target can be detected at 10 km. FCS 2-12 is a combined gun and missile FCS. FCS 2-23 is an upgraded version with better CW injection for missile guidance. It is an MTI set using a TWT transmitter for frequency agility. FCS 2-22 is an upgraded FCS 2-21 (GFCS) capable of tracking up to 100 deg rather than 82 deg elevation.

FCS 3 has better ECCM features than FCS 2. FCS 3 is a rotating C-band (5-cm) TWS phased array. The prototype went to sea in 1990. The array spins very rapidly, and directors are slaved to it via its computer. The original concept was a 4-faced array, but the prototype had 2 faces.

◆ Sea Gnat

Orders for Sea Gnat rounds, as of December 1990, were as follows:

	Mk 214	Mk 216	DLA launchers
Denmark	1000	—	—
Netherlands	3500	—	—
Spain	1000	—	—
United Kingdom	3500	10,000	48
United States	33,000	7,000	—

ISRAEL

EXPENDABLES

Known users of the Rafael decoy system (distraction system) are Chile, Israel, South Africa, and Taiwan. Other users are probably Argentina, Singapore, Sri Lanka, and Thailand.

Known users of the Elbit ACDS chaff system are Chile (22 systems), Israel (122), South Africa (28; 8 more scrapped), and Taiwan (208). This system fills a large volume by firing all 45 chaff barrels simultaneously.

ITALY

EXPENDABLES

The Breda lightweight chaff system has been abandoned; none had been sold.

SCLAR users are Argentina (the MEKO 360H2 class, supplemented by DAGAIE), Denmark (6 bought for the *Niels Juel* class, not installed), Ecuador (the *Esmeralda*-class corvettes), Germany (the *Hamburg* and *Luneberg* classes; planned for the Type 123 frigates), Italy (major surface combatants, down to frigates; a total of 52 launchers), Nigeria (the *Aradu*), Peru (the *Lupo* class), Turkey (36 launchers on board 9 FRAM destroyers, 6 on board 3 *Koln*-class frigates), and Venezuela (the *Lupo* class).

ESM

The following is further information on Italian Elettronica ESM systems. The standard systems are all variants of Newton. Some systems listed separately in the text are actually variants of Newton Beta erroneously listed under the designation of minor subcomponents (see below). Newton is presumably the successor to FARAD, incorporating an integrated control unit (ELT 211) and a new noise jammer (ELT 318 vice ELT 361). Some ships have cylindrical antennas much taller than the usual ELT

814 and apparently stabilized. In what follows, they are denoted large ELT 814s.

Versions of Newton (designating letter indicates the number of separate jammers) are as follows:

Newton Alpha 100–500-ton ships. ELT 211 plus either ELT 318 noise jammer (ELT 814 antenna) or ELT 521 deception jammer (ELT 828 antenna). Elettronica sold no systems, so it sold all rights to Elta of Israel, which manufactured its version of the system as MN-53.

Newton Beta 250–1000-ton ships. ELT 211, ELT 318 (with 2 large ELT 814 antennas), and ELT 521 (with 2 ELT 828 antennas). ELT 715 is the data-transmission unit used in the Moroccan version of this system, on board the *Lt. Col. Errhamani* (which has 2 large ELT 814s but lacks ELT 828s). The Chinese license-built version uses an ELT 939 transmission box (on board Jianghu-IV and -V class corvettes for China and Thailand). These ships have 2 ELT 814 antennas.

Newton Gamma ELT 211, 1 ELT 318, and 2 ELT 521s (2 or 3 ELT 828 antennas).

Newton Lambda ELT 211, 1 ELT 318, and 3 ELT 521s, or 2 ELT 318s and 2 ELT 521s, in each case with 4 ELT 828 antennas. It may be significant that the Italian navy's version is SLQ-D (i.e., Delta).

Newton Epsilon 5-unit system for the *Andrea Doria* class and *Vittorio Veneto*, with ELT 211, 2 ELT 318s, and 3 ELT 521s. On board the *Caio Duilio*, it currently uses 4 large and 3 small ELT 814s (large ones on the forward starboard side of the bridge, on the port and starboard after sides of the bridge, and on the starboard side aft above the deckhouse atop the helicopter hangar; small ones on the after port and starboard sides of the bridge and on the after deckhouse, both near the corresponding large ELT 814s).

Nettuno is a development of Newton Delta with a second console added to the ELT 211 for ESM analysis (with a larger threat library and a better computer) and to integrate the system directly with a ship's CDS. It also has 2 new phased-array ESM antennas (replacing 2 of the cones of the earlier versions). The jammers feed 4 ELT 828. This is the system on board the *Giuseppe Garibaldi* and the *Audace*- and *Ardito*-class missile destroyers.

NETHERLANDS

◆ MW-08

MW-08 is the 3D air-search radar in both the Greek and the Portuguese MEKO 200-type frigates.

◆ MR-05

A recent Signaal brochure shows transmitter power as 10 kW. Maximum (free space, PD 0.5) range on air targets is 80 km on a 0.5-m² target (SW 3 case), 95 km on a 1-m² target (SW 1 case), and 110 km on a 2-m² target (SW 1 case). Maximum unambiguous target speed (for MTI filtering) is Mach 5. Instrumented range is 107 or 214 km. Resolution is 3.5 deg in bearing and 90 m in range. If a tracker is fitted, it has a capacity of 160 air and surface targets. Antenna width is 4.8 m; weight is 600 kg.

◆ FCS Radars

STING is the current Signaal tracker. It differs from *STIR* in that it incorporates an integrated K-band transceiver (to track low targets) and uses hydraulic rather than electric drive for higher slewing and elevating speeds. *STING* includes an automatic signal processor. Versions are *STING BS* (basic), *STING CW* (adds CWI), *STING EO* (adds IR camera, laser, and TV tracking unit), *STING SW* (Sea Wolf: adds command link, gyro, gathering unit for missiles).

LIROD is K-band radar plus television. Extended *LIROD* adds a laser range-finder (or laser tracker) and an IR camera.

POLAND

◆ Wrobel 2MR

This is a combined gun-missile system (equivalent to the land-based ZUR-23-2S) consisting of a twin 23-mm gun and a single 72-mm Strela 2M (SA-7 series) missile launcher on top. It was first mounted on board the new minelayer/transport *Gnieszno*.

SWEDEN

◆ RBS-70

When she was sent to the Persian Gulf, HMAS *Westralia* was provided with RBS-70 missiles from the Australian army's 16th Air Defence Regiment. Her predecessor, HMAS *Success*, may have been similarly armed. These 2 ships were the first to have been so armed. *Westralia* was also given four 50-cal machine guns for defense against small boats.

EXPENDABLES

Known users of the Philax system are Finland (4, plus more for the Helsinki-II class) and Sweden (82, plus 24 on order). Users of Protean are Egypt (24), Korea (88, plus 16 on order), and Nigeria (2 for the *Erin'mi* class). Protean was also reportedly sold to civilian shipowners during the Iran-Iraq War.

SWITZERLAND

◆ ADATS

It was reported late in 1990 that Oerlikon had abandoned work on the naval version of ADATS (announced in October 1988) because of the lack of any firm customer.

USSR

◆ Head Lights

Recent very clear photographs (such as the one reproduced below) of Head Lights, the SA-N-3 radar, suggest strongly that it is not a monopulse set (as claimed in the main text). It is probably a TWS radar, in which one dish is scanned horizontally while the other is scanned vertically (the 2 small dishes operate similarly to track the outgoing missiles). Such a system can reasonably expect to track 2 missiles flying against 1 or more closely bunched targets. In this case, Pop Group would be the first Soviet naval, monopulse, missile-control radar.

◆ SA-16

A 1990 Soviet brochure for SA-16 (called Igla 1EH) claims that the maximum effective range is 3.0 km (with a maximum altitude of 3.5 km and a minimum of 10 m) and the maximum velocity is 680 m/sec. Activation time is 13 sec (presumably, to ready the missile to fire), and reaction time from target detection to firing is 4.5 sec. Claimed probabilities of engagement against various targets are as follows:

	Head-On	Tail-On
F-4	0.33	0.48
A-10A	0.15	0.19
F-15	0.11	0.32
AH-1G	0.34	0.42
ALCM	—	0.20

As the latest version of the SA-7 family and the first with claimed head-on capability, SA-16 is presumably carried aboard many Soviet and client-state ships (see SA-N-5/8 and SA-N-10). The total system weight is 16.65 kg. The Soviet industrial designation is 9M39 (original version); the developed version is designated 9M313.

SA-19, which may be the missile associated with CADS-1, is designated 9M311.

Recent reports suggest that the MiG-29 fighter's radar suffers from a very narrow search sector, perhaps only 30 deg wide (one report suggests 10 deg), which would be appropriate for a ground-controlled intercept system but might be less effective

for an aircraft operating from a carrier without any associated AEW system.

◆ MiG-29 Weapon System

The weapons-system computer apparently selects which weapon to fire based on radar input. The main safety feature of the system is that several widely separated switches have to be depressed to lock on the radar and fire the weapon. In addition, the radar has a very narrow FoV. Iraqi practice was apparently to tape down some of the switches for quicker engagement. As a consequence, an Iraqi MiG-29 shot down its wingman when the latter crossed into the radar's FoV.

UNITED KINGDOM

◆ Type 1022

Late in 1990 it was reported that the Royal Navy was experiencing sidelobe problems with its Type 1022 radar and that a get-well program was underway.

◆ Naval Radars

Versions of some current British naval radars are as follows:

911(1) GWS 25 Mod 3, 6-barrel launcher for Type 22 Batch II and III frigates.

911(2) Vertically launched Sea Wolf for Type 23 and *Fort Victoria*-class replenishment ships.

911(3) Lightweight Sea Wolf for Type 42 Batch III destroyers and the *Invincible* class.

996(1) Type 992 replacement for both *Invincible*-class and Type 42 destroyers (can support Sea Wolf); also on the *Fort Victoria* class.

996(2) Version for Type 23 frigates.

1006(1) 9650 MHz for submarines.

1006(2,3) 9445 MHz for major surface units.

1006(4) 9425 MHz for mine-countermeasures craft (Hunt and Ton classes).

The Royal Navy no longer uses Types 1002/1003, but they may survive on board exported *Oberon*-class submarines.

The Type 994 designation has been applied not only to the converted Type 993 but also to AWS-4 as installed on board *Argus*- and *Castle*-class OPVs.

British fleet auxiliaries (RFAs) operating in the Persian Gulf in 1991 were each provided with 1 battery of Royal Artillery (8 Javelin handheld missiles) for self-defense.

Type 996 (AWS-9) has been sold to Turkey as part of the Track-II version of the MEKO 200 frigate. This is its first export sale.

◆ Laser Dazzle Sight

Film of HMS *London* operating in the Persian Gulf clearly showed a laser dazzle sight (DEC) slaved to the ship's Type 911 radar. The laser dazzle sight is reportedly standard issue on board British warships in the Gulf, and that shown on board HMS *London* seemed to be a production version of the earlier and cruder type previously seen.

◆ Sea Dart

Operating in the Persian Gulf, HMS *Gloucester* engaged the Iraqi Silkworm missiles fired during Operation Desert Storm. Of 2 Silkworms fired, 1 fell into the water soon after it was fired. The official British spokesman stated that a radar operator detected the incoming missile, and that 50 sec after detection 2 Sea Darts were fired. One intercepted the Silkworm at a range of 4 nm, and the other passed through the debris. It appears, then, that detection was semiautomatic at best. The British spokesman stated that the alert watchkeeper noticed a small, fast-moving target, and that this contact was evaluated before it was engaged. If the missile was moving at about 10 nm/min,

it closed about 8 nm during evaluation. Initial detection would have been at about 12 nm, probably about the distance between the destroyer, operating fairly close offshore, and the missile launcher. The dual launch was presumably standard doctrine; at this range, there would not have been any chance for a second attempt to intercept the incoming weapon. The *Gloucester's* success against a missile probably approaching at fairly low altitude suggests that the Sea Dart get-well program was successful. Later it became apparent that the Silkworm was initially detected by the destroyer's UAA-2 ESM set, which provided the bearing onto which her Type 909 was slewed for engagement. The Sea Dart missile was up on the rail and pointed toward the target before the 909 acquired the Silkworm. Reportedly, both UAA-1 and -2 worked very well in the Persian Gulf war, to the extent that ships equipped with them were sometimes used for ESM watch. Reportedly, too, UAA-2 is designed to localize emissions within 2 deg, but it can sometimes do as well as 0.5 deg.

◆ SADIE Processor

As of March 1991, SADIE was reportedly in deep trouble because the parent British MoD program had been canceled. Several systems nominally incorporating it actually use Kongsberg KS500 processors as an interim fit. KS500 has about 10% of SADIE's throughput; it was bought because it has an instruction set compatible with that planned for SADIE. The problem was reportedly a window-addressable memory that was not working as of March 1991. The problem came to light because 2 Canadian ships in the Persian Gulf, the *Athabaskan* and *Protecteur*, were given Kestrel ESM devices as an emergency upgrade; they found that the systems incorporated the Kongsberg boards, not SADIE. It turned out that Cutlass E in the UAE navy also had KS500 boards. Reportedly, the German FL1800S is experiencing great difficulties and was in February 1991 the subject of an AEG-Racal get-well program.

EXPENDABLES

◆ Barricade

Users are Chile (12), Denmark (8 on Stanflex 2000s), Finland (4 on the *Pohjanmaa*), Italy (12 on the *Minervas*), Kenya (4), Malaysia (8), Oman (14), Saudi Arabia (2, plus 10 on order, for the *Sandowns*), and the United Kingdom (28, plus 38 on order). The manufacturer claims that Barricade is also used by a tenth navy. This system reportedly suffers because it is not connected directly to an ESM device; hence the Finnish choice of Matilda/Philax for Helsinki-IIs.

◆ Corvus

Users are Chile (the "County" and *Leander* classes), Greece (the *Kortenaer* class), India (the *Viraat*), Indonesia (the *Fatahilah*, *van Speijk* [note that the Netherlands navy used SRBOC on these ships], and "Tribal" classes), Pakistan (the "County" and *Leander* classes), and the United Kingdom (Type 42 destroyers, the *Bristol*, the *Amazon* class, Type 22 frigates, and the *Leander* class).

◆ Shield

Users are Brazil (16, plus 28 on order), Canada (4, plus 56 on order), Pakistan (12 for FRAMs), Thailand (30 on order), and the United Kingdom (60, plus 48 on order).

UNITED STATES

The FY92/93 program (announced in February 1991) called for the following (cost figures are for FY92):

	FY91	FY92	FY93	Unit Cost
AMRAAM	265	191	159	\$1.07 million
SM-2	790	525	550	\$791 thousand

No further Phoenix production is expected. The program gave no figures for new Sidewinders or Sparrows, although modified versions of both are under development or in production.

◆ SPS-49

Versions of SPS-49 are as follows:

- (V)1 was the original version for cruisers, destroyers, and carriers; all are to upgrade to (V)5.
- (V)2 was for frigates; it has been upgraded to (V)4, which is similar to (V)3 (i.e., it adds a radar video processor), but, like (V)2, lacks the coherent sidelobe canceler (CSLC) of other versions.
- (V)5, which adds ADT, is the upgrade for all (V)1 and (V)4.
- (V)6 is in the first 3 *Ticonderogas*; all are to upgrade to (V)7.
- (V)6 has a radar video processor.
- (V)7 has full ADT. (V)6 and (V)7 differ from earlier SPS-49s in that they use the Aegis cooling system rather than separate coolers of their own.

The radar video processor (RVP), based on UYK-20 in the case of a frigate, is used on board ships that lack the full SYS-2. (V)5 is required to support SYS-2.

◆ SPN-47

SPN-47 is a shipboard version of the marines' TPN-30 MRAALS (marine remote-area approach and landing system) combined with a stabilized glide-slope indicator pedestal. It will presumably replace the current SPN-35 (itself a stabilized version of a land-based controlled landing system) on board amphibious carriers (LHA, LHD, LPH).

◆ SYS-2

Versions of SYS-2 are as follows:

- (V)1 is New Threat Upgrade with SPS-49(V)5 and SPS-48E.
- (V)2 is for *Perry*-class frigates, with SPS-49(V)5 and Mk 92.
- (V)3 is for the LHD 1 class, with SPS-49(V)5 and SPS-52C.
- (V)4 is for carriers, with SPS-49(V)5 and SPS-48E.
- (V)5 is for the LHDs, with SPS-49(V)5 and SPS-48E.

SYS-2 entered service in 1987.

◆ Mk 92 Mod 6

UNISYS claimed in March 1991 that Mod 6 (CORT) offers the following improvements over Mod 2: twice the transmitter power; twice the instrumented range (search and track); 100:1 improvement in clutter rejection; coherent cancellation of second/third time around clutter; an order of magnitude reduction in the minimum radar cross section the system can handle; improved capability to handle target velocities; better ECCM; twice the MTBF; half the MTTR. The STIR tracker provides a horizon-search capability. UNISYS also offers a simplified Mod 6 (for small combatants) without the STIR. In both versions, the combined antenna system (equivalent to the Signaal "egg") offers 8 TWS channels, 2 of which can be used for GFCS (the other 6 are used for track management). The system can engage surface targets while controlling 2 surface-to-air missiles (1 by CAS, 1 by STIR). The CAS feeds a Mk 106 Mod 1 weapons-control console; the STIR feeds a Mk 107 Mod 0 weapons-control console, and the system also incorporates an OJ-194(V)3/UYA-4 PPI display. All 3 consoles receive external (SPS-49, -55 in a frigate) video as well as Mk 92 radar video.

◆ E-2C Upgrade Block III

The FY92 budget includes the Block III upgrade: the airplane will be fitted with a new mission computer, an IRST sensor, and a satellite link.

◆ Sparrow

AIM-/RIM-7P is the current production version, superseding AIM-/RIM-7M. This version has improved low-altitude guidance (LAG), superior subclutter visibility, a reprogrammable missile-borne computer (MBC—see below), an uplink capacity, and an internal digital data bus that provides a better interface to the shipboard or airborne FCS before launch. Raytheon claims that the operational ready rate and reliability are double the specified requirements.

AIM-/RIM-7R, now in full-scale development, was displayed at the 1991 U.S. Navy League show. It adds a nose IR sensor to the usual semiactive radar seeker. AIM-/RIM-7R is being developed under the joint Raytheon/General Dynamics MHIP (Missile-Homing Improvement Program). MHIP also applies to the Standard Missile (SM-2 Block IIIB). The Sparrow missile carries its IR sensor at the tip of its nose because the radar dish usually looks to 1 side as the missile flies a proportional-navigation path. The SM-2 MHIP version has a separate IR sensor in a fairing on 1 side. As of March 1991, a decision on the future course of the MHIP program was expected late in May.

MHIP required a considerable increase in computer capacity. AIM-/RIM-7M had the first programmable missile-borne computer (MBC) in the Sparrow series. Reprogramming required that the missile be decanned, the computer pulled out, and its EEPROMS changed and burned in. A reprogrammed missile had to be tested after modification. AIM-7P uses ERPROMS and can, therefore, be reprogrammed by wire from its umbilical. AIM-7R's requirements were developed while the AIM-7P computer was being redone. Increased capacity was needed mainly for IR-seeker signal processing. The -7P computer was redesigned to free space for 3 IR processing boards. Total computer power is an order of magnitude greater than in the earlier -7M. AIM-/RIM-7R also has a new radome, and the RF-signal processor must compensate for very different internal reflection (including reflection from the IR seeker).

The new front end is wholly retrofittable to existing -7M missiles. The tentative plan is to retrofit existing weapons, beginning with the earliest -7Ms.

◆ Sidewinder

Loral Aeroneutronics (formerly Ford) displayed AIM-9R at the March 1991 U.S. Navy League show. It is currently in full-scale development. This version uses an imaging IR seeker (a visible imaging, focal-plane array and 3-axis-stabilized, high-resolution optics) for increased acquisition range and better clutter and countermeasures rejection. It also has an increased FoR to track off-boresight and maneuvering targets and better aim-point selection and terminal guidance for increased kill probability. AIM-9R is electronically reprogrammable to incorporate future software upgrades. The new front end is completely interchangeable with the existing AIM-9M/9L missile's after end.

Boa-M is a jointly funded General Dynamics/China Lake program to demonstrate the feasibility of modifying the basic missile to fit the tight internal stowage of future stealthy fighters such as the F-22 and F-23. An AIM-9M was modified by fitting the smaller canards of a -9D and by halving the size of the tail fins. A digital autopilot provided dynamic control to make up for the inherent stability thus sacrificed; the result was analogous to a fly-by-wire airplane, which sacrifices inherent stability to achieve greater maneuverability. In a demonstration late in 1990, this Boa-M missile successfully intercepted an F-86 drone from a range of 2 miles (having been fired off center). This shot demonstrated not only the practicality of the reduced-size missile but also its greater agility.

◆ Standard Missile

The prototype SM-2 Block IIIA missile flew at White Sands on 2 March 1991. Performance improvements in this version include ordnance improvements, which may mean a directed-explosion warhead (i.e., the missile rolls toward its target and then fires its warhead directly at it).

For details of Block IIIB, see the discussion of Sparrow above.

◆ RAM

The standard 21-cell launcher is now Mk 49; Mk 43 has been dropped. The project to convert some cells of Sea Sparrow (Mk 29) launchers has been essentially abandoned partly because some major modification of launcher motors would have been required to maintain train and elevation rates. There would also have been major computer changes. In addition, many Sparrow installations are moving to vertical launchers. On the other

hand, the carriers cannot accommodate RAM unless their Mk 29 launchers are modified.

As of March 1991, General Dynamics was under contract for Mk 49 launchers for the U.S. Navy for 2 LCCs (replacing BPDMS) and 4 LHAs (2 each, fore and aft). In each case, TAS Mk 23 is to be added for target designation. On the LCCs, the requirement for fore and aft mountings would entail a redistribution of armament. U.S. Navy planning in March 1991 called for RAM on board the *Spruance* class, the LCCs, the LHAs, and the LSD 41 class.

The Phalanx/RAM program was originally a General Dynamics IR&D project, but the U.S. Navy is now supporting the program. This system will probably be required for the LSD 41 class because they will not be fitted with TAS Mk 23. They will probably use the Phalanx search radar for designation, together with the ship's ESM system.

The first RAM delivery to the German navy is scheduled for the first quarter of 1992; it will probably be operational by mid-year. The prototype German RAM launcher has been installed on board 2 fast patrol boats, first as a stand-alone device and then connected to the boat's command system, which could designate targets and point the launcher. The launcher was then moved to the German land-based test site at Wilhelmshaven for integration with the destroyer, frigate, and fast-patrol-boat combat systems.

The Royal Danish Navy is still an observer in the program; it plans to compete its StanFlex 300 defensive system. The Danish-designed RALS launcher was first test-fired on the Danish naval firing range in June 1990. The most likely competitor is Mistral (Denmark briefly considered the Israeli Barak, too).

General Dynamics and Contraves are developing ISDS (Integrated Self-Defense System), a Contraves Sea Shield gun mount with 5 RAM missiles (from a RALS launcher) on top of it. The total weight will be 6416 kg above decks, 1590 kg below decks.

The RAM II upgrade is intended for IR lock on after launch. If a nonradiating target is detected by shipboard radar, the system selects the all-IR mode (upgraded configuration). Typically, the radar would be the 2D TAS Mk 23. It would, then, generate only a bearing. The seeker is instructed to conduct an expanded vertical search in flight (which would probably involve a 1-bit indication in the launch message). General Dynamics claims that the improved missile will acquire even low-IR-signature threats. General Dynamics is developing the seeker while BGT of Germany develops the signal processing.

◆ SWPS

An industry briefing was held in January 1991, but as of March the acquisition plan was still being drawn up. A formal RFP was to be issued 60 days after the acquisition plan was approved (probably in June). Likely competitors were the AAI/Rockwell gun and missile mount, the Boeing Avenger, the LTV Crossbow, and at least one other (most likely the Bofors Trinity in modified form). This weapon is being bought to equip the new SEAL-insertion craft (a modified version of the Vosper-Thornycroft "Province"-class fast patrol boat), but it may also replace existing 25-mm and even 3-in/50 mounts on board larger ships.

◆ ASAT

The ASAT program was canceled in January 1991. The U.S. Air Force wishes to cancel its participation in the NATO Mk XV IFF program. It may, however, buy Mk XV sets for aircraft operating in Europe.

◆ NAAWS

NAAWS was canceled late in 1990, and efforts early in 1991 to restart the program appeared to have failed. Accounts of the reason for the demise of NAAWS vary. It has been blamed on U.S. reluctance to agree to further technology transfer (ironically, the purpose of NAAWS was to transfer Aegis technology to allied navies). There has also been a suggestion that there was no real willingness to pay for anything beyond the core system concepts worked out by the competitors. Further

NAAWS work would have involved expensive hardware, in the form of new radars and, ultimately, new missiles.

The main fall-out from NAAWS will probably be a number of new distributed CDSs, such as the Raytheon ICDS described in the Surveillance and Control section. Raytheon would have used a tail-controlled Sea Sparrow with a new and more energetic motor. Hughes clearly hopes to apply its work on display subsystems to the QRCC/SRAAWS program. The company had hoped to use a higher-power, extended-range variant of its AMRAAM missile as the NAAWS interceptor. Its team's multifunction radar was the GE/RCA FARS variant.

◆ QRCC/SRAAWS

With the demise of NAAWS, the former U.S. NAAWS project office is looking at an all-U.S. system built mainly from existing components, QRCC (Quick-Reaction Combat Capability). QRCC is to link existing autonomous hard- and soft-kill devices for greater effectiveness. This is a development of the RAIDS concept. For example, the RAM/Phalanx combination is being developed as a basis for a QRCC system. The computer that coordinates the 2 and passes Phalanx radar data through to the RAM mount can also accept SLQ-32 data and can in theory accept SAR-8 inputs. The computer can set and change jammer frequency and fire chaff.

In a larger sense, QRCC exploits the work that several U.S. NAAWS competitors did on weapons-system-oriented CDSs ("cores"). Like the Aegis CDS, these cores were intended as weapons-direction systems, grown up to handle further CDS tasks. As it happened, the rules of the NAAWS competition required the companies to develop Aegis-like cores without the associated radars.

Hughes is to mount a TPQ-36A Firefinder radar back-to-back with its prototype ITAS (the pedestal is heavy enough to take both). The result should be an X-band horizon-search radar mounted with an L-band volume-search set. The same pedestal will also support a Saab 700 FLIR. The sensors will be integrated through the ongoing TAS integration program. The system will use a Hughes-developed TEWA running on a UYK-20 (later UYK-44) computer (TAS Mk 23 now uses 1, and the double system would need 2). The display would be a standard UYQ-21.

SRAAWS (short-range AAW system) is an earlier term used for the U.S. equivalent of NAAWS.

◆ Antiaircraft Laser

At the March 1991 U.S. Navy League show, TRW displayed a model of an antiaircraft laser fitting within the envelope of a VLS "B" module. It is a repackaged version of the Sea Lite chemical laser that shot down a Vandal (converted Talos) drone missile at White Sands. The laser fuel (NF₃-ethylene-helium-deuterium) is carried in the module. To fire the laser, NF₃ is combusted with the ethylene to form hot fluorine, which reacts with deuterium to form excited DF, which lases. The laser itself is well below decks; the device above decks is the beam director, with a 1.5-m clear aperture (about as in the White Sands test). The model is far more compact than the White Sands installation because the latter used large steam-ejector pumps to compress the lasing mixture. In the module, 24 small jet engines are used instead. The laser exhaust is heavily diluted with air to make it less toxic; TRW claims that it is considerably less toxic than the blast from the vertical launcher module it replaces.

The TRW weapon is a CW laser; TRW chose CW over pulsed operation because the underlying technology is so much more mature. TRW also claims that, at least at the powers available, CW and pulsed lasers would both kill their targets mainly by heating and burning them (a very high powered pulsed laser might have almost a projectile effect, blasting a hole through its target). It is easier to shoot down a crossing than an approaching target because the laser beam slews as it tracks the crossing target. A beam pointed continuously in 1 direction

tends to bloom as it heats the air through which it passes; a slewing beam encounters no such problem.

As of March 1991, TRW claimed that it could build a test module at once, and that incoming missiles could be killed at roughly Sea Sparrow's range.

◆ Phalanx

In 1990 General Dynamics received a contract to develop and integrate a new and much faster Control Data AMP computer using R3000 RISC processors (and said to be 100 times as fast as the current unit) into Block 1. A further version, Block 1R-III, will incorporate some new radar components, including a Thomson-CSF transmitter and a new signal processor. RFPs for Block 2 FSD are expected (as of late 1990) late in 1991 or early in 1992, with contract award expected late in 1992 (and Block 2 entering service at the end of the decade). Block 2 is likely to entail additional sensors (EO/IR) as well as better accuracy, a higher rate of fire, and increased projectile energy (e.g., greater caliber). General Dynamics has awarded Oerlikon a contract to mount its new 25-mm Gatling 5000 gun (as used in the Italian Myriad) on a standard Phalanx turret. The Oerlikon gun differs from other Gatlings in that it carries its ammunition in a trough fixed to (hence elevating with) the barrel. The designation refers to its rate of fire, 5000 rnd/sec. Other candidates include Tround, the telescoped 25-mm Gatling, and a 4-barrel 30-mm GAU-13/A gun used in Goalkeeper.

Block 2 models shown at the March 1991 U.S. Navy League exhibition had their search radars moved to a separate pedestal. The tracker was retained atop the gun, but in place of the search radar was a pair of EO sensors (television and IR). General Electric was advertising a new 35-mm telescoped-case gun for Block 2 because the earlier 25-mm proposal would not have provided enough firepower (the smaller caliber is still proposed for other applications).

Block 1 is currently operational in the U.S., Australian, British, Greek, Japanese, and Taiwanese navies. Remaining operators of Block 0 are Canada, Israel, Pakistan, Portugal, and Saudi Arabia.

◆ ETC

The navy is studying an electro-thermal-chemical gun for point or area defense under the BTI program. In March 1990 it awarded contracts to both FMC and General Dynamics for cartridges for a new ETC gun, using a navy-supplied Israeli (IMI) 60-mm gun and recoil mechanism. FMC also has a contract for an autoloader, and as of early 1991, a further contract was to be let for the design of a smart projectile (SCSM, small-caliber smart munition). The FMC project is based on earlier work on CAP guns. General Dynamics had worked on ETCs for DARPA as part of the missile defense (SDI) program, using a 105-mm gun. The experimental 60-mm gun is to be mounted on a Phalanx trunnion assembly, and the total weight will approximate that of the Phalanx gun (less its radar, presumably).

The object of the experimental weapon is to achieve a useful high muzzle velocity without the violent acceleration associated with a conventional gun, and thus without damaging the heavy (up to 3.5 kg) smart projectile. The minimum acceptable muzzle velocity is 1 km/sec [3280 ft/sec], which is very high for such a projectile, and the actual velocity may be 2 km/sec or more (some other technology, such as a pure electromagnetic gun, would be needed to achieve or exceed 3 km/sec). The gun itself is 4.2 m long (70 cal), including its chamber (about 28 in, or 71 cm, long). The rate of fire should be comparable to that of a Bofors 57-mm gun, i.e., well over 100 rnd/min. Projectiles will be fired in bursts of 10 per target, and the weapon will be able to fire conventional as well as special ammunition. The original Israeli gun was developed for tanks and light armored vehicles.

Prototype cartridges are to be delivered in August 1991, and firing trials are scheduled for the end of 1992.

FMC is also considering an ETC version of the current 5-in/54, but only on an internal basis. The navy is currently com-

paring the merits of large and small calibers for this technology, also on an internal basis.

◆ Mk 105

Mk 105 target-acquisition consoles were installed on board the PHMs as an interim means of detecting and targeting enemy emitters. They were to have been replaced by ALR-66(V)6 (which was first evaluated in FY88), but that was done in only 2 ships (PHMs 4 and 6).

◆ SLQ-20

Seesaw II augments the shipboard-countermeasures capability of ships deployed to particular areas. It is a log-periodic antenna mounted on SPS-49(V)1 radar antennas, replacing their AS-2182/UPX IFF antennas. This device first appeared in 1968. Most surface combatants equipped with SPS-49 radars can carry it.

◆ SLQ-22/26

These old threat-reactive systems survive only on board a few carriers: SLQ-22 on board CV 61 and SLQ-26 on board CVs 59 and 67. SLQ-22 is an operator-controlled threat-reactive system, used with ULQ-6. SLQ-26 is an analogous automatic threat-reactive system, also used with ULQ-6.

◆ SLQ-32

The current upgrade is an improved UYK-19 with more memory (512k), higher speed (3 times), and an embedded hard disk. Current plans call for SLQ-32(V)3 to be installed on board all *Spruance*-class destroyers and for (V)5 (Sidekick) to be installed on board all *Perry*-class frigates.

At the 1991 U.S. Navy League show, Raytheon displayed an improved console (based on the unit developed for FDDS) that could be used for SLQ-32 but would also be suitable for a next-generation system. Unlike the current single-screen, monochrome, character-oriented (i.e., cursive or stroker) monitor, the improved console has 2 large, color, raster-scan screens and a big embedded processor. The new console uses the same display technology as the abortive FDDS console, with militarized Silicon Graphics architecture. It fits the same footprint as the existing SLQ-32 console. Raytheon would prefer to go to a new console similar to that introduced in the submarine CCS Mk 2, using a RISC-based computer (MIPS R2000, upward-compatible with R3000). The new console would retain the current UYK-19/UYK-64 display processor because the processor is so tightly coupled to the SLQ-32 receivers. Moreover, this arrangement would preserve the large software investment represented by the current system. At the same time it would be suitable for the likely next great advance in shipboard combat systems, a distributed combat system.

◆ SLQ-50

The next-generation replacement for this specialized terminal is to be a version of the E-Systems MIST (Miniaturized Interoperable Surface Terminal).

◆ SLQ-54

SLQ-54 is the next-generation shipboard countermeasures set formerly known as AIEWS (Advanced Integrated Electronic Warfare System). It is to combine the short-range defensive features of SLQ-32 with long-range precision ESM. The program is now being competed, and the navy hopes to put SLQ-54 in service by about 2000.

◆ Night Surveillance Sensor (NSS)

Martin Marietta displayed this covert surveillance device at the U.S. Navy League show in March 1991. It is a semisubmersible carrying a periscope, ballasted to show 1 or 2 ft of mast. The total weight is 250 lb; the total height is 5.5 ft (length 10 ft). The hull's outside diameter is 8 in. The endurance is 2 hr at 5 kt; the maximum speed is 6 kt. The guidance system can maintain a heading to within 1.5 deg. The sensor is a low-light-level

CCD television camera with a zoom lens (17.5–108-mm focal length), operating in the near IR. The vehicle carries a 10-W video transmitter and a 10-W radio data link. Potential markets include the U.S. Coast Guard for drug interdiction.

◆ **RBOC/SRBOC**

Users are Australia (the *C. F. Adams*, ANZAC, and *Perry* classes), Belgium (The *Wielingen* class), Brazil (the *Garcia* class), Canada (the *Annapolis* and *Restigouche* classes), Egypt (the *Descubierta* class), Germany (the *C. F. Adams* and *Bremen* classes), Japan (surface combatants, down to frigates), South Korea (frigates), the Netherlands (the *Tromp*, *Karel Doorman*, *Jacob van Heemskerck*, and *Kortenaer* classes), New Zealand (the ANZAC and broad-beam *Leander* classes), Pakistan (the *Brooke* and *Garcia* classes), Portugal (the MEKO 200 class), Saudi Arabia (the PCG and PGG classes), Spain (the *Principe de Asturias*, *Perry*, *Baleares*, and *Descubierta* classes), Turkey (the MEKO 200s), the United Kingdom (the *Invincible* class, Type 42 destroyers, and some Type 22 Batch 1 and 2 frigates), and the United States.

ANTISUBMARINE WARFARE

ARGENTINA

◆ **S-2E**

The Argentine S-2Es are being upgraded by Israel Aircraft Industries, which is providing a new avionics suite of unspecified origin. Presumably, the upgrade includes a new sonobuoy processor, a new ELINT system (presumably Owl), and a new radar. Given the Argentine experience in the Falklands, the S-2Es would presumably be used to detect targets for Exocet-armed Super-Etendards.

CANADA

◆ **CTS-36/CMAS-36**

C-Tech claims that CTS-36's MTBF is greater than 500 hr. The operator-selected frequency is 36 or 39 kHz; the range scales are 250, 500, 1000, 2000, and 4000 m (there are range rings at $\frac{1}{4}$, $\frac{1}{2}$, and $\frac{3}{4}$ full scale). There are 5 discrete power levels: full, -5 dB, -10 dB, -15 dB, and off. The 450 (dia) $\times$ 910 mm [17.7 $\times$ 35.8 in] transducer has 540 elements (270 channels); the pulse length is 1–150 msec. In directional mode, 36 elements/sector are driven. There are 3 independent tracking channels. The Doppler filter resolution is 1.25 kt over ± 20 kt.

CMAS-36 is the mine- and obstacle-avoidance sonar installed (on an emergency basis) on the 3 Canadian warships sent to the Persian Gulf. It is optimized for shallow-water operations. It normally operates at 36 kHz (39 kHz optional). In surveillance mode it searches a 76-deg zone centered on the bow. There is also an ODT search MCC mode using a broad, depressed (30-deg) receiving beam. The color display is 1280 $\times$ 1024 pixels. The electronic beam tilt is continuously adjustable between +8/-24 deg. The source level is 223 dB. Pulse lengths are 0.2 to 15 msec. The transducer matches that of CTS-36, with 540 elements.

◆ **CSAS-80/CSS-80AS**

C-Tech's harbor-surveillance sonar competes with Saab's Bottle Cap and is entered in a current (1991) competition for a Swedish navy harbor-protection sonar (trials were conducted in the fall of 1988). This sonar was being considered by Kuwait just before the August 1990 invasion, and it is being considered by at least one Asian country. CSAS-80 uses technology similar to that in the C-Tech Omni sonars (CTS-36 and CMAS-36) to search a 6-, 12-, or 24-deg conical field that can be tilted 24 deg up or down. Targets are automatically detected and tracked, and static targets can be suppressed automatically. Range scales are 250, 500, 1000, 1500, and 2000 m.

The related CSS-80AS provides 360-deg coverage in a 3-deg cone that can be stepped through a vertical sector of ± 15 deg. It operates at 80 kHz (source level 211 dB, pulse length 1–20

msec). The range scales are 62, 125, 250, 500, and 1000 m. The transmitted beam is ODT (4 deg in the vertical). The received beam is 17 deg (adjustable to 3 deg) $\times$ 5 deg. The bearing resolution is 0.56 deg. The transducer can be up to 2000 m from the dry-end electronics.

CHINA

◆ **EAJ-1**

This Chinese antisonar and antitorpedo jammer for surface ships and submarines hovers at depths of 30, 60, and 100 m [100, 200, and 330 ft] and operates at 15–40 kHz. Dimensions are 118 $\times$ 800 mm (weight is 8 kg). EAJ-1 can be launched at depths to 200 m [660 ft].

FRANCE

◆ **Salmon**

Singapore bought this sonar, not the EDO 786, for the new *Victory*-class fast attack boats.

◆ **SS 312**

Thomson Sintra announced this new small-boat towed array in February 1991. Like the earlier SS 12, it is an adapted helicopter dipping sonar (HS 312). It is very light (3–4 tons in all) and can go almost twice as deep as Salmon (300 m vs. 170 m). Handling gear has been adapted from that developed for Salmon. SS 312 was proposed for the Coast Guard's small-boat sonar program.

◆ **Spartacus**

The Lacroix torpedo decoy weighs 50 kg (diameter is 130 mm) and carries 25 liters of bubble-generating material or pyroacoustic noise-generating material. It can reach a range of 50–200 m in less than 3 sec.

GERMANY

◆ **Marine Target Simulator**

This modified (and lengthened) Mk 37 torpedo was first shown by Honeywell Regelsysteme (Germany) at Defendory in October 1990. Development began in 1989, and it will enter service in 1991. Endurance is 4 hr at 8–9 kt and 1 $\frac{3}{4}$ hr at 12–15 kt; the device tows an array of transducers and hydrophones and carries transducers in its body.

JAPAN

OQS-3 is a license-built SQS-23; OQS-4 is a signal-processing upgrade. OQS-101 is a Japanese-developed, 3-kHz sonar roughly equivalent to SQS-26/53.

NETHERLANDS

◆ **PHS-32**

Two are being made to replace old EDO sonars on board the 2 Dutch *Tromp*-class destroyers.

NORWAY

◆ **SS 245 Series**

This is Simrad's current series of 24-kHz, preformed-beam, hull sonars, which operate in ODT, sector, or directional transmitting modes. There is also an MCC mode using a broad vertical transmitting and receiving beam. Transmission and reception beams are tiltable (+10 to -20 deg) in 19 steps. The 32 beams are interpolated to form 64 display beams on the 20-in raster-scan display. There are no staves. Instead, the transducer is an array of 7 circular 27-element parts, arranged so that the spot transducers form a checkerboard to generate a more even pattern. The transducers' dimensions are 432 $\times$ 280 mm (weight is about 300 kg). Versions are SS 245 (hoistable, no dome), SS 246 (hoistable, with GRP dome), SS 247 (fixed, with GRP dome), SS 248 (hoistable transducer and dome), and SS 249 (hoistable, with inflatable rubber dome).

◆ SS 304

The display is a 14-in, 6-color (3 for symbols, 3 for echoes), 512-line, raster-scan CRT (frame rate 50 Hz). The beam is 9×7 deg. The source level is listed as 232 dB, but the output power to the transducer is 4 kW.

◆ SU Sidescan Sonar

The British "Isles"-class OPVs also use this sonar.

UNITED KINGDOM

◆ ADS

As of February 1991, for the next-generation helicopter sonar, to be called ADS (Advanced Dunking Sonar), the British were to choose between Cormorant and FLASH. HELRAS, Osprey, and HIPAS were all rejected. Reportedly, the front-runners had been HIPAS and Cormorant, which were considered about equal on technical merits. However, FLASH represents Anglo-French cooperation, and it may, therefore, enjoy decisive political backing.

◆ Torpedo Presetters

Plessey Naval Systems is developing a family of torpedo presetters to supersede the current standard Mk 264, Mk 309, and ATLAPS (i.e., low end fully manual, semiautomatic, and fully integrated). All are capable of presetting all the current major lightweight torpedoes: Mk 44 and 46, Stingray, A244/S, and Murène. Likely designations are PMW 55, 56, and 57, respectively, but they had not been approved as of March 1991. The U.S. Mk 264 and Mk 309 panels are limited to Mk 44 and Mk 46 torpedoes. ATLAPS, developed for the Royal Navy, can preset the Mk 44 torpedo but not the Mk 46 (Mk 46 would require a new module; it can be developed and supplied if a customer requests it). It was intended primarily to support the Stingray torpedo but can also control the A244/S.

◆ Plessey Torpedo Launchers

Plessey Naval Systems is developing a new series of universal lightweight torpedo tubes (i.e., with connections for Mk 44/46, Stingray, A244/S, and Murène). The designations are PMW 53 (3 barrel), PMW 54 (2 barrel), and PMW 60 (1 barrel). The current Mk 32 cannot fire Murène without major modifications to accommodate the torpedo's different connectors.

PMW 49a is an export version of the Royal Navy's STWS 1. Current export users are Nigeria and Thailand.

◆ STWS 3

STWS 3's export designations are LWL 1 (lightweight launcher) and DMTS 90.

UNITED STATES

◆ BSY-2

BSY-2 is the first fully integrated submarine combat system, all the sensors, data processors, consoles, and weapons controls riding the same high-capacity Flexnet bus. The consoles can, therefore, be switched among all the command/control tasks; there is also a separate geosit (geographical situation, i.e., PPI) console. BSY-2 is the first application of the EMSP (UYS-2) signal processor, which has been used in development work since 1989. BSY-2 incorporates 25 display surfaces (10 two-screen combat-system display consoles, 3 command displays, 2 tactical-situation monitors), 3 beam-former cabinets, 6 EMSPs (UYS-2), and 3 data processors. It can fire 8 weapons at a time and can control 4 wire-guided torpedoes simultaneously.

BSY-2 incorporates a unique ASIC (application-specific) beam-former chip (40,000 gates using VHSIC technology), which is presumably needed to exploit the great sensitivity of the big wide-aperture arrays (WAA) on the submarine's flanks. Another critical electronic item is the outboard electronics (OBE), a signal conditioner mounted external to the hull. Because it reduces the data load into the internal signal processors,

the OBE reduces the hull penetrations (and overall structural footprints) for the various submarine sensors. OBE is important not only for the new *Seawolf* but also for *Los Angeles*-class submarines, which are very space-limited, fitted with the new WAA.

The data bus is Flexnet, a packet-switched, fiber-optic bus with a capacity of 50 Mbits/sec (1000 messages/sec).

All the system computers use militarized 68030 chips (often combined with 68882 math coprocessors on a single small board). System software is written in 6 series (threads); the submarine can go to sea without the full set (but also without some capability). Total software includes 2979 kslocs (thousands of software lines of code) of unique software. Through 1990 there was some question as to whether all of this software could be written in ADA because of the paucity of ADA programmers. That situation raises the question of just how wise the shift to ADA has been.

The standard console, CSDC (combat-system display console) has 2 high-resolution, raster-scan, color displays (it is the basis of the Librascope naval workstation series). It is the first high-resolution color monitor with magnetic compensation to have been shock-tested (September 1990). The software provides 6 tactical aids: automatic contact following/aided detection (ACF/AD), automatic contact correlation (between arrays), automatic aided contact classification, automatic TMA, recommended weapons presets, and operator alerts.

System design and development was conducted in 1985-88, followed by detail design work in 1988-90. As of early 1991, the bulk of the critical items in BSY-2 had been tested, and the system was entering limited production. The WAA will also enter service in stand-alone form as BQG-5; the first such unit is to go to sea in 1993 on board a *Los Angeles*-class submarine. It will use the same beam-former hardware, software, and display as in the integrated BSY-2 system.

◆ SQQ-89

As of February 1991, the following *Perry*-class frigates will not receive SQQ-89: FFG-10, -24, -27, -31, -34, -37, -51, -52, and -54. The following ships have already been fitted: FFG-8, -28, -29, -32, -38, -55, -56, -57.

◆ SQR-17 Versions

(V)1 4-channel processor displaying raw acoustics in A- or B-scan format, with hard copy in gram format. It incorporates an RD-420 14-track magnetic tape recorder.

(V)2 Upgraded version that can also process towed-array data. The tape recorder is upgraded (to RD-420A), and this version incorporates a digital multiplexer encoder/decoder (DMED) to convert 32 channels of towed-array-hydrophone data, plus own-ship course and speed and track-bearing data into high-density digital format for recording.

(V)3 New-generation version with FDALE (Frequency Domain Adaptive Line Enhancement) for better detection of periodic signals buried in broad-band noise. This version was the first fleet ASW processor to incorporate adaptive line enhancement.

A(V)1 and A(V)2 Sixth-generation systems (the first was SQS-54, 1969). They are totally integrated, with 8-channel receivers and 28-channel RD-420B tape recorders. They add DIFAR, DICASS, and VLAD processing. Capacity is 8 LOFAR channels or 2 DIFAR/DICASS channels. The computer can conduct TMA (MATE/MLE). The main acoustic data display (19-in, high-resolution, raster-scan screen showing grams plus integrated grams) is supplemented by 2 auxiliary 9-in video-monitor displays for selecting the proper operating modes. SQR-17A can operate with buoys (data received via either a helicopter data downlink or an ARR-75 receiver), and it can feed data to an ASW FCS or to a hull sonar.

SQR-17 succeeded the 2-channel SQS-54, which was introduced in 1969.

◆ U.S. Sonar Transducers

The following comparative data have become available:

Sonar	Transducer	Frequency	Staves	Dimensions (in)	Wt (lb)
SQS-4	AT-363	14 kHz	48	39.0 × 40.7	3500
SQS-4	TR-114	10 kHz	48	45.92 × 45.735	10,250
SQS-4	TR-115	8 kHz	48	64.5 × 53.149	11,000
SQS-4	TR-116	14 kHz	48	40.5 × 41.395	3,730
SQS-4	TR-255	8–10 kHz	48	56.7 × 49.6	10,000
SQS-10	AT-349	20 kHz	48	18.8 × 25.8	1000
SQS-11	AT-354	25.5 kHz	48	18.8 × 23.9	800
SQS-17	TR-166	12–14 kHz	24	19.0 × 35.75	
SQS-23	TR-208	5.0 kHz	48	100.5 × 63.0	
SQS-30B	TR-195*	10.0 kHz	48	24.375 × 32.5	
SQS-35	TR-229*	11.9–14.1 kHz	24	19.5 × 29.0	
SQS-35	TR-230*	8.08–8.8 kHz	24	12.0 × 15.0	
SQS-36	TR-204	13 kHz	24	19.0 × 35.75	
SQS-38	TR-231*	11.9–14.1 kHz	24	19.5 × 9.375	

Dimensions are diameter × overall height. Early transducers are all magnetostriction types. Asterisks indicate ceramic transducers. TR-166 is made of ammonium-dihydrogen-phosphate. TR-196, for SQS-17A, used redesigned inductors (3 in 1) and had a mounting plate (the overall height increased to 38 in). TR-195 (SQS-30B above) is the smaller-scale transducer used in SQS-4-series VDSs (SQA-10 fish and hoist). TR-204 is made of barium-titanite. TR-208/208A is lead-zirconate-titanate. TR-229 is the transducer used by both SQS-35 and SQS-38. TR-231 is the MCC (maintenance of close contact) part of the SQS-38 transducer, not the entire transducer. This list is not complete, but it does give some idea of relative sizes. SQS-10 and -11 have 2 independent sections, each of 48 staves, stacked vertically.

◆ Lightweight Sonar

About March 1990 NUSC New London conducted an evaluation of lightweight sonars for small Coast Guard patrol boats. As of late March 1991, the final report had not been released. The competitors were DRS/Sparton, Massa, and Sanders (presumably, a variant of the company's ALFS competitor).

The DRS/Sparton version, the company's Portable Lightweight Sonar (PLS), was shown at the 1991 U.S. Navy League show. It consists of a new portable lightweight sonar processor that can work with either a new dipper or with standard DICASS sonobuoys emplaced by patrol boat, helicopter, or airplane. The dipper is essentially an enlarged (double height) DICASS (SSQ-62) transducer using a different ceramic. The total weight of the shipboard system is less than 1500 lb, including the winch and other mechanical equipment (less than 650 lb).

The PLS dipper is a sprint-and-drift system rather than a true towed VDS. DRS claims that it can detect a small (Type 209) diesel submarine out to 10,000 yd in good conditions. The body can be dipped to 50–500 ft in depth and can operate in sea-states up to 4.

◆ Sonobuoy Processors (AQA series)

The data that follow come from a declassified 1972 document. They retain their value because they give an indication of early LOFAR/DIFAR procedures. None of these figures is likely to characterize current U.S. equipment (modifications since 1972 have been extensive), but they do give some idea of the factors involved in sonobuoy operation. To the extent that Soviet sonobuoy practice reflects the U.S. systems of the 1970s, these data may also describe current Soviet practice (as in the use of Type 75).

The processors in use in 1972 were AQA-4, -5, and -7 aboard P-3As (Deltic), P-3Bs, P-3B DIFAR Retrofit, and P-3C. The buoys were SSQ-41 (LOFAR omni) and SSQ-53 (DIFAR). P-3B DIFAR Retrofit and P-3C could each process 8 channels of acoustic information simultaneously on dual signal-data recorders (SDRs) and another 8 channels on the bearing-frequency indicator (BFI). P-3As and P-3Bs were limited to 4 channels. The

frequency ranges were as follows: AQA-4, 10–200 Hz; AQA-5, 10–300 Hz; AQA-7 and P-3B DIFAR Retrofit, 10–2400 Hz. The much wider range was associated with electronic, rather than hard-copy, processing. Electronic processing made available automatic line integration (ALI) for automatic target detection. Unlike the earlier processors, AQA-7 could also operate in multiple modes. The normal LOFAR range was defined as 10–300 Hz, and a processor could operate over either the entire range or over the high or low half. AQA-7 could also extend the frequency range by adopting a coarser setting, to 80–2400 Hz (or high or low halves). The integration times were as follows: normal, 80 sec; medium, 2.5 min; long, 5.0 min for the normal band (corresponding times for the extended band were 40 and 80 sec and 2.5 min). Two grams on each processor (2 AQA-7s on board a P-3C) were available for DEMON, a process for recovering LF signals from broad-band noise. The broad-band frequency range, 300–2400 Hz, equated to a modulated band of 2.5–75 Hz. In each case, data could be processed over half a band. As a measure of frequency resolution, it was assumed that a weak signal could be dominated by a stronger one within 0.8 Hz (6.4 Hz in the extended-frequency mode). In this case the bearing computer associated with DIFAR buoys would see only the interfering signal. Similarly, it would be unable to distinguish 2 signals of roughly equal strength within 0.2 Hz (1.6 Hz in the extended-frequency mode). In this case, the computer would yield a bearing equal to the vector sum of the 2 sources. Tests in 1970 showed that the version of SSQ-53 then in use could locate targets within about 13 deg, although buoys could suffer badly when swamped by strong shipping noise at CZ ranges. Because both buoys used point hydrophones, they automatically combined direct, BB, and CZ sound paths.

◆ Mk 114 FCS/Mk 53 Attack Console

Mk 53 Mod 4 is a further digital version of the basic analog Mk 53 console, incorporating a second embedded UYK-44 computer. It was developed by Ocean Technology Inc. (OTI) as part of the projected FF 1052-class ASW upgrade. The full upgrade would have included FFISTS, the digitized Mk 114, and the SQR-17A signal processor. FFISTS would have functioned as the surrounding combat system, but only the Mk 114 it fed could have launched weapons. The second UYK-44 was intended primarily to perform TMA, as in the later versions of Mk 116; the entire upgraded suite would have been analogous to SQQ-89, albeit less capable. Mod 4 also includes a second graphics generator that would have driven a remote monitor (e.g., a large-screen display) and would have accepted inputs from remote peripherals. Hull sonars would have been upgraded to SQS-53B configuration. With the demise of the *Knox* class, potential Mod 4 installations in the U.S. Navy are probably limited to the 8 ships of the class that are to be retained for training. Other U.S. ships with Mk 114 FCSs are unlikely to need the full Mod 4 capability because they lack towed arrays (an active hull sonar

imposes a much smaller processing load). However, there may be a substantial foreign market among navies that currently operate Mk 114 systems (the Pakistani navy has already shown interest).

No at-sea test of Mod 4 as such is planned (it has already been tested at NOSC). The prototype Mod 2 was to be tested on board the *Gridley* in the late summer or early fall of 1991. Presumably, further units will be installed on board the missile cruisers.

OTI developed much of the Mk 116 software. Mk 53 Mod 4 was conceived as a down-sized and modified equivalent.

◆ Librascope Submarine FCS

The Librascope Israeli submarine system was for a Gal-class modernization. Three systems were manufactured, but the Israelis began to cancel the program in 1987 as the system was nearing completion, reportedly for fear of jeopardizing the Dolphin program. The modernization program began about 1985.

◆ Photonics Mast

At the March 1991 U.S. Navy League show, Rockwell announced that it was teamed with Barr & Stroud to compete for the contract for a U.S. Navy nonpenetrating photonics mast (the other major competitor is Kollmorgen). The 2 companies are already responsible for a penetrating photonics mast for the new Australian Type 471 (*Collins*-class) submarines. The proposed U.S. mast will use Barr & Stroud masts, Rockwell being responsible for overall system integration and in-hull electronics.

◆ UYS-2 (EMSP)

As of late March 1991, the future of UYS-2 in the ALFS program (as compared to commercial signal processors) had not yet been settled. AT&T has delivered an SEM-E version of the processor to the P-3C UPDATE IV program, and its throughput is equivalent to 24 UYS-1s. The same software can run on either a 1-processor or a 6-processor version.

UYS-2 is a modular machine designed to accommodate changing technology. AT&T claims that it embodies 4 important advances: (i) graphical programming using a Very High Order Language that is written symbolically or pictorially; (ii) a true-data flow architecture, which can accommodate devices transmitting data at quite different rates; (iii) a distributed operating system, which does not require time-line programming and which automatically optimizes the computer's operation; and (iv) a data-networking device, which can support multi-sensor processing and sensor fusion.

UYS-2 is designed to be programmed in a navy-supported Signal-Processing Graph Notation (SPGN), a very high order language expressed in flow charts. Each chart consists of a series of primitives (operations) connected by data-flow arrows and affected by control arrays. Typical primitives are beam-formers, FFTs, FIR filters, normalizers, and thresholders. UYS-2 uses an ECOS (EMSP Common Operational Software) based on work begun at NRL about 1980. AT&T claims that this graphical technique offers a substantial reduction in initial programming costs and also a 6-fold reduction in software-maintenance costs. Coding is entirely separated from hardware details, so programs are easily transported from machine to machine (AT&T has successfully run programs written for the SEM-B version on the SEM-E version).

UYS-2 is built out of 7 kinds of functional elements (FEs), which are connected through a 16×16 Data Transfer Network (DTN). The DTN is unidirectional and asynchronous, with full access to and from each connected device, and no data flow blocks any other. It carries 32-bit words at a rate of 7 Mwords/sec (SEM-B version) or 10 Mwords/sec (SEM-E version). DTN can be supplied in various sizes: 2-16 ports, 8-64 FEs.

Other FE types are

- Scheduler, which assigns processing tasks to available processing resources. It initiates node processing, scheduling up to 8000 nodes/sec. Capacity is 65,000 queues and 32,000 nodes.
- Global Memory (GM), sized in 4- or 8-Mword (16-bit

words) modules built of 1-Mbit DRAM and ASICs (125,000 gates/device).

- Arithmetic Processors (APs), which execute the preprogrammed primitives residing in their local memories (and are, therefore, well adapted to the SPGN language). The APs work in 16- or 32-bit format at 84 MFLOPS (SEM-B) or 120 MFLOPS (SEM-E).
- Input/Output Processor (IOP), which accommodates up to 16 channels at a total of 5 Mwords/sec (16-bit words); it has a 1-Mbit buffer memory and, in the SEM-E version, a 68020-chip CPU with math coprocessor.
- Command Program Processor (CPP), a UYK-44 in the SEM-B version and a 68020 with math coprocessor in the SEM-E version.
- Input Signal Conditioner (ISC), which performs analog/digital and digital/analog conversions, filters, demodulates, preprocesses, and provides programmable input gain and bandwidth limitation. It contains a 16-bit VLSI signal processor capable of 7M fixed-point multiplications/sec.
- Data Processor (DP), the only element not yet completed. It is to be a user-programmable (ADA language) processor in the SEM-E version, with its own I/O capacity, using a 68020 chip with a math coprocessor.

A DTN can carry a number of APs, GMs, and DPs, fed largely by an I/O Processor and an Input Signal Conditioner and controlled by a CPP and a Scheduler.

The DTN has already been used as the basis of an integrated avionics/sensor fusion system for the YF-23 fighter. AT&T's point is that widely different sensors all need much the same sort of signal processing and that, once processed far enough, their outputs can all be used together. The UYS-2 variant in the YF-23 is responsible for 4 different sensor groups for all core data processing, data fusion, and data display. DTN is also the basis of both alternative avionics suites for the army's new light helicopter (LHX).

AT&T published the following list of requirements for the alternative ALFS processor to show why UYS-2 would be superior. UYS-2's requirements and AT&T's comments are given in parentheses:

- 8 analog/digital input channels with growth capacity to 12, plus a dipping sonar (UYS-2: 16 channels plus sonar; UYS-2 can grow to 32 analog/digital channels via programmable ISC)
- 1 dual-redundant 1553B bus, with growth to 2 (UYS-2: 2 dual-redundant 1553B buses)
- 2 Proteus Digital Channel (PDC) interfaces (UYS-2: 2 full-duplex PDC channels with growth to 4; 4 PDCs will support the 13-AP output of the P-3C UPDATE IV)
- An interface with the ARR-84 sonobuoy receiver (UYS-2: ARR-84 receiver, analog and digital)
- No data-link-transmitter interface; requires sync word for active ping (UYS-2: provides sonic gate and supports 8 channels for data-link transmission; compatible with LAMPS III)
- No requirement for a DC gate (UYS-2: supports DC gate operation for active sonobuoy; also supports sonar trigger)
- 50% growth capacity required (UYS-2 for ALFS is 3 APs and 2 GMs, expandable to 3 APs and 3 GMs, and ultimately to 6 APs and 3 GMs, to give a capacity of 720 MFLOPS and to equal 24 UYS-1s)
- A sampling range of normal DIFAR plus Nyquist (UYS-2: much greater)
- Sonar modes and concurrencies: requires 4 directional buoys (not clear whether DIFAR or DICASS) plus sonar (UYS-2: meets P-3C UPDATE IV requirement for simultaneous broad-band and narrow-band [CR, CPR, Vernier] processing; 16 processing paths per computer, and 16 analysis bands per path)
- Nonvolatile memory: no set requirement (UYS-2: 16 Mbyte, expandable to 24 Mbyte)

The P-3C UPDATE IV version uses 9 APs, 6 GMs, 1 IOP, and an ISC.

AT&T and NAVSEA PMS-412 are currently running a customer expansion program (CXP) to support UYS-2 in such programs as BSY-2, SQQ-89, ALFS, and SURTASS/LFA (low-frequency array). Tasks include development of new and revised SEM-E interface and memory modules for NTDS, high-speed channel, small-computer-system interface, nonvolatile memory, and 16-Mword bulk memory. Software is also being revised.

◆ Neural-Net Signal Processor

GTE is developing a neural-net sonar-signal processor in hopes that it will be a much less expensive VME-architecture alternative to a future UYS-2 upgrade.

◆ Tomahawk ASW Missile

At the March 1991 U.S. Navy League show, General Dynamics displayed a model of a torpedo-carrying Tomahawk, a possible replacement for Sea Lance. The company had proposed just such a weapon during the initial standoff-weapon competition more than a decade earlier. In each case, the issue was that the missile would arrive at the submarine datum some considerable time after the submarine had been detected. To be worthwhile, it would have to be usable out to CZ range, in which case it would have to reacquire the target. General Dynamics proposed to do that just the way a LAMPS helicopter would, with passive sonobuoys that the missile would monitor. At the time, it seemed unlikely that the missile could relocate the submarine using self-contained electronics. This time the signal processing can be much more compact. General Dynamics has a current contract with DARPA to develop automatic relocation techniques. Moreover, it is now using an active pinger with passive-buoy receivers; the missile can carry up to 24 A/3-size buoys (the buoys have also shrunk since about 1980). The proposed torpedo-carrier is a development of TLAM-D, the submunition-dispensing version of Tomahawk.

◆ Mk 48 Torpedo

In 1991 the GAO reported that Mk 48 averages a 75% hit rate during weapons training and accuracy tests.

◆ Mk 46 Torpedo

Mk 46 Mod 5A(S) is the shallow-water version. It is in production as of March 1991, development having begun about September 1989. As of March 1991, the new Mk 50 is so expensive (and, therefore, its production rate so slow) that many Mk 46 torpedoes are being modernized. Alliant, the manufacturer, claims that Mk 46 Mod 5A(S) meets the NATO 40-m minimum-launch-depth requirement. It can operate in both passive and active modes.

◆ Mk 32 Torpedo Launcher

At least 1 Mod 5 was delivered to the PRC, which will probably copy it. However, the PRC had difficulty copying the Mk 46 torpedo because it was built in imperial (ft-in) rather than metric units.

◆ TDAS

The Torpedo Detection and Alerting System was advertised by Rockwell at the March 1991 U.S. Navy League show. TDAS is a data processor applied to existing shipboard sensors to provide rapid warning after a torpedo has been launched. It can also use sonobuoys or a temporary towed array as the acoustic sensor. TDAS provides an audible alarm and displays a threat bearing, as well as enhanced audio and a LOFARgram display for rapid confirmation and classification of a threat after the initial warning. Rockwell claims that TDAS has already been tested at sea aboard both surface ships and submarines.

◆ Countermeasure C2 System

At the March 1991 U.S. Navy League show Magnavox announced that it was working with the U.S. Navy on a next-

generation countermeasure command/control system, plus the associated smart countermeasures, for submarine self-protection. Magnavox hopes to use cooperating expert system software working with the submarine signal processors and providing the commanding officer with situation assessment, threat assessment, recommendations, and rationale. The project began as a Magnavox private venture. At present it is a software package that can run on a variety of computers.

◆ Low-Cost ASW Weapon (LCAW)

As of April 1990 three countries (Germany, Norway, and the U.S.) remain in the PG 34 Program. The Norwegian and German alternatives are all rocket-thrown. The U.S. alternatives are the Lockheed LENS and a low-cost version of the U.S. Mk 46. Both would be tube-launched. The Mk 46 version will use some new technology to greatly reduce complexity and cost (target for unit cost is \$50,000). For example, the twenty-one circuit boards of the standard Mk 46 are reduced to a single board with greatly increased capability. The Mk 46 LCAW is closely related to a U.S. Navy-sponsored Mk 46 SLEP program. The failed General Dynamics LCAW proposal was for an unpowered gliding (downward-spiraling) device with a downward-looking sensor. It would have fired a charge downward while passing over the target submarine. This device was rejected as insufficiently proven.

◆ E 90

The Franco-Italian collaborative torpedo is to be designated E 90.

MINE WARFARE

IRAQ

At the cease-fire talks at the end of the Kuwait War, the Iraqis stated that they had laid about 1200 mines, of which coalition forces detected and/or destroyed at least 350 before the end of the war. None seems to have been the new types displayed in 1989. Iraq used Soviet-designed contact and bottom mines (reportedly magnetic-acoustic), plus Italian-supplied Mantas. All components of the contact mine were produced locally, but the electronics of the bottom mine were supplied by the Soviets. In addition, the Iraqis emplaced standard land mines atop poles as an anti-invasion measure on the Kuwaiti coast. It is not clear whether the Soviets supplied Iraq with any pressure mines.

NORWAY

The new MICOS MCM control system (for the new surface-effect mine-countermeasures ships) uses an SBC 3000 processor (using 80386 chips) and programmed in "C." Each Simrad ATC900 console has 2 SBC 3000 processors and a 20-in raster-scan screen. There are 6 consoles in the minesweeper version: commanding officer, dynamic positioning/navigator, officer of the watch, tactical, avoidance sonar, and mine-warfare officer (the dynamic positioning and OOW consoles are mounted together). All consoles are connected to a dual Ethernet, to which the mine-avoidance and echo-sounding electronics are also connected (the mine-avoidance-sonar console is connected directly to the avoidance sonar, not to the system bus). In the mine-hunter version, an ROV-control console is added alongside the tactical console, a separate detection-sonar console (for the TSM 2023 minehunting sonar) is added, and 2 mine-warfare consoles are added alongside an additional dynamic positioning console. The minehunting sonar is replaced by a detection sonar; there is no mine avoidance system (or console).

UNITED KINGDOM

◆ Demon

Demon is a camera minehunting video system used on board British Lynx and Sea King helos in the Persian Gulf. It is designed to detect moored mines close to the surface by means of a computer comparing light of different colors.

UNITED STATES

◆ SQQ-14

SQQ-14 is essentially UQS-1 with an added classification sonar, the latter reportedly copied from the British Type 193.

◆ AQS-20

AQS-20 is envisaged as an AQS-14 replacement, adding further sonars to -14's side-looking arrays. It will sweep out the entire volume of the water, from near-surface moored mines down to mines moored near the bottom and ground mines; it will also look ahead. A major technical issue, then, is how to handle the very large amount of sonar data the towed body will collect. The RFP is due out on 1 April 1991. Likely competitors are EDO/Westinghouse, Bendix, Raytheon, and Thomson-CSF.

◆ Pressure and Acoustic Sweeps

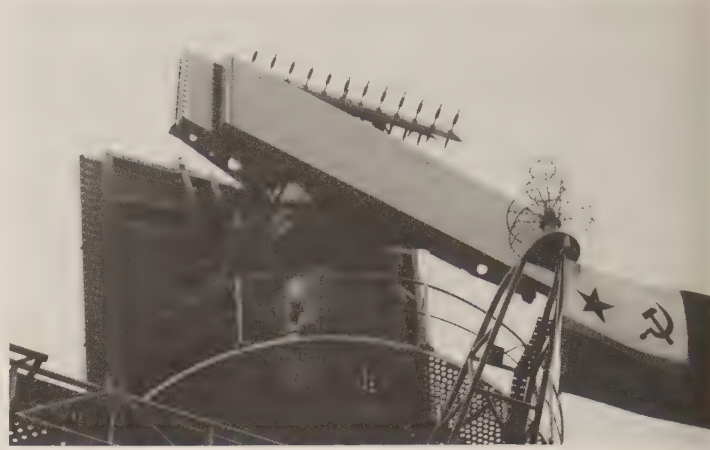
At the U.S. Navy League show in March 1991, EDO displayed a photograph of an internally developed helicopter-towed bag pressure sweep. The bag would fill by ram pressure as it was towed. This basic approach has been tried, unsuccessfully, before.

There was an attempt to use 2 PHMs in tandem to create a shiplike pressure pulse, but unfortunately the PHMs were vulnerable.

In the early 1980s NAVSEA tried HIPAM, a pressure-acoustic-magnetic sweep.

Acoustic sweeps are currently a problem because all the U.S. noisemakers are speed dependent and, therefore, must be towed

The Operations Room (CIC) aboard HMCS *Halifax*, with the standard multifunction displays of the SHINPADS system. (Paramax)



Cage Flask (with Top Plate and its IFF in the background) on board a Soviet *Sovremennyy*, 1990. (H. J. Verhoefen)

at fixed speeds to be effective. The other likely future U.S. programs are rapid shallow-water mine clearance (for the marines) and buried minehunting. At present the only means of rapidly clearing a path through shallow water is a line charge (fuel-air explosives were a possible alternative).

◆ Trident

Due to the shut-down of plutonium processing and production at Rocky Flats, there are sufficient W88 warheads for only the first 2 *Ohio*-class submarines armed with Trident II (D-5) missiles. Until production is resumed, probably in 1992, W76 warheads (as on Trident I missiles) will have to be mounted on the D-5s.





A Soviet "Krivak" shows, from the top, Salt Pot (IFF), Hour Glass, and Headnet C radar. The small radome at the lower left is Shot Dome; on the right is Cage Flask and a pair of Cage Bare. (H. J. Verhoefen)



Trawl Net (on the right) on the mainmast of a *Sovremennyy*. (H. J. Verhoefen)



A *Sovremennyy* shows Cat Cage next to her Palm Frond surface-search radar on her yardarm. (H. J. Verhoefen)



Pole Star is the array at the extreme left. The radar is Palm Frond; the original of this photo shows a set of dipoles, presumably for IFF, on its feed. (H. J. Verhoefen)



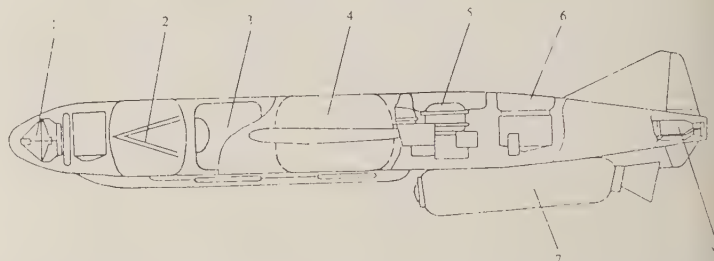
The Helstar naval UAV. (IAI)



The Hughes OJ-663/UYQ-21 display console. The screen shows typical windowing. (Hughes)



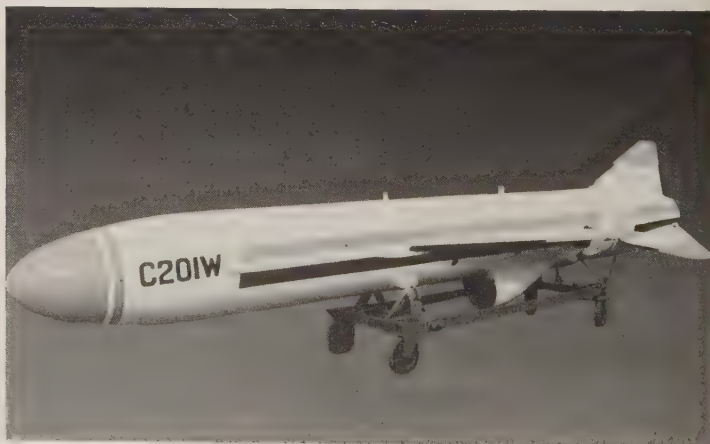
The warhead of an HY-2 missile. The hollow of the shaped charge is clearly visible at left. (*Missiles and Spacecraft*, PRC)



The arrangement of the HY-2 missile: (1) radar seeker, (2) fuel tank, (3) shaped-charge warhead, (4) oxidizer tank, (5) auto-pilot, (6) terminal homing electronics, (7) booster, (8) sustainer rocket motor. The related C201W carries its terminal homing electronics in place of the oxidizer tank of HY-2; the turbojet takes up the after electronics compartment. (*Missiles and Spacecraft*, PRC)



A C101 missile in flight. (CPMIEC)



C201W, showing the turbojet air intake under its body. (CPMIEC)



C601 under the wing of a PRC Badger (B6D) bomber. (CPMIEC)



C801 next to its shipping and launching container. (CPMIEC)



C802, showing its underbody air intake. (CPMIEC)



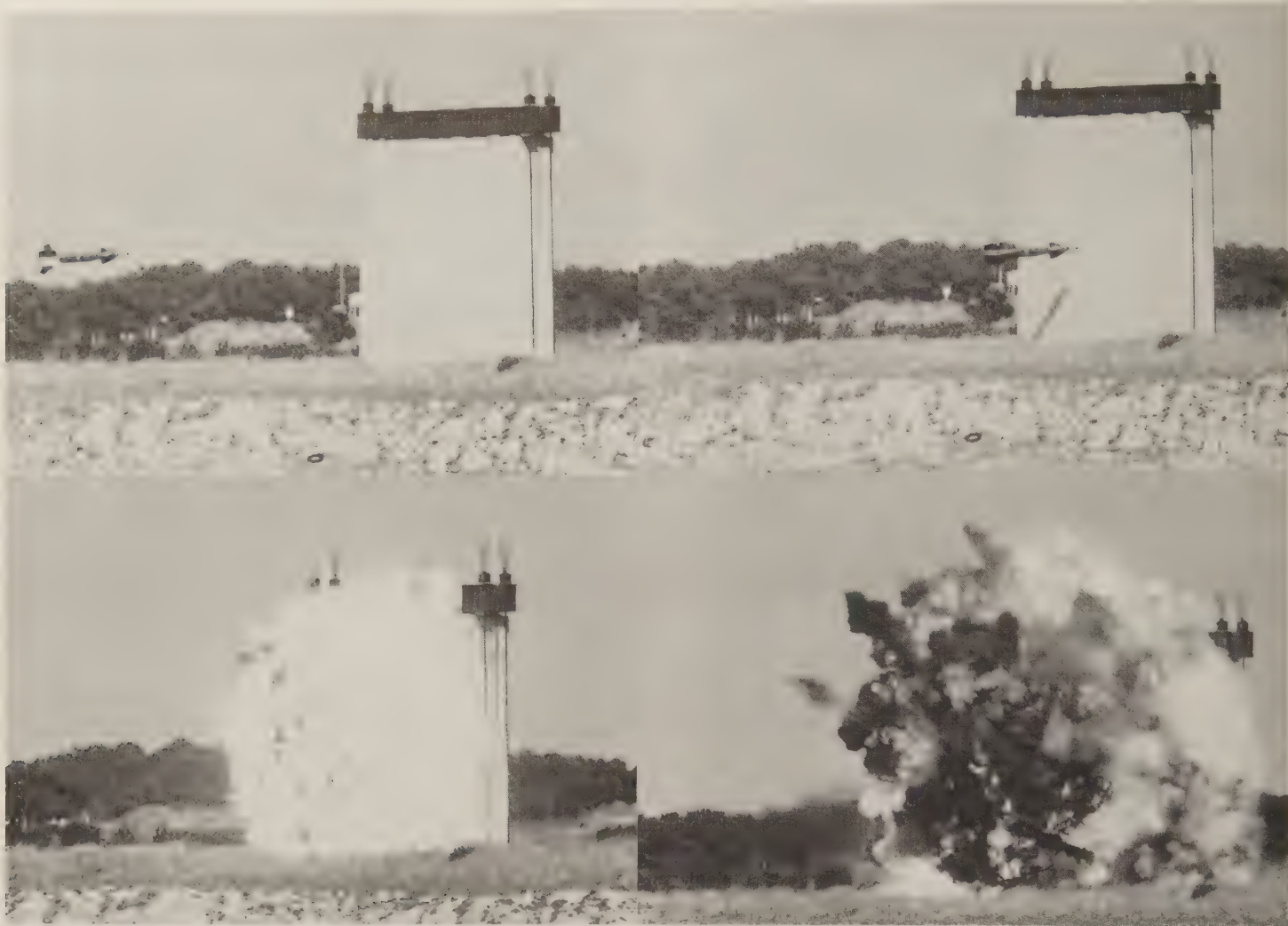
ARMAT antiradar missiles carried by a French Air Force Mirage 2000 (the smaller weapons are Magic 2s). (MATRA)



Standard French air-to-surface weapons on display at Bourget Naval 1990: AS 30L is in the foreground, and the lighter AS 15TT is behind. Note the laser-seeker window in the nose of the larger missile. As of February 1991, AS 30L had already been used in Desert Storm. (Author)



ANS at Bourget Naval 1990. (Author)



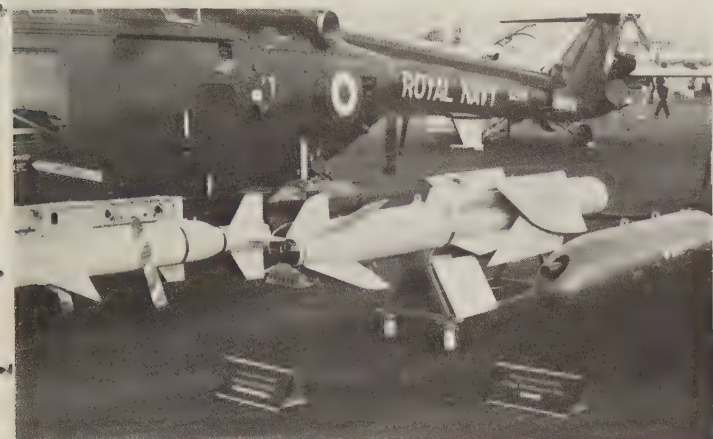
A MATRA BGL 1000 laser-guided bomb in action; note that the bomb approaches horizontally. (MATRA)



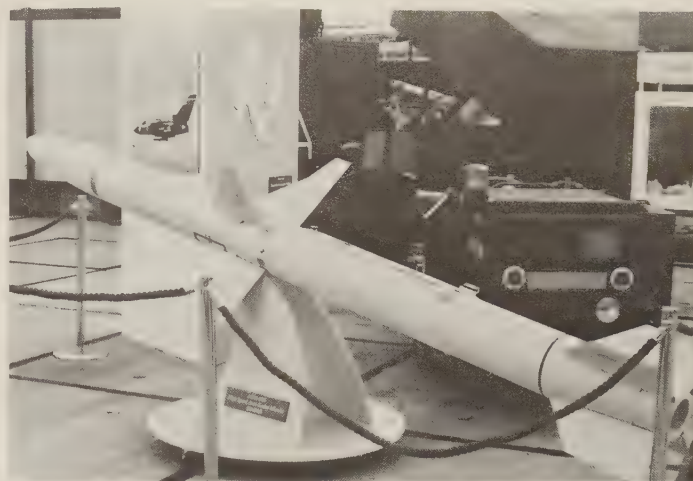
Durandal. (Author)



Marte Mk 2, with an underbody booster allowing launch by a hovering helicopter, displayed at Farnborough in 1990. (Author)



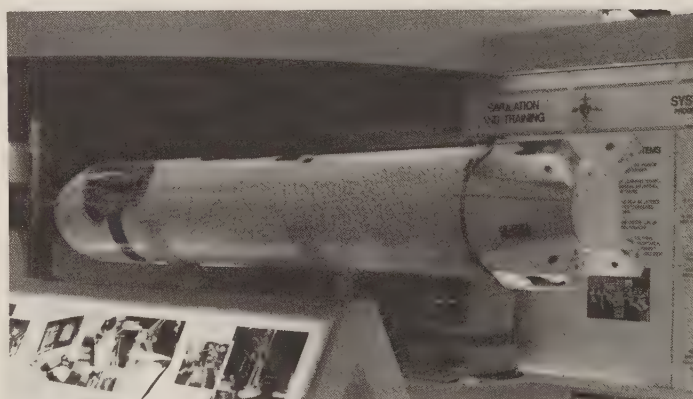
Penguin Mk 7 Mod 2, with a competitor, Sea Skua, in the background at left in 1990. The helicopter is a Lynx. (Author)



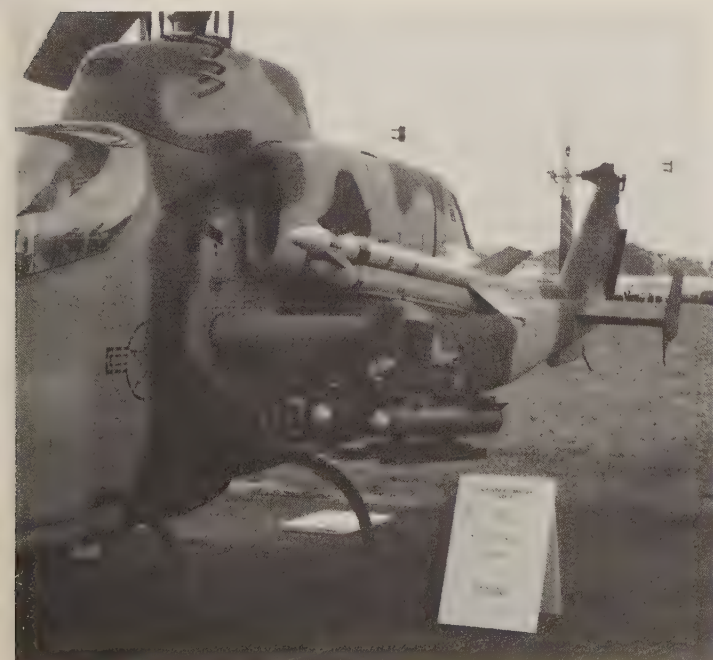
HARM in 1990. (Author)



A pair of Sea Skuas on standard rails alongside a Lynx helicopter in 1990. (Author)



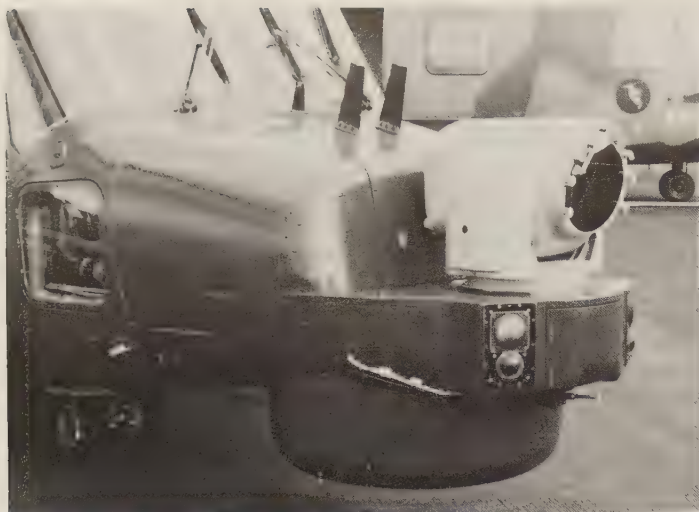
Rockeye, with bomblets just visible in the cut-away section at the nose. (Author)



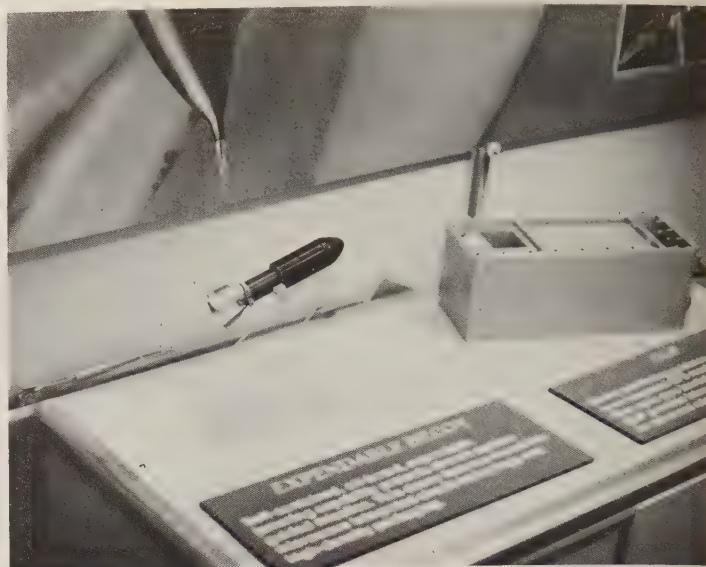
A marine AH-1 helicopter carries Sidarm, a pair of Hellfires, and a standard rocket pod in 1990. (Author)



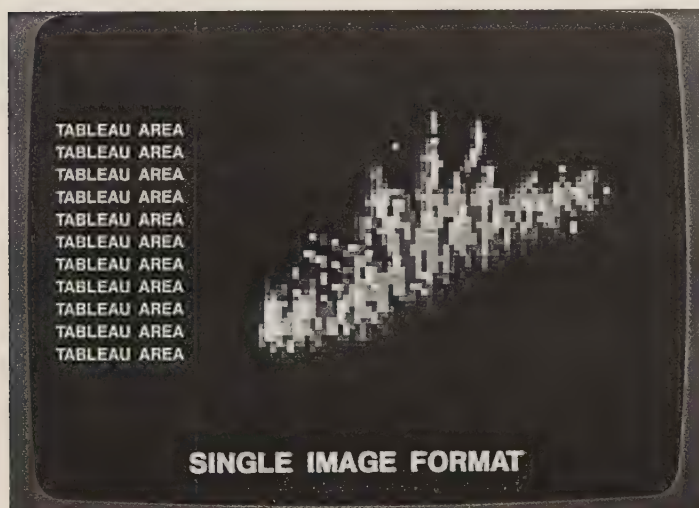
RDY radar; the small dipoles are for IFF. (Thomson-CSF)



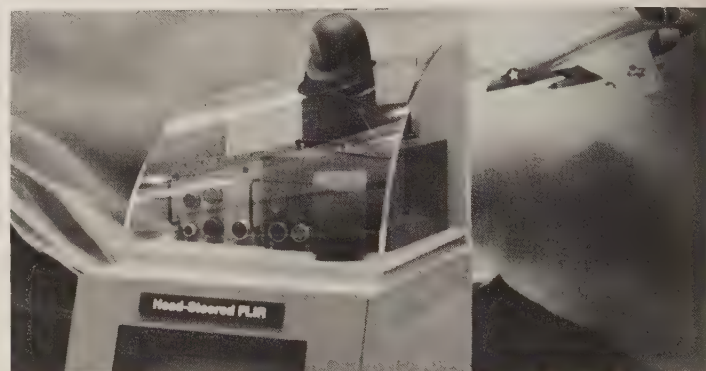
Sea Owl on the nose of the prototype Lynx HAS.8 helicopter in 1990; the spiral antennas of Orange Crop are below Sea Owl, and the radome of the Seaspray radar is below the nose. [Author].



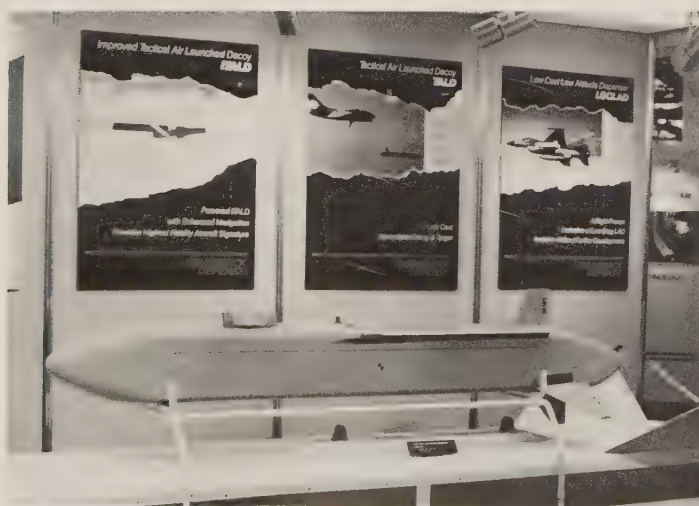
Texas Instruments's expendable decoy (GEN-X). [Author]



A typical ISAR image. (Texas Instruments)



Texas Instruments's model of a head-steered FLIR (i.e., slaved to the pilot's helmet), displayed at the 1991 U.S. Navy League show. It would be valuable for off-centerline target detection and recognition and would have 2 FoVs. A prototype has been flown over 100 hr in various mission profiles. A FLIR of this type could do away with the requirement for night-vision goggles for off-axis viewing. [Author]



A TALD decoy, with its wings folded, on display at Farnborough in 1990. The poster at left shows the Brunswick proposal for a powered ITALD, the intake for which would be below the device's body. [Author]



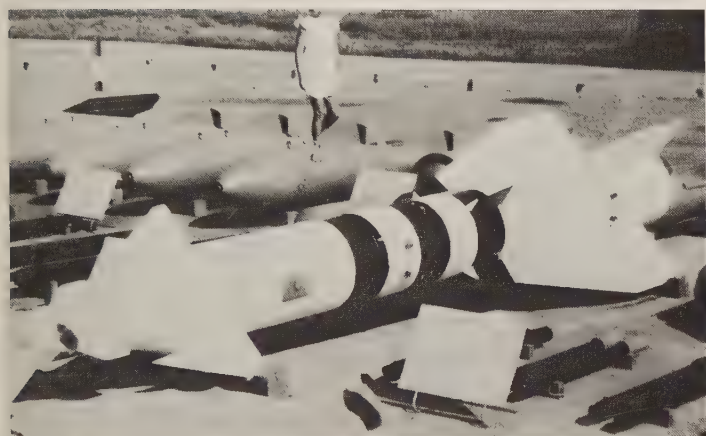
AS-9 antiradar missile. Note the strong family resemblance to the much larger AS-4 and AS-6. This example was displayed in Baghdad in 1989. The missile in the background is Nissan-28, apparently a Soviet-supplied AA-7 mocked up to simulate an antiship weapon.



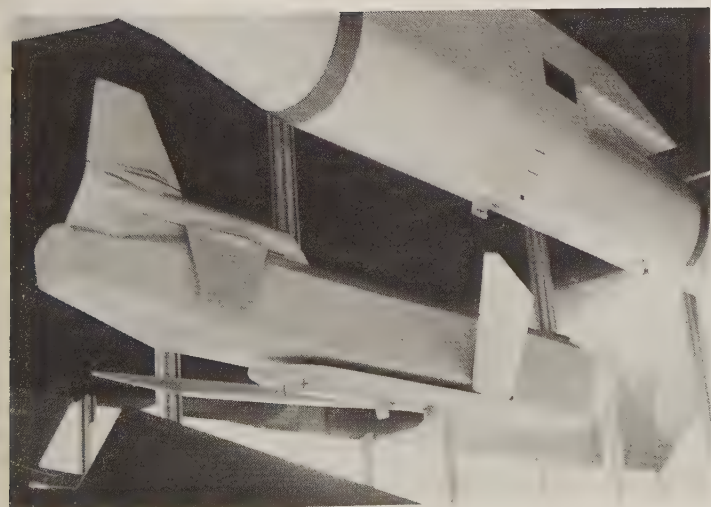
AS-10, with a large-caliber unguided rocket to the far left.



AS-11.



AS-14.



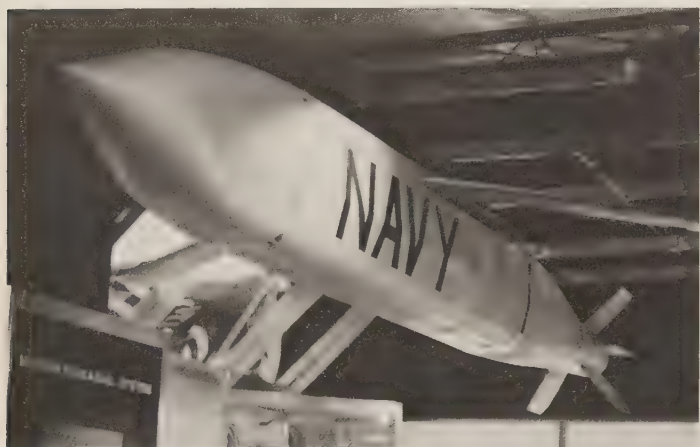
The Hughes/McDonnell Douglas version of AIWS shows folding tail fins and angled sides for minimum direct radar reflection. The missile below is the Raytheon-Hughes version of AAAM. (Author)



HARM Block IV seeker head, displayed by Texas Instruments at the 1991 U.S. Navy League show. The object in the background is a radar antenna through which a missile of this type had passed, signed by the members of the development team. Note the spiral antenna in the missile's nose. (Author)



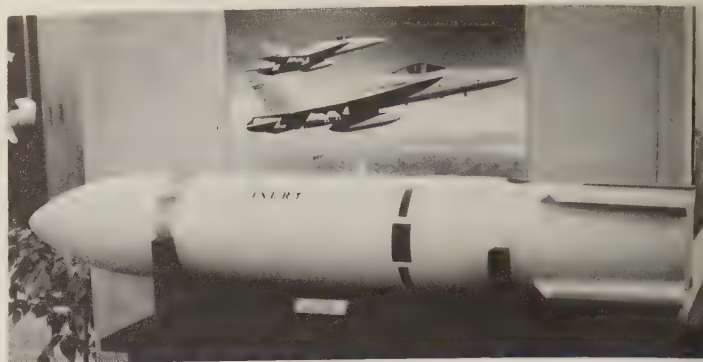
Boeing's version of AIWS, displayed at the 1991 Navy League show. (Author).



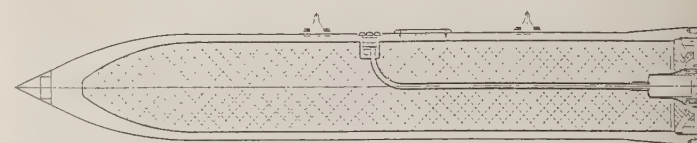
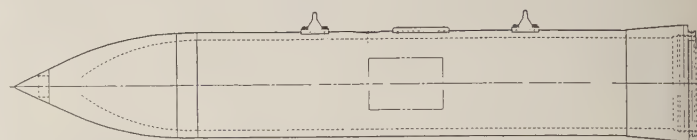
The Texas Instruments/LTV version of AIWS, displayed at the 1991 Navy League show. (Author)



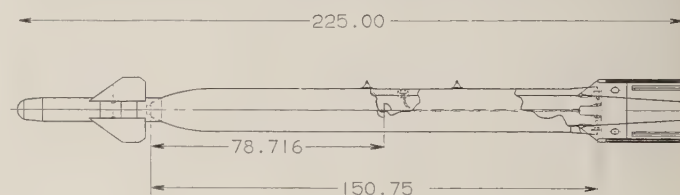
The Martin Marietta version of the Advanced Bomb Family, as displayed in 1991. The bomb control units would be inserted to provide inertial guidance. (Author, from a Martin Marietta poster)



The McDonnell Douglas version of a 500-lb Advanced Bomb Family bomb. (Author)



BLU-109/B hard-target penetrator, used extensively against Iraq. (Lockheed)

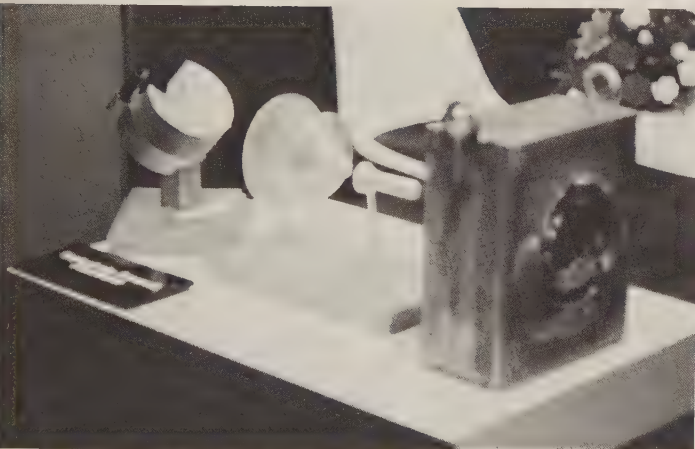
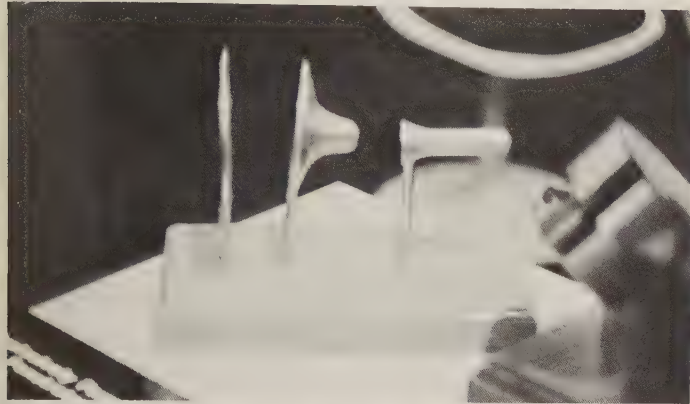


WEIGHTS (LBS)

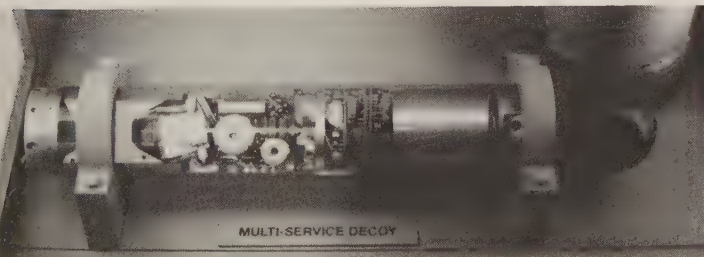
PENETRATOR	44.4
GUIDANCE KIT	258

TOTAL WEIGHT	4672
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GBU-28 hard-target penetrator, used at the very end of the war against Iraq. It went from concept to use in only 22 days. (Lockheed)



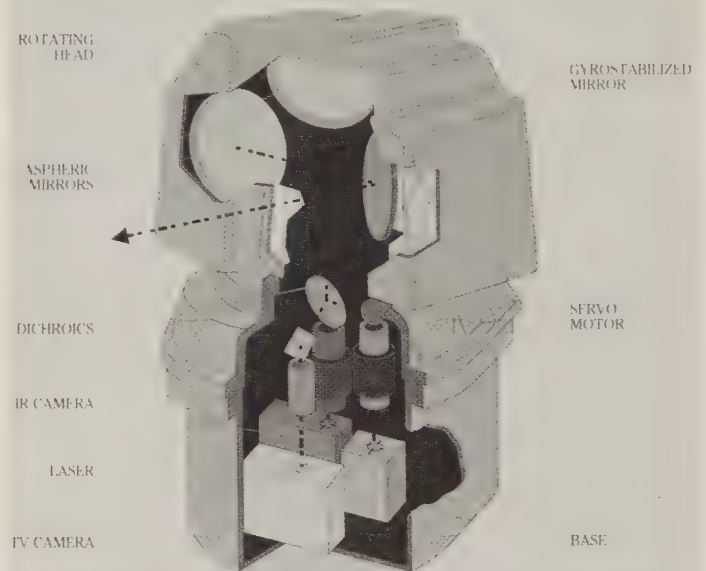
A typical armor-piercing slug formed by a modern bomblet, in this case a Sensor Fuzed Weapon, i.e., a bomblet that explodes at a standoff from its target (the object is cut away to show its cross section). The 3 pieces of metal represent stages in the formation of the slug, and the armor plate shows what it can do. This is a modern shaped charge, using very little cone angle to produce a very considerable effect. This type of technology in turn makes for smaller bomblets, more of which can be packed in a standard-size dispenser. This weapon was displayed by Textron at the 1991 U.S. Navy League show. (Author)



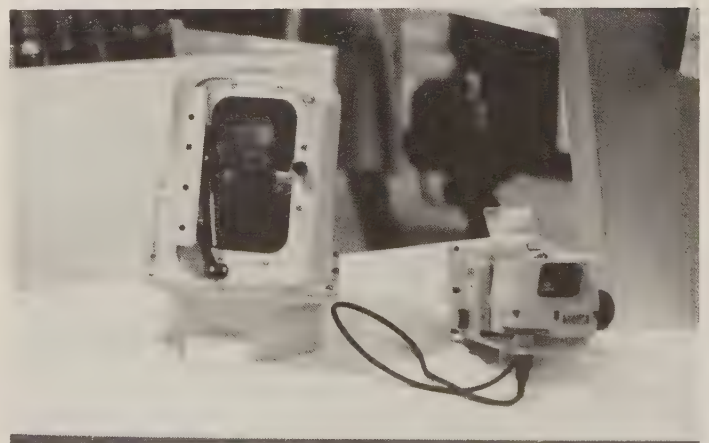
The Naval Research Laboratory (NRL) displayed this multiservice decoy (MSD) at the March 1991 U.S. Navy League show. It is a towed airborne decoy developed in response to a 1987 request by the JAEDO (Joint Air Expendable Decoy Office). It has been under flight test since 1988 to explore both decoy aerodynamics and overall system effectiveness.



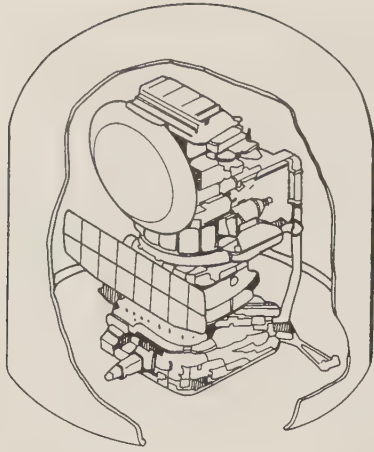
MRR, the successor to Triton, as shown at Bourget Naval in October 1990. The upper antenna is IFF. (Author)



The operating principle of the Volcan IRST. (SAGEM)



The two smaller members of the Volcan family, VIGY 50 and SAS 90 (left and right) in 1990. The base of a Volcan is just visible at upper left. (Author)



The Japanese FCS 2-12. (*Ships of the World*)



MW-08 on board the new Portuguese frigate *Vasco da Gama* in 1990 (Signaal)



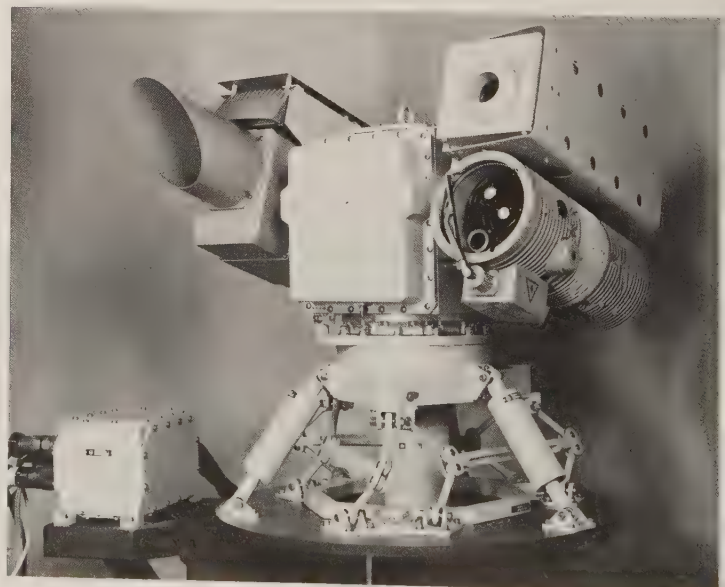
The MR 05 antenna. (Signaal)



SCOUT, the new Signaal stealthy radar. (Signaal)



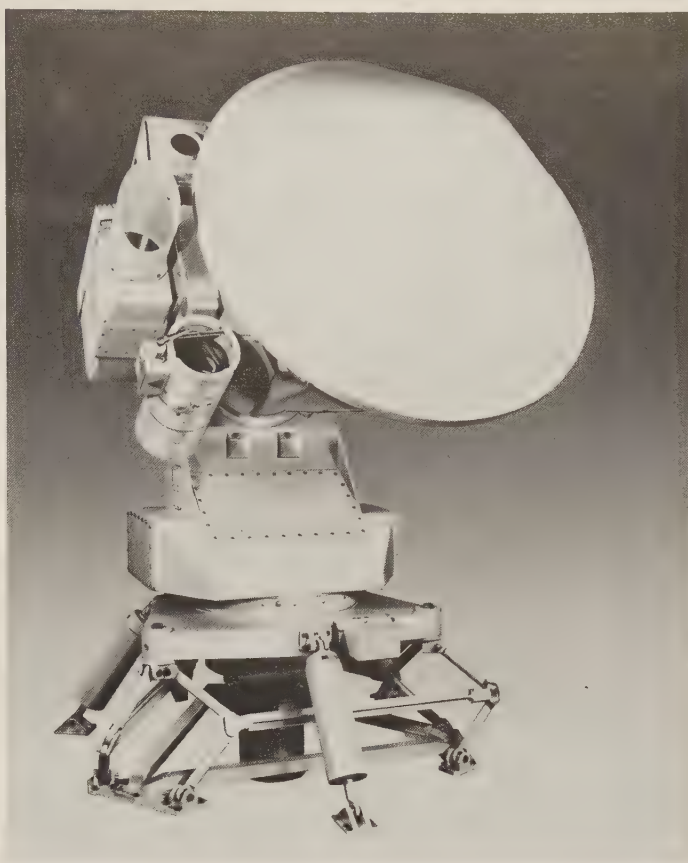
SMART. (Signaal)



A LIOD optronic director carrying a daylight television, FLIR, and laser range-finder. (Signaal)



LIROD, the radar version of LIOD. (Signaal)



STING, Signaal's missile-tracking system, shows a laser range-finder, a daylight TV camera, and a FLIR camera at left, in 1990. (Signaal)



Gemini carries the X-band acquisition radar developed for Goalkeeper (the long slotted array) and a Ka-band tracker (as in LIROD) as well as a laser range-finder in 1990. The director can also carry a FLIR. Gemini has not yet been sold, but apparently it is now being marketed in container form. (Signaal)



Head Net C with Hour Glass atop it on board a Soviet Krivak-class frigate, 1990. (H. J. Verhoefen)

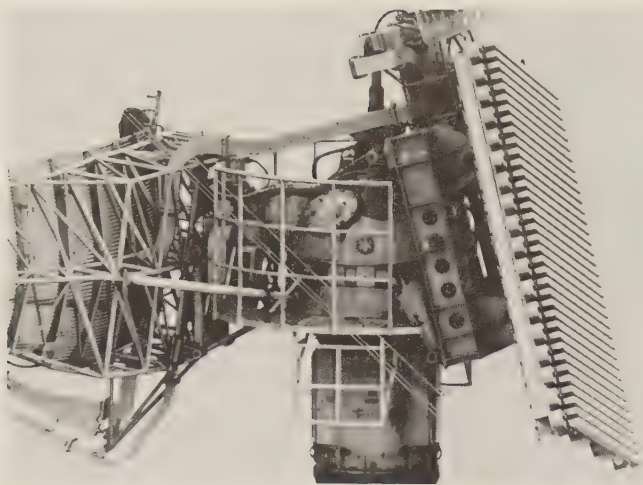


Plate Steer. Note the 2 waveguides feeding the antenna at left; the larger (lower-frequency) of the 2 extends back up to the IFF array at right and is presumably used for IFF by both antennas. The characteristic serpentine feed of a frequency-scanning radar is visible on the outer edge of the right-hand antenna. Note that the array is not vertical.

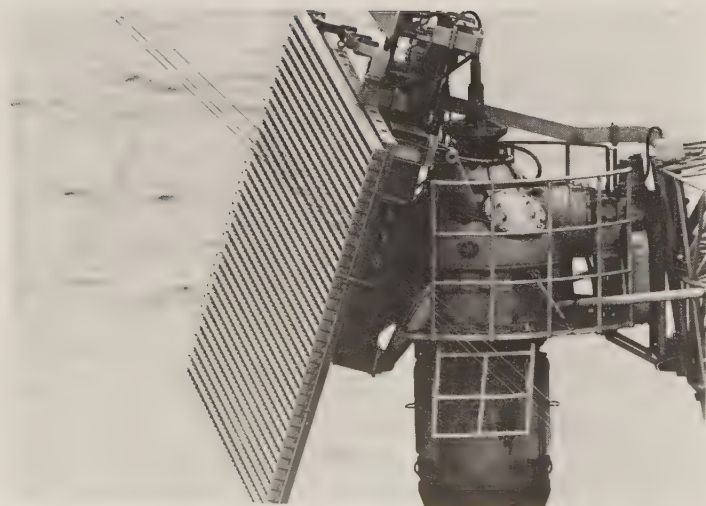
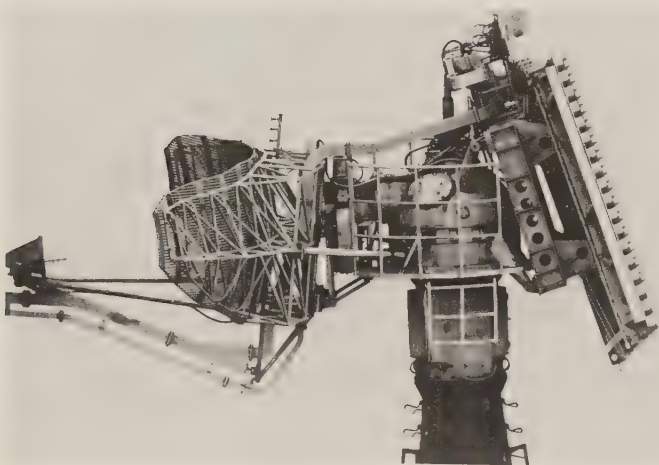
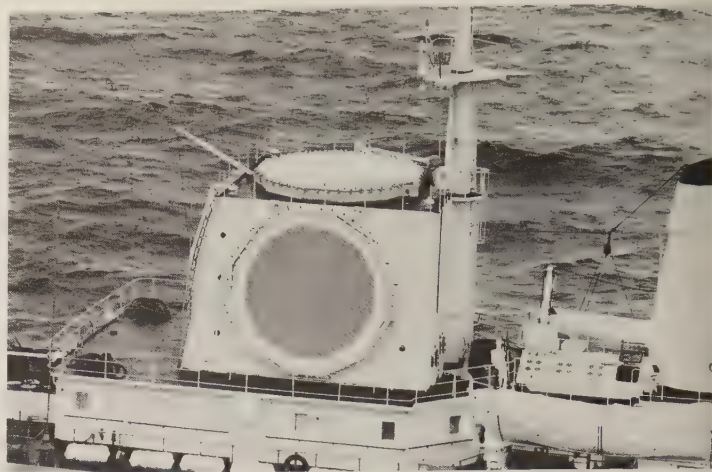
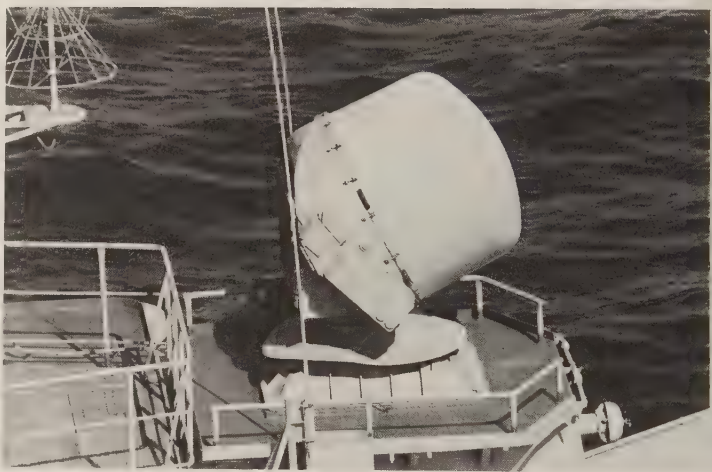


Plate Steer.



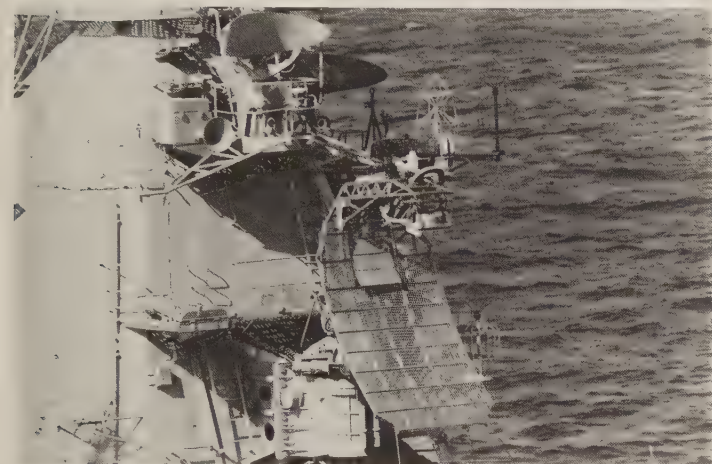
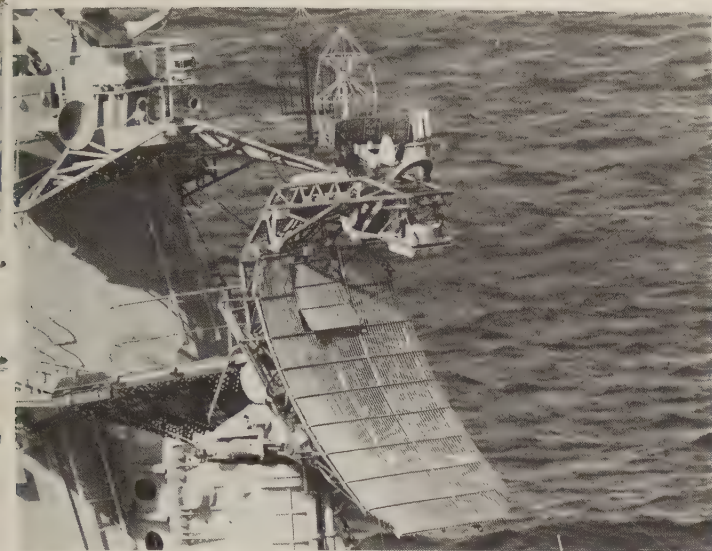
Mad Hack. Note what appear to be arms to lift the flat plates; they may well be covers for some device inside the deckhouse rather than antennas of any sort. The top plate lacks the darker-colored pattern of the side plate, which may have been intended to simulate an antenna.



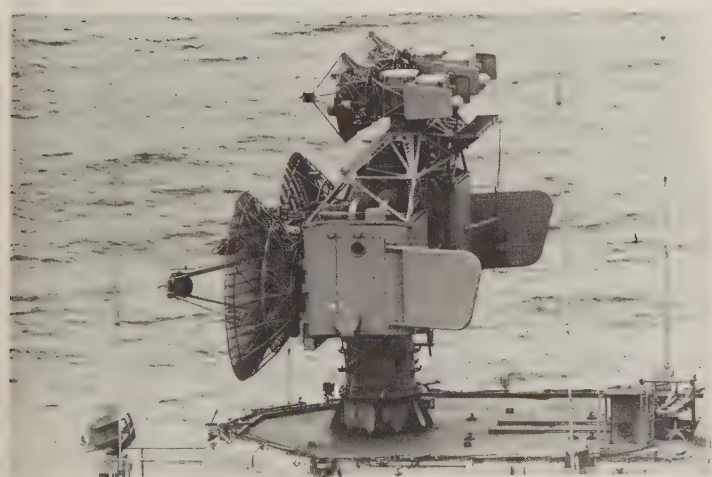
Bass Tilt.



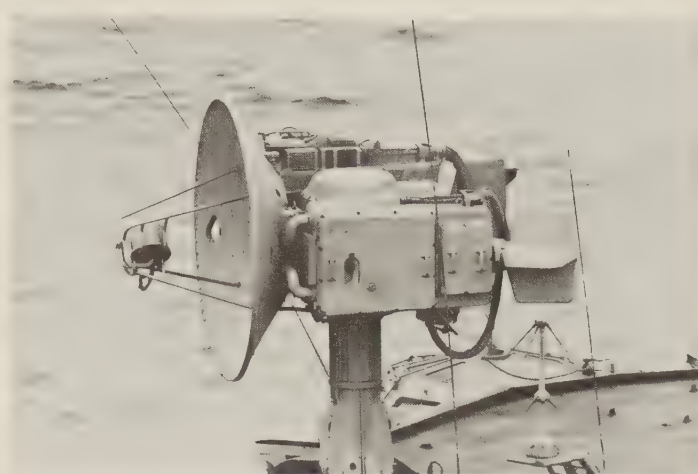
Drum Tilt radar at the masthead of the former East German training ship *Wilhelm Pieck*, which was visiting London in 1990. The slotted arrays are the standard TSR-333 used on board many East German warships. (B. Sullivan)



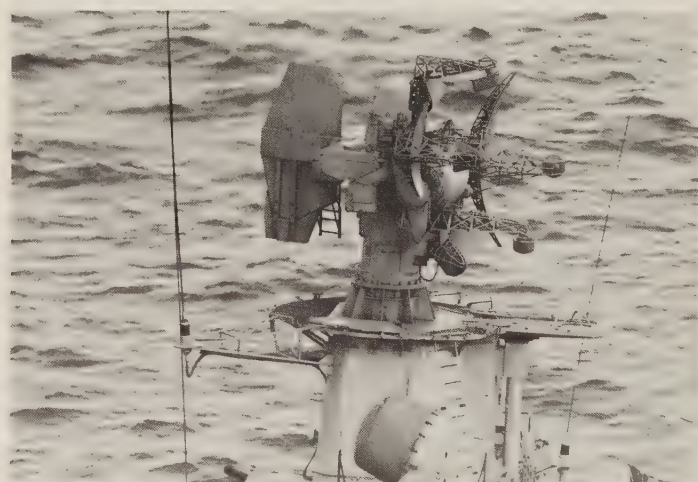
Front Door/Front Piece on board a *Slava*-class cruiser, with what appears to be a surface-search antenna mounted directly atop it. This small antenna is presumably used to acquire the beacon signal from the missile. The larger surface-search radars are Palm Fronds.



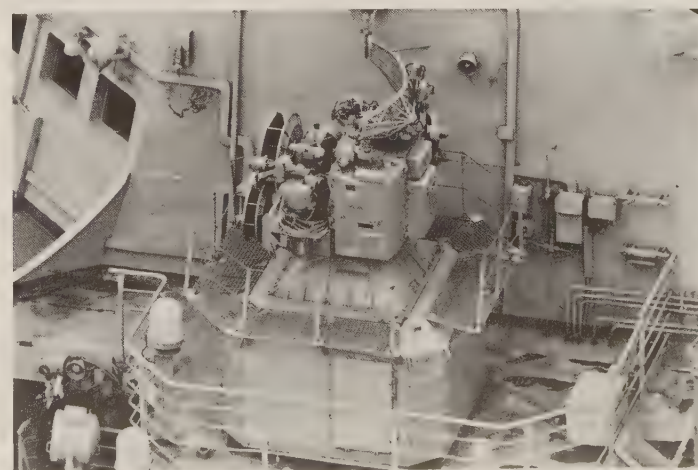
Head Lights. The circular shape of the feed on the left suggests a vertical scan rather than a monopulse cluster. The barely visible but apparently cylindrical feed of the other antenna appears to be horizontal. That would suggest that, like Peel Group, this director scans separately in elevation and in train (using the far-side antenna for that). In that case it continues the TWS technology of the earlier systems, each pair of antennas (large and small) constituting a single TWS unit.



Owl Screech, showing the characteristically canted cylindrical feed and the opening in the antenna for an EO camera.



Peel Group.



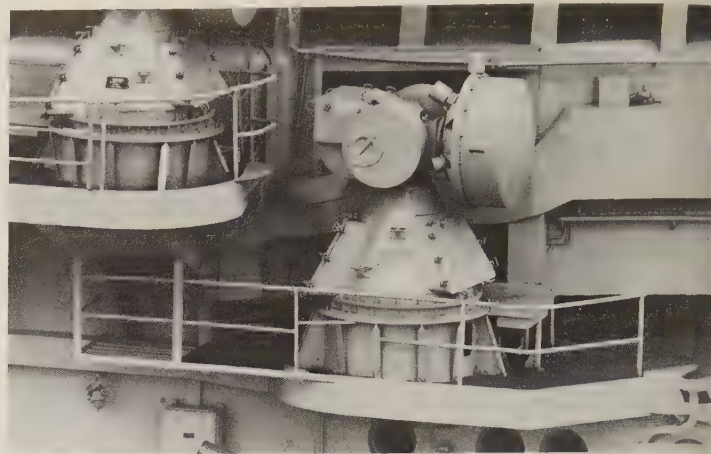
Pop Group.



An optical director on board a *Sovremennyy*-class destroyer, 1990. (H. J. Verhoefen)



Top Knot (TACAN equivalent) on board the Soviet carrier *Kiev*, with Top Plate in the background and Vee Bars long-range communication antennas.



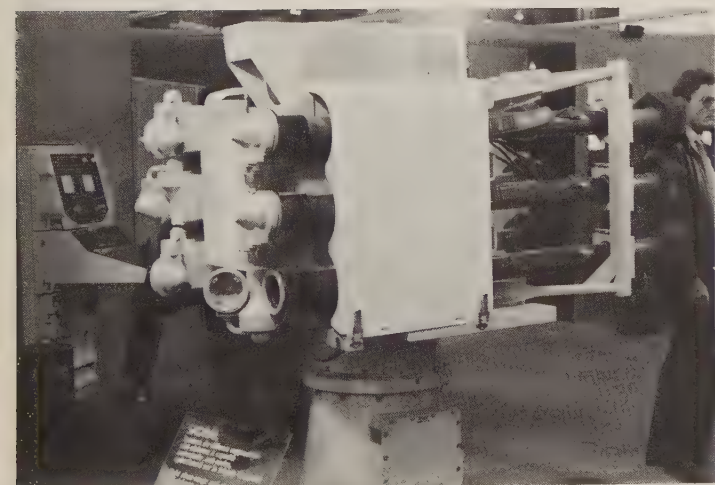
Fly Traps for carrier-controlled landing, these devices appear on board Soviet carriers and helicopter-carrying surface combatants.



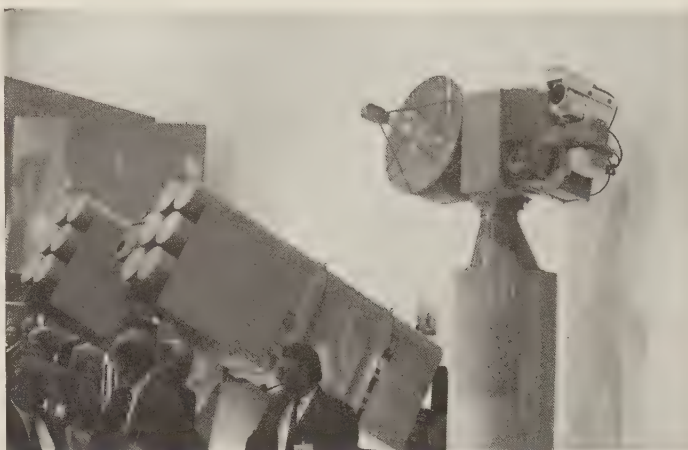
The *Kiev* shows a pair of SA-N-3 missiles on her after launcher. They appear blunter than they are because the dark nose radomes blend with the ship's superstructure. Note the 2 elevated dishes (missile trackers) of the ship's after Head Lights missile director. The small radomes alongside the lower one of the upper pair of Side Globes are Bell Bashes; the lower pair (not visible here) is associated with Bell Thump.



NAJIR Mistral displayed at Bourget Naval, October 1990. (Author)



Sadral, the 6-missile automatic Mistral launcher. Note atop the launcher the optronic sensor that acquires and tracks a target before the missiles are fired and in front the doors that protect the missile seekers before launch. The missile tubes are removed whole for reloading (note the straps atop the tubes at right). (Author, 1990)



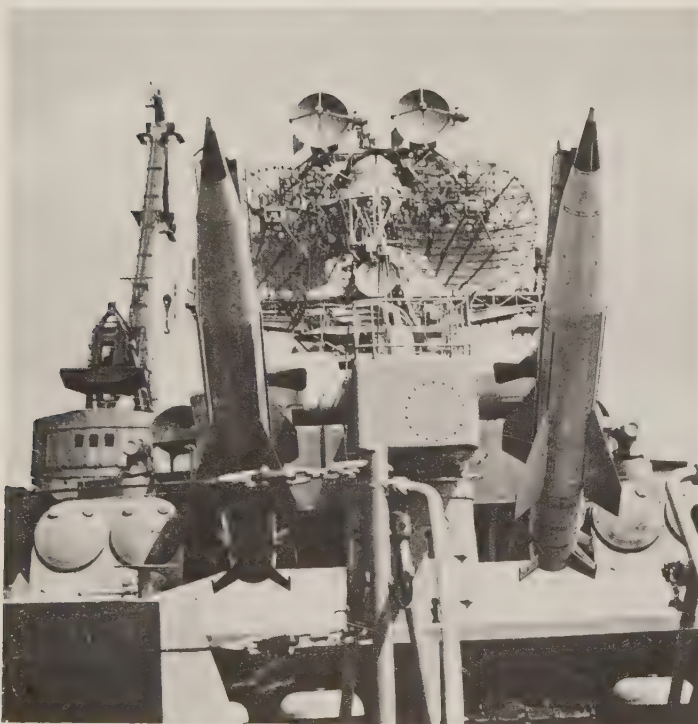
The Crotale NG launcher (left, with the optronic sensor mounted between the 2 banks of missile tubes) and its associated CTM radar/optronic director (right), as displayed by Thomson-CSF at Bourget Naval, October 1990. (Author)



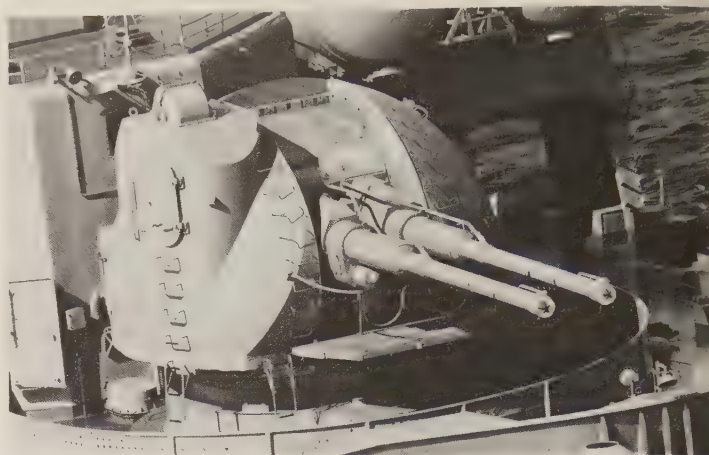
The VT1 missile of the Crotale NG system in 1990. (Author)



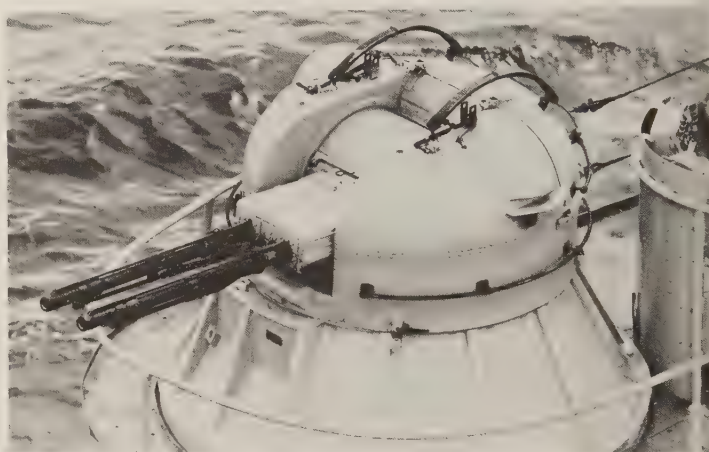
The Mauser Vierling CIWS gun. The Mauser Vierling is also now being called Taifun. First sea trials (1991) will be run with a modified Bofors L70 mounting. An entirely new mount should be ready in 1993. Meanwhile, the German navy is leasing Goalkeepers as interim replacements for the RAM missiles planned for its frigates. (Mauser)



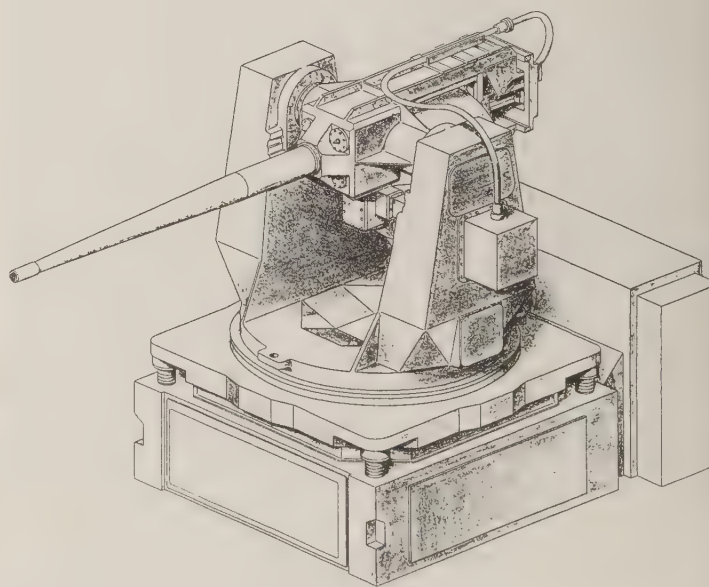
A pair of SA-N-3 missiles are shown on their rails on board a Soviet Kara-class missile cruiser, with their Head Lights fire-control radar visible between them. The large tubes are for SS-N-14 ASW missiles.



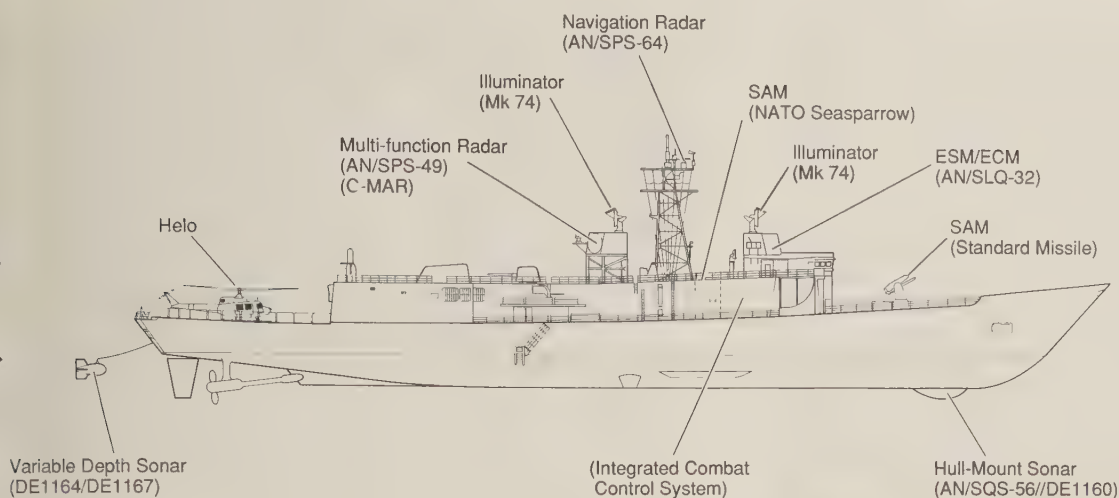
A standard Soviet twin 130-mm mount.



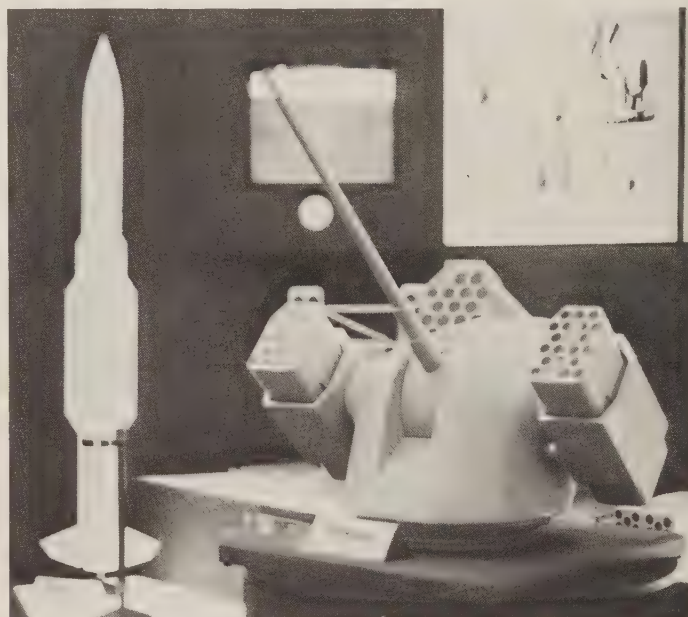
Soviet twin 30-mm (AK-230) mount. Presumably, the tub at right is for local control.



The FMC ETC gun being developed as a possible future close-in defensive gun. (FMC)



Raytheon's version of a modified *Perry*-class frigate shows its C-MAR phased-array radar (above the bridge and abaft the mast; the forward faces are incorrectly marked "ESM/ECM" because the SLQ-32 is abreast the forward phased-array block). The Mk 74 MFCS replaces the Mk 92 "egg" and STIR of the standard U.S. frigate. This is presumably the version that Raytheon has proposed to Taiwan for its eighth *Perry*-class frigate. (Raytheon)



General Dynamics's Sideshooter proposal: two 21-rnd RAM launchers alongside a 5-in/54 mount (the third launcher, visible above the gun mount, is separate). (Author)



AIM-7R and RIM-7R will have both IR and semiactive radar seekers. This is the nose of an AIM-7R Sparrow, displayed at the March 1991 U.S. Navy League show. (Author)



A model of SM-2 Block IIIB at the March 1991 U.S. Navy League show has a bulge forward for its IR sensor (visible on the right-hand side of the missile). The square objects visible near the tail are clips for the launch rail. (Author)



The General Dynamics/Westinghouse version of AAAM. Note the vectored-thrust controls in the booster and the strong family resemblance to the Standard Missile. (Author)



The Hughes/McDonnell Douglas version of AAAM, showing folding tail fins for tighter packing. (Author)



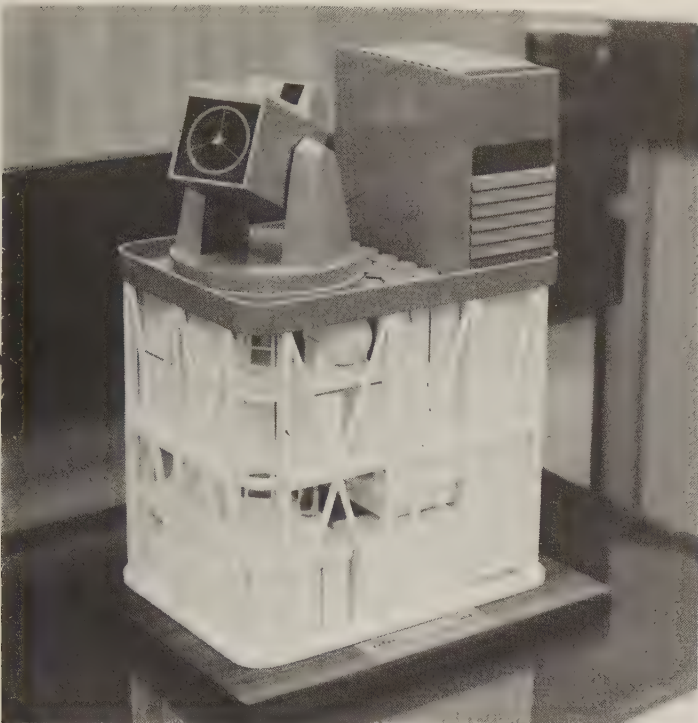
The General Electric version of Phalanx Block II, using a 35-mm telescoped-case gun. Note the separate tracking radar and the slit for 1 of the electro-optical sensors atop the tracking radar. (Author)



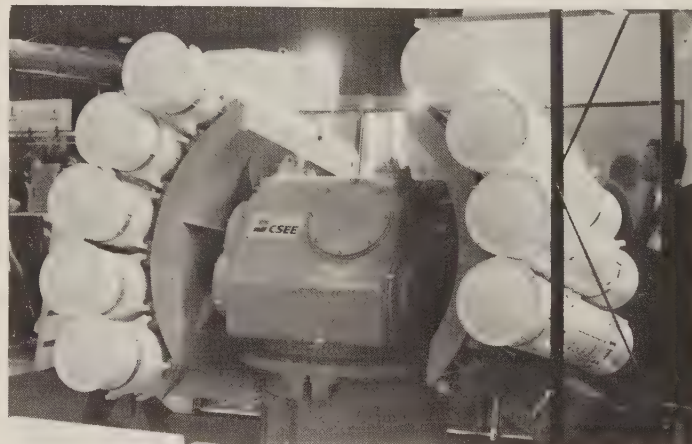
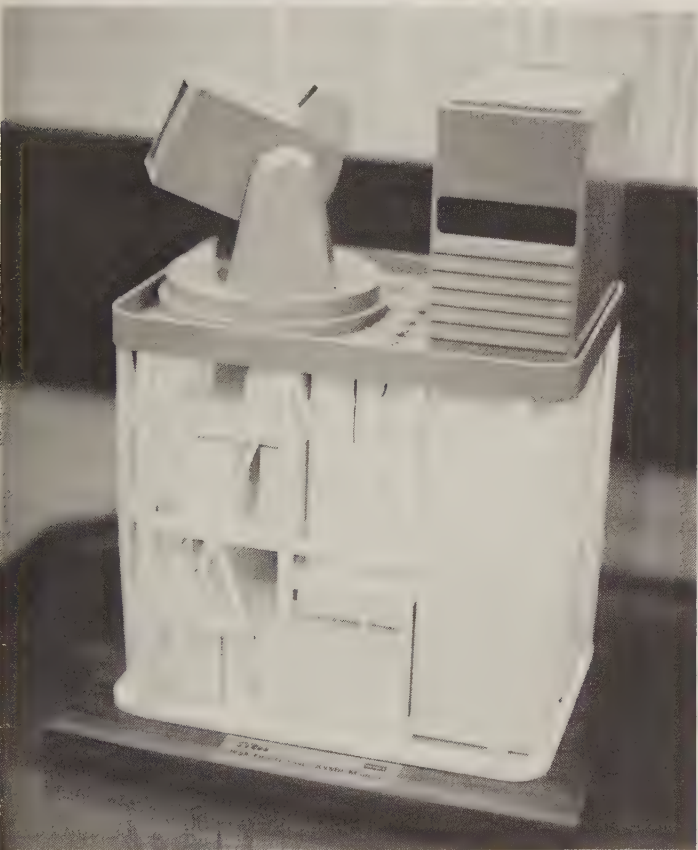
A General Dynamics Phalanx Block II concept using twin 25-mm telescoped-case guns. (Author)



General Dynamics models of possible Phalanx Block II guns, with the radar/EO dome removed to make them clearer. The model on the left shows the Oerlikon 25-mm gun. On the right is a 6-barrel Tround. (Author)



DAGAIE Mk 2 in 1990, showing the SAGAIE tubes between the standard "suitcases." (Author)

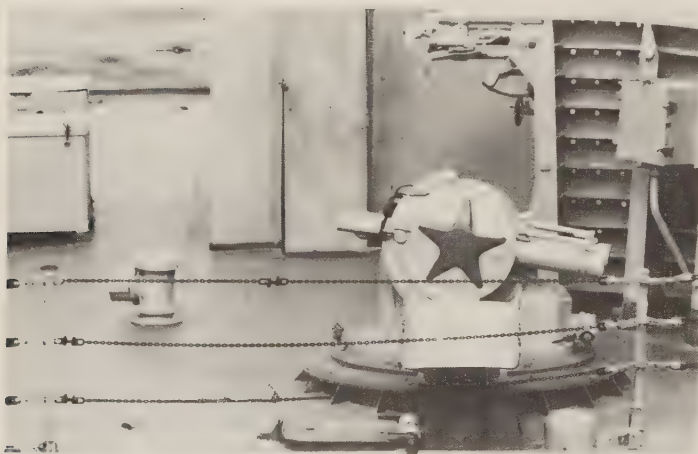


SAGAIE in 1990. (Author)

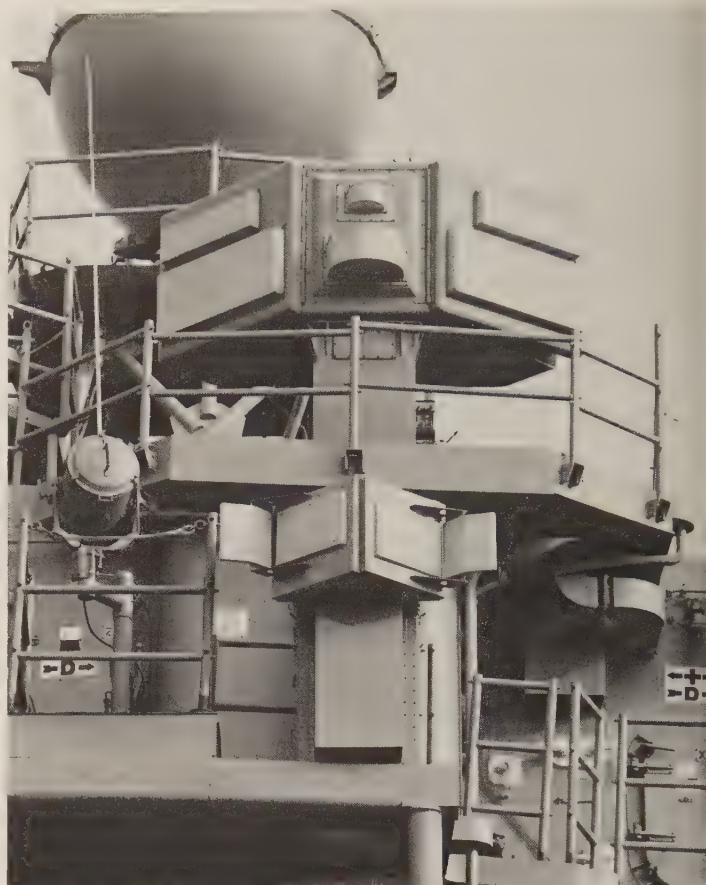
TRW's model of a shipboard air-defense laser, displayed at the March 1991 U.S. Navy League show. The beam director is at the left, the exhaust stack at the right. The tubes just to the right of the beam director contain the fuel. The entire system occupies the same space as a VLS launcher. (Author)



Current and future French decoys in 1990: at left is the SAGAIE IR decoy, and at right the new active decoy (LAD, *leurre actif decalé*). (Author)



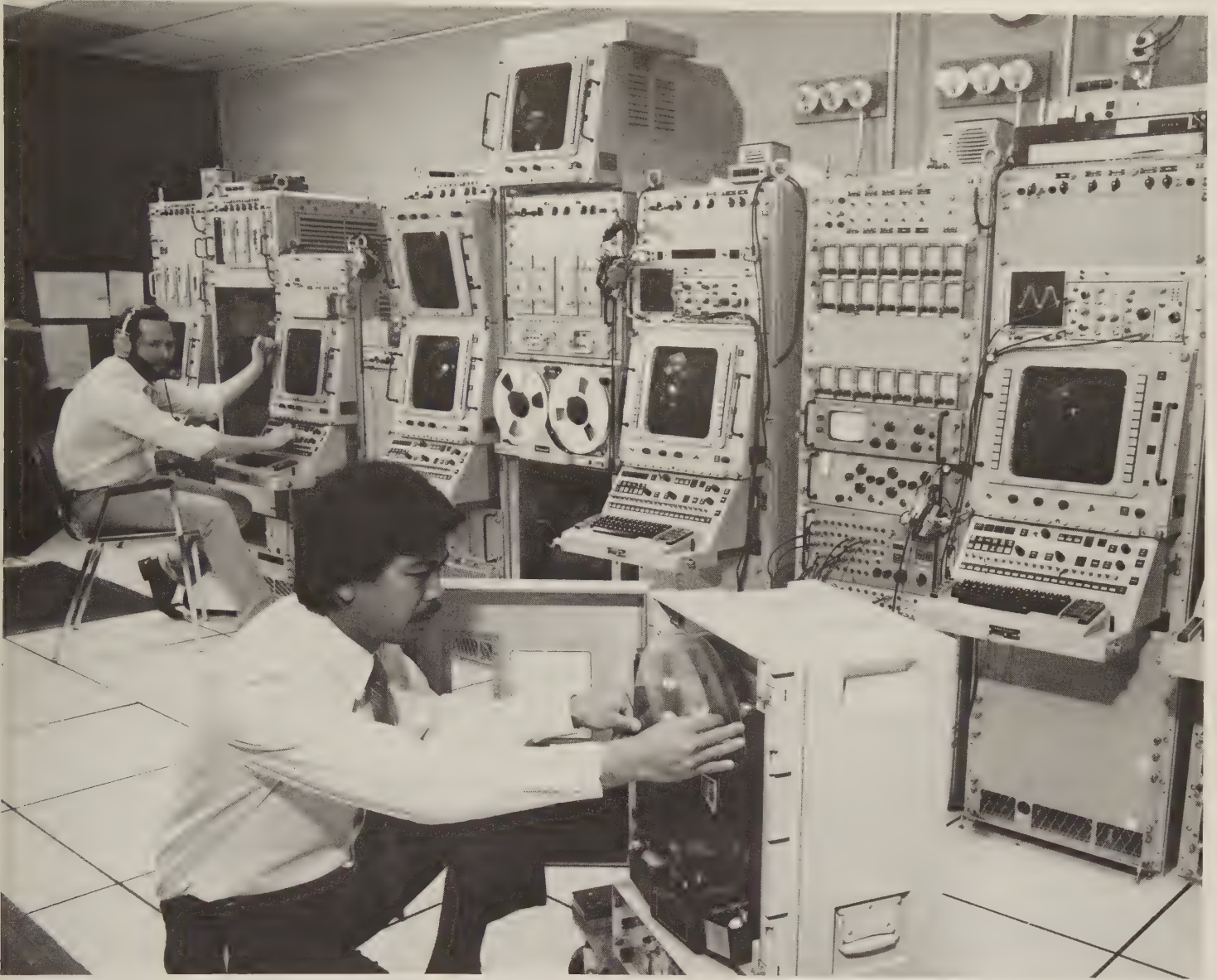
A standard Soviet twin chaff launcher.



SLQ-32(V)2 (above) and Sidekick (below) on board a *Perry*-class frigate. (Raytheon)

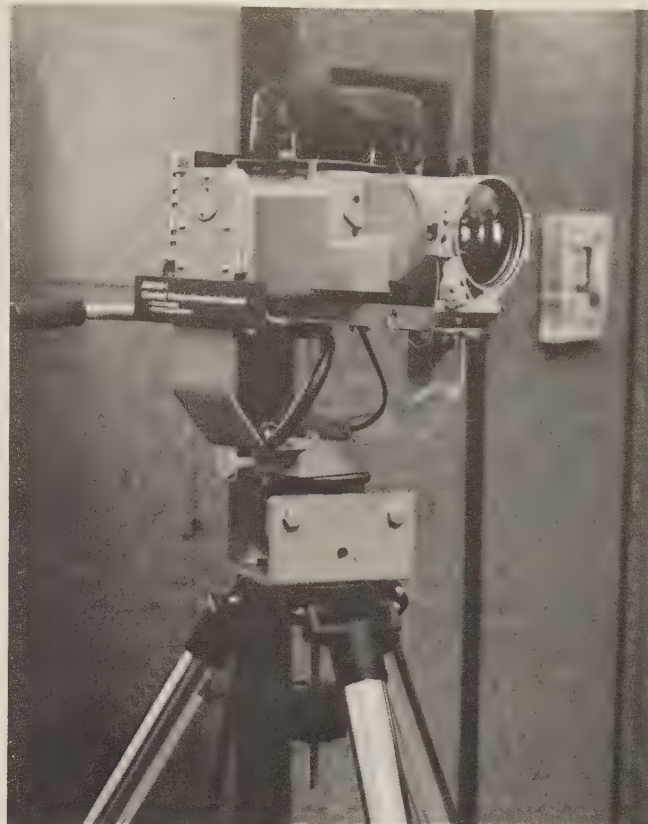
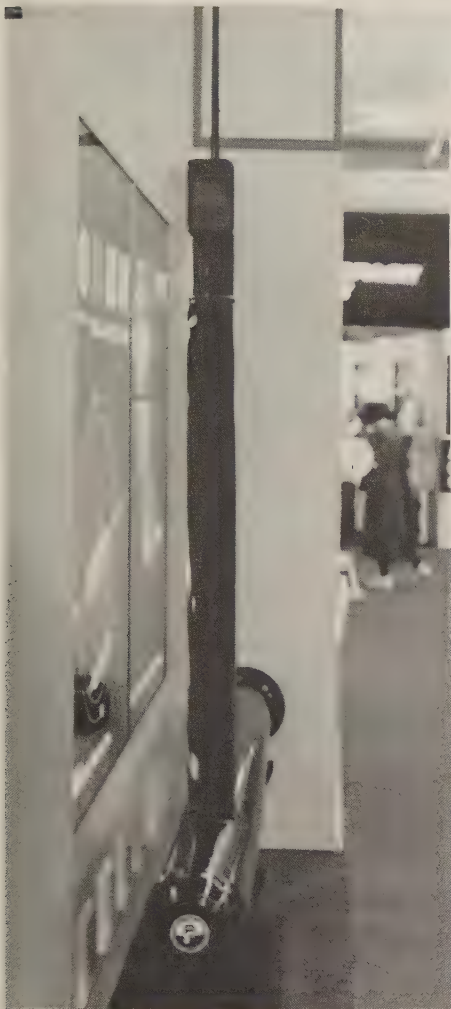


Raytheon's Advanced Electronic Warfare Console, as displayed at the 1991 U.S. Navy League show. (Author)



WLQ-4 under test and installed on board a submarine (looking aft on the outboard side). By the time production of the basic version had been completed in 1987, 43 had been made for use on board SSN 637-class submarines. A modified version will equip the new *Seawolf*. WLQ-4 automatically searches the assigned portion of the spectrum, acquires, and processes signals. Reporting, logging, and bookkeeping are all automatic. Real-time-measured data is semiautomatically fused with external system inputs. All of this requires 400,000 lines of UYK-20 code plus 50,000 lines of executable code in 40 microprocessors. (GTE)

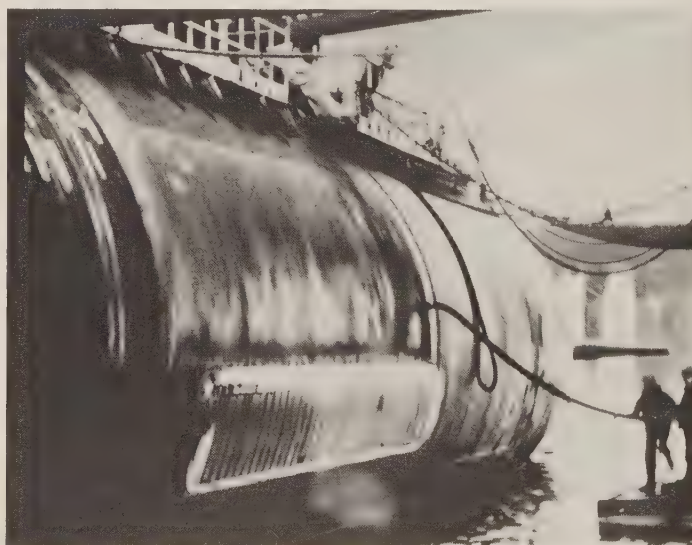




The Brunswick KAS-1 laser, chemical-warfare directional detector (CWDD) uses a common-module, 60-element FLIR (with 2 FoVs). It is the U.S. Navy's current standard standoff nerve-gas detector. A comparison of images in the filter's 3 bands is used for gas detection; the FLIR can also be used for night surveillance, navigation, and search and rescue. FoVs are 3.4×6.8 (resolution 0.40 mrad) and 1.1×2.2 (resolution 0.13 mrad) deg. Minimum resolvable temperature is 0.3 deg at 3 cycles/mrad, 6 lines/m at 1 km. The sensor weighs 28 lb (plus 18 for the power control unit). (Author)



Martin Marietta's Night Surveillance System (NSS). (Author)



The Thomson Sintra submarine flank array. (Thomson Sintra)



The French Salmon VDS fish in 1900. A model of the standard handling equipment is in the background of the side view. (Author)



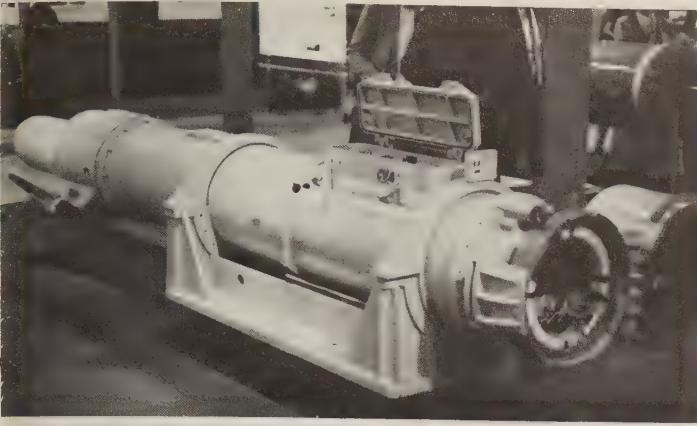
The SAGEM PIVAIR periscope head in 1900. (Author)



Standard French sonobuoys, showing a rotachute atop the passive DSTV 4M at left and ballute/antenna floats on the DSTV 7B and the range-only active buoys. (Thomson Sintra)



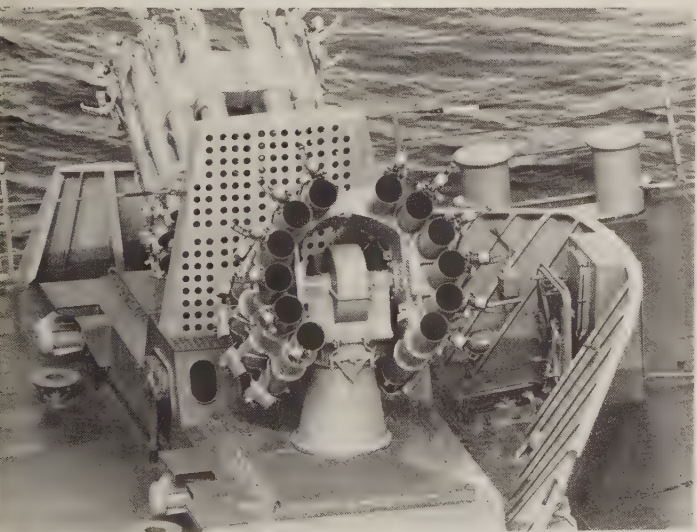
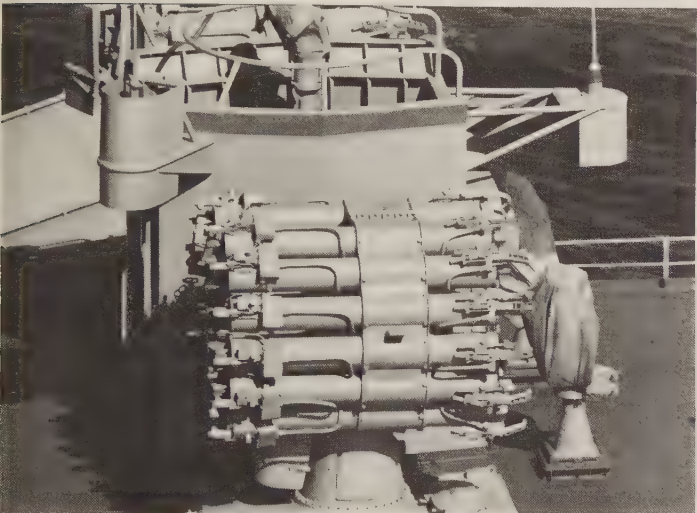
ATAS transducer body in 1900, showing the vertical stack of flextensional transducers. (Author)



The KU69 torpedo tube designed to fire Murène, 1990. (Author)



Spartacus, the French torpedo-countermeasure system. In this version ATAS is the initial detector. (Thomson Sintra)



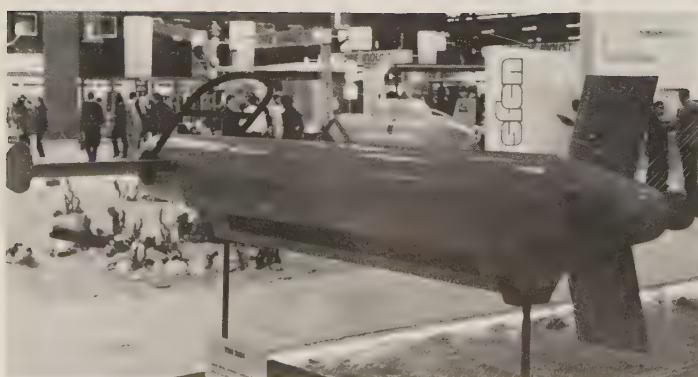
RBU 6000.



Thomson TSM 2023N minehunting sonar for the Norwegian navy, 1990. (Author)



IBIS VII self-propelled VDS minehunting sonar, 1990. [Author]



TSM 2054 towfish of the IBIS 43 system in 1990. [Author]



Sterne magnetic body, 1990. [Author]



McDonnell Douglas and Hughes launched their first advanced interception weapon system (AIWS) on 10 December 1990. The AIWS is designed to replace current standoff weapons such as Maverick, Skipper, Walleye, and laser-guided bombs. (McDonnell Douglas)



A Soviet Victor-III-class submarine displays her towed array pod atop her vertical fin. This particular submarine had fouled the towing cable of a U.S. towed array, and her crew was trying to break the cable. The submarine was trimmed down by the bow, so her unusual double propeller (two 4-bladed propellers in tandem, turning together) is visible. This type of propeller was adopted by many early steam-torpedo and destroyer builders as a way of transmitting considerable power without cavitation and without accepting unduly large propellers. The scale of the pod and fin are clear from the figure of the Soviet crewman trying to cut the cable. This photograph was taken in the fall of 1983. [U.S. Navy]



The DRS/Sparton lightweight shipboard dipping sonar, on display at the 1991 U.S. Navy League show. The electronics are at left (note the use of a laptop computer for system monitoring and control, with the larger screen reserved for the system display). At the right, the dark cylinder is the dipping transducer, with a DICASS buoy next to it for comparison. (Author)



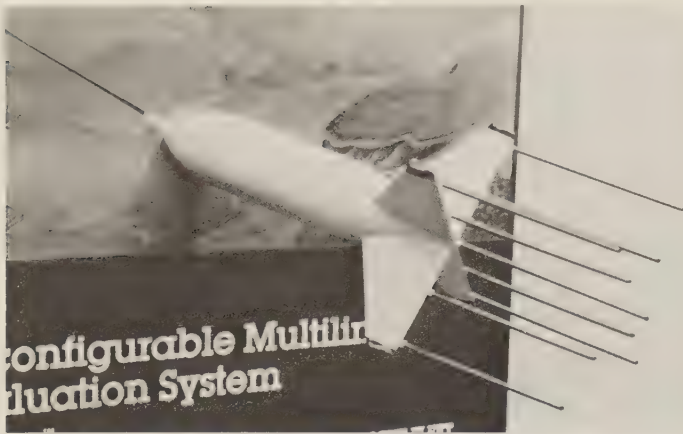
Librascope's multifunction console for the Australian *Collins*-class submarine combat system. (Author)



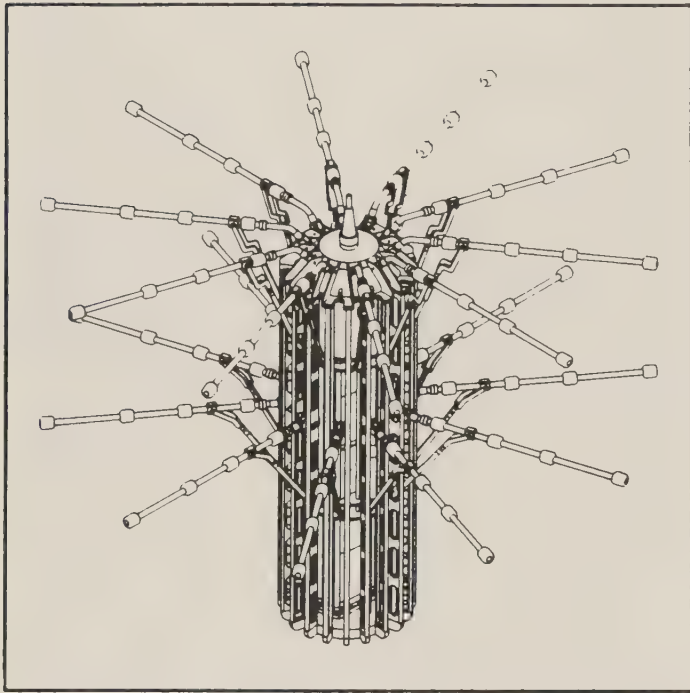
DRS's SQR-17A console. (Author)



Raytheon's CCS Mk 2 console, which the company hopes also to use for its new integrated combat system. (Author)



Martin Marietta displayed its RMES (reconfigurable multiline array evaluation system) at the March 1991 U.S. Navy League show. Long and short arrays can easily be plugged into the fish to form horizontal or vertical or crossed arrays. (Author)



Martin Marietta's HIPAS (high-performance active sonar) sonar transducer, a candidate for the U.S. ALFS (advanced low-frequency sonar) program, for the British ADS (advanced dunking sonar), and for the Canadian APTS (acoustic processor tethered sonar). The flextensional transducer (the active transmitter) occupies the centerline of the dipping body, inside the framework. The receivers are on 2 sets of umbrella-like struts, 10 at the top and 10 below, with 4 spot transducers on each strut (for a total of 80). Martin Marietta claims twice the usual direct-path range (probably 20,000 yd), plus BB and CZ capability. Presumably, HIPAS operates at 3 kHz or below. HIPAS is designed for rapid (30 min) installation. It probably uses fiber optics to carry its 80 signal channels from dipping body to processor, and the signal processor is the Martin Marietta advanced systolic arithmetic processor (ASAP). (Martin Marietta)

USSR

The information given here is taken from a new monograph, A. de Sam Lazaro, *Soviet Electronic Warfare* (Washington, D.C.: Delphic Associates, 1991). Captain de Sam Lazaro served in the Indian navy in 1963–83, operating Soviet-supplied ships (ultimately, he commanded a Nanuchka squadron) and attending Soviet naval schools. He was executive officer of the Osa-class missile boat that sank the Pakistani destroyer *Khaibar* during the 1971 Indo-Pakistani War.

◆ Data Link

A short-range data link was introduced about 1973–74 to transmit a ship's radar picture to a command ship within a group. Doctrine was then being formulated. The link was to be used continuously in an air-threat environment but only intermittently in a surface-threat environment (when the radar picture would not change as rapidly). This system operated on much the same frequency as local television stations, presumably VHF/UHF.

◆ Styx Missile (SS-N-2; P-15, P-20, P-21)

P-15, P-20, and P-21 are different missiles despite their common NATO designator. P-15 (SS-N-2A) uses a barometric altimeter and, therefore, cannot approach a target at very low level (cruise altitude is 150–300 m); it dives toward its target at a 19-deg angle. P-20 (SS-N-2C) uses a radio altimeter and cruises at 25–50 m. P-21 (SS-N-2D) uses a Doppler radio altimeter, which reduces missile drift in altitude during flight. It cruises at a 25-m altitude. P-21 also has an IR seeker. All have a diameter of 750 mm, but P-20 and P-21 are considerably longer (6.55 rather than 5.8 m) and heavier (2600+ kg compared to 2300 kg). The P-15 warhead weighs 454 kg; that of the later missiles weighs more than 500 kg. Range is increased from 40 km in P-15 to 80 km in P-20 and to 100+ km in P-21. The claimed single-shot hit probability of P-15 was 0.72 and about 0.63 for the longer-range P-20 at maximum range. The original fuel was kerosene, oxidized by fuming nitric acid. Current P-20/P-21 missiles have a different combination for greater range.

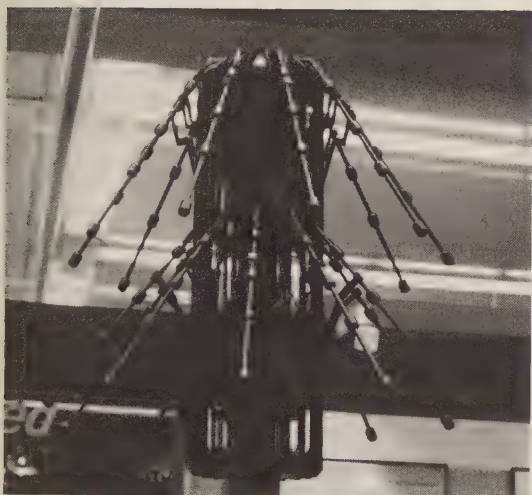
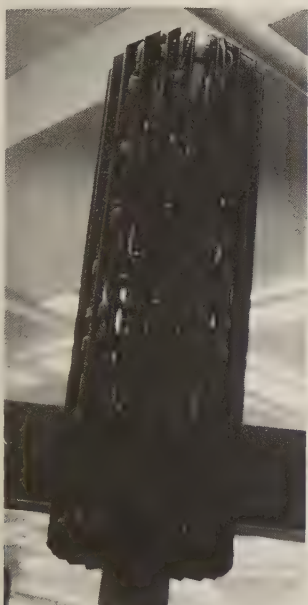
Construction is modular, with standardized parts (such as gyros, power supplies, and waveguides). The policy is repair by replacement: a seeker head can be changed in 10 min without removing the missile from its tube.

The oldest surviving Styx seeker is MS 2, which was originally used by all versions. It seems likely that the original Styx used an earlier conscan seeker, presumably MS 1. The current seeker in P-20 and P-21 missiles is MS 2A, which has 4 horns and scans on receive only (but is not a true monopulse set). Some MS 2 and MS 2A ECCM features were retrofitted into Styxes supplied to India and Iraq in the early 1980s.

The vacuum-tube version of MS 2 was introduced in the early 1960s. By 1969 it was in its 8th version; much effort had gone into increasing the peak power and making the range gate flexible enough to ensure capture of a target at the designated distance (i.e., allowing for target movement during the missile's flight). The computed hit probability at this time was 0.72. Captain de Sam Lazaro reported that Indian modifications to the seeker were later adopted by the Soviets and passed to Algeria and Iraq.

The condition for lock-on is that the radar receive echoes from 8 consecutive pulses. The closer it gets to the target, the greater the apparent angular motion of the target. If the missile tracks the target all the way in, it tends to hit aft (to chase the target, in effect). The Soviet solution was to bias the missile away from target motion at the very end of its flight, using what was called a throw-off gyro, which took over control when the missile was within a minimum range of the target. The early version was designed to activate when received pulses rose above a set strength. Because that rarely happened, early P-15 missiles generally made stern hits. Later missiles use a throw-off gyro that is continuously realigned during flight to lead the target. Gyro angle is compared to a correcting vector generated by the missile's autopilot. When the 2 angles match, the throw-off gyro is released so that the missile hits the target broadside-on.

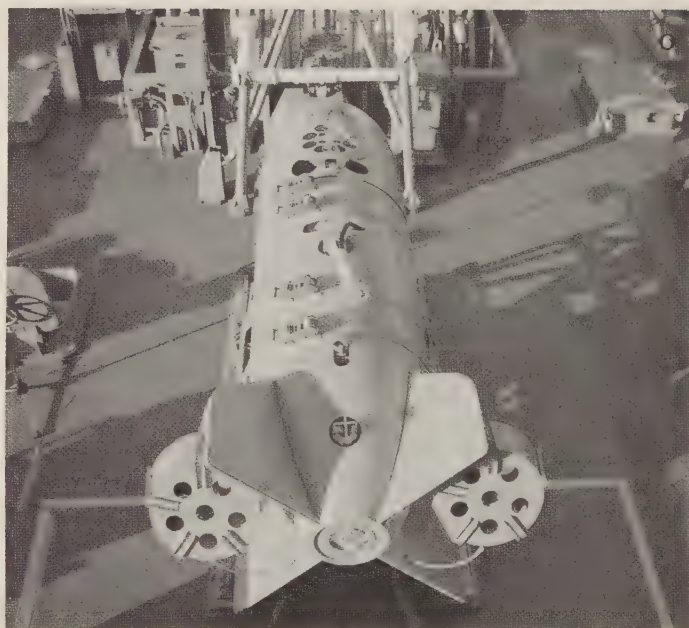
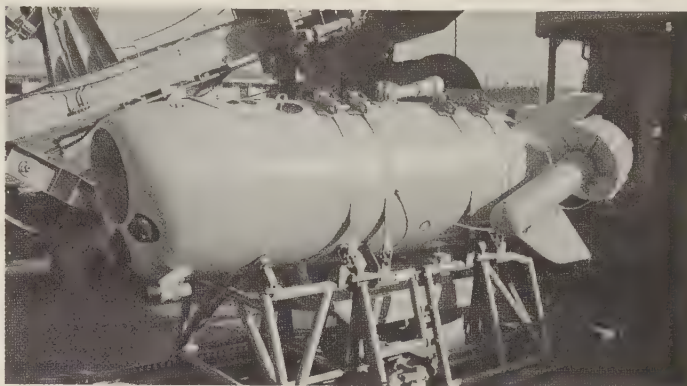
The range gate is about 1 km on either side of the target. Attempts to halve the range gate and to introduce home-on-jam were unsuccessful. Seeker PRF is manually adjusted and can vary considerably from missile to missile. Typical base missile PRFs might vary between 400 and 600 pps. Superimposed on the base PRF is a 100-Hz random wave that jitters the PRF. Feedback in the range cycle causes the transmitter to increase



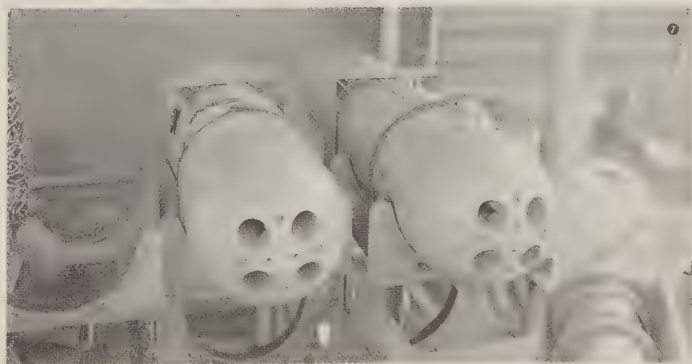
The Martin Marietta HIPAS transducer, shown folded and unfolding, at the 1991 U.S. Navy League show. (Author)



General Dynamics's proposed torpedo-carrying Tomahawk, at the March 1991 U.S. Navy League show. (Author)



The new Japanese S-7 remotely operated underwater vehicle (ROV) for medium-depth sweeping. (*Ships of the World*)



Japanese mine-destruction charges used with the S-4 and S-7 ROVs. (*Ships of the World*).

base PRF as the missile approaches the target. Variable PRF is intended to make it difficult for a jammer radiating into the missile's sidelobes to pull off the range gate. Because the jammer is not in the missile's line of sight, the jammer must simulate a target there by locking into the seeker's PRF pattern (the seeker cannot tell where the sidelobe radiation originates). In this case, outbound-range-gate stealing, the missile rejects jammer pulses at the wrong PRF. The missile can still be confused by a range-gate-stealing decoy that is in its line of sight, however, because in that case PRF matching is not needed. It turned out that a large and sudden variation in PRF often confused the seeker's receiver. Thus a later version of the seeker uses a more stable PRF.

The Indian Defense Research and Development Laboratories (DRDL) at Hyderabad modified the seeker to shut down if it received what it recognized as a jamming signal, the tracker remembering the last measured rates. A deception transmitter about 100 MHz from the seeker's frequency was activated to confuse the jammer. The real tracker would then transmit in short bursts to confirm and correct the rates.

Styx tactics were designed to reduce a target's jamming opportunities. The FCS was intended to compute a course so that the missile would fly on autopilot until it was about 3.5 nm from the target's computed position, giving just enough time for the missile's seeker to receive its 8 pulses and lock on.

After the 1971 war with Pakistan, Indian (and Soviet and probably other) MS 2 seekers were modernized with solid-state electronics, greater peak power, 2 additional magnetrons (for pulse-to-pulse frequency agility), and a phase-sensitive receiver (presumably for MTI). These changes were incorporated in the new MS 2A seeker, first supplied to India in 1975. MS 2A was further developed after 1975. The current version is PRF-agile (the 100-Hz AC is superimposed on a PRF that varies continuously with range). Moreover, the receiver opens only for selected pulses, so it automatically rejects some jamming pulses. That probably counters most inbound range-gate-stealing techniques. MS 2A also has passive (home-on-jam) modes.

During the late 1970s and early 1980s P-21 missiles were fitted with auxiliary IR seekers in a bulge under the nose of the missile. The missile switches to IR mode when its seeker is jammed; it begins a search pattern and locks onto the hottest IR source it can see.

In the Indian navy, Osas carry P-15s, but Nanuchkas and Kashins carry P-20s (Kashins also carry P-21s). A Nanuchka cannot fire P-21s because of limitations in its test system. Captain de Sam Lazaro indicated that Styx has been copied by India and perhaps by Iraq. He recalled a price of only \$20,000 per missile, presumably about 1980. This may be the cost of manufacture in India.

NAVAL RADARS

MR in Soviet radar designations means *Morskaya radiostantsiya*. The radars described below (and also the Styx seeker described above) all incorporate a manually tunable cavity resonator (an *ekho-kamera*) in their waveguides to protect the set against jamming signals slightly off the radar's operating frequency. The resonator also limits the amount of energy that can pass through it, so it grounds out large spot-jamming signals that might otherwise enter the receiver (and that would burn out the TWT preamplifier). Square Tie, Drum Tilt, and Muff Cob all share the same TWS mode of operation, although the 2 GFCS radars do have an additional fine tracking mode for air targets. Finally, the Soviets' official insistence on avoiding WARM modes in peacetime, i.e., on limiting all radars to a single operating mode, does cause some interference problems. Presumably, they worsen considerably as more ships spend more time operating together.

◆ Square Tie (Rangout)

This radar operates in X-band at 2 alternative power levels (20 and 100 kW); the displays are a PPI and a B-scan. The gyro-stabilized antenna scans at 4 or 12 rpm (the stabilizing device is a

bellows presumably similar to that used by Contraves in Sea Hunter 4). There are 4 preset frequencies, each of which can be tuned through ± 10 MHz; the frequencies are normally set about 10 MHz apart. The receiver uses a tunable TWT preamplifier (i.e., an approximately 10 dB amplifier inserted between the antenna and the relatively noisy superheterodyne receiver proper). The Soviet designers of the set believed that weak signals might well exceed the external noise and clutter and yet still be swamped by receiver noise unless they were amplified first. Captain de Sam Lazaro claimed that this technique so improves the signal-to-noise ratio that Square Tie can detect a target with about half the peak power of a comparable Western set. However, it can be quite difficult to tune the TWT amplifier, particularly under conditions of radar silence. Moreover, particularly strong signals can burn out the TWT (he recalled several such cases in the Soviet fleet).

Square Tie can normally detect a carrier or tanker beyond 30 nm (the maximum instrumented range is 40 nm). However, in parts of the Black Sea and the Indian Ocean (particularly the Persian Gulf and the North Arabian Sea) there is often a duct extending about 12 m above the surface. Some of the Indian navy's Square Ties (on board Nanuchkas, where they are low enough to take advantage of ducting) have been retrofitted to increase their instrumented range to 60 nm to use this atmospheric condition (at high power level, Captain de Sam Lazaro recalled detecting a Kashin at 55 nm). The antenna is gyro-stabilized. This radar is connected to an electromechanical fire-control computer, a KLEON in Soviet parlance. Targets are designated to the computer by means of a *vilka* (fork) and a movable range marker, both controlled by the operator's joystick. As in many other auto-track systems, 2 consecutive detections suffice for auto-tracking to begin. Typically, the radar is turned off once the computer has calculated range and range rate; it is turned on only intermittently to check the accuracy of the tracker. The FCS is designed to accept intermittent data so that the radar need not radiate continuously (it has a dummy load for use when not radiating).

The typical tuning time at sea is 3 min when the radar is in a standby mode and up to 10 min if the set must be warmed up first. A set can remain on standby time for only a limited (unspecified) period.

◆ Drum Tilt (MR 104)

This X-band search and FCS radar operates at X- and C-bands with a peak power of 100 kW. In search mode it covers the entire horizon and elevations of 0–40 deg. The maximum tracking range is about 23 nm, though targets have been detected at 35.5 nm under some conditions. The gyrostabilizer limits continuous running time to about 4 hr. The electromechanical MR 104 computer limits the system to targets closing at up to 400 kt. The warm-up time is 5 min (mainly to run up the gyrostabilizer), and MR 104 cannot run continuously for more than 4 hr. Although the radar normally scans automatically, it can be made to stop and radiate in 1 direction (Captain de Sam Lazaro recalled Soviet sailors often used this mode to cook sausages held in front of the radar).

The transmitter is located directly under the nacelle to minimize waveguide losses (albeit at a cost in reliability because the transmitter is vulnerable to water damage). Each set is provided with 2 magnetrons of different dimensions (for different resonant frequency ranges) to provide frequency diversity (1 is for WARM modes only). Each magnetron has 2 basic frequencies, so the radar as a whole will operate at base frequency, base plus 200, plus 800, and plus 1000 MHz. The set can be fine tuned within up to 5 MHz around any of the base frequencies. Such tuning is usually manual but can be automatic. In the event of jamming, the set can continue to transmit on 1 magnetron (with the appropriate receiver shut down) while using the other. In theory, a spot jammer will be locked onto the first signal and will miss the second. Special permission is required to shift to the war reserve frequencies of the 2 magnetrons.

There are 2 modes, search and track, with a separate operator for each. As in Square Tie, targets are designated to FCS computer track by means of a joystick, which maneuvers a pair of angle marks (a fork) and a range strobe on the face of the PPI. The computer measures angle rates; the operator merely keeps the tracking beam on the target. A key literally switches the waveguide leading from the transmitter from mode to mode. In search mode, the radar scans vertically while it rotates. The waveguide leads into a spinner rotating at 40 rpm, feeding a series of horns in sequence. The horns in turn radiate signals that, when they are focused, emerge at a series of elevations of 0–40 deg. When the radar is switched to track mode, the nacelle stops training. A separate mechanism scans the beam in a cross-shaped pattern around the target position derived from the tracking mode, ± 3 deg in elevation and ± 5 deg in train. It seems likely that the radar can auto-track in this mode because the beam excursions around the target position should provide it with error signals. At low elevations (less than 5 deg) the lower part of the vertical scan is cut off to reduce sea clutter. The radar can switch from feed to feed by means of a tilting plate analogous to the mirror in a single-lens reflex camera; the cross-shaped tracking feed is in the center of the tilting plate. The tilting plate is covered by lines of conductors at a 45-deg angle to the vertical; the nacelle cover has similar vertical lines of conductors.

As in Square Tie, the radar performs rate-aided tracking. The limitations of the computer make it very difficult to track fast crossing targets; Captain de Sam Lazaro recalled that a Soviet instructor considered this limitation immaterial because the system was intended mainly for point defense, in which case angular rates would not be very large.

The Indian government laboratory (DRDL) developed a replacement for MR 104, using the same antenna but a new transmitter for better ECCM and a new solid-state computer for better search and tracking (maximum closing rate increased to 900 kt). Work was completed in the early 1980s, and this new radar will presumably be retrofitted on board Indian Osas, Nanuchkas, and Kashins. In contrast to earlier Indian-developed modifications to Soviet equipment, this one was not reported to the Soviets.

◆ Bass Tilt (MR 105)

Muff Cob is similar in concept to Drum Tilt but is somewhat less sophisticated, slower, and less efficient; its stabilizer is older and less reliable. The associated coaxial television camera is used only for visual target identification (which is necessary in firing at towed targets) and apparently not as a backup in case of jamming. As in MR 104, there are 4 preset frequencies, but in this case there is only a single tunable magnetron. Tuning to the second frequency is by solenoid, but tuning to the third and fourth frequencies is manual and is limited to a range of 100 MHz. The maximum range is about 24 nm. Like MR 104, MR 105 scans 0–40 deg in elevation. The associated computer carries ballistics for 30-mm, 57-mm, and 76.2-mm guns.

SHIPBOARD ECM

Captain de Sam Lazaro reported Soviet insistence on virtual EMCON. The radars described above, for example, are designed to transmit briefly and then to project target position ahead, transmitting only intermittently. Similarly, he described very disciplined communications policy. Any commander making an unauthorized transmission must submit a special report, which may cause him considerable trouble. Yet the Soviets have failed to realize their ideals, and the U.S. Navy can rely on passive targeting. Captain de Sam Lazaro reported that the Indian navy adopted Soviet communications practices and used them successfully during the 1971 war with Pakistan. For example, the ships of the task force attacking Karachi closed each other to communicate by wire telephone and loud hailer; detailed instructions were passed in writing by high wire.

One observed consequence of the very limited transmission

policy was that ships could not tell when their radios had drifted off the assigned frequencies. Captain de Sam Lazaro reported that in small-attack-boat units about half the radios typically wandered off frequency, so communication was nearly impossible. A policy review was planned, but as of 1984 it had not been carried out.

As of the late 1970s, it was Soviet practice to designate a single ship of a squadron as radio communications ship. Communications within the group were, as far as possible, either visual or line-of-sight radio. Similarly, when ships operated in formation, radar transmissions were minimized by designating one ship as short-range guard ship and another as air-warning radar guard ship (it is not clear how, if at all, ships transmitted radar data without extensive data linking). Surface-search radars operated in single-sweep mode to avoid interception. During peacetime all radars of a given type operate at a fixed frequency to avoid disclosing war reserve operating modes (WARMS). Captain de Sam Lazaro recalled that the use of spot jammers was generally discouraged but that broad-band noise jamming was frequently exercised.

The typical ESM equipment on board an Osa-class missile boat is as follows:

- VHF search receiver (100–300 MHz); some sets can be set to ignore up to 50 channels used for friendly signals. The antennas are an omnidirectional monopole passing through a horizontal loop (a ski pole) and a dipole typically at the end of a yardarm. The antennas have considerable blind zones, so an operator switches from antenna to antenna to maintain continuous reception. The combination of very high self noise and external noise limits the effective range of sets on board Osas to 12–15 nm. The bearing accuracy is about 5 deg (using a PPI). The set also has a digital frequency display and a panoramic (A-scan) display. This receiver can also function as a main communications receiver (ship-to-ship or ship-to-air).
- X–C-Band Search Receiver for missile targeting, probably based on technology acquired from Signaal. During the 1970s at least the Black Sea Fleet considered retrofitting newer Osa-IIs and Nanuchkas with this device. These receivers were supplied to such foreign customers as India, Iraq, Somalia, Vietnam, and Yemen. On board Indian Nanuchkas, its nearly cylindrical antenna (containing a directional spinner) shares the big Band Stand radome with a Square Tie surface-search radar; it occupies the after side of the mast on board an Osa-II. The receiver is set for either X- or C-band signals. Its displays are a digital frequency readout, a B-scope (signal strength and, presumably, PRF), and a PPI for bearing (correct to 2 deg at night, slightly more by day).

Typically, a squadron of Osas would use a single watch frequency, such as 136.5 MHz, for DF reporting and triangulation.

In the early 1970s the Soviets reportedly adopted a standard jammer in Nanuchkas and in Kashin-class destroyers (and then in earlier ships in 1974–78). It was capable of both broad-band noise jamming (at about 900–1300 MHz over a 20–40-MHz band) and range-gate stealing, using small, rotating, horn-shaped antennas mounted on the yardarms. A later version uses a fixed reflector with what amounts to a rotating feed. The receivers (not the jammers) use TWT amplifiers.

Current (1988 and later) Indian ships with Soviet equipment have jammers that can lock on to the target signal and can conduct continuous ESM search for radars. A single-loop/whip DF system on board a submarine (presumably a Kilo) was credited with the ability to pick up and analyze a radar after a single azimuth sweep lasting only about 3 sec. Radars are now fitted with circuits that automatically warn the operator that an enemy jammer is active. It is not clear whether these are local improvements or Soviet-supplied modifications.

Captain de Sam Lazaro reported that the Soviets use both chaff rockets and chaff balloons. The Nanuchkas are the smallest units with chaff rockets (12 rockets/launcher). The launch-

ers cannot be trained, but they can be elevated by manual control, the range being set directly by reference to a graduated quadrant. Each rocket has a manually set time fuze, and it is fired by electric squib. The navigating officer uses a nomogram table to determine the firing range, which, in the smaller ships, is passed orally to the chaff operator at the launcher. Quite elaborate firing doctrine has been developed for formations, only

very simple messages being required to open chaff fire. Captain de Sam Lazaro reported that, depending on conditions, chaff clouds could persist for 6-45 min.

It appears that the Soviets first became interested in shipboard chaff with the advent of U.S. radar-guided antiship missiles, which the Soviets thought could overcome their active countermeasures.

ABOUT THE AUTHOR

Norman Friedman is recognized worldwide as a leading naval writer and defense analyst who specializes in technical and strategic issues. His work shows both an understanding of current technology and profound appreciation of history and its application to the present. As a consultant to various U.S. governmental agencies and defense contractors, he has examined the technology of national mobilization, Soviet responses to U.S. naval innovation, the utility of ballistic-missile defense, and strategic conflict with the Soviet Union, among other subjects.

Praised for his ability to explain complex technology to the layman, Friedman has written many successful books on naval ships and weapons that combine technical analyses with an examination of the historical, political, and economic influences on design and development.

His popular illustrated design histories published by the Naval Institute Press include *U.S. Destroyers*, *U.S. Aircraft Carriers*, *U.S. Cruisers*, *U.S. Battleships*, and *U.S. Small Combatants*. Among his other books are *U.S. Naval Weapons*, *Naval Radar*, *The Postwar Naval Revolution*, and *Submarine Design and Development*.

Friedman writes articles on a wide range of defense subjects that appear regularly in journals throughout the world. He also contributes a monthly column on world naval developments for the Naval Institute's *Proceedings* magazine.

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Norman Friedman is an internationally respected defense analyst specializing in strategic and technical issues. A longtime consultant to U.S. government agencies and former deputy director of national security studies at the Hudson Institute, he is known for his ability to explain complex technology to the layperson.

Dr. Friedman, who holds a Ph.D. in physics from Columbia University, has written many successful books on navy ships and weapons that combine technical analyses with discussions of the historical, political, and economic influences on design and development. Among his seventeen books are five illustrated design histories of American warships; studies of naval radar, U.S. naval weapons, and British carrier aviation; and the first in-depth analysis of the war against Iraq.

Dr. Friedman also writes articles on a variety of defense subjects for journals published worldwide and contributes a monthly column on world naval developments to the Naval Institute's *Proceedings* magazine.

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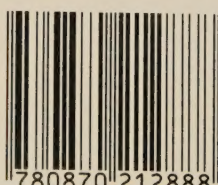
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