

U S NAVAL WEAPONS

Every gun, missile, mine and torpedo used by the US Navy from 1883 to the present day

by NORMAN FRIEDMAN



US Naval Weapons

This truly encyclopedic work is the first to include every significant weapon system employed by the US Navy from the birth of the 'New Navy' in 1883 to the present day. For each gun, missile, mine or torpedo a detailed tabular specification is given, but these entries are backed with an authoritative discussion of why the weapon was developed and how well it functioned in service.

This emphasis on a balanced appreciation separates 'US Naval Weapons' from the conventional military reference books, which are principally concerned with quoting data that is often meaningless outside the tactical, political or economic background. To complete the picture, this book also includes full descriptions of the essential electronics – fire control systems, airborne radars, sonars and other sensors – plus analyses of US Navy thinking on strategy and tactics as it affected weapons development and procurement.

The author

A physicist by training, Norman Friedman is Deputy Director of National Security Studies with the Hudson Institute of New York, where he specializes in the technical and strategic aspects of current and future US naval policy. His work includes both an understanding of current naval technology and a profound appreciation of history and its application to the present. His five major works to date, *Battleship Design and Development*, *Modern Warship Design and Development*, *Carrier Air Power*, *Naval Radar* and *The US Destroyer*, successfully combine history and technical analysis, and all have proved popular with layman and specialist alike.

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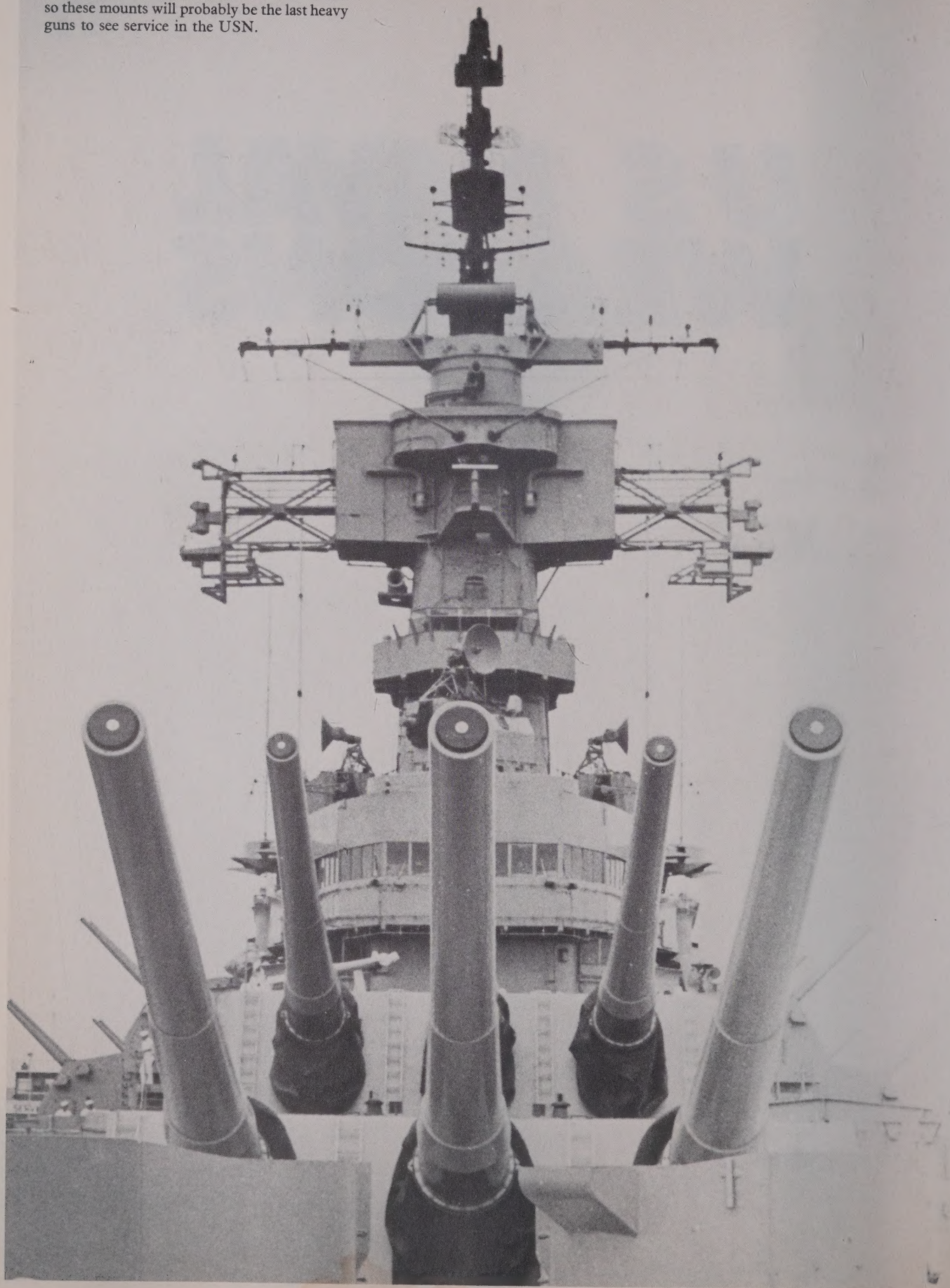
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U S NAVAL WEAPONS

The forward 16in/50 guns of the *New Jersey* in 1968-69. The ship was reactivated in 1982 and so these mounts will probably be the last heavy guns to see service in the USN.



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*Every gun, missile, mine and torpedo used by the
US Navy from 1883 to the present day*

by NORMAN FRIEDMAN

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Norman Friedman

Introduction

This book is an attempt to bring together in a single volume the weapons and associated systems (such as fire controls and sonars) which have armed the US Navy since the birth of the 'New Navy' in 1883. This is a natural starting point, because it was only then that the long decline of the post-Civil War years was halted, the US Navy adopting wholesale the products of the ongoing revolution in naval technology, until that time almost wholly a British and continental European preserve. The evolution of US naval technology from that time through the beginning of World War Two was very nearly a continuum, the only really new elements being aircraft and antisubmarine weapons. On the other hand, during the war the programs which led to most of the modern naval weapon systems were begun; there are few current systems which cannot be recognized in embryonic form in the Navy of 1945-46.

It is common to distinguish the weapon-system-dominated ships of the post-1945 Fleet from the much simpler Fleet of earlier days, in which two ships each with, say, eight 8in guns were much more truly equivalent than are two ships each with two twin medium SAM launchers. The argument of this volume is that matters were never nearly that simple. Gun mounts determined rates of fire, which might well vary from ship to ship by a factor of five; crew training was, of course, also a most important issue. Fire control determined both hitting probability and the number of targets a single ship could engage simultaneously. As Jon Sumida has pointed out in the context of the British Fleet of World War One, subtle changes in fire control computer systems could have significant effects on hitting probability, changing the number of hits in battle at long range from zero to as many as five. Shell design, too, could be decisive. Yet none of these factors would figure in a conventional comparison of two Treaty cruisers built between 1920 and 1939. The current study is only a beginning in this direction, but it does lay out the factors of consequence in the major naval weapon areas, both past and present. Hopefully it will form a useful complement to studies I have published on the evolution of the ships themselves.

Throughout this book the systems aspect of the weapons, and their tactical context, have been emphasized, *ie* not only the gun or the missile but also the fire control and the weapon-direction equipment and the connection with the various naval tactical data systems. Weapon effectiveness has always

depended on such 'invisible' elements as fire control and even shell fuzes; in an era of guided weapons the system elements are, if anything, even more significant. Thus Part III deals with underwater weapons but also describes and lists US sonars. However, the full list of US naval (shipborne) radars has already been published in a companion volume (*Naval Radar*, 1981), and it would be too lengthy to repeat in this one. Details of airborne systems are, however, given.

There are two major omissions in this book: electronic (including sonar) countermeasures and mine countermeasures. Each would require a book of this length to do it justice, and each is somewhat peripheral. Each is also subject to greater security than is most of the present subject matter. Shipboard countermeasures are described, although not in exhaustive detail, in *Naval Radar*. There have been several recent books on naval mine warfare, including minesweeping technology, at least up through 1945. Finally, it has not been possible to include a full account of sea surveillance systems, which are more and more an important element of the US Navy, when the Navy as a whole is considered as a weapon system. They include SOSUS, which is discussed (in Part III), the pre-World War Two network of strategic (radio) direction-finders, and various current and future programs sometimes described under the head of Extended Horizon Command and Control.

The divisions within this book are necessarily somewhat arbitrary, but they do reflect the watershed represented by World War Two. The first three parts include most of the technology of the Navy which fought that war: surface-to-surface guns; surface-to-air guns; machine gun and cannon-armed fighters; and mines, torpedoes, and a variety of ASW weapons and systems. In the surface-to-surface gun and the underwater ordnance cases the connection with pre-1945 weapons is so strong that postwar developments have been included. However, jets, missiles and nuclear weapons so changed postwar naval air defense that a separate section was required. Although both include prewar systems, the bulk of Parts V and VI (air-to-surface and surface-to-surface non-gun weapons) are postwar. In most cases of dual-purpose weapons, the weapon is described under its primary function: thus 5in dual-purpose guns are in Part II rather than Part I - air defense rather than surface-to-surface warfare.

Many of the dates in this book, particularly dates of procurement, are given in terms of the

fiscal, rather than the calendar, year. Until 1977 the fiscal year ended on 30 June of the calendar year: FY42, for example, began on 1 July 1941 and ended on 30 June 1942. However, the Congressional budget process trailed the fiscal year, causing considerable problems; FY77 began on 1 October 1976, with a 'transitional' period, designated FY77T, separating it from FY76, which had ended the previous 30 June.

The actors in the weapon development process deserve special mention. At the beginning of the New Navy, the administrative structure of the service was dominated by the independent Bureaus, responsible only to a civilian Secretary of the Navy, who might be advised by the Admiral of the Navy - at that time David Dixon Porter, who was, incidentally, an advocate of torpedo warfare. There were also a variety of specially constituted boards during the 1880s and 1890s, most of them set up to study special issues such as the design of the next battleship, or the long-range shipbuilding program, and most of them advisory at most. The Bureau of Ordnance (BuOrd) was responsible for weapons and armor; it controlled the Naval Torpedo Station (Newport), the Naval Proving Ground (Dahlgren), and the Naval Gun Factory (Washington Navy Yard). To some extent, too, it relied on civilian firms such as Midvale and Bethlehem Steel, and E W Bliss for torpedoes. The Bureau of Construction and Repair (C&R, later the Bureau of Ships - BuShips - after it merged with Engineering in 1940) designed the ships, and the independence of the two Bureaus caused some problems, most notably in the case of the *Iowa* class battleships in 1938. Engineering was responsible for naval electronics, and BuShips managed search radars; however, BuOrd developed the fire control sets. This, too, made for problems as the search and fire control series began to merge in the late 1950s, in the Typhon missile system. The third major technical Bureau, Aeronautics (BuAer), emerged in 1921. It controlled aircraft design and, for much of its career, had much more operational authority than did its sister Bureaus. Thus both BuAer and BuOrd were able to claim responsibility for guided weapons (pilotless aircraft in the case of BuAer) during World War Two, with considerable friction as a result.

Perhaps most importantly, there was little administrative connection between the Bureaus, which jealously guarded their independence. In 1889 some measure of coordination was achieved by the formation of a standing

Board on Construction, on which the Bureau Chiefs sat. As it dealt largely with details of ship fittings and layout it was not concerned with broader issues of tactics or strategy, which were left to special (and ad hoc) Boards appointed directly by the Secretary of the Navy. Moreover, these latter were at most advisory and so had no statutory power. After the experience of the Spanish-American War the Secretary of the Navy formed a General Board, headed by the new Admiral of the Navy, George Dewey, to carry out long-range strategic planning. Inevitably it became concerned with the long-range building program and with the detailed design of new ships and their weapons. After severe criticism of the Bureau system (as reflected in the *North Dakota* class), the General Board was given authority over the staff requirements (Characteristics) of ships and weapons. Its influence over weapons was as much indirect as direct: a new weapon was unlikely to enter production, then as later, without a dedicated platform to carry it. However, the Board had little impact on the details of the weapons, and BuOrd tended to be far more independent of its power than were C&R or BuShips.

In 1915 another player was added: the Chief of Naval Operations, or Opnav. The original justification for this office was that without it there was no single professional naval officer who could coordinate the operational employment of US warships without the direct participation of the Secretary of the Navy. In theory, then, the CNO was responsible for current operations and the General Board for long-range planning. However, during the interwar period Opnav formed Divisions of War Plans and Fleet Training which had considerable influence on weapon and ship design. Moreover, a great deal depended on the personality of the CNO, since the General Board was advisory only, even in the matter of Characteristics. In particular Franklin D. Roosevelt's first Secretary of the Navy, Claude Swanson, was ill for most of his tenure (1933-39); the Chief of Naval Operations (first William H. Standley, 1933-37, and then William D. Leahy, 1937-39) often served as acting Secretary and so could make final materiel decisions. In many cases, too, General Board papers were forwarded to the Secretary via the Chief of Naval Operations, who ultimately became the principal naval advisor of the President. For example, in 1937 its proposed Characteristics for the *North Carolina* class were overturned. After Admiral King became both Commander-in-Chief US Fleet (Cominch) and Chief of Naval Operations (CNO) in 1942, the influence of the General Board declined further; by 1945 there was a Ships Characteristics Board (SCB) within Opnav doing much of its previous job, though without the perspective of long-range planning.

When he became CNO Admiral King decided to concentrate executive power in his office to the detriment of the Bureau system; formerly the Bureaus had been entirely independent. He wished to reorganize the Office of the Chief of Naval Operations along functional lines, with Deputy Chiefs reporting to him via a Vice Chief of Naval Operations responsible for materiel and production decisions. The only such office that he was able to establish in wartime was a DCNO for Air, Op-05, a change which in itself both moved the

operational part of the Bureau of Aeronautics into the CNO organization (Opnav) and helped to give the aviators a measure of recognition which many of them felt was lacking. In 1945 Opnav included, in addition, Op-03 (operations, including the formulation of strategic plans and policies), Op-04 (logistics, including ship production) and Op-06 (special, *ie* nuclear, weapons). The DCNO system, first proposed by King in May 1942, was realized by the creation of Op-05 on 18 August 1943. No other platforms received DCNO 'sponsors' until the 1970s.

However, the Opnav organization did change during the 1940s and 1950s to reflect special Navy concerns. For example, early in 1947, Op-31, the Assistant CNO for Operations, became the Undersea Warfare Division, to coordinate decisions on underwater weapons and platforms across Bureau lines. It was Opnav which organized the series of special ASW Conferences held between 1946 and 1959. The DCNO for Special Weapons was disestablished, and guided missiles handed instead to a Guided Missiles Division, Op-57, within the DCNO (Air) organization; nuclear weapons became Op-36. Missiles remained within Op-05 (as Op-51 after 1950) until they had become so widespread in the fleet that they could no longer be considered a separate branch. By the mid-1950s, however, the breadth and significance of research and development required a new Division: in 1954 Op-37 was created as the New Developments and Operational Readiness Division (Research and Development Division after 1957). A new DCNO for Development, Op-07, was established on 28 April 1959, and Op-36 and Op-51 transferred to it. The DCNO for Development was disestablished in 1971, as a new CNO, Admiral Zumwalt, sought to reorganize his office to parallel missions/functions and hardware. He also abandoned the system of long-range planning which had operated since 1955.

At present, then, there is an Op-02 for submarine warfare and an Op-03 for surface warfare, as well as the old Op-05. Op-60 is responsible for strategic planning (*eg* for the use of strategic weapons) within an Op-06 organized in 1954 as the DCNO for Plans and Policy.

There has, then, always been tension between sponsors of particular forms of hardware (often known as 'the barons') and sponsors of warfare areas which cut across weapon and hardware lines. Shifts back and forth in the Opnav organization show an attempt to achieve coordination, as in the case of Op-31 in the 1940s. In the mid-1960s Op-95 was established at equal (three-star admiral) level to the 'barons' to oversee ASW, *ie* to try to coordinate the Bureaus and the forces to respond to the considerable perceived threat of Soviet submarines. More recently, Op-95 has been reborn as a Naval Warfare (*ie* tactics) office to oversee anti-air and antisurface as well as antisubmarine warfare – a shift reflecting recent thinking emphasizing the air and surface threat (and also the reemphasis on cruiser-destroyer types for independent roles in conjunction with the new generation of cruise missiles). Separate offices, Op-090 (Navy Program Planning) and its subordinate, Op-96 (for systems analysis) also were formed in the 1960s to coordinate Navy budget planning and actions, and so to operate in the new environment of

Secretary McNamara's Defense Department.

The value of long-range planning has been a very controversial issue. The General Board was abolished in 1951 after completing a study of naval requirements in 1950-60. However, in 1955 a new Long Range Objectives Group (LRO, Op-93G) was formed within Opnav, and there was also a new Standing Committee on the Long Range Shipbuilding and Conversion Program. The LRO tried to project both technical developments and strategic requirements, and appears to have had some considerable influence in its first five years. However, after 1961 Robert McNamara increasingly centralized the management of naval and other defense research and procurement, and employed an annually updated five-year plan as his dominant budget tool. The influence of the LRO inevitably waned, and it was eliminated completely by Admiral Zumwalt in 1970. After the disestablishment of the LRO, there were several ad hoc planning efforts, such as Sea Plan 2000 (1974). In 1980 a new long-range organization, Op-00X, was formed outside the budget formulation process dominated by Op-90, Op-96 and the 'barons'; it is much too soon to gauge its influence.

In 1959 the two rival weapon Bureaus, Aeronautics and Ordnance, merged to form BuWeps, the Bureau of Naval Weapons, a step which recognized the emergence of the new missile era out of the earlier period of guns and torpedoes. At this time, too, the new generation of homing torpedoes was increasingly characterized as one of underwater guided missiles, subject to the kinds of technology already being developed in the aerospace industry. In the event, the combination proved unworkable. In 1966 there was a general reorganization of the Navy Department, the old Bureaus becoming Systems Commands under a Chief of Naval Materiel, himself responsible to the CNO. BuWeps split into a Naval Air Systems Command (NAVAIR) and a Naval Ordnance Systems Command (NAVORD); the Bureau of Ships became NAVSHIPS. In 1974 there was yet another shift, and NAVORD and NAVSHIPS merged to become the Naval Sea Systems Command, NAVSEA. There were also at least two important special organizations: the Special Project Office set up initially to create Polaris and later to be responsible for the evolution of Navy ballistic missiles; and the Surface Missile Systems organization, responsible, from 1962 onwards, for solving the problems of the '3-T' fleet air defense missiles and then for Aegis. In each case (and there were many others) offices created within Opnav managed to coordinate the independent technical Bureaus, largely by determining operational requirements and production runs.

Perhaps more importantly, the influence of technology rather than concrete tactical requirements was very great in the immediate postwar period. One student of this era, David Rosenberg, speaks of a 'technological enemy' rather than a strategic one, of a need to assimilate what seemed at the time to be an unmanageable excess of revolutionary developments. The Navy of 1946, too, was relying for almost the first time in its history on civilian rather than uniformed tactical analysis. During World War Two the problems, first of ASW and then of air warfare, had brought into the Navy an Operational Evaluation Group of operations analysts; the OEG survived the

war, and evolved into the Navy's equivalent of RAND, the Center for Naval Analyses (CNA). At the same time, it must have appeared to some that the new technology was beyond the grasp of line officers; for example, the Applied Physics Laboratory (APL) of Johns Hopkins University came to dominate Navy thinking in surface-to-air missile systems.

The Navy turned to civilian scientists for technical advice during both World Wars. In 1915 the Secretary of the Navy asked Thomas A Edison to form what became the Naval Consulting Board, which screened proposed inventions and made a variety of proposals for new weapons and associated systems. Its final recommendation was that the Navy form its own permanent research laboratory, which became the Naval Research Laboratory (NRL). Among its major achievements were US naval radars and the various automated naval tactical data systems of the postwar period. In 1940 the United States again organized its scientific community for war, under an Office of Scientific Research and Development (OSRD) directed by Vannevar Bush, which in turn operated through a National Defense Research Committee (NDRC) chaired by James C Conant. NDRC covered most of the spectrum of ordnance research, including operations research (OEG), underwater sensors and weapons, rockets (at the California Institute of Technology, CalTech), and radar (most notably at MIT, at the Radiation Lab). There was also a major established industrial laboratory, Bell Labs, which made important contributions in fields such as fire control radar, and which continued its naval connection postwar. Unlike the post-World War One Navy, the post-World War Two fleet continued its reliance on the non-naval industrial research base, which permitted it to expand rapidly into fields the prewar fleet had not even envisaged. APL typifies this evolution, but is hardly unique.

The changing pace of weapon system development has also been a very controversial issue. During World War Two, entirely new concepts such as radar, the VT fuze and naval rockets passed from concept to large-scale operational use in as little as two years, a pace rarely matched before or since. Indeed, there is a general feeling that of late the pace of US military innovation has been little more than glacial, and that the qualitative edge the United States forces enjoyed over those of their most probable enemy, the Soviet Union, is rapidly eroding, even if American prototypes remain considerably more advanced. Several reasons for this state of affairs have been adduced. One is bureaucratic: the number of possible vetoes in the development process has increased enormously. That is, from the late 1950s onwards, and particularly from 1961, the Department of Defense exerted a veto over and above that within the Navy Department. Secretary of Defense McNamara in particular tried to force the Services to achieve complementary rather than rival capabilities. He was responsible for much of the development of general-purpose, as opposed to strategic strike, naval forces during the 1960s, although some might trace intense naval interest in such systems from the LRO studies of the 1950s. Certainly McNamara's interest in non-nuclear war made it much easier for the Navy to justify the large amphibious and escort (and underway replenishment) programs of the 1960s.

As time has passed, the Defense Department procurement process has become more and more systematic, with the avowed intention of avoiding waste through incorrect decisions; however, the concomitant effect is to avoid the technical risks which themselves contribute to American technological superiority. The series of formal 'milestones' or DSARCs (Defense Systems Acquisition Review Councils), a system introduced by Deputy Secretary of Defense Packard in 1970, under the Nixon Administration, is associated with this development. More recently, the executive Office of Management and Budget (OMB) has produced Circular A-109, demanding that the Services specify, not the technical approach they want to apply to a problem, but only the performance desired, for maximum competition. The net result seems to have been the cancellation of workable programs and the prolongation of the development process, for a questionable improvement in performance. Finally, in the past decade Congress has come more and more to intervene, not only in the procurement process, but also in the choice of developmental programs. To some extent this has been the consequence of growth in Congressional staffs, but it is also the consequence of a breakdown in the former unanimity of military advice on programs. Particular committee staff members can become extraordinarily influential. This is not an entirely new development: Representative Carl Vinson was an important figure in US naval shipbuilding for almost half a century. What is new is the emphasis on particular weapons and aircraft.

It might be fairer to say that the weapons have come under scrutiny as their unit costs have risen, and as the number of alternative systems have fallen. For example, in the lean times of the late 1930s the Navy was developing, simultaneously, two major-caliber single-purpose and at least one dual-purpose fire control systems (Mks 34, 38 and 37), one major automatic weapon (1.1in cannon), four or five major-caliber weapons (16in/45 and /50, 12in/50, 8in/55, 6in/47), and three torpedoes (Mks 13 through 15), as well as radar, sonar and mines. In 1983, the major weapon programs in development are limited to three anti-aircraft systems (Aegis, RAM and advanced Sea Sparrow) and three antisurface weapons (Harpoon, Tomahawk and Trident), with several others (many of which will never even receive names) in the talking stage. Each of the weapons is expensive enough to rival the limited number of individual ships now being built, whereas in the late 1930s the debate was limited almost completely to numbers of ships. Congress was not even informed (in any detail) of particular weapon programs.

Another factor is the maturity of particular technologies. One might speculate that any particular technology passes through a long period of relatively slow evolution, after which a takeoff point is reached, and very rapid development becomes possible, given sufficient funding. However, that rapid development period is soon saturated, and any further substantial improvement requires disproportionately more time and money. Several important technologies reached the takeoff stage in the period just before World War Two, but they did not achieve rapid development at once due to limited funding. Thus NSRDC and the Navy could produce many spectacular new

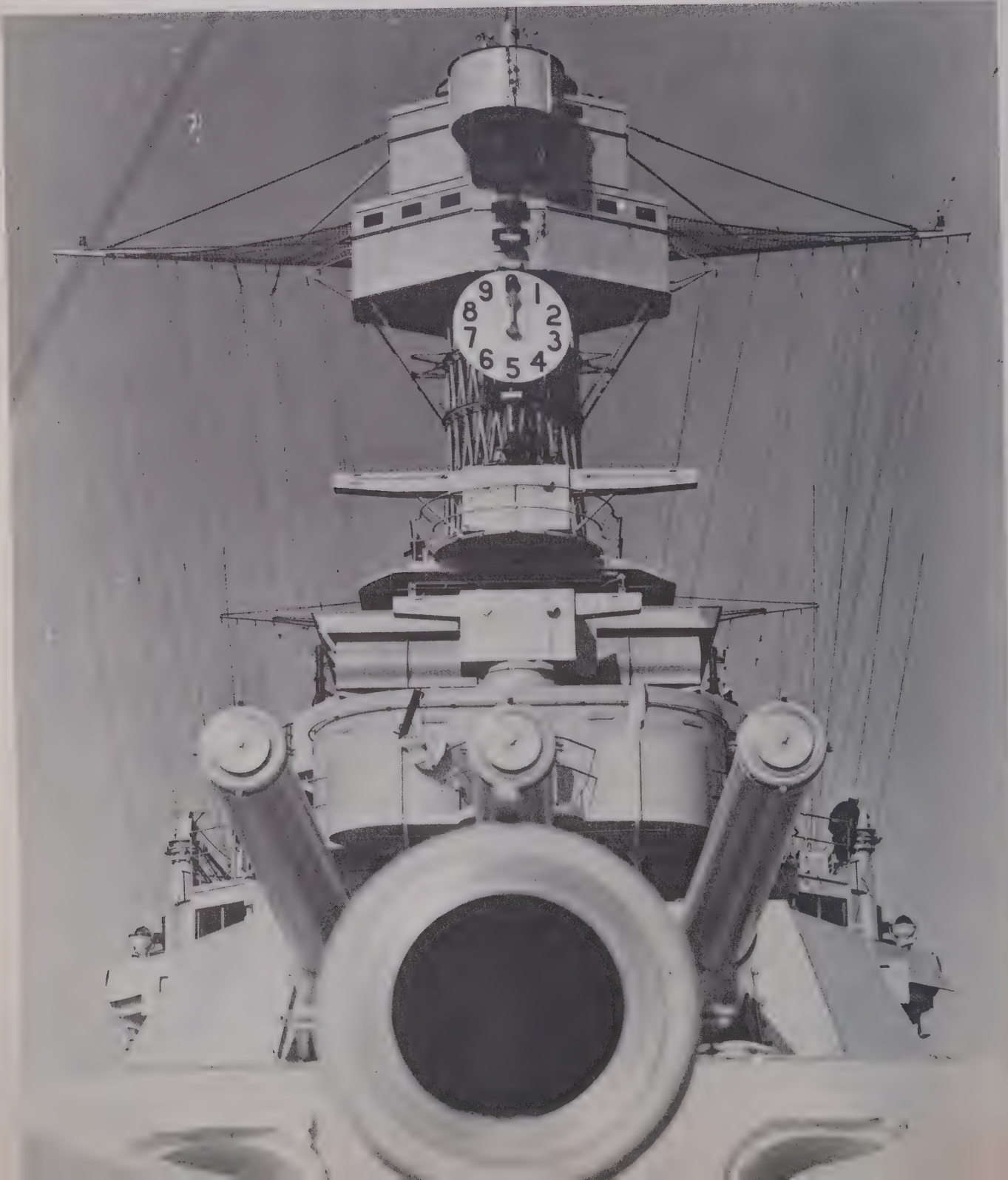
weapons very rapidly, well in time to affect the course of the war. Nevertheless, some of the weapons in sight in 1945 had not yet reached takeoff, and the time required for their development surprised those who had seen radar, for example, evolve from 1937 to 1945. Surface-to-air and air-to-air missiles were major cases in point. Both achieved rapid development between the late 1950s and the early 1960s, but major improvement since that time has been surprisingly slow. Of course, it has also been retarded by tight finances: between Vietnam and the late 1970s the net US defense budget, in real terms, actually declined.

Funding for development rather than production has been a major consideration. In 1945 there was so much new technology in prospect that the Navy made almost a conscious decision to spend its money on research and development, at the cost of a sharp decline in operating forces. This gamble was later proven justified, as the supposed Soviet threat of the time was much overstated, whereas the research of the 1940s made possible the viable US fleet of the 1950s and 1960s. Later, despite massive investments in shipbuilding, the cost of the new generation of weapons began to 'squeeze' the shipbuilding budget, and by 1957 unpleasant choices were being made between entire categories of weapons. It was about this time, for example, that such anti-surface-ship weapons as the Petrel missile and the Mk 16 destroyer torpedo were abandoned in favor of investment in ASW. The choice to build Polaris further complicated matters. Unlike earlier naval weapon systems, Polaris was not a means of protecting a unified fleet, or of enhancing the projection of its power. In effect it competed with a more conventional image of US seapower, yet it had to be financed within a constricted naval budget. Indeed, there was some bitterness over the extent to which general-purpose forces had to be sacrificed in favor of a 'national' (strategic) program which some felt should not have been financed out of a restricted Navy budget.

From 1945 onwards the main arm of the US Fleet, the carrier task force, was envisaged as a means of striking quickly at the periphery of the Soviet empire, in wartime; to a lesser extent it had an ability to reply promptly to any Soviet attack on the United States. Above all, it was a means of fighting a war, rather than a permanent deterrent to Soviet action, and it was as effective in a limited as in a major war. Polaris, on the other hand, was a deterrent, permanently in place as a threat should the Soviets strike, but essentially unconnected with traditional naval concerns: except by striking at Soviet naval bases, it could not contribute to sea control. Indeed, such specialized strikes would have violated its rationale; it was as much a central US strategic system as an ICBM in a silo. The Navy wanted it funded on that basis, but instead Polaris was built out of the Navy budget, indirectly cutting general-purpose forces at just the time the nuclear balance made them most important, in the era of limited warfare, the 1960s and beyond. Current and projected investment in Trident may well result in similar problems.

Part I

Guns (surface fire)



1. Introduction

Modern naval guns were among the very first products of the revitalized US naval industry which built the 'New Navy' of the 1880s and 1890s. Indeed, the same Navy Department *Annual Report* which announced the recommendations of the Naval Advisory Board also reported the construction of a prototype 6in breech-loader. This weapon was the culmination of a careful attempt by Captain William N Jeffers, Chief of the Bureau of Ordnance, 1873 through 1881, to provide the United States with the basis for modern naval ordnance despite an almost total lack of interest on the part of Congress, and considerable opposition within the Navy itself. Jeffers designed his program not merely to improve US naval firepower, but much more to develop a domestic industrial base. Given the large stocks of obsolete iron weapons left over from the Civil War (and from a new production program for 15in Dahlgren guns in 1870–72), he inevitably concentrated on the conversion of these smoothbores into rifles, some of them breech-loading. The metallurgical progress reflected in the tubes used for these conversions carried over to the guns which armed the New Navy from 1883 onwards. The 6in gun itself (which in fact was not test-fired until that year) Jeffers perceived as a prototype and also as a demonstration that the United States could

obtain perfectly modern weapons from domestic sources, that it would not have to apply abroad when naval modernization finally came to pass. Jeffers began his program of new gun development with a 3in breech-loading boat howitzer. Although hardened bronze, a well-known material, would have sufficed for these weapons, he deliberately produced them of steel, to give domestic manufacturers experience in modern gun metallurgy at a time when most US steel production was for railroad track.

The conversion program was extensive, and it is of interest here because it armed most US warships operational during the 1880s. During his early years in office Jeffers deplored proposals for the conversion of existing weapons, largely because he felt that the result would be an ineffective weapon and that its existence would tend to discourage Congress from paying for proper modern rifles. However, in 1874 the Army successfully converted some of its Rodman guns by inserting wrought-iron rifled liners, the caliber decreasing from 10in to 8in. Tests between October and December 1874 so demonstrated the value of the conversion that the chief of army ordnance, Colonel Stephen V Benet, proposed the conversion of all 1294 Rodman guns then mounted in US coast defenses. Captain Jeffers was well aware of the results achieved by the Army, and in January 1875 asked the Secretary of the Navy to ask Congress for funds for Navy conversions. In fact Congress approved the sale of existing obsolete weapons, the proceeds to be used for conversions. Under this program Jeffers over four years acquired and converted fifty-one 11in Dahlgrens, which became 8in rifles. The first passed its proof test on 17 April 1876; the first ten became the main battery of the largest US warship built between the Civil War and the advent of the New Navy, the steam frigate *Trenton*. These rifles were rated at 25 percent more muzzle energy and at 200 percent more energy at 200yds (due to the lesser air resistance of their projectiles) than were the original 11in guns; Jeffers considered them quite comparable to British 8in built-up muzzle-loading rifles mounted on cruisers in the 1870s. Most of the 30 weapons built after those for the *Trenton* became pivot guns on large US ships; the last ten went to the old frigate *Lancaster* when she refitted for service in European waters in August 1881. She did not have them removed until June 1894.

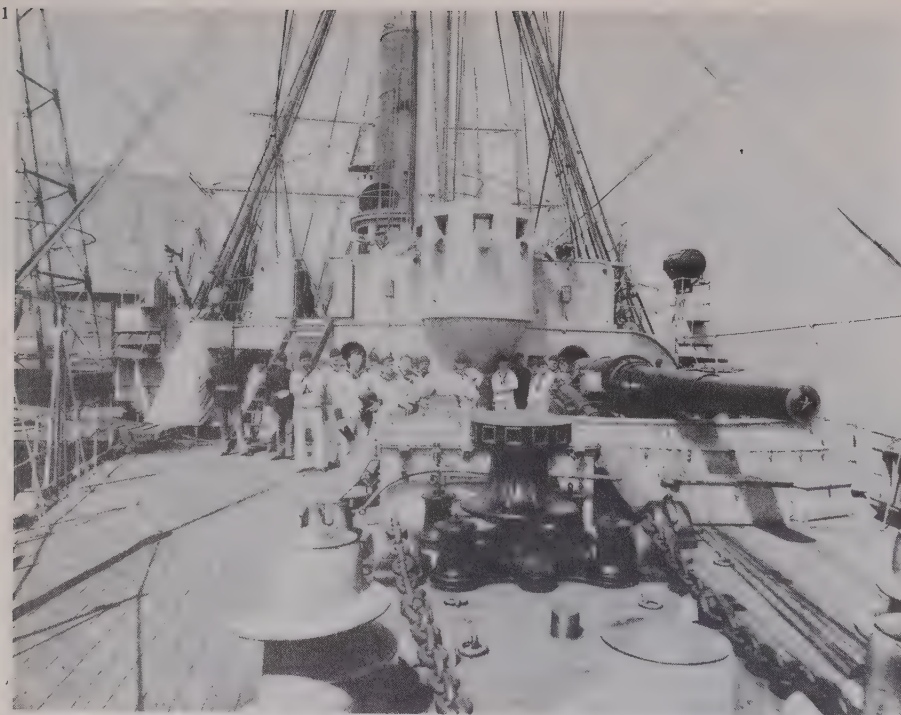
The other series of conversions was more sophisticated, combining rifling with breech-loading. In November 1875 Jeffers sketched a Parrott gun converted into a rifled breech-loader by the insertion of a new liner, the replacement of the former iron reinforcing ring

around the breech, and the provision of an entirely new breech. There was a considerable range of Parrott guns on hand; he was interested at first, in conversions of 8in 200pdrs and of 6.4in 100pdrs. Ultimately only the latter program was pursued, the gun becoming an 80pdr. It was first test-fired in mid-February 1877, but the program was stopped after the first ten in January 1879 because it provided little improvement over the original muzzle-loader, only about 7 percent more energy. Prototype 20pdr and 30pdr conversions were not repeated. Instead, Jeffers shifted to the next largest size below 100pdrs, a 60pdr. The first was installed aboard the gunboat *Nipsic* which recommissioned in October 1879. A total of 29 were converted through 1883, most serving aboard the small gunboats which had been built after the Civil War.

Finally, Jeffers began construction of a prototype modern rifled breech-loader, modeled on a new weapon which the British Elswick works had demonstrated in 1878. It had a longer barrel than had previously been accepted, to permit the powder charge to build up a higher muzzle velocity; it also introduced an enlarged chamber for that charge, so that more powder could be used in the first place. In April 1878 this 6in/25.6 (70pdr) weapon demonstrated a muzzle velocity of 2000ft/sec, 500ft/sec more than that of existing weapons. Jeffers saw in such high velocities the potential for the United States to develop relatively small-caliber (12in) armor-piercing weapons quite the equal of earlier European 'monsters' of 16.25in or 17in caliber, which would have been far more difficult to build. He decided to use the extensive information his Bureau had collected abroad to forego the range of experimentation which had produced the Elswick gun, and instead to duplicate or even surpass what was, for its time, a revolutionary performance. Moreover, he was determined to use only material of American manufacture. In January 1879 he sketched a 6in/24 which he hoped would fire an 80lb projectile at 2000ft/sec. It would initially be completed with a 7in powder chamber (compared to 7.78in for the Elswick weapon) but Jeffers hoped to increase the powder capacity later, to an 8in chamber.

Jeffers himself was not sure at first that Congress would provide money for his prototype; through 1879 all he could do was ask his suppliers for price quotations. Finally he formally accepted the offer of the South Boston Iron Company on 5 January 1880. Unfortunately, although the gun tube proper could be obtained in the United States, the jacket surrounding its breech could not be manufactured successfully, and had to be imported from Firth & Sons of Sheffield. The weapon

The *California*, seen here in 1938, displays standard US battleship fire control systems of the interwar period. She carries armored rangefinders atop both her conning tower and her bridge, the former for use in secondary battery fire control, and therefore with a shorter base; armored shutters are visible in both. The conning tower also carried periscopic spotting glasses, but the top on her cage mast was the primary long-range spotting position, carrying a main battery director on the upper level, and two secondary battery directors below it. Not visible here are two antiaircraft directors (Mk 19), each with a separate rangefinder, on the bridge wings. The battleship carries a range clock, but there are no bearing markings on her turrets. The entire system was designed to achieve, at the same time, maximum effective range (*ie* maximum height above water for the key elements) and maximum survivability (*ie* duplication of those high elements by armored ones): the armored rangefinder atop the bridge, for example, corresponded to armored turret rangefinders, one of which is barely visible to either side of No 2 turret. *California* also shows 0.50-caliber antiaircraft guns, to discourage strafing attacks on her upperworks, *ie* on her fire control system: two in splinter shields forward of her conning tower, with another (and a corresponding one on the other side) on the forward side of her main battery fire control top.



1 The first 'New Navy' cruiser, the *Atlanta*, shows typical weapons of her time in this photograph, which was taken about 1886. As in many contemporary foreign ships, her heavy 8in gun is unshielded except for a fixed barbette. Above, from left to right, are a single-shot rapid-fire gun, probably a 3pdr; a Gatling gun; and a Hotchkiss revolving cannon, the latter superficially similar to early Gatling guns. Note the shoulder pad used to control the small rapid-fire gun to the left, and the armored covers for the conning tower ports.

2 Crew members of a US Navy destroyer in a British port prepare for sea during World War One. The gun is a 3in/50. Note the shield (which the crewman is holding) to protect the pointer from the ejected cartridge case, and the pointer's handwheel and telescope, with the trainer's telescope on the other side of the gun. The two cylinders beneath the gun tube are recoil cylinders. Note the trainer's seat on the twin torpedo tube on the ship in the background, and the ship's lathe (background) and forge (foreground).

3 An 8in/35 aboard the protected cruiser *Columbia* typifies the weapons of the New Navy. Note the absence of sights, and the inclined recoil cylinders alongside the gun; the weight of the gun itself helped return it after firing. Unlike later mounts, this one rested much of its weight on the training circle around the outer edge of the gun carriage. At the breech end, note the short tray into which the breech block withdrew before swinging aside, after being turned by the handle at the side of the gun. Wheels for elevation and train were both on the same side of the gun, and they acted relatively slowly. This type of gun mount was closely related to the types used aboard warships of the muzzle-loading era.

was assembled in mid-1882 and first fired on 10 February 1883, a time span which suggests the low estate of the US arms industry of the time. Nor was it entirely successful: it fired a 68lb shell at 1945ft/sec. Jeffers valued it, not as a production weapon, but as a means of testing powders and gun carriages for the new generation of ships already in prospect.

In the event, the existing US steel industry was unable fully to meet the demands of even the modest naval rearmament which began in 1883. Midvale Steel did provide ingots for the early 5in and 6in guns, most of which were built by the nascent gun factory at the Washington Navy Yard. However, the heavy steel forgings for the main batteries and armor of the first three New Navy cruisers and for the monitor *Miantonomah* had to be bought from British companies. In March 1885 a new Secretary of the Navy, William C Whitney, ended the foreign purchases and instituted a policy of buying only US material, as Jeffers had advocated. In addition, after a series of studies of foreign naval ordnance production, Congress decided to build a domestic factory for modern naval guns at the Washington Navy Yard; the appropriation was passed in August 1886 and construction began in 1887. After 1887, too, Bethlehem Steel was able to provide all gun forgings required, and as of 1889 the United States might be considered self-sufficient in naval ordnance for the first time since the Civil War. The only foreign-built guns used by the Navy after that were a variety of Hotchkiss light guns of the late 1880s and Armstrong 6in/50 and 4.7in weapons aboard the cruisers *New Orleans* and *Albany*, purchased in 1898. Foreign designs entered the US inventory only with the Hispano-Suiza, Oerlikon and Bofors guns of World War Two, and then with the modern OTO-Melara 76mm/62 Mk 75.

Major early gaps in US industrial capacity included an inability to produce, as early as the British, large-caliber quick-firing (in US parlance, 'rapid-firing' or RF) guns or high-velocity large-caliber guns. In these and similar

cases the US response was often to substitute an alternative, available, technology. Foreign evaluations ranged from amusement at US naiveté (as in the case of the Zalinski dynamite gun), to a belief that the Americans were more interested in the impression they made than in the efficiency of their ships (as in the case of the 8in intermediate battery), or to a belief that the Americans, discarding outworn conventions of naval architecture, had valuable lessons to teach a hidebound British Admiralty (also in the case of the 8in gun). The US motive and the foreign reactions are interesting in retrospect, because they seem applicable to the case of a modern underdeveloped naval power seeking to match its more experienced rivals: the Soviet Union. In its case cruise missiles were, in part at least, a means of circumventing a great Western superiority in a complex technology, that of carrier aircraft. It remains to be seen whether, having mastered at least some aspects of the latter technology, the Soviets will adopt it in preference to their cruise missiles. That was certainly what the United States did. For example, it appears that the first three major classes of US battleships, from the *Indianas* on, were armed with an intermediate battery of 8in slow-firing guns primarily because the United States could not match the 6in quick-firer of British ships. Contemporary observers tended to ignore the difference in volume of fire between a small 8in battery and a more numerous 6in one: to them, all 6in guns were equivalent in any case. However, once the United States did have the requisite technology, it reverted to the British-style two-caliber system, in the *Illinois* class (four 13in and fourteen 6in) designed in 1896.

It is important, too, to distinguish between the ability to design and build prototypes or small lots of weapons and the industrial capacity to provide the same weapons in numbers. In many cases the state of American industry made for slow production of both warships and their weapons; at the same time the rate of ship authorization was very rapid, particularly near the turn of the century. In

both guns and ships, several generations might elapse before the first entered service. For example, the armored cruiser *Maine*, designed in 1886, did not enter service until 1895, by which time her entire design was quite obsolete, not to mention her battery – and by which time the first generation of true US battleships, the *Indianas*, were entering service. Meanwhile two more classes, the *Iowa* and the *Kearsarge*, had been designed, and the RF technology which would produce a radical shift in a fourth class (*Illinois*) was well along. The *Indianas* in effect represented US 1890 technology, which was probably equivalent to the British technology of the late 1880s. By the time they fought the Spanish Navy in 1898, both medium and heavy guns had changed radically. Even so, the lessons of 1898 were assiduously applied to much later weapon designs to determine the character of the last generation of American predreadnoughts, the *Virginias* and *Connecticuts* classes. For example, the 8in gun, cheerfully discarded in 1896, was enthusiastically revived. Once again, intentions and authorizations ran well ahead of production, and the new ships did not enter service until 1905–08.

By that time the guns themselves had not evolved much further, but fire control, which was quite as important, had. Given better fire control, the gunners had found it profitable to increase the rate of fire very markedly. This, for example, made the elaborate double turrets of the *Virginias* far less effective than expected: when the 8in guns could no longer fire far more rapidly than the 12in, interference within the four-gun turret became excessive and net rate of fire suffered badly. Quite soon, too, advances in gunnery extended effective battle range to the point at which the 8in (and, for that matter, the 6in it had originally replaced) became useless as a battleship gun, and the dreadnought emerged.

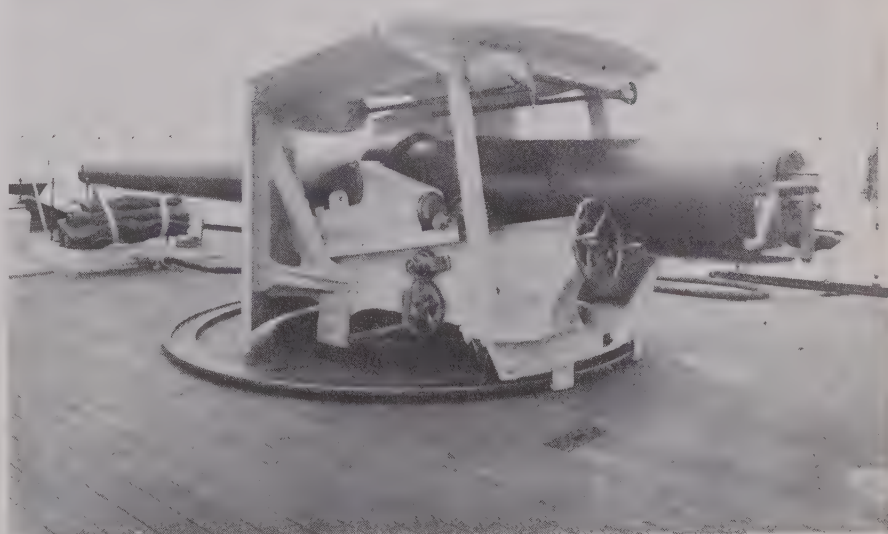
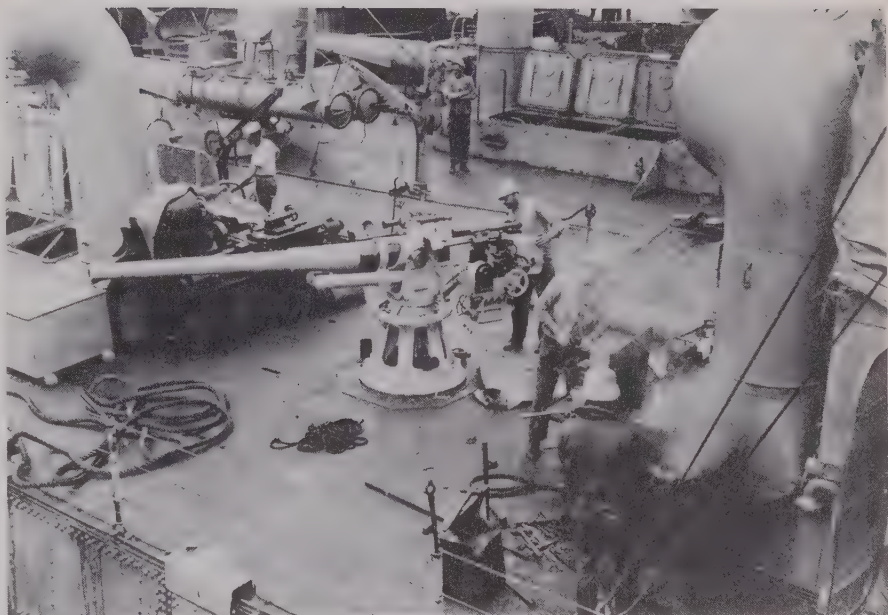
2. Gun design and development 1883-1983

Early Rapid Fire Guns

When the United States began building modern naval guns, there were in effect three classes: very heavy, slow-firing weapons; medium-caliber guns; and light automatic or semiautomatic weapons incapable of penetrating armor but effective against unarmored craft and against exposed personnel topside. The last ranged upwards from Gatling guns and the medium calibers ranged upwards from 4in, whilst the heaviest guns in foreign navies had calibers as great as 17in (although lesser ones were far more common). In cruisers and battleships it was usual to combine a few relatively heavy guns with a battery of medium weapons which could fire more rapidly but with diminished effect. Given the state of naval gunnery, battle ranges probably would not exceed 1000–1500yds, at which distances small-caliber weapons, the successors of Nelson's sharpshooters, would be effective. Moreover, such weapons were the appropriate counter to the torpedo boat, which had to close its target in order to be effective.

The small-caliber weapons achieved their high rates of fire largely because they employed compact, fixed ammunition – ammunition in which the propelling charge was enclosed in a cartridge case fixed to the projectile. At the moment of firing, the cartridge case expanded to help seal the breech, and breech design was thereby considerably simplified, for quick operation. Probably the greatest ordnance achievement of the 1880s was the upward spiral in the caliber of guns which could be so operated, and which might therefore be described as quick-firing. Since 100lb was the effective limit on the weight a man might easily (and rapidly) handle, quick-firing guns above a certain size required semifixed ammunition, in which the cartridge was handled separately; even so, they achieved much higher rates of fire than did their breech-loading predecessors, in which the powder was loaded separately in silk bags, and in which more complex breech closures were required. In addition, the use of a bag gun required that the bore be cleaned (of the residue of the bag) after each round, further slowing fire. On the other hand, manufacture of the brass cartridge case was itself an obstacle to the production of rapid-firing guns, particularly high-powered ones, *ie* ones using very large charges. In 1894 the largest US rapid-fire weapon was the 5in/40, and within two years there was also a 6in/40 RF; but there was never a 7in, and an 8in case gun was introduced only half a century later, and then with power operation in mind.

'Rapid-firing' and 'slow-firing' were very much relative terms; by later standards there were no really fast-firing weapons in the 1880s and 1890s. For example, in 1897 the US 6in/40 BLR was rated at one round every 90 seconds, the 8in/35 at one every 120, and the 12in/35 at one round every 300 seconds (five minutes).



These figures were immensely improved by more careful loading practice and better training, so that a decade later the same weapons were clocked at, respectively, one round every 8.2 seconds (*ie* about 7.3 rounds per minute), one every 30 seconds (2 per minute), and one every 51 seconds (1.2 per minute). However, in the 1880s and 1890s it was assumed that any advance in the rate of fire would have to come from new technology, *ie* from RF guns. It did indeed appear to have had dramatic effects, and in 1897 the US 6in/40 RF was rated at 40 seconds per round, compared to 90 for the bag gun. The training improvements

of the next decade improved matters for the RF guns, but not nearly so much as for the bag types: the firing interval of 40 seconds dropped to 7.9 (7.6 per minute). Later, when improved training practice had been well absorbed, cartridge case guns were once more at an advantage, since they were far more amenable to automation, as in the case of the 8in/55 of the *Des Moines* class.

The growth of RF ordnance more than kept up with the rise of the torpedo boat, and then of the destroyer; it also produced a range of fast-firing weapons which could and did influence the basic design of battleships, just when the

I. GUNS (SURFACE FIRE)

United States began building such warships. As late as 1906 the standard antitorpedo weapon was the 3in RF gun, but about twenty years earlier Armstrong had introduced a 6in QF gun which for a short time seemed about to become the most effective naval weapon, capable as it was of firing the new high-explosive shell in great volume. Existing battleships, however, were designed to resist the relatively few hits of very heavy naval guns firing solid shot. Such projectiles had little destructive effect except when they entered the vitals of a ship, at or near the waterline; battleships were therefore heavily armored about their waterlines, but unprotected elsewhere.

Against this 'all or nothing' system a rain of high explosive shell would be deadly: the ship might not sink, but she would cease to be effective. The British *Royal Sovereigns* of 1889 were among the first battleships adapted to the new weapons, with a secondary battery of ten 6in QF guns as well as a relatively thin (anti-QF) upper belt to complement her thick waterline one.

The 8in/35 Gun

The original range of US naval guns included, at its lower end, a 4in/40 which was soon adapted to fixed ammunition, as well as 6in and 8in guns. A 5in/40 RF was soon added, but in 1890 the 6in was considered too massive for fixed or semifixed ammunition. The 8in fired slowly, but it was faster than the heavy end of the spectrum, which consisted of a 10in (mounted only in the armored cruiser *Maine*, and in several monitors), a 12in, and the 13in/35. It seems interesting in retrospect that there was no weapon directly comparable to the ubiquitous British 9.2in; American cruisers had 8in guns where British ones mounted the 9.2in.

The one-inch difference between US 5in RF and British 6in QF guns translated into a US shell weight little more than half that of the larger weapon. Since such guns fired high-explosive shells, what mattered was total shell weight. It appears that the US Navy consciously adopted instead a slower-firing weapon with a much larger shell, the 8in/35. This advance in caliber would buy a shell about 2.3 times the weight of the 6in, and about four times that of the 5in RF. Moreover, it could be argued that 8in shells would defeat light armor designed to resist the 6in.

This was by no means an ideal solution; it was forced upon the US Navy by the limits of US industry. The 8in gun was heavy and cumbersome, and in a short ship built on a limited displacement it imposed severe blast problems. For a given total weight of guns and ammunition, a 6in battery could devote more weight to ammunition and could also develop a far better rate of fire, in terms of weight of shell per unit time. Exactly these arguments were advanced against the 8in gun in 1896, when the *Illinois* class was designed – and when a semifixed-ammunition 6in/40 was available. Ironically, after the QF problem had been solved and the unwieldy 8in dropped from US battleship designs, it gained new popularity due to its performance in the Spanish-American War.

In that context the key was probably the overall poverty of US naval gunnery coupled with the very low rate of fire of the heavier guns. The 8in had to make more hits. In particular, at Santiago, 13in guns made no hits

at all, whereas the 8in made 13 (out of 319 fired, which was hardly a good showing). Officers present at this and other battles were very favorably impressed with the range and flat trajectory of the weapon; it was no surprise that the existing slow-firing 6in made much less of an impression. What is surprising is that, when these lessons were applied to new construction, no one pointed out that they amounted to lessons learned with 1890 (or even earlier) technology in a period of particularly rapid technological progress. Thus the postwar *Virginia* class reverted to an 8in gun (albeit a greatly improved one) which had originally been adopted to overcome US technological inferiority, at just the time that that inferiority had been decisively overcome. This anomaly was masked to some extent by the contemporary foreign movement towards the use of a heavy intermediate battery, such as the British 9.2in, as the rate of fire of even such massive weapons improved greatly.

The 6in/50 and 7in/45 Guns

The last of the US predreadnoughts had four distinct batteries: their heavy armor-piercing guns; their 8in guns; their medium (rapid-firing) guns; and their antitorpedo guns. The *Virgins* had 6in/50s, which fired bag ammunition and so could not properly be called rapid-fire. However, advances in gunnery practice had so increased the rate of fire of such weapons that their ammunition was considered only a small impediment to rapid fire. On the other hand, compared to the British (Armstrong) 6in/50 cartridge gun, they achieved a muzzle velocity of 2600ft/sec rather than 2300. Indeed, it was accepted that the true test of whether a gun could fire rapidly was, as we have noted, whether a man could easily handle the heaviest unit load involved, *ie* the projectile, which for the 6in weighed 105lb. In the next class (*Connecticuts*) this principle was taken to its logical extreme, the 6in/50 being replaced by the 7in/45 with a 165lb shell. Many commentators, even American ones, ridiculed ships with mixed batteries of 7in and 8in guns, suggesting that a single caliber, 7.5in, would be better. They ignored the fact that shell weight rose not in proportion to the caliber, but rather to its cube, so that the 8in shell weighed 260lb, which made for very different capabilities and a very much slower rate of fire.

These intermediate-caliber guns vanished with the advent of the dreadnought, which was itself a consequence of the other major line of development of the late nineteenth century, the advance in heavy gun design. However, large medium-caliber guns remained, both as a cruiser battery and in order to counter the growth of torpedoes and their carriers. Throughout the period before World War One, the torpedo rivaled the heavy naval gun as a major threat to surface warships. Increases in effective battle range were always at least partly motivated by improvements in torpedo range and lethality. At least twice, too, American naval officers seriously suggested building capital ships whose main batteries would be underwater torpedo tubes rather than heavy guns. The 3in/50 of predreadnought anti-destroyer batteries gave way to a 5in/50 in the *Delaware* class, and then to the most powerful of US secondary weapons, the 5in/51. Even it was not considered enough, and the last of the US dreadnoughts, the *South Dakotas* (BB-49

class), were to have had instead a 6in/53, the weapon also mounted aboard the *Omaha* class scout cruisers.

The 13in/35 Mark I and 12in/35 Mark I Guns

The other major line of gun development was the very heavy gun. In 1890 the Policy Board which directly inspired the construction of the *Indiana* class called for a variety of heavy calibers, all the way up to 16in, which was far beyond the US capacity of the time. The best that could be had was a 13in/35, which was specified for short-range, heavily armored ships. The Board also had in mind the construction of a squadron of battleships for more distant duty. Weight would have to be saved in their construction: the Board was willing to accept a 12in gun. As in the case of ammunition, the one-inch difference in caliber translated into very considerable weight savings. For example, the 12in/35 Mk I weighed 45 tons, the 13in/35 Mk I, 60.7 tons. Projectile and powder weights were in similar proportion. Even the dimensions of the two weapons were very different. At the chamber, for example, the 12in gun had a diameter of 45in, the 13in one of 49in.

For heavy guns the key development was slow-burning powder. Early gunpowders exploded violently, giving the shell a short, sharp kick. The longer the barrel the greater the loss of energy to friction after most of that impulse had already been exerted – which is why the major naval guns of the 1880s were quite short, often less than 20 calibers in length. That short, violent impulse also had the effect of detonating the somewhat unstable explosives of the period, making high-explosive shells impractical – and inspiring the design of the unique Zalinsky pneumatic gun. The next step was brown, or cocoa, powder, which did burn more slowly, but which wasted a great deal of its energy in forming thick smoke; by weight, only about 43 percent of it was gasified. Its other major defect was gross instability. The brown-powder era was typified by guns about 30 calibers in length, such as the first generation of US naval guns. They were succeeded by still longer guns firing smokeless powder, *ie* powder which gasified almost completely. Such a propellant was both more efficient and longer-burning, and could accelerate a projectile all the way along a gun 40 or more calibers in length.

The 12in/40, 10in/40, 8in/45 and 6in/50 Guns

Longer guns meant higher velocities: a lighter, faster shell could penetrate armor more effectively than could a heavier, slower one. Penetration depends upon kinetic energy, *ie* upon a figure proportional to the square of shell velocity but only indirectly proportional to shell weight. At short range, the shell retains most of its muzzle velocity: every navy progressed from larger-caliber short guns to lower-caliber longer ones. An incidental benefit was flatter trajectory, for more accurate fire, which became available at the same time (about 1900) that naval gunnery experienced its own revolution in accuracy. Moreover, the lower-caliber guns weighed less than their predecessors, which made for lighter (or better-armored) gun mountings. In the US case the smokeless powder revolution was announced in the form of a new generation of naval guns,

in 1899: these included a 12in/40, an 8in/45 and a 6in/50. By 1901 a 10in/40 had been added. As in the Royal Navy, with the new powder the 10in was sometimes considered suitable for battleships; indeed, one of the sketch designs for what became the *Mississippi* class showed an all-big-gun battery of twelve 10in/40. As an example of contemporary perceptions, *Jane's Fighting Ships* rated the 8in Mk V of 1899 equivalent to the 12in gun of the *Iowa*; the 10in Mk III was rated equal to the US 13in/35 battleship gun and slightly superior to the Royal Navy's 13.5in weapon, as aboard HMS *Royal Sovereign*.

As in the case of the quick-firing guns, the United States somewhat lagged behind Britain. In view of the general foreign trend towards smaller-caliber, higher-powered guns, BuOrd wanted to make its 12in/35 standard after the completion of the 13in *Indianas*; for example, the sketch designs for the *Kearsarges* all show mixed 12in/8in batteries. However, proving ground tests (1895) showed that although the 12in could not penetrate a target representing the *Iowa's* armor, the 13in could easily penetrate at a realistic battle range, (1500yds). Thus the larger weapon was retained through the *Illinois* class, completed in 1900-01. The Royal Navy, however, had reverted to the 12in (though of 35.5 calibers) in its *Majestic* class, completed in 1895-98. Moreover, gun length did not tell the entire story, as the Royal Navy was able to extract higher performance from its weapons. Its 35.5-caliber 12in was rated at 2350ft/sec, compared to 2100 for the US 35-caliber weapon, and 2400 for the US 12in/40 smokeless powder gun – as finally de-rated. The British 12in/40, adopted in 1901-02, was rated at 2525ft/sec. On the other hand, the Royal Navy used an 850lb projectile, whereas US practice favored one of 870lb.

To some extent, too, the British guns were able to tolerate greater stresses because they were better strengthened against the outward pressure of firing. In their construction they were 'wire-wound': that is, they were wrapped tightly with very strong wire, which could be made to take a much greater stress than could the cylindrical 'hoops' of a US built-up gun. However, the US Navy always preferred its hooped structures on the ground that they better resisted any tendency of the gun to droop. Such measures were particularly important in the case of very long high-velocity guns: the lack of rigidity of the British 12in/50 undoubtedly contributed heavily to its inaccuracy, whereas the US Navy appears not to have found such long weapons at all unsatisfactory.*

The 12in/45 Gun and the Velocity Problem

The new high-velocity guns had their own problems. They suffered from increased barrel wear (bore erosion), and in some cases had to be considerably de-rated. For example, the 12in/40, the first such weapon to enter US service, was de-rated from 2800 to 2600 and then to 2400ft/sec (muzzle velocity) to improve its firing lifetime. The later 12in/45 began at 2850ft/sec (with an estimated lifetime of 125 firings) but was later operated at only 2700. Short gun-life became a more acute problem as the rate of fire rose in response to improvements in accuracy, and as magazine loads rose in proportion to the improvement in

rate of fire. For the US Navy, the problem was compounded by a lack of the industrial capacity needed for mass re-gunning: in January 1910 the Bureau of Ordnance estimated the life of current 12in guns at 100-150 rounds, and probably not over 125 for the 2850 and 2950ft/sec weapons of the newer ships. The predreadnought *Minnesota* had already fired 68 rounds from each of her guns, but it would be four years before she might be withdrawn for re-gunning, during which time over 125 would have been fired. 'If war should then occur, she cannot even fire her meager sixty....' The Bureau suspected that large-caliber weapons would be more satisfactory, but had to admit that gun-life was not really known with any certainty. It was not even clear whether reduced charges for training would solve the problem.

A large part of the Bureau's effort between the wars went into solving this problem, with a combination of reduced muzzle velocity, better alloy steels for gun construction, chromium-plated gun liners and, probably, improved powders. There were special projectiles for practice, the firing of each being equivalent to only a small fraction of an 'equivalent standard round' (ESR), *ie* a full armor-piercing round. Still later, in the early 1960s, 'Swedish additive' was developed. Wrapped around the propelling charge, it drastically reduced bore erosion. 'Swedish additive' (titanium dioxide) was credited with the extraordinarily long gun-lifetime experienced by the *New Jersey* off Vietnam: she fired 5688 16in rounds, but in 1981 her guns (which were not replaced during the war) were at the 42 percent point in wear, suggesting a rated gun-lifetime of well over 1500 rounds. In 1967 it had been expected that re-gunning would be necessary during Vietnam operations, which shows the value of 'Swedish additive'.

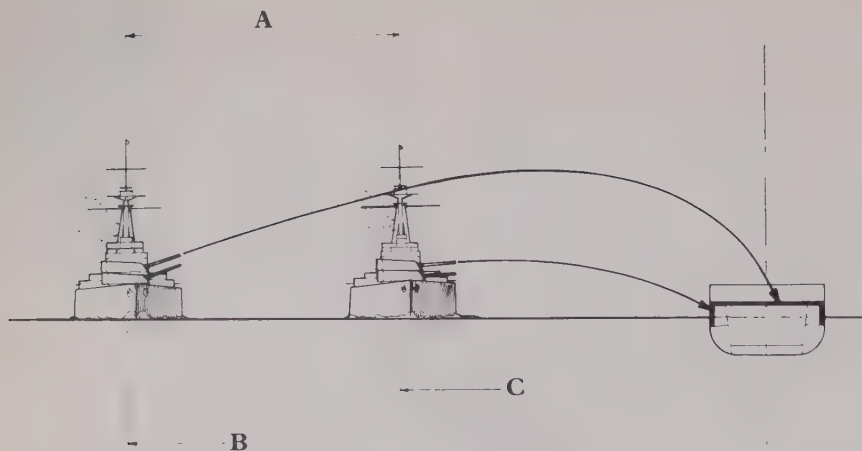
The bore erosion problem extended to guns of less than capital ship caliber. In 1935 the Bureau of Ordnance became concerned with gun tube wear in heavy cruiser weapons (8in/55), which were then rated at 3000ft/sec, for a theoretical gun-life of 125 rounds. This life was defined as the number of rounds after which a gun battery would fire a pattern no more than 50 percent larger than that fired when the guns were new. The Bureau noted that each heavy cruiser was provided with a wartime allowance of 155 rounds of 8in, and considered a life of at least 250 rounds necessary. That is, each ship should be re-gunned when her remaining gun-life was less than the capacity of her magazines, *ie* when firing off her magazines in combat with full accuracy was no longer possible. That in turn could be bought by reducing muzzle velocity or, alternatively, by shortening the projectile (from 4.5 to 4.0 or even to 3.5 calibers in length), thereby accepting a considerable loss of range. A table showed gun-life at 210 rounds at 2800ft/sec, 250 at 2750, 290 at 2700 and 330 at 2650. In each case powder temperature was 90°F. If it were lowered 20°, there would be a further improvement, so that even at 3000ft/sec accuracy life would be 155 firings, whilst at 2800 it would be 240. Chromium-plating of the bore would in itself increase gun-lifetime in each case by 20-50 rounds.

Operationally, the consequences of de-rating were loss of range and loss of penetration at range. Maximum range (40° elevation) would fall from 30,800yds to 27,600 in the case

of a 2700ft/sec gun. Penetration was measured in terms of ranges at which shells would no longer be effective against particular armor thicknesses, a variation on the theme of the 'immunity zone' – the zone in which a particular combination of deck and side armor is proof against a particular gun. At shorter ranges, the gun can penetrate vertical side armor, but it falls too shallowly to penetrate horizontal (deck) armor. At greater ranges, the deck may still be proof, and the gun will no longer be able to penetrate side armor. However, at still greater ranges, the ship is no longer immune: although her side cannot be penetrated, the shell now falls steeply enough to penetrate her deck. Lower initial velocity (or a heavier shell) would actually steepen the angle of fall of shot, and so reduce the outer limit of the immunity zone. For example, the 2700ft/sec gun could penetrate 4in deck armor at any range down to 21,100yds, whereas the corresponding figure of 3000ft/sec was 26,900yds, actually beyond the rated range of the gun. On the other hand, penetration of side armor was lost as muzzle velocity was reduced. Thus the 3000ft/sec gun could penetrate 6in at any range below 17,400yds, whereas the 2700ft/sec gun was considered effective only out to 14,300yds. The Chief of Naval Operations chose 2800ft/sec, even though re-gunning charts produced during World War Two show a standard muzzle velocity of 2700ft/sec – with a life of 550 rounds for plated guns.

The strategy of trading shell weight for higher velocity had its own limits; the 8in/55 was an unusually high-powered gun because its caliber was restricted by the Washington Treaty. No such limit applied to battleships between 1905 and 1920, and calibers steadily rose. The reason was the increase in accurate range. That a gun could project a shell over a very great distance was nothing very new; for example, at an elevation of 30° even the old 12in/35 could reach 21,000yds, and at about 16° the 13in/35 could reach out to 13,000. However, when these guns were designed the Navy expected to fight at 1500yds, and the results of Santiago threw some doubt on even

*There is some question of whether British guns drooped quite as badly as has generally been supposed. The Royal Navy found worse droops in Bethlehem Steel 14in/45 guns, supplied for the *Abercrombie* class monitors during World War One (and similar in design to US 14in Mk I guns): an average of 4.5 minutes of arc in ten 12in Mk XI guns, *vs* an average of 8.5 in six Bethlehem 14in, construction numbers 989-994. In his study of British monitors, Ian Buxton reports that performance was erratic, sometimes due to variation in the ammunition and to copper deposited by the driving bands of the shells, but more due to the hooped construction of the gun, it being difficult to lock together the hoops so securely that the gun would behave as a single homogeneous steel mass. Thus HMS *Roberts* generally shot better after her guns had warmed up, *ie* after their parts had expanded to lock together. Gaps of up to 0.2in were sometimes found, and some guns drooped as much as 1/4° at the muzzle, causing them to whip. The official British assessment criticized poor locking and droop, as well as the thin 'A' (or inner) tube and a low safety factor; on the other hand, the long inherent life of the guns was appreciated and it was concluded that, if large forgings of sufficient quality could be obtained, an all-steel gun of two or three tubes would be superior to a wire-wound unit; Buxton notes that from 1930 onwards the vast majority of British naval guns were all-steel, *ie* hooped.



THE 'IMMUNITY ZONE' CONCEPT

- A. Immunity zone:** the vitals are immune to shell attack by opponents at ranges within the zone.
- B. Outer edge of immunity zone:** defined by greatest range at which a plunging shell just fails to penetrate.
- C. Inner edge of immunity zone:** least range at which a shell just fails to penetrate belt armor.

2 Refitted for service in Vietnam, the battleship *New Jersey* retained her World War Two main battery fire control system, including a Mk 13 radar at the foretop. The large boxlike extensions to either side of her fire control tower carried active and passive electronic countermeasures, directed primarily against North Vietnamese antiship missiles. Similar equipment appeared in other US warships at about the same time (for example, it was mounted on the ECM masts of FRAM destroyers). With the recommissioning of the *Iowa* class battleships, these 16in/50 mounts, designed in 1938-39, will probably have outlived the last US heavy gun mounts to be designed, the 8in/55 automatics of the *Des Moines* class.

that modest claim. By 1903 standards had risen considerably and 3000yds seemed reasonable. Five years later the Bureau of Ordnance was announcing 8000-8500yds as a physical limit on effective shellfire, but only two years after that, in 1910, experimental firing at 12,000yds was successful. In 1912 the battleship *Delaware* repeatedly hit the target ship *San Marcos* at 16,000yds, using careful salvos and spotting. The battleships designed in 1918 (*South Dakota* class) were expected to fight at 18,000yds or more, and when the *North Carolinas* were designed in 1936 opening ranges as great as 24,000yds were contemplated.

Air resistance rises sharply with shell velocity, so that the longer the range, the smaller percentage of initial velocity remains. Moreover, the heavier the shell (per unit of frontal area), the more slowly it loses its velocity. Since frontal area rises as the square of the caliber, and weight as the cube, the greater the caliber, the heavier the shell per unit frontal area. Beyond relatively short range, then, the larger-caliber gun would once more show a considerable advantage. In May 1916, Admiral Joseph Strauss, Chief of the Bureau of Ordnance, noted that 'we went to the 14in gun to use less velocity and still get the same striking energy and longer life of guns'. He acknowledged, too, that part of the pressure for greater calibers was public opinion; indeed, at this time he was being pressed to develop a 16in/50, having already built a prototype 16in/45. Even though it might be fired at a lower muzzle velocity, the heavier shell would retain more of that velocity to the end. Everything then depended upon the increased sophistication of fire control, which continued to make great progress through and after World War One.

The argument in favor of lower velocity and heavier shells gained force as fire control permitted hitting at very long ranges. At such distances, the greatest target area presented to the shells is a ship's deck; most hits are plunging rounds, and they are most effective if they are heavy shells falling steeply. In the 1930s the Bureau of Ordnance began to increase the weight of its armor-piercing shells to take advantage of improved fire control. The 14in guns were given 1500lb (rather than 1400lb) shells, and the 16in 2240lb rather than 2100lb. These figures represented the limits set by shell hoists aboard existing capital ships, but the new generation of battleships was provided

with a 'super-heavy' 2700lb shell. Firing it, a 16in/50 was considered comparable in deck penetration to the 18in/48, which was a major reason why the United States never breached the 16in caliber barrier. The comparable 12in shell, for the *Alaskas*, weighed 1140lb - as against 870lb for earlier 12in AP projectiles.

The 14in/45 Gun

The turn back to heavy calibers was relatively slow. In the summer of 1908 there was a widespread feeling in the naval world that the standard battleship caliber would soon rise above 12in. It was known that Great Britain had under construction a 13.5in weapon, and Germany appeared ready to abandon her 11in gun, which many assumed was already equivalent in penetrating power to the 12in of other navies. At Newport the General Board voted in favor of a heavily armored, ten-14in-gun type for future construction; some officers wanted the *Utah*, then in the final planning stage, armed with eight 14in rather than with the ten 12in then planned. No 14in gun yet existed, but it was clear that the 14in would set an entirely new standard of destructiveness, making existing ships, and even ships under construction, obsolescent. Hence the reluctance of the various navies to move toward it. Moreover, the problems of the existing 12in/45 had not yet been cured. The Bureau of Ordnance, confident that 8000-8500yds was the physical limit on battle range, noted that the 12in could penetrate any armor at that distance.

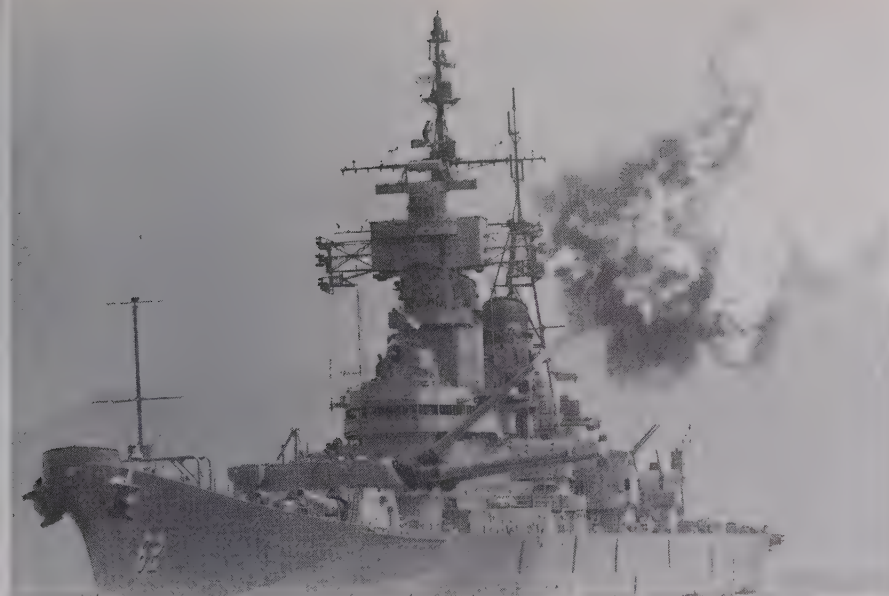
Ordnance considered three factors in comparing the proposed 2600ft/sec 14in/45 to the existing 2800ft/sec 12in/45: rate of fire, destructive effect, and accuracy. Erosion was expected to limit each gun to 150 rounds, although Ordnance would later admit that any difference would probably favor the larger caliber. The greater bulk of the new gun would slow firing rates, probably in the ratio of calibers, ie of shell dimensions. The flatter-trajectory 12in would be more accurate: its greater danger space would tolerate a greater error in the estimate of range. At 8000yds, it was estimated that a single 14in gun would make about 10 percent fewer hits. Destructive effect would involve several factors, but the ratio of shell weights, 3 to 5 in favor of the heavier shell, was used to estimate them. Multiplying through, the ratio of values might be taken as $14 \times 10 \times 3$ vs $12 \times 9 \times 5$, or 7 to 9 in favor of the 14in gun. This conclusion was

slightly modified by the probability of hitting under standard conditions of salvo fire. Under the system just being introduced in 1908, a salvo consisted of one round per turret, aimed centrally. It could be argued that the probability of hitting depended not only upon the probability that the range was sufficiently accurately known (as in 9 to 10 in favor of the 12in), but also on the number of rounds per salvo, ie upon the number of turrets. This would certainly favor the more compact weapon.

In 1908 it appeared that the alternatives open to the United States were eight 12in on 21,500 tons (*Utah*, for a value of 70, or 3.2 per thousand tons); twelve 12in on 26,000 tons (for a value of 84, also 3.2 per thousand tons); eight 14in on 25,000 tons (value 72, 2.9 per thousand); or ten 14in on 27,000 tons (value 90, 3.3 per thousand - but too large for most existing facilities). In fact both the twelve 12in and the ten 14in solutions were pursued; Ordnance proposed that a new 12in/50 be developed at once from the existing 12in/45 as a low-risk option, and that the 14in/45 be developed for later construction. At this time Bethlehem was already building a 12in/50, for delivery in July 1909. The twelve-gun alternative became the *Arkansas* class and the 14in design the next battleship, the *New York*.

The 14in/50 and 16in/45 Guns

Once the rise to 14in had been accepted, pressure built for the logical next step, to 16in. Indeed, there even exists a rough sketch design (in the series preceding the *Pennsylvania*) for a ship with a 15in guns, although such a caliber does not appear to have been contemplated by BuOrd. At first the Bureau resisted. For example, in April 1910 Admiral Strauss rejected proposals for a 16in/40, citing the power of the new 14in/45. However, on 6 November 1911 he proposed a 16in/45 which would fire a 2100lb shell at 2600ft/sec. It would have 50 percent more energy than the 14in, and nearly double that of the existing 12in gun. The General Board approved, and indeed was to incorporate the 16in gun into its proposals for the next class of battleships. The Secretary of the Navy, on the other hand, was inclined to see the 16in gun as yet another jump upwards in cost. In February 1912 he declined to permit construction, although plans were to be prepared. The weapon was finally approved in October 1912; initial drawings were submitted in August 1913, and the pilot weapon



was proof-fired on 16 July 1914.

As in the case of the 14in/45, there was a certain reluctance on the part of the Secretary of the Navy (*ie* on the part of the civil government) to incur the expense of the next step upward in caliber – and in battleship size. Probably as a low-risk backup to the 16in/45, BuOrd developed a 14in/50. After Secretary Daniels ordered that the next class of battleships (*Mississippi* class) essentially duplicate the *Pennsylvanias*, the Bureau suggested (August 1914) that it incorporate the new weapon. At a cost of 7.5 tons, much of it in stiffening to avoid barrel droop, the new weapon would add 200ft/sec, equivalent to 2in more penetration at 10,000yds. Half of the improvement came directly from the greater length, half from an enlarged chamber which made sense only for a longer gun.

The 18in/48 Gun

Two years later the pattern was again repeated. An 18in/45 was sketched in December 1916, and a prototype (48 calibers in length) actually ordered; design work began in 1919. No ship mounting it was ever seriously contemplated, but 18in guns did figure in a series of 1917 studies on an 'ultimate' battleship undertaken at the behest of Senator Benjamin Tillman. He wanted to know how far the competition in battleship sizes might be expected to go, and for his pains was shown 80,000-ton ships with fifteen or sixteen 18in guns each. In 1917, presumably for similar reasons, a 20in/45 (4100lb shell, 2600ft/sec) was sketched. At that time there was considerable talk of super-calibers; for example, Admiral Fisher had advocated the construction of battlecruisers each armed with six 20in guns; the Navy may well have wanted to know whether such schemes were at all realistic. The notional 20in gun was revived in 1934 when it became important to judge the possible consequences of Japanese withdrawal from the Washington Treaty and its 16in limit; once more very large battleships were sketched so that their characteristics might be estimated. Again, the estimates do not appear to have been directly related to any American weapon project.

The 18in was a more serious scheme, one

gun actually being ordered. It ran foul of the Washington Treaty, and was extended and lined down to 16in, becoming the 16in/56 Mk IV. In 1928 and again in 1938 it was briefly considered as an alternative to improved versions of existing 16in guns; it was rejected partly because of its weight, and partly because its very high velocity was counterproductive in plunging fire. In 1938 the 18in/48 itself was rejected in view of the superiority of the 16in/50 firing the 'super-heavy' shell.

The 16in/50 Gun

As in 1914, the Navy in April 1916 began plans for a higher-velocity version of the existing weapon, in this case the 16in/50 Mk II. The first proof-firing followed on 8 April 1918. Unfortunately, the ships for which the Mk II had been designed – the battleships and battlecruisers of the 1916 program – were all canceled due to the Washington Treaty; the guns were stored, some of them going to the Army for coast defense. There was very little real development in interior ballistics between wars: in 1938 the *Iowas* were to have been armed with these same Mk IIs.

In fact a new gun was developed. The *Iowa* was a very tight design, just within the new 45,000-ton limit reached by application of an escalator clause in the new 1936 (London) Treaty. It was clear even at the time of Preliminary Design that any change in barbette diameter might have a disastrous effect on the design as a whole, since the hull curved in sharply (for the specified very high speed of the ship). That is, were the barbettes to grow beyond the diameter specified by the preliminary designers, they would have to be moved, the ship lengthened, and considerable displacement (about 2000 tons) added. With this in mind, the preliminary designers in the spring of 1938 chose one of several possible turret designs provided by the Bureau of Ordnance. When both Bureaus presented more detailed plans to the General Board that November, it was suddenly discovered that Ordnance had not developed the alternative around which Preliminary Design had built its battleship: that had been considered far too congested. The two Bureaus had not found it

necessary to consult at all, and a furious General Board ordered them to find some way out of the mess they had created. Fortunately, advances in gun construction since 1916 saved the day: the new Mk 7 was only 49in in diameter at the chamber (*vs* 56.5) and weighed only 106.8 tons (*vs* 128.1 tons).

As Appendix I-1 shows, similar savings were achieved in the abortive 14in/50 originally planned for the *North Carolinas*, as well as in the 16in/45 Mk 6 which actually armed those ships. The changes were dramatic: for example, both of the new 16in guns were built of three hoops, whereas the old ones required seven.

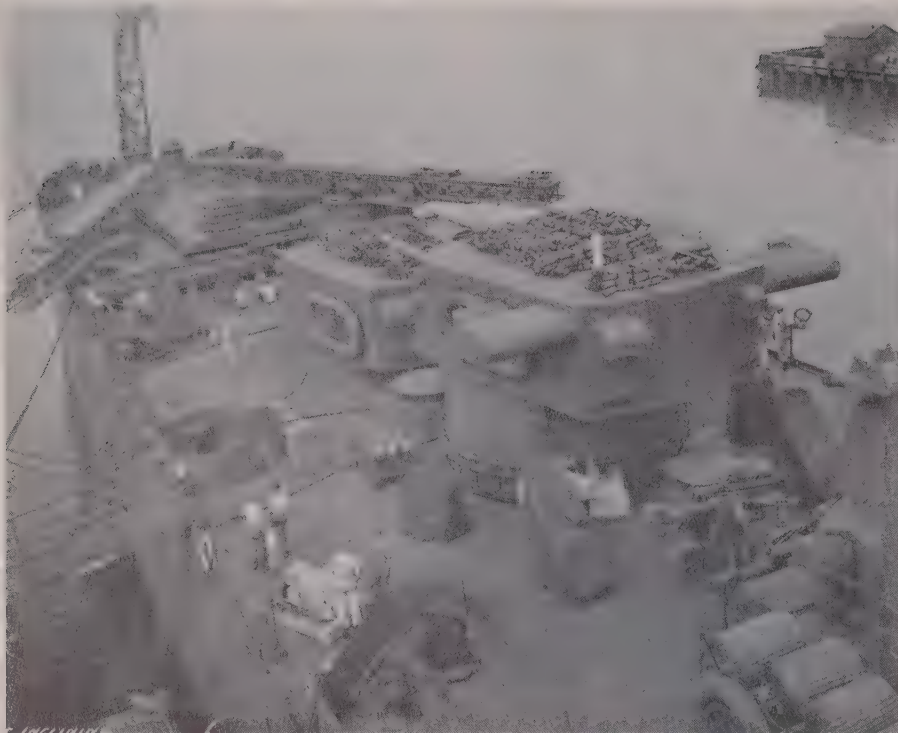
Interwar 6in and 8in Guns

Between wars the principal US naval construction was in heavy cruisers and carriers; thus the principal heavy gun efforts of the Bureau of Ordnance were in 8in and then in 6in guns. The US Navy had looked toward the 8in as a principal cruiser gun even before the conclusion of the Washington Treaty, primarily to outshoot the 7.5in gun of the British *Hawkins* class. Moreover, it was argued that, mounted in a true turret, the 6in/53 with its lighter shell would not show any very great advantage in rate of fire over the heavier 8in.

This was certainly the case as long as the 6in remained a bag gun. However, in the late 1920s BuOrd designed a new fast-firing 6in with semifixed ammunition, de-rated from 3000 to 2700ft/sec (47 rather than 53 calibers in length). Firing rates as high as 12 rounds per gun per minute were claimed, whereas the 8in/55 was limited to three or fewer. Even so, the 8in was preferred by many, due to its great range. Through the interwar period, the 8in cruisers were assigned to the Scouting Force and the 6in cruisers to the Battle Force (as screen ships); in other words, the heavier gun was favored for independent operations (where enemy heavy cruisers might have been met), but the lighter one for service with the Fleet, where it might usefully break up destroyer attacks with its great volume of fire.

War experience showed problems with both concepts. In the night actions in the Solomons, the 8in generally fired far too slowly to catch radically maneuvering Japanese warships. The 6in/47 fired quickly enough, but did not have the range, particularly in view of the existence of the Japanese 'Long Lance' torpedo. Meanwhile the Bureau of Ordnance was developing a dual-purpose automatic 6in/47, the weapon which would eventually arm the *Worcester* class cruiser. Similar concepts were applied to the 8in/55, resulting in the fast-firing weapon of the *Des Moines* class – which appeared well after the need for such an antiship weapon had passed.

There were also considerable advances in the design of gun tubes. Monoblock construction, in which a single forging was stressed radially to build up the appropriate structure within it, was extended upward in caliber, with a considerable saving in gun tube weight. For 6in guns, it first appeared in the 6in/47 (Mk 16), the tube of which weighed only 4.3 tons compared to 8 tons for a built-up 6in/50, or 9.9 for the 6in/53 of the *Omahas*. In 8in gun design, the Mk 12 of late Treaty cruisers was a radially expanded tube with a shrunk-on jacket; it weighed 16.6 tons, compared to about 29 for a conventional built-up type. The ultimate development of this technology was the



Mk 16 gun of the *Des Moines* class, which consisted of a monoblock radially expanded tube and a 'loose-liner' held by a locking ring, on a weight of 16.7 tons.

BuOrd was particularly proud of this weapon, which was the largest semifixed-ammunition gun it had ever built. In addition, unlike all other naval guns, it did not have to visit a Navy Yard for relining. When the gun was cold, the loose-liner could be withdrawn with relatively little effort for relining. At the time of firing, however, it expanded against the monoblock main gun tube. Although at least the Germans and the Italians had also devised loose-liner guns, it seems that BuOrd had developed this one independently.

It appears in retrospect that until well into the 1930s the heavy naval gun was considered almost exclusively an antiship weapon. The standard 'Orange' war plan did contemplate the seizure of Japanese-held islands, but little attention was paid to the problems of amphibious warfare, including shore bombardment. Attitudes did change late in the 1930s; one consequence was the development of specialized high-capacity (HC) shells for heavy naval guns. Since high explosives have considerably less density than steel, they were always lighter than armor-piercing projectiles, and caused considerably less bore erosion – which was fortunate, since pre-landing bombardments always required very heavy firing. In 1944, with a reduced charge, the 16in/50 fired a 1900lb HC round at 1900ft/sec, equivalent to only 3 percent of the barrel wear of a 2700lb AP shell fired at 2500ft/sec; the gun was rated at 300 ESR, or 10,000 rounds of HC.*

After 1945 the situation was reversed: there were no ship-to-ship duels in sight, but amphibious warfare was still important. Heavy-gun ships were expensive to man, and were retained only as flagships and for training. The Korean War demonstrated the value of shore bombardment, the 8in apparently being preferred to the 6in because of its greater destructive effect. The United States had so great a surplus

of heavy-gun ships that there was no incentive to continue heavy-gun development: no one could expect any new ships to be built. Effort therefore shifted to projectiles. In the early and mid-1950s it was generally accepted that the next war, however limited, would see the widespread employment of tactical nuclear weapons – including weapons for shore bombardment. Indeed, the destructive power of such weapons might just make up for the dearth of shore bombardment ships. Manifestations of this view included both the nuclear version of the Terrier surface-to-air missile (advertised as an antiship and shore bombardment weapon) and 'Katie' (Mk 23), the nuclear 16in shell. The latter appeared just at the end of the *Iowas*' operational lives; each ship was to have had ten rounds, but it is not clear whether any actually went to sea. *Wisconsin* was to have been the test ship, but instead a 16in gun was shipped to the nuclear proving ground for a test shot.

The Major Caliber Light Weight Gun

By the late 1950s, the outlook for free use of nuclear weapons was far dimmer, and the end of the existing stock of heavy-gun ships was in sight. Moreover, the Long Range Objectives Group was predicting a world in which the United States and the Soviet Union, balanced in strategic power, would be unable to fight each other. Wars would probably be fought around the perimeter of Eurasia, and they would almost certainly involve Marine amphibious assaults. This accurate prediction led to an unfortunate conclusion: quite soon the only shore bombardment gun in the fleet would be the 5in dual-purpose (see Part II), a gun outranged by some existing Soviet-bloc coast defense guns (such as the 130mm) and incapable of destroying some types of field fortification. By 1962 the Naval Warfare Analysis Group, an arm of LROG, was calling for the development of a new Major Caliber Light Weight Gun.

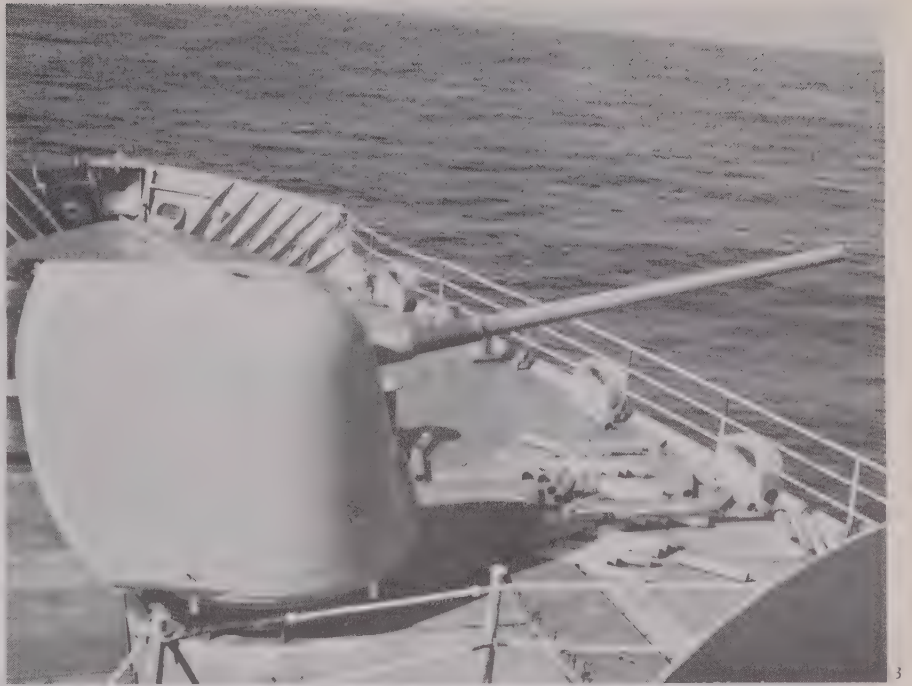
It was clear by then that there would

probably never again be large heavy-gun ships; the new weapon would have to fit aboard destroyers, or at least aboard ships of roughly destroyer size. Manning was already a major constraint, and so it would have to be essentially automatic. For a time an adaptation of the Army 175mm cannon was planned; later an 8in/55 was adopted, partly in view of the size of existing stocks of that ammunition. The Marines were very pleased with the new weapon program, and produced studies showing the necessity for 8in as well as 5in support for opposed landings. Although a specialized fire support ship (LFS), which would have been armed with the 8in/55, was canceled, the new *Spruance* class destroyer was designed to permit rearmament with it. Trials aboard the *Forrest Sherman* class destroyer *Hull* were promising, and in the mid-1970s it appeared that the 8in would once again be a truly formidable weapon, combining a substantial explosive charge with long range and high accuracy through laser guidance.

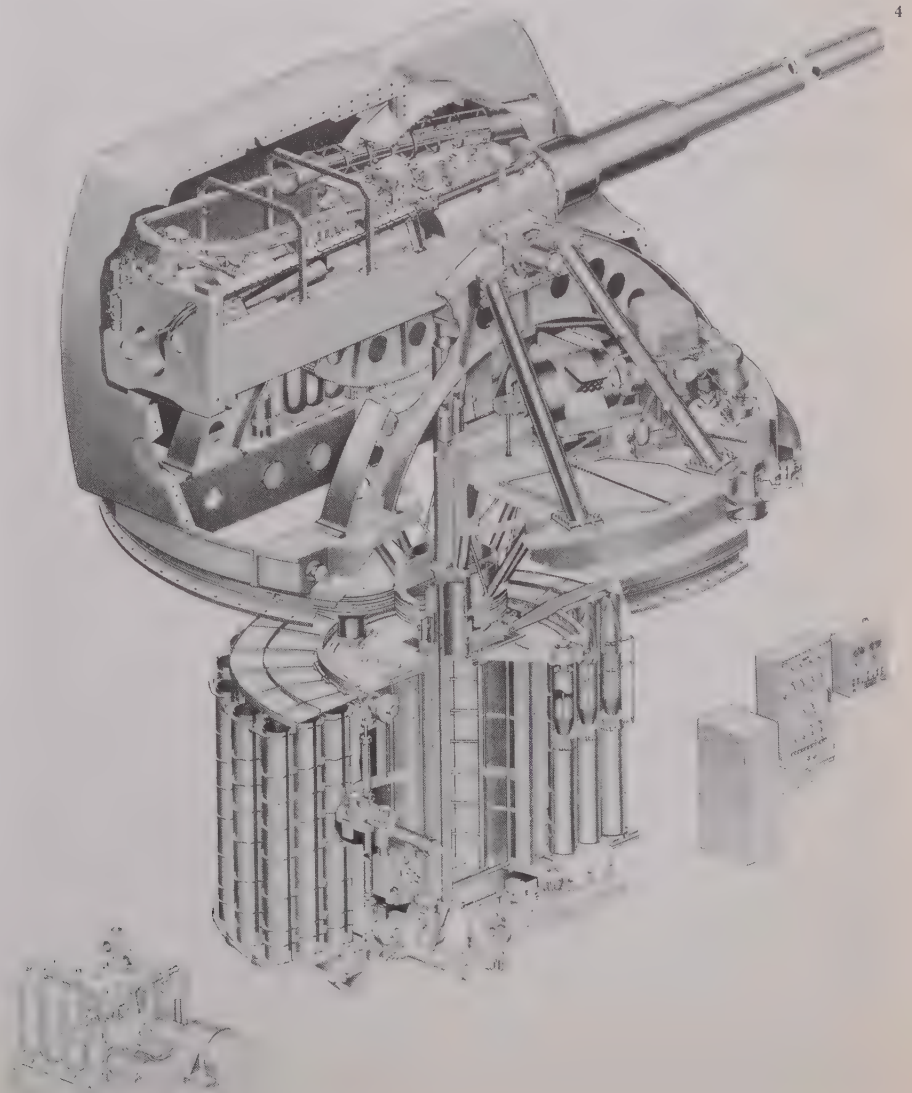
Then the program began to unravel. The Navy, caught up in the post-Vietnam mood of the country, was less than enthusiastic about funding fire support weapons, given its general shortage of funds and personnel. It had justified buying the 8in gun in part because accurate long-range fire was needed, but had tried to avoid facing the true cost of the system by omitting laser guidance from its package; the General Accounting Office complained that the existing 8in did not have the requisite accuracy – which was perfectly true, as the laser system had always been considered part of the solution to the accuracy problem. Given the urgent needs of the remainder of the Navy, it was no great surprise that the 8in program was canceled entirely in 1978. There have been periodic attempts to revive it since, led largely

*US practice in HC shell design differed from that in Britain and Germany, where HC shells matched AP in weight and in ballistic characteristics.

The triple 6in/47 turret was surely the most widely produced of any US major-caliber mount of the World War Two period: these are the after mounts of the newly completed light cruiser *Biloxi*, 21 August 1943. All three guns were in a single sleeve, and they used cartridge-case (semifixed) ammunition; both features are implicitly visible here. Each mount has only three projecting sights, two on the left (as shown) and one on the right; the two on the left are for the trainer and checker, that on the right for the single pointer controlling all three guns in elevation. Nets extending below the mount in the foreground (and clearly visible in the original print) were intended to catch brass cartridge cases ejected from the bottom of the gun house as it fired. Note, too, the characteristic pair of air intakes, similar in principle to those on the sides of US battleship turrets of the 1930s, and the stowage for floater nets atop the mount. The object in the foreground, on the centerline, is a 5in loading machine, essentially a representation of the breech area of a 5in/38 gun, for training gun crews. The hangar aft is indicated by the flat door (between the catapults) covering it; US cruisers (but not battleships) had protected storage for their floatplanes, which were themselves an important element of the gun control system.



The cruiser *Cincinnati*, refitting at New York Navy Yard on 4 July 1942, displays the 6in/53 designed for the *Omaha* class and specified as the secondary battery of the abortive *South Dakota* class battleships and *Constellation* class battlecruisers; it was proof-fired in October 1918, and in the cruisers was mounted both in a twin splinterproof gun house and in lightly protected broadside double-decked emplacements, as shown. Note the openings on either side of the guns for sights; the two guns of the twin mount did not elevate independently. The 6in fire control system included a protected Mk 35 rangefinder atop the pilot house (3) and a director inside the top at the head of the tripod foremast; note the absence of any rangefinder in the 6in gun house proper. The large cylinder atop the gun house is presumably a compressed air supply, unprotected by any armor. The tub forward of the bridge (extreme foreground) accommodates a 1.1in director, a Mk 44.



In the early 1960s the US Navy abandoned the medium gun as an air defense weapon and looked for a reliable system for low-angle fire. The Mk 45 was the first result of this program: a fully automated 5in/54 whose rate of fire approximated to that of the older semiautomatic guns. Ammunition enters the breech from below, which is why elevation is limited to 65°. Proposals for a rapid-fire version and for a twin version died in the mid-1960s when the decision was made to develop the Major Caliber Light Weight Gun, which became the Mk 71.

FMC Corporation.

With the demise of the US cruiser force, it became necessary for the US Navy to develop some weapon more powerful than the destroyer 5in gun, which could be outranged by shore defense guns standard in the Communist world. A naval version of the Army 175mm gun was developed, but in the end the lightweight 8in/55 (Mk 71, Major Caliber Light Weight Gun) was adopted, to be installed in the new *Spruances* in place of their forward 5in mounts. However, by early 1979 it had been canceled, the 8in mission to be performed by improved (including guided) 5in ammunition.

FMC Corporation.

by the Marines who remember the value of heavy fire support from several wars. In 1983, with increased defense spending and great interest in a Rapid Deployment Force (probably built around Marine units), it is quite conceivable that the 8in will reemerge in some form; perhaps even the LFS will be revived.

RAP and Laser Guidance.

The story of the surface-to-surface gun in the modern Navy is not complete without mention of the two major developments of the 1960s: rocket assistance and laser guidance. In each case the new technology was applicable to surface-to-air as well as to surface-to-surface firing, but it was typically associated with the latter.

Rocket-assisted projectiles (RAP) came first. The standard 5in/38 RAP is about 2½in longer than the standard 5in/38 projectile, and its solid-fuel motor burns for about 40 seconds, to give it a maximum effective range against surface targets of about 22,000yds, compared to about 14,000 for the conventional round. The penalty is weight of explosives delivered: 3.5lb for the RAP, 7.9 for the conventional round; even so, the conventional shell is lighter, at 41.6 rather than 55lb. The rocket boost is also useful against air targets; at any elevation, the RAP round reaches out about 3500yds further in effective range. Similar gains were claimed for the 5in/54: a 34-second rocket motor stretched useful surface-to-surface range to about 28,000yds (compared to 22,000) and increased effective surface-to-air range by about 4000yds at any elevation. Explosive weight fell from 7.9 to 3.8lb, with little change in total projectile weight. Finally, an 8in RAP was tested in Vietnam, fired by the cruiser *St Paul*. A range of 40nm was reported.

RAP was particularly welcome because it could redress the imbalance between destroyer gun range and the range of standard Soviet-type coastal artillery. However, there were considerable sacrifices in accuracy and in explosive effect. The latter could not really be corrected, given the limiting dimensions of shell hoists and hence of the shells themselves, but modern guidance technology did promise great improvements in accuracy through positive (post-firing) guidance.

Laser guidance of ballistic projectiles was first applied to gliding bombs in Vietnam, but in the late 1960s a guided shell program ('Pave-way') was begun, successful demonstrations of an 8in shell (CLGP, Cannon-Launched Guided Projectile) following in 1971. The Navy side of this joint Army-Navy program included both 5in and 8in rounds, and guidance could be either by shipboard or by hand-held laser: CLGPs could be effective both in antiship and in shore bombardment roles. For example, during the tests of the 8in lightweight gun, the destroyer *Hull* made five hits out of five shots on a moored ex-destroyer. These and contemporary CLGP rounds are fully ballistic, but clearly the great potential of CLGP lies in its combination with RAP technology.

In effect this combination changes the character of the shipboard gun. Guns have always been far less expensive than guided missiles per round fired, since much of the investment in a gun system is the one-time investment in the gun proper. The price paid is reduced accuracy per round, which is one reason guided missiles have become so popular even for traditional gun functions, such as antiship warfare. The CLGP or CLGP/RAP alters this balance. It is not nearly as expensive, on a round-for-round basis, as the fully guided missile, because the gun tube does guide it into a 'basket' near its target. On the other hand, once it has been tossed into that basket, it is guided much more precisely than a traditional

shell – and potentially at much greater range. CLGP thus places less stress on gun accuracy, and indeed can accept very low muzzle velocities and very steep angles of descent onto the target. It can also, in theory, operate over the horizon, as long as some third party is available with a targeting laser. Since many ships operating 5in guns also operate LAMPS helicopters, such operation is a distinct possibility in future. From a ship-to-ship point of view, perhaps the most important difference between guided shells and missiles is that the shells are available (in magazines) in overwhelming numbers. For example, the standard allowance of 5in shells is 600 per gun. Even allowing ten rounds per ship-kill, that is 60 engagements; the standard allowance for Harpoon, which probably cannot kill one ship per shot, is eight.

As in the case of RAP, CLGP is hardly without cost. Much of the volume of the shell is taken up by the guidance system, although a lower initial velocity can translate into a thinner-walled projectile, and the CLGP shell actually carries a larger explosive charge than its conventional predecessor. Considerable volume, too, is consumed by the fins which control the weapon in flight, and which deploy after it is fired. The projectile is much longer than a conventional one, and must be 'double-rammed', ie loaded, cleared of its protective plastic case, and then mated with its cartridge case in a second loading operation. The effect is roughly to halve the rate of fire. In 1981 Northern Ordnance, the chief builder of post-war Navy guns and missile launching systems, was proposing a new vertically loaded gun system better adapted to CLGP/RAP rounds, with some Navy interest; options include a short 8in gun, which Northern Ordnance refers to as a 'tube missile launcher'.

There was also a considerable irony. In 1975 the Chief of Naval Operations committed all major and intermediate caliber guns primarily to the surface strike role, and the 8in Major Caliber Light Weight Gun was then very much a live program. At the same time, however, CLGP technology (using IR guidance) began to become attractive in the antiaircraft role, where its high rate of fire (and high rate of engagement) made it an effective complement to longer-range surface-to-air missile systems. Indeed, antiair effectiveness was a major reason for retaining 5in guns in the Aegis missile ship (*Ticonderoga* class). Among the major current naval gun systems, only the OTO-Melara 3in/62 Mk 75 is too small to accept CLGP guidance. Ironically, this weapon had been chosen for the *Perry* class frigate in preference to the lightweight 5in/54 precisely because of its supposedly superior AA performance.

Both semiactive laser and infrared homing guided projectiles (IRGP) were developed under the same program, with similar rocket motors and fins; the latter were intended specifically for antiaircraft use, the gun projecting the shell into an intercept 'window' computed by ship fire control systems. The IRGP program died after FY81 due to budget constraints. Twenty rounds were built at Dahlgren for tests during the summer of 1981 (first delivery April 1981), and it was expected that development would lag behind that of the semiactive laser shell by about a year.

The surface-to-surface Semi-Active Laser Guided Projectile (SALGP) program appears

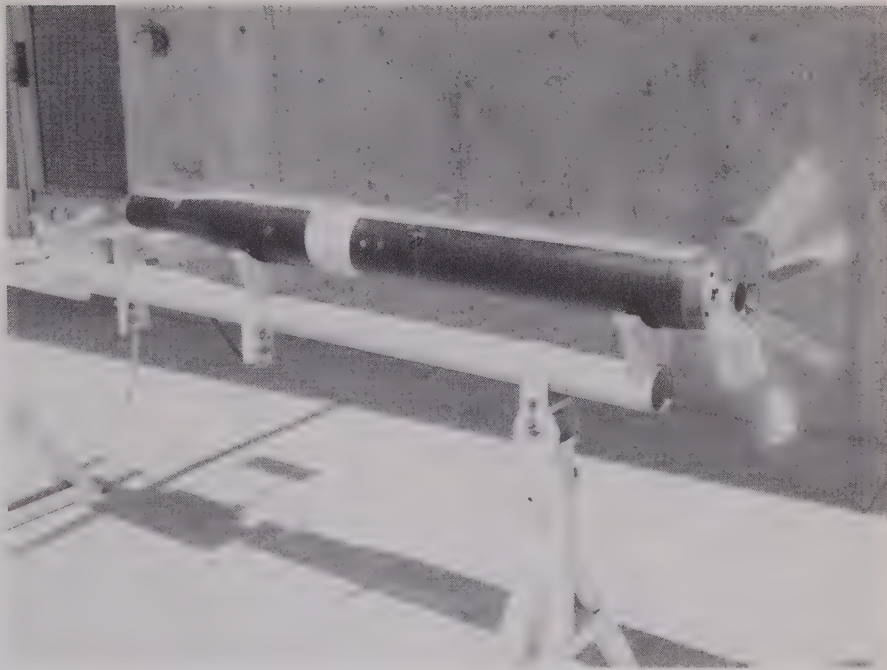
to be far healthier, although, somewhat surprisingly, no Operational Requirement for the SALGP had been issued until April 1977. The Seafire electro-optical fire control system was developed specifically to support the SALGP, but it was not funded in the FY82 program, Navy representatives explaining in budget hearings early in 1981 that increases in the sophistication of (primarily missile) shore defenses throughout the world had considerably reduced the value of ship guns for shore bombardment, so that Seafire's applicability was considerably less than had originally been supposed. However, Seafire and SALGP have been kept alive at Congressional behest as part of the DDG-51 program. Thus the FY83 authorization shows a demand that \$60 million be spent on these programs, and makes release of DDG-51 funds contingent on the integration of the 5in SALGP/Seafire with that new ship. The SALGP was first tested in April 1980.

The Future

There are further interesting possibilities. For some years there have been active proposals to recommission one or more *Iowa* class battleships, arming them with a combination of cruise missiles, V/STOL aircraft, and their existing heavy guns. Large reserves of 16in shells remain, and when the *New Jersey* was deployed to Vietnam it was claimed that numbers of reserve gun tubes had been found at Subic Bay. In 1974 the Center for Naval Analysis suggested recommissioning on the theory that a battleship would be less vulnerable than a carrier, and might have considerable destructive impact with CLGP/RAP. It does not appear that any such shells then existed, but certainly the technology to produce them exists at present, and certainly a 16in shell would be far more destructive than any 5in or 8in.

The reserve of 280mm high-explosive shells produced for the Army's 'atomic cannon' can be fired to extreme range by a 16in/50 gun, using sabots. In the spring or summer of 1967 such weapons were proposed as a means of extending the effective range of the battleship *New Jersey* to 100,000yds; the Naval Ordnance Station at Indian Head, Maryland, proposed a \$4 million, 18-month program to use 23,000 surplus rounds, fitted with a sabot, and fired out to 50nm at 45° elevation. It was, however, feared that heat effects on the fuzes from extreme velocities would create serious problems, which might take up to two years to solve (as well as up to \$5 million); that stable flight would not be assured, and indeed that stability and sabot separation would be high risk areas of technology; and that merely establishing a firing range would cost over \$1 million. An exploratory program was established, however, with Indian Head contracting with the Army's Picatinny Arsenal and with the Space Research Corporation of North Troy, Vermont (which had used surplus 16in tubes to fire small research loads into space at very high velocities). Firings were held at the Yuma Proving Grounds (up to 60,000yds) and at the private (Space Research Corporation) range in Barbados, the latter with old surplus 16in gun tubes, at a total cost of only about \$225,000, between August 1968 and February 1969. 'Swedish additive' coolant liners were used in all shots, but the originally intended quantity of 6 percent of the propellant weight was

reduced to 2 percent when a large amount of unburned residue was found after the first (low-pressure) shot; presumably such quantities were characteristic of the use of Swedish additive in operations off Vietnam. The fuzes appear to have been a proximity type, the Army's Harry Diamond Lab monitoring fuze oscillations during flight to test how well the fuzes survived the heat and stress of firing. In February 1969 the Barbados gun fired an 835lb round at 40° elevation and 4230ft/sec out to 74,650yds; somewhat earlier, in November 1968, a 745lb round had been fired at 4600ft/sec out to 83,850yds. It was estimated that at 45° elevation, the light shell, fired at 4550ft/sec, would have a range of 102,000yds, or of 93,000yds at 40°. In each case, between 710 and 780lb of powder was used. There is no indication of dispersion, but at 50nm it must have been significant. In any case, after indicating early interest, Opanav abandoned the study, even though many of the early objections were overcome.



A 5in guided projectile shows its tail fins in this 24 April 1973 China Lake photograph. This particular shell was intended for an unguided air drop, and the rings at its center helped secure it to the airplane. Some recent guided projectile designs incorporate fins further forward as well.

3. Fire control

The Fire Control Problem

After 1900 the chief driving force in surface-to-surface gun system development was improvement in effective battle range through better fire control. Initially, that meant more accurate shooting by individual guns, with both range and rate of aimed fire rising dramatically. From about 1904 onwards, it increasingly meant more effective concerted fire by a ship's entire battery. The basic concepts which remained in force to the end of the big-gun era had been established by 1914, although developments between then and 1945 were certainly impressive. Throughout, there were two central problems: first, how to shoot effectively from a rolling, pitching ship; second, how to find the range to a distant target. The second was worth solving only if a shipboard gunner could be sure of firing round after round at the same effective range despite the motion of his ship. Moreover, rangefinding became a problem only for ranges beyond the first few thousand yards. It became a more and more urgent problem as the range opened to the point where trajectories were relatively steep, so that there were less and less tolerance for error.

'Danger space' was one measure of inherent gun accuracy, *ie* of the ability to hit a target

despite errors in rangefinding. The danger space is that distance through which the shell passes at or below target height en route to impact, *ie* the distance short of the estimated range at which the shell would still hit the (vertical) target. The flatter the trajectory, the greater the danger space. For example, the 5in/51, a very high-velocity weapon, had a danger space (against a 20ft high target) of 137yds at 5000yds (3150ft/sec). At the same range and against the same target the low-velocity (2035ft/sec) 5in/25 had a danger space of only 18yds. At some ranges it was impossible to miss: at 2000yds the 5in/51 had a danger space of 2000yds. Even much lower-powered weapons had high accuracy at very short range. For example, the 2000ft/sec, 6in/30 BL gun had a danger space (20ft target) of 1000yds at a range of 1000yds, although at 2500 the danger space shrank to 154yds, only 6 percent of the range. These figures go a long way towards explaining the limit of about 1500yds on battle range in a fleet without effective rangefinders.

Once ranging had become accurate, very small danger spaces could be tolerated: the 6in/47 of World War Two was considered quite effective at 10,000yds where its danger space against a 20ft target was only 39yds. For

the 16in/50, firing its 2700lb shell at 2500ft/sec, the danger space at 30,000yds was only 12yds, yet such ranges were considered realistic. At such ranges, too, the danger space concept ceased to govern, as most shells struck the deck of a ship – a target larger than the danger space, perhaps 33yds across.

It should be noted at the outset that errors in rangefinding were not the only reason shells missed. Any gun, any battery, has a 'dispersion' about the aimed-at range due to a wide variety of random causes; guns do not fire quite identically shot after shot. Particularly at very long range, salvo fire was a means of counterbalancing such random errors, providing enough shells per salvo for some of them to hit. Pattern size had to be large enough to make up for random errors, but not so large as to spread the shells too thinly. At very long ranges, then, misses would be frequent – but successful hits might be extremely destructive. As an example, in the night battle of Guadalcanal, the battleship *Washington* fired seventy-five 16in shells at *Kirishima* to obtain nine hits at 19,000yds – 12 percent, even with radar ranging. Those nine, however, finished the Japanese ship. In 1944, off Samar, US observers commented that Japanese patterns



The cruiser *Chester* displays typical features of a US fire control system in this April 1935 photograph. Her tower foremast is surmounted by a Mk 24 8in director; the windowed top below it contains the forward fire control (battle lookout) station, with a range clock (concentration dial) below. The 8in battery obtains ranges from the armored 12ft rangefinder on the bridge, as well as from the protected units within the three 8in mounts. *Chester* had six 21in torpedo tubes, with directors on the wings of the pilot house roof. There was a second fire control station abaft the second funnel, with a 5in director (Mk 19) on a pedestal, an open (antiaircraft) rangefinder and, below that, a second 8in director. Searchlight and torpedo controls were in the small roofed house at the base of the tripod mainmast. In the succeeding *Portland* class, three separate armored Mk 38 rangefinders were mounted on the pilot house roof, and two Mk 19 AA directors were placed there, on either side; the light battery was doubled, and the torpedo tubes eliminated. The top had three levels: from top to bottom, an 8in director, an 8in fire control station, and a battle lookout.

(200–300yds) were too small to obtain many hits.

In gunnery parlance, it was important to distinguish between the geometric range to the target and the range set on the sights of a gun ('sight-bar range') which might hit that target. Reasons for the difference might include barrel wear, powder temperature, local air density, and humidity. It was important, too, to take into account the difference between range at the moment of firing and range when the shells might be expected to strike a target. The latter, the range which mattered, changed with time more or less systematically depending upon the courses a ship and her target might steer. Thus effective firing required the ability to project forward an enemy's course on the basis of a series of timed observations of the range; such projections would be corrected by reference to the observed fall of shot around the enemy ship. The entire concept of range projection evolved relatively slowly, from the level of range cards marked up on the basis of the most simplistic assumptions, to sophisticated mechanical computers and plotting tables.

Continuous Aim and 'Single-Key'

The first great development of what would become the gunnery revolution was the ability to fire guns accurately despite the roll of the ship. Standard practice in the nineteenth century had been to set the gun (and its sights) relative to the ship's deck, the gunner firing when the sights came 'on' during the roll. The results were chaotic, partly because very few gunners could have quick enough reactions or, for that matter, could be sure of the precise moment when the sights were 'on'. It fell to Captain Percy Scott of the Royal Navy to discover that, at least for the lesser weapons, a gun crew could elevate and depress them to keep them continuously on target, *ie* to maintain a constant elevation with respect to the sea (and the target) rather than with respect to the ship. This 'continuous aim' system was adopted by William S Sims of the US Navy who, like Scott, was assigned to a ship in Asiatic waters. With it, gunnery improved radically. Encouraged by such improvements, Sims and Scott both pressed for much higher rates of aimed fire.

Continuous aim was introduced into the US Navy in 1902, largely because of the support President Roosevelt was willing to provide Lt Sims. It was first tried out on the Asiatic Station, on which Sims was serving, and won over many of its critics in view of a disastrous 'battle efficiency practice' held aboard the battleships *Kearsarge*, *Alabama* and *Massachusetts* in the winter of 1901–02.

Continuous aim of the heaviest guns was considerably more difficult, depending as it did on the development of sufficiently sensitive controls for the elevating motors of the turret guns. It appears that a new mechanical control gear was first tested aboard two battleships in 1907; the urgency of fire control is suggested by the statement (in the FY08 Annual Report of the Navy Department) that it had been extended to turret guns in three battleships, and to all heavy guns in three others: 'it gives control through a wide range of rolling speeds,

making it much easier to keep on the target than has been the case heretofore'. By late 1910 a total of 204 sets had been ordered under an appropriation for modernizing turret elevating gear, and all battleships as well as all armored cruisers but the *Colorado* class, *Montana* and *North Carolina* class had been fitted.

Ironically, just as this level of sophistication had been reached, an alternative method of canceling out the roll in the heaviest guns had been developed: single-key firing at the top or bottom of the roll. In this system, all guns were fired together, and they could be fired when they were stationary (with respect to the sea) at one end of the rolling cycle. Given the single-key system, it was essential only to correct for the additional angle introduced by the roll, the gun sights being set for range plus this 'director correction' angle. It now appears that this system had entirely or largely replaced continuous aim by 1914, although guns continued to be fitted with local sights for which continuous aim would have been essential. US director practice down through World War Two preserved this relationship, the director being designed around a telescope which was kept trained on the horizon and so could indicate to the guns the points at top and bottom.

A more subtle change was the institution of competitive firing, which encouraged individual gunnery officers to invent and to use new instruments: the plotting board, for instance, was the invention of a junior gunnery officer. In 1906 the gunnery lieutenant commander described this system as based

... (1) upon fair competitive target practice, (2) enlistment of the personal initiative of all officers, and (3) the dissemination of information gained at each target practice... amongst all officers concerned. A direct effect of this is to keep all defects in ordnance material under the criticism of hundreds of competent officers, who are directly interested in getting the best results and winning distinctions. Consequently there has been a rapid improvement in all ordnance material.

Gun sights, essential for locally controlled fire, were a particular example. The first recorded target practice was held in the spring of 1904; sight defects immediately became apparent. In particular, the sights could not be adjusted to correct for wind and speed (deflection), nor could they remain in adjustment as the guns fired. Replacement with effective sights was so rapid that although in the spring of 1905 'no ship in our navy fired with sights that would have been suited to battle', in 1906 even the Asiatic Fleet had been fully equipped.

Range-Projection Instruments

Given the many factors which distinguished geometric range from sight-bar range, the key to effective long-range fire (*ie* to hitting despite small danger spaces) was the ability to fire successive rounds on an equivalent basis, so that their effect could be used to check estimates of proper range and bearing. Only then could observation of the fall of shot ('spotting') be used to correct for the next salvo. Generally a spotter aloft could estimate the error and call down corrections in range. In fact, since the range changed from salvo to salvo, range-projection instruments were an essential element of fire control.

There were three standard instruments, developed by most navies in the decades before 1914. The first was the 'plotting board', on which current enemy and own-ship positions could be graphed so as to estimate enemy course and speed. The basic input was successive rangefinder readings at specific intervals of time. Second, the 'rate of change of range projector', could convert enemy course and speed into a rate at which the range was changing, so that enemy range could be predicted for the immediate future. In effect this was a mechanical, or analog, computer, a mechanical model of a two-ship engagement. The third device was the 'range clock' on which the rate of change of range could be set, and the changing range read off. The base against which the range was assumed to be changing could be adjusted according to spotting information and the rate of change altered while the clock ran.

Jon Sumida has pointed out that most fire control systems of the World War One period were deficient in not properly calculating the rate of change of range. For example, the British Dreyer system applied what amounted to a geometrical approximation to what was actually the solution to a differential equation. The same might be said of early US range projectors. In Britain a private inventor, Arthur H Pollen, devised a differential analyzer which he marketed as the Argo clock, but the Admiralty bought very few. Pollen's system was, however, sold to the Russian Navy; Sumida suggests that it accounted in large part for the extraordinarily good shooting of several Russian battleships during World War One, often under conditions of rapid change of range. During World War One the US Navy acquired a somewhat similar technology in the form of the Ford rangekeeper, although this device could not generate predicted enemy bearings. Partly as a result of improvements in its fire control, the US Navy was able, during the interwar period, to adopt very long-range artillery tactics; the development of shipboard spotting aircraft was also a factor in this evolution. So confident was it of the efficacy of its fire control that, for example, it

removed the principal short-range weapon (the torpedo) from its heavy cruisers; officers who were trained in fire control prewar testify to that confidence.

Gunnery Practice

The earliest US spotting practice was carried out by the battleship *Alabama* off Pensacola, in April 1904. According to a contemporary official report,

...the object of this experimental firing was to determine the accuracy with which observers, stationed at various points on the firing vessel, could observe the fall of shot at various ranges, while one gun was firing and also, while a number of guns were firing at the same time. The experiments were carried out from a vessel at anchor, under the most favorable weather conditions, in order to obtain the maximum results possible. There were other points which it was desired to demonstrate such as, the maximum accuracy of gun fire at various ranges, and the accuracy with which ranges could be estimated by the eye. The instructions were very carefully prepared and the experimental firing conducted in such a way that the results could be relied upon and definite conclusions arrived at... Eight days were required to carry out the program of firing... The results were very satisfactory and the effects were, and will be, far-reaching. It justified those who had always advocated long range hitting, and it gave hope to those who had desired it, yet felt doubtful of ever accomplishing it.

It was evident, as soon as the subject was carefully considered, that there were variable errors of gun fire, and as a result the sight-bar range necessary to hit a target must always be different from the actual distance measured; therefore, it was necessary to note the fall of the shot and make the necessary correction in the sight-bar to bring the shots on the target. This has been termed 'spotting' from the very beginning of the new system of training and target practice...

The key development was the passage from short- to long-range spotting. In the former, an observer could follow the entire trajectory of a single shell almost from gun to target. Beyond a point, which might be about 4500yds for a 13in shell, this would be impossible; the spotter would have to rely upon the 'splash' made by the shell. In fact he would use the slick this splash would leave on the water for a short time after the splash itself had subsided. But now it would be impossible for any given spotter to distinguish the slick made by one shell of a given caliber from that made by another – hence the need to fire the guns in unison at ranges selected for the ship as a whole.

Gunnery practice was quite primitive at this time, generally involving ships at anchor firing at fixed targets. Lt Cdr M L Bristol described a special autumn target practice in 1905 at which

...certain qualified pointers fired at long ranges, at night practice, and at rolling practice; also there was a limited amount of unmeasured range practice, firing one gun at a time on a run. The long range practice, both at night and in the day time, was for the instruction of officers in spotting. It was carried out at anchor, target distant 4000 yards. The unmeasured range practice (at about 3000 to 2500 yards for 5 and 6 inch guns, and 1800 to 2000 for 3 inch guns) was the simplest form of a battle practice, one gun being fired at a time, and the pointers relieving each other in succession without an interruption of the fire... It was very gratifying to see how readily the corrections for sight-bar setting were made to bring the shots on the target at the beginning of the run, or at any time thereafter if they began to miss. The range-finder was used simply to measure the range at the

beginning of the run for the initial setting of the sight bar, and all corrections were made thereafter by observing the fall of the shot. In place of a range-keeping clock a card was made out to give the range at successive equal increments of time, taking the sight-bar range, established by observation, as a starting point each time.

Meanwhile a more realistic form of target practice was being carried out in the Far East. The Royal Navy actually had observers aboard the Japanese ships, but the US Navy had no such good fortune. Lt Cdr Bristol again:

It is not likely that we shall ever obtain very exact information in regard to the great naval Battle of the Sea of Japan on account of the secretiveness of the Japanese, especially as regards the shots fired and the hits made. Ships were sunk by gun fire, so there must have been some very effective hits, but of course the number of these will never be known. Also it is doubtful if we will ever know at what range these effective shots were delivered, or if they were delivered before or after the ships' batteries had been put out of action. All information that can be obtained shows that no effective work was done at the longer ranges, and the ships were sunk at the shorter ranges, about 4500 yards. Ensign Robert Henderson, USN, has made some curves that go to show that the fire of the Japanese was really only effective when the two fleets were steaming in the same direction and nearly parallel; that is, when the necessity for fire control was very little. Further, we know that the ships that escaped were not hit many times. They had not come to close action. The upper works of the ships that were captured were a mass of wreckage so that individual hits could not be readily distinguished. The demolition of the light upper works was greatly due to the high explosive shells. In other words, everything seems to point to the fact that the Japanese did not make many hits at long range, or when the ranges were changing much; that is, they did not have good fire control. It is doubtful if the Russians will ever add much exact information on these points that we desire most to know about.

The Japanese were undoubtedly aided by all the information in regard to gunnery that Great Britain could give them. We know that the British were not then proficient in their battle practices, because they did not understand the principles of fire control; therefore, it is hard to believe that the Japanese, if they used the same methods, could have obtained better results in action than the English at their battle practices. It is fair to believe that the Japanese were no more proficient in fire control than were [their] teachers. It is known that up to the first of the year 1905, the English were quite wrong in regard to the way to control gun fire in action, and it was only late in that year they adopted the right principles. Their battle practice in the summer of 1905 was very unsuccessful.

I had a conversation recently with a prominent Russian officer. He was in the Battle of the Sea of Japan as executive of one of their cruisers, and succeeded to command when the Captain was killed. He attributes their defeat to three principal causes: (1) the HE shells of the Japanese, (2) the lack of these on the part of the Russians, who used AP entirely, (3) the large quantity of ammunition that the Japanese had, which allowed them to open the action with a very rapid fire and continue it from time to time. The Russians had instructions to fire deliberately and save their ammunition. The HE shells, bursting short, formed a curtain of smoke, shutting out the Japanese ships from the Russians so that they could not use their range finders, and the fragments of the shells cut away the rigging and topmasts and destroyed the range finders and range finder crews, and as the projectiles struck the water closer the upper works were destroyed and the gun ports penetrated: officers and men were wounded and killed, guns disabled, powder charges set on fire, and fires

I. GUNS (SURFACE FIRE)

started wherever there was anything inflammable. The Russians had no system of fire control except that they set the sights from the observations by range finders. The range finders were destroyed at the very beginning of the action; hence they must have fired at random after that. They had voice tubes and electric range transmitters from the gunnery officer in the conning tower to the guns. They had telescopic sights that had been installed on the guns just before leaving Europe, but these sights were never tested for accuracy. One target practice was held at Madagascar after leaving Europe. It consisted of firing three or four shots from each gun, with the target and ship stationary, and no attempt was made at rapidity of fire.

This Russian officer had the impression that the Japanese concentrated the fire of their ships on the head of the Russian column, establishing a zone of fire short, and maneuvering so as to make the head of the Russian column pass through this zone. He said he observed this not only at the beginning of the action, from his position in the rear of the column, but at other times later on. This might seem to indicate that the Japanese had some system of fire control, and applied the idea of spotting, in a manner similar to the fire control necessary with improvised means of communication and no fire control instruments...

In fact we now know that the Japanese did have rangefinders, but that their means of passing ranges were extremely primitive and ineffective. It appears that what impressed the British were a very few important heavy gun hits at long range, *eg* hits which wiped out ship damage control parties.

The 1905 and 1910 Fire Control Boards

On 21 November 1905 the Secretary of the Navy ordered the formation of a Fire Control Board, which set the course of US naval gunnery for the next few years. It was headed by Ret Cdr G W Denfeld of the Bureau of Equipment, assisted by the young gunnery officers: Sims, now a lieutenant commander; Bristol; and Lt Cdrs L H Chandler and G B Bradshaw. They were to '(a) recommend a system of fire control and (b) a system of information [*ie* of data transmission]'. In effect they formalized the ongoing fire control revolution; their report was ready by 30 December, its main points being:

- (1) The fire of each separate caliber of main battery guns, when firing at the same target, should be controlled by a separate fire control officer.
- (2) The fire control officers of main battery guns should occupy as elevated a position as possible, especially when controlling long-range gun fire... [(3), (4) and (5) omitted]
- (6) The CO should communicate to the fire control officer of each caliber of guns, to the torpedo-defense fire control stations and to the torpedo firing stations, his general battle orders, and leave to such officers the details of obtaining and transmitting the ranges and the necessary battle orders.
- (7) It is considered as an essential that the system of communicating ranges and deflections to the guns be *rapid* and *continuous* and that the ranges and deflections be made to appear on an indicator directly *in front* of the eyes of the sight-setter when he is at his station.
- (8) Means are essential for communicating regular battle-orders direct from the fire control stations to each gun controlled therefrom. Though a method which would permit orders being received by the sense of sight rather than hearing would be preferable, the Board knows of no satisfactory system which accomplishes this purpose and hence recommends the use of loud speaking telephones and voice tubes. Means should, however, be provided for signalling certain battle-orders which,

being of peremptory character requiring instant transmission, should be given by a display, such as 'Check Fire', 'Continuous Fire', 'Slow Fire'.

The Captain must be provided with means for instantly stopping the fire of the ship.

To control fire the Board envisaged the standard system which within six years had spread through the Fleet: a central station containing rangekeeping instruments and connected by telephone and other communications (displays) to the guns and to spotting positions; two fire control tops, each with 'a separate fire control station for each different caliber of main battery guns...as high as practicable, and so arranged as not to be seriously interfered with by smoke from the funnels...Each fire control top should be provided with an efficient range finder, and a range projector or other means of determining the course and speed of enemy, if possible; and each fire control station should be supplied with the latest type of stadimeter.' The anti-torpedo attack guns would be controlled by quadrants, their control stations at a moderate height, commanding a clear view of the arcs involved and 'as free as possible from the blinding effect of the flash of the guns and interference by the rays of the searchlights'.

In an appendix on principles of fire control the Board emphasized the importance of centralized control exercised from a point aloft, which came to mean the cage mast, in which the main observation post was carried atop the mast, with a torpedo defense platform within the mast below the level of the searchlights, *ie* out of their glare. Ultimately centralized control from aloft would come to mean spotting by one party aloft, data being transmitted to the guns via the gunnery central - but that would come somewhat later.

The Fire Control Board began to exert an influence only after three US dreadnought designs, through the *Utah*, had been completed, even though the Secretary of the Navy ordered the implementation of its findings in March 1906. The technical Bureaus were to

...proceed, without delay, to make preliminary plans and estimates for installing on the USS *Virginia* a fire-control system on the general lines herein laid down by the Fire Control Board, and in laying out this scheme for that particular vessel will afford to the prospective Commanding Officer [Captain Seaton Schroeder] an opportunity to submit such suggestions as may seem desirable in connection therewith. The Bureau of C & R is authorized to enlarge the communication room in the *South Carolina* and *Michigan* as far as may be practicable, in order that subsequent changes as may be decided upon as a result of the practical test of the experimental installation on the *Virginia* may be carried out with the least expense practicable. The plans of the *South Carolina* and *Michigan* will not, however, be changed in order to make provision for any other installation which may or may not be decided upon as the result of the prospective tests on the USS *Virginia*.

Meanwhile, serious battle practices were begun. According to the confidential 'Notes on Fire Control (1912)',

The first battle practice, or semblance to a battle practice, in the US Navy, was held in the fall of 1906. On this practice and the next two succeeding, 1907 and 1908, the target was anchored.

In the practice[s] of 1906 and 1907 the course relative to the target and distance from the target and speed of ship, were laid down in the instructions. In 1908, this information was all contained

in sealed instructions issued by the Navy Department, and these instructions were not opened until after getting under way for the practice, at which time the contents of the sealed instruction were divulged by the chief umpire.

In 1906 and 1907 there were no sub-stations and no permanent fire-control systems. The fire control party was in the fore top, the spotters in the crow's nest and the ranges were kept by a range card or 'dope sheet'. Telephones and visuals had been installed by the ship's force for this practice.

Just previous to the practice of 1907 a few range clocks, purchased in England, were distributed to the fleet and a few ships used them on this practice.

In 1908 the use of range cards was prohibited, and as sub-stations had been built and fire control systems installed on all the ships, and spotters' stations built aloft, the ships were, for the first time, in a position to carry out a satisfactory battle practice.

By this time all ships had been supplied with range clocks and range projectors, and this practice which was with an anchored target was conducted, without any exceptions, by the range projector and range clock method of keeping the range. The target being anchored the range projector could be used with more or less accuracy which disappeared the first time the target was towed at an unknown course and an unknown speed.

In 1909 the target was towed, course and speed unknown to firing ship. The method of making the approach, time of turning and bearing of target at 'commence' were all contained in sealed instructions and after firing on one side for six minutes the firing ship turned and after a certain specified time opened fire with the other battery.

The conditions of this battle practice being much more difficult than all previous practices - it was apparent that something better than a range projector and range clock method for keeping the range would be necessary.

A few of the ships discarded the range projector and range clock and used a plotting instrument, several types having been devised since the practice of 1908. The main object was to get an instrument or devise a means for getting the range and not to guess at it.

In 1909 the ranges were very much greater than ever before, and trial shots were allowed preparatory to 'commence firing'. Plotting methods were used to a greater extent than on previous practices; a few ships, however, adhered to the range clock and range projector method.

All ammunition not expended on preliminary and battle practice was distributed after battle practice to four ships selected by the CinC to form a division for our first 'division battle practice'.

The practice in 1910 was not materially different from the 1909 practice - however, longer ranges were used and the ship instead of making a double run, firing one battery and then turning and firing the other, had two separate runs on different days, and all divisions had division battle practice.

The increase in battle ranges and the advent into the fleet of the one caliber ship was a great handicap for the three caliber ships. In the 1911 practice this was partially overcome by rules providing for separate runs and shorter ranges for the broadside guns of the three caliber ships.

The rules in 1911 provided, also, for casualties to materiel and personnel.

Plotting was used in one form or other, but the inaccuracies of the range finders and range finder operators, together with those of the present small magnetic compasses, at the increased battle ranges, led to some very misleading 'lines' and consequently poor results.

The general demand for better trained range finder operators, with the adoption of the gyro compass and improvements in range finder instruments and methods will undoubtedly increase the battle efficiency of the fleet.

In 1910 a new Fire Control Board met. Its recommendations included a discussion of the merits of specialized, armored fire control towers projecting from the conning towers of battleships; and it proposed that rangefinders be mounted in one or more turrets, *ie* behind armor. The proposed revolving armored fire control tower was also to house a large rangefinder. Turret rangefinders first appeared in the *New York* and *Texas*, which in effect were the first US battleships with something approaching a modern fire control installation. These were 20–22ft coincidence instruments, the largest yet ordered for the US fleet. In addition, the Fleet Flagship was to be fitted with a special 15ft rangefinder, which would permit the flag staff to plot enemy course and speed, and thus give the commander of the Fleet an appreciation of the operations of the enemy fleet as a whole.

Meanwhile practice in the actual firing of the guns continued. The larger the salvo, the easier and hence the more efficient spotting would be. In March 1910 the Bureau of Construction and Repair noted that

... on the US battleship *Vermont*, which has won the battleship trophy for battle practice two years in succession, the distinctive feature of the management of the guns adopted by Captain Fletcher was that, so far as possible, all guns aboard the ship were fired simultaneously... if broadside firing is to become the standard method in the near future, it is very desirable that this development be anticipated in order that the Technical Bureaus may be prepared to make resulting departures from previous practice in future designs. The time now seems to be ripe for a thorough investigation of the possibilities of turrets carrying more than two guns of one caliber. Heretofore, in the US service, and, the Bureau believes, in all the leading naval services, it has usually been regarded as necessary to fire one gun in a turret at a time; and owing to the unavoidable interference between the two guns in a single turret when following this practice it has heretofore been considered that two guns in one turret were markedly inferior to two guns in two turrets. It appears, however, that on the *Vermont* the two guns in a turret are fired simultaneously with great effectiveness. If this is to become standard practice, it is obviously desirable to place more than two guns in a turret.

The mechanical and other difficulties in the way of firing simultaneously three guns in a turret would seem to be but little greater than those in the way of firing two.

This was the origin of the US triple turret; the design of such a mount, in which all three guns shared a common slide, began in April 1910. There was no interest in the ability to elevate separately because the US Navy then fired full-broadside salvos. Moreover, it was felt that by rigidly linking all the guns it would be possible to eliminate 'the question of the skill or ability of several gun pointers acting separately...'

Since the heavy guns could not be aimed continuously, they had to fire at the ends of a double roll, *ie* approximately at 30-second intervals. With two guns, if one fired on the roll towards and the other on the roll away, this meant a 15-second interval; for three guns it would be only $1\frac{1}{3}$ rounds per minute. In practice it was possible to achieve one round per minute in a two-gun turret; if simultaneous

fire were not to succeed, the triple turrets would be worse than an equivalent battery in twin turrets. BuOrd noted that

... for a number of years it has been the practice of the superposed turrets to fire one of the 12 or 13in guns in salvo with the two 8in guns over it, with a single firing key. The results... have been surprisingly good, and it is only to be regretted that most of this firing has been done under the most favorable conditions, so that the results are not decisive... [*Vermont* also used a single key for both guns, but her] excellent firing at the last battle practice was done in smooth water, and final conclusions cannot be drawn...

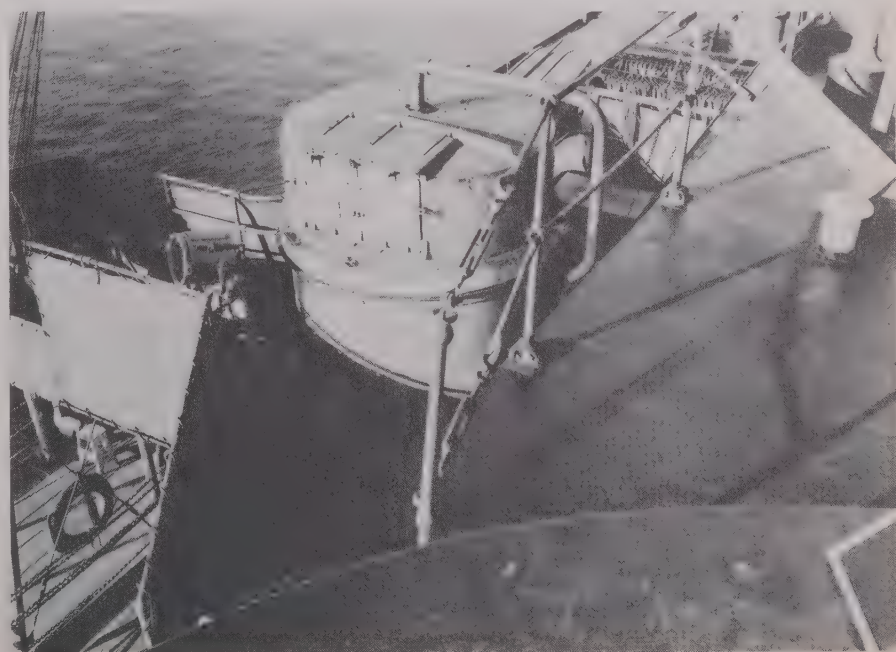
Captain Fletcher had tried firing on a roll of up to 3° either side and target movement of up to 5kts; his results were not as yet conclusive, but seemed to give an advantage as great as 100 percent. He wrote that 'it is known beyond doubt that the English, and presumably the other nations, have not adopted this method and if this data could be held confidential it would give us an enormous lead'. In fact the Grand Fleet would be most impressed by US full-salvo firing in 1917–18, where the Royal Navy would fire only one gun per turret in a salvo, *ie* four or five guns against eight or ten – or twelve, in the US triple-turret ships. Indeed the single rigid slide would be abandoned in the *Mississippi* class not for fire control reasons – typically the guns were locked together – but rather to overcome the danger that a single hit, jamming the one common slide, would put an entire turret out of action. Thus, although the single slide was abandoned in battleships, it was a fixed feature of the US cruiser mounts of the 1920s; it was abandoned in cruisers as bore spacing was increased to avoid interference between adjacent guns.

The Fire Control System in 1912

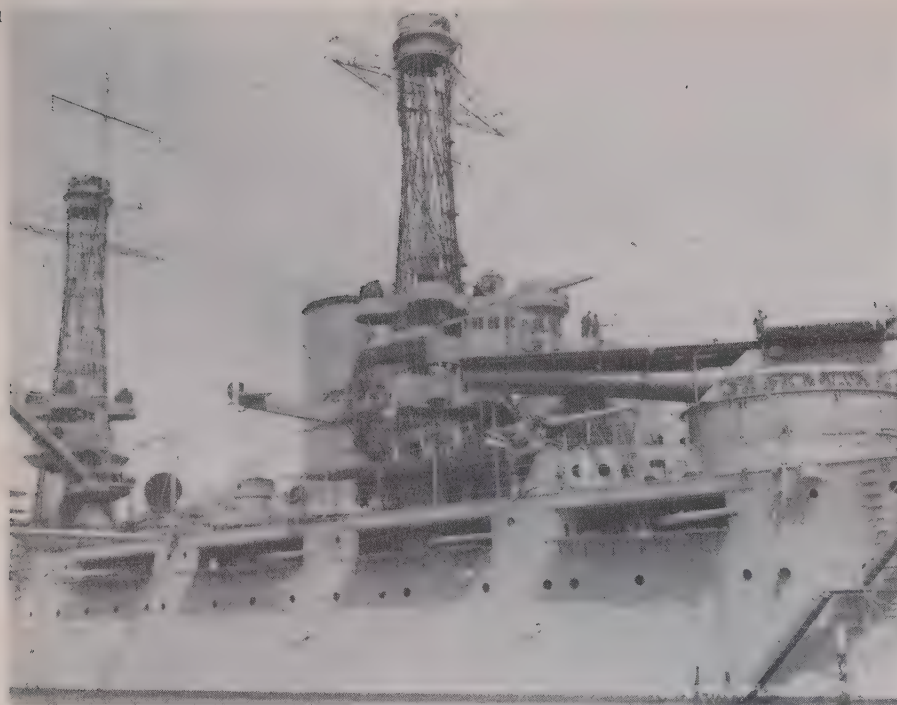
By 1912 all of this effort had crystallized into a standard fire control system, which was described in the official confidential 'Notes on Fire Control (1912)'. The chief fire control officer would sit in a special fire control tower within the conning tower; there would be a central, or central station, below decks; spotting tops would surmount the masts; and

of course there were the gun mounts themselves. At this time the standard spotting top installation was a 3m rangefinder, a salvo-firing panel, a visual transmitter to the central, a cease-firing gong switch, and a visual range-receiver. Here 'visual' meant an instrument displaying numbers *visually*, and hence more reliably than they could be transmitted by telephone or voice tube – both of which were also available. In the fire control tower would be another rangefinder, an indicator by which enemy bearing could be transmitted to the central, a salvo panel, visual indicators from each spotting top, visual transmitters to the central, a visual range-receiver, a cease-fire gong switch, and a telescope for the chief fire control officer. The central would contain plotting boards, a salvo-firing panel, a bearing indicator, and deflection and train transmitters, as well as indicators of ship speed and course, since the central was also an emergency steering position. The salvo panel was not a means by which one officer could himself fire all the guns together; rather, it enabled an order to fire to be transmitted by buzzer to all guns, which would be fired locally. A gong would sound to alert the gun crews to an imminent salvo buzzer, and the time between salvos could be used to reset sights and to load.

Orders were to be transmitted from the central to the guns, the gunnery officer designating the target at the captain's request, and supervising spotting in the sense that he could intervene in the process if he detected what he considered serious errors. Otherwise data would be fed continuously from the spotters to the central, processed there and sent to the guns. A great deal depended upon the smooth and accurate communication of data from one point to another, and upon the accuracy of spotting corrections, since those in the central could not check the accuracy of their plot directly. Because the orders to the guns incorporated ranges rather than angles of elevation, this system could function for multicaliber as well as single-caliber ships; in any case, the problem of multiple calibers disappeared as battle ranges receded beyond the reach of anything less than the heaviest gun.



A Vickers-type (Mk 7) 5in director aboard the battleship *Mississippi*, 21 January 1919. Aft it can be seen the battleship's 'flag bag'.



1 The battleship *Oklahoma* shows the state of US capital ship gunnery at the end of World War One. Her turrets (No 2 is shown) were marked off to show their angle of train, and she had a range clock above her bridge to show the range at which she was firing, both innovations having been adopted from the British Grand Fleet, and both intended to permit her to pass on target information to nearby ships which might be unable to see the same target. She carries rangefinders both atop her bridge and in her superfiring turrets (the latter is the small 'ear' near the turret face), and the cage mast carries a 'top' for spotters. The open mounts in her hull carry 5in/51 antidestroyer guns, another of which is visible below the barrels of her twin 14s; abaft it is a 3in/50 antiaircraft gun, and then a pair of saluting weapons. In this view a Sopwith 1½-Strutter spotter is being hoisted onto her flying-off platform; the airplane represented, at the time, the latest means of extending the range of shipboard gunfire. *Oklahoma* was photographed in Guantamo Bay, about 1921.

2 The forward fire control position of the battleship *New Mexico*, 31 December 1941, shows Mk 31 directors for both main and secondary batteries: the main battery unit is surmounted by a Mk 3 fire control radar. Forward of it is a large armored rangefinder, the frame below, which in this view carries only running lights, originally holding a range clock. The entire assembly is surmounted by a Mk 28 antiaircraft director, with a stereoscopic rangefinder and, as yet, no radar.

There were variations on this system. For example, in many cases the range clocks (and indeed the range projectors) were in the tops, since spotters required a current range against which to test the fall of shot. Moreover, it is important to keep in mind the long time interval required for full data processing through the central. A ship moving at a relative speed of 15kts would cover about 250yds in a 30-second interval; that might well be a greater distance than the size of a pattern of shells.

This was not 'director-firing' of the sort the Royal Navy began to introduce in 1912. In that system the director transmitted elevation and bearing data directly to the guns. The US system was sometimes characterized as a semi-automatic director, differing from the British system largely in the stress it laid upon plotting. In the Royal Navy projection of enemy course and speed was largely automatic, director and rangefinder inputs being used to drive an analog computer called a 'fire control table'. The US system depended more on the judgment of plotting officers, and assumed that the mechanical inputs of the British system were subject to severe and possibly disabling error – a reasonable assumption, given the imperfections of the time.

World War One

The system described in 1912 was continued into World War One, with some minor simplifications. For example, the rangefinders and salvo panels were removed from the spotting tops, partly because it was expected that they would be swept away early in an action. Longer-base rangefinders began to appear atop turrets and on conning towers (*Utah* and *Wyoming* classes). Such instruments, which could rotate independently, could be used to estimate the range before ships engaged, *ie* before a target had to be chosen. Moreover, during action they permitted a commanding officer to find the range to a ship other than the one under fire. Such instruments were for a very long time characteristic of US battleships; they were often called

'navigational', which belies their essential role in battle.

There were two major innovations in US fire control between 1912 and US entry into World War One: the 'directorscope' and the degree of automation achieved through the work of Elmer Sperry. The directorscope was a telescope laid to cross the target at the top or bottom of the roll, and hence to gauge an elevation correction for the guns. This 'director angle' was transmitted to the central station along with range and spotting data, and then transmitted back to the guns as part of an effective new sight-bar range. The director function was therefore relatively simple, which made for a very small instrument, 18in in diameter (200–300lb), about one-fifth the weight of the British director, and far easier to mount aloft.

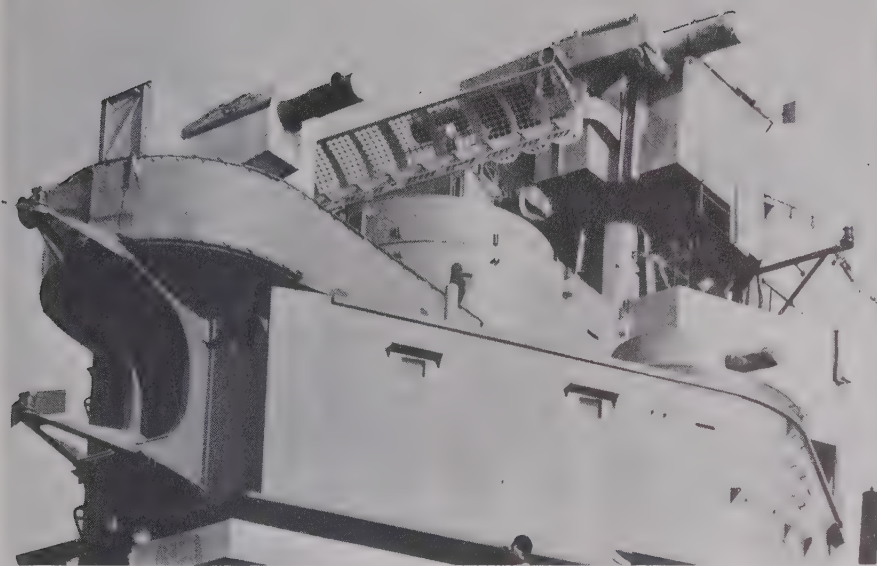
From 1912 onwards, then, a director in US naval parlance was a centralized means of compensating for the roll of a ship. The correction had to embrace both gun elevation and gun train, since the proper direction for a gun pointing off the beam depended upon the angle of roll ('trunnion tilt'). Indeed, as ranges increased, the movement in train associated with continuous aim greatly increased. Director fire was initially called 'director correction fire', a director correction angle being added to the gun elevation order associated with the proper aim; guns were maintained at the appropriate angle and fired when the director line of sight crossed the target. Continuous aim could be discarded. Alternatively, the director could be held on the target and the director correction continuously varied, to achieve (in effect) continuous aim, although the pointers would be maintaining their dials in synchronism with the director orders rather than keeping sights on the horizon. At very long ranges, angular errors in train could become more important than elevation errors, and the gun train orders no longer always varied steadily; heavy gun turrets could not be kept continuously on target. It became standard, then, between wars to maintain continuous elevation control, but to correct the gun train order for a preselected

value of trunnion tilt, and then to fire when the actual trunnion tilt (angle of roll) equaled that value. This method became the primary means of main battery control during the interwar period, the only exception being that the cross-level angle of the director rather than the trunnion tilt angle was used; it was called 'selected cross-level fire'.

The early directors were optical means of detecting the roll of the ship: they employed telescopes trained either on the horizon or on the target (which was effectively on the horizon), even though under some circumstances of smoke and weather the horizon might not be visible. Again, during the 1930s a new class of plotting-room directors were developed, incorporating gyros which themselves defined a vertical direction and which could, therefore, define level and cross-level independently. In the earliest type, the Mk 30, the 'stable element' or gyro was mounted separately, transmitting to the director via servos and shafting; the later Mk 32 incorporated a stable element within its casing. Typically an operator could select a cross-level angle and set the director; when the ship reached that angle, the contacts on the director would close and the guns would fire.

The ultimate development of such gyros was the generation of gun train and elevation orders which could operate servos on the gun mounts; this level was reached just before World War Two. It had the advantage over selected level fire of permitting a much higher rate of fire effectively independent of the rate of roll of the ship, since (as in continuous aim) the guns could now be held steady on their target despite ship motion. Selected level fire was then retained as a standby mode in cases of relatively violent ship motion, beyond the capabilities of the servos.

Automation was the work of Elmer Sperry of gyro fame. He first became interested in fire control when the Navy bought his gyrocompass in 1910 as a more precise base or reference line for gun-training. He soon provided gyro repeaters for the fire control tops and for the



plotting room, *ie* standardized references for target bearing. Ultimately an observer in a fire control top could automatically transmit the target bearing to the plotting room, where it was displayed by a 'battle tracer'. The latter automatically plotted own-ship course and speed (from the gyrocompass and from a revolution counter) and enemy ship range (from rangefinders) and bearing. The same follow-up technology permitted the plotting room to order turret bearings, and to receive confirmation that the turrets matched them. The next step was an automatic computer to predict enemy range. According to the BuOrd official history,

... early in 1916 reports from abroad indicated the necessity of maintaining the sight-bar range by means other than spotting, especially as the use of smoke screens in battle had become common. The Vickers range clock was not effective for this purpose, and L Cdr Martin, then in charge of the fire-control Section, discussed this subject with Mr H C Ford of the Ford Instrument Co. ... a year later the first Ford range keeper was tested ...

It formed a natural complement to the battle tracer and, like it, was protected in the plotting room.

Comparison with British Practice

During World War One the United States acquired the patents for the Pollen fire control computer system, at least one such system being installed aboard a US battleship of the Grand Fleet. It seems likely in retrospect that the existing Ford rangekeeper was modified to incorporate Pollen's concepts; the Pollen device added a second computer which fed bearing rate data into the range estimator and so (in effect) replaced one of its external inputs with an estimate based (in turn) on the output of the range calculator.

British practice was to send sight-bar range from plot to director, the latter automatically adding in the change in elevation of the directorscope. Spots could be applied at the director, the Royal Navy claiming that such a practice would reduce the transmitting interval

and so increase the rate of fire. They used only a single director because transmission was by step-by-step motion, *ie* two different directors could not properly be synchronized. The American system made it easier to switch from one director to another, but transmission was slow; indeed at the end of 1917 BuOrd was trying to solve the problem by automating transmission. Perhaps the principal difference between US and British practices was the emphasis the US Navy placed on its plotting room (central station): the British transmitted elevation directly from director to guns, whereas in an American ship everything passed through the plotting room for processing.

On a more practical level, the British used 'follow-the-pointer' systems for information transmission: the man at the gun had merely to match his dial with a pointer synchronized with one on the director. In the US case, range was sent to the guns by means of Corey visuals (electric counters) from which the range would have to be read. In 1917 some of them did have Sperry follow-the-pointer systems to indicate azimuth (train) to the gun turrets. However, follow-the-pointer in elevation did not appear until 1918. The chief problem turned out to be maintaining synchronism between the master pointer and the pointers in the turrets; the first installation was made aboard the new battleship *New Mexico* in September 1918. The synchronism problem continued after the end of the war; in the 1930s self-synchronous mechanisms began to appear. These mechanisms were particularly valued because they increased the overall survivability of the fire control system. That is, it was much easier to shift from one director to another (in the event of battle damage) if there was no need to wait to synchronize.

On 2 October 1917 Captain C C Plunkett described the two systems to the General Board:

The British system loads up control, but probably permits firing in spite of a changing list (*eg* during a turn) rather more readily than our system does. The 'follow-the-pointer' transmission looks at-

tractive but of course it is no more peculiar to one system than to the other. The British have the whole director tower rotate on rollers like a turret. This makes the installation rather complicated, and in fact they do not attempt to combine it with the fire control tower, but even this dissimilarity is not a basic difference...

A careful comparative study fails to convince us of any superiority of the principles of the British director system. Their 'follow-the-pointer' transmission of ranges is something for us to think about, though. It will be a necessity in director train when we come to it.

Plunkett noted that the British directors were so massive that they could be mounted only in a top, whereas the US type could be placed in at least five positions per ship – fire control tower, tops, turrets – and three would be armored. In addition, the British appeared to lack the flexibility of the American system. On the other hand, theirs was simpler and required fewer personnel. Finally, BuOrd was even then fitting spotting glasses with an azimuth repeater which repeated in turrets, plotting room and fire control tower. Just such a repeater, combined with the director as operated from the plotting room, would give US pointers and trainers the combined system. 'The only difference between the British system and ours is that the British follow-the-pointer system takes the initial movement from the control of the directorscope. Ours is the better system'.

In particular, the US system would probably be better able to divide the fire of one ship between two targets:

One of the most amazing things I have gotten from the English officers is that, outside of the Gunnery Officer, it does not seem that any other person in the ship knows very much about gunnery. Therefore their instruments must be of the most simple make.

There are many things we do and have done which the English did not do until the war was upon them; *eg* our spotting practice ... today our spotters should get on target quicker than the English because we employ no bracket system, and we fire all guns in opening salvo, so as to give the spotters an opportunity to see what a salvo looks like. We would probably come nearer in getting the sight-bar range of the enemy than they in their one-half gun salvos; that is, our second salvo ought to be on the straddle of the target; and this year we are firing in the neighborhood of four hundred 12in shells, so as to give our spotters thorough experience.

[They claim as] reasons for firing half salvos greater rapidity of fire, and less patterning. They have encountered the same difficulty in regard to the ships firing for a score. This is due to small allowance of ammunition for a practice.

Cdr D C Bingham reported on 16 October that American practice placed far more responsibility on the spotter; the Royal Navy had instead a gunnery officer (not in the highest position in the ship) who would decide which 'ladder' to use, *ie* how far to correct the range on the next salvo. The basic difference in gunnery practice was that the US Navy placed far more stress on the plotting room in which data from rangefinders and director and spotters could be processed. It seemed to Americans that there were such large errors inherent in all incoming data that it was well to have personnel in the plotting room who could themselves sense trends in errors by watching graphs of spotting. In British practice, by way of contrast, the plotting room became a transmitting station, and the apparatus in it

was an analog computer which automatically processed incoming data. Bingham considered the graphic method superior precisely because the effective range of the gun was *not* the range entered in its range table: sight-bar range did not equal rangefinder range. By plotting gun and rangefinder ranges, gunnery personnel could estimate their corrections from an observed trend.

The British had no turret bearing instruments, to show those in the plotting room the bearing of all turrets. Once again, this was a matter of who controlled fire: in the British system the 'transmitting station' was primarily a mechanism for correcting range, whereas in the US the plotting room controlled the guns.

Bingham noted that the British expected to achieve one round per minute per gun. They could load in 20–25 seconds; 'we are faster but probably not so safe and reliable for long periods'. At this time the British expected 10–15 percent hits at 16,000–20,000yds. Their patterns (of fall of shot) were consistently smaller than US patterns, but Bingham suspected that part of the reason might be that they consisted of half as many shells. On the other hand, British projectiles were longer than American, a fact which would deserve further study. In the summer of 1918 the Bureau of Ordnance, stung by repeated complaints on the issue of pattern size, would claim that most of the unsatisfactory US patterns were so only because of the presence of one or two bad shots out of ten or twelve, that US shooting really was effective if only the few poor shots were discounted.

American officers attached to the Grand Fleet were certainly impressed by its performance. For example, on 29 September 1917 a Lt Cdr Castle reported after service aboard HMS *Emperor of India*, a division flagship. Unlike the US Navy, the Royal Navy combined gunnery and tactics, a very natural consequence of actual war experience. British officers claimed that the Germans were able to get on target very rapidly but that they became ragged afterwards, which practice was ascribed to German dependence upon a gyro which could be knocked out if a ship were hit. German rangefinders were considered superior. Castle considered the main British deficiency their plotting room: 'ours is better'. However,

... the British system I think is decidedly superior for battle operations. They apparently found [at Jutland] that at times they had four to eight ships which were able to bring their guns to bear on only one or two or possibly three German ships and considered that they were not trained in concentrated or massed fire and so were unable to take advantage of their superior positions and numbers. So since the battle they have developed massed fire to the point that they can fire four ships concentrated on one almost as successfully as they can fire one ship against one. They lay great importance on this and consider if through the smoke or mist two of the enemy ships show up and they can bring the guns of eight ships to bear efficiently and effectively they will break up the enemy's line as Nelson accomplished it by sending through fast frigates, whereas if they were not able to take advantage of massed fire the enemy would probably escape.

He saw several analyses of division practice and selected one at random. After two minutes of trial salvos they landed four 5-gun salvos on target in 50 seconds. A recent US Navy Battle Division practice had shown nineteen

hits on a target at 20,000yds in two minutes.

The Grand Fleet fired by division, with the flagship or second ship the master ship. A radio in each plotting room enabled ships to exchange range data; they averaged by ship over the various rangefinders aboard, then radioed ranges to the others in line. Firing was in successive time blocks: the master fired her salvo, at which the others started their stopwatches which were marked in sectors. The master ship would fire at the lowest range, the next ship up 400yds, and so on; all spotters in the division would spot all shot. There would be 14 or 15 seconds per division because that was roughly the period of roll of any one ship.

Castle was much impressed with the British use of director fire for the secondary guns, for which there was no US equivalent. Such a system compensated for the wetness of the broadside guns by moving the sights well above the weather deck. 'To break up a destroyer attack firing ahead they divert the forward turret and open fire at 20,000 yards thereby establishing a barrage until their own destroyers appear to break up the attack, or the enemy destroyers get within range of broadside guns.'

Cdr H E Kimmel, who would later command the US Fleet (at Pearl Harbor), reported in February 1918 that the Grand Fleet showed smaller range errors than did the US ships attached to it; he was impressed by the fact that British ships did not fire in a ripple, but instead fired all their guns together. He did not mention that this was because all the guns were fired by a single firing key in the director. If a gun could not fire for some reason, it would have to wait for the next salvo. In the case of firing by division, this rule also applied; Kimmel noted further that the British stopwatches (and, for that matter, rangefinders) were superior to the American at this time.

The US observers did seem to be unanimous in their preference for the US system, which emphasized the superior initiative and intelligence of American seamen, who did not need automatic simplified instruments, but could be relied on to operate more subtle systems. One observer, Lt Cdr H F Leary, did note that one value of automation was that it might make up for considerable loss of concentration under intense fire.

It appears, too, that American gunnery improved greatly as the ships practiced with the Grand Fleet. In February 1918 Kimmel reported that *New York* had reduced her pattern to 400yds; by June there were still complaints of large patterns in the fleet, about 800yds (400 in *Florida*) at 18,000yds; it appeared that the secret of pattern reduction in the Royal Navy had been reduced muzzle velocity. In October 1918 Captain Leahy of BuOrd thought that patterns could be reduced to about 500yds, but even in the 1920s the Navy was plagued with excessive patterns. On 27 June 1918, for example, *New York* and *Wyoming* achieved spreads of 1043 and 1086yds, respectively, at 18,600–16,950yds; *Florida* and *Delaware* achieved, respectively, 559 and 720 at 17,900–15,900. However, HMS *Revenge*, *Resolution* and *Ramillies* made 375–550yds at about 21,000yds on 24 June 1918. The average number of guns actually fired in these 'full salvos' were, respectively (with the full battery number in parentheses), 9.3 (10), 11.75 (12), 7.8 (10), 8.3 (10) and 6.75

(8) for the British ships. In the 1920s, although the 16in/45 ships fired well (according to one annual report, with 'the smallest patterns ever achieved'), the 14in battleships were poor at best: firing with a full charge, *Nevada* achieved only 1058yds at 18,000, *New Mexico* 1121 at 18,379, and *California* 1352 at 23,959. However, *Oklahoma*, with two twin turrets, made 576yds at 17,955 and there was suspicion that poor performance was due to interference between the guns of the triple turrets. In the same 1924–25 battle practices, *Maryland* made 558yds at 24,850 and the worst of the 16in ships, *West Virginia*, made 758 at 24,514. All of these figures are averages. The previous year excessive patterns had been observed even when the ships fired with reduced charges (*Mississippi*, for example, made 1097yds at 13,100; a year later she made 1116 at 17,800). In his FY27 report the CinC US Fleet reported that 'the firings of recent years, and particularly that of the current year, when full service charges were used, have proven conclusively that the performance of the 14in/50 compares unfavorably with that of any other turret gun in service. In fact the dispersion of this gun is so large, that it would require at least *two* ships with 14in/50 batteries to produce the same density of hitting at the target as one 14in/45 or 16in ship...' At the same time the 16in/45 ships were performing excellently at 29,000–32,000yds. In the mid-1930s there were again pattern problems, this time with the high-powered 8in/55 of the heavy cruisers; in this case the guns were de-rated and their rifling changed.

For their part, the British were less than impressed with US fire control. Cdr R T Down RN reported to the Admiralty after a May–June 1917 visit to the United States that

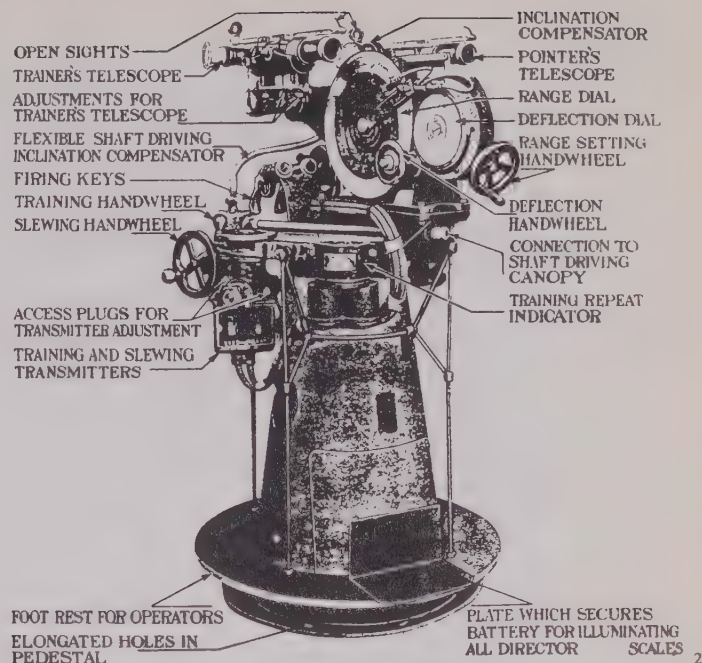
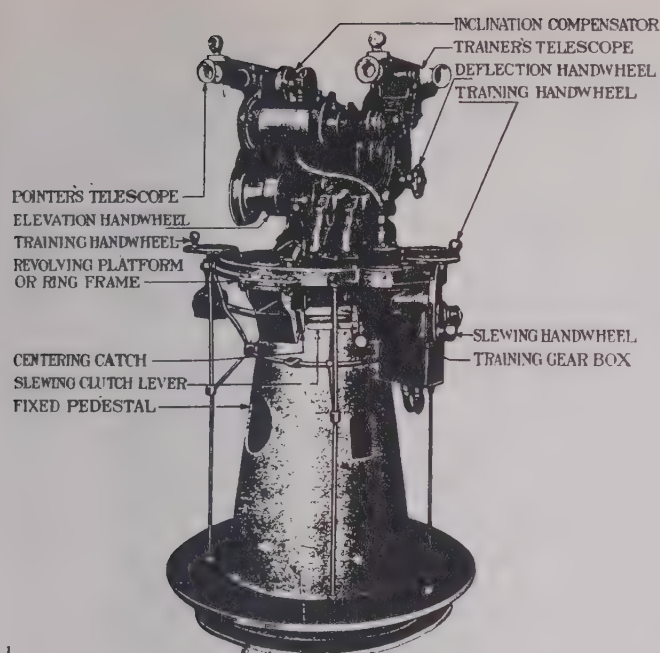
The Director has not been developed to anything like the same extent as with us and until quite recently its importance had not really been fully realized...

Rangefinders. In this respect it seems to me we have a good deal to learn from the US Navy. They have taken rangefinders very seriously and have developed both instruments and training steadily and scientifically.

While their control system and organization is in no way dependent on rangefinders they place great reliance on them provided their use is in the least practicable. This is partly no doubt due to the generally good weather conditions obtaining in waters in which they exercise but results in good and reliable instruments and training. Without exception they profess the most profound astonishment at our placing any reliance on the 9ft rangefinder except as a purely navigational instrument. They maintain that it cannot be considered as accurate for practical gunnery purposes at ranges over ten thousand yards.

That a 12ft rangefinder is accurate only up to 12000 yards...[a] 15ft [rangefinder to] 15000 [yards, and an] 18–20ft [rangefinder to] 18–20000 yards.

They mean 'accurate' in a very literal sense and the results they get, weather and light conditions apart, certainly justify the assumption that real accuracy under almost all circumstances in which a rangefinder can make observations *can* be obtained given a sufficiently good instrument with a large base. They contend with much emphasis and practical reasoning backed up by innumerable rangefinder diagrams – many of 20,000 yards and over – that in relying on a 9ft rangefinder we are trying to make bricks without straw. The majority of their ships have 18–20ft instruments; the two latest classes afloat 25 foot base, and ships building 30 and 38 foot rangefinders.

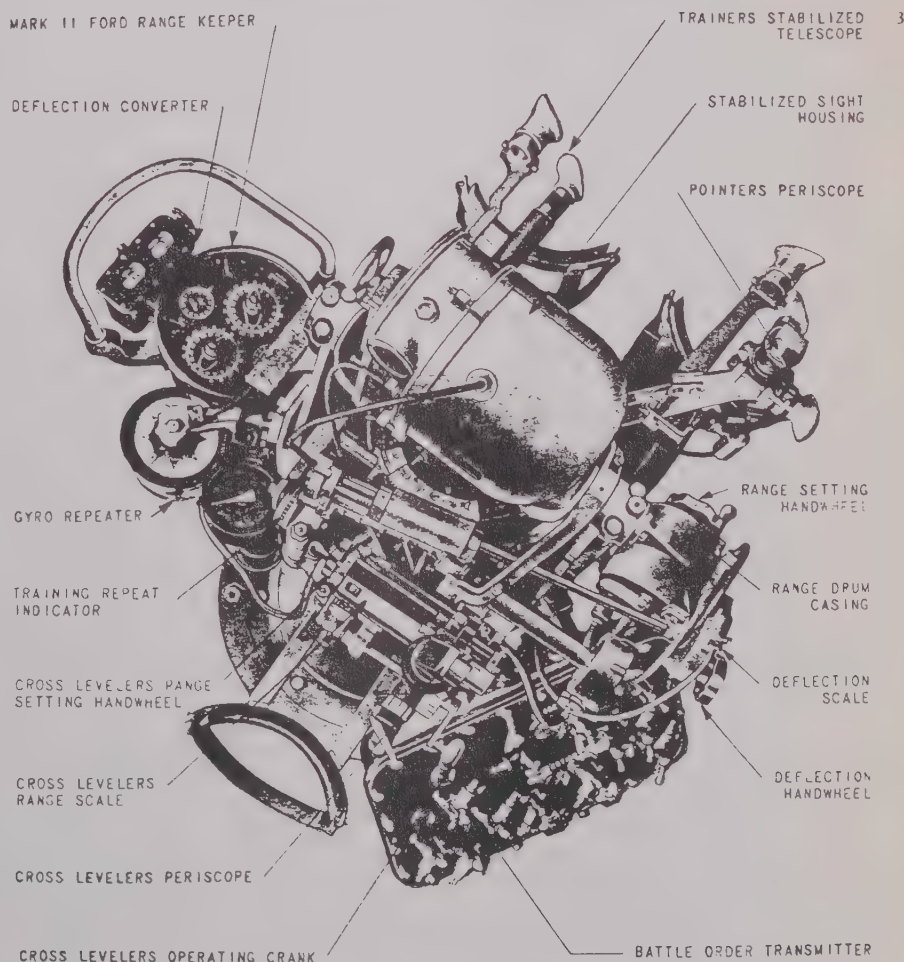


Plotting forms a definite part of the control system but at present exists in a very elementary form and while it seems to do in this way more or less what is required of it, it is at the same time slow and inaccurate. The inaccuracies made in practice are readily observable to an onlooker and are more or less inevitable though this defect has been partly lost sight of owing to the big spread usually obtained casting a kindly veil over and swamping all minor inaccuracies in range transmission. In this connection I should here observe that ranges are passed in fifties and not in 25's as with us. Experiments have been going on for some time in a desultory way with a rangekeeper. . . The instrument is very similar to Pollen's clock and possesses about the same merits and demerits when compared with our system. Though they thoroughly understand their present system and use well what they have got my general impression is that in this branch of control the US Navy are about ten years behind the times though I hope and believe new impetus is being given in the direction of further trials and improvements.

It appears, too, that the Ford rangekeeper was, at this time, relatively well appreciated by many gunnery officers, but was as yet being resisted by senior fleet officers, who preferred to retain the plotter.

Interwar Developments

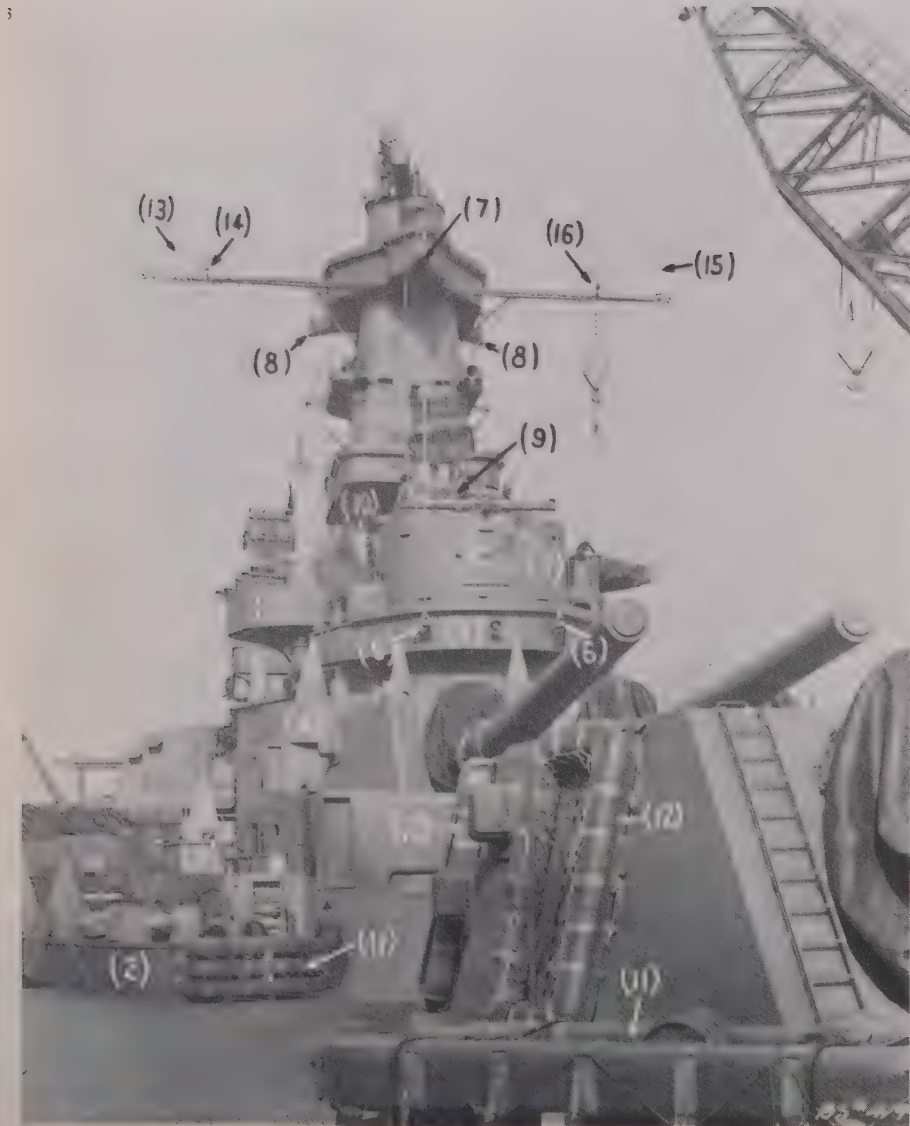
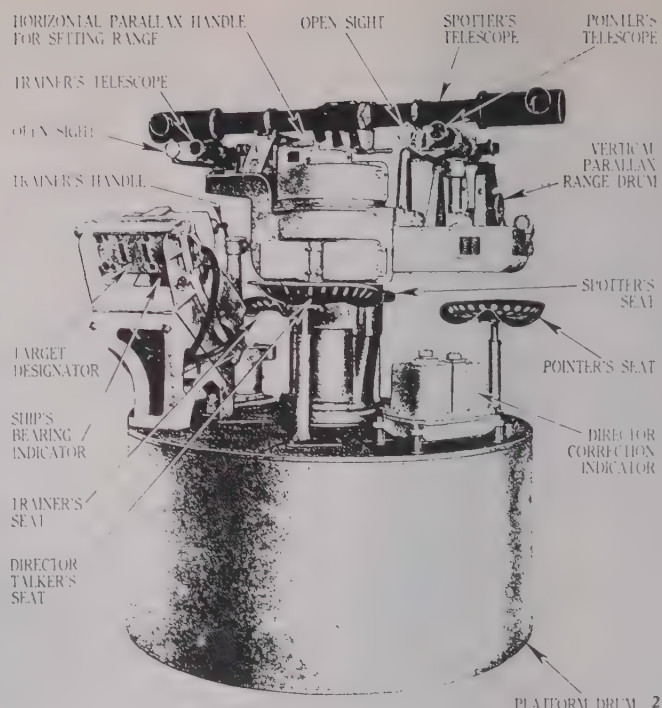
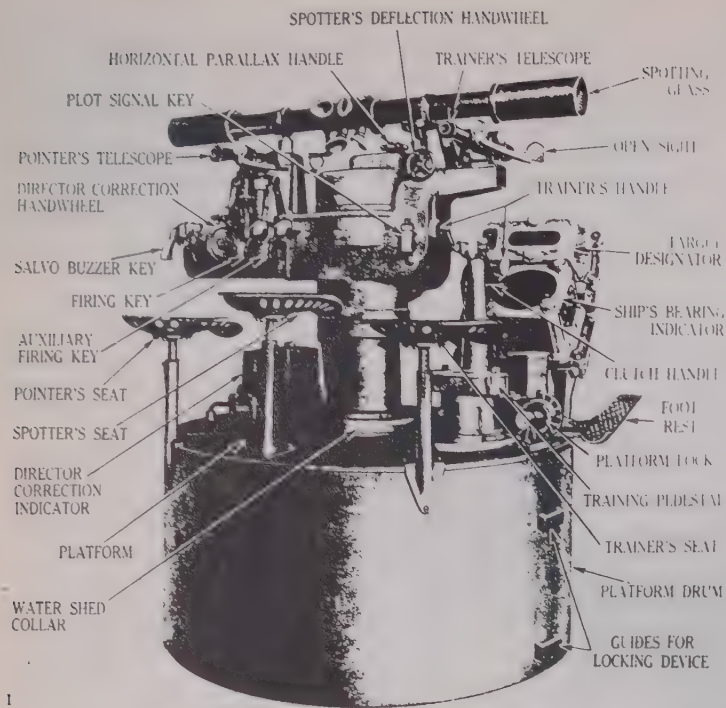
Perhaps the most fundamental change to American practice resulting from the Grand Fleet experience was the introduction of director control for secondary batteries: in the US Navy in 1917 the secondary guns were individually sighted, with some assistance from a fire control party in a 'torpedo defense station' on each cage mast; the latter also controlled searchlights on the mast. Vickers, which manufactured the British equipment, almost immediately provided plans, so that in October 1917 BuOrd could move to install two directors on each beam of each battleship from the *Michigans* on, a scheme ultimately carried through. Actual installations were made during the first postwar refits; generally one director would be mounted on each side abeam the bridgework on the O1 or O2 level, and another further aft on the weather deck directly above the bulk of the secondary battery. In the flush-deck coal-burning battleships the after director



was bracketed to the after end of the deckhouse amidships. It would later be claimed that such positions (main deck or deckhouse) were not very useful, and that indeed their uselessness portended the impotence of the low main battery control positions later proposed for battleships to be reconstructed in the 1920s.

- 1 THE DIRECTOR MARK VII
Rear view.
- 2 Trainer's side.
- 3 THE DIRECTOR MARK VIII
Top view.

I. GUNS (SURFACE FIRE)



- 1 THE DIRECTOR MARK XI
Pointer's, spotter's and trainer's stations.
- 2 Range station view.
- 3 Refitting at New York Navy Yard on 20 February 1943, the new battleship *South Dakota* displays the final generation of US battleship turrets and main battery fire controls, the latter including the Mk 38 director atop her tower mast. Her conning tower carries both a long-base spotting glass (just above the running light, marked 17) and a Mk 3 ranging radar (9). Next to the life rafts (12), her No 1 turret shows characteristic sighting ports, similar in theory to those introduced in the *South Carolina* more than three decades earlier. The two anemometers (14 and 16) also fed information (on wind speed and direction) to her fire control system. Other features visible here include a new bridge windshield with venturi (1), new 20mm and 40mm anti-aircraft guns, a small sponson carrying the ship's bell and, above it, an SG radar (7) for surface search (and, by extension, for assisting surface fire control) and a new IFF antenna (BL, 13). Ships of this type were deliberately designed with minimal open bridge space, on the theory that control should always be exercised from within the protection of the conning tower - hence the size of the walkway. *South Dakota* herself had a second conning tower level, as she was designed to be a flagship; she had to sacrifice two twin 5in/38 as weight compensation. The guns were set much further apart than in earlier US battleships, to overcome suspected interference between adjacent barrels firing together.
- 4 THE FORD RANGEKEEPER MARK VII
Top view.

There was also a major external change. During World War One, the Grand Fleet devised two visual means for transmitting fire control data between ships of a division, some of which might not be in visual touch with a target at which all were firing: bearing marks on turrets, and as we have seen, range clocks on masts. The US Navy initially adopted both, but the bearing markings appear to have been abandoned by the early 1920s. Range clocks ('concentration dials'), however, remained until World War Two, and were a prominent feature of all US battleships and cruisers of the interwar period.

Fire control development in the 1920s might best be described as the consolidation of the makeshift system of the First World War. The basic principle, control dominated by the plotting room, did not change. Thus 'Notes on Fire Control (1933)' describes the aloft director as very restricted in function: most of the calculations were still done in plot, where a master director was used to send gun elevation and train orders to the turrets. A major development since 1918 had been the replacement of directorscope (elevation) and bearing transmitter by a single instrument.

The elevation component of the aloft director had been primarily a means of ensuring that the guns fired (together) at a constant point in the ship's roll. Soon after the end of World War One developments in gyros suggested that this function could better be accomplished by a gyroscope in the plotting room. Were such a development to succeed, the entire main battery fire control system

would be well protected: ranges would be taken from the turret rangefinders, appropriately averaged; spotting could be done from the conning tower as well as from the spotting tops; and now the horizon observed by the directorscope could be replaced by an artificial one observed inside the plotting room.

Unlike the Royal Navy, the US Navy of this period used no aloft rangefinders. Some American officers with the Grand Fleet had suggested their introduction, since at times the target could be seen *only* from aloft, but the proposal had been rejected, perhaps partly because of the instability of the cage masts themselves. Thus the main battery directors of the time were small mechanisms entirely enclosed within the large fire control tops, in glass cupolas within which they could rotate freely.

The gyroscope was incorporated into a 'stable vertical', an instrument which could, in theory at least, continuously sense the relation between the ship and the plane of the sea. Such instruments first appeared in the *Maryland* class, but were not immediately successful. The earliest ones, referred to as directors, employed a telescope fixed on the gyro to transfer its motion to fire control instruments. Only in the 1930s would this crude arrangement be replaced by automatic sensors - indeed, only as late as his FY34 annual report did the CinC US Fleet remark that he considered the trunnion tilt (*ie* level and cross-level) problem solved with the new Mk 32 director (stable element). At the outbreak of war in 1941 *Arkansas* was fitted with the old

Mk 9 stable element; the modernized ships had either Mk 30 (*New Mexicos*) or Mk 32. From 1941 on new-construction battleships had Mk 41 (stable element) directors, except for the *South Dakotas*, which received a newer Mk 43.

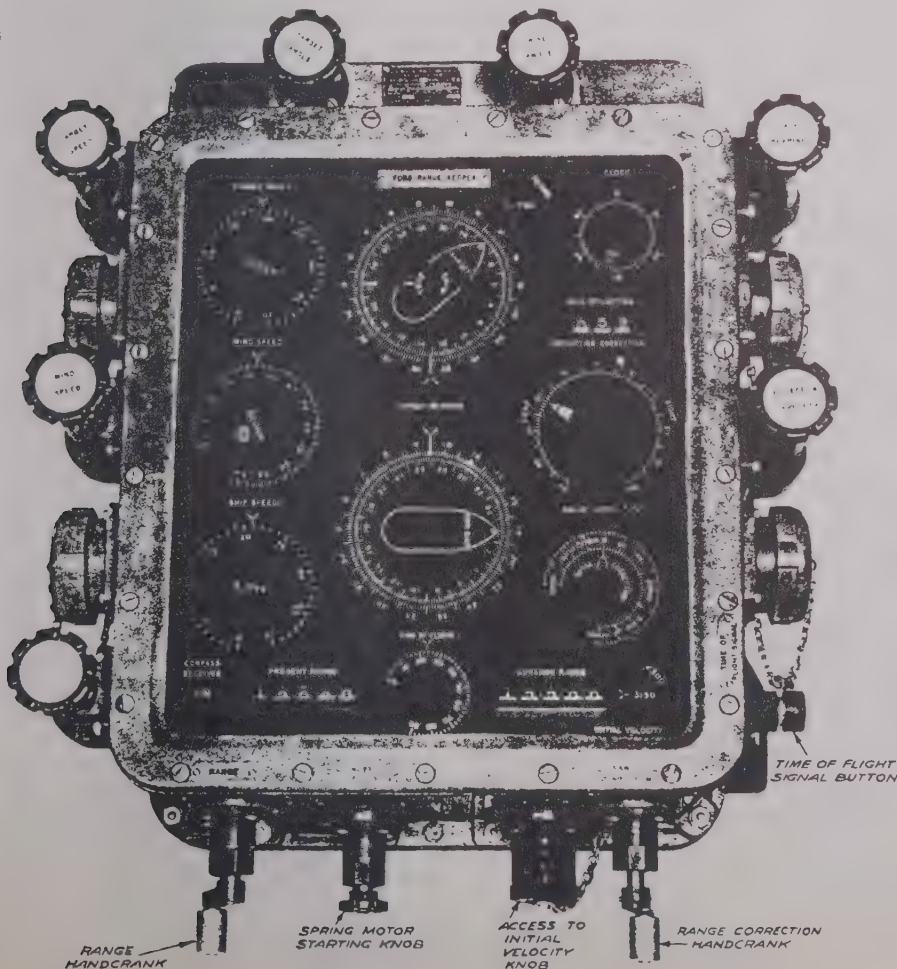
Automation

The next step was to automate the movement of the guns, to introduce, in effect, continuous aim for the heavy guns. Automatic pointing and training was first introduced in the heavy cruisers and then appeared in the new battleships; the stable element could either maintain continuous aim, or it could fire the guns at a constant point in the roll. Generally the latter mode was only used in very rough seas. Such automation did not appear before World War Two. In a June 1939 General Board Hearing, BuOrd testified that remote control was already successful for 5in batteries and was close to fruition for 6in guns; moreover, it was on order for the new 8in cruiser *Wichita*.

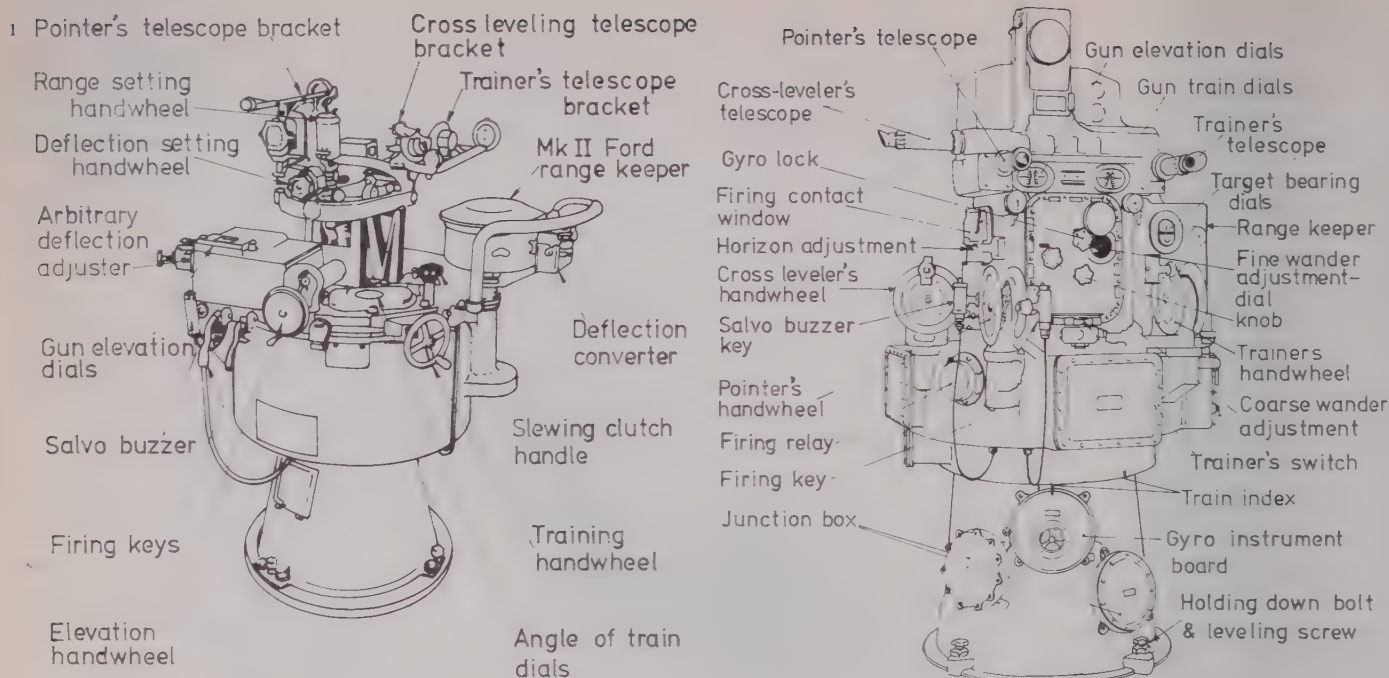
By 1941 automatic operation was a reality aboard the new battleships; this type of operation was extended to the *West Virginia*, *California* and *Tennessee* during their post-Pearl Harbor reconstruction. As no special equipment had been designed for them, speed gears designed for 6in/47 turrets were adapted. The results were so successful (particularly at Surigao Strait) that similar modifications were demanded for the *Maryland* and *Colorado*. The Mk 34 director and remote control equipment were gradually extended to the earlier heavy cruisers in wartime, beginning with *Portland* and *Indianapolis* and continuing with the *Louisville*, *Chester* and *Augusta*. A system comparable to that in light cruisers was authorized for *Pensacola* and *Salt Lake City*, but only the former was actually refitted. Top-weight precluded the installation of Mk 34 in the *New Orleans* class, but they were also modernized with automatic (remote) control systems. Indeed, by 1945 even the 5in/38 controlled by a Mk 37 DP director was capable of automatic operation.

Automation was also applied to data transmission within a ship. One major advance was the self-synchronous ('selsyn') system for 'follow-the-pointer' transmitters. Early systems were 'step-by-step,' *ie* as some initial time master and slave dials were synchronized, and then the slaves were instructed to advance by increments. Unfortunately, any shock (*ie* that of firing a salvo) might well temporarily knock out one or more of the slaves, so that later increments would be added to the wrong base. The *Marylands* introduced the selsyn system, in which each position of slave or master dial was associated with a unique voltage, so that temporary casualties would not disable the entire system.

This was only a beginning. In the early US systems virtually all data transmission to the plotting room was by telephone, numbers being entered into the computer (rangekeeper) by hand. Such a system correctly assumed that targets would move relatively slowly, but it could be (and, in World War Two, was) dislocated by violent maneuvers by the firing ship. Moreover, there was typically a 10-30 second interval between data-taking and the arrival of the data at the rangekeeper - indeed, this interval had itself to be estimated and fed into the computer. The range of data required was listed in 'Notes on Fire Control (1933)':



I. GUNS (SURFACE FIRE)



Initial Range (hand input based on phoned data from rangefinders)
Own Course (automatic, from gyro compass repeater)
Own Speed (hand input from pitometer log)
Target Angle (hand input)
Estimated Target Speed (hand input)
Target Bearing (automatic input from director bearing)
Computed Ballistic Correction in Range and Spotting Data (hand inputs)
Computed Ballistic Correction in Deflection and Spotting Data (hand inputs)
Range Finder Data (hand input from phoned data from rangefinders)

The systems of the late 1930s and war construction were far more completely automated. For example, it was standard for the rangekeeper to drive the director, so that a correct rangekeeper solution of enemy bearing would keep the director telescopes continuously on target. Personnel manning the director could then transmit bearing corrections back to the rangekeeper simply by manually keeping their instruments on target. Similarly, manual level and cross-level from the director could act as corrections to the stable vertical. In fact, stable verticals had begun as backups to what amounted to optical levels and cross-levels; but the latter became less and less important as stable verticals improved in reliability.

Directors

Probably the most noticeable difference between World War Two directors such as Mk 34 and Mk 38 and their predecessors of the 1920s and 1930s was the provision of a rangefinder in the later systems. It grew out of something quite different: the spotting glass mounted on, but not connected to, the director. The glass was mounted on the director so that the spotter would not have to orient his glass independently. Spotting glasses resembled, but did not operate as, rangefinders. The Mk 11 director of the *Colorados* incorporated an 8ft spotting glass, but in the *New Mexicos* a longer-base instrument was employed and, as the

directors were not now enclosed, the spotting glass became visible.

The new battleships were at first to have had similar installations, and spotting glasses (15ft) were also specified for their conning tower roofs. The latter were actually installed, but the control tower directors had long-base (26.5ft) stereoscopic rangefinders instead. Ultimately the spotting glasses on conning tower roofs were displaced by small radar rangefinders (Mk 27). In retrospect it seems clear that directors, at least for battleship and cruiser main batteries, served at most a backup purpose, once reliable stable verticals had appeared. They survived into World War Two largely because of the incorporation of rangefinders (and radar rangefinders), but it should be noted that the last US conventional cruisers, the *Worcesters*, had only a radar antenna mount, and no true director at all.

Battleship secondary battery directors were descended from the British Vickers type, and hence concentrated in their structures more of the fire control function that did their main battery counterparts. They were not connected to plotting rooms, and so incorporated computing equipment. Generally the secondary control system comprised both directors and separate, unarmored rangefinders: four directors and two short-base rangefinders, fore and aft. In the *Texas*, for example, the rotating secondary battery rangefinders were mounted one on the pilot house roof and the other atop No 4 turret. In the *Nevadas* and *Pennsylvanias*, as rebuilt, the rangefinders were mounted on the pilot house and on a mainmast bracket; they had bases of 12ft (aft) and 20ft (forward). The *New Mexicos* had 15ft rangefinders on centerline brackets at the ends of the forward and after superstructures. Plans for the new battleships from the *North Carolinas* on all show 12ft rangefinders on No 3 turret and on the forward superstructure just before the fire control tower; only the *North Carolinas* were so completed, however. As for the five unmodernized ships (the 'Big Five'), for a time they had after rangefinders bracketed to their

cage mainmasts, but these were soon removed and all rangefinders concentrated in the bridgework: one 20ft instrument atop the pilot house and two 12ft instruments on the upper bridge wings. Flagships had, in addition, a single 12ft rangefinder for Flag use, atop the conning tower. A 1939 drawing of *California* shows no secondary rangefinders alongside the bridge, but instead a pair of instruments reserved for AA use, separated from the AA directors. The principal of protection for fire control may be noted: the main battery fire controls, and particularly the main battery rangefinders, were all under armor, consistent with the armored protection of the main battery itself. The unarmored secondary battery had an unarmored control system.

The step to rangefinding in secondary battery control systems was not a great one, and was made through the development of dual-purpose fire control systems such as Mk 37 (see Part II), which incorporated a 15ft stereo rangefinder in its structure. Hence the new battleships were able to dispense with the secondary control rangefinders originally included in their designs.

Stereoscopic Rangefinders

As in the case of guns, the principal BuOrd development effort in fire control between wars was intended for large cruisers. Flush-deck destroyers and *Omaha* class light cruisers were all provided with simple directors immediately after World War One, similar in theory to the Vickers types controlling battleship secondary batteries. A similar system was fitted to the first US Treaty cruisers, the *Pensacola* and *Salt Lake City*. However, it was soon apparent that these large vessels would be capable of hitting each other even at long range, and in the next (*Northampton*) class, the fire control system was placed under armor, *ie* was made quite comparable to that of a battleship, with a plotting room under the waterline. From then on cruiser and battleship director development proceeded in parallel – the *New Orleans* class cruisers and the rebuilt *New*

- 1 THE DIRECTOR MARK XVI MOD 2
Left front view.
- 2 THE DIRECTOR MARK XVIII
Pointer's and trainer's side.
- 3 THE DIRECTOR MARK XVIII MOD 1
Rangekeeper's side
- 4 THE DIRECTOR MARK 34
Front view.

Mexico class battleships, for example, shared a common system. The battleship Mk 38 director of World War Two appears to have been quite similar to the Mk 34 standard in cruisers.

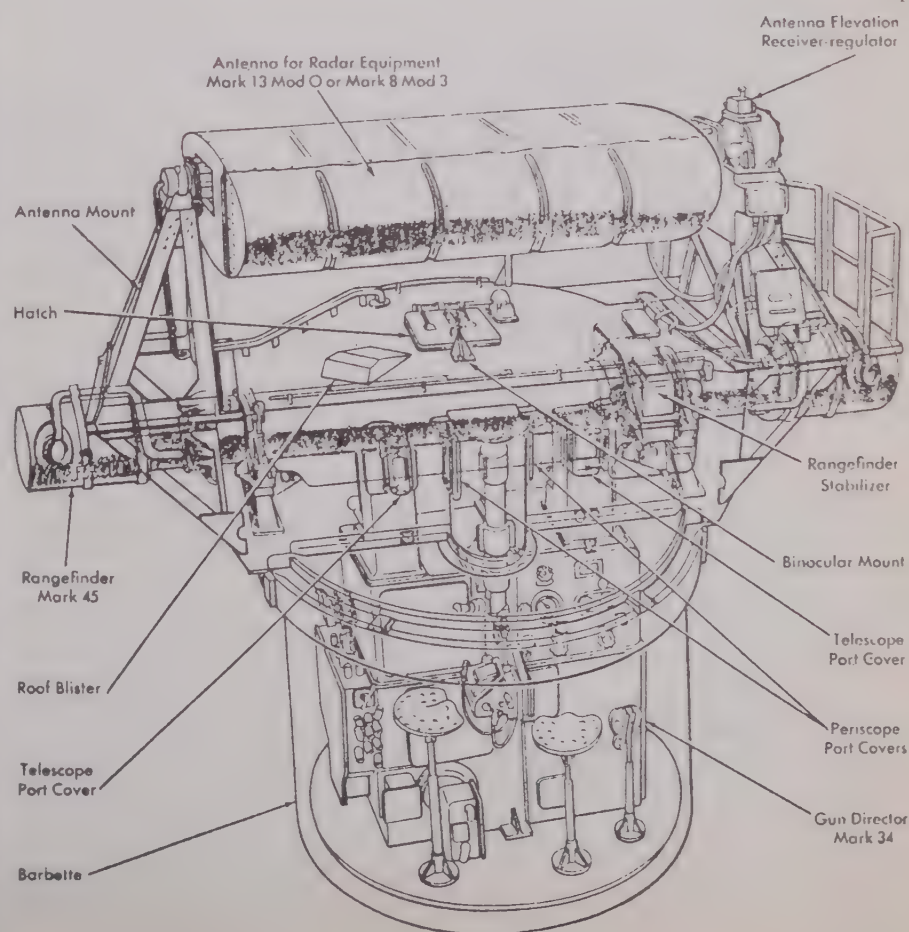
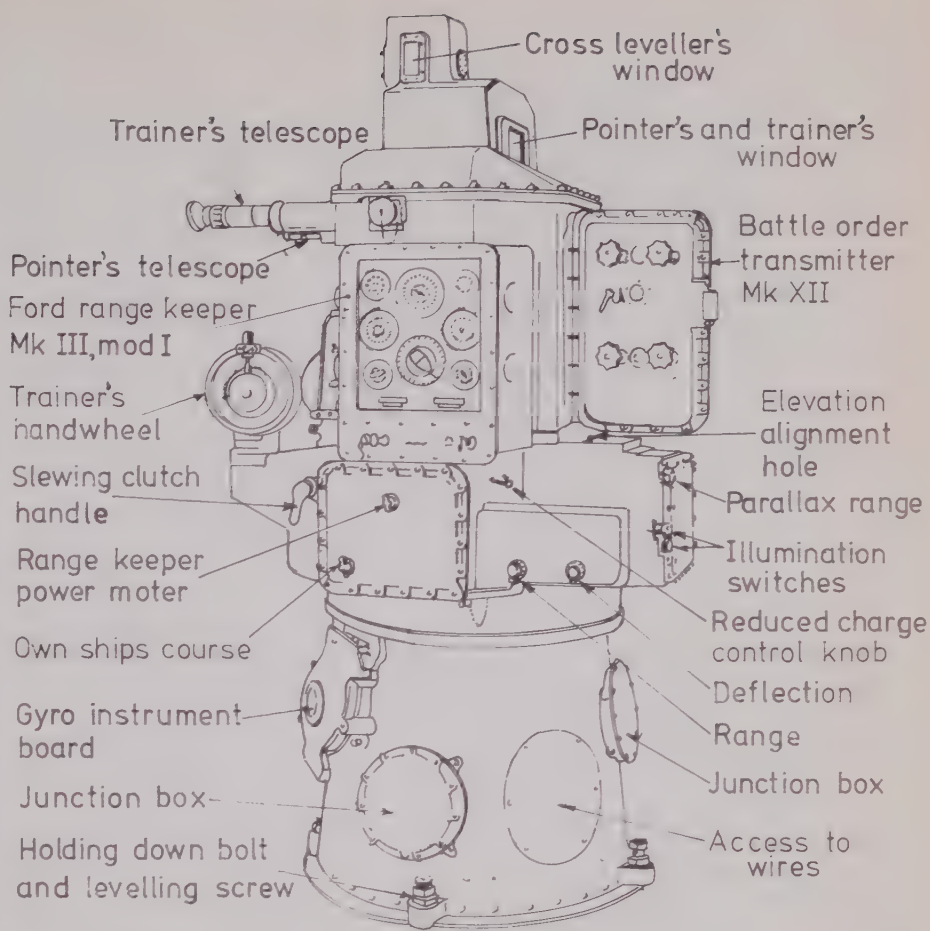
In both battleships and cruisers, the major shipboard innovation of the late 1930s was the introduction of stereoscopic rangefinders in place of the earlier coincidence type. The coincidence rangefinders employed prisms to bring the two halves of a target image into alignment, operating much as a rangefinder camera does. Such systems depended for their success on the existence in the target of distinctive vertical lines, breaks in which could be observed. Indeed, much of British World War One naval camouflage was designed specifically to break such lines. For their part, the Germans preferred the alternative stereoscopic system, in which each of the observer's eyes was connected to a separate telescope, the psychological phenomenon of stereoscopic vision being used to measure distance in relation to markings generated by the rangefinder. The US spotting glass was, in effect, a stereo rangefinder, although it was never classed as such.

In post-World War One analyses the British claimed that this system, although perhaps superior to their coincidence type, would require very highly trained personnel, who would break down under the stress of battle: the perception of stereoscopic effects was a very subjective phenomenon. The US Navy disagreed, and during the 1930s extensively tested stereo instruments. In 1940 they began to appear in battleship turrets; and all the new directors had stereo rangefinders, which appear to have been quite successful in battle.

The Mk 34 (cruiser), 35 (destroyer single-purpose) and 38 (battleship) directors were the last single-purpose directors produced in quantity for the US Navy. Mk 38 was criticized in 1945 as cramped and obsolete in concept, compared to the new generation of dual-purpose instruments; Mk 54, which just missed the war, and which served only in the *Des Moines* class, was considered far better. Postwar gun fire control systems have generally been designed either for anti-aircraft or for dual-purpose operation (see Part II). All of the directors formed a single numerical series, and therefore are listed together in the Appendices.

Air Spotting and the Advent of Radar

The other major interwar surface fire control innovation was air spotting for indirect fire. Quite early it had to be accepted that for fire control parties in the tops, the horizon could not extend much beyond 22,000–26,000 yds; but in fact the guns could fire good patterns at much longer ranges, which meant that they could achieve hits if only their splashes could



be observed. In 1922–23 experiments, fire was directed from the air at points below the horizon, and in 1925–26 against a target obscured from the firing ship by an island. This explains the great significance of spotting aircraft and the willingness, in early battleship reconstructions, to sacrifice fixed spotting positions (on the mainmast) for them.

It is important here to distinguish between aircraft employed for scouting and those employed primarily for spotting. The US Navy was well equipped with carriers from 1943 on, yet, unlike the Royal Navy, its battleships and cruisers did not discard their aircraft until well after World War Two – and then only when reliable helicopters became available. The reason was a division of roles: the aircraft were to be used to spot the fire of their ships, not for general scouting – carrier aircraft could be relied on for the latter. On the other hand, cruiser aircraft were generally considered scouts, as the cruisers themselves would have independent roles as well as functions within the fleet – hence the attention paid to protect (enclosed) hangar facilities for cruiser, but not battleship, aircraft.

The advent of radar brought great changes, although not perhaps so great as might be imagined. Early gunnery radars, such as the Mk 3 of 1942, provided very accurate range but had relatively broad beams, so that a ship firing at a concentration of vessels might well be unable to distinguish the individual target. Moreover, she could not fire completely blindly, because the radar would not provide sufficient accuracy in bearing. At Guadalcanal in November 1942 the battleship *Washington* opened fire at 18,500yds using radar range but optical train. Later a target was tracked entirely by radar, in both range and in bearing, at 8400yds, but it was subsequently engaged by optical train; radar train and generated train (enemy target bearing estimated by the fire control computer) were used when the target was obscured.

Later in World War Two, centimetric fire control radars such as Mk 8 and 13 had beams so narrow that they could control guns in both range and train; indeed, both were used to spot splashes due to shells missing in bearing as well as in range. Such instruments could be used to

achieve completely blind fire. Moreover, since the radar horizon is one-third farther away than the visual one, they could be used for over-horizon fire control, and spotting aircraft were no longer essential. The Mk 8 and its associated fire control system proved particularly effective at Surigao Strait, where the three ships equipped with it, *California*, *Tennessee* and *West Virginia*, all had a firing solution in main battery plot long before the order to open fire came at just under 23,000yds. By way of contrast, the older ships, with Mk 3s, did relatively poorly. *Maryland* had to range on *West Virginia*'s splashes, *Mississippi* managed only one salvo, and *Pennsylvania* never opened fire.

During World War Two, a typical US battleship salvo was all nine guns. All were generally aligned to one elevation unless one barrel was more worn than the others, and the entire salvo, if fired properly, would leave no gap between the splashes. A ship ranging on a target would fire her turrets in laddering patterns, a typical one being 200yds up, 200 down and 400 down on the initial range estimate, three guns per range, and timing differences between 'rungs' of the ladder were used to avoid confusion. Once the range had been found, a ship would switch over to rapid fire with full salvos. This doctrine continued prewar practice, and contrasted with Royal Navy use of half-salvos. The US gunnery officers took particular pride in being able to open fire at maximum range, and indeed much of the cruiser doctrine of the late 1930s reflected beliefs that maximum firing ranges would be practicable.

The cruisers also achieved very high rates of fire. On the Asiatic station, the *Augusta* made a Short Range Battle Practice record, 9 hits in 9 rounds fired, all in less than 30 seconds. However, the cruisers had enormous patterns, sometimes as much as 2000yds, so that they could often straddle without hitting. Some of the problem lay in the guns themselves, with their very large powder charges (for very high velocities) and with shells which did not seat properly. About 1933 some were tested in Manila Bay with the assistance of the Coast Artillery, and the results sent to the Bureau of Ordnance. Corrections included a general

down-rating of the weapons as well as relining. Another problem was trunnion tilt; as a ship rolls with her guns off the broadside, they describe a figure-eight pattern in space. Although the up-and-down element of that pattern could be corrected (eg in the cruiser *Augusta*'s rangekeeper), the side-to-side motion (which resulted in errors in line) could not be. Subsequent heavy cruisers, which had different gun and turret arrangements, corrected these problems.

The World War Two fire control system was not fast enough to cope with violent maneuvers (as in the Solomons night actions). As such it was severely criticized at the end of the war: according to a Pacific Fleet report on lessons learned, the existing system could not properly determine target rates of turn; probably graphic plotters would be needed. 'The inadequacy of the system is clearly indicated by the restrictions imposed on ships firing duel type practices where both course and speed are carefully limited for safety... the inflexibility of the [computer] resulted in a vast confusion when new projectiles of increased weight and new charges with changed velocity were introduced. In general the solution is exact for only one velocity and a departure from that velocity produces increasing errors.' Probably the prewar US Navy was satisfied with the slow-firing 8in for anticruiser combat on the theory that target ships would steer relatively steady courses to make *their own* fire control effective: that did not, of course, apply for a 'fire-and-forget' weapon, the Long Lance torpedo.

As in the case of torpedoes, there was considerable sentiment within the operating forces against the Washington establishment of the Bureau of Ordnance. For example, early wartime range tables had a defective correction for powder temperature, a particularly important factor in warm areas such as the South Pacific. The Bureau refused to solve the problem until Admiral W A Lee made his own tests. There were other problems as well: the new *Iowa* class battleships initially made relatively poor shooting because of poor gun alignment, a problem not solved until after Leyte Gulf.

4. Gun mounts and turrets

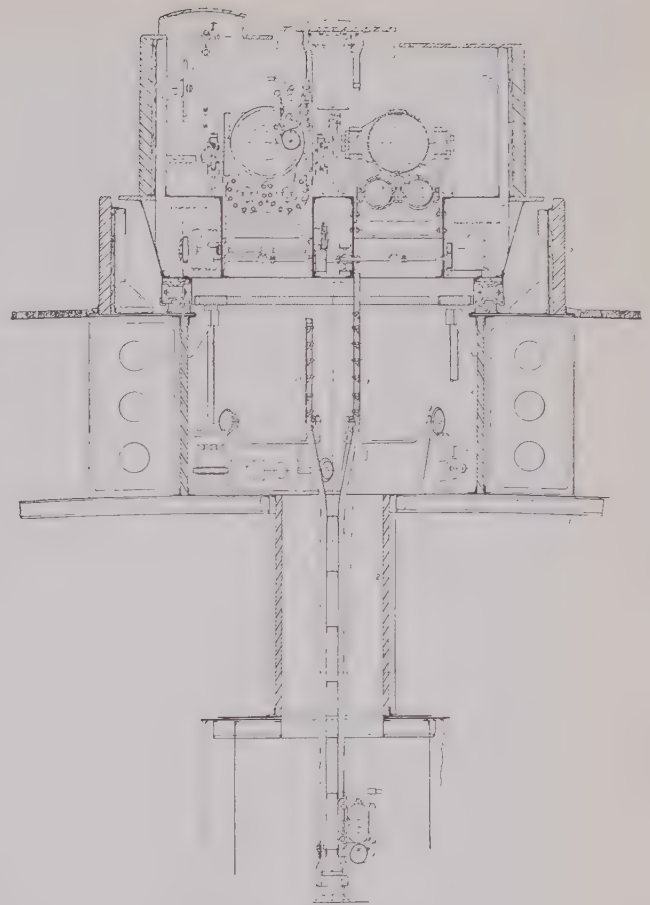
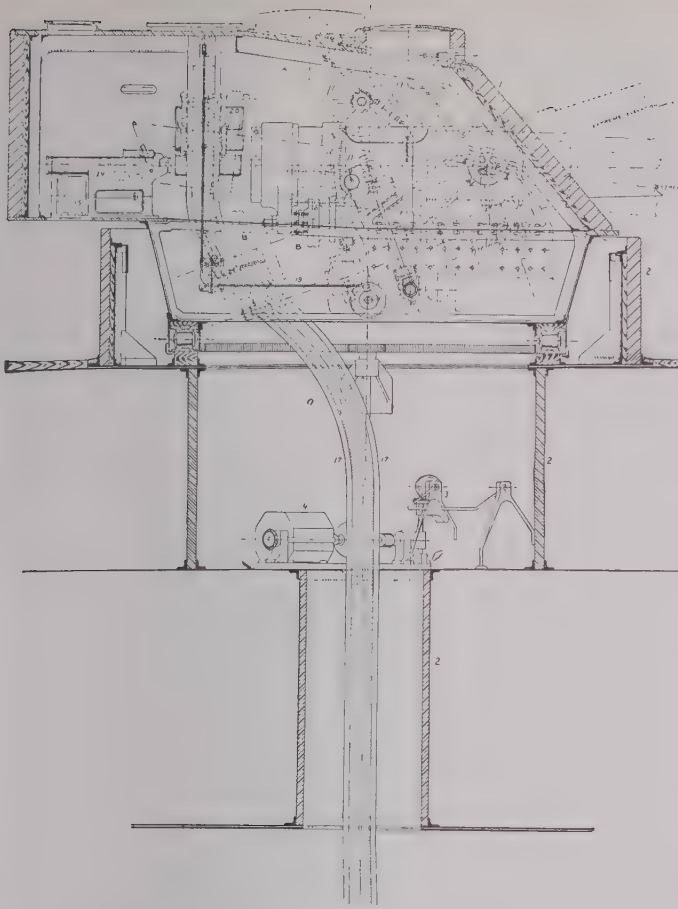
Definitions

In the US Navy the traditional distinction has been between 'turrets', requiring assembly aboard ship (and generally having heavily armored barbettes), and 'gun mounts', which could be shipped whole or nearly whole to the yard for direct installation. For example, in World War Two the 6in/47 triple mounting was a turret, but the twin and triple 8in/55 of Treaty cruisers prior to the *New Orleans* class were considered gun mounts, partly in view of their extremely light protection. Later 8in/55s were turrets, as were all heavier pieces. The last US turret designs were the rapid-fire twin 6in/47 and triple 8in/55 developed in 1942–43 and installed just after the war in the *Worcester* and *Des Moines* classes. All weapons since that time have been placed in gun mounts, which

are generally intended for dual-purpose operation. Among the lighter weapons, one essential distinction divided 'pedestal' from 'base-ring' mounts. In the latter, the entire gun mount turns on a race of bearings leaving, for example, a space in the center through which ammunition can be fed; the various fully enclosed 5in/38 mounts were base-ring types. Probably the earliest important base-ring mount in the US Navy was the twin 6in/53 of the *Omaha* class cruisers, followed in the 1930s by a variety of 5in/38 types. During World War Two base-ring construction was extended to lesser calibers. Although there was no need for ammunition passing from beneath the gun, the base-ring distributed the weight of the mount better than did a solid pedestal. The wartime twin and quadruple 40mm and the

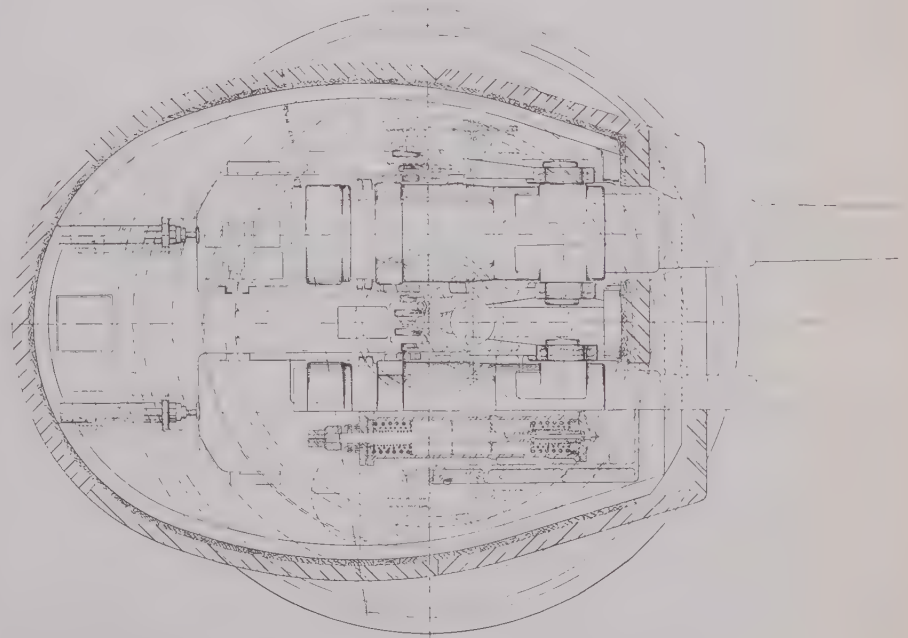
postwar automatic 3in/50 were all base-ring mounted.

Control of the gun on the mount was generally by a 'pointer' (elevation, ie range) and a 'trainer' (bearing), each with his own sight. At first there was only a single open sight. For example, in the 5in/40 BLR, the sight was on the left side of the gun, the rear sight working by a worm gear set into the breech and the forward sight screwed into the bronze sleeve which took the place of a trunnion band. The sight-bar proper was marked on its left side with ranges in yards up to 8400, on its front face with degrees of elevation, and on its right side in times of flight. Drift, the movement of the shell due to its rotation ('Coriolis effect'), was compensated for by inclining the rear sight-bar 2°45' to the left, and giving it an offset, at level,



of 0.1in to the left. Such a sight greatly complicated the task of the gunner; it was both difficult to focus on the target (and on the fore sight), and also difficult to compensate for motion in both elevation and train simultaneously. The first problem was solved by the introduction of the telescopic sight (which in the US Navy was credited to Bradley Fiske), the latter by the use, in all calibers, of two separate sights, one for each dimension. Ultimately each sight had a 'sight-setter' who adjusted it for the appropriate deflection or elevation, so that the pointer or trainer had merely to follow his target. These points were of consequence in the development of multiple-gun mounts, which sharply reduced the number of pointers required.

The other important issue in gun sight arrangement, at least in large enclosed mounts, was to avoid the blast of adjacent weapons. The successful development of turrets which could be aimed despite the firing of nearby turrets permitted the US Navy to build dreadnoughts with superimposed turrets. Before 1905 most navies placed their gun sights in small cupolas atop the turret roof. In the *South Carolinas* the sights were moved to the turret sides, and protected with blast shields. It appears in retrospect that with the appropriate shielding even roof sights could be made blastproof, as these ships still retained a trainer's sight on the turret top. In the 14in battleships (*New York* class), the sights were moved *below* the guns, looking through the gun ports. It was argued that this would reduce the target area represented by the turret, and at the same time would place the sights in a more protected location. In January 1910 the Bureau of Ordnance claimed that the new location would



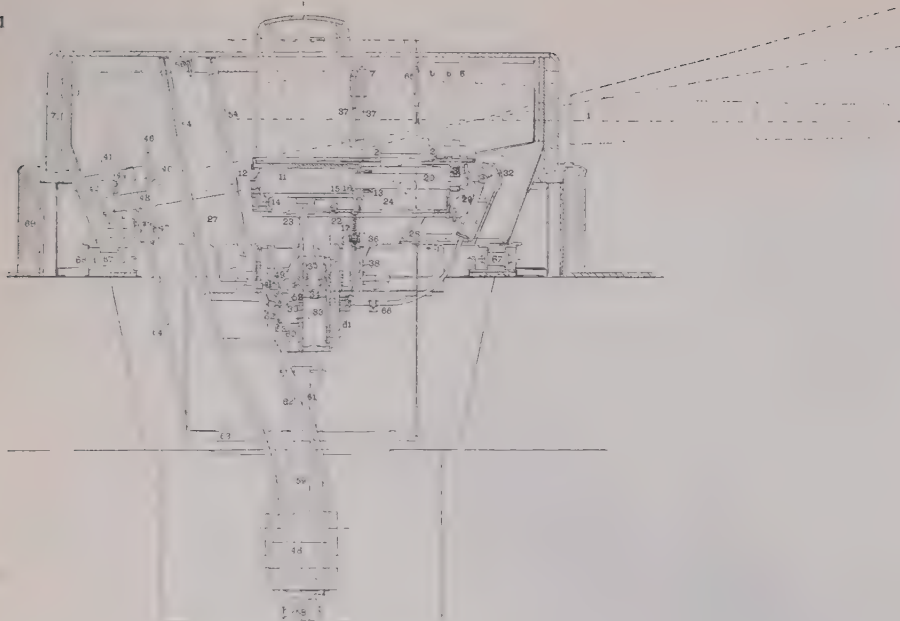
also make for better shooting: it would be possible to use a 'firer' on each gun, who will have nothing to do but fire the gun when the sight is on, the 'elevator' only endeavoring to hold continuous aim after the gun is 'ready'. This arrangement required a periscope, the sight-user sitting in the gun pit beneath the gun. It continued in force in American battleships through to the end of the dreadnought era, with the *Marylands*. Post-World War One cruisers, which were considered essentially unprotected, had a much simpler telescopic arrangement, with pointer and trainer

THE 8in MOUNT MARK XII

outboard of the guns, and their instruments looking through separate ports cut in the gun mount face. Such a system became less and less attractive as gun elevation increased, since it required larger and larger holes cut in the face plate. The later cruisers therefore had instead periscopic telescopes mounted horizontally, projecting through the gun house sides in a fashion reminiscent of that of the earliest

I. GUNS (SURFACE FIRE)

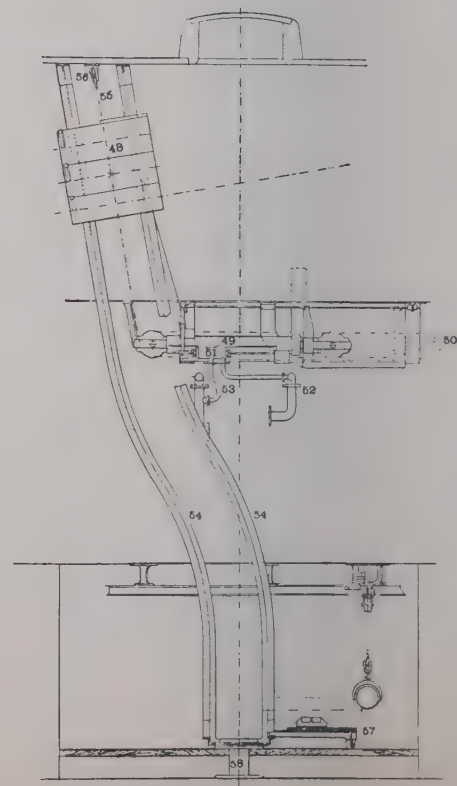
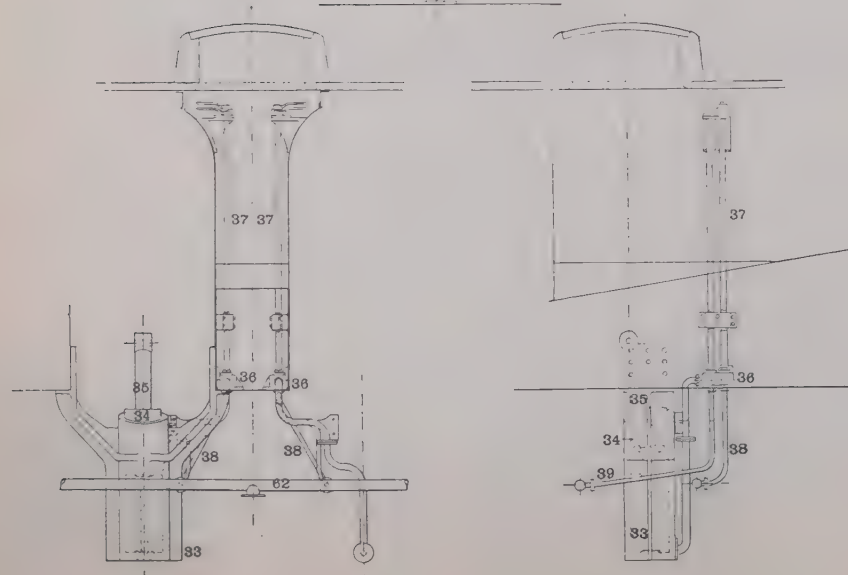
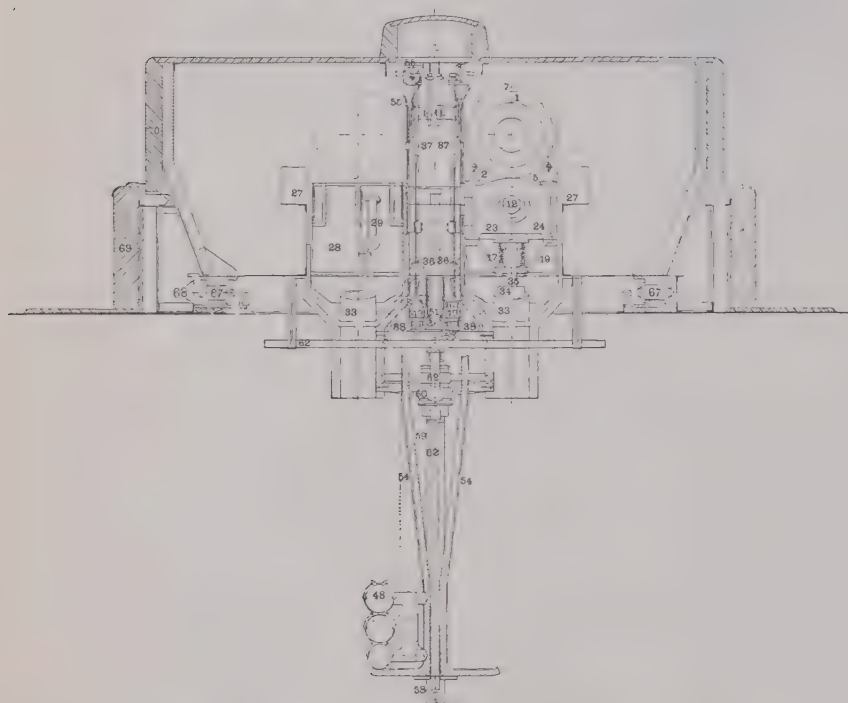
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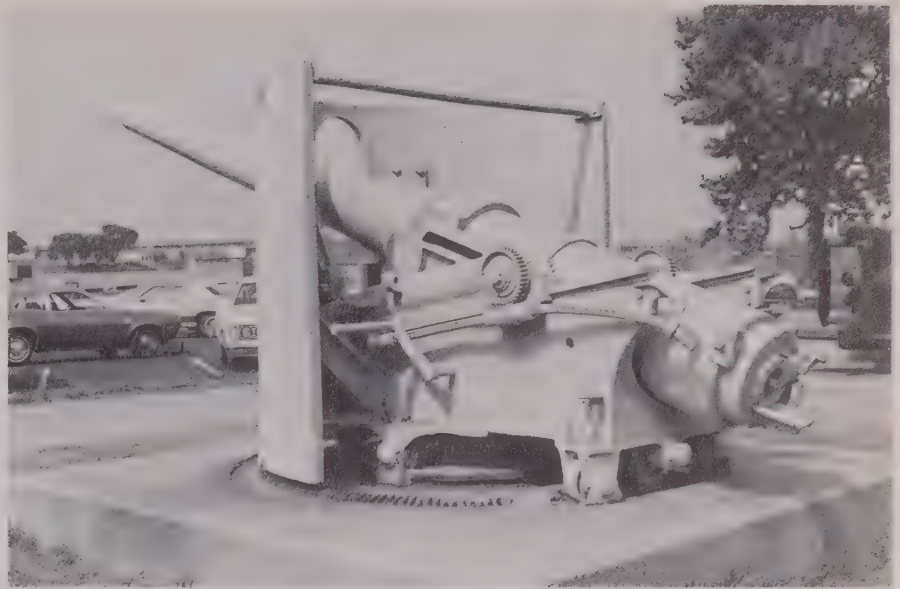
1 THE 10in MOUNT MARK II

Key

- 1 10in BLR
- 2 Sleeve
- 3 Recoil lug
- 4 Holding-down clips
- 5 Holding-down gibs
- 6 Front straps
- 7 Rear straps
- 8 Front-sleeve bolts
- 9 Rear-sleeve bolts
- 10 Hole for locking bolt
- 11 Recoil cylinder
- 12 Rear bonnet
- 13 Stuffing box and gland
- 14 Opening for pump pressure and check valve
- 15 Pressure side
- 16 Reverse side
- 17 Spring valve
- 18 Relief valve (center one)
- 19 Yoke
- 20 Piston rod, head and nut
- 21 Overflow chamber
- 22 Connection for waste pipe
- 23 Lug for elevator connecting rod
- 24 Slide
- 25 Holes for pivot bolts
- 26 Stop-piece
- 27 Turret girders
- 28 Deck lugs (carriage)
- 29 Collar for pressure pipe
- 30 Locking lugs
- 31 Locking levers
- 32 Pivot bolts
- 33 Elevator
- 34 Elevator piston
- 35 Elevator connecting rod
- 36 Elevator valves
- 37 Elevator valve rods and levers
- 38 Elevator pressure pipe
- 39 Elevator exhaust pipe
- 40 Hydraulic rammer in loading position
- 41 Hydraulic rammer in firing position
- 42 Hydraulic rammer brackets
- 43 Hydraulic rammer transom
- 44 Hydraulic rammer trunnions
- 45 Hydraulic rammer valves
- 46 Hydraulic rammer operating lever



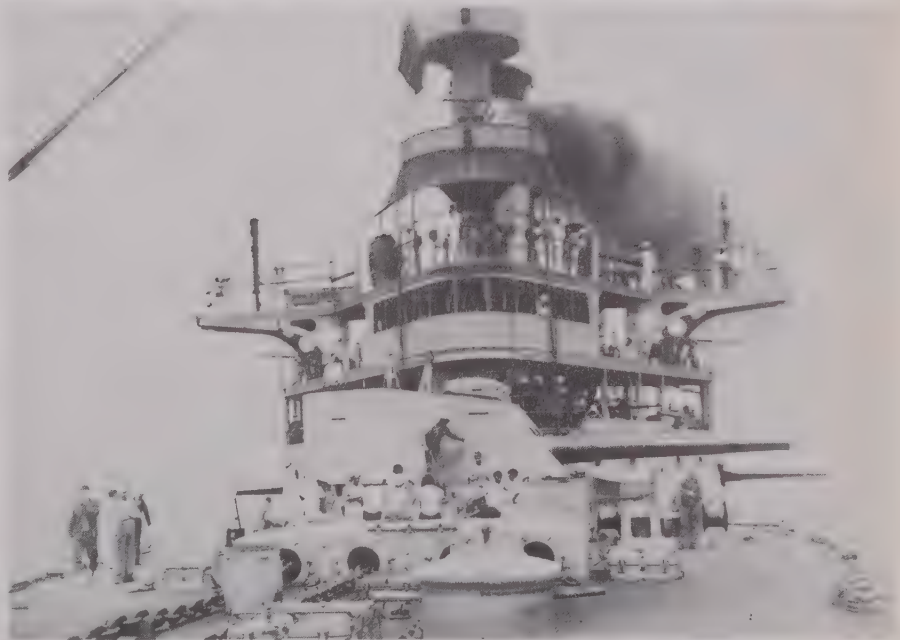
- 47 Hydraulic rammer fulcrum for lever, and guide for valve stem
- 48 Ammunition car
- 49 Ammunition car motor run in
- 50 Ammunition car motor run out
- 51 Ammunition car motor valves
- 52 Ammunition car motor pressure pipe
- 53 Ammunition car motor exhaust pipe
- 54 Ammunition car guide rails
- 55 Ammunition car wire rope fall
- 56 Ammunition car bracket and sheave
- 57 Car and turntable for handling projectiles
- 58 Pedestal for central column
- 59 Central column
- 60 Water section
- 61 Pressure pipe
- 62 Exhaust pipe
- 63 Platform
- 64 Ladder to turret
- 65 Sights
- 66 Valve
- 67 Rollers
- 68 Roller paths
- 69 Barbette
- 70 Turret



2

- 2 A 6in gun salvaged from the battleship *Maine* (and shown here at the Washington Navy Yard in 1975) shows typical features of New Navy guns and mounts. The breech block at the rear was turned by an arm moved along a geared track on the outside of the breech end of the gun; it was withdrawn along the tray visible to the rear of the gun, the size of which suggests the full length of the breech block. Later guns employed tapered blocks which could be hinged to the rear of the gun proper, and needed no cumbersome tray. This 'barbette' mount was probably a Mk 3 or Mk 4.

- 3 The armored cruiser *Maryland* displays a typical US heavy-gun mount, firing on the target range in Manila Bay, about 1906. The US Navy first adopted sloped turret faces in the *Illinois* class battleships, completed in 1900-01. Note the sighting hoods above the guns for one trainer and two pointers, and the small rangefinder in the 'top' above the bridge. Fear of concussion through the exposed hoods deterred many navies from adopting what is now the standard arrangement of superfiring, i.e. of one gun turret firing above and behind another; the United States introduced sights set in the turret sides to eliminate this problem, in her dreadnought battleships.



3

dreadnoughts. These wing sights were introduced in the *New Orleans* and *Brooklyn* classes, and were a feature of World War Two enclosed gun mountings from the 5in/38 twin up; the 5in/38 single mount was the only one which retained sights in its face. The new 16in turrets of World War Two were unusual in having two separate pointer and trainer stations, each group being in a separate compartment on one side of the gun house, to provide a reserve against damage to one of them.

These particular mounts were designed with servo operation in mind. The pointers and trainers transmitted signals to three gun-layers and a train-operator on a machinery deck within the barbette, who in turn matched pointers on their dials. Alternatively, those signals could come directly from the fire control system, or the entire process could be switched to automatic control for the director.

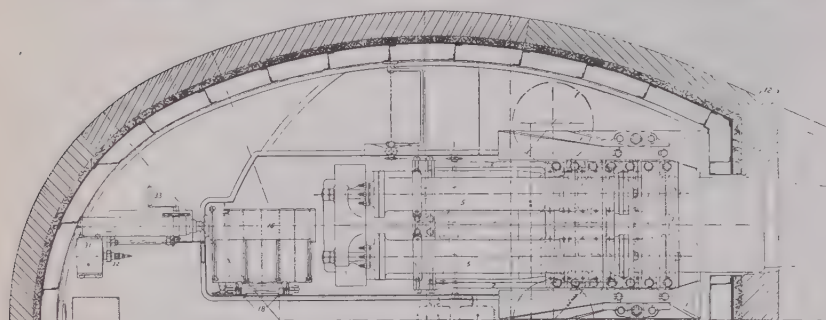
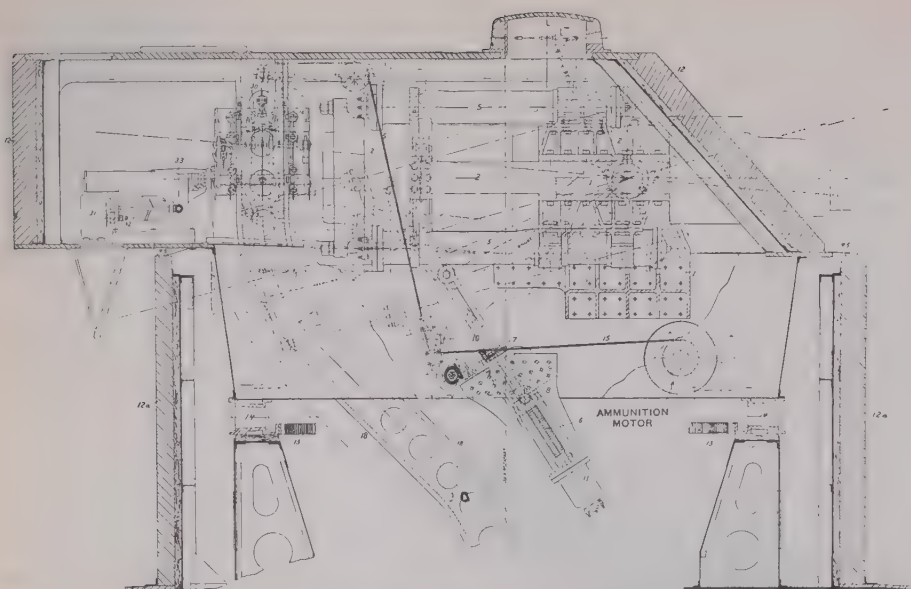
Pointing was the origin of one of the characteristic features of American gun mounts from about 1914 onwards, the preference for mounts in which all of the guns were rigidly linked for elevation, so that there was only a single pointer per mount. Such mounts were described as 'twin' rather than 'two-gun', or as 'triple' rather than 'three-gun'; they appeared aboard battleships (through the *Pennsylvania* class), on cruisers (*Omahas*,

Brooklyns, *Clevelands* and *Pensacola* through *San Francisco* classes) and even destroyers (beginning with the twin 4in/50 of World War One and including the standard 5in/38 twin mount of World War Two). Even the three-gun mounts of the later 14in battleships were intended for operation as triples. However, during the 1920s it began to be suspected that neighboring guns interfered with each other, creating inaccuracies. Proposed solutions generally involved either firing partial salvos (with a consequent loss in the effect of fire), or else employing special coils to achieve slight delays in the firing of adjacent weapons. By about 1935 the General Board had become convinced that the only appropriate solution was increased separation between adjacent guns, a separation which resulted in the reversion to two- or three-gun turrets from the *Wichita* onwards. Although the dual-purpose 6in/47 was mounted in a two-gun turret, it should be noted that the triple 6in/47 adopted with the *Brooklyns* was not abandoned; and a triple (rather than three-gun) mount for the rapid-fire 8in/55 was seriously considered.

Early Turrets and Barbettes

The first enclosed American gun mounts were turrets directly descended from that of the original Civil War *Monitor*, cylindrical enclosures rotating within a larger cylindrical armored breastwork, the latter protecting turret-training gear and the ammunition hoists. The latter were open, with a single stage from magazine to gun breech. Moreover, because the turret was circular, the guns had to be mounted quite close to their ports, if there was to be sufficient space for loading and ramming from the hoists. It followed that the turrets were not well balanced; in the *Indianas*, for example, training both main turrets to one side caused a noticeable list.

Such circular turrets were displaced, both in the United States and abroad, by the barbette/gun house type, in which the armored enclosure for the guns rode atop and largely outside the cylindrical fixed armored barbette, permitting an extension to the rear which counterbalanced the guns themselves. In the US Navy such mountings were introduced in the *Illinois* class, designed just when the



THE 12in MOUNT MARK IV



No account of American naval weapons can exclude the 'double turret', a combination of 8in and 12 or 13in weapons in a single mount. This is the 12in/8in mount of the battleship *Virginia*, about 1914. Cage masts were adopted to carry spotters aloft, and to survive multiple shell hits in battle. Their main defect was their flexibility, which caused them to 'spring' in a seaway or after a salvo. Note, too, the canvas-covered rangefinder atop the gun mount, also a common feature before and during World War One, and the mechanism atop the mount, which was used for training.

Sloping the turret face, and moving the trunnions closer to the face, limited the size of the gun ports and therefore the vulnerability of the mount (and of the powder and shell hoists).

Indianas entered service, in 1896. Inclining the face plate permitted the use of much smaller gun ports, and also provided better protection. Indeed, the value of inclined armor had been appreciated much earlier, and the plans produced by the 1890 Policy Board all showed round turrets with inclined sides. Such turrets were abandoned only when it became evident that they provided insufficient internal space at the gun breeches.

The Double Turret

The 'double turret' was probably the most interesting expedient of early US battleship designers. It was an attempt to mitigate the design problems inherent in the 8in gun. In a ship of limited length, 8in broadside turrets were at best a blast hazard; they also seemed a waste of length which could be devoted to useful rapid-firing broadside batteries. It was more efficient to mount fewer 8in on the centerline, but then they consumed scarce length. Finally an ensign in the Bureau of Ordnance, Joseph Strauss, suggested that the 8in turrets be combined with the main-battery ones. The inefficient gunnery of the time made it unlikely that the 8in guns would be aimed at a different target than the 12in or 13in main battery: it would be one ship against a single enemy, and a common point of aim would be as good as any. Finally, due to advances in turret design, it was actually possible to build the four-gun turret on a lesser weight than that consumed by the existing two-gun turret of the *Indiana*.

The result was certainly controversial, both within and without the service. For example, William S Sims, who served in *Kearsarge* (the first of the double-turret ships) on the Asiatic station soon after her completion, described her as 'a crime against the White race'. Some foreign observers were impressed; others considered it no more than the American ideal of 'licking creation'. To some extent, too, the basic merits of the idea were overshadowed by defects in its execution. For example, because the mounts in the *Kearsarge* were enclosed in old-type turrets, the gun ports were huge; Sims claimed he could see the magazine from outside the gun ports, and that direct hits on the magazine would therefore be almost inevitable in battle. The 8in gun itself was dropped from US battleship design immediately after the design of the *Kearsarges*, so that it is not clear how the designers viewed the double mount.

Certainly it did reemerge with the revival of the 8in in the *Virginia* class, although at that time (1900) there was a strong faction within the Navy opposing it. There they fell victim to improvements in the rate of fire. Rear Admiral Seaton Schroeder commanded USS *Virginia*:

... the great increase in the rapidity of fire of our heavy guns from, say, one shot in three minutes to three shots in one minute, virtually neutralized the advantage of having 8in guns where they could be fired without interfering with the 12in. Whenever a gun is fired in a turret there is a certain amount of concussion which precludes firing another for a few seconds; and, even with smokeless powder, the heated gasses linger for an appreciable time in front after each discharge, making it impossible to point for the next shot until they have wafted away. With the two 12in in a turret firing alternatively, and each able to fire every twenty seconds, there would be only about ten seconds between 12in shots; and if the 8in were to 'butt in', they would probably interfere with the next 12in shot - the last thing to be thought of. As that

problem gradually developed, and the rapidity of fire increased, each ship tried different combinations of fire to obtain maximum opportunities for fire – single-barreled salvos, double-barreled salvos, double-barreled 8in salvos combined with single-barreled 12in, and so on. But the ultimate conclusion was that rapidity of fire had knocked out the superposed turret.

Ironically, however, the double turret was rejected for the next (*Connecticut*) class before any of the *Virginias* went to sea, the victim of a shift in technical opinion within the Bureau of Ordnance.

Operation

The US Navy was an early champion of electric power for auxiliaries; the cruiser *Brooklyn* introduced electric power for turret operation, two of her four 8in turrets employing it. She was followed by the two *Kearsarge* class battleships, also featuring electrically powered turrets. All subsequent US warships had electrically driven gun mountings, the US Navy apparently having become convinced of their efficiency and reliability. By way of contrast, the Royal Navy preferred hydraulics in the belief that electrical power was unreliable; the Germans, with a very advanced electrical industry, employed electric power on an even larger scale than did the US Navy.

All of the American predreadnoughts were designed with open, single-stage hoists running directly from ammunition handling room to gun breech, the guns generally loading at a fixed angle of elevation, which varied from ship to ship. There was a single shell and powder car, and the rate of fire was reduced to some extent by the need to wait for it to rise, load and return before another shell and powder load could leave the handling room. Moreover, the open hoist was very dangerous, as became apparent with the advent of rapid-fire practice in 1903. In April 1904 the battleship *Missouri* suffered the loss of five officers and twenty-nine men when one of her guns flared back after its breech had been opened for reloading. Ships were refitted with automatic shutters separating the two ends of the ammunition cycle, but this proved inadequate. In April 1906 an unused charge being withdrawn from a 13in gun aboard the *Kentucky* was ignited by an electrical short; eight of the twelve men in the turret were killed. Further modifications were made: electrical equipment was removed from the turrets, bulkheads were fitted between the guns, and gas ejectors were installed at the breeches to prevent flarebacks.

No modifications could overcome the fundamental flaws of the single-hoist system, particularly the hazard it represented in battle. Indeed, Jutland would show that even far more sophisticated systems were extremely dangerous. In 1904, however, many officers, particularly those in BuOrd, were reluctant to admit as much. The hoist issue became a political one, officers such as William S Sims charging that the Bureau's backwardness in gun mount design was evidence of fatal flaws in the entire Bureau system. The Royal Navy had abandoned the single-stage hoist as early as the *Majestic* class, completed in 1895–98. Sims' detractors claimed that the *Missouri* accident showed not that her design had been defective, but that the new system of gunnery practice was intolerably dangerous. President Roosevelt stood by Sims, and indeed the Bureau designed two-stage hoists for its first all-big-

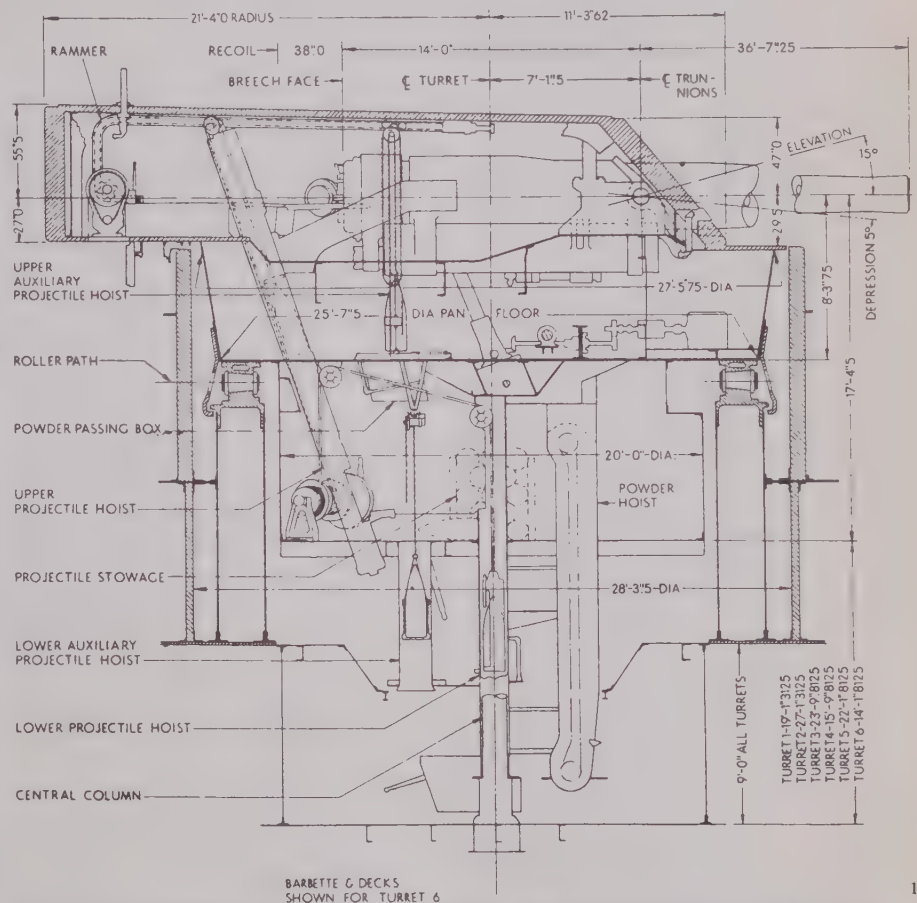
gun battleships, the *South Carolinas*. However, even after those mounts had been designed, Sims and his associates continued to use the hoist issue as proof of the inadequacy of naval administration; it became a factor in the 1908 Senate Hearings on defects in American battleship design.

The Mk VII mounting of the *South Carolina* class introduced two-stage hoists and all-angle (of elevation) loading. Cars now carried both shell and powder from lower to upper handling room, where they were rammed by hand through flap-covered openings into upper hoist cars, which in turn carried them to the guns. In such systems the cars could be balanced like buckets in a well; in the single-stage hoist, by way of contrast, there was

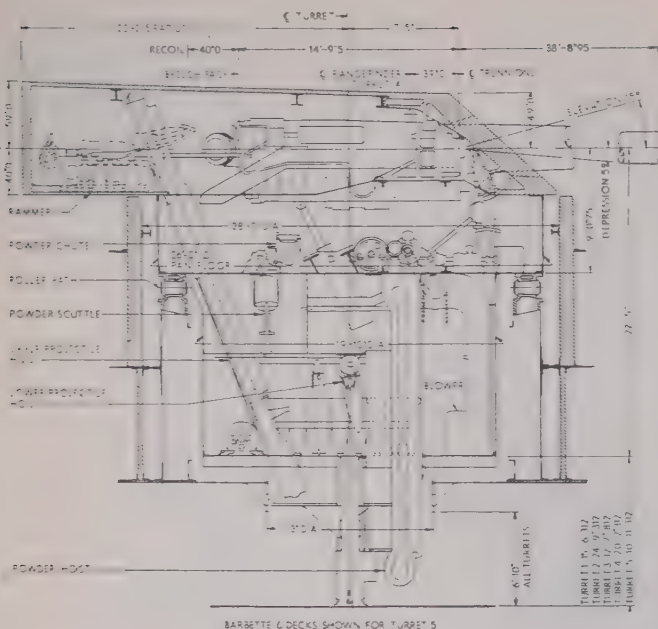
generally only a single car. Double-staging also made for more rapid fire. All-angle loading had a similar effect, as the gun did not have to travel back to its loading angle between shots. Its chief drawback was greater complexity: the rammer had to be carried with the guns, housed under them when not in use. In a fixed-angle system, on the other hand, the rammer could be housed on the roof of the turret when not in use, designed to align with the guns only

1 THE 12in/50 TWO-GUN TURRET (BB-33)

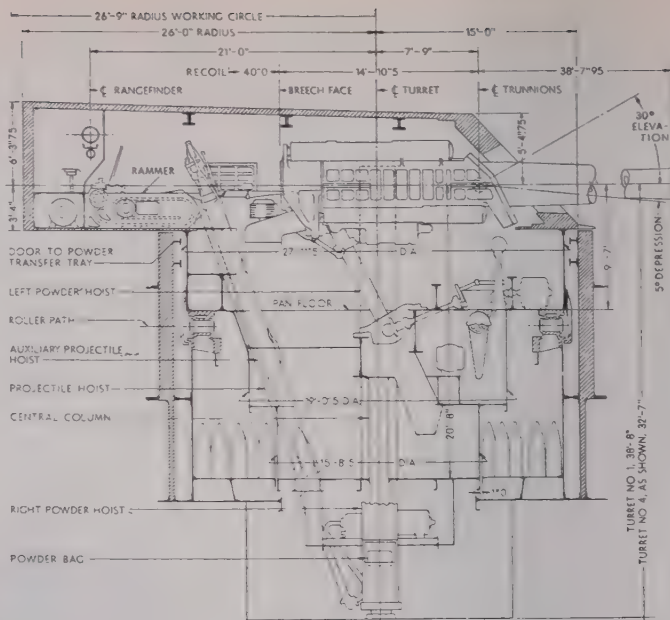
2 Three 12in Mk 7 turrets of the dreadnought battleship *Delaware*, about 1913, with small-caliber spotting rifles in place for training.



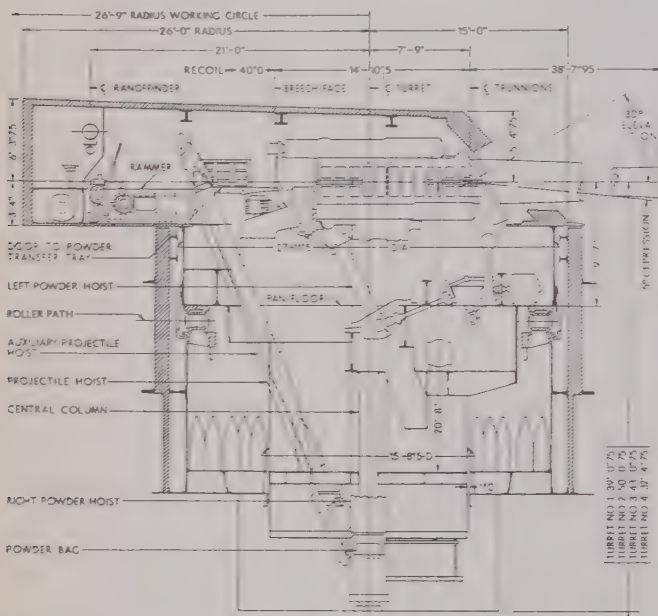
I. GUNS (SURFACE FIRE)



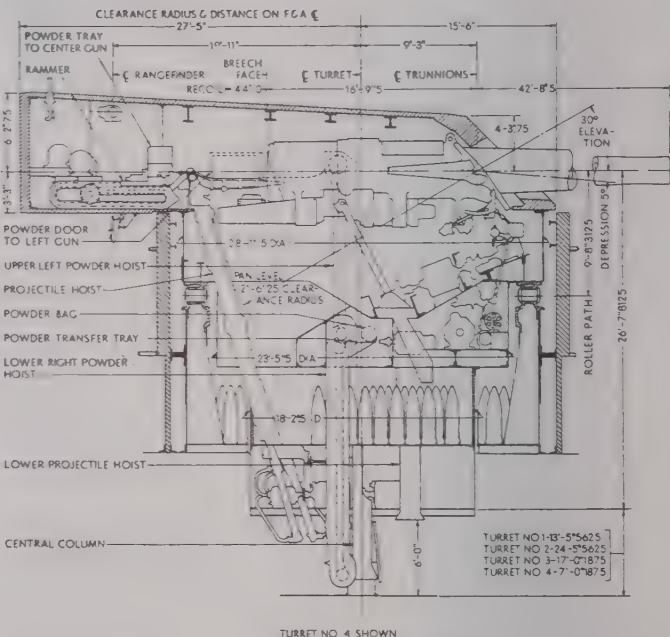
THE 14in/45 TWO-GUN TURRET (BB-34)



THE 14in/45 TWO-GUN and TRIPLE TURRETS (BB-36)



THE 14in/45 TRIPLE TURRET (BB-38)



THE 14in/50 THREE-GUN TURRET (BB-40)

at one angle, and supported by the turret floor. The *Delaware* had Mk VII turrets, and the Mk VIII of the *Utah* class was similar.

The next step, which was taken in the *Arkansas* class (Mk IX), was to reduce shell hoisting to a single stage; the shells, after all, presented only a negligible explosive hazard. They were stowed in an upper handling room, which was actually part of the rotating turret structure. Powder, on the other hand, was stowed in magazines on the lower deck, and passed up from there, ultimately to a 'passing box' in the turret floor. This box was provided with two doors, only one of which could be open at a time. The 14in/45 two-gun turret of the *New York* class was similar in principle. In each case fixed-angle loading was reintroduced, the loading angle being 0°, as in the *Virginias* and *Connecticuts*.

The choice of loading angle was dictated in large part by gunpower and by the expected battle range. The closer the loading angle to the average elevation to be experienced in battle, the less time lost in elevating or depressing between loads. The 12in/35 of the early monitors and the 13in/45 of the *Indians* loaded at 10°; in the *Iowa* this was reduced to a more realistic 3°, which also simplified ramming. In the 12in/40 mounts the loading angle was further reduced to 2°, which with an initial velocity of 2600ft/sec, translated into a range of about 4500yds – a reasonable battle range for about 1904. Loading angles did not begin to rise in US battleships until the *Californias* (1°), but the *North Carolinas* loaded at 5° – about 10,000yds for the 2240lb AP shell fired at 2520ft/sec, for which they had been designed. The 16in/50 had the same loading

angle (also 10,000yds, for the 2700lb AP shell fired at 2700ft/sec). High loading angles were adopted in heavy cruisers as a way of increasing the effective rate of fire: they increased from 5° in the *Pensacolas* (10,000yds) to 9° in the *New Orleans* and later classes (about 15,000yds).

Before they went to the Pacific, as part of the Fleet Cruise of 1907–08, the battleships *Vermont* and *Louisiana* had their 8in power hoists replaced by hand hoists; firing during the cruise was so successful that similar modifications were extended to the other battleships in commission. Advantages included complete separation from the handling rooms, and much less liability to breakdown, so that firing could be faster. Experiments were then extended to the heavy-gun turrets, initially aboard the *Idaho* and *Oregon*, and in view of these successes the turrets of the

Arkansas class, originally designed for two-stage power operation, were redesigned for hand power loading. Many of their shells would be stowed in the gun chambers proper and immediately beneath them in the upper handling rooms; the rest were in the usual shell rooms. The gun chambers were effectively sealed from the handling room at all times. In single-stage turrets ammunition cars were removed; a single-tube shell hoist was provided for each gun, and powder buckets in the hoist closed the path from turret to handling room, while the powder bags were passed through a powderbox in the turret floor. Even hand ramming was used.

Advocates of manual operation were impressed by the high rate of fire which could be maintained, using the shells in and around the turret. However, there was soon a shift of opinion. Large turret crews were required, and even they could not keep up a high rate of fire once the shells near the guns had been exhausted. The Bureau of Ordnance declared that rate of fire should be based, not on a short burst, but rather upon the expenditure of the entire supply of shells, and in the *Nevada* class power loading reappeared.

The Triple 14in/50 Mount

The triple 14in/50 mount of the *California* class was representative of US turret design at the end of the dreadnought era. It is of particular interest because there exists a long description of turret operation by a British naval constructor, Stanley V Goodall (later DNC), who was seconded to the Bureau of Construction and Repair during World War One and was therefore familiar with both British and US practice. He was particularly impressed with the compactness of the mount: 'from [the constructor's] point of view [it] is excellent. The absence of shell rooms and the high position of the magazines gives him an opportunity to shorten the citadel and

economise considerably in weight... Space, and consequently important target area and weight, have been reduced to a minimum.' For example, there was no plating or framing behind the barbette armor. The use of electric motors (which Goodall did criticize as noisy and as vulnerable to water damage) saved some space, in that there was no need for the space taken up in British mounts of the period by hydraulic piping leading into gun mounts, or by hydraulic engines. However, the electric motors generally drove hydraulic couplings within the turrets, which Goodall considered complex and cramped; for example, the turret was so designed that any one of the elevating motors could elevate all three guns. Goodall presumably did not appreciate that this arrangement had originally been intended to permit three-gun salvo firing of the turret.

The rotating structure of the turret held a powder handling room and, below it, a shell handling room which actually carried shells; in a typical arrangement, there were 68 on their bases within this room, with another 33 in the turret proper, and the bulk of the shells, 174 of them, in the space just inside the ring bulkhead and between its stiffeners, at the level of the shell room. They were stowed on their bases, and could be rotated on their bases ('parbuckled') through four arched openings in the shell handling room; once inside, they were parbuckled to the hoists. The powder room above was completely shut off from the turret proper. Its roof was recessed to take the recoil of the guns, and the armored tubes of the shell hoists passed completely through it.

There were no shell rooms in the British sense; a few shells were stowed below the level of the handling room (in the installation cited, 50 on the deck below, 20 within the base of the barbette, and another 7 in a passageway), but they could be brought up only very slowly, and could best be considered a reserve for use between engagements. There were two shell

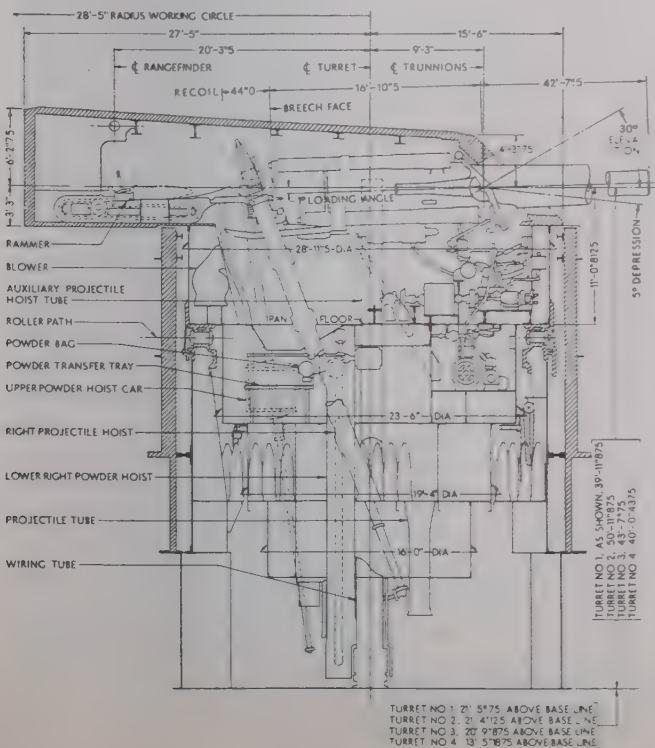
hoists for the three guns; ammunition for the center gun was passed behind a wing gun and through the bulkhead separating it from the former. Goodall commented that 'almost naturally shell and ammunition come up the center of the mounting, and over this sits the center gun. So far as I see it, that is the inherent difficulty and, in my opinion, clever as this design is, a sure and sustained rapid supply to the center gun has not been provided.'

Powder was transferred from magazine to powder handling room by means of two power hoists, with a manual backup; from there to the breeches there were three hoists, that for the center gun being offset. Goodall felt that particular attention had been paid to the stowage and supply of ammunition, presumably in contrast to British practice.

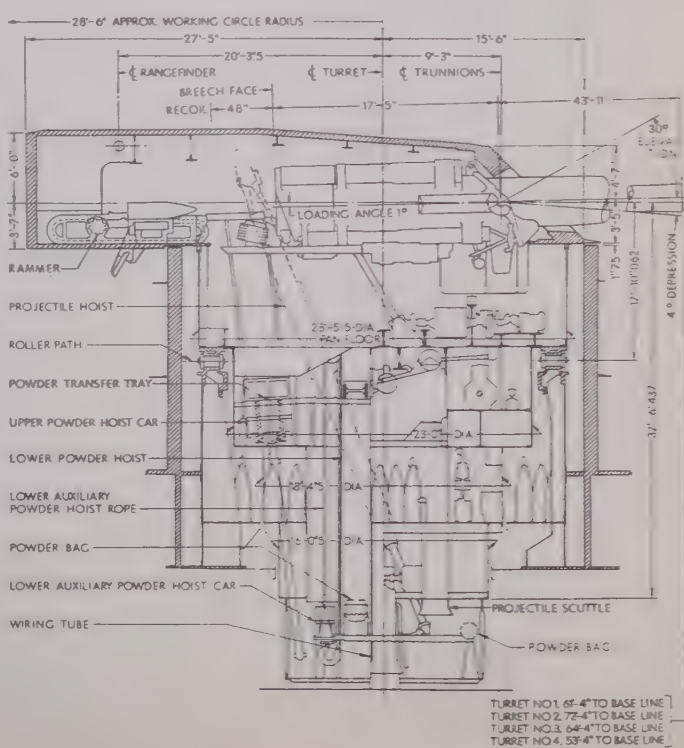
He considered that a substantial price had been paid for light weight and compactness:

The trunnion is close to the front shield plate with the advantages of a small gun port and a reduction in barbette diameter, but with the disadvantage that a blow on the front plate may damage the trunnions and jam all three guns. The guns are very close together, with the advantages of small barbette diameter and less whip when a wing gun is fired, but with the disadvantage that to get at the trunnions for examination and overhaul, the front of the shield must be dismantled. Shells and cordite [*sic*] are close to the loading position so that time and power necessary for their transport are reduced, but the magazines are consequently imperfectly protected against long-range fire. The method of shell handling may damage the fuzes, it may break down in a seaway, and is dangerous to the personnel. Space has been saved by accepting only two shell hoists for three guns, with the result that supply to the centre gun is not so good as to the wing guns. The guns are light and long, but American officers have told me that they might accomplish more accurate shooting with a heavier, stiffer weapon. Then again, reduced space has resulted in crowding the machinery which is more than absolutely essential, owing to duplications and stand-by fittings; as a result, it is difficult to

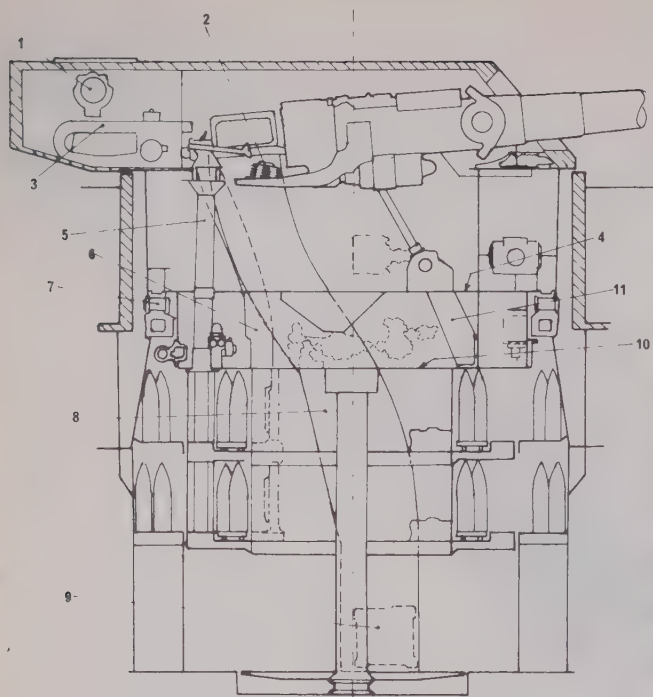
THE 14in/50 TRIPLE TURRET (BB-43)



THE 16in/45 TWO-GUN TURRET BB-45



I. GUNS (SURFACE FIRE)



1 THE 16in/45 TRIPLE TURRET (BB-55)

Key

- 1 Rangefinder
- 2 Breech block (open)
- 3 Chain rammer
- 4 Pan floor
- 5 Center projectile hoist
- 6 Left projectile hoist
- 7 Roller path
- 8 Powder hoist
- 9 Powder car
- 10 Electric deck
- 11 Elevating cylinder

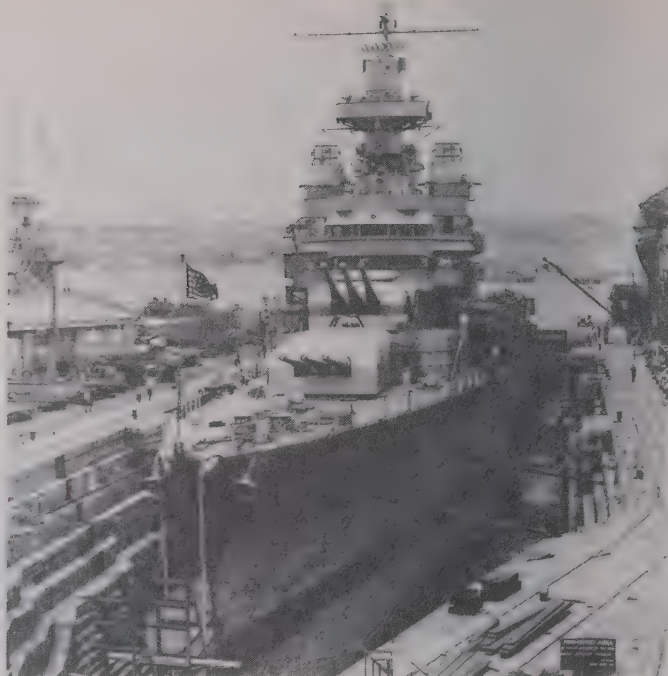
2 The cruiser *Portland*, refitting at Cockatoo Dockyard, Sydney, Australia, in 1942 shows typical US triple 8in turrets, all three guns clearly in the same sleeve. Shutters to either side of the guns cover pointer's and trainer's sights, and each turret carries an armored rangefinder. Fire control was by the Mk 27 director at the foretop, surmounted in this case by a Mk 3 radar, and with splinter shields for 20mm guns surrounding its base. Below and to either side are Mk 33 anti-aircraft directors to control the 5in/25 battery, each topped by a Mk 4 radar. Also visible are two antine measures: degaussing cables along the hull, passing just above the number '33' and then aft; and chains for paravanes, suspended from the eyes of the ship. The two search radars above the main battery director are SC and SG (surface search), but as yet the ship has no IFF.

3 Refitting at Mare Island after battle damage at Guadalcanal, the heavy cruiser *San Francisco* shows the 8in turret adopted in the mid-1930s, carrying three guns, further separated and better protected, but still elevating together, as indicated by the single pointer's sight. Later triple turrets carried independent guns, further apart, as a response to problems of dispersion discovered about this time and analogous to the problems of battleship gun dispersion of the 1920s. In many cases delay coils were employed to fire the guns at short intervals and so reduce mutual interference even in turrets with guns very close together. Cruiser turrets with independently elevating guns could be distinguished by the separate pointers' sights; in the *Baltimore* class, for example, each pointer had a periscopic sight projecting above the turret roof.

The *San Francisco* and later classes also had much better protected turrets, so much so that the earlier enclosures were often referred to as 'gun houses'. This particular refit included large scale reconstruction of the bridgework for better overhead vision against air attack: the former bridge wings were eliminated in favor of an open bridge atop the former bridge structure. The Mk 31 heavy-caliber director atop the bridge structure is surmounted by a Mk 3 fire

control radar; atop it is a Mk 28 anti-aircraft director, itself surmounted by the Mk 4 dual-purpose fire control radar. The search radar atop the mast is SC-2, as yet without the characteristic IFF 'billboard', and the yardarm carries an IFF 'stovepipe' and a TBS tactical radio antenna. In the turrets, note the 'ears' at the fore end for trainer's and pointer's sights, and the armored rangefinders at the rear. Circles indicate alterations, including a special stub at the bows to handle paravanes.

4 The heavy cruiser *Pensacola* was refitted at Mare Island; she is shown here on 3 July 1945, with the unfortunate *Indianapolis* visible in the background. She and her sistership *Salt Lake City* were unique among US heavy cruisers in having no plotting rooms below decks, and they therefore could not accommodate the Mk 34 directors (such as one aft on *Indianapolis*) which were then being fitted to the earlier heavy cruisers. Instead, she received a Mk 35 taken from an 1850-ton destroyer leader, with modified ballistics;



the destroyer had 5in/38 single-purpose guns. Note the periscopes emerging from both of her forward 8in turrets, and the removal of the rangefinder from No 1 turret as a weight-saving measure. The small dish antennas atop her quadruple 40mm mounts (in the bridge wings) are part of Mk 63 blind-fire radar control systems. Note, too, the Mk 33 5in anti-aircraft director, immediately above her bridge. Both it and the Mk 35 carry the small dish antenna of the Mk 28 radar system.

5 THE 6in/47 TRIPLE TURRET (CL-40)

examine and overhaul parts, and the personnel are cramped. A clear flat roof is a good feature, but the sights are in a very poor position and, in fact, for the forward turrets they would be useless in bad weather.

He reported, too, that the *New Mexico*, encountering heavy weather, had had 'a good deal of water from seas breaking over the forecable [which] entered the foremost turret and damaged the elevating motors just below the gun ports'.

Elevation

Beside compactness, these mounts exemplified a major thrust in US battleship gunnery of the time: increased maximum elevation for greater range. In the low-powered predreadnoughts, maximum elevation was 15° in the *Indianas*, falling to 14° in the 12in/35 *Iowa* and then rising to 20° in the Mk 5 mount of the *Virginia* class, where it was equivalent to about 19,500yds (2600ft/sec), far beyond the capabilities of the fire control of the time. High elevation required a large hole in the turret face plate, even though this cut was minimized in US turrets with their trunnions very close to the face. Thus the *South Carolina* mount elevated to 15° (about 17,500yds at 2700ft/sec). This limit was standard through the *Pennsylvania* (21,140yds) and *Idaho* (23,450) classes, but on 30 April 1915 Admiral Joseph Strauss, Chief of the Bureau of Ordnance (and, it will be recalled, the originator of the double turret), wrote the Department that a slight change in the turret design would gain 5° of elevation (28,325yds in the *Idaho*). Most likely neither range would ever be exceeded or even reached in action, but the extra elevation might compensate for the list of a damaged

ship. Studies soon showed that 30° was about the limit without major structural changes and an increase in barbette diameter. It would extend maximum gun range to 33,300yds.

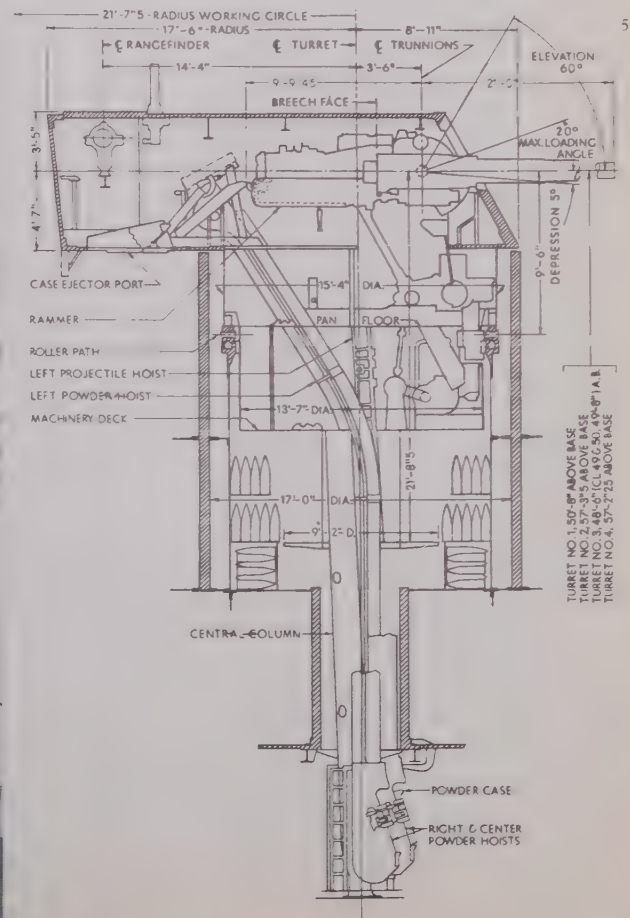
US observation of the war in Europe was a major impetus to change. On 26 May 1915, for example, the CinC of the Fleet, Admiral Fletcher, noted (of the *Vermont* salvo firings) that reports from Europe suggested that recent German designs could elevate to 30° (which was not true) and that engagements and bombardments had been carried out at extreme range (which was); a newspaper clipping appeared to indicate an elevation of 30° for the guns of the new British *Queen Elizabeth*. Moreover, in protracted engagements and in target practice, where reduced charges would be used to conserve the guns, great elevations would be needed. For example, at 2100ft/sec the 12in/45 and 14in/45 would require 25° or 26° to reach 20,000yds, and at 15° they could reach out only to 10,000–12,000yds. Admiral Fletcher advocated a minimum of 38–45°, but the Fleet had to settle for 30°, which required a wider gun girder and hence a somewhat heavier turret than in the *Idahos*. This reasoning was carried a step further in the last US capital ships designed during the dreadnought era, the *South Dakota* (BB-49) class battleships and the *Constellation* (CC-1) class battlecruisers. Their 16in/50 guns were to have elevated to 40°.

Battleships rebuilt between wars had their gun elevation increased, although the first few such efforts were canceled due to British protests under the terms of the Washington Treaty. Thus the *Utah*, *Wyoming* and *New York* classes were never modified, funds for the latter two being provided and then rescinded just before the United States entered World

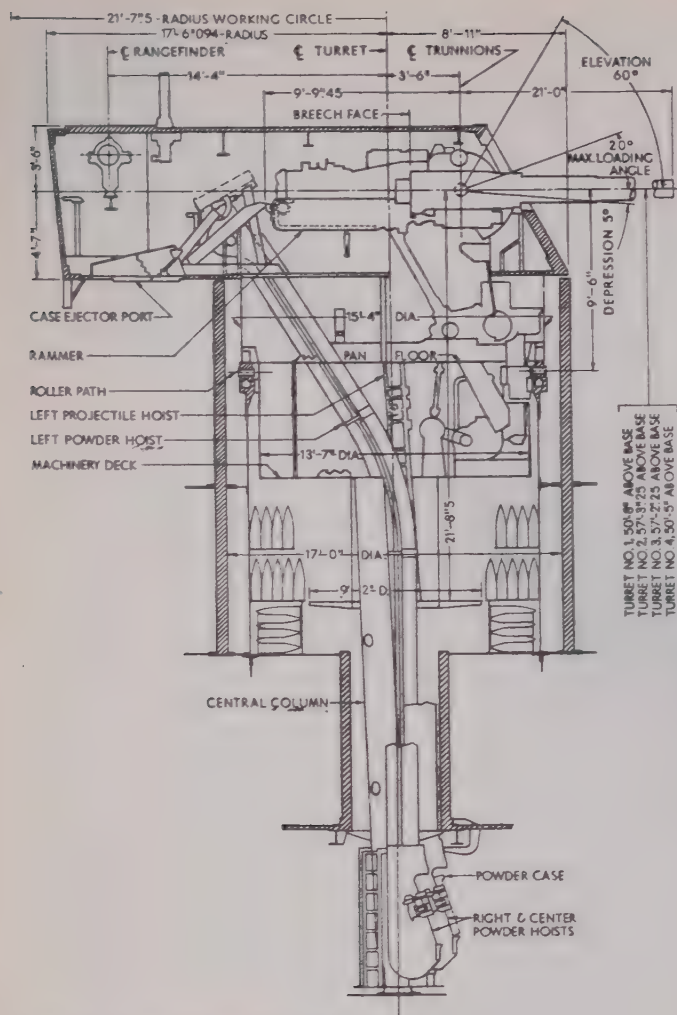
War Two. The *Nevada*, *Pennsylvania* and *Idaho* classes all had their maximum elevation increased to 30°, and a 45° elevation was standard in the *Alaskas* and in the battleships of World War Two. There was a similar evolution in cruisers: the *Omaha* could elevate her 6in/53s only to 20°, but 41° was standard in Treaty cruisers, with the 6in/47 designed for possible modification to 60° (although gun ports were originally cut to 40°), a change actually made in wartime. The 41° limit persisted through the *Des Moines* class, although in the 6in *Worcesters* a much higher elevation (78°) was provided to permit dual-purpose fire.

Cruiser Mounts

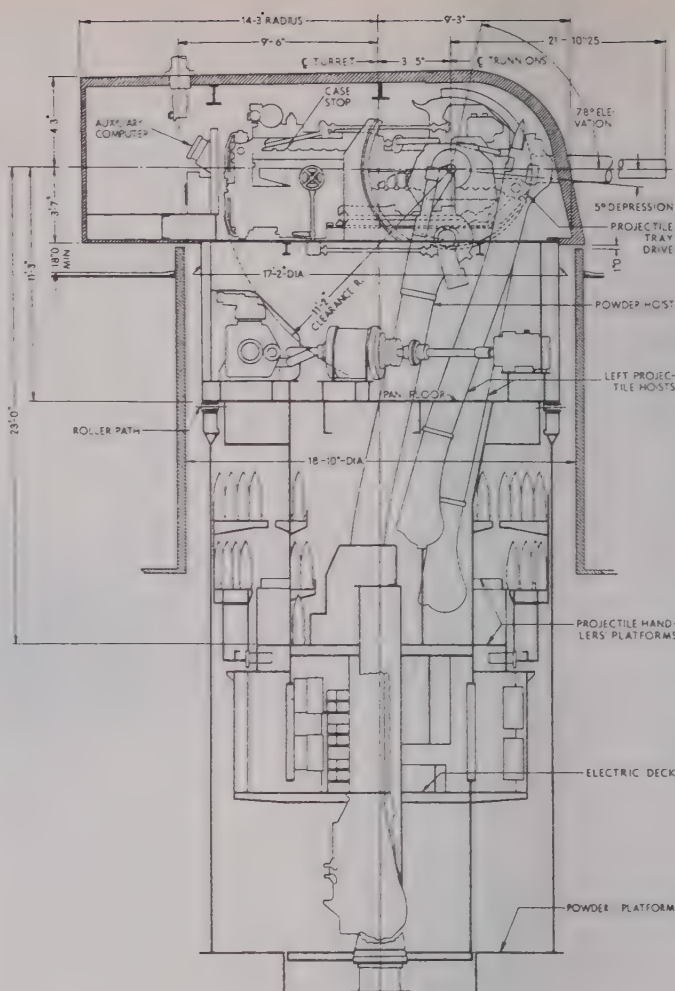
Cruiser turret (or gun mount) design practice generally followed that of the battleships, with one vital difference. When the early US Treaty cruisers were designed, it was believed that the main threat to their survival would come, not from long-range shellfire, but rather from underwater explosions (including near-misses by bombs). There was therefore, considerable pressure to move powder away from the bottom of the ship, even though this might place it above the waterline in a poorly protected location. Thus in the *Pensacola*, *Northampton* and *Portland* classes the shells were still stowed around the mount below a powder handling room, but there was no lower powder handling room: the system reverted, in effect, to a single-stage hoist, rising from the 'electric deck', the level above the shell handling room. The mount was too small to accommodate shells within its rotating structure, as in the battleships.



I. GUNS (SURFACE FIRE)



THE 6in/47 TRIPLE TURRET (CL-55, CL-106)



THE 6in/47 TWO-GUN TURRET (CL-144)

It was soon appreciated that these thinly protected cruisers could indeed hit at very long ranges with their 8in guns. Even before any US Treaty cruisers had been completed, the order of priority in protection had been reversed to place shellfire first, the result being the *New Orleans* class. In these ships substantial armor was placed on their gun houses, in place of the splinter protection of previous classes. In addition, the powder was moved back beneath the shell room, the former powder handling room becoming a 'powder transfer room' between upper and lower powder hoists. In contrast, although it stowed its powder beneath its shells, the contemporary triple 6in/47 (*Brooklyn* and later classes) employed only a single-stage powder hoist. However, it did not suffer from the hazards presented by silk-bag powder, since it employed semifixed ammunition. Similarly, the semifixed ammunition turrets of the *Des Moines* class employed only single-stage mechanical hoists.

Turret Construction

BuOrd carried out instrumented firing trials with the new battleship *California* in 1921; a dynamic analysis by Professor William Hovgaard led to further tests, including firings on an 8in gun during which portions of its supporting structure were cut away between firings. It was concluded that the turret stool beneath the turret needed no stiffeners: if the top and bottom held true to their circular shape, the vertical plating connecting them

sufficed. The final analysis, by Lt WP Roop of C&R, was sufficiently convincing that BuOrd was able to omit stiffeners in the *Quincy* (CA-39) and *Brooklyn* (CL-40) turrets, the prototypes of World War Two cruiser mounts. In the case of the heavy cruiser, it then became possible to cone the barbette armor, for equivalent or better protection at long range with a reduction in barbette thickness – and weight.

In the subsequent battleships, the value of eliminating the turret stool stiffeners was in the space freed, which permitted much more efficient ammunition supply. That is, in earlier ships, once shells had been moved into the rotating shell handling room, they still had to be moved 10 or 15ft to the hoists, which consumed enough time to limit the rate of fire to about one round per gun per minute. However, if the shells were stowed on a rotating ring, they could be brought opposite openings in the hoists and the parbuckling distance reduced to about 1.5ft. In its official history, BuOrd claimed that 'the system of projectile handling was considered by many authorities to be the most important advance in fifty years in safe and easy handling of big projectiles in large numbers... This was done by having two projectile handling flats, each containing a projectile in the proper place to be loaded in the hoists. Firing cycle was 20 seconds with the gun at the loading position.' That is, each gun had its projectiles on two levels, either of which could deliver them directly to the hoists. On each level there were,

in effect, three concentric rings of shells. The outer one was fixed, forming a shelf attached to the turret foundation. Inboard of it came the rotating structure of the turret, carrying the three shell hoists. The inner ring could rotate independently of the turret, to bring shells into position for hoisting. Because the hoists rotated *between* fixed and moving rings, they could be loaded from either.

Given the great variety of unfortunate experiences with powder explosions which the United States Navy (and, for that matter, the Royal Navy) had had, it seems remarkable in retrospect that the 16in turrets designed for use in World War Two had single-stage powder hoists. Powder bags were passed through a flameproof scuttle, into a hoist-loading space, and then into a powder car which delivered them to the guns. Presumably there were sufficient interlocks for safety: a manually operated sliding door through which the car was loaded, and which had to be closed before it could be raised or lowered; and a door in the turret, which, when open, prevented the car from rising. Thus it was (at least in theory) impossible to have both loading and delivery doors open simultaneously.

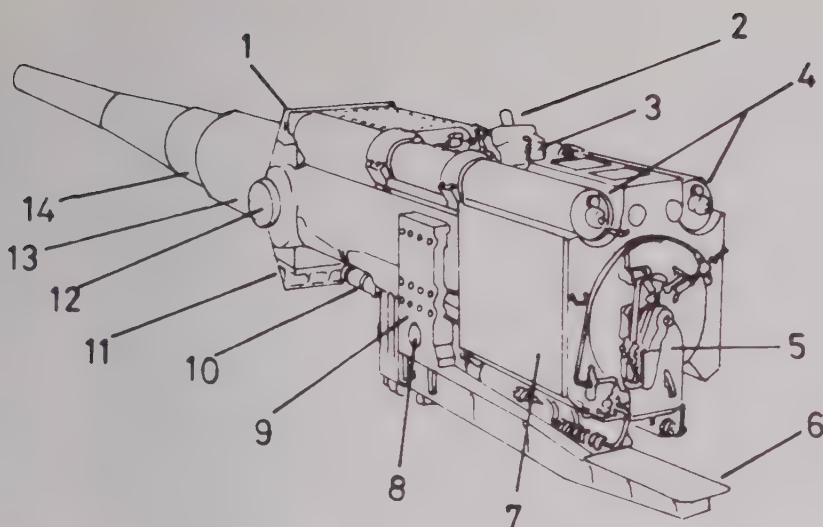
The 12in/50 and Rapid-Fire 8in/55 Mounts

The turrets installed in the large cruisers (*Alaska* class, 12in/50) generally resembled those of the new battleships, but had two-stage powder hoists

1 THE 16in/50 GUN (BB-61)

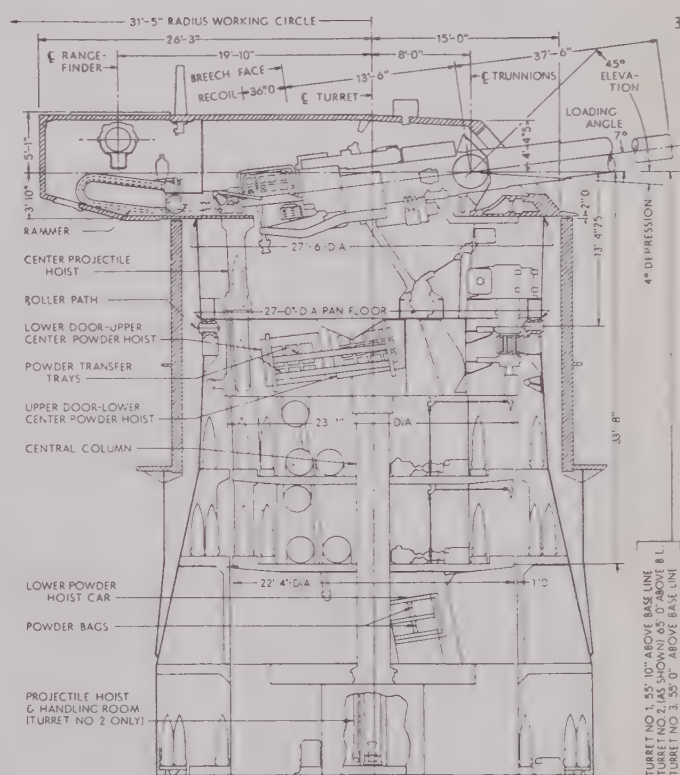
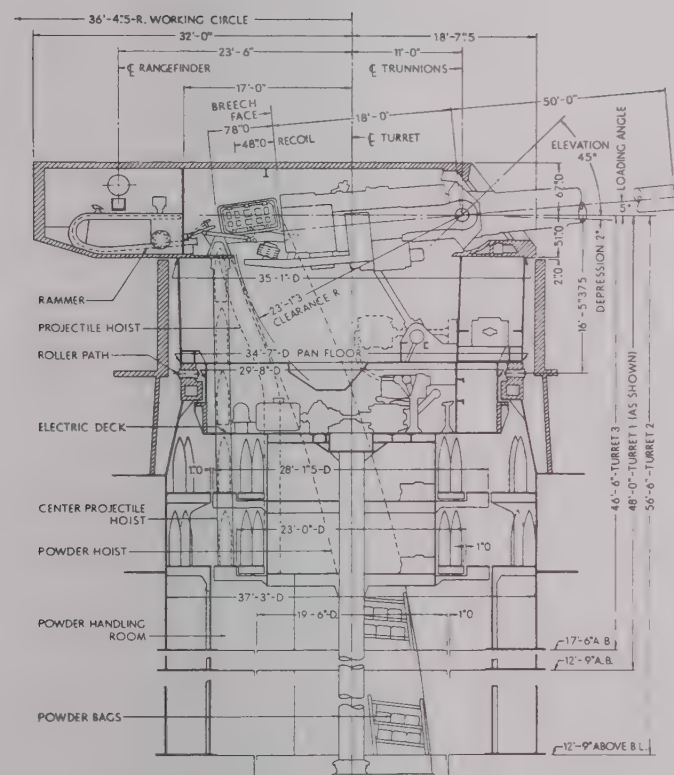
Key

- 1 Upper shield plate
- 2 Depression buffer
- 3 Yoke locking link
- 4 Counter-recoil (run out) cylinders
- 5 Downward-opening breech
- 6 Loader's platform
- 7 Yoke
- 8 Slide locking pin
- 9 Rear end bracket
- 10 Recoil system expansion tank
- 11 Lower shield plate
- 12 Slide trunnion
- 13 Neoprene gun cover
- 14 Gun slide cylinder



2 THE 16in/50 THREE-GUN TURRET (BB-61)

3 THE 12in/50 THREE-GUN TURRET (CB-1)



... in order to increase the rate of fire and insure a greater degree of safety... Separate hoists for each gun had separate car-type electro-hydraulic hoists independently controlled but arranged with interlocking controls [which] prevented simultaneous opening of upper and lower hoist doors of either hoist or the two doors in each of the three powder transfer rooms on the machinery flat. The use of the intermediate powder handling level resulted in saving approximately five to six seconds in the firing cycle... Projectiles were stowed on two handling levels in each turret. Each turret was provided with a rotating projectile ring which was indexed by an electric hydraulic drive which automatically positioned the projectile at the base of the three projectile hoists. The number two turret had additional projectile stowage on a larger projectile ring at (its) base...

A unique feature of the design was the provision of a projectile room for transferring shells from fixed stowage to the rotating ring.

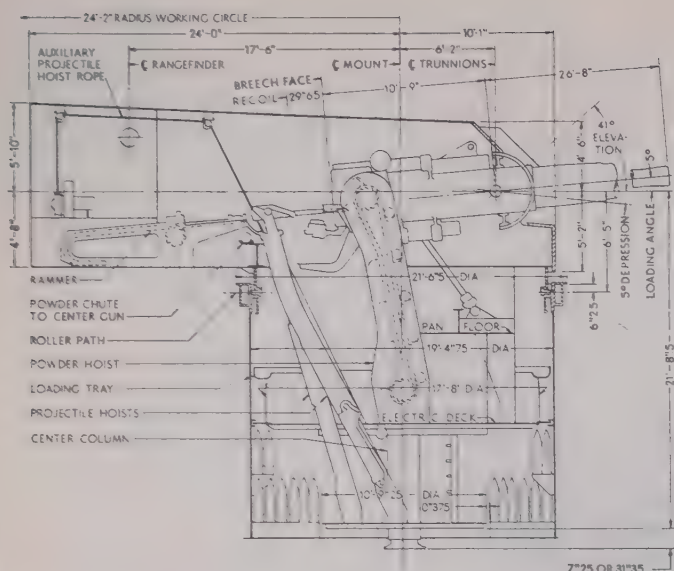
However, this feature was not entirely satisfactory, and there was considerable discussion about removal of the transfer ram... projectile transfer rams were not installed in the *Hawaii*, and were removed from the upper projectile handling flats of the *Alaska* and *Guam*... forces at sea were fearful that the turret would be started in motion while the transfer was occurring, thus causing a jam.

On the whole, the turrets caused considerable problems because they had been designed and built so rapidly, and thus could not be properly tested; BuOrd ended by noting that

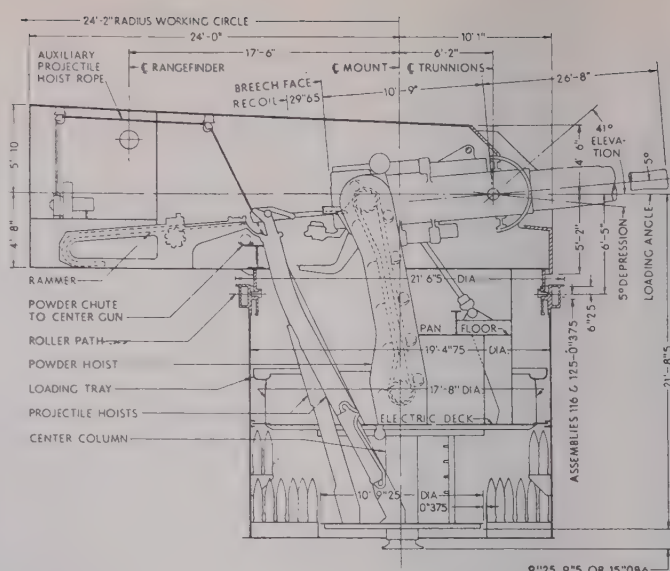
'this turret is an outstanding example of a case where prior testing of a new design by the manufacture of a pilot model was required'.

The other major wartime turret projects of the Bureau of Ordnance were the two-gun 6in/47 and the three-gun 8in/55. The former, a dual-purpose weapon, is discussed in Part II. The latter was described by the Bureau after the war as an outstanding development, extremely advanced for its time. Work began in May 1943, after the design of the 6in/47 dual-purpose mount had shown that a large-caliber weapon could be made to fire rapidly. At that time there was considerable unease about existing 8in bag guns, which could not fire nearly fast enough to deal with rapidly

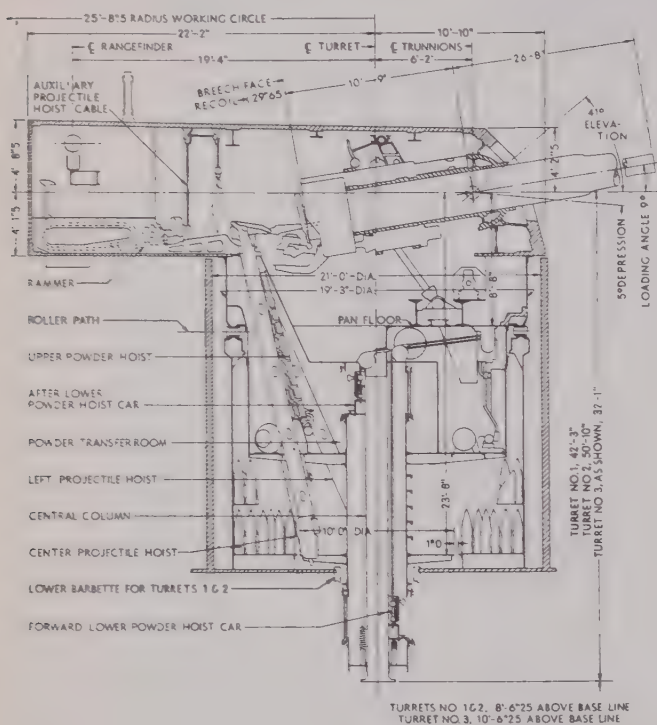
I. GUNS (SURFACE FIRE)



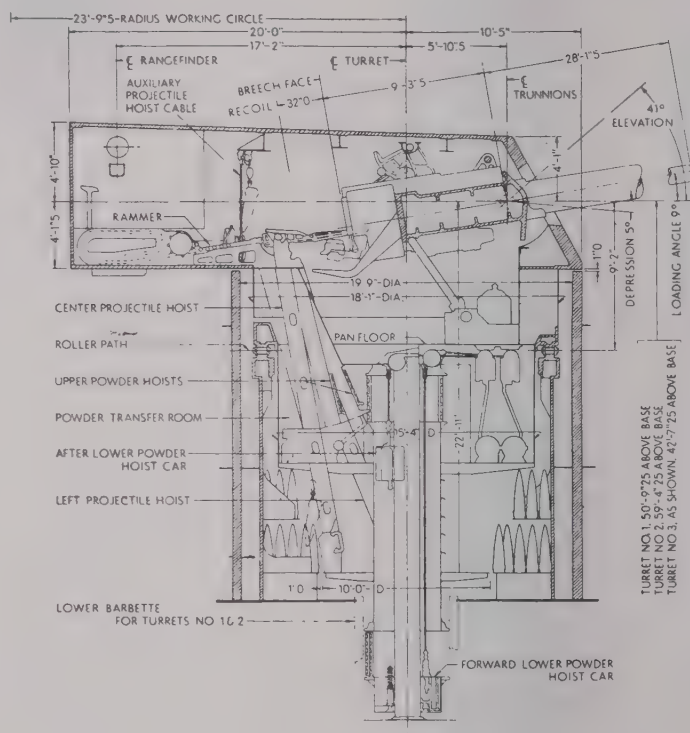
THE 8in/55 TWIN and TRIPLE MOUNTS (CA-24)



THE 8in/55 TRIPLE MOUNT (CA-27)



THE 8in/55 TRIPLE TURRET (CA-32)



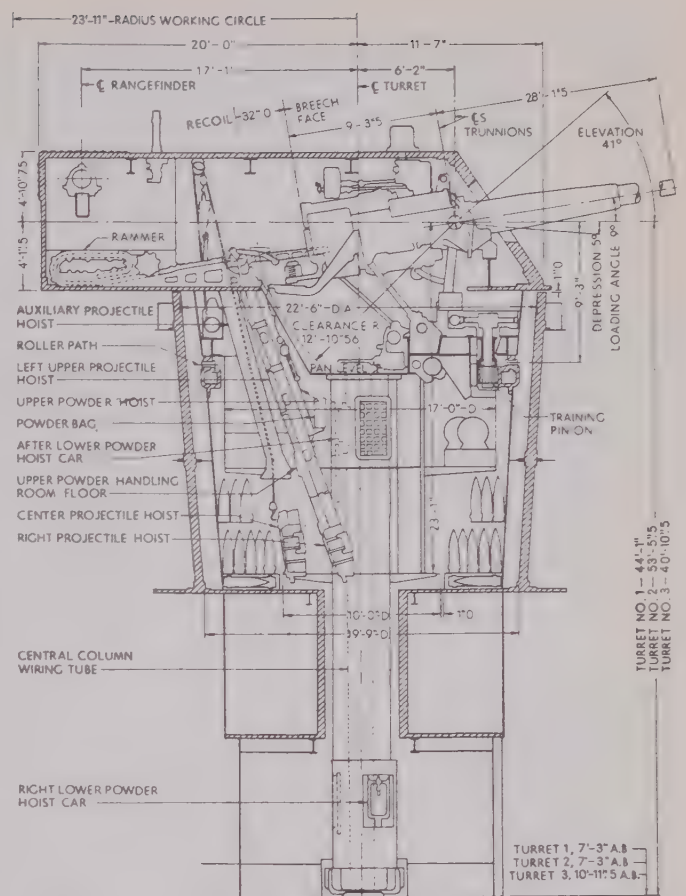
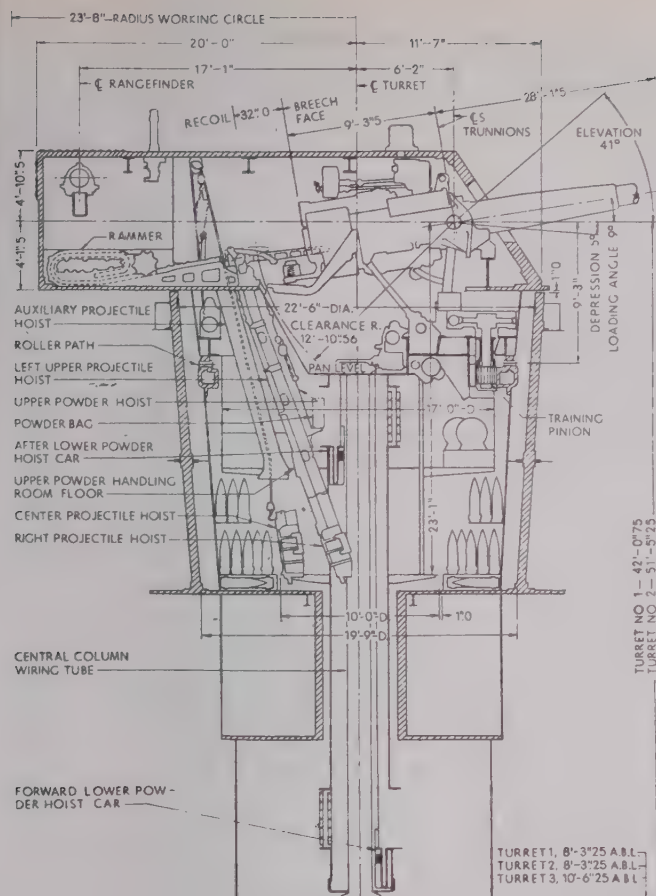
THE 8in/55 TRIPLE TURRET (CA-37)

maneuvering cruisers and destroyers – a problem occurring almost nightly in the Solomons. Although the existing 6in/47 could fire fast enough, thanks to its case ammunition, it did not have the requisite range. So important was the rapid-fire 8in/55 that ships intended to carry it very nearly displaced the entire light cruiser program from 1943 onwards; only the end of the war cut the class to three ships. After the war, the 8in/55 was considered far more satisfactory as a gun than was the 6in/47 dual-purpose, which is why the *Des Moines* class survived the *Worcesters*.

A high rate of fire was achieved by all-angle loading with semifixed ammunition, the latter being mechanically handled from hoist to slide, from which shell and case would be power-rammed with a single stroke. Hoisting, too, was entirely automatic, and the shell moved from hoist to slide on a cradle which could swing about the gun trunnions. The latter contained an automatic fuze-setter. Shell stowage consisted of inner and outer projectile rings, each two shells deep. Both were capable of independent motion. Inboard of the outer ring was a projectile handling platform, part of the

rotating mass of the mount, carrying the right and left gun shell hoists; the central part of the structure, inboard of the inner ring, carried the center gun hoist. The powder cases, each of them a full charge, were loaded from a level below the shells. Each gun had a pair of hoists, one for shells and one for powder.

In operation, the shell passed up its hoist into a cradle, which swung back parallel to the gun, then passed it into a transfer tray, which in turn moved into position in front of the rammer. Similarly, the case moved up a hoist, swung back and over, and was placed behind



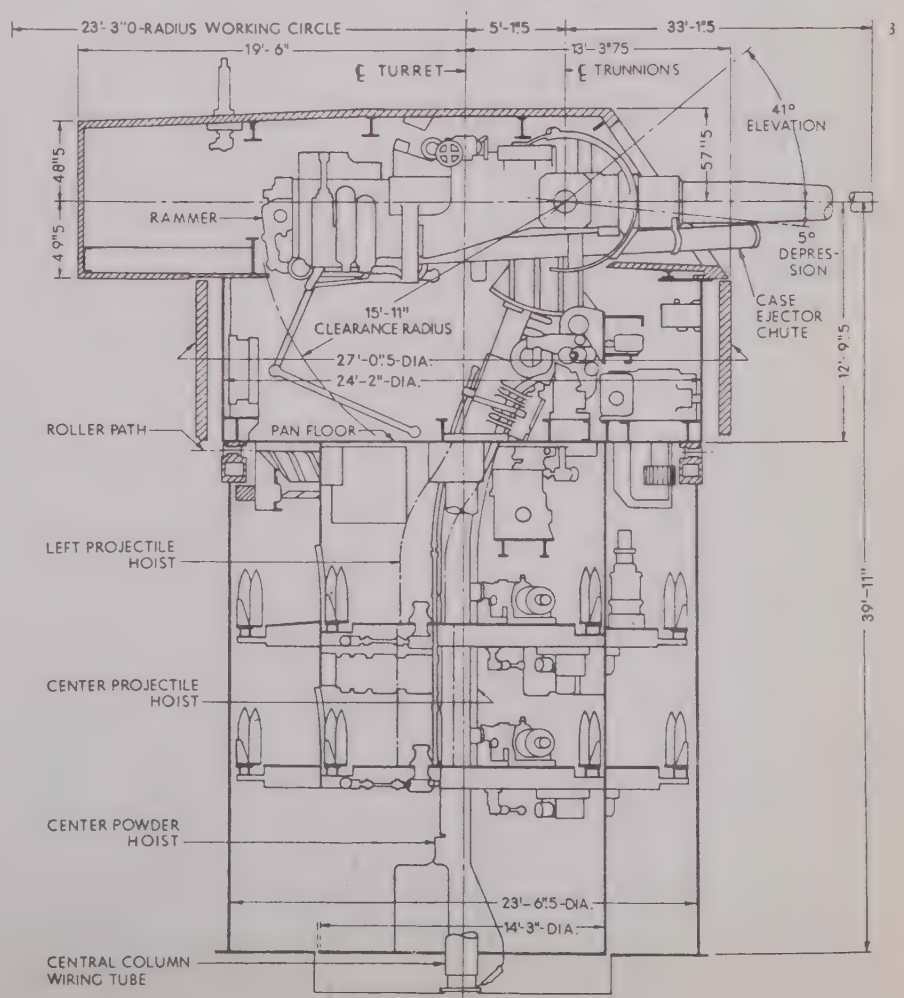
1 THE 8in/55 THREE-GUN TURRET (CA-45)

2 THE 8in/55 THREE-GUN TURRET (CA-68, CA-122)

3 THE 8in/55 THREE-GUN TURRET (CA-139)

the shell, after which both were rammed together. The vertical sliding-block breech closed and locked and the gun fired, after which the empty case was extracted, ejected forward of the turret. The mechanism was complex but effective; in its entire career the turret had only one bad accident, a fire in the *Newport News* - which did knock out one turret, although two out of the three guns survived.

The mount had several unusual features. It was the only major US turret to elevate by arc and pinion instead of the usual elevating screw and oscillating bearing. It was also the only major US turret without an optical rangefinder, radar being substituted. There was some uneasiness concerning the possibility of the radar jamming, but by the time the question had been raised there was too little space or weight left in the mount for a conventional rangefinder. The compromise solution was to install two radars per turret, and to provide a 26.5ft (rather than a 15ft) rangefinder in the Mk 54 director controlling the weapon. A three-gun design was adopted in preference to a triple mount in view of the possibility that damage to one gun would disable an entire triple mount. Nonetheless, the *Newport News* explosion and fire did wipe out her entire No 2 mount.



5. Torpedo defense

Early Rapid-Fire Guns

From the first, major US warships mounted a wide range of light, rapidly-firing guns for defense against torpedo boats. These included, at first, a variety of Gatling guns. By 1894 there were 37mm and 47mm Hotchkiss revolver cannon, which resembled the Gatling gun externally; 1pdr (37mm, or 1.457in), 3pdr (47mm, or 1.85in) and 6pdr (57mm, or 2.244in) Hotchkiss rapid-fire guns; and 1pdr, 3pdr and 6pdr Driggs-Schroeder rapid-fire guns. Early versions of the 37mm revolver, all of the 47mm revolvers, and early Hotchkiss rapid-fire weapons had been manufactured in France, but with the invention of the Driggs-Schroeder production and design were passing to the United States. In 1895 the Navy adopted a 1pdr version of the new Maxim machine gun (the 'pom-pom'), which was attractive partly because it could be mounted aloft, since it was much lighter than the Hotchkiss revolver cannon. Unlike the rapid-fire guns and the revolving cannon, it remained in service (ultimately as an anti-aircraft weapon) through World War One. Many of the other rapid-fire light guns were brought back into service during the First World War to arm small craft.

These were all lightweight, short-range weapons, well matched to a short-range threat. For example, in December 1902 an Ordnance publication claimed that the 6pdr 'will limit the torpedo boat to 1000yds, as the penetration of the shell is over two inches at that range'. In fact the development of battleship secondary weapons over the next two decades was very much a competition with longer and longer ranged torpedoes, just as the advance of battle ranges was to some considerable extent an attempt to overcome advancing torpedo ranges.

Up to a point the torpedo manufacturers had a distinct advantage. They could improve the torpedo itself without having to alter the ship carrying it very much; thus, for example, the US Navy could carry 21in torpedoes on hulls originally designed for 18in types. In modern terms the torpedo was a 'low impact' weapon: beyond a certain ship size, it had little effect on the design of the ship.

The antitorpedo weapon was a very different matter. It had to be mounted high in a ship – or, at the least, should have been mounted high in a ship – to attain a good command and dryness, as destroyers of advancing tonnage could attack in worse and worse weather. That meant that a reasonable antitorpedo battery could present significant topweight problems. Larger rapid-fire guns also presented considerable problems of fire control at long range (eg confusion with the splashes of heavy guns) and of sufficient ammunition supply.

In some ways these considerations parallel those found later in anti-aircraft defense: it was far easier for an enemy to build larger aircraft than for naval architects to refit ships already in

existence with materially better passive defenses, although active defense was another matter. As evolution continued, larger aircraft size translated into an ability to carry effective standoff bombs, weapons which retained their accuracies over ranges beyond those of ship-board guns. Then, as in the case of the destroyer, defense became as much a matter of forward defensive units (fighters *vs* bombers, cruisers and destroyers *vs* destroyers) as of weapons on the target proper.

In 1904 destroyers could hope make hits on a massed fleet from ranges as great as 2000yds, and it seem reasonable to open fire on them from 3000 or more. At such ranges the flatter trajectory of a heavier gun (the 3in/50) might more than make up for its slower rate of fire; that year Lt Cdr Sims maintained that the heavier gun was more than three times as effective as the 6pdr then in use (danger space 101yds *vs* 30 at 3000); at 2000 it was twice as accurate (133 *vs* 61yds) and even at 1000 it was 1.8 times as accurate (392 *vs* 204yds). Sims believed that, were both guns mounted equally efficiently, this improvement in accuracy would balance the faster fire of the 6pdr at about 2000yds to give equivalent hits per gun per minute. However, under actual service conditions the heavier gun would be far more effective because its much greater danger space would allow for a greater latitude of error. The adoption of the 3in/50 as the sole US anti-torpedo weapon of the time can be dated from the General Board's 1904 request for a semi-dreadnought (12in and 10in guns); even earlier, efforts had been made to achieve large 3in batteries in the last of the predreadnoughts and in the large armored cruisers.

Torpedo ranges, however, continued to increase; the only practical limit was found to be the loss of accuracy at long range due to the long run of the torpedo, during which its course could not be corrected to allow for target course changes. By 1903, 3000yds was considered an effective torpedo range, and within three years there was a 3500yd, 26kt type. By 1911 a torpedo range of 6000yds was being quoted, and the torpedo was considered a very serious threat to the future existence of heavy capital ships.

The 1907 Board on Torpedo Defense

Torpedo attack was primarily *night* attack at this time, and in 1907 a special Board on Torpedo Defense spent much of its time on the proper location for searchlights. It decided that each pair of defensive weapons (which should be 5in or even 6in guns) should be controlled in connection with its searchlights by a separate officer located below the light and above the gun. Lights were essential for fire control, but if they were used to search for approaching torpedo craft they would merely give away the position of the battleship.

From observation of night practice in the Atlantic Fleet and experiments which have been made, there is little doubt in the mind of the Board that the use of searchlights is of greater value to the attacking boats than to the battleships... From experiments conducted by the Board, it was conclusively proven that the most advantageous location of searchlights is as high as possible... The apparent result of a low light is in the brighter illumination of the foreground, and this is attended by the disadvantage of direct reflection. To interpose the beam between the target and the observer is comparable to introducing a screen of fog... With the light higher than the observer, it was noted that a diffused light illuminates the water under the beam, and it is only with the beam striking the water in front of the target that the screening effect occurs...

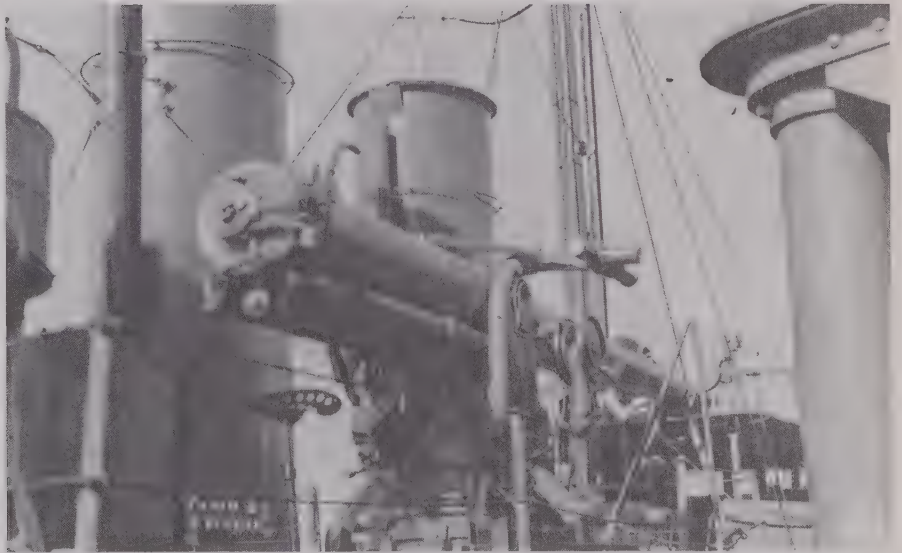
The direct effects of this Board were, therefore, the 5in/50 antitorpedo gun (soon to be replaced by the 5in/51) and the high searchlight positions standard in US battleships before World War One. The threat continued to grow through the period before 1914, and at one time it was even suggested that antitorpedo batteries were so futile that they might well be dispensed with, the weight saved going instead to better passive protection. In addition, with the development of smoke screens, destroyers were able to attack in daylight, as part of a general fleet action, as well as at night, when they would precede or follow such an action. The only option open to the battleship designers was to increase the caliber of their weapons, a 6in ant destroyer gun being suggested about 1906 and again in 1913. It did not materialize until the *South Dakota* class of 1917. These ships were originally to have had the standard 5in/51, but in the fall of 1917 the General Board, considering battleships for the FY19 program (BB-52-54) asked for 6in guns in place of the fourteen 5in/51 of the FY18 ships (BB-49-51). Ultimately all six ships were redesigned to this standard, as were the six *Constellation* class battlecruisers.

By this time, too, there had been a more important advance, in the advent of director control for the secondary (antitorpedo) battery. With the Washington Treaty, US work on new antitorpedo weapons effectively ceased; by the time new battleships were contemplated in 1928, dual-purpose secondary batteries were being specified. Indeed, the 5in/38 adopted for US battleships in World War Two actually represented a retreat (from an anti-surface-ship point of view) from the 5in/51 of World War One. On the other hand, it represented a greater emphasis on antiship fire than did the earlier purely anti-aircraft 5in/25, the later 5in/54 (which had been specified for the *Montanas*) representing a further retreat from pure anti-aircraft capability.

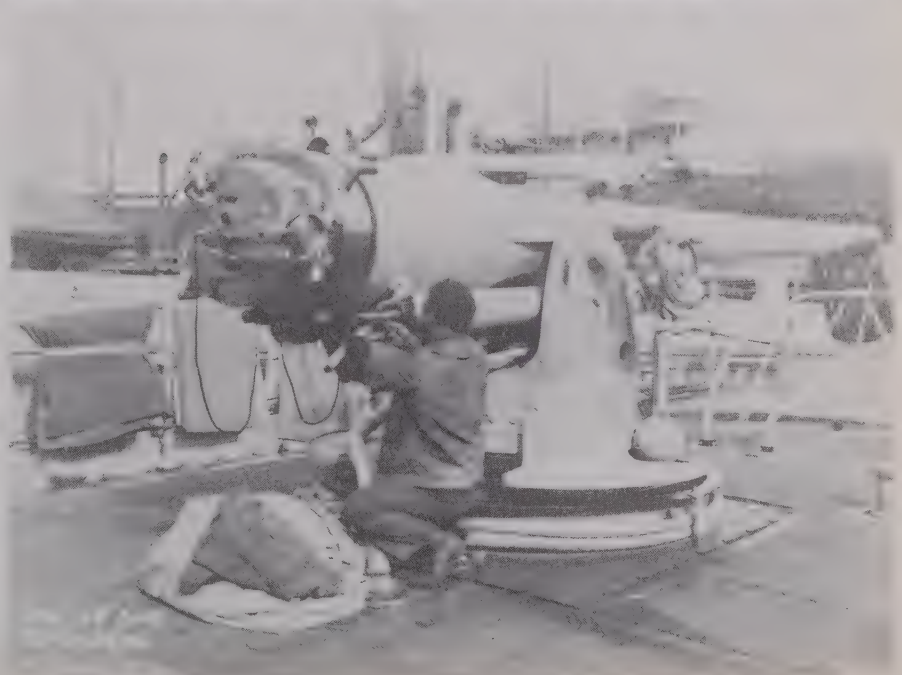
Rapid-fire small-bore cannon were intended, at first, primarily as a defense against torpedo boat attack. At the very short battle ranges possible late in the nineteenth century, they could also pick off crewmen topside, including those manning heavy guns. This is a 37mm Hotchkiss gun aboard the cruiser *Atlanta*, with a smaller-bore (probably 0.30-caliber) Gatling on the left, the latter without its magazine.



The standard US destroyer gun of World War One was the 4in/50, shown here aboard a destroyer, about 1919. The yoke carries a sight mount, below which is a trainer's handwheel; note the pointer's seat on the other side of the gun, useful because the pointer had to keep elevating and depressing the gun continuously to hold it on target.



For many years the 5in/51, one of which is shown here aboard the destroyer *Gilmer*, was the standard US battleship secondary weapon, preferred because of its very high velocity and consequent flat trajectory. It was, however, relatively unhandy, the 5in/25 antiaircraft gun being much easier to maneuver against a fast target. The classic 5in/38 of the 1930s and World War Two was a compromise choice, to achieve both effective antisurface fire and quick maneuvering by hand. The telescopic sights have been removed for maintenance, but the double handwheel (for quick movement) is clearly visible, as is the platform for the trainer and what appears to be a spotting rifle (for training) above the gun. The handle on the breech opens it, and the wire is probably for firing.



6. Submarine guns and weapons for light craft

Submarines

The earliest submarines were unarmed except for torpedoes, partly because they were not large enough to be effective surface gun platforms and partly because it was never envisaged that they would willingly remain on the surface in the presence of enemy surface ships. However, as submarines grew the subject of deck guns became more and more important, American submarines retaining theirs well after World War Two. It should be kept in mind that, until after 1945, submarines were best described as 'submersibles' – surface ships capable of limited submerged operation and therefore most effective on the surface, using their diving ability to escape or to evade detection and counterattack. On the other hand, it was often argued between the two World Wars that the presence of an unnecessarily powerful deck gun would encourage a submarine commander to fight on the surface rather than submerge, and so would make the loss of his boat more likely. This particular argument considerably slowed development of a 5in submarine gun before and during World War Two.

Deck guns were first included in the Characteristics for Submarines 40-47 ('L' class) in May 1912, at which time BuOrd began work on a 3in 'wet' gun which would be sealed at the muzzle and breech when submerged. There were delays, but a variety of 3in weapons were standard from then on, until the middle of World War Two. Most were adaptations of the same 3in/50 which became the standard early anti-aircraft gun. However, the numerous 'S' class submarines, the earliest which remained in combat service during World War Two, had a 4in weapon, and the 'cruiser' submarines of the period immediately after World War One had even larger guns: a 5in/51 in the three *Barracudas*, and two 6in/53s in *Argonaut*, *Nautilus* and *Narwhal*. The *Dolphin*, which followed, reverted to a 4in/50, after which the 3in/50 was standard. At a submarine officers' conference in 1937 seven out of the nineteen officers present voted to adopt a 5in dual-purpose gun (with two others calling for a 5in single-purpose), but it was rejected; however, foundations strong enough for a 5in/51 were designed into what would become the standard production submarine of World War Two.

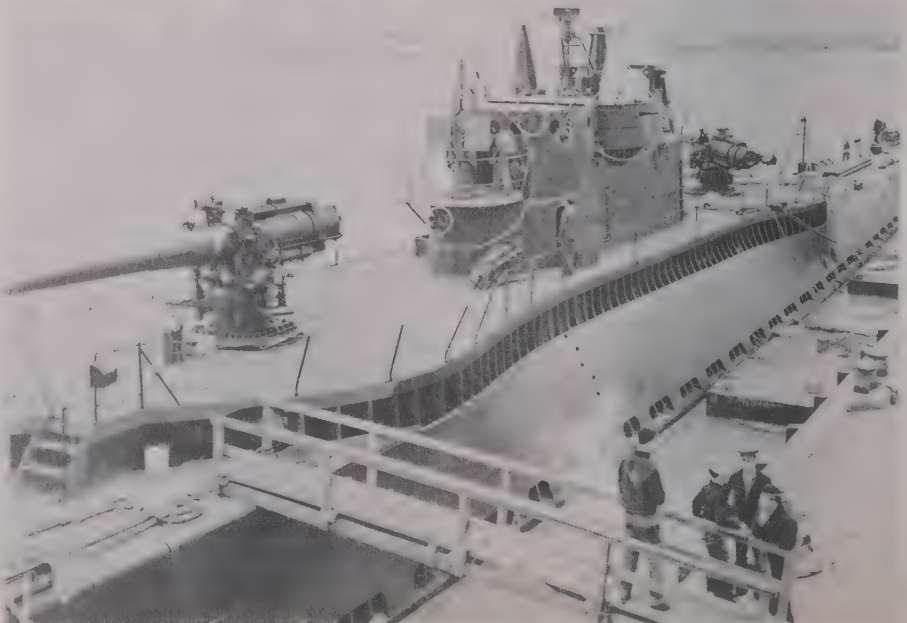
The existing 3in/50 was found inadequate in combat; in another connection, the British commander of a US-built destroyer escort complained that 'everyone knows it can't put a dent in a pat of butter'. BuOrd designed a new 4in/50 wet mount, but that was not considered satisfactory; in 1942 work began on a 5in/25 wet gun. Muzzle and breech covers were eliminated, the gun being produced from noncorrosive materials. In its postwar official history, BuOrd was proud that work on this weapon had begun early in 1942, even before the submariners had been able to formulate their complaints.

By the end of the war, the surface guns had proven extremely useful, so much so that in January 1945 the Pacific Fleet Submarine Force informally asked BuOrd to install surface fire control systems for two 5in/25 guns in several submarine 'gunboats' as soon as possible, to combat small Japanese picket boats. A system was developed, and the equipment delivered early in June 1945; three submarines were equipped, two of which departed on war patrols before the end of the war. However, none saw action, and although

there was active work on such fire control at the end of the war the shift in submarine requirements soon swept it away.

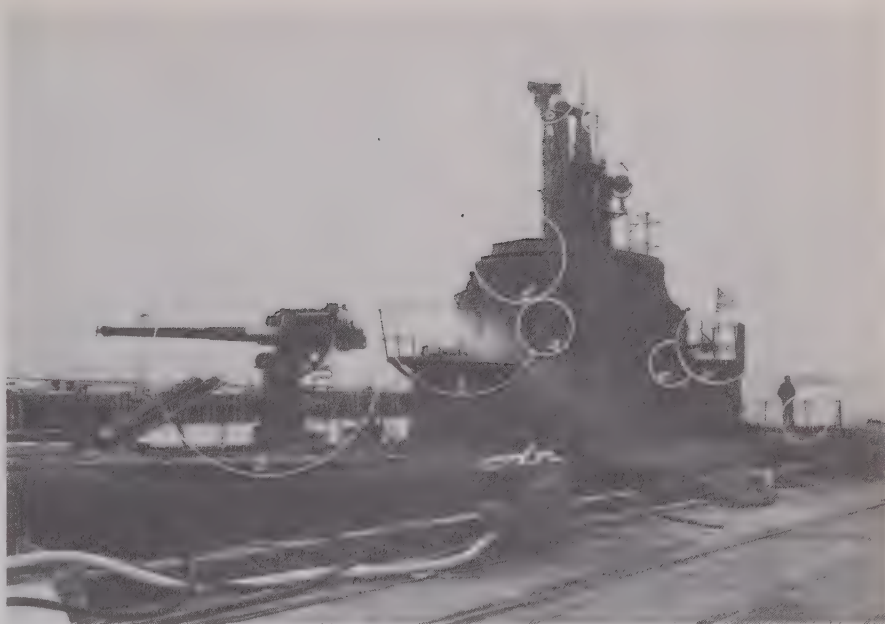
PT-Boats

It appears in retrospect that nearly all the weapons used by the PT-boats and their successors were extemporized at best. Mention must be made here of the extensive use, first of aircraft-type 0.50-caliber machine gun mounts, and then of the use of the standard Army Air Corps 37mm gun, as originally



mounted in the P-39 Airacobra. It is easily recognizable in photographs by the shape of its magazine, designed to fit within a fighter nose. In at least a few cases boats had been armed with the standard Army single-shot (rapid-fire) 37mm antitank gun, the wheels being removed. The other principal wartime PT-boat weapons were the 20mm and 40mm machine cannon, the 81mm mortar, and the 4.5in or 5in rocket. The ability to place such weapons aboard depended upon the weight expended in torpedoes and torpedo tubes. Early PT-boats required tubes to stabilize their torpedoes before they struck the water, and the additional weight in turn restricted their non-torpedo batteries. However, with the adoption of the Mk 13 aircraft torpedo, designed to be dropped into the water, they could be replaced by lightweight racks and the weight saved invested in other weapons.

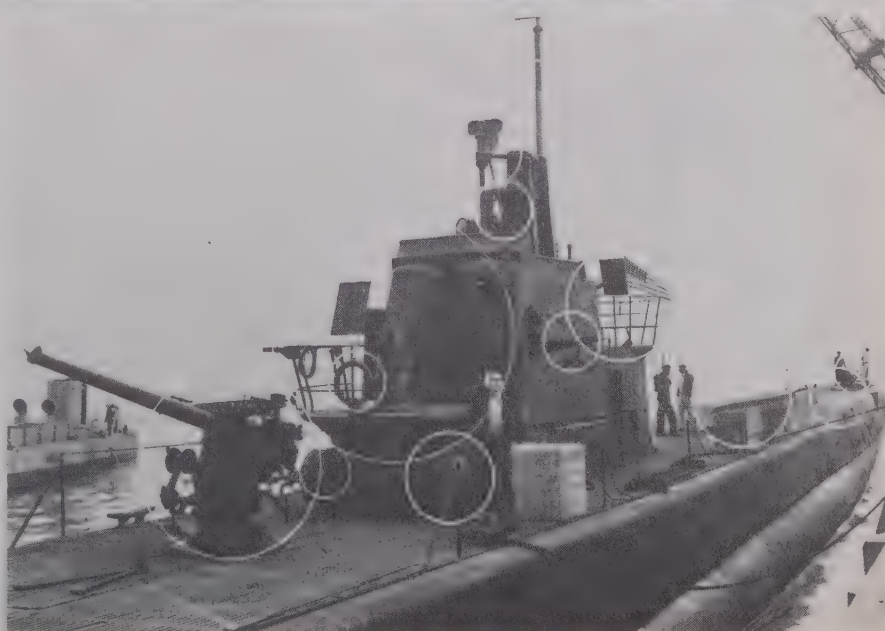
Pressure for increased gun (vice torpedo) batteries was an indication that PT-boats were employed much more as gunboats than as



- 1 The 3in/23 began as a boat gun, but was adopted for submarines and as a destroyer antiaircraft weapon. This one is shown aboard the converted yacht *Isabel*, about 1933; she was often considered equivalent to a small destroyer. Unlike the larger destroyer guns, the 3in/23 had a 'sliding wedge' breech, a block which swung aside to open the bore. The slot in the gun proper, just visible here, permitted shells to be loaded and cartridge cases withdrawn, and the brass of the cartridge case sealed the breech. There was only a single pointer/trainer; note the shield to protect him from a hot ejected cartridge case, and also his sight and the ring sight at the front of the gun. Part of the outline of the breech block is visible on the near side of the gun. Sliding wedges were used in guns employing cartridge cases, such as the 5in/25, 5in/38, 5in/54 and the rapid-fire 6in/47 cruiser weapon.



- 3 The standard US submarine gun of the interwar period was the 3in/50, shown here aboard the *Grouper*; the change indicated by the circle was to move it forward of the superstructure. The 3in/50 was chosen (over the objections of many submarine officers) for its antiaircraft capability, and specifically because its small caliber would discourage attempts to fight it out on the surface. By way of contrast, the 4in/50 had been standard at the end of World War One, and many submariners demanded much more firepower during World War Two. Note the installation of 'cigarette decks' fore and aft of the conning tower with mounts for 20mm antiaircraft guns.

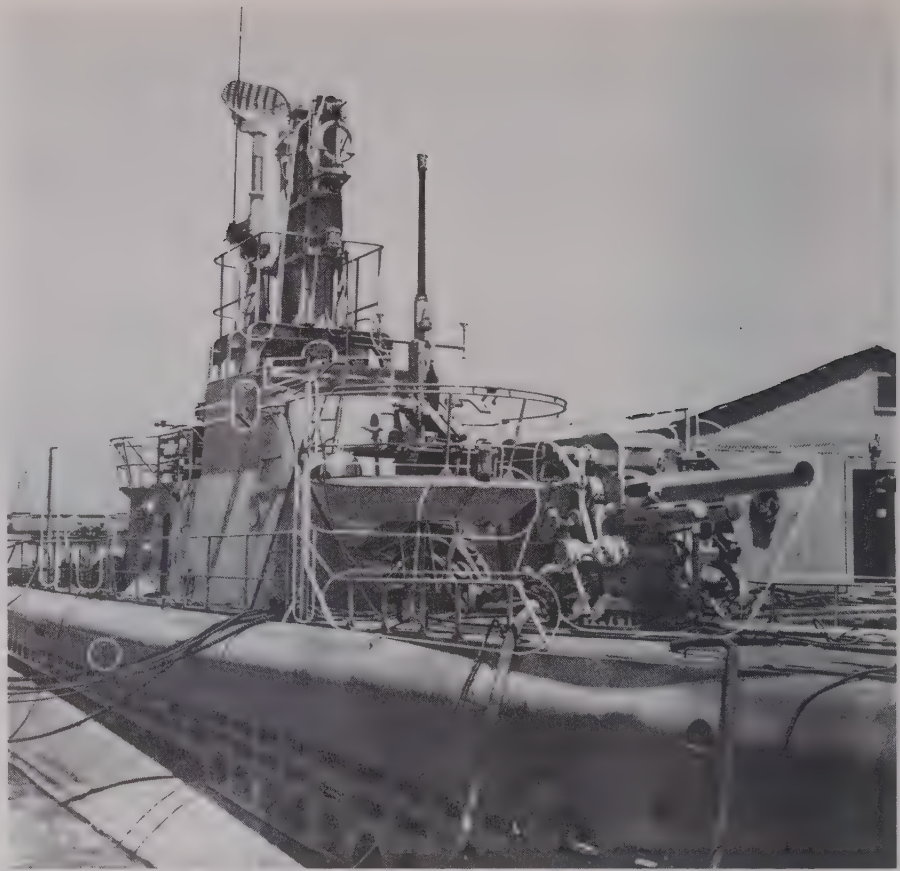


- 4 Many US submarines were refitted with 4in/50 deck guns during World War Two in an attempt to improve their surface firepower, but in 1943 Rear Admiral Charles A Lockwood, commanding Southwest Pacific submarines, ordered 5in/51s installed aboard several submarines. This is *Hake* as refitted at Mare Island, 30 November 1943; the huge gun required an oversized sponson.

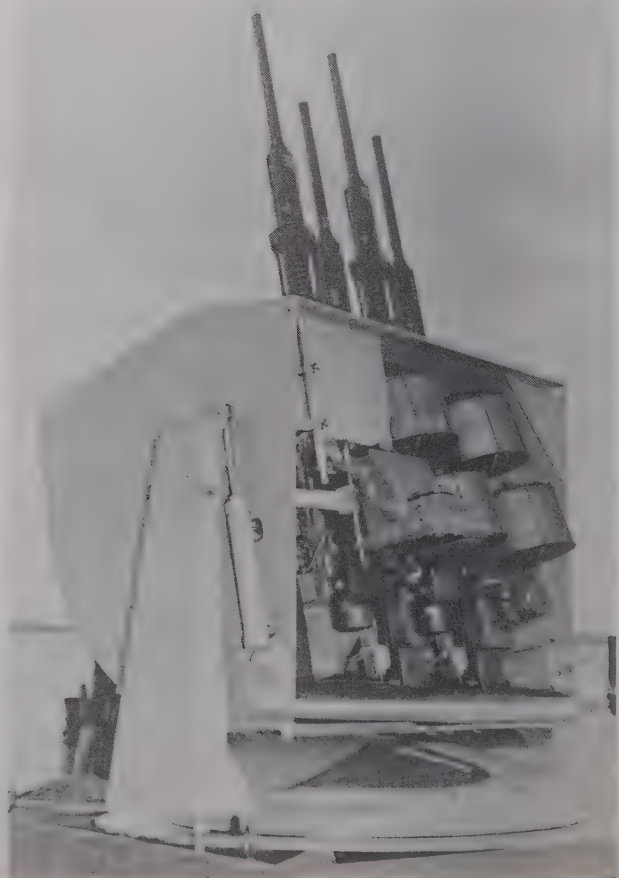
- 5 The submarine *Sturgeon* shows a 3in/50 wet mount; note the hinged tampon which seals the bore at the muzzle. It is a much lower mount than the dual-purpose type fitted prewar, reflecting the realization that submarines would not generally remain surfaced to face aircraft. Indeed, the SD radar (visible as a horizontal bar atop a tall pole on the conning tower) was provided specifically to warn submarines to dive in time to avoid air attack. This Mk 18 could elevate only to 40°, compared to 85° for the Mk 19 or Mk 21.

I. GUNS (SURFACE FIRE)

- 1 The 'wet' 5in/25 was the ultimate US submarine gun of World War Two, unique in requiring no bore closure underwater. Ballistically similar to the 5in/25 dual-purpose gun, it was limited in elevation to 40°. Here it is shown, newly installed, aboard the submarine *Grouper* at Mare Island, 17 July 1945. The first was fitted aboard the newly completed *Spadefish* (SS-411) at Mare Island early in 1944.
- 2 *PT-631* shows a standard PT-boat battery at the end of World War Two in this 1 March 1945 photograph. The gun on her foredeck is an ex-Army 37mm cannon, originally developed for the P-39 fighter; its ancestry shows in the unusual shape of the ammunition feed, which could fit inside the airplane's nose. The eight-barrel rocket launchers (Mk 50) fired a 5in spin-stabilized rocket to a range of 10,000yds. Further aft were two twin 0.50-caliber machine guns and, right aft, a 20mm cannon (pointed vertically) and a 40mm gun (whose magazine cover can be seen). The torpedo tubes of earlier boats were replaced by simple racks at the sides, since the aircraft torpedoes (Mk 13) in use in 1944-45 did not require tube launching to line up their gyros. The radar is an SO-8. In 1943, before the 37mm automatic cannon became available, some PTs, reportedly including *PT-109*, mounted ex-Army single-shot antitank guns (37mm) forward.
- 3 The 'Thunderbolt' quadruple 40mm mount, developed during World War Two for use aboard PT-boats (Elco Model 102-C-4, October 1943).
US Navy, by courtesy of Al Ross



Higgins Industries, Inc.
New Orleans, La.
PT 658 Class
BOX VIEW FROM ABOVE
Contract HDBs 1680
2/1/45



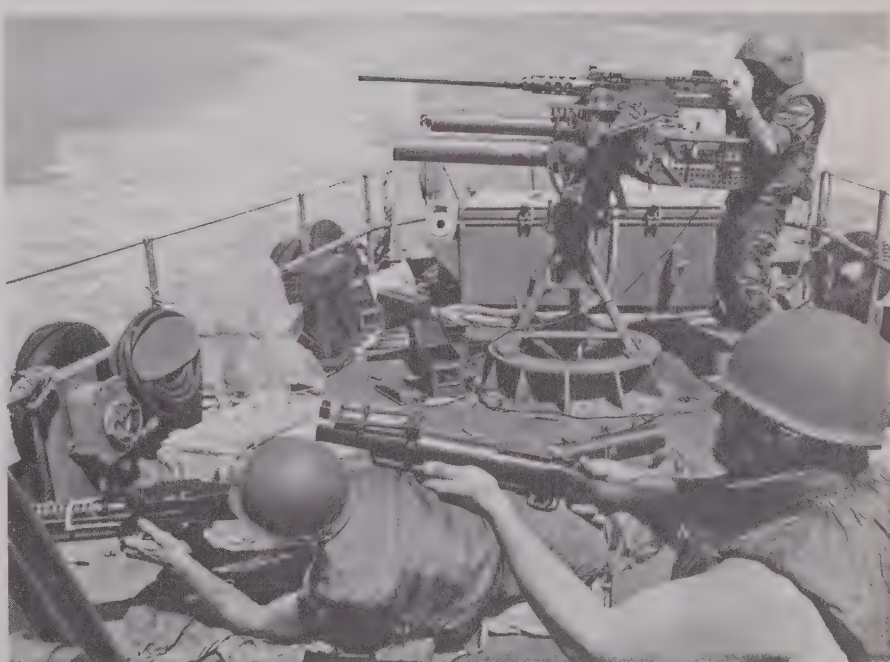
torpedo boats, as was the case with many similar British craft in the Channel and the Mediterranean – hence the pressure for greater firepower. However, it would appear that the only weapons ever developed specifically for PT-boats were quadruple 20mm mounts, some of which were later adapted to major unit antiaircraft use.

As an indication of standards, in November 1944 a 'standard (ultimate)' battery was set by the Office of the Chief of Naval Operations for all Elco 80ft and Higgins 78ft boats: four Mk 1 Mod 1 side-launching racks with two Mk 13 torpedoes; one Army-type 40mm gun on the centerline aft; six 0.50-caliber machine guns (four in twin scarf-ring mounts, and two in single pipe-stem mounts on the forward torpedo racks or in the cockpit); one 20mm gun on the port side forward in an Elco boat, or on the centerline forward in a Higgins boat; one 37mm M9 Army type gun forward; two Mk 50 rocket launchers (see Part VI); and an FM smoke generator. At the discretion of Forces Afloat, additional weapons could be mounted: one 20mm in place of the 40mm aft; two more torpedoes, in lieu of the rockets; two depth charges; and a 60mm mortar. For the future, Opnav proposed two 37mm guns, two twin 20mm, two twin 0.50-caliber, four torpedo racks, four Mk 50 launchers, an 81mm mortar, and a smoke generator; BuOrd preferred one 37mm, but also wanted a power-driven quadruple 20mm gun (several versions of which had been developed), two 20mm and four 0.50-caliber twin mounts, six torpedo racks (with four torpedoes), and the 81mm mortar and smoke generator. All of the weapons named were representative of wartime and early post-war practice.

Although the United States built several experimental coastal craft postwar, it does not appear to have made much progress in their weaponry during that period. However, several multiple weapon mounts were developed during and after the Vietnam War, including the combination 0.50-caliber machine gun and 81mm mortar and the lightweight 7.62mm Gatling gun. All are described briefly in the list of gun mounts.

1 The combination 81mm mortar/0.50-caliber machine gun was developed for use in Vietnam, and in 1983 remains a standard US small-boat weapon. Here one is fired from a 'Swift' (PCF) inshore patrol boat during an Operation 'Sea Lords' coastal raid, November 1968. Visible in the foreground are an M60 7.62mm machine gun (being fired from deck) and an M79 40mm grenade launcher. Note that, unlike conventional mortars, the 81mm type visible here is a breech-loader, as evidenced by the shield for the cartridge-case ejection mechanism. Similar weapons were sometimes mounted without the machine gun.

2 A river patrol boat ('plastic') displays her twin 0.50-caliber machine guns in this February 1969 photograph. Note the searchlight mounted with the guns, and the flash-hiders at the muzzles, for night firing.



7. Projectiles

Types of Shells

As the Royal Navy discovered to its cost at Jutland, the details of projectile design, quite as much as those of guns and fire controls, could determine battle effectiveness. US evolution generally followed that of other nations, but there were major differences, particularly as the US industrial base matured after World War One. By 1941 the United States had a distinctive family of unusually heavy, low-velocity, armor-piercing shells, well adapted to attacking deck armor at the long battle ranges called for in US doctrine, and practicable in view of advanced US fire control systems and air spotting. The United States also showed unusually great interest in high-capacity projectiles for shore bombardment, again presumably in connection with the type of war which seemed likely. In addition, like the Japanese Navy, the US Navy appears to have developed shells well suited to attacking ships underwater, in that they would not explode on water impact, but would be able to burst after an underwater trajectory. It would appear that this development was connected with increased US interest in protecting the underwater hulls of battleships from just such hits, as in the *South Dakota* design of 1937.

The US Navy was the first to introduce a long-nosed (7 caliber head radius) shell, for extremely long range; in the fall of 1908 the Secretary of the Navy reported that the most important development that year had been the introduction of a new projectile with much reduced air resistance. For example, at 9000yds the long 12in shell (fired at 2700ft/sec) was expected to penetrate 13.1in of face-hardened armor, whereas an earlier 12in shell would have penetrated only 12.2. On the other hand, the US Navy never 'boat-tailed' its heavy shells to achieve greater range (as compared to, say, Japanese practice) and preferred conventionally shaped, squared-off, long-nosed shells.

Shells are divided by function and explosive content, the typical categories being armor-piercing (AP), common (with a higher explosive content), high-capacity (thin-walled), antiaircraft common (AAC), antiaircraft (AA), and shrapnel. As of 1915, common and AP shells existed for all calibers, but were no longer being manufactured for calibers above 5in; they were intended for attacking light armor (typically one-third to one-half of the shell caliber in thickness) and had a larger charge (typically 6 percent of shell weight in larger calibers and 3–3.5 below 6in *vs* 2.1–2.6 percent of shell weight in pre-World War Two AP shells). After World War One, when cruisers were built with 6in and 8in guns, both common and 'special common' shells were introduced in both calibers, the latter with considerably smaller charges (*eg* 2.1 percent in special common Mk 27, about 5.5–6 percent in common Mk 20, 24 and 28 6in shells; the percentages in 8in were much

closer). There were also a variety of high-capacity or thin-walled projectiles developed during World War One for special purposes. They included flat-nosed shells capable of traveling through water with reasonable accuracy, for attacking submarines, for 3in, 4in, 5in, 6in and 8in guns; the 8in flat-nosed shell devoted 26.2 percent of its weight to explosive. During World War One BuOrd developed land mountings for both the 7in/45 and the 14in/45 guns, and bombardment projectiles for them; the 7in/45 Mk 14, for example, devoted 15.6 percent of its weight to explosive, and the 14in Mk 9, 11.5 percent. For World War Two yet another, similar category was created, the HC shell, designed for 4in/50, 5in/51, 6in, 8in, 12in, 14in and 16in guns, except for the 14in batteries of the *New York* and *Texas* and the 12in batteries of the *Arkansas* and *Wyoming*, whose hoists could not accommodate them. Nor were special projectiles developed for the 5in dual-purpose guns, whose AAC shells were considered sufficient. HC rounds were to be used for shore bombardment, against light surface craft, and against aircraft; production deliveries began in October 1942 for the 12–16in, in August 1942 for the 5in/51, and in November 1942 for the 4in/50; the 6in and 8in HC shells predated June 1942. Typical explosive loads varied from 12.6 percent (6in HC Mk 34, 105lb) down to a more typical 8.08 percent (16in HC Mk 13, 1900lb). Late in the war both HC (Mk 41, 10.84 percent) and common shells were designed for the new 5in/54, only the HC reaching production.

Antiaircraft shells were nose-fuzed only, with relatively high capacity, as they destroyed their targets by fragmentation. They were fired only by 40mm and 3in guns; 5in guns fired instead an AAC round with nose and base fuzes. In each case the charge ratio was considerably higher in other types. For example, 5in AAC Mk 28, for the 5in/25, had a ratio of 14 percent, compared to 3.46 percent for 5in common Mk 15 (for the earlier higher-velocity 5in/50 and 5in/51) or 3.69 percent for 5in 'special common' Mk 46, for the 5in/38. There were also several unconventional projectile types, including illuminating, white phosphorous smoke, and window (chaff).

Heavy Shell Development

Probably the most characteristic feature of US shell evolution was the trend towards the 'super-heavy' shell. Immediately after World War One Midvale Steel 'unbreakable' shells were designed for the 12in, 14in and 16in guns. In the late 1930s, however, a new family of shells of greater weight was introduced (14in 1500 rather than 1400lb, 16in 2240 rather than 2110lb), with considerably improved oblique penetration. Both were virtually identical in design; there was no 12in version in view of the impending demise of the sole surviving 12in battleship, the *Arkansas*.

The next step was an even heavier shell. The General Board strongly recommended adoption of a 2700lb 16in shell on 26 June 1939; it closely approached the performance of a standard (3200lb) 18in shell. The new projectile was 4.5 calibers in length and so could not be accommodated by the hoists of existing battleships (the 2240lb shell was 4 calibers long). Increased penetrating power was measured by a sharp reduction in the immunity zone of a typical battleship (17.3in sides, 6.25in deck) against a 16in/45 gun, from a total of 11,900yds down to only 5900; against the 16in/50, the reduction was from 10,400yds down to 3900. The US battleships of the prewar program had been designed to withstand the existing 2240lb shells; it took considerable enlargement to scale up their protection to comparable immunity against the 2700lb projectile. A new family of lesser shells was also developed: 6in Mk 35 (130lb), 8in Mk 21 (335lb), 12in Mk 18 (1140lb), all similar to the 16in AP Mk 8, all 4.5 calibers long and all designed for the same muzzle velocity of 2500ft/sec.

All of these shells had a new, blunt nose design and very limited bursting charges, a typical figure being 1.5 percent, compared to 2–2.5 percent for most other navies.

There was also a change from soft nose-caps to face-hardened ones which might more effectively crack the armor surface on striking and thus improve penetration largely through reduced damage to the projectile proper. The wartime 6in and 8in rounds used almost entirely hardened caps, softened only at the edges to permit them to be crimped to the nose of the shell. Generally the result was much improved deck penetration; in turn a low-velocity heavy shell could be expected to fall at a steeper angle. For example, even the lighter 14in shell could penetrate 7.25in of deck armor at a 55° angle, whereas a comparable British 14in shell fired under the same conditions would merely have gouged the plate. The standard US shell filler, from World War One onwards, was an extremely insensitive explosive ('Explosive D') which in itself made penetration more practicable, and US prewar penetration standards were unusually high by international standards. The 14in and 16in AP projectiles were tested for acceptance at 35–40° obliquity against 13.5in 'Class A' armor. By way of contrast, the British 1920 standard was 20° against plates 67–75 percent of projectile caliber, increasing to 30° by World War Two. The Germans, the most exacting at the end of World War One, demanded that a projectile penetrate a plate as thick as its caliber at 90° (zero obliquity), or half its caliber at 30° obliquity (60° to the plate), while remaining *intact*. US common projectiles were required to penetrate 'Class B' (STS) armor, generally used for decks at 45° and in thicknesses of up to 67 percent of their caliber. Such projectiles were generally superior to AP under these circumstances.



Shells and bag charges for the battleship *California*, 1938. From left to right are five different 5in/51 shells, a 5in/51 tank, a 5in/51 powder charge, a 5in/25 'fixed' round including both shell and brass cartridge case in one unit; and a 14in/50 armor-piercing shell. The two right-most 5in/51 shells are star and illumination; that on the left is the standard armor-piercing type.

Fuzes

Again, as at Jutland, fuze development made a very considerable difference. The earliest fuze categories were 'base-detonating' (BD), generally with no inherent delay, and 'time', to permit bursts at a fixed range, either for shrapnel effect or for anti-aircraft fire. Early versions of the latter involved a powder train, 'cut' to the requisite delay, and initiated at the time of firing. They were considered inherently unsafe, and by World War Two had been replaced by clockwork 'mechanical time' (MT) fuzes, the first being Mk 18. The clocks were both safer and more accurate, although at first they appear to have suffered from unreliability.

Mk 11 appears to have been the earliest US base-detonating fuze with an inherent delay to set it off after it penetrated armor. It was an unusually complex fuze with a special impact-sensitive plunger which could adjust the delay to the deceleration experienced by the shell, *ie* to the thickness of the armor penetrated, the goal being an average travel of 50ft beyond penetration, with an error of about 20 on either side. Mk 11 could also burst an AP shell after it had penetrated several thin plates, whereas most such fuzes would permit an AP shell to pass entirely through an unarmored ship (as at Samar in October 1944). Finally, it would keep a shell from detonating until deceleration had ceased, so that a shell armed with it would not explode upon contact with water. Nathan Okun has observed that such a property would be particularly well suited to attacks against ships underwater, as was the case with many Japanese ships; he has speculated that the design of the Mk 11 coincides with American interest in protection against just such hits (about 1937). In fact, Mk 11 was too complex to be satisfactory; the adjuster for its delay often functioned poorly, causing duds, particularly when it struck armor obliquely, as in the standard proving ground tests. Some 8in shells equipped with it even exploded prematurely in the air. It was, therefore, replaced on an interim basis by a modified version, Mk 23, with a fixed time delay, and by 1944 had been completely replaced by a new Mk 21. Delays in the transition were due to the large number of

8in shells involved; in contrast, the 6in AP shells were always equipped with the Mk 21 fuze. In the modified fuzes a black powder pellet provided a fixed delay of 0.02 seconds, and the total delay was about 0.035 seconds, due to the slowness of the cocked-spring deceleration firing element. Mk 21 had a similar inherent delay.

There were still, at the end of World War Two, a variety of World War One base fuzes in service. Most were 'base-ignition' (BIF) types in which a plunger ignited a black powder charge, which in turn fired the fuze; the later BD fuzes incorporated an insensitive high-explosive charge within the fuze body. The development of appropriate insensitive explosives was a major issue of the interwar period. In 1945, the major survivors of the earlier era were Mk 2 (for the 7in/45) in both BIF and BDF forms; Mk 3 for 6in common and 7in and 14in bombardment rounds; Mk 8 for small-caliber shells (1pdr, 3pdr and 6pdr), and Mk 10 for 4in and 5in common shells. There was also a Mk 7 nose (point-detonating) fuze for the 7in/45 bombardment shell. None of these early base fuzes had any inherent delay.

Of the later generation, Mk 13 was a base-detonating fuze for the 5in/38, abandoned due to excessive prematures. Mk 19 (6in common and special common), 20 (4in and 5in common and special common) and 21 were very similar, with 0.01-second rather than 0.35-second delays in the lighter-caliber fuzes. Mk 20 was adapted as a 5in base fuze (Mk 28); ultimately it was used for all calibers from 4in up, for attacks against light vessels, bursting after penetrating only $\frac{1}{4}$ in or $\frac{1}{2}$ in of steel, or after striking water. For major-caliber weapons, it had to be replaced by Mk 39, essentially a Mk 28 with weaker arming springs – arming was accomplished by the centrifugal force of a spinning shell, and the heavy shells did not spin rapidly enough. Mk 39, introduced in November 1943, was considered unsatisfactory due to the lack of any delay action, and in June 1944 was replaced by Mk 48. Mk 31 and 36 were similar fuzes, considered relatively insensitive, for the 4in HC shell, introduced in November and

October 1944; Mk 31 had no delay, and Mk 36 (and 48) 0.01 seconds. Late in the war a Mk 64 was developed for the proposed 5in/54 common shell, with the stronger body of Mk 21 and the 0.01-second delay of Mk 36.

The principal wartime AP fuze, Mk 21, was not without problems. At Casablanca, the battleship *Massachusetts* hit the French *Jean Bart* five times with Mk 21 fuzed shells, but only one burst was observed. With Jutland very much in mind, BuOrd analyzed the results. It claimed that at least one more shell had burst (in an empty magazine), and that another had quite possibly done so under water. Of the duds, both had struck very obliquely, losing base plugs, fillers and fuzes; even so, one of them had jammed the French ship's only operating turret. Mk 21 remained in service. There are reports of considerable wartime trouble with all base fuzes due to inadequate moisture-proofing.

A considerable variety of other fuzes were developed in wartime. Mk 12, for the 1.1in machine cannon, appears to have been the earliest modern US point-detonating fuze (PDF, or nose fuze). It was extremely sensitive, to burst its small shell against any part of a lightly-built airplane – in fact it was too sensitive, and in March 1943 was replaced by an improved Mk 34, which had been under development since the preceding June. Mk 26 was developed by the Navy from an Oerlikon design (for the 20mm machine cannon) from May 1941 onwards; although very effective, it was not bore-safe and was not adopted. On the other hand, Mk 27 (40mm, March 1942) was very well liked, achieving better than 99 percent performance on its acceptance tests. There were also nose fuzes for larger calibres: Mk 29 (July 1942), based on an Army M48 fuze, for calibers from 5in up (and described by the BuOrd history as 'very effective though not entirely safe'), and the similar Mk 30 (September 1942) for 3in to 6in shells. Finally, Mk 66, for the 5in white phosphorous shell, began development in February 1943 and was just entering production at the end of the war.

Considerable effort went into the development of mechanical time fuzes, which re-

mained important for shore bombardment even with the success of the proximity (VT) fuze, and which were produced through the war. The original Mk 18 had a 0.6–45-second delay, amounting to a range of up to about 39,000yds; Mods 0 and 1 were set for 2.4–45 seconds. An alternative smaller-shell Mk 22 had a 1.4–30-second delay (Mods 4–6, 0.6–30 seconds). Mk 25, under development at the outbreak of war, was intended for the 5in/54 and 6in/47 dual-purpose guns, its long delay of 0.6–45 seconds corresponding to their great range. The original design was unsatisfactory; ultimately it entered service combining the shape of the 30-second Mk 51 with the clock of Mk 50, the more streamlined shape being required to fit the new shells. Mk 18 was unsatisfactory due both to moisture and to erratic performance when fired from large-caliber guns. The latter had too slow (and too changeable) a rate of rotation to run its clock properly, and in Mk 42 (August 1944) the clock was run by a mainspring. It in turn was withdrawn due to erratic timing and too many duds, to be replaced by Mk 62 (developed between March and June 1945). Mks 50 and 51 (May and October 1944) were moistureproofed

variants of Mk 18 for 4in and 5in guns; Mk 57 was a new time fuze (0.8–1.0 minimum, 45-second maximum delay) for the new 8in rapid-fire dual-purpose gun (development begun July 1944), and Mk 61 (begun December 1944, completed January 1945) was a wholly new development, a modified Mk 18/50 for the 5in/38 fired with a special reduced charge, at 1200ft/sec, with a delay of 0.9–1.0 minimum, 45 maximum seconds. Mk 62, for heavier guns, operated with an extremely weak set-back force, and Mk 63 replaced Mk 51. It was identical to Mk 61 but set for a higher spin rate.

There were also the auxiliary-detonating fuzes, or ADFs. The ADF was a safety feature, intended to prevent the main fuze from detonating before the projectile had spun enough to arm it; it was also to disarm the nose fuze in the event the shell struck without bursting. Mk 17, the first, was never completely satisfactory. Originally designed for 3in through 16in shells, it was later restricted to 3–6in projectiles and redesignated Mk 46 (September 1943). It, too, was unsatisfactory, as its fulminate of mercury primer rapidly deteriorated, causing duds. Modifications of Mk 17 with weaker springs

(for heavier-caliber shells) became Mk 35. Mk 43 was a redesign for the long narrow noses of 5in/54 and 6in/47 rounds (developed between September 1943 and April 1945); it was not tested in battle, but was very similar to Mk 54. Mk 44 (December 1943) for 3–6in shells proved quite successful. The similar Mk 52 was designed with weaker springs, to arm heavier-caliber shells (8in through 16in) which spun at a lower rate; production began at the end of World War Two. Finally there were Mks 54 and 55 (August and October 1944) for, respectively, medium- and major-caliber guns, and intended for longer shelf-life, with lead azide in place of the the earlier mercury detonator. Mk 54 was satisfactory except that it would burst a 5in HC shell on a $\frac{3}{8}$ in mild steel plate before the base fuze had activated; Mk 55 shared this problem.

Wartime fuze designations in a 100 series were reserved for rockets, running from Mk 100 through Mk 166 (with some higher marks for VT fuzes); bomb fuzes were designated in a Mk 200 series. As of 1983, the wartime fuze categories remain valid, although it is not clear to what extent wartime fuzes and fuze types remain in service.

Part II

Fleet air defense before 1945



The 40mm Bofors gun was the heavier companion of the Oerlikon, replacing it in many cases in 1945 in the antkamikaze refit program. Each gun was fed with four-round clips, the guides above the gun carrying up to two clips so that fire could be continuous. Note the ready-use clips inside the shield of the 40mm quadruple mount firing aboard

the carrier *Hornet*, February 1945. The trainer is standing; note his foot pedals for power control. However, the pointer can be seen at left, just visible beyond an ammunition passer. The talker stands between the paired guns. The quadruple Bofors was, in effect, a pair of twins joined together rigidly atop a power mount.

1. Introduction

From their first use at sea, aircraft represented a threat to the fleet on several levels. Some could be countered by shipboard weapons; others required counteraction by aircraft organic to the fleet, since they involved air operations beyond the range of shipboard weapons. The second category actually came first, in the form of airborne reconnaissance – in August 1916 German Zeppelins were able to warn the High Seas Fleet of the approach of the British Grand Fleet, and so avert a disaster. The British soon learned that shipboard gunfire could not drive off a scouting Zeppelin, and by 1917 many of their capital ships carried fighters. So important was the anti-Zeppelin mission that the loss of these aircraft after their missions was accepted. Spotting was the other distant (but potentially decisive) aircraft task at sea: it permitted battleships to obtain hits at much longer ranges, so that the fleet which could maintain air superiority over a battle (*ie* which could guarantee the security of its own spotters while denying the air to the enemy's) might well expect to win while remaining entirely out of range of enemy shellfire. By 1918 American observers with the British Grand Fleet were well aware of both possibilities, and of British aircraft operating procedures. In the early postwar period there was, for a time, hope that catapult aircraft carried aboard the capital ships of the fleet could perform both the spotting/scouting and the air superiority roles, although by the 1930s increases in aircraft performance had made floatplane fighters entirely obsolete.

Direct attack on warships was another matter, as generally an airplane had to come well within gun range to carry it out. The earliest airborne antiship weapons were torpedoes; Americans with the Grand Fleet were familiar with British experiments with carrier torpedo-bombers, and with British plans to use them to cripple the German fleet in harbor. Float torpedo-bombers had been used operationally by both the British and the Germans during the war. Other airborne threats at the end of World War One were level bombing (generally from relatively high altitude) and strafing. The latter might be important in battle, as strafers might, for example, prevent effective spotting. However, level bombing was never very effective against rapidly moving ships. Bombs were not sufficiently accurate, and too much 'dead time' elapsed between the release of the bomb and its arrival at its target, dead time during which a ship might well maneuver out of the way. That was why dive-bombing, introduced in 1926, was so startling. By aiming his airplane at the ship target, the pilot could greatly improve his accuracy. The bomb was not released until the pilot had fallen to about 2000ft, so that its time of flight was greatly reduced. Moreover, because the pilot was descending very rapidly, he was very difficult to hit, particularly by slow-firing guns controlled by directors calculating relatively slowly.

Shipboard counters to the different close-range threats varied considerably. Against the

torpedo-bomber, pre-World War Two gunnery doctrine called for torpedo defense batteries (5in/51) to create shell splashes in the path of oncoming aircraft. After all, coming at very low level and relatively straight, the torpedo-bomber was, from a gunnery point of view, not too different from the destroyers the guns had originally been designed to counter. The level bomber, maintaining a steady course and speed, could be countered by director-controlled barrage fire. Bomber motion could be predicted sufficiently well (by mechanical analog computers) for relatively slow, aimed fire to be effective. Antiaircraft guns were designed for a compromise between a high rate of fire, handiness (rapid movement), and a shell large enough to be lethal even if it near-missed. Direct hits were not considered likely, given the small size of the target and the great range, but shells were time-fuzed, in hope that they might explode close enough to the target airplane to damage or destroy it.

Heavy shellfire was entirely useless against the strafe or dive-bomber, as the range in each case changed far too quickly for calculator or fuze-setter to follow. The only solution was a machine gun or machine cannon, which could fire a stream of solid or impact-fuzed explosive projectiles, each of which might be lethal if it hit. Fire control would, therefore, reduce to leading the airplane sufficiently well to direct the stream of fire into it, and rangefinding would be far less important than in the case of the heavy antiaircraft gun.

In fact it was recognized, before World War Two, that actual hits by any type of antiaircraft weapon would be rare. However, the prospect of being hit would tend to distract the pilot and bombardier of an incoming bomber. Since his own chance of hitting a maneuvering ship could not be considered very great, any dislocation might save the ship. This doctrine persisted until the advent of the guided bomb and the kamikaze late in the war. The guided bomb would persist until it was destroyed or its guidance link jammed; in fact only the latter proved practicable. As for the kamikaze, its pilot, wishing to die, would actually steer towards heavy antiaircraft fire. Moreover, if it were hit at too short a range a kamikaze might well continue on into its target. The modern equivalent is the fear that an antiship missile, hit at too short a range, will 'go ballistic' and continue on to its target.

Before World War Two fleet air defense was primarily the responsibility of fleet gunners. Heavy antiaircraft guns mounted on destroyers contributed to the defense of heavy fleet units, since they could reach aircraft trying to attack the battleships; on the other hand, machine guns and machine cannon were always individual ship defensive weapons. Thus, for example, destroyers were provided with dual-purpose guns and with elaborate dual-purpose directors because it was assumed that the US Fleet would encounter Japanese air attacks en route to battle in Japanese home waters. Later, in World War Two, destroyers armed primarily with 5in/38 guns (and with inferior

light batteries) were considered suitable as carrier task force escorts; very large additions of light weapons were made only when the Fleet encountered kamikazes which might attack the destroyers themselves.

As for carrier aircraft, without early warning of incoming attacks they could not hope to counter them effectively. By the late 1930s there was a doctrine of aerial pickets for fleet defense, and some limited early warning was provided by screening ships at a distance from the major units. However, Navy tests of the standard Army sound-warning system were disappointing at best, and it was not until the advent of radar that fighters could be considered very valuable fleet air defense assets. Increased interest in fighter protection shows, for example, in the provision of a double fighter squadron in the *Essex* class designed in 1940.

Given radar early warning, the fighters soon became the dominant element of fleet air defense, so important that destroyers were converted into radar picket/fighter control ships in 1945. With radar, a standing combat air patrol (CAP) could be vectored efficiently towards approaching enemy formations. Such standing patrols were effective precisely because, with radar, they did not have to cover all possible directions of approach. Radar was, in effect, a force multiplier. In addition, by 1944 US fighters were available in sufficient numbers to achieve great attrition against enemy land-based airfields at the outset of an operation, considerably reducing the threat the Japanese could mount.

The same radar technology which contributed to the effectiveness of carrier fighters also greatly increased that of the shipboard antiaircraft guns. There were radar-controlled directors for all calibers from 40mm up, permitting night firing with greater accuracy than had been achieved in day firing before 1940. Moreover, from 1942 onwards there was the proximity (VT) fuze (see below, Section 6). Previous antiaircraft weapons had been time-fuzed, requiring both a director calculation and a delay while a fuze was set. The VT fuze, in effect a small range-only radar, decided for itself when it was within lethal range of a target. One of the uncertainties of heavy-caliber antiaircraft fire was thereby eliminated. By 1945 there were VT fuzes for calibers down to 3in; the existence of a 3in VT fuze explains the choice of the 3in/50 as the primary weapon of the BuOrd antikamikaze program of 1945. There was no 40mm VT fuze until well after the war.

2. Heavy antiaircraft guns

Early Installations

As early as 1914 the Characteristics (staff requirements) of US warships contemplated for future building programs included provision for 'aeroplane guns'. In the battleships, the first class so affected was 'Battleship 1915' (*Mississippi* class), with four 3in/50. In fact the prototype installation was aboard the *Texas*, in 1916, and the *Pennsylvania* was the first battleship completed with the four-gun battery. By 1918 it was standard, and in the first round of postwar refits (1919–21) it was doubled in all the battleships. The seriousness with which air attack was taken is indicated by the cost accepted: two open-mount 5in/51 anti-destroyer guns were landed. As for cruisers, tentative Characteristics for a scout cruiser showed two AA weapons, and the *Omaha* Characteristics of 1915 show two heavy and two light (machine gun) antiaircraft guns. Postwar these ships were completed with four 3in/50 each. 'Destroyer 1916', the *Caldwell* class, was the first whose Characteristics included antiaircraft weapons. However, the previous *Sampson* class was completed in 1916–17 armed with two 1pdr 'pom-poms' and a pair of 0.30-caliber machine guns. A similar battery was specified for the wartime 'flush deckers', but in view of the scarcity of pom-poms most had the new 3in/23 instead. In many cases, too, a third machine gun was provided.

All of these weapons had been adapted from existing antiairship types. BuOrd's first attempts

at antiaircraft guns were conversions of 3in/50 and 4in/50 antidestroyer guns and a conversion of a 1pdr pom-pom machine cannon. By the late fall of 1914 the pom-pom was complete, and the 3in/50 nearly ready; the Bureau was all set to test them against targets towed by aircraft. Within a year the 3in/50 was in production and 1pdrs in stock were being given antiaircraft mountings; a 4in/50 prototype was 'highly satisfactory' in trials but it did not enter production; it was later criticized as clumsy. There was also a design for an entirely new 1pdr AA gun, which was to be the basis for a more powerful weapon. In fact, however, the US revival of the pom-pom recalled British use of the Vickers 2pdr at about the same time. As for the 3in/23, it had been developed hurriedly to replace existing 6pdrs aboard 110ft subchasers as a surface-action gun. It had no special antiaircraft properties and was never considered particularly effective; its principal merit was that it could fit spaces originally chosen with the pom-pom in mind.

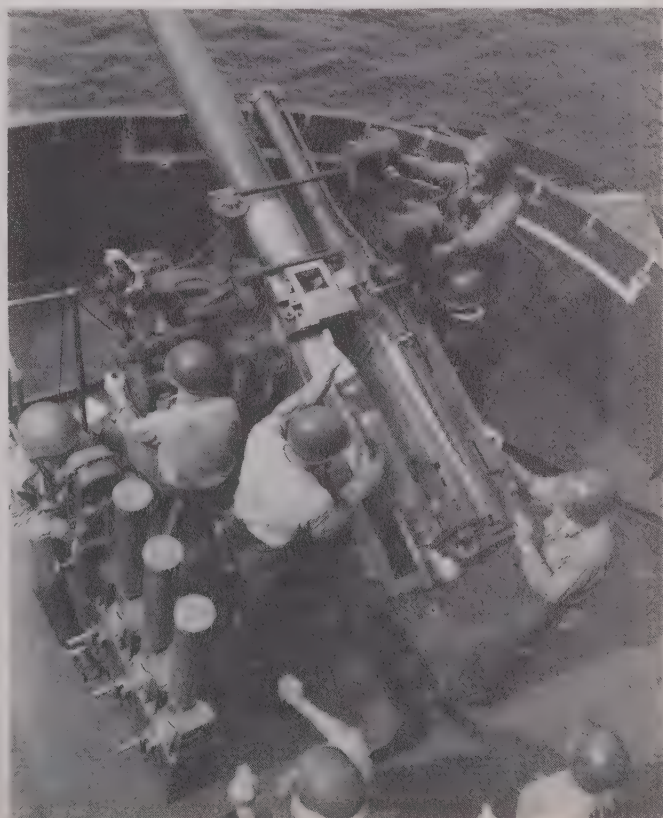
The 5in/25 Gun

In 1921, BuOrd began work on a new antiaircraft weapon, which would form the basis for subsequent US heavy naval AA guns – the 5in/25. The principal considerations were weight of shell (for explosive effect), rate of fire, and handiness. Given its expectation that barrage fire would be needed to counter level bombers, the Bureau of Ordnance was far less interested in a high muzzle velocity. A high rate

of fire required fixed ammunition for rapid hand loading and power ramming, the latter being necessary at high angles of elevation. Thus the total of shell plus cartridge was limited to about 100lb. Handiness in turn required a relatively light weapon with a limited moment of inertia (resistance to turning), ie one with a relatively short barrel. Finally, ease of operation, particularly of loading, translated into a requirement for a limited trunnion height, ie for limited recoil, since the trunnions would have to keep the breech clear of the deck in recoil at maximum elevation.

1 The 3in/50 was the first US Navy heavy antiaircraft gun, and it was brought back into production during World War Two. This weapon, aboard the old destroyer *McCormick*, belongs to the later series, identifiable by the prominent counterweight above the sight-setting yoke. The vertical sliding-wedge breech block is lowered, exposing the bore of the gun for loading; note the ring sights on the pointer's side.

2 The 5in/25 was the first US Navy antiaircraft gun designed for the purpose, with high elevation and fixed ammunition. Here a round is just being thrown into the vertical sliding-wedge breech, while pointer and trainer maneuver the mount. The sight-setter occupies the railed platform on the forward right side of the mount, with axles projecting across to the pointer's side of the gun. These weapons used time-fuzed shells, three of which could be set simultaneously (at left, with the fuze-setter seated at his machine). The loader is behind the gun to the left, and the 'hot case' man behind to the right ready to receive the spent cartridge case. Bearing markings around the gun tub permitted quicker train in response to verbal instructions. The very similar 5in/38 required a larger charge to achieve higher velocity, for effective surface fire: it had a separate cartridge case, which was more cumbersome. This gun was photographed aboard the battleship *New Mexico* off Guam, July 1944. US National Archives



Full power operation was rejected as increasing the vulnerability of the weapon to minor battle damage, and indeed it would not be accepted until the end of the 1930s. In addition, long recoil was to be avoided as the Navy would not accept the complication of a gun pit to receive the recoiling breech. The new gun would, after all, arm existing ships at minimum cost in structural alteration.

These factors added up to a large-caliber, low-velocity gun. At 54lb, the 5in/25 shell weighed about as much as that of the 5in/51, but the powder charge was 9.5lb, compared to 23.8; muzzle velocity was 2200ft/sec, compared to 3150. Recoil in both mounts was about equal at 15in, but in the 5in/51 this had been bought by using a much heavier barrel assembly, 10,824lb (Mk 9) vs 2125. The anti-aircraft character of the 5in/25 shows in its heavy breech assembly, which acted as a counterweight: including the breech, it weighed 5175lb, whereas the 5in/51 breech added only 551lb to its total weight. Low velocity was quite acceptable in an anti-aircraft weapon, as long as the targets were at relatively low altitudes, such as 10,000ft. Surface fire was an entirely different matter, since the low-velocity gun had a very limited danger space at normal antidestroyer surface ranges, eg 6000yds.

Even so, the handiness and the high rate of fire of the 5in/25 made it an attractive anti-surface gun: it could fire 15–20 rounds per minute, whereas the 5in/51, with bag ammunition and without power ramming, could only achieve 9. When the 5in/25 first appeared aboard battleships in 1926, gunnery officers began to think of it as a dual-purpose gun, and they began to fire it in the annual surface gunnery practice, often with impressive results.* Meanwhile the first of the US Treaty cruisers were under design. Their Characteristics called for four 5in/51 starshell guns for illumination,

and eight automatic anti-aircraft guns, which were to be a new 37mm type under development by the Army. However, progress with the lighter weapon was slow, and the two *Pensacolas* were redesigned with four single 5in/25 in their place; since these weapons could fire starshell, the originally planned pair of twin 5in/51 were dropped. Early in the *Chester* (CA-26 class) design, word was received of progress with the 37mm, and for a time the contract design of that class showed eight paired 37mm and the four starshell guns, but then early in November 1926, with the plans almost complete, BuOrd notified the designers that they should revert to the all-5in battery. Although these weapons were considered anti-aircraft guns, they had to be counted as antisurface (or at least as anti-destroyer) weapons as well. That is, the cruisers were armed only with a long-range, slow-firing 8in/55, which would be ineffective against any destroyer which succeeded in approaching to within torpedo range; only the fast-firing 5in/25 could counter such a threat.

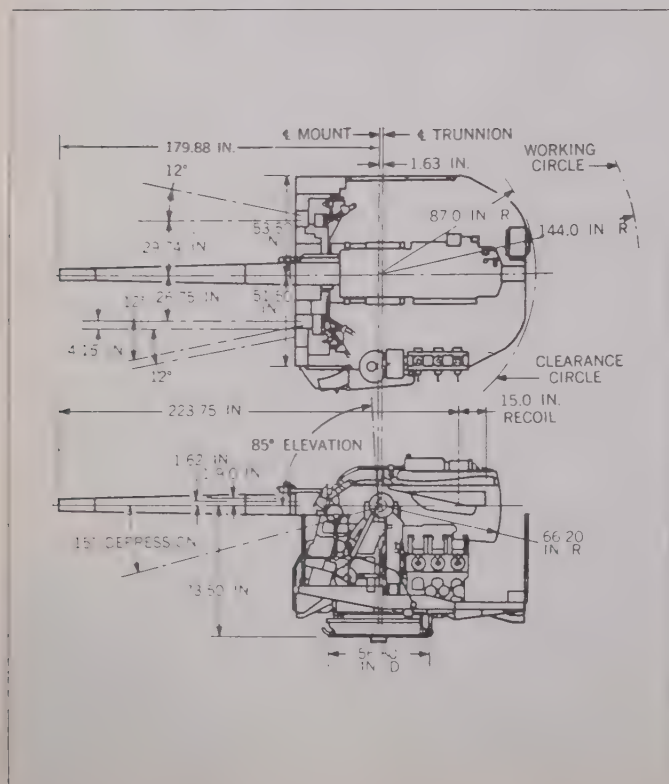
The 5in/38 Gun

In 1928 the US Navy began to design battleships for construction after the end of the building 'holiday' decreed by the Washington Treaty. Experience with the 5in/25 made a uniform battery of dual-purpose weapons attractive, and 5.3in and later 5.4in guns were proposed. At the same time, designs being prepared for destroyer leaders showed 5in/25 batteries, and proposals began to be made for the replacement of existing 4in/50 guns aboard the 'flush deckers' by the new 5in/25. Although the subsequent analysis showed that the 5in/25 would not be effective as a destroyer gun, it did lead directly to the development of a true dual-purpose weapon, the 5in/38, the standard US secondary-battery and destroyer gun of World War Two.

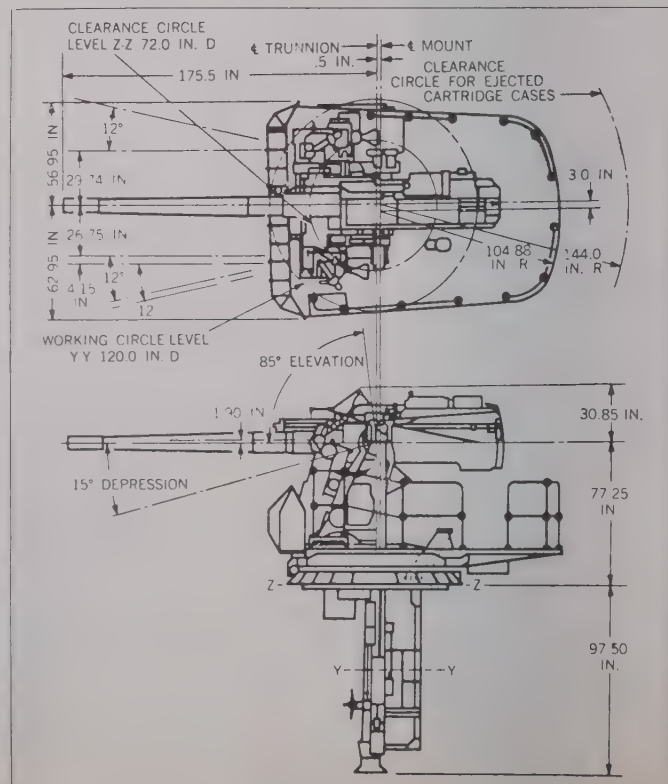
The problem was accuracy at long range. For the ten highest-scoring destroyers in the 1928–29 Long Range Battle Practice, 80 percent had spotting errors of over 60yds, and 60 percent beyond 120yds, at a range of 6780yds. It followed that one salvo of high-velocity (2900ft/sec) 4in/50, the standard destroyer gun, would make 96 percent hits (danger space about 67yds) with a 60yd plotting error, and 80 percent at 120. Under the same circumstances, a 5in/25, with about half the danger space of the 4in, would make, respectively, 80 and 40 percent. Thus it would need a considerable improvement in fire control accuracy to make up the difference. In 1931 it was estimated that at 6000yds a 4in destroyer would make about 1.6 times as many hits as would the 5in/25. If, however, a larger shell were considered necessary (for example to counter the larger foreign destroyers), the 5in/25 was far superior to the 5in/51 in handiness. A 1930 study showed that, in train, the 5in/51 had about three times the moment of inertia of the 5in/25. The destroyer *Gilmer* was rearmed with the 5in/25, and tests at sea showed that the high rate of fire could be maintained in a seaway, even though at low elevations the breech of the gun was at the height of a man's shoulder and hence difficult to reach rapidly. This height had been accepted in the original design as the cost of rapid loading at high elevations. Even the objection that the gun required compressed air for its power rammer was disposed of. However, rearmament of the existing destroyer fleet was rejected due to cost and to the limited margin of improvement (over the existing 5in/51) which it represented, for surface fire.

*Testimony at General Board Hearings as early as 1922 suggests that BuOrd was already thinking in dual-purpose terms, with a 5in/40 at the talking stage.

THE 5in/38 MOUNT MARK 24 MOD 6



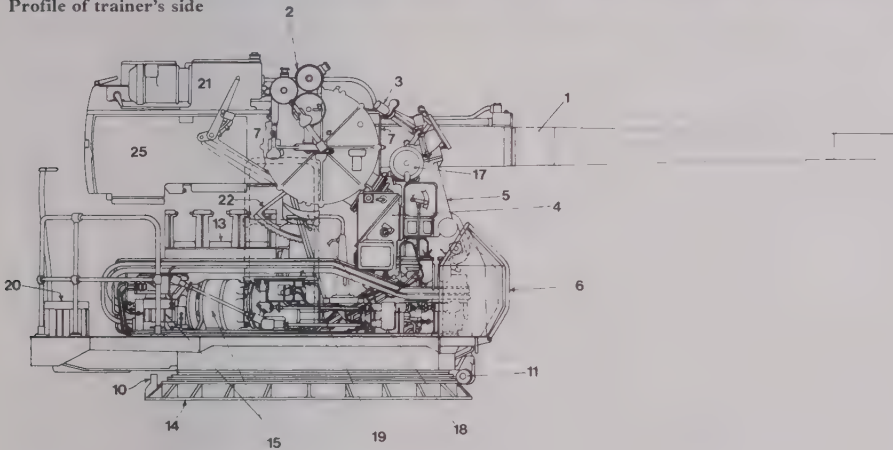
THE 5in/38 MOUNT MARK 30 MOD 8



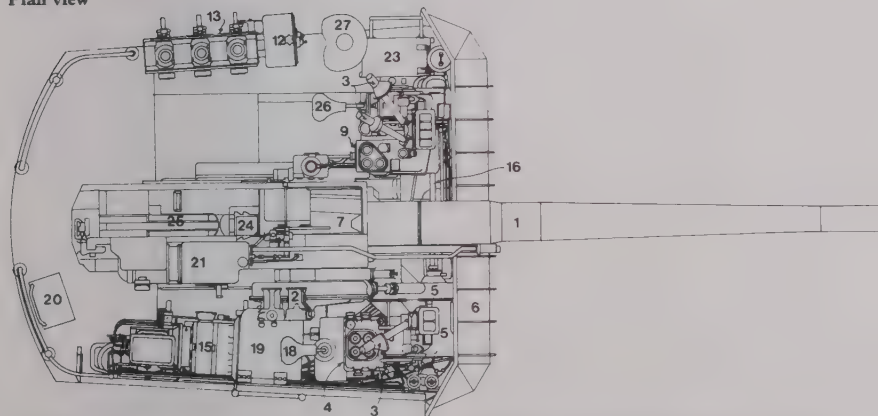


The 5in/38 was distinguishable from its smaller cousin by its use of semifixed rather than fixed ammunition, as is evident from the shells in the hands of these sailors. The pair of dials indicate elevation and train instructions from a director; the sight-setter matched pointers against them, or followed the talker's verbal instructions. The lower (left-hand, in this photograph) dial showed deflection (angle in bearing), the upper showed sight angle (elevation); in each, an inner dial was controlled by the director or computer, the outer by the sight-setter. The assembly above the gun is the electric-hydraulic rammer and its drive; the massive block at the breech acts as a counterweight, making the gun easier to elevate rapidly. Note the prominent open sights. This weapon was No 3 gun aboard the destroyer *Shaw*, July 1942. *US National Archives*

Profile of trainer's side

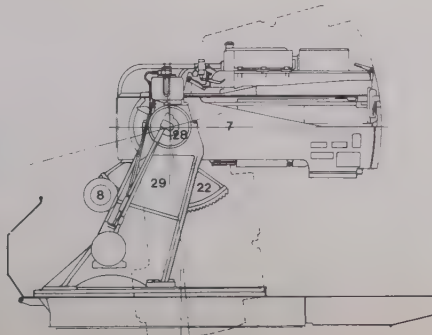


Plan view



Front elevation

Profile of left trunnion bracket and gun slide

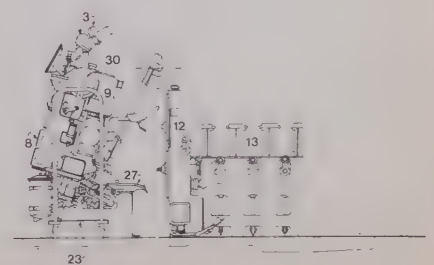


THE 5in/38 MOUNT MARK 30 MOD 33

Key

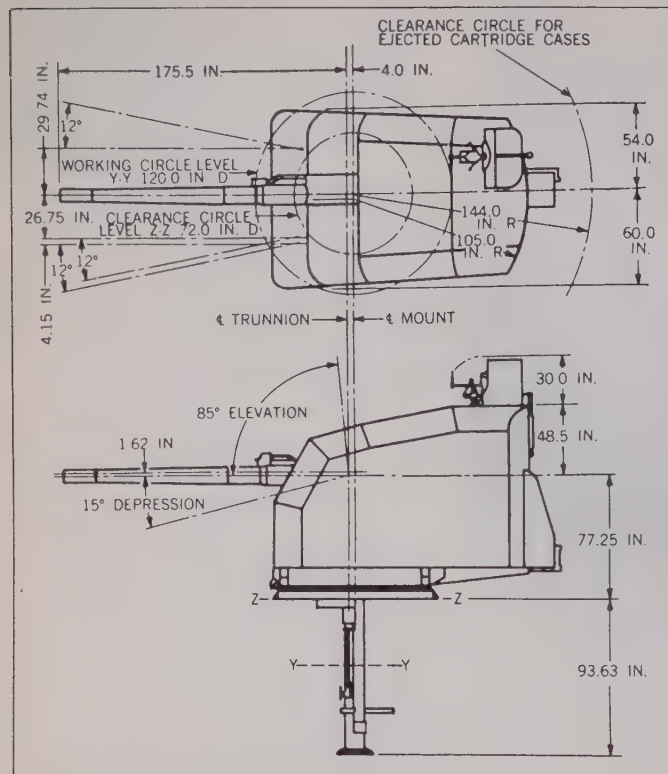
- 1 Mk 12 gun
- 2 Sight-setting gear
- 3 Telescopes
- 4 Gun training indicator regulator
- 5 Training gear
- 6 Spray shield
- 7 Gun slide
- 8 Elevating gear
- 9 Gun elevating indicator regulator
- 10 Training stop
- 11 Training buffer
- 12 Fuze-setting indicator regulator
- 13 Fuze-setting machine
- 14 Stand
- 15 Electro-hydraulic training motor
- 16 Elevating cross-shaft
- 17 Training crank
- 18 Trainer's seat
- 19 Sight-setter's platform
- 20 Loading platform
- 21 Rammer pump
- 22 Elevating arc
- 23 Checker's platform
- 24 Breech block
- 25 Rammer
- 26 Pointer's seat
- 27 Fuze-setter's seat
- 28 Trunnion
- 29 Trunnion bracket
- 30 Elevating crank

Pointer's side of platform

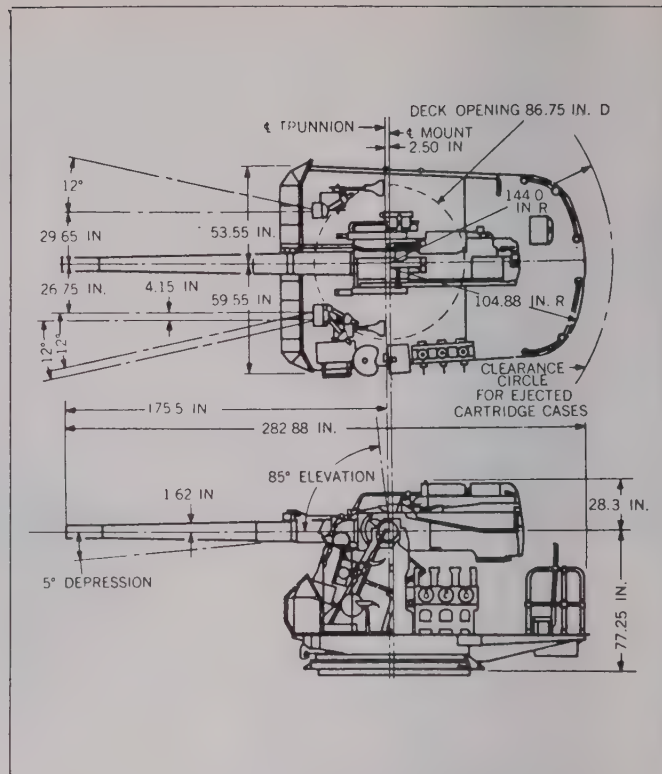


II. FLEET AIR DEFENCE

THE 5in/38 MOUNT MARK 30 MOD 18



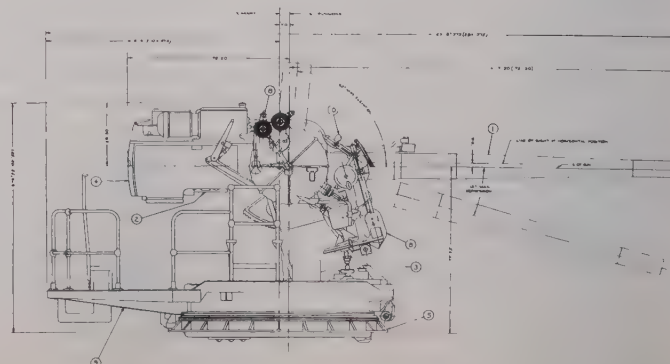
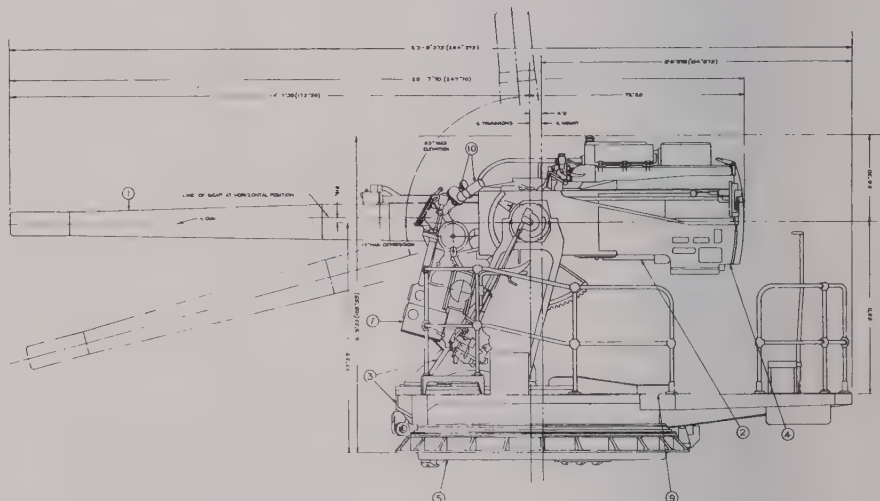
THE 5in/38 MOUNT MARK 30 MOD 51



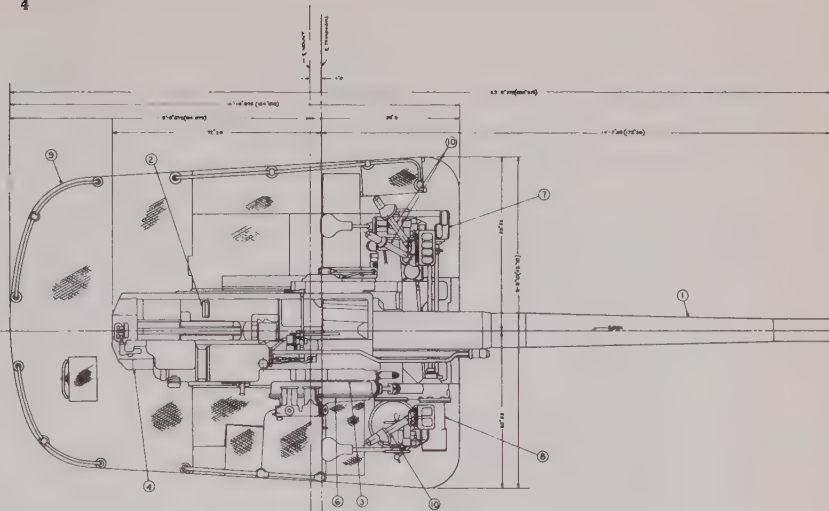
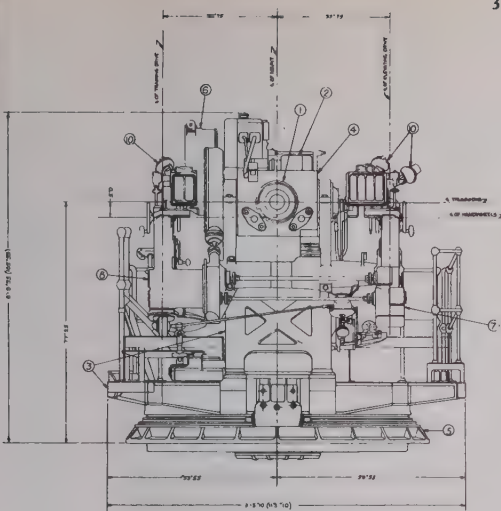
The existing 4in/50 was considered inadequate, in view of poor results in test firings against four elderly Yangtse gunboats. Fuzes were not sensitive enough, and fragmentation appeared poor. Nor was the rate of fire encouraging: typical rates were no better than those with the 5in/51 – 6–8 rounds per gun per minute. Although BuOrd promised a new shell to overcome the defects of the existing one, its arguments do not appear to have been convincing. Even the 5in/51 had its limits: compared to the 5in/25 it had a much smaller bursting charge (1.7lb *vs* 5.63 for the latter), since it had been designed to penetrate thin armor, whereas the 5in/25 was intended to damage an airplane at a distance.

The General Board considered a variety of alternative medium-caliber guns, including 4.5in and 4.7in types, but fixed on a developed 5in/25 with a higher muzzle velocity (2600ft/sec) for greater accuracy in surface fire. Some reduction in the rate of anti-aircraft fire had to be accepted; to achieve its greater power the new gun used semifixed rather than fixed ammunition. Thus power ramming remained possible. Danger space did improve; at 6000yds it was 56yds, compared to 34 for the 5in/25 – but 87yds for the high-velocity 4in/50 and 96 for the 5in/51.

The 5in/38 gun and its mount were enlarged versions of the 5in/25, including the inconveniently high breech and the fast-acting vertical sliding-wedge breech block. It was originally procured for destroyers; with limited funds, there was no money available for the development of a second dual-purpose gun for the new battleships ordered in 1937, although there was sufficient dissatisfaction with the 5in/38 for a new gun to be designed before the outbreak of war. Given a dual-purpose weapon aboard destroyers, it became necessary to develop a new family of destroyer directors, Mk 33 and, later, Mk 37. These instruments contributed in



THE 5in/38 MOUNT MARK 30 MOD 48 (see next page for key)



THE 5in/38 MOUNT MARK 30 MOD 48 (contd)

Key

- 1 Mk 12 gun
- 2 Housing
- 3 Carriage
- 4 Slide
- 5 Stand
- 6 Sight
- 7 Elevating gear
- 8 Training gear
- 9 Platform
- 10 Telescope

large measure to the success of the guns in war-time. However, it does not appear that the 5in/38 was originally bought because of a large demand for a dual-purpose gun in the destroyer force: the General Board was perfectly willing to revert to a single-purpose 5in/38 in the 1850-ton 'leaders' in order to buy eight guns rather than six. Only when proposals were made in 1936 to switch to single-purpose guns in standard destroyers was the value of a dual-purpose main battery examined in detail.

By this time the destroyers with their director-controlled 5in batteries were seen as a major defense for the Battle Line on its way to the Western Pacific, and anti-aircraft (and, for that matter, ASW) was considered as important as antiship capability. Since the single-purpose gun had been suggested as a means of increasing torpedo batteries, the argument in its favor ended. Ultimately a compromise was reached: new destroyers were fitted with four rather than five 5in/38, and with four rather than three quadruple torpedo tubes.

During the 1930s the 5in/38 progressed through three distinct types of mounting. It began with a pedestal mount similar to that of the 5in/25. In 1937 the *Craven* class appeared with a new base-ring mount incorporating shell and powder hoists on the axis of the mount, for more rapid fire (15–22 rounds per minute). Fuzes were set in the hoist. Moreover, since it was no longer necessary to pass shells and powder through the rear of the mount, it could be completely enclosed. A full shield provided considerable protection, but also added weight and necessitated power operation. Although the latter ultimately simplified the introduction of remote control (for much more effective anti-aircraft firepower), it was resisted at first, since it increased vulnerability to battle damage. For example, the need to be able to operate at least some guns after the loss of the main power plant was one reason for increased emergency diesel power in US destroyers of the late 1930s. The single enclosed 5in/38 was, in any case, barely capable of being man-handled in an emergency; the same could not be said of the next development, the twin 5in/38.

This had almost as complex a history as the 5in/38 itself. In 1930, just as it was investigating a new destroyer gun, the General Board became concerned with the vulnerability of cruiser secondary batteries (5in/25) to strafing

and to fragment damage. The obvious solution was an enclosed twin 5in/25, which was specified for the cruisers then under construction: *Wichita*, *Helena* and *St Louis*. However, *Wichita*, limited by Treaty to 10,000 tons, proved a very tight design. In view of the advantages of the single enclosed 5in/38 over even a twin 5in/25, the former was substituted in her design in 1936. That left two cruisers, which would be the sole platforms for an entirely new twin 5in/25. They had more reserves of weight than did the heavy cruiser, and a new twin 5in/38 was substituted, the forerunner of twin mounts for battleships, cruisers, carriers and destroyers. The only earlier twin 5in/38 had been the single-purpose Mk 22 of the 1850-ton 'leaders'.

The new twin 5in/38 definitely required power operation, and there was some resistance to its appearance aboard destroyers on that score. Its weight, compared to that of the earlier single-purpose twin mount, shows in the sacrifice necessary in the battery of an 1850-ton destroyer converted to dual-purpose guns: five 5in/38 (two twin and one single) DP in place of eight 5in/38 SP (four twin mounts). Great increases in light-caliber firepower contributed to the reduction in 5in mounts, but ultimately rearmament involved the replacement of about 280,000lb of SP guns by about 238,000 of DP plus 15,000 or 25,000 of Bofors guns and a new, heavier, fire control system.

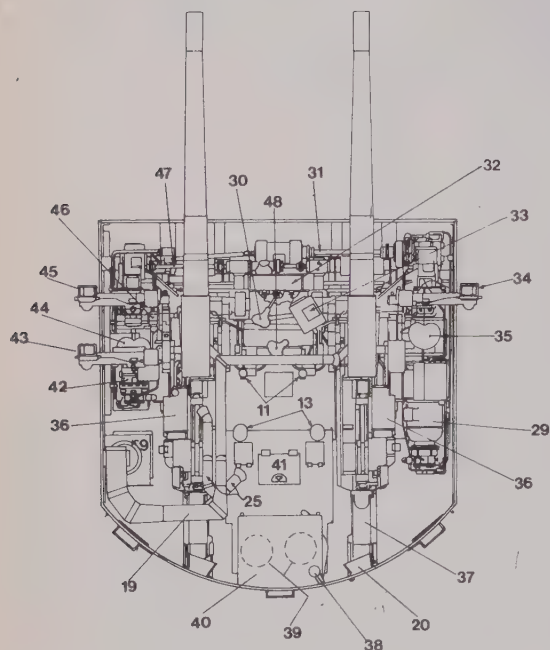
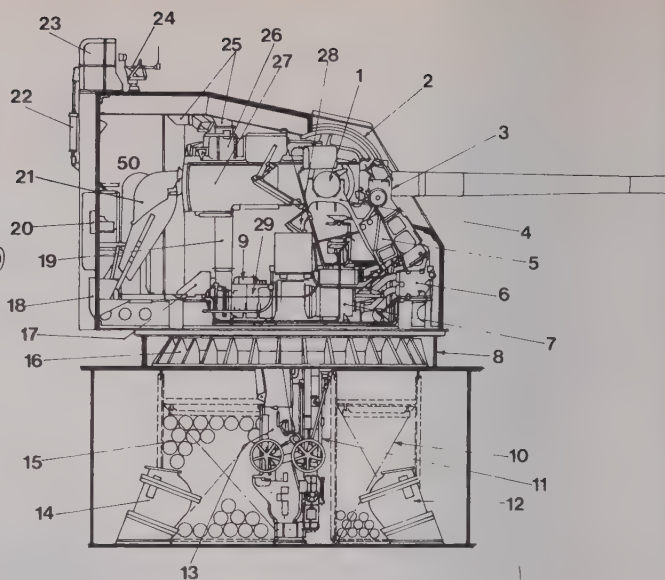
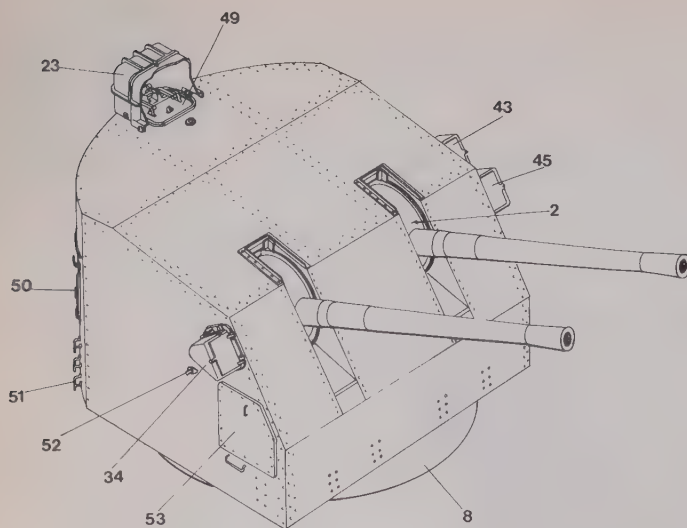
There is no question but that the 5in/38 was very well liked: the 1945 Pacific Fleet Ordnance Board described it as outstandingly accurate, fast-firing and easy to maintain, with a long barrel life. Criticism was very limited, although the power drive was considered inferior to that of the 6in/47.

The 5in/54 Gun

Although the 5in/38 remained the primary US heavy anti-aircraft gun through World War Two, that did not mean that no replacement had been proposed. In 1937, with the United States limited to 8000 tons for future cruisers (under the London Treaty of 1936), BuOrd proposed a new 6in/47 dual-purpose weapon which would increase cruiser firepower by doing away with the secondary battery. The General Board was interested, but at the crucial moment the Bureau had to admit that the new weapon was not nearly ready for construction. No workable 8000-ton design was

possible, and the 6000-ton *Atlanta*, armed only with the twin 5in/38, was adopted instead. The next year, with the same Treaty limits in force, the twin dual-purpose 6in/47 was again proposed, and this time a design embodying it (five twin 6in/47) was adopted for what were to be Cruisers 55 and 56, *Cleveland* and *Columbia*. There was no question of operating so large a mount by hand power, and the Characteristics required sufficient diesel emergency power to operate half the battery even if the main power plant were lost. This requirement proved fatal. Even at 8000 tons the light cruiser design was extremely tight, and there was not nearly enough weight available for a large enough diesel with its generator. As attempts were being made to overcome the problem, war broke out, and the Treaty was, in effect, suspended. A relieved General Board dropped the 8000-ton project, and adopted instead a modified version of the existing 10,000-ton mixed-battery *St Louis*, which became the *Cleveland* as actually built. The dual-purpose 6in/47 was resurrected in wartime as the basis for the large anti-aircraft cruisers of the *Worcester* class.

In 1939, however, BuOrd and the General Board looked towards a new generation of dual-purpose guns, more satisfactory than the existing 5in/38, to arm the new battleships, carriers and cruisers. Calibers up to 6in were considered, the 5in/54 ultimately being selected. In November 1939 the General Board summarized its requirements: a rate of fire of not less than 15 rounds per minute at any elevation; a unit ammunition weight of not over 75lb; weight of metal at the target of not less than 1000lb/min; muzzle velocity not less than



THE 5in/38 TWIN MOUNT MARK 32

Key

- 1 Trunnion
- 2 Gun port shield
- 3 Training gear handwheel bracket
- 4 Right gun carriage
- 5 Training indicator regulator
- 6 Training gear box, B-end
- 7 Training gear box, A-end
- 8 Barbette (fixed to ship)
- 9 Ventilating system motor
- 10 Ready-service projectile stowage in handling room
- 11 Projectile hoist (mount)
- 12 Projectile hoist (ship)
- 13 Powder hoist (mount)
- 14 Powder hoist (ship)
- 15 Ready-service powder stowage in handling room
- 16 Base ring (training rack on inside)
- 17 Air intake compartment
- 18 Case ejection chute door on back of shield
- 19 Air vent trunk
- 20 Auxiliary case-ejection port, in back of shield
- 21 Case ejector
- 22 Roof hatch counterbalance
- 23 Mount captain's blast hood
- 24 Open sight
- 25 Air intakes
- 26 Rammer motor
- 27 Right gun slide
- 28 Elevating arc (fixed to gun slide)
- 29 Training gear motor
- 30 Sight-setter's seat
- 31 Training connecting shaft
- 32 Sight-setter's indicator
- 33 Fuze-setting indicator regulator
- 34 Trainer's telescope
- 35 Trainer's seat
- 36 Rammer pump
- 37 Case ejector chute
- 38 Voice tube
- 39 Ammunition hoist motors, under captain's platform
- 40 Mount captain's platform
- 41 Hatch
- 42 Elevating gear motor
- 43 Checker's telescope
- 44 Pointer's seat
- 45 Pointer's telescope
- 46 Pointer's foot firing pedal
- 47 Elevating cross-shaft
- 48 Fuze-setter's seat
- 49 Roof hatch
- 50 Rear access door
- 51 Foot rungs
- 52 Side access door retaining hatch
- 53 Side access door

2700ft/sec; slant range (45° elevation) not less than 14,000yds (with sight elevation not to exceed 12° for this range); a maximum surface range of not less than 18,000yds (30° elevation); a gun tube life of not less than 800 rounds; a clearance circle of 12ft or less; and easy handling, which meant that in single mount form the gun could be held on an air-plane by hand power alone.

These figures were far beyond the limits of the existing 5in/38. Firing fifteen 54lb shells per minute, for example, it could put only 810lb per minute on a target; its muzzle velocity was only 2600ft/sec; its slant range was only 11,900yds; and its surface range was only 16,500yds. It did have a gun tube life of 1500 rounds and its clearance circle was only 11ft 11in. Some improvement was possible. For example, the gun could be boosted to 2700ft/sec, at the cost of a reduction in gun life to 800 rounds, although BuOrd felt that the pressure required would be excessive. Alternatively, projectile weight could be increased to 60lb (2500ft/sec, life reduced to 1200 rounds and weight of metal increased to 900lb/min; slant range would increase to 12,300yds and surface range to 17,000). With the heavier

shell, boosting to 2700ft/sec, although still conceivable, would be well outside the strength of the gun, and even theoretical lifetime would fall to 400 rounds. Moreover, neither the 5in/38 nor any of the other guns which would be proposed would meet the General Board's desire for hand operation. BuOrd did comment that 'The 5in/38 can be made to meet this requirement under certain special conditions of smooth seas and minimum maneuvering on the part of the target. [It] is the only gun which will meet the requirements of a minimum clearance circle and a rate of fire of at least 15 rounds per minute.'

The upper limit on shell weight restricted caliber to 5.4in, although BuOrd continued to advocate its 6in/47. The requirement for weight of metal on the target implied a caliber of at least 4.7in, and in fact BuOrd considered only weapons of 5in and greater calibers. Muzzle velocity and gun tube life also determined the choice of caliber and shell weight. For example, if gun tube life were set at 1000 rounds (which BuOrd considered an effective minimum), then the 5in/54 might fire a 70lb shell at 2600ft/sec or a 65lb shell at 2700, at, respectively, 13 and 14 rounds per minute

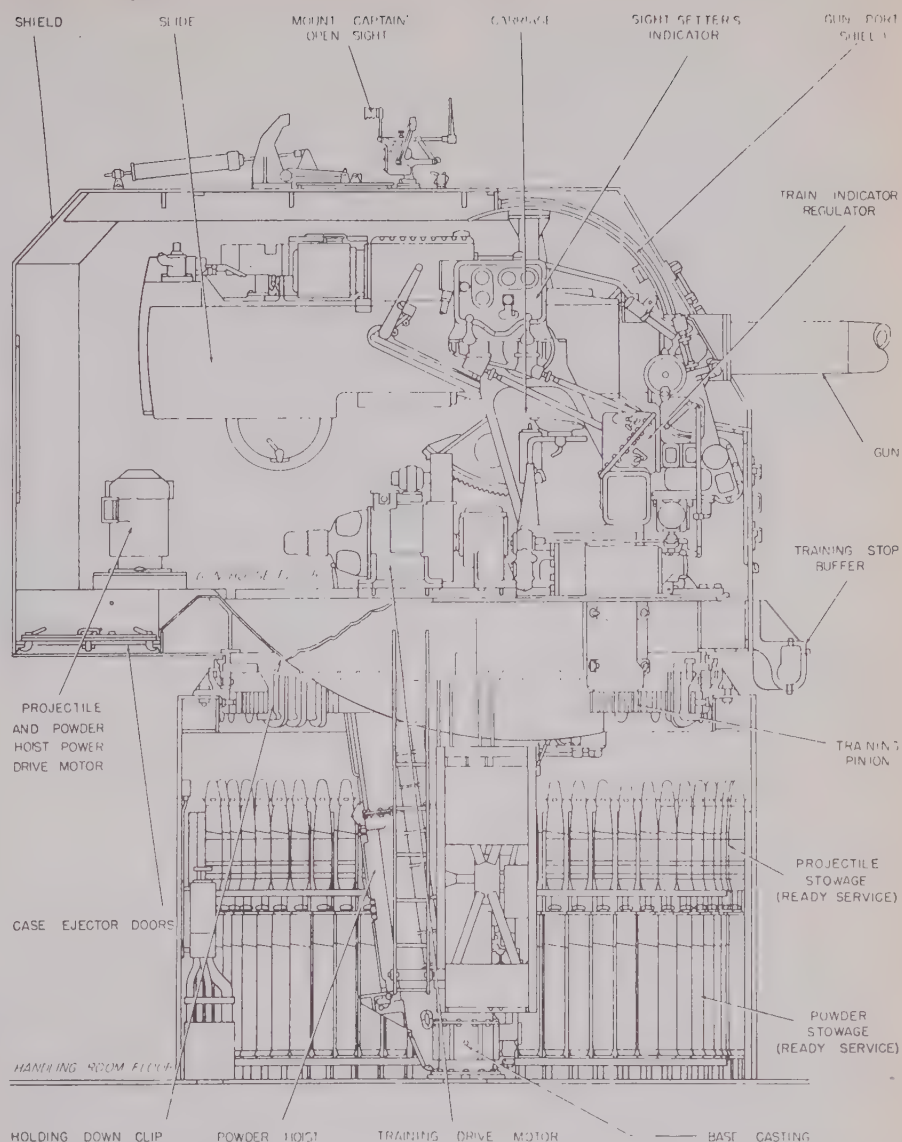
(910lb/min). Similarly, the 5.4in/48, firing a 75lb shell 12 times per minute (900lb/min) could achieve the 2700ft/sec velocity. The 6in/47, however, would last only about 550 rounds (10 rounds per minute, or 1050lb/min using its 105lb shell). BuOrd argued that the 5in/54, 5.4in/48 and 6in/47 all satisfied the General Board's range requirements, although the 6in could not satisfy the tube life limit. Clearance circles were stated as 13ft 6in for the 5in/54 and 5.4in/48, and 19ft 2in for the 6in.

In October, BuOrd presented an elaborate study of alternative dual-purpose guns, based on gun tube life; on the number of bursts possible against given attacking aircraft between opening fire and bomb release (as well as on the weight of metal thrown up); on the penetration of armor, in the antiship role; and on the number of guns which might be carried on a given displacement. Although the 6in/47 had only half the tube life of the other guns, its lower rate of fire might make that lifetime acceptable. As for the number of bursts, the 5in/38 fired faster than the other guns but the others could put up a greater weight of fragments. For example, the Bureau considered defense against a 200kt airplane flying at 10,000ft. Fire would open at a range of 10,000yds. The highest-velocity gun, the 6in/47, would actually be able to engage the airplane for slightly longer, 50.1 seconds compared to 47.1 for the 5in/38; and it would fire 985 *vs* 690lb of shell, or 725 *vs* 505lb of fragments. This advantage would increase at higher altitude: at 20,000ft, for example, it would be 735 *vs* 485lb of shell. Even the 5in/54 would show a decided advantage, due to its heavier shell. In addition, the 5in/54 would be able to get the first fragments on a 10,000ft target 1.6 seconds before the 5in/38; at 20,000ft the advantage would be 2.7 seconds. However, the 5in/54 would weigh far more. BuOrd suspected that eight twin 5in/38 would be equivalent in weight to six 5in/54: 'It will be seen that the advantage of 90 lbs of fragments and 1.6 sec shorter time in getting off the first burst... will not compensate for the loss of four guns either for anti-aircraft or surface fire... a double purpose gun can not be chosen on the characteristics of the guns alone, but on the size of ship they are to go in...'

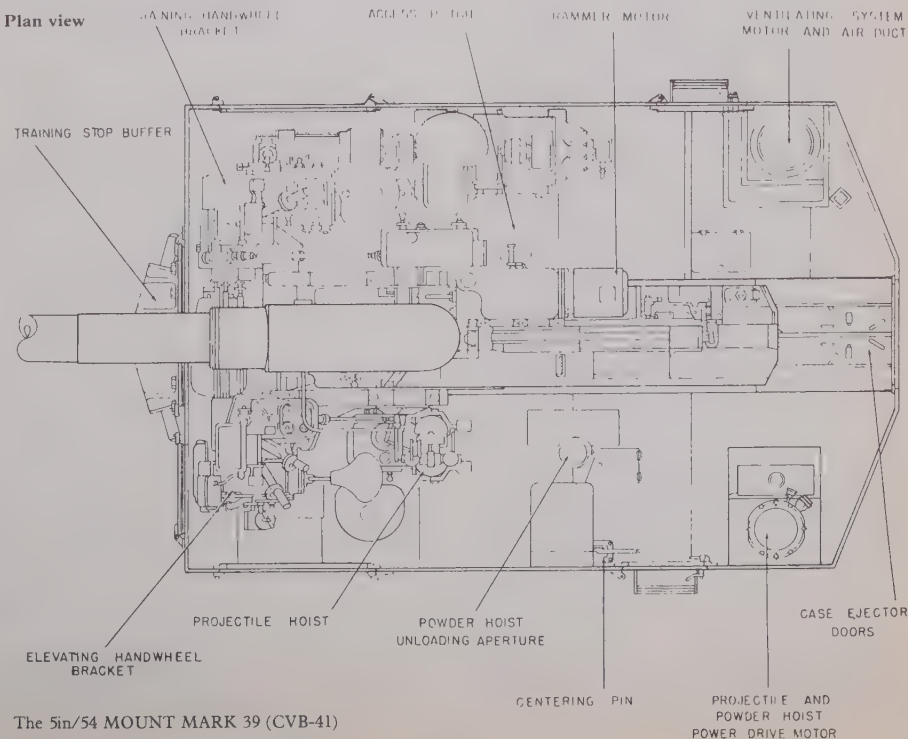
As for penetration, the 5in/54 could pierce 0.5in more armor than the 5in/38 at 8000yds, and 0.3in more at 16,000, both with common projectiles. Thus the 5in/38 would suffice against destroyers, but not against a light cruiser like the *Omaha* (1.96in–0.98in side), as at 10,000yds it could penetrate only 1.5in. The Bureau noted that the 5.4in was no better than the 5in/54 in this respect. Further, the 5in/54 would be useless against any well-protected cruiser:

Even the common shell for the 6in/47 double purpose gun will not penetrate the side armor of our 10,000 ton CLs and CAs at 12,000 yards, except the steering gear and machinery spaces of CA 24–31 and CA 33–35. This shell is not as good as the 6in/47 special common in the *Brooklyn* class, as to avoid complications in the FC system the common shell for surface fire used in a double purpose gun must have the same flight characteristics as the AA shell. The 6in shell used in a single purpose gun has better flight and therefore better penetration than can be given to the blunter-nosed AA projectile which is made to conform to the flight characteristics of an AA projectile carrying a nose fuze.

Right side, longitudinal section



Plan view



The 5in/54 MOUNT MARK 39 (CVB-41)

II. FLEET AIR DEFENCE

With reference to the battleships then under design (*Montana* class), the Bureau noted that they could carry either 5in or 6in secondaries:

A battleship will be attacked by guns of a battleship or, possibly, an 8in cruiser. Our battleships could oppose those two types with their main batteries. If our battleship had a 6in/47 single purpose secondary battery, it could penetrate with our special common projectile the sides of all our 6in and 8in cruisers up to 16,000 yards, except seventeen of our 10,000 ton CLs and CAs built since CA 32. With a double purpose common projectile, the 6in/47 will not penetrate any of our 10,000 ton CLs or CAs, except the steering gear rooms of CA 26 to 31 and 33 and 35.

It is considered that for a battleship, its main battery, and not its secondary battery, would be used against 10,000 ton cruisers, and that its secondary battery would be used against lightly armored vessels such as destroyers and against planes and that, therefore, the battleship should not waste space and weight by carrying a 6in gun, but should have a smaller gun to get more rapid fire and to get a greater number of guns in the battery...

Antiaircraft efficiencies were calculated, for example, on the basis of sighting a plane or a group of planes at 15,000yds at 9000ft; the battery might require a minute to obtain a director solution and set fuzes. During that time the plane (at 200kts) might approach 6667yds to a range of 8333. The 6in/47, firing at that moment, might place its first burst at 7112yds, *ie* a flight time of 11.2 seconds later. It would be able to fire seven bursts before the plane reached bomb-drop. By way of contrast, the 5in/38 would set its first shell at 14 seconds, by which time the airplane would have closed to 6779yds; there would be enough time for nine bursts, a total of 3551b of fragments (540 for the 6in/47). When the increased weight of the heavier guns was taken into account, BuOrd could see no particular superiority for them, and preferred the 5in/38 for battleships; 'the need of a great number of guns is particularly evident if a battleship is attacked by destroyers and planes simultaneously'.

The only point favoring the 5in/54 was its armor penetration against very lightly protected ships, which might be valuable in a cruiser designed to fight destroyers. In fact just such a ship was being considered at the time, an enlarged *Atlanta* which was not, in the event, built. As for the 5.4in/48, it was briefly considered as an alternative main battery for the 8000-ton 6in/47 cruiser, after the failure of the original design. However, the Bureau noted that the development of a twin 5.4in mount would require about 30 months just to get the gun to the proof stage. The first full battery might be available a year later. A choice in favor of the 5in/54 would save about 3-4 months, as some 5in tooling might be used.

By January 1940 the General Board had chosen the 5in/54, with its 70lb round, and its muzzle velocity of 2650ft/sec. The first design actually to incorporate it was the *Montana*, followed by the *Midway* class carrier. Late in World War Two it was specified for an abortive class of antiaircraft cruisers, and then for a new large destroyer, which ultimately became the *Mitscher* class. Postwar, the 5in/54, in a variety of mounts, has become the standard US naval gun. With the demise of the lightweight 8in/55, it is the most powerful weapon available to the surface Navy, and it is also the only weapon capable of firing RAP or guided shells. These issues were, of course, entirely

unknown when the weapon was developed during World War Two.

The gun itself was essentially a scaled-up 5in/38, with the same vertical sliding-wedge breech block. A twin mount, comparable to the standard 5in/38 twin, was planned for the *Montanas*, but died with them. The *Midways* had a single enclosed 5in/54 semiautomatic mount, again similar in concept to the 5in/38 single. The result was not entirely satisfactory, and in particular did not make its designed rate of fire. One consequence was that BuOrd began work on a new single-barrel automatic 5in/54, which became Mk 42.

By 1944 efforts were well underway to design a new and more powerful type of destroyer, which would be armed with the 5in/54. That July BuOrd began work on its twin mount, which was to be smaller than the battleship mount previously designed. Its streamlined shield was to be smaller than that of the twin 5in/38; it was to incorporate on-mount radar fire control (GUNAR Mk 1); it was to fire 18 rounds per gun per minute at all elevations; it was to require fewer personnel on the mount (10-12 *vs* 27 in a twin 5in/38); and the hole in the deck would be no larger than that for a 5in/38. The guns were to be only 26in apart (84in in the standard twin 5in/38). Perhaps the most unusual feature of the design was that projectile and cartridge were separately but simultaneously loaded into the hoist, and treated thereafter as a single unit, for simplicity of operation.

The twin semiautomatic 5in/54 never entered fleet service. Instead a new single-barreled fully automatic mount, the Mk 42, with a rate of fire slightly better than that expected for the earlier twin mount, was developed. In effect it retained the two loading systems of the twin mount, but both fed a single barrel. Each system began with two independent drums, each carrying twenty units of ammunition - shells in the upper drum, cartridges in the lower. The two drums generally rotated together as a unit, and the combination of shell and powder emerging from the pair remained together throughout the loading operation. However, because the shell drum could rotate independently, alternative types of projectile could be selected at loading time. Rising alternately from the two loaders, complete rounds were moved from lower to upper hoists, and thence into cradles which swung up to throw them into a transfer tray from which they could be rammed. The entire operation generally resembled that of the 8in/55, designed by BuOrd at about the same time. The loaders were manually fed, and indeed this feed was the only manual element of the mount cycle.

Like other heavy automatic weapons of its time (such as the 3in/70), the Mk 42 was mechanically complex and subject to jamming. Many in the Fleet contrasted it unfavorably to the reliable twin or single 5in/38, particularly when it was the sole 5in gun aboard a missile frigate or destroyer escort. For example, jamming was relatively common on the gun line off Vietnam, where sustained operation was the rule. Ultimately, in its later mods, the Mk 42 came to be considered quite reliable, but that in turn required de-rating, the nominal rate of fire falling from about 40 rounds per minute to 28, in sustained fire. Late versions were also lighter, and required fewer men (13 in Mod 9, compared to about 20 in earlier types) with

about a 10 percent saving in power consumption.

The principal defects of the 5in/54 Mk 42 were its manpower requirements and the space and weight it represented. The Navy of the late 1950s, committed to increasing missile employment, could ill afford either on what it considered a secondary weapon system. There was no question of doing away with guns altogether, but by the early 1960s work was well underway on the lightweight Mk 45, which would have no men at all in the mount proper. Limits on antiaircraft capability were accepted as the cost of weight and manning reductions: the new gun elevated only to 65° (compared to 85°) and was designed from the first for a nominal rate of fire of half that of the Mk 42, 16-20 rounds per minute. If the Mk 42 were considered an automated equivalent to the twin semiautomatic 5in/54, Mk 45 might be considered an automated equivalent to the earlier single mount, the type installed aboard *Midway* class carriers.

The Mk 45 was designed for maximum simplicity. Since its elevation was limited to 65°, it could be fed from below (the breech rising for loading) by a cradle swinging out and up from a fixed ammunition hoist in the center of rotation of the mount: there was no need for the complex cradle system required to move ammunition around the gun and then throw it into a loading tray from above. Rounds could be rammed directly from the cradle, which followed the rotation of the mount; the hoist into the cradle was fixed in rotation. It emerged from the center of a drum loader, which rotated to present the next round to the hoist. The loader, located roughly where the transfer station was in the Mk 42, was fed in turn by a lower hoist, manually loaded. In this design only a single loader drum was required, in place of the pair of independent drums of each Mk 42 loader. All of these measures made for a very light mount; it is claimed that the Mk 45 is the lightest 5in/54 mount available. However, it is limited to 20 rounds per minute.

The range of lightweight naval guns was also to have included a 3in, and it extended up to the 8in/55 Mk 71. Proposals included two faster-firing 5in/54s. Mk 65 was to have fired at 48 rounds per minute, using a total of eight ammunition drums (12 rounds each) and a central carrier ring holding 16 more. The drums required manual replenishment. Mk 66, which at one time was specified for the proposed fire support ship of the mid-1960s, was essentially a pair of Mk 65s, with a net rate of fire of 96 rounds per minute, using a 100-round loader for each gun. In each case, a single man could fire all of the ready-service rounds without assistance. Neither project appears to have reached the prototype stage, but each seems to have shown that light weight and minimum manning were not barriers to a high rate of fire. High elevation was another matter: the key to the simplicity of the Mk 45 was its limited elevation.

Mk 45 was entirely a postwar development, but it is included here as the natural culmination of a line of heavy antiaircraft weapons begun in 1921 with the design of the 5in/25.

The 6in/47 Gun

The only heavier antiaircraft gun developed and deployed by the US Navy was the automatic 6in/47 of the *Worcester* class, a weapon suffering from intermittent en-

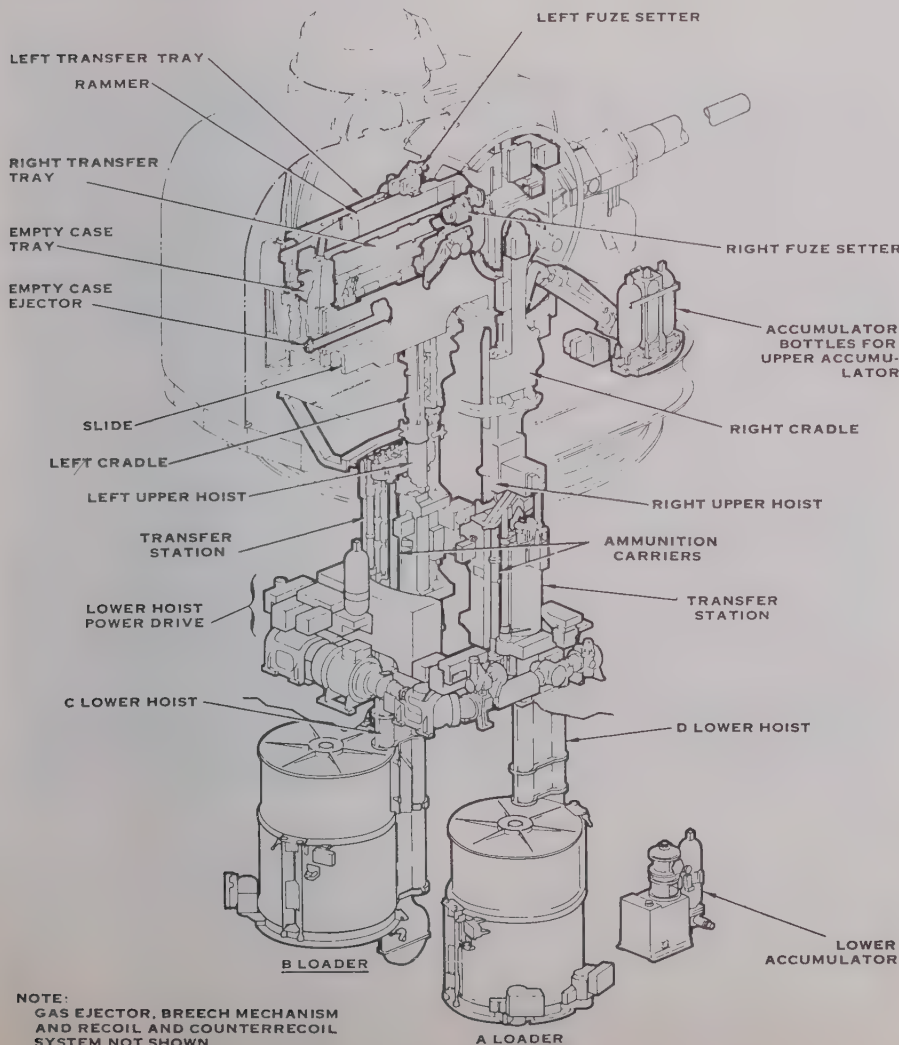


THE 5in/54 MOUNT MARK 42



1 The Mk 42 5in/54 automatic gun is credited with about 40 rounds per minute, or twice the rate of fire of the World War Two semiautomatic 5in/38. A high rate of fire is achieved partly by feeding the weapon alternately from right and left ammunition drums: in effect there are two independent feed systems with a single breech and barrel – 1½ guns rather than 1. Rounds carried alongside the gun in the mount permit some fire even in the event of a breakdown in the automated feed system. Most Mk 42s have two raised 'frog-eyes', one on the right for antiair and one on the left for antisurface local control. In many cases the starboard dome was later removed, as local AA control was considered futile.
FMC Corporation

2 Model of the proposed 5in/54 Mk 66 Mod 0 lightweight, rapid-fire, dual-purpose twin mount; the project died at the end of the 1960s.
US Navy, by courtesy of Norman Polmar



thusiasm. Work on it effectively ceased in 1939 with the failure of the 8000-ton cruiser project, and it will be recalled that BuOrd's own analysis effectively killed it as a prospective battleship secondary weapon. In 1941, interest in a heavy antiaircraft cruiser revived, as aircraft operating altitudes sharply increased. The gun itself duplicated that of existing light cruisers: it was a case gun well suited to rapid fire. However, the ammunition feed system of the light cruisers was designed to load only at elevations of 20°. The new mount would maintain a rate of fire similar to that claimed for such low-angle mounts, but at much higher elevation.

The September 1937 proposal called for a rate of fire of 12 rounds per gun per minute; each gun would be provided with two projectile and one powder hoists, with manual transfer from hoist to loading tray. In the weapon as actually built, however, powder was transferred mechanically from hoist to tray. As in contemporary large-caliber systems, the new 6in/47 twin incorporated rotating-ring projectile stowage (with stowage fixed to the turret rotating structure inboard of it), for easier loading at the lower end of the hoists. In effect the twin 6in/47 was the mechanical prototype for the 8in/55 (See Part I). As in the case of many prototypes, it was judged far less successful mechanically than was its more highly automated successor.

'Zeus'

In 1945, with guided missiles as yet a rather distant hope, the Navy remained interested in very large-caliber antiaircraft weapons. There

were serious proposals for a new twin (as opposed to two-gun) 6in/47 dual-purpose turret, which might be installed in place of the triple 6in/47 aboard *Cleveland* class cruisers, converting them into fleet air defense units. Sketches for an antiaircraft battleship (produced from the incomplete hull of the *Kentucky*) showed triple or even quadruple 8in/55 weapons. In addition, there was Project 'Zeus', for a guided 8in antiaircraft shell. This distant predecessor of the CLGP was, for a very long time, the last gasp of the large-caliber antiaircraft weapon.

'Zeus' originated with a program established at the Naval Ordnance Laboratory in June 1947, for studies of gun-launched guided missiles. Originally described as the 'Gun Launched Guided Projectile - Arrow Shell' 'Zeus' was later designated XSAM-N-8 in the

Army-Navy guided missile series. It was a finned 4in 72lb shell which a smoothbore 8in/55 gun could fire at 3150ft/sec, using a 75lb charge; with a 100lb charge, rather beyond the capacity of the standard gun, it could attain 4000ft/sec or almost 2400kts. At this time BuOrd was experimenting with a variety of very high-powered antiaircraft guns. For example, the single-shot kill probability of the 5in/70 against a standard maneuvering target at 5000yds was calculated as 0.025; with one step of guidance, the Zeus I SSPK at the same range was 0.300; alternatively, Zeus I could equal 5in/70 effectiveness at three times the range, 15,000yds. Given a single-shot kill probability of 0.025 it would take about 25 rounds to achieve a 50 percent chance of destroying a target. Zeus was removed from the missile to the gun fire control program early in 1950, in

compliance with a directive from the Secretary of Defense. Up to that time, 115 missiles had been fired from the smoothbore 8in gun, 12 of them deflection shots to test the stability of flight of the missile under the effect of the rocket unit.

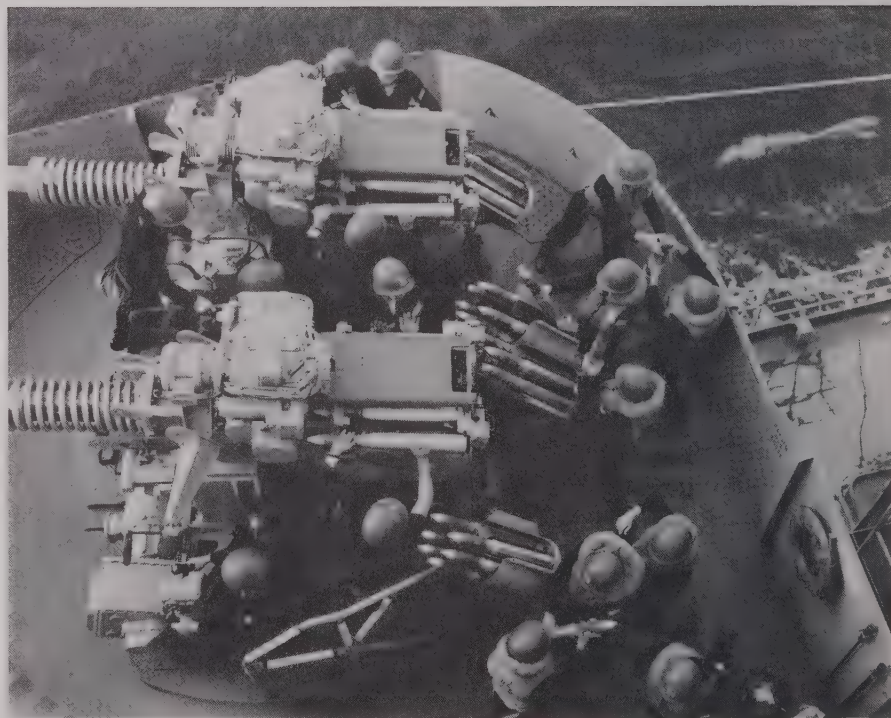
Guidance was achieved by a small rocket motor firing at right angles to the axis of the shell; it could correct for inaccuracies in aim or for target maneuvers after the moment of firing. It was not nearly as effective as modern laser guidance because the latter is continuous, but in 1948 it was a most impressive advance. Plans called for rocket propulsion (in addition to the guidance motor) in an improved Zeus II, but the entire project was abandoned in a shakeout of missile projects, as the post-World War Two squeeze on funds tightened.

3. Medium antiaircraft guns

The 3in/50 Gun

The 5in guns replaced almost all 3in/50s in the Battle Fleet as ships were refitted or rebuilt in the 1920s and 1930s; by the late 1930s they remained only in the earliest classes (*Arkansas* and *New York*) and in *Omaha* class light cruisers. At that time, however, the 3in/50 was the only effective dual-purpose gun available in any numbers, and its weight approximated that of the new quadruple 1.1in machine cannon. In 1940 the King Board, responsible for improving the air defense of the fleet, proposed four quadruple 1.1in for each battleship and cruiser, with single, locally controlled 3in/50s as interim replacements. At about the same time the Bureau of Ships had under design a new ocean escort, which became the destroyer escort, armed with two 4in single-purpose guns. The British Admiralty, the first buyer of these craft, asked that they be armed instead with a dual-purpose weapon of US manufacture, and again the 3in/50 was the only one available. The mounts existing in 1939 were the obsolete Mk 11s; to utilize a large stock of spare barrels BuOrd developed an interim Mk 20 mount, while a modern antiaircraft mount, Mk 22, was designed. It was installed in hundreds of destroyer escorts, as well as battleships, cruisers and auxiliaries. The semiautomatic 3in/50 was also substituted for the single-purpose 4in/50 aboard some 'flush deckers', to provide them with effective AA firepower on their very limited displacements.

All of these weapons were quite limited in their effectiveness. They were not power-operated, and so could not be fully director-controlled, as could be the larger 5in guns. On the other hand, they were the smallest guns which could fire VT-fuzed projectiles. In 1945, as an emergency antikamikaze measure, efforts



The twin 3in/50, the standard postwar automatic antiaircraft weapon, was intended to replace the quadruple 40mm on a one-for-one basis, although in fact it was closer to two for three. Rounds were loaded in the revolving racks at the rear of the mount, from which they were passed into each gun from each side, as shown here; cartridge cases were ejected from the rear of the gun, as in the 40mm. The right-hand gun-layer was responsible for surface firing, the left-hand for antiaircraft fire, and the mount captain stood between the guns. Many mounts carried Mk 34 or SPG-34 radar dishes operating with off-mount Mk 63 directors; that shown here was controlled by a Mk 56 director with its own

radar. Each gun-layer could control the entire mount with a joystick, twisting to train, and pushing up or down to elevate or depress. This mount is aboard *Canberra*, 1964.

were made to provide existing single 3in/50 mounts with power drives as Mk 26s; Mk 24 was a new dual-purpose single mount designed during the war by the Northern Pump Company (later Northern Ordnance). BuOrd's more effective solution to the kamikaze problem, however, was a rapid-fire version of the 3in/50, work on which began early in 1944. In principle a twin automatic 3in/50 could replace a quadruple 40mm gun on a weight-for-weight basis, and a single mount could replace the standard twin 40mm. In this role the 3in/50 was no longer a distant barrage weapon: rather, it became a close-in weapon, desirable because its relatively large shell could destroy an approaching kamikaze which the Bofors could merely damage severely. In modern terms, the 3in/50 could prevent the kamikaze from 'going ballistic' and so damaging its target despite the loss of control (eg due to the loss of wings or pilot).

In the fall of 1945, CinCPac went so far as to consider a single 3in/50 with director control and VT ammunition superior to a 40mm twin or even to a quadruple mount; however, if it lacked either the director or the VT fuzes, the 40mm twin would be preferable. This referred to a *slow-firing* 3in/50.

Although the automatic 3in/50 project had very high priority, guns did not begin to appear until 1948. By that time BuOrd was well along with a far more advanced antiaircraft weapon, the 3in/70, and often 3in/50 installations in new ships were considered no more than interim substitutes for the more satisfactory weapon. In older ships, plans to replace existing 40mm batteries were slowed by a lack of funds, and rearmament did not really begin until the Korean War. The 3in/50 was rather heavier than expected, and when replacements were made they were generally on the basis of two 3in/50 for three twin or quadruple Bofors guns. For example, the *Iowas*, designed for twenty quadruple 40mm, were to be rearmed with sixteen twin 3in/50. On the other hand, *Fletcher* class destroyers rearmed with three twin 3in/50 surrendered one of five single 5in/38 when the 3in guns replaced two quadruple and one twin 40mm. As a final irony, the mechanical complexity of the 3in/70 ultimately defeated it, so that the interim heavy automatic antiaircraft gun long outlasted it; indeed, the 3in/50 became the standard of the postwar Navy.

Given its relatively light fixed ammunition, the automatic 3in/50 was quite a simple design. An automatic loader was designed to adapt the original semiautomatic weapon to rapid-fire (nominally at 50 rounds per minute), and the complexity of fuze-setting was avoided by recourse to VT fuzing only. The loader in turn was fed manually from each side, sprockets drawing rounds alternately into its feed mechanism. The sprockets were motor-driven; shells drawn into the center of the loader were dropped onto a transfer tray which catapulted them into the breech for ramming. The entire loading mechanism was concealed inside the massive square box atop the gun, and all loading prior to insertion into it was manual – the 3in/50 incorporated a multistage loading system for greater speed, in rough analogy to the two-stage hoists of much larger ships (see Part I). Rounds were dropped into rotating six-round hoppers attached to each side of the rear of the gun, from which they were loaded into the gun by men on the mount proper.

Although nominally a dual-purpose weapon, the automatic 3in/50 was initially considered ineffective against surface targets because of its all-VT ammunition. In 1956 the *Leahy* class frigates (later missile cruisers) were designed with batteries consisting of Terrier missiles and 3in/50s, and there were objections that they would be unable to deal with opposing ships. The solution at the time was a combination of a nuclear Terrier (for primary antiship fire) and an armor-piercing round for the 3in/50. The latter became particularly important with the retirement of the 3in/50 from the antiaircraft role in 1978. This retirement shows in the removal of some 3in guns and all Mk 56 fire control systems from many US auxiliary and amphibious ships; ultimately the surviving 3in guns will probably be replaced by Phalanx Close-In Weapon Systems.

The 3in/70 Gun

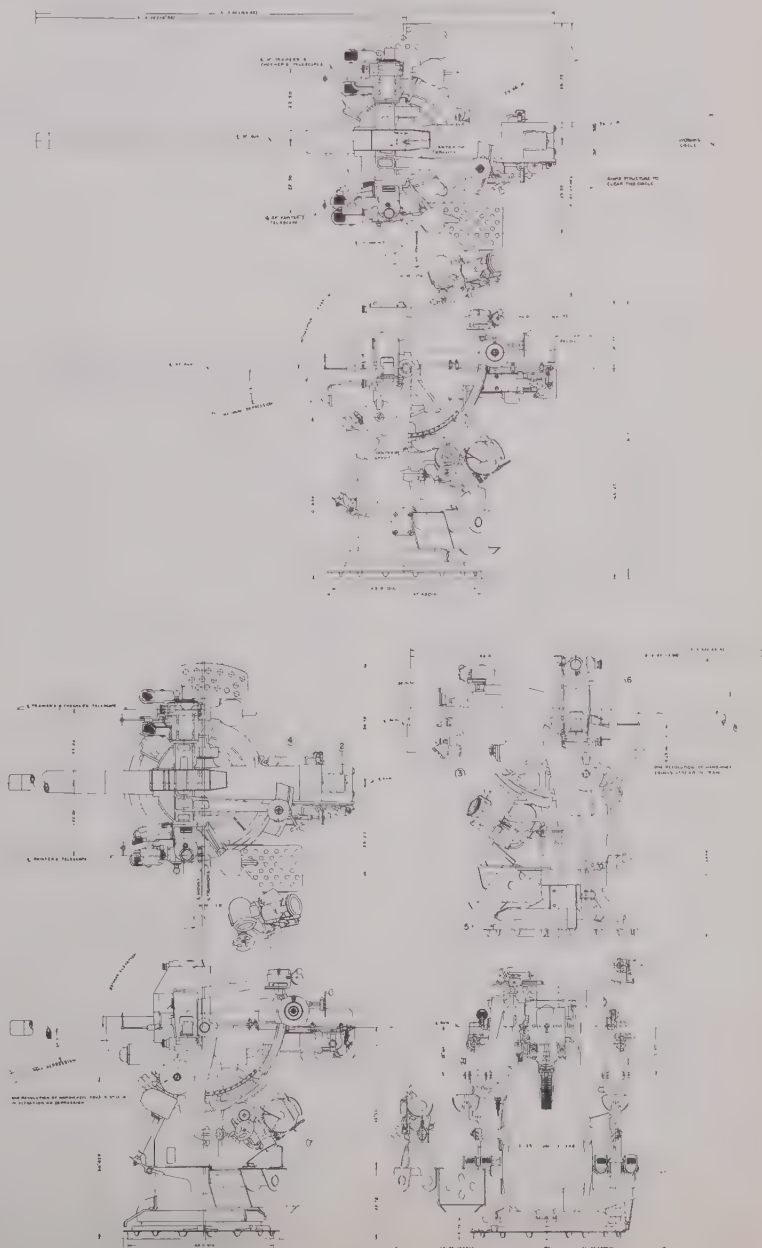
In 1945 BuOrd began development of what it supposed would be the ultimate medium-caliber antiaircraft weapon, a twin 3in/70.

Barrel and ammunition development was an Anglo-American project, but the two navies produced completely different gun mounts – each of which encountered its own difficulties. The 3in/70 fired a new shell weighing 15lb (compared to about 13lb for the 3in/50), and required a 36lb cartridge case (compared to only 6.5 or 7lb in the 3in/50), to attain a muzzle of 3400ft/sec (rather than 2650). BuOrd considered it superior to the 5in/54 as a defense against fast aircraft and guided missiles. Indeed, for a time the postwar destroyer (which became the *Mitscher*) was to have been

THE 3in/50 MOUNT MARK 22

Key

- 1 Mk 21 gun
- 2 Housing
- 3 Carriage
- 4 Slide
- 5 Stand
- 6 Sight
- 7 Fuze-setter



armed solely with the new weapon, the 5in/54 surviving only because of its value against surface targets, including surfaced submarines. A rate of fire of 90 rounds per gun per minute was specified, the magazine rotating with the gun mount, in which both barrels were fixed to a single slide. Other design features included on-mount radar fire control and the use of VT fuzes only. The barrel incorporated a smoothbore section at its muzzle to reduce loss of velocity (and to act as a flash-hider).

A very high rate of fire entailed a complex loading system. Rounds were stowed horizontally in a 60-round cross feed, which loaded them into a 10-round elevator, which in turn loaded them into a transfer (capacity two rounds). The transfer in turn fed them into an ammunition hoist holding four rounds in clamps; the hoist carried them up in front of the gun trunnion, over it, and into the rammer behind the gun. As in other rapid-fire high-angle guns, this elaborate system was necessary if the gun were to be able to elevate to 90°. The only other path to the breech, from below, was

foreclosed by the choice of very high elevation. The rammer itself was a power-driven cylindrical case which pivoted sideways to place the round just behind the breech, moving forward rapidly and then stopping suddenly to catapult a round into the gun. The sliding-wedge breech blocks were arranged horizontally to permit very close placement of the two guns, and thus to minimize the dimensions of the mount. Even so, at a total weight of 125,500lb the 3in Mk 37 considerably outweighed a twin 5in/38 and was quite comparable in weight to the rapid-fire 5in/54 Mk 42 (145,930lb in its Mod 1 version).

The 3in/70 never had a particularly good service reputation. It was far too complex to be easily maintained; for that matter, it was far too complex for quick development. In 1945 BuOrd estimated that mounts would be ready within four years, and many postwar design projects, such as the large flush-deck carrier and the submarine killer (*Norfolk*) incorporated it in their designs. In fact it did not appear until 1956, by which time anti-aircraft shellfire

was already clearly of very limited value. It was also badly overweight, requiring weight compensation when it was installed as originally planned, as in the *Mitscher* class frigates (large destroyers). Within a few years of its appearance it was gone. Mounts aboard the command cruiser *Northampton* were removed in 1962 in view of maintenance problems, and at about the same time the converted *Gearing* class destroyers (DDE) armed with the 3in/70 were rebuilt under the FRAM program, and their mounts replaced with standard twin 5in/38s. Existing 3in/70s were removed from the *Mitschers* as these ships were refitted in the early 1960s, and the only ship to retain the 3in/70 to the end of her career was the large ASW frigate *Norfolk*.

The modern 3in/62 (Mk 75), which arms the hydrofoils (*Pegasus* class) and the *Perry* class frigates, bears no close relationship to the 3in/70, and indeed represents an entirely different class of weapon and tactic. As an element of current fleet air defense, it is discussed in Part IV.

4. Light anti-aircraft guns

Early Machine Guns

The 3in/50 and 3in/70 in effect bridged the gap between the heavy, slow-firing, long-range anti-aircraft weapons and the heavy machine guns, typified during World War Two by the Oerlikon 20mm cannon and by the Bofors 40mm cannon. Where the heavy guns were designed to destroy or at least to discourage the high-level bomber, the machine guns were intended to counter much shorter-range targets, at first strafers but above all dive-bombers. Where the cannon could contribute to a kind of area defense of the fleet (eg when they were mounted aboard screening destroyers), the lighter weapons were always intended for point defense. Machine guns became more and more important as dive-bombers became more effective, and particularly as their weapons grew from 30lb to 1000lb bombs. This latter evolution was extremely rapid: from its official beginnings in 1926, dive-bombing grew to the principal US air threat against warships within five years. In the early 1930s, for example, it was so important that the carrier *Ranger* was designed without torpedo stowage: she would rely entirely on dive-bombers for her offensive firepower. For a time it even seemed that torpedo-bombers would be abandoned entirely. US Navy interest in countermeasures against the dive-bomber reflected this trend.

The first Navy machine guns widely installed were water-cooled versions of the 0.30- and 0.50-caliber Browning. During World War Two the Navy also used air-cooled versions of both weapons, as well as World War One Lewis guns. In the early 1920s the Navy looked, in addition, toward a twin version of a much

larger automatic weapon, the Browning 37mm cannon, then under development for the Army. The latter actually appeared in battleship and cruiser Characteristics, but development was suspended when John M Browning died in 1926; the 5in/25 was mounted instead aboard the new Treaty cruisers. Although the Army renewed efforts to develop the 37mm in 1935, Navy interest did not revive, largely in view of the existence, by then, of the multiple 1.1in machine cannon.

As for the light machine guns, in February 1929 the General Board reported to the Secretary of the Navy that although

... results against diving-bombing attacks are not definitely known, the destructive effects of these guns against airplanes in general have been disappointing. An explosive projectile effective against the wing area would increase target area tenfold. The Bureau of Ordnance is studying such a gun, caliber 1.1in, with projectile weight slightly in excess of one pound. . . . In the fleet thirty-pound bombs are being launched at 1500 feet with forty percent hits. The General Board attaches great importance to the early development of a multiple barrel rapid fire gun to meet this attack, eight such guns to form part of the battery of the new battleships. . . . such a gun would have an important role also on new light cruisers and on destroyers, especially on the destroyer in lieu of its present 3in anti-aircraft gun, which is not very effective. . . .

The Division of Fleet Training was more explicit. In January 1929 there were already sixteen types of aircraft in US service capable of making a dive-bombing attack, and two could carry a 500lb bomb; by 1930 there would be two types capable of diving with a 1000-pounder.

Maximum speeds during the diving attacks range between 225 and 300 miles per hour for the fighting plane types, and between 180 and 240 miles per hour for the observation plane types. Other services are presumably developing along similar lines. When it is considered that a dive-bombing attack can be developed and executed in a matter of seconds, the urgency of the defense problem begins to be apparent. A formation of light planes, approaching at an altitude of say 15,000 feet, may remain undiscovered by reason of sun glare, cloud protection, or the like, until in a position to dive for their objective. Diving with full power at a speed of 240 miles per hour, such a formation will reach an altitude of 1500 feet, a favourable one for bomb release, in about 36 seconds.

Assuming an average velocity of 2000 ft/sec for a projectile fired from guns used against this diving squadron, a projectile fired at the instant the planes start their dive will require about six seconds to reach the point in its trajectory at which it will meet planes diving from the altitude assumed. In other words, even if the defensive fire begins at the earliest possible instant in such an attack, only about thirty seconds of actual firing time are available to get on the attacking planes and damage them sufficiently to prevent the attack from being completed. It will be readily seen that any delay or reduction in the initial altitude will reduce the time available for defensive firing to an almost negligible figure.

Considering such an attack made by a number of planes, on different bearings, on lines of approach between 70 and 80 degrees about the horizontal, the prospects of stopping even a small proportion of them by gun fire are not good to say the least.

Such planes may attack with demolition bombs, with gas filled containers, or with light case high explosive bombs against auxiliaries, transports, or unarmored vessels, such as cruisers or destroyers. The effect of such an attack on even a heavily



The 0.50-caliber water-cooled machine gun was the primary antiaircraft weapon of the interwar period. Here reservists train on one at the Washington, DC, armory, about 1940. Weapons of this type lined the gallery decks of US aircraft carriers early in World War Two; prewar they were mounted aloft in warships from destroyers to carriers.

armored vessel is bound to be disastrous to fire control parties, secondary and anti-aircraft gun crews and other exposed personnel and materiel. With increased efficiency in aircraft performance an increase in the size and destructive power of bombs launched in this manner may be expected.

At present we have but few machine guns in the service available for use against such attack. Various recommendations are on file, covering suggested locations for small caliber machine guns, etc. None is fully satisfactory, and all involve structural difficulties to overcome which will require the expenditure of considerable funds. The 30 caliber machine gun is of too small hitting power to be effective for anti-aircraft use, and an analysis of the 50 caliber machine gun performance indicates that it is but little better than the 30 caliber because of the type of trajectory and of certain ballistic characteristics. Neither the 30 caliber nor the 50 caliber projectile is capable of carrying the explosive charge necessary to damage a plane sufficiently to ensure its failure in flight, even were this permitted by International Law.*

The Bureau of Ordnance has under consideration various types of guns of calibers in the neighborhood of one inch. It is understood that these give promise of excellent ballistic qualities, effective explosive projectile, and satisfactory volume of fire. It is recommended that this development be pushed and that a gun of this type be perfected and issued to the service as soon as may be practicable.

This was the origin of the 1.1in machine cannon, but the weapon would not enter service for another full decade. Fleet Training well characterized the threat against which automatic weapons were designed, and which they alone could counter, until the advent of the VT fuze during World War Two. Its arguments were entirely persuasive, but for some time to come the best available US automatic anti-aircraft weapon was the 0.50-caliber machine gun. In 1933, for example, standard allowances were eight for a battleship, eight for a heavy cruiser, four for a light cruiser and two each in a flush-deck destroyer. The new 1500-ton destroyers were to have four each, and the 1850-ton 'leaders' two 0.50s plus (it was hoped) two quadruple 1.1in. Carriers were considered the primary dive-bomber targets, and in conse-

quence they were given very heavy light batteries: forty 0.50s in the new *Ranger*, and 25 (plus four quadruple 1.1in) in what would become the *Yorktown* (CV-5) class. Forty 0.50-caliber machine guns were planned for the large carriers *Lexington* and *Saratoga*, with twenty-six 0.50s and four quadruple 1.1in as an alternative, desirable in view of the recent change to 1.1s in the CV-5 class.

There was, as yet, very little data on defense against dive-bombing, yet the problem remained urgent. The General Board recognized that light guns might well fail to hit a diving airplane, but

...the value of defensive weapons against such attack lies not only in the results of actual damage inflicted on the attacking planes but in the deterrent effect of the pilots, influencing them to release their bombs from a greater range than if unopposed. There will be times when a carrier will not be able to defend herself with her own planes alone. Neither the 5-inch nor the 3-inch anti-aircraft guns can be made effective against dive-bombing. The 30 caliber machine gun has been proven unsatisfactory...

That left the existing 0.50 and the developmental 1.1, and there was insufficient evidence on which to make a determination. Army test-firings seemed to show that a 0.50 would make very few hits on a dive-bomber, yet it could be argued that an airplane diving directly at a ship would make a good target. As for mountings, there had been unsuccessful attempts to develop a twin 0.50 (which in 1929 was mounted aboard the battleships *Colorado* and *Maryland* and the carrier *Saratoga*) and a sextuple 0.30 (two of which were mounted aboard the carrier *Lexington* in 1929). In each case the preferred replacement was the Mark III single mount.

In fact installation of the 0.50 continued until 1941, as no satisfactory weight-for-weight substitute was found until the adoption of the 20mm Oerlikon. The new *Benson* and *Fletcher* class destroyers were all designed with six 0.50s each, and anti-aircraft improvements to destroyers in the North Atlantic in the spring of 1941 generally involved the addition of 0.50s.

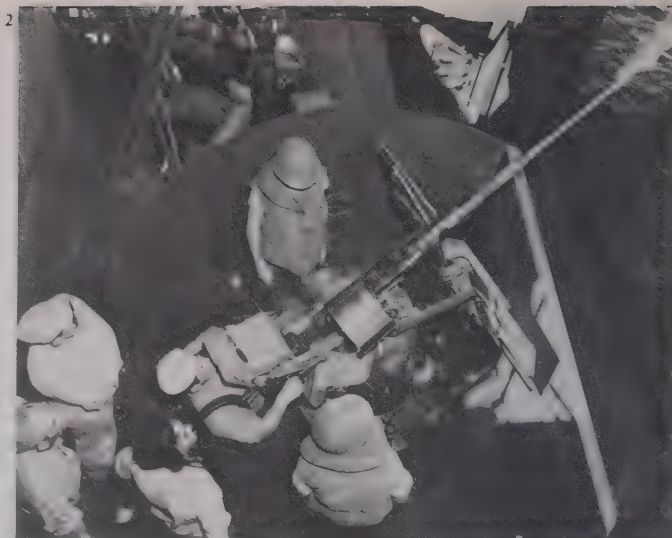
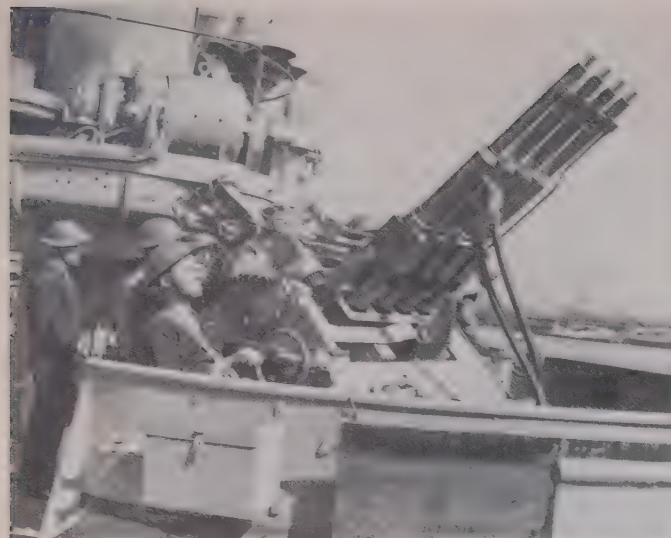
The 1.1in Gun

Meanwhile the 1.1in was developed. It began with a BuOrd Board on light machine cannon convened in October 1928; design began in March 1929, with tests on an initial single-barrel model run from March to May 1931. By 1933 a rate of fire of 140 rounds per minute had been demonstrated; BuOrd contemplated a quadruple mount, which would match the rate of fire of the single 0.50 (500 rounds per minute) in order to achieve a reasonable number of hits on a fast-diving airplane. Compared to the 0.50, the 1.1in fired a projectile about ten times as heavy (0.92lb vs 750 grains, or 0.093lb); its single cartridge weighed 2lb (compared to 1/3lb); and its muzzle velocity was higher (2700 vs 2525ft/sec), for a slightly greater ceiling (16,000 vs 15,000ft) and horizontal range (7800 vs 7500yds). However, these last figures were misleading, since the gun was effective only so long as its tracer could be seen. Under average fleet conditions, the 0.50 tracer was visible out to 1200yds, but in 1933 tracer visibility of the 1.1in was expected to be at least 3000yds.

Perhaps most importantly, the 1.1in fired an explosive shell, employing a super-sensitive fuze which 'will function on impact with a single thickness of airplane wing fabric and which has such a short delay that the projectile will explode in the wing section. The damaging effect of this projectile is remarkable. A hit on any part of the plane will probably cause a forced landing', according to a report for the General Board made in November 1934. There was some fear that spent 1.1in shells which had missed their targets might explode upon falling onto friendly ships, and there had been some prematurely bursting shells. There was also a nagging fear of jamming; the 1.1in was described as a direct descendant of the unsatisfactory Army 37mm automatic cannon.

The 1.1in was turned over to the Naval Gun Factory for production in 1934, financed by public works (NIRA) rather than Navy funds. The first quadruple mount emerged in April 1935. It was extremely complex. Given the possibility that aircraft might dive at up to 90°, conventional train and elevation (which extended to an unconventional 110°) were not considered sufficient; traverse (in the plane formed by the trunnions and guns) to 30° on each side of the mount centerline was added. In view of the force of recoil of the powerful cannon and the overall weight of the mount, power operation was specified, although no 1.1in director was developed, at least at first. So urgent was the need for an effective anti-dive-bomber weapon that the 1.1in was rushed into production as soon as it had passed its proving-ground tests. Many defects soon appeared: for example, in view of excessive vibration, broad steel stiffening plates were added to the mount

*International law forbade explosive shells below one pound, which in early weapons equated to 37mm. The original intent was to eliminate explosive or deforming bullets, such as 'dum-dums'; recently similar arguments have been advanced against weapons with tumbling bullets, such as the M16.



between carriage and base, and a new mount was designed. The traverse feature was locked out, and directors were developed. The gun also earned a reputation for jamming, realizing earlier fears.

In retrospect it appears that the defects of the 1.1in were no more than teething problems, that the BuOrd design was basically sound. However, it had one fundamental drawback: its shell was too small to stop aircraft in service by the time it began to appear in numbers, in 1940. In addition, because its ammunition did not self-destruct, a pilot under 1.1in fire (at least in daylight) did not face the sort of deterring display of bursts which a larger-caliber weapon would have produced. In 1940, in connection with a proposed installation of the 1.1in aboard *Cleveland* class cruisers, one officer remarked that probably no airplane had yet been shot down by machine gun fire, but that many had had their aim thrown off. In 1945 the captain of a destroyer escort armed with the 1.1in wrote that it worked well enough as a gun, but that despite its high rate of fire it lacked the range and the stopping power of the Bofors gun. Moreover, its power drive 'has been erratic and at times dangerous, necessitating an inordinate amount of overhaul by ship's force to be kept in even fair operating condition'. All surviving 1.1in guns and mounts were ordered scrapped in 1945, although some of the power drives, suitable for the twin Bofors gun, were retained.

The 20mm Oerlikon

Thus in 1940 both of the standard US naval automatic weapons were considered inadequate, although there was a major ongoing program for their production. Arguments could be made in favor of both free-swinging (as in 0.50-caliber) and power-operated (as in 1.1in) mounts. A free-swinging gun could react more quickly to a surprise attack, and could also be installed more easily. On the other hand, a heavier weapon (which would probably have to be power-operated) would almost automatically have far greater stopping power and, moreover, might fire a shell large enough to self-destruct and thus to deter an oncoming pilot. In each category the outstanding candidate was a foreign gun: the Oerlikon 20mm for the free-swinging weapon, the 40mm Bofors for the 1.1in replacement, each of which had proved very effective in the Spanish Civil War. Ironically, the development of each had been paid for

in part by the Axis powers. In 1935 the US Navy had rejected the Model 1934 Oerlikon in view of its low rate of fire (265 rounds per minute), but the Japanese Navy had adopted it, saving the Oerlikon Company from bankruptcy, and permitting it to develop the gun further. The Bofors had begun life in 1918 as a Krupp design, the Bofors Company being owned by German interests until 1930.

Adoption of the Oerlikon followed extensive British experience, beginning with 1937 tests to find a suitable weapon for the defense of light vessels such as merchant ships and minesweepers against dive-bombing and close-range air attack. The British obtained a manufacturing license (but continued to buy their guns from the Swiss); in June 1940 with Switzerland cut off they decided to establish a production line in the United States as a source of the weapons. In September 1940, however, approval for this production was withdrawn, as it was US policy that no clearance would be given for complete guns which were not standard to those used by the US armed forces. The British now began to campaign for US adoption of the Oerlikon, as the United States was the only source they had. Meanwhile, Captain W H P Blandy, then BuOrd Anti-Aircraft Type Assistant and later Chief of the Bureau of Ordnance, had already concluded that the Oerlikon was the best available weapon. It was approved by Admiral Furlong, Chief of the Bureau, on 9 November 1940.

The Oerlikon was not the only 20mm gun available; both Army and Navy were already using a Hispano-Suiza aircraft gun, and its adoption would have had the advantage of standardization. However, according to the BuOrd history,

... the Oerlikon offered greater reliability because of [its] greater reserve of power. It was operated by maximum gas pressure, about 23 tons per square inch, and by springs which were correspondingly powerful. On the other hand the Hispano-Suiza was operated by reduced gas pressure of about 8 tons per square inch and by springs similarly weak ... the forces at work in the Oerlikon were consequently greater than those in the Hispano, and hence such factors as friction, the effect of different elevations, cold weather, rain and the like, were too small in proportion to the operating forces to cause stoppage. Primarily as a result of this reserve power, the Oerlikon did not require skilled service maintenance. One of the greatest

1 The quadruple 1.1in machine cannon was developed during the 1930s as a counter to dive-bombers. Although it was replaced in major units by Bofors guns, it remained in service aboard destroyer escorts through 1945, overcoming its early reputation for unreliability. It was, at the least, a rather complex design. This photo shows the gearing allowing the four guns to be slewed from side to side independent of train, to follow a dive-bomber even when the guns were pointed at very high elevations, where train would have little effect. Cooling hoses are also visible.

US National Archives

2 The 20mm Oerlikon gun was surely the most widely used naval automatic weapon of World War Two, appearing in single, twin and even quadruple mounts. The example shown is provided with the Mk 14 gyro lead computing sight, which also formed the basis of the Mk 51 director. The gun was self-powered, and could be bolted down almost anywhere. A talker stands behind the gunner, with a loader to his right carrying a spare magazine. The canvas bag below the gun took expended cartridge cases.

US National Archives

advantages of the Oerlikon... was [that] it had a barrel which could be replaced in about 30 seconds. Since an airplane gun fired very short bursts, and was mounted in the wings of a plane moving through the air at a high rate of speed, it did not present much of a cooling problem. The Hispano was therefore designed without any thought of permitting a change of barrels during action; in fact, it was hardly possible under such conditions. At sea, however, against multi-plane dive bombing attacks, prolonged firing was necessary... The magazine employed with the Oerlikon was superior... the Oerlikon magazine could be kept fully loaded without any tension on the springs while in the Hispano the spring was compressed as long as the magazine was loaded, a condition which brought about occasional spring collapse. Secondly, the magazine had a greater reserve because of the easier task of feeding at 490 RPM as against the Hispano's 690. Thirdly, the Oerlikon magazine had a straight tangential lead through its mouthpiece, whereas the Hispano had a 90 degree bend...

The sea experience of the British with the Hispano-Suiza proved the superiority of the Oerlikon. After the fall of France supplies of Oerlikons from Switzerland were cut off, and as a stop gap Hispano guns were installed on several escort vessels. The results were uniformly bad. Ships reported frequent stoppages from the unsatisfactory design of the cradle, salt water corrosion around the breech block, unlocked tappets, and the collapse of the magazine springs... when water got into a hot gun barrel stoppage was likely at the reopening of fire. The guns were so unreliable that one vessel reported that she preferred not to open fire with her

Hispanos in the hope that the Germans would think she was not a warship. Opposed to this, British experience with the 100 Oerlikons at sea in November of 1940 was uniformly excellent.

The first American-made gun was test-fired on 8 June 1941, and by Pearl Harbor 379 had been delivered. Their reception was enthusiastic, the 20mm replacing the earlier 0.50 on more than a one-for-one basis. Single Oerlikons dominated many anti-aircraft batteries until the appearance of the Bofors in numbers in 1943, and this dominance was reflected in the high percentage of Pacific Fleet aircraft kills attributed to the gun, 32 percent for the period between Pearl Harbor and September 1944. However, as ranges increased and as the Japanese turned to night attacks the Bofors and then the VT-fuzed 5in gun became more and more significant. Thus the Oerlikon's share in 1944 amounted to only 25 percent, compared to 48.3 for the second half of 1942. The Fleet began to demand more Bofors guns and fewer Oerlikons, although BuOrd continued to defend its free-swinging weapon. However, it had to admit that the Oerlikon would rarely be able to defeat an attacker before he released its weapon: it had become a 'revenge' gun, able only to keep him from living to attack again. Probably the nadir came with the kamikaze attacks, when the gun was clearly unable to provide useful protection. In May 1945 the captain of the destroyer *O'Brien* reported that 'after experience with suicide attacks at Leyte, Ormoc, Mindoro, Lingayen and Okinawa [he] advocated heavy continuous fire as the ship's best defense and recommended replacing 20mm with 40mm guns ... the 20mm had a negative psychological

value, the saying among the crew being "When the 20mm opens fire, it's time to hit the deck".' Another destroyer reported that 20mm fire was a signal to the engine room to shut down blowers to keep the flash of the explosion from a suicide hit from being drawn into the machinery spaces.

Despite such negative reviews, the Oerlikon was retained into the 1950s, and was even incorporated in some new designs, such as the SCB-27A carrier reconstruction project. There, however, it was justified on morale grounds: however ineffective it might be, personnel found attacks easier to bear if they could fire back. When SCB-27A grew too much in weight, its 20mm battery was deleted: morale was valuable, but not quite that much.

BuOrd saw matters differently, as it was still impressed with the gun's high rate of fire and its ability to come into action very quickly. Early in 1944 it began work on a twin mount, the first of which was completed in September 1944. The lightweight twin 20mm was a means almost of halving the weight of existing 20mm batteries without reducing the number of barrels (although it certainly did reduce the number of targets a ship could engage) and so figured heavily in the rearmament programs of 1945, as Bofors were added in large numbers and weight compensation was sought. BuOrd continued to support the concept of a free-swinging anti-aircraft weapon postwar. Many plans, for example, show a proposed 35mm gun, but the interim free-swinging gun, the twin 20mm, was all that ever appeared.

By June 1945 Navy policy called for giving priority of space and weight to heavy automatic weapons (the existing Bofors gun and the new 3in/50) and their fire control with regard to

displacement of existing 20mm; however, the maximum number of 20mm were to be mounted, the goal being a minimum of one 20mm barrel to every two 40mm barrels. The new Mk 24 twin mount could be installed on the same foundation and with the same working circle as the single mount; with the Mk 14 sight, on a weight-for-weight basis, three twins could replace four Mk2 or 4 singles (gaining two barrels while saving four men), or they could replace five lightweight Mk 10 single mounts (gaining one barrel and saving two men) without, in either case, any reduction in ammunition per barrel. There was some loss, as the twin mount generally did not have twice the firepower of two singles. Smoke and vibration increased, to reduce the effectiveness of the lead-computing gun sight. As might be expected, handiness suffered, and there were reports of torque when one of the guns stopped firing. An SCB memo offered, as a tentative evaluation, that three twins (with Mk 14 sights) were equivalent to four singles, and two twins to three singles on smaller ships without the special sight. It concluded that 'if this ratio works out in actual combat there will hardly be a gain and possibly some decrease in overall

THE 20mm SINGLE MOUNT MARK 4

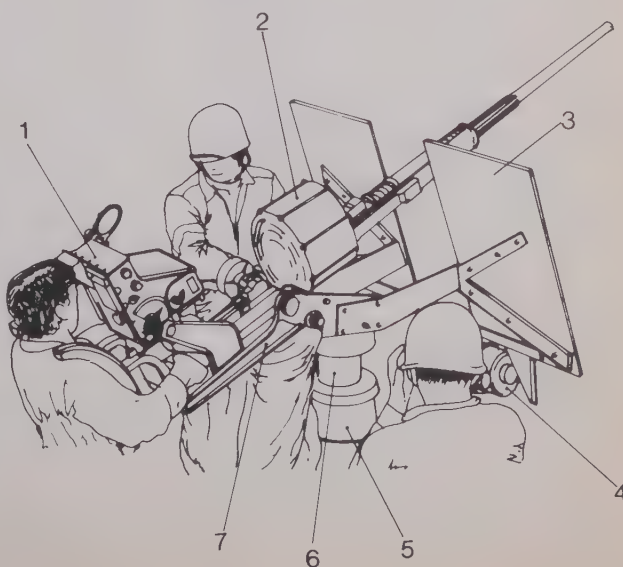
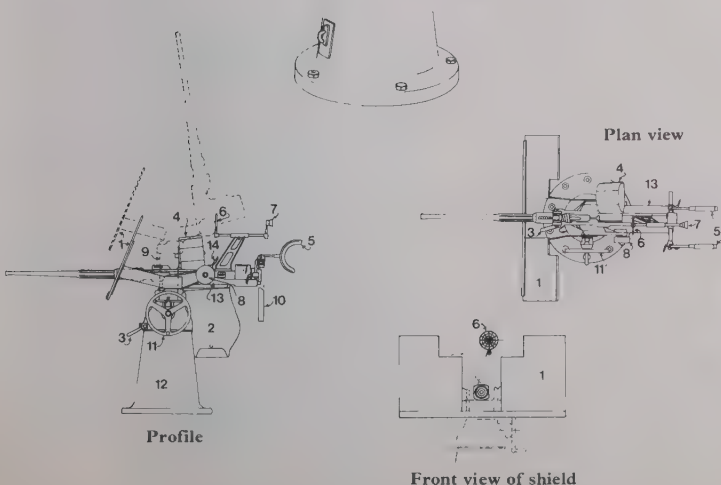
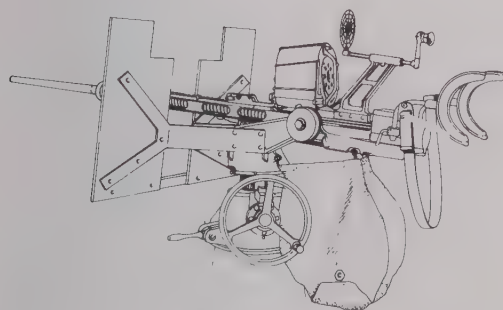
Key

- 1 Shield
- 2 Cartridge bag
- 3 Clamping lever
- 4 Magazine
- 5 Shoulder rests
- 6 Fore sight
- 7 Back sight
- 8 Elevation counterbalance spring case
- 9 Column
- 10 Back strap
- 11 Column raising handwheel
- 12 Pedestal
- 13 Cradle
- 14 Magazine catch

GENERAL VIEW OF 20mm OERLIKON AND CREW

Key

- 1 Mk 14 gun sight
- 2 Magazine
- 3 Shield
- 4 Power unit
- 5 Pedestal
- 6 Raising column
- 7 Cradle



20mm firepower on the weight for weight basis, [and] a definite loss on the barrel for barrel basis. The profit in the extensive work involved [in conversion] may be open to question.' However, the goal of replacement was generally either to clear arcs (some 20mm guns had been spaced less than 10ft apart, so that they could not turn freely; others were extremely poorly located) or to permit massive increases in the most effective antkamikaze weapon, the Bofors gun. Priorities for installation, set in the summer of 1945, were (i) combatant ships, including landing and close-in support types; and (ii) within the combatant category, 'those requiring 20mm twins as weight compensation, and those with meager AA batteries such as DD, DE, AM, DM, and DMS to take precedence over heavy ships with large numbers of 5in and 40mm guns... only ships destined for Pacific to be considered'.

More powerful 20mm mounts were tested. The first was Mk 15, a quadruple power-driven mount originally intended for PT-boats. It was installed aboard the battleships *Massachusetts* and *Maryland*, and by June 1944 had been authorized also for the training ship *Wyoming* and the battleships *Arkansas*, *Colorado*, *West Virginia* and *Washington*. The Pacific Fleet recommended further installations (including four cruisers) in view of the success of the first two, but nothing came of the project, partly because BuOrd considered the 20mm most valuable as a free-swinging weapon which could still be used after all shipboard power had been lost; apparently the order to procure two hundred Mk 15s came from above. Meanwhile, in 1944, it had under development a Mk 19, and was investigating the Canadian Inglis mount, powered by a self-contained gasoline engine. All had been considered primarily as PT-boat weapons, and BuOrd felt uncomfortable with efforts to turn them into major unit air defense weapons. Interest soon waned.

It revived with the kamikazes, and several multiple mounts were designed in 1945. The only one to see service was an adaptation of the standard Army quadruple 0.50-caliber machine gun, which appeared as the Mk 31 aboard the fleet carriers *Wasp* and *Lexington* (6 each, in place of ten twin or fourteen single 20mm) and the escort carrier *Cape Gloucester* (4 mounts, in place of six twin or nine single 20mm). Under development was Assembly 334, consisting of the standard Army quadruple 0.50 mount with four Hispano guns (T31 or M3), and designated Mk 22 Mod 1 in the Navy 20mm series. It was self-contained, as it was driven by a gasoline engine, and it had 200 rounds per barrel on-mount, with a spectacular rate of fire – 2800 rounds per gun per minute. The working circle, 14ft, was comparable to that of the twin 40mm. Development of this concept continued postwar, a sextuple mount ('blizzard buggy') appearing briefly, with a new machine gun, the T34.

The 40mm Bofors

The 40mm Bofors gun was the other major US Navy automatic weapon of World War Two, replacing the 1.1in. Just as the latter had been considered a most urgent requirement, its successor was urgently sought as a counter to the primary air threat, the dive-bomber. In 1940 the Navy Department Anti-Aircraft Board (King Board) considered the lack of an effective close-range anti-aircraft weapon 'the most serious weakness in the readiness of the

Navy for war', recommending both increases in 1.1in production and a search for a more effective successor, the twin Bofors. Unlike the Oerlikon and the 1.1in, the Bofors used the energy of its recoil to operate its breech and its feed; its prominent spring surrounding the barrel forward of the breech mechanism was a characteristic feature of the weapon. An unusual feature was that the trigger controlled only the rammer; once ramming began, loading and firing were automatic. Much of the Bofors' popularity (which was enormous) could be traced to the much greater power of its ammunition compared even to that of the 1.1in which had been considered powerful for its size. Muzzle velocity rose to 2890ft/sec, and the standard tracer round burned for 8.5–10.5 seconds (4200–4500yds). Although no 40mm VT fuze was developed during the war, there were armor-piercing, high-explosive and incendiary rounds, with a projectile weight of just under 2lb, over twice that of the 1.1in. The rate of fire per barrel slightly exceeded that of the earlier weapon at 160 rounds per minute, so that the fire of a twin Bofors would slightly exceed in weight that of a quadruple 1.1in. The weight of the twin mount was only marginally greater (for example, about 13,000lb for a Mk 1 twin vs 12,000–14,000lb for 1.1in Mk 2 Mods 3–6), so that the twin 40mm could replace the 1.1in on a one-for-one basis; indeed, the power drive of the Mk 2 Mod 6 1.1in was interchangeable with that of the Mk 1 Mod 2 twin Bofors.

The Bofors was liked for its high power, its ruggedness, and its simplicity of operation and maintenance. The percentage of aircraft kills attributed to it grew as the Japanese came to rely more heavily on suicide tactics late in World War Two, so that between 1 October 1944 and 1 February 1945 about half of all aircraft shot down by US surface ships were credited to the Bofors. The same sort of popularity shows in the extensive kamikaze rearmament program of 1945, in which many fleet destroyers were fitted with additional Bofors guns at the expense of their torpedo tubes. Earlier, destroyers and destroyer escorts operating against very heavy air opposition in the Mediterranean had exchanged their torpedo tubes for single (Army-type) 40mm guns. Only at the very end of the war was there any feeling that a replacement was needed, as the Bofors might not be able to destroy an approaching kamikaze soon enough to keep it from hitting. Firing a much heavier shell, the 3in/50 could put up more metal than could the twin 40mm, and it could do so more effectively, since those shells would be VT-fuzed.

In all versions of the Bofors gun, ammunition was loaded in the form of four-round clips atop the breech mechanism, each full fixed round weighing about 4.8lb, for a total of about 19. The Bofors feed atop the gun could hold two clips, so that fire could be maintained continuously by passing clip after clip into gun. By way of comparison, the eight-round clip of 1.1in gun weighed about 34lb – almost 3lb per round, and 10 for the enclosed clip. Clips had, then, to be fed to the 1.1in about seventeen times a minute, to the Bofors about forty. Both figures contrasted with the rate of fire of the 5in/25, whose single round weighed far more than either, about fifteen rounds per minute at best.

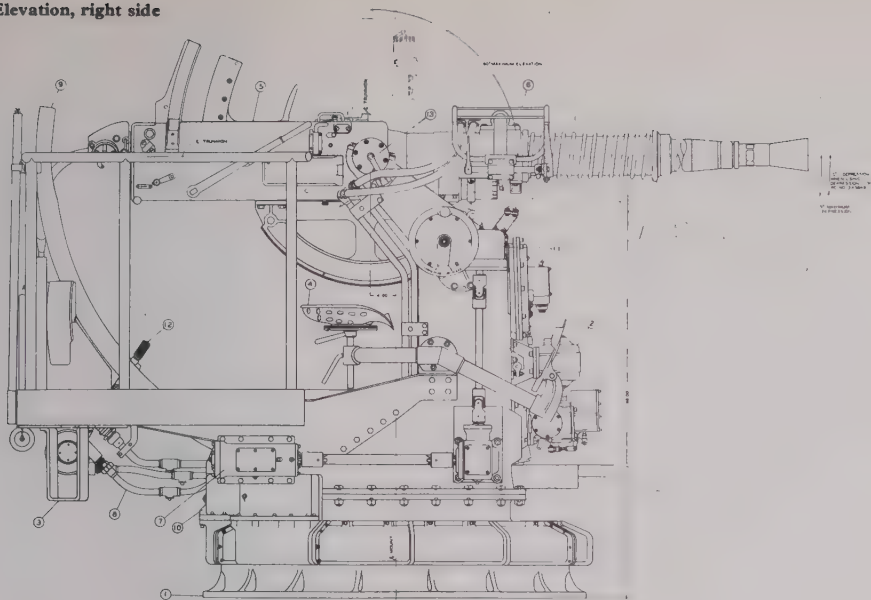
The path from the Swedish Bofors company to US warships was complicated. According to the official BuOrd history, it began with a Swe-

dish businessman and a large stockholder in Bofors, a Mr Wenner-Gren, who in the spring of 1939 interested an American engineer and businessman, Henry Howard of Newport, Rhode Island, in it. When he went to Europe for the Copenhagen convention of the International Chamber of Commerce that June, Howard also visited Stockholm, where he saw the Bofors gun demonstrated. On his return he visited Admiral Furlong, Chief of the Bureau of Ordnance; after a second visit Furlong decided to buy one for tests. This twin 40mm gun arrived in New York on 28 August 1940, bound for the Proving Ground at Dahlgren. Meanwhile, J A Cunningham, Assistant to the President of the York Lock and Safe Company, had also witnessed a firing demonstration, and his company became interested in license manufacture of the weapon. Admiral Furlong approved, suggesting only that any agreement include provision for US use of the guns, one of which he wanted to purchase for tests. A York delegation started for Sweden in April 1940, but had to turn back due to the German invasion of Norway. That left the US naval attaché in Stockholm, who was able to buy the air-cooled (rather than the desired water-cooled) twin mount which arrived in August, having been shipped through neutral Finland.

Bofors guns were already in wide use in other navies. In particular, in August, the Dutch naval attaché in Washington arranged a demonstration of the weapons aboard the gunboat *Van Kinsbergen*, equipped with a German fire control system. The heavy cruiser *Tuscaloosa* provided aircraft to tow the targets for tests off Trinidad. The Americans were unimpressed with the fire control system, but felt otherwise about the gun. Within a month the US twin mount was firing at Dahlgren, showing its superiority over all alternatives, which had included the British 2pdr and the Army 37mm, the weapon which had been specified for the Treaty cruisers in the mid-1920s. It was soon dropped, but the British 'pom-pom' did receive serious consideration. The Royal Navy was anxious to have it adopted by the United States, as that would greatly simplify supply. Moreover, it had proved itself in action. However, it used cordite, which was not manufactured in the United States, and it could not be adapted to American powders. Its low muzzle velocity, 2350ft/sec, was an important drawback. Moreover, by 1940 British Army experience with the Bofors could be cited, and the Royal Navy decided in favor of the gun soon after the American decision to adopt it, in November 1940. Admiral Furlong himself later claimed that there had never been any real question of adopting anything but the Bofors, and that the arguments favoring the pom-pom (whose design predated that of the 1.1in) were academic.

Production remained a major problem. Upon his return from Trinidad, Captain Blandy, who was in charge of the BuOrd anti-aircraft program, asked the Dutch for drawings. Although the Netherlands had been occupied, prints were found in the Dutch East Indies and microfilms sent to the United States. More drawings were obtained from the British; the British Army soon began to manufacture its own Bofors guns in Canada. The US Army, which had first tested the gun in 1937, now decided to procure it, using British drawings which they turned over to Chrysler for production. Remarkably, these production

Elevation, right side

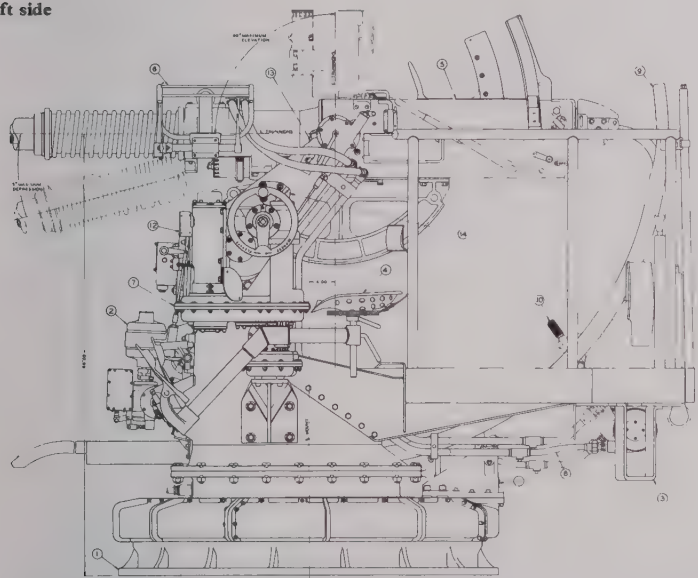


THE 40mm TWIN MOUNT MARK I

Key

- 1 Stand and base ring
- 2 Firing mechanism
- 3 Platform
- 4 Seat and foot rest
- 5 Gun
- 6 Sight
- 7 Training gear worm
- 8 Cooling system
- 9 Case chute
- 10 Training buffer
- 11 Training gear manual drive
- 12 Training centering
- 13 Carriage

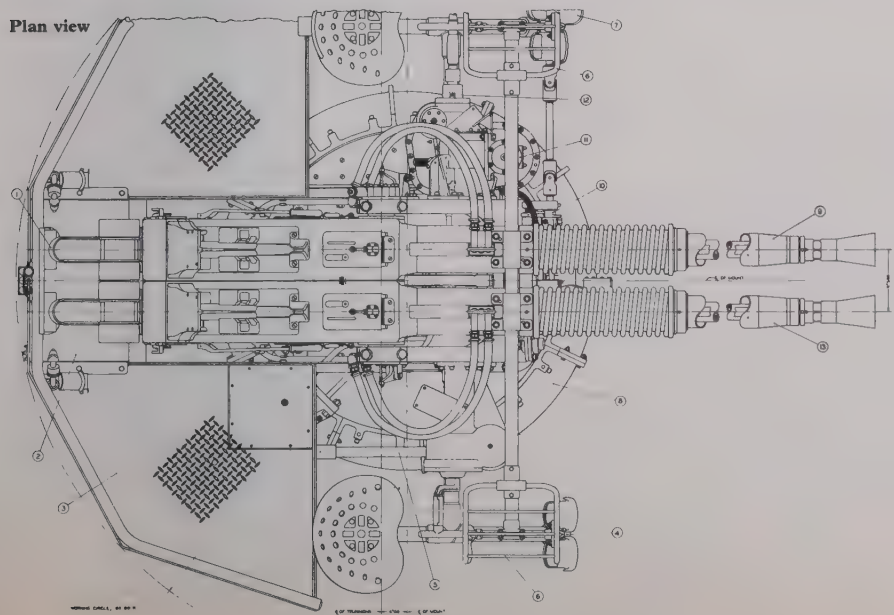
Elevation, left side



Key

- 1 Stand and base ring
- 2 Firing mechanism
- 3 Platform
- 4 Seat and foot rest
- 5 Machine gun mechanism
- 6 Sight
- 7 Elevating gear manual drive
- 8 Cooling system
- 9 Case chutes
- 10 Training centering
- 11 Training buffer
- 12 Elevating gear worm
- 13 Carriage
- 14 Elevating centering

Plan view



Key

- 1 Case chutes
- 2 Cooling system
- 3 Platform
- 4 Seat and foot rest, right side
- 5 Training gear manual drive
- 6 Sights
- 7 Seat and foot rest, left side
- 8 Stand and base ring
- 9 Left machine gun
- 10 Firing mechanism
- 11 Elevation gear worm
- 12 Elevation gear manual drive
- 13 Right machine gun

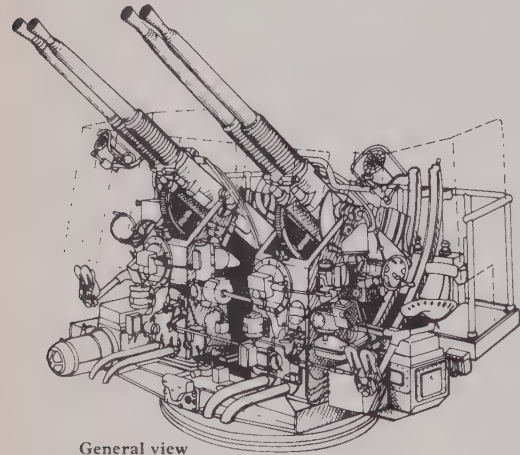
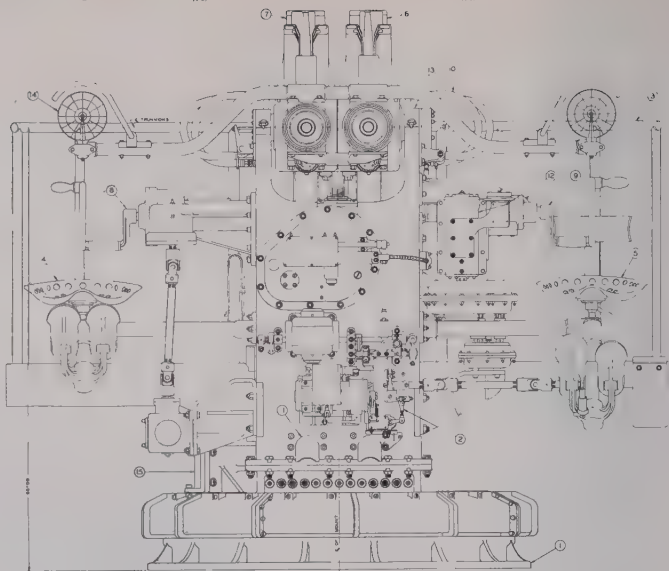
II. FLEET AIR DEFENCE

I THE 40mm TWIN MOUNT MARK I (contd)

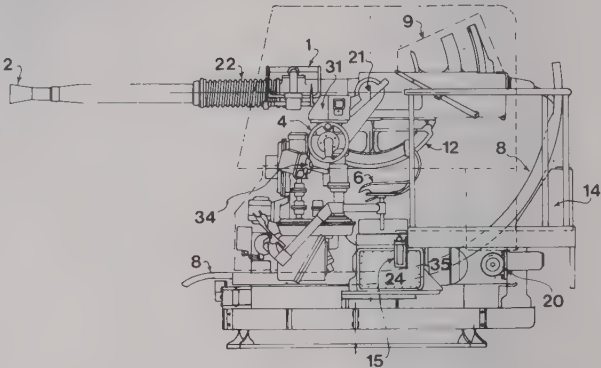
Front elevation

Key

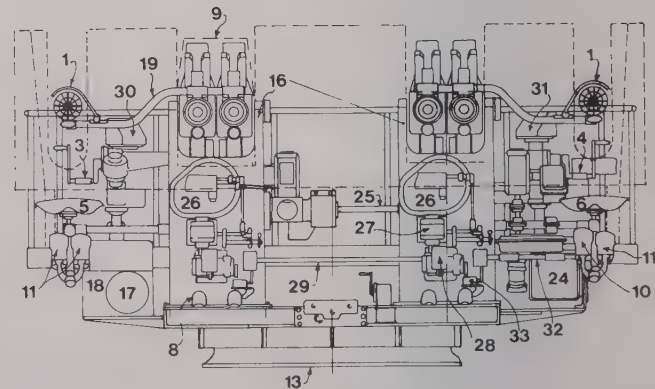
- 1 Stand and base ring
- 2 Firing mechanism
- 3 Platform
- 4 Seat and foot rest, right side
- 5 Seat and foot rest, left side
- 6 Machine gun mechanism Mk 1
- 7 Machine gun mechanism Mk 2
- 8 Training gear manual drive
- 9 Elevation gear manual drive
- 10 Cooling system
- 11 Case chute
- 12 Elevation gear worm
- 13 Carriage
- 14 Sight
- 15 Training gear worm



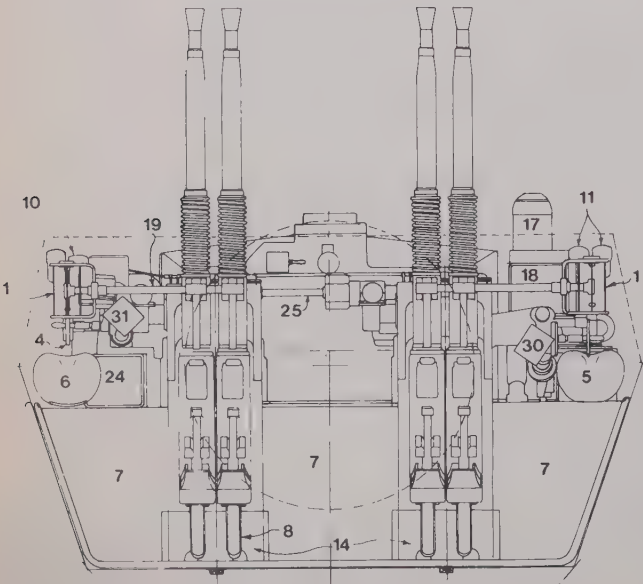
General view



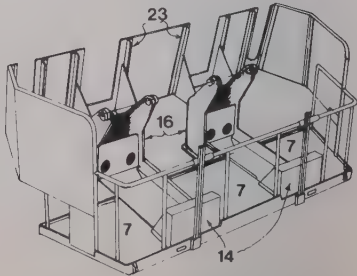
Pointer's side



Front elevation



Plan view



General view of shield and platform

THE 40mm QUADRUPLE MOUNT MARK 2 (see next page for key)

Key

- 1 Open sight
- 2 Flash guards
- 3 Training crank
- 4 Elevating crank
- 5 Trainer's seat
- 6 Pointer's seat
- 7 Loading platform
- 8 Case discharge chutes
- 9 Outline of loader hood
- 10 Firing pedal
- 11 Foot rest
- 12 Elevation arc
- 13 Stand
- 14 Coolant water tanks
- 15 Firing motor starters
- 16 Carriage
- 17 Train power motor
- 18 Power unit for train power drive
- 19 Sight bar
- 20 Cooling motor and pump
- 21 Trunnion
- 22 Recoil springs
- 23 Stiffening angle bars
- 24 Power unit elevation power drive
- 25 Cross-connection elevation drive
- 26 Firing stop-cam housing
- 27 Firing motor
- 28 Firing solenoid
- 29 Cross-connecting firing shaft
- 30 Train lag meter
- 31 Elevation lag meter
- 32 Firing pedal shaft
- 33 Firing switch
- 34 Local power joystick control
- 35 Elevation power motor

decisions had all been made in advance of negotiations with Bofors for the right to manufacture the weapon in the first place. So urgent was the requirement that BuOrd had decided to go ahead whether or not Bofors provided its license. For a time the Swedish government tried to bargain for licensing and export concessions from the United States to its aircraft industry, but these demands were withdrawn and a contract drawn in June 1941, although ultimately some of the Swedish requests were granted. Bofors provided production drawings to supplement the incomplete ones which had been provided by the British and Dutch; however, American engineers still had to translate these drawings to US units and, perhaps more importantly, to American production standards. York completed its first pilot twin mount in January 1942 and its first quadruple mount that April. The first ship installations were a quadruple mount aboard the gunnery training ship *Wyoming* (22 June 1942), and the first twin was mounted aboard the new destroyer *Coghlan* (1 July 1942).

As adopted by the US Navy, the Bofors was a water-cooled weapon in a twin power-driven, generally director-controlled, mount. Two twins elevating together formed a quadruple mount. At first the standard policy was to fit twin mounts in place of quadruple 1.1s, on a one-for-one basis, but quite soon the quadruple displaced the twin in 10,000-ton cruisers and larger ships. Of the first series of quadruple mounts, six each were allocated to new *South Dakota* class battleships, four each to older battleships (*Nevado* and *Idaho*) and to the cruiser *Helena*, and two each to new *Cleve-*

land class cruisers. Although production accelerated very quickly, in many cases ships did not have their assigned Bofors batteries until well into 1944 – a large number of destroyers spent the first two years of the war armed only with Oerlikons (as well as their 5in/38s).

The Army used a much lighter version, air-cooled and, originally, manually operated. The Navy procured it for lighter ships, such as landing craft, and then as a supplement to the power-driven batteries originally approved. Single Army-type Bofors guns were mounted in place of destroyer and destroyer escort torpedo tubes in 1944 in the Mediterranean, and this modification ultimately extended to most destroyer escorts. The Army Bofors gun also appeared aboard PT-boats and submarines. In some cases it was power-operated, with a Navy modification of an earlier Army power drive. In the extemporized destroyer installations, however, it was hand-driven, which made for a much simpler mount. Since it was not director-controlled, pipe rails had to be fitted to keep such guns from firing into the ships; in later, power-driven installations, the pipes were not needed.

Although BuOrd planned to replace virtually all 40mm guns in service in 1945 with the new 3in/50, in fact the lighter weapon remained through the 1970s, partly because the rearmament program was never fully funded. Eventually a VT fuze was developed for it, but even then there seems to have been no interest in a new 40mm development. Foreign navies, such as the Royal Navy, clearly felt otherwise, and both Bofors and the Italian firm of Breda have developed a variety of 40mm successors, often with automatic belt feed.

5. Antiaircraft fire control

The Mark 19 Director

The antiaircraft fire control problem resembled the surface problem in principle, and at first similar means were used to solve it. The first US director, designed to control 5in/25 guns, was the Mk 19, which appeared in 1927 and went to sea the next year. Until its advent there was no means of precision fire control for 3in or 5in AA weapons, which were restricted to laying down a barrage in the path of the oncoming aircraft, using preset fuze times and 'barrage charts' or 'barrage cards' to estimate the appropriate angles of elevation and train. By way of contrast the Mk 19 and its successors were designed to place bursting shells within lethal range of an airborne target, although war experience would show that this was difficult at best. Antiaircraft fire control was more de-

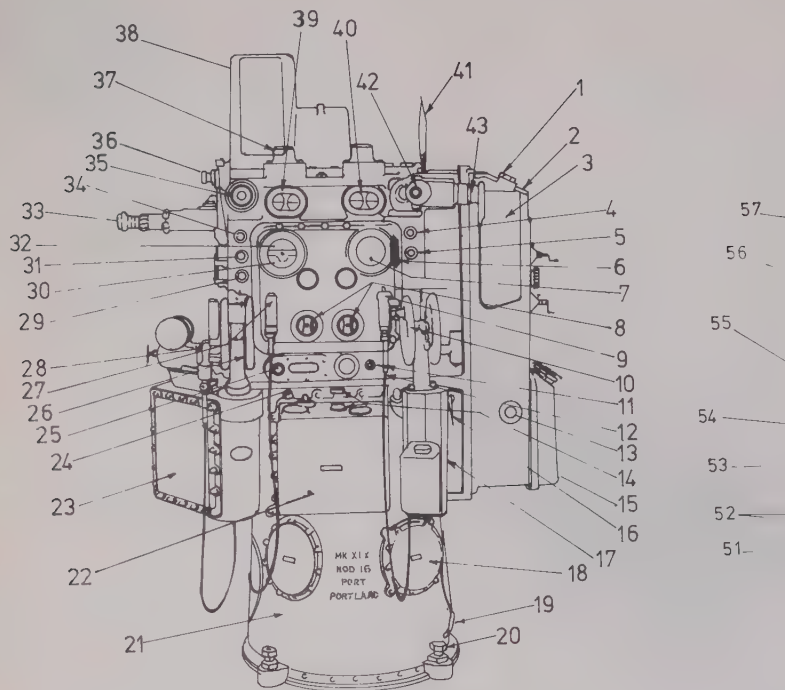
manding than surface fire control not only because the target moved much faster, but also because the range had to be computed far more accurately, as a time fuze had to be set to explode near the (much smaller) target. That is, a 5in shell might have a lethal radius of a few tens of feet at most, which might be compared to the danger space of a 5in/51 amounting to over 100yds (in range) at 5000yds, and to a similar distance in bearing (corresponding to the length of a ship).

Mk 19 and its successors for heavy-gun fire control were all 'linear-rate' systems. Initial estimates of target speed and altitude, taken from a rangefinder (which, at first, was not mounted on the director proper) were fed into a rangekeeper (computer) which predicted future target position. One set of predictions

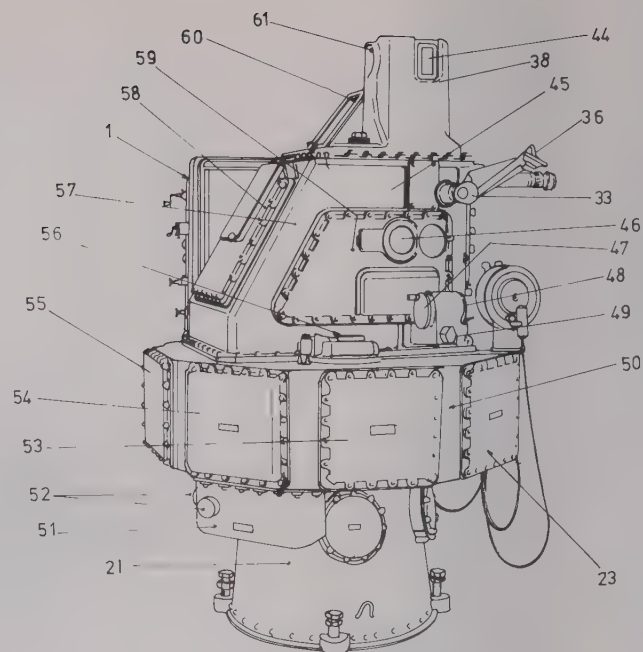
was used to drive the director, so that the pointer and trainer could check the rangekeeper's output and so, in effect, spot. A later prediction was used to aim the guns so that they would appropriately lead the target; the system also produced predictions for time fuze setting at the guns. Computing was mechanical, and the Mk 19 was additionally complicated by arrangements for optical as well as gyro stabilization: like the heavy surface-fire directors, it included among its operators a leveler whose special sight showed views of the horizon along and perpendicular to the line of sight of the director. Because the analog rangekeeper incorporated into the shape of its cams the ballistics of the 5in/25 gun, Mk 19 could not be modified to control the 3in/50 AA guns of the oldest battleships and of the *Omaha* class

II. FLEET AIR DEFENCE

THE DIRECTOR MARK 19 MOD 16/17



Target and leveler's side



Pointer's and trainer's side

cruisers without a major effort, which was precluded by a shortage of funds and by the small number of 3in/50s in service.

Even given its major limitations, Mk 19 was a considerable achievement. In 1946 BuOrd claimed that it had been the first heavy anti-aircraft director to enter service in any navy. For example, the Royal Navy did not receive its High Angle Control System Mk I until the early 1930s. Moreover, given the shortage of funds in the 1930s, Mk 19 was not replaced until well after the outbreak of war: in September 1939 it controlled 5in/25 batteries aboard nine battleships (all but the *Idaho*), aboard the carriers *Lexington* and *Saratoga*, and aboard *Pensacola* and *Northampton* class heavy cruisers. It had been heavily modified with, the BuOrd history notes, very limited success; perhaps the most visible change was the incorporation of a 15ft stereoscopic rangefinder in the fall of 1940, which merely duplicated improvements already made in the design of later units. Mk 19s were carried by heavy cruisers as late as 1943, and four of them were sunk with the *Lexington* at Coral Sea.

The Marks 28, 33 and 37 Directors

The next major system was Mk 28, built by General Electric (rather than Ford) with a Ford rangekeeper and an Arma stable element. It incorporated a stereo rangefinder; in effect, all elements of the anti-aircraft fire control system were grouped on a single pedestal. Sixteen were bought in 1933, to equip the three rebuilt *Mississippi* class battleships and the first five *New Orleans* class cruisers. Probably the chief defect of the Mk 28 was its weight, which made hand drive too slow to get onto and then to follow fast targets. In wartime matters worsened as radar was added; modernization was impossible. Mk 28 was in effect a transitional

Key

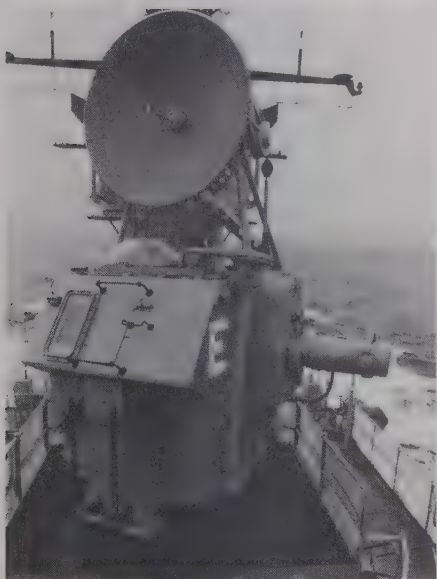
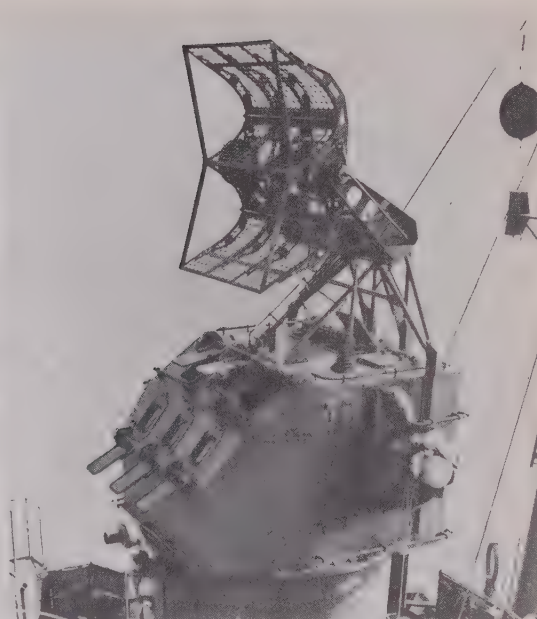
- 1 Ford Rangekeeper Mk IV Mod 6
- 2 Access to rangekeeper mechanism
- 3 Access to range motor
- 4 Power motor switch
- 5 Dynamotor switch
- 6 Gyro wattmeter
- 7 Target bearing designator
- 8 Rate dial windows, elevation and bearing
- 9 Trainer's rate key
- 10 Trainer's handwheels
- 11 Fuze control switch
- 12 Rate control switch
- 13 Time of flight dial
- 14 Initial velocity switch and dial
- 15 Access to rangekeeper, clutches, follow-ups, switches, etc.
- 16 Quick-acting clamp
- 17 Access to fuzes
- 18 Junction box
- 19 Lifting hook
- 20 Leveling and holding-down bolt
- 21 Pedestal
- 22 Access to ballistic computer
- 23 Access to sight deflection, sight angle and fuze-setting transmitters
- 24 Pointer's and trainer's control knob
- 25 Pointer's altitude lock
- 26 Pointer's handwheels
- 27 Pointer's firing key
- 28 Pointer's rate key
- 29 Interior illumination switch
- 30 Target elevation designator

- 31 Dial illumination switch
- 32 Voltmeter, 22V circuit
- 33 Leveler's telescope
- 34 Cross-wire illumination control
- 35 Pointer's telescope
- 36 Pointer's collimator sight
- 37 Light well
- 38 Optical cap
- 39 Sight elevation dial
- 40 Sight train dial
- 41 Trainer's open sight
- 42 Trainer's telescope
- 43 Check sight
- 44 Cross-leveling window
- 45 Pipe connection
- 46 Leveler's window
- 47 Cross-leveling handwheel
- 48 Leveling handwheel
- 49 Leveler's control knob
- 50 Transmitter belt
- 51 Access to dynamotor
- 52 Access to dynamotor regulator
- 53 Access to gun elevation and train transmitters
- 54 Access to sight train and elevation transmitters
- 55 Access to compass receiver, 'B' and 'C' clutches, power motor
- 56 Gun elevation and train dials
- 57 Case
- 58 Access to stabilizer unit, train integrator
- 59 Access to stabilizer unit, elevation integrator, clutches
- 60 Pointer's and trainer's window
- 61 Leveling window

development en route to Mk 33. Similar in concept to Mk 28, the new system was power-driven and so could accommodate additional weights in wartime, such as radar and a much heavier shield. It controlled 5in/25 and 5in/38 batteries aboard ships completed from 1934 onwards, beginning with the carrier *Ranger* and the heavy cruisers *Quincy* and *Vincennes*.

Mk 33 represented the limit of complexity which could be mounted in a single light, fast-turning director. As long as computing remained mechanical, greater target speed had to

require larger systems which in turn increased weight at the director and made rapid movement more difficult. In 1936 the Bureau of Ordnance began work on a solution, Mk 37, in which the computer was moved below decks, leaving a more compact (and better protected) position above, dedicated solely to tracking targets and to rangefinding. Although the Bureau history does not say as much, it would appear that the crucial development leading to the Mk 37 was reliable automatic electrical transmission of data. The history does claim Mk 37



1 The United States Navy was among the first to introduce anti-aircraft directors: a Mk 19 is shown aboard the heavy cruiser *Chicago* at Mare Island, 1931. It is the relatively small box covered with dials atop the platform abaft the funnel; note the absence of any rangefinder. It appears to be flanked by 0.50-caliber machine guns (under canvas).

2 Almost as familiar as the 20mm and 40mm guns was the Mk 37 fire control system, the first US AA director associated with a below-decks computer, as in major-caliber surface systems. This early one, with a Mk 4 radar, was photographed aboard the destroyer *Nicholas* on 17 January 1944. From left to right, the ports cover train and elevation telescopes and a director officer's telescope. Later in World War Two, the need to shift very rapidly from target to target caused the elimination of the latter in favor of an open slewing sight in a blister on the right side of the director. All three personnel acted as lookouts (through the hatches atop the director) until they had a target to track. Then the control officer designated a target, estimating target angle, speed, and rate of climb if necessary, which he telephoned to the computer. The pointer and trainer (elevation and train) kept their telescopes on the target to feed back target data to the computer, while a rangefinder operator sat in the rear of the director. Typically the shield also accommodated a radar operator and an illumination officer and, if necessary, a talker to transmit messages from other control centers to the director control officer.

3 The Mk 68 fire control system was the functional successor to the wartime Mk 37; this one was photographed aboard the frigate *Pharris*, May 1978. It carries an SPG-53 radar. Note its compactness: it accommodates only a director officer, a director tracker and a rangefinder operator. The director officer sits under the bubble, training the director and controlling its optics and radar in elevation. He acquires the target; the tracker, with a 6- or 10-power telescope behind the window, tracks it optically. The newer Mk 86 dispenses with both, but does have a remote optical tracker using a television camera.

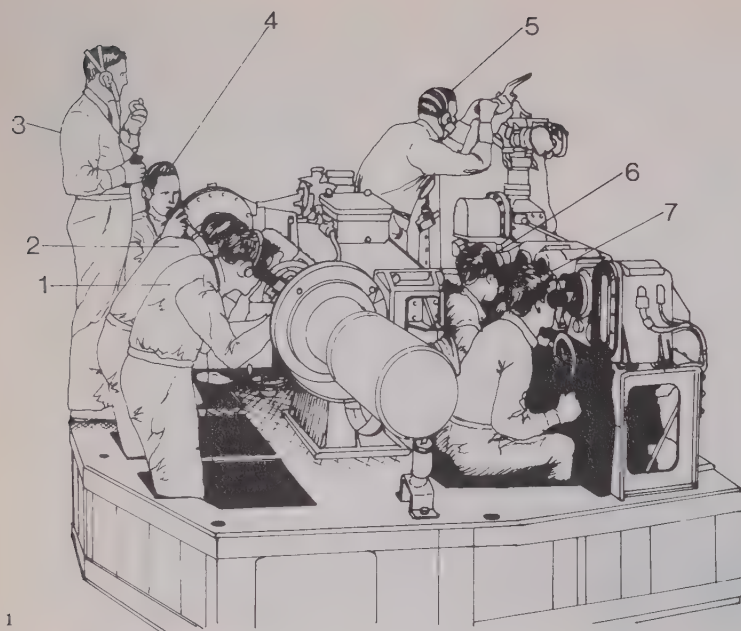
4 The Mk 33 director, unlike the Mk 37, carried its computer topside – indeed, most of the equipment visible in this photo of a Mk 33 aboard *Ranger* is the computer. The two men peering through the director (Nos 85 and 61) are exercising 'rate control' in range and in angle, as in the earlier Mk 19; the talker can also be seen. The front of the director carries a stereo rangefinder and a Mk 4 radar antenna, and the entire assembly is gyro-stabilized.

US National Archives

as the first director designed from the beginning to employ radar, for which its clear flat upper surface was specifically designed.

Mk 37 was first tested in 1939, and it became the standard wartime dual-purpose director. BuOrd considered it enormously successful, fully adequate until the advent of the Japanese jet-propelled suicide bomb (Baka) late in World War Two. Innovations included a much more effective rangekeeper (which was re-designated Computer Mark 1), high-speed controls, and a fully automatic rate control in the computer which could reach a target solution without operator aid. The director and computer represented a closed control loop, an important innovation – and a major development problem, given the previously unappreciated effects of servos in the system.

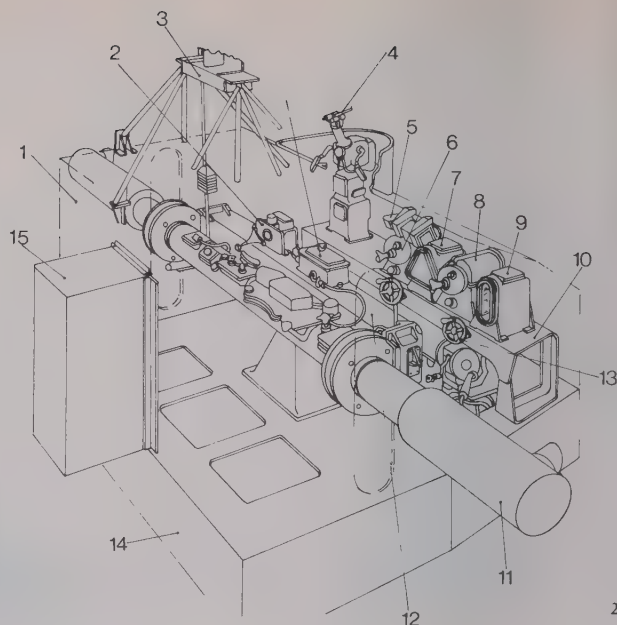
By 1945, Mk 37 was subject to criticism that its solution time was too long and its target speed limits too low (for excessive errors against a maneuvering target), but CinCPac warned that 'it has been an excellent step toward the solution of an exceedingly complex problem; it should not be damned for its failure to be the complete answer'. One problem was



1 THE DIRECTOR MARK 37 (CREW POSITIONS)

Key

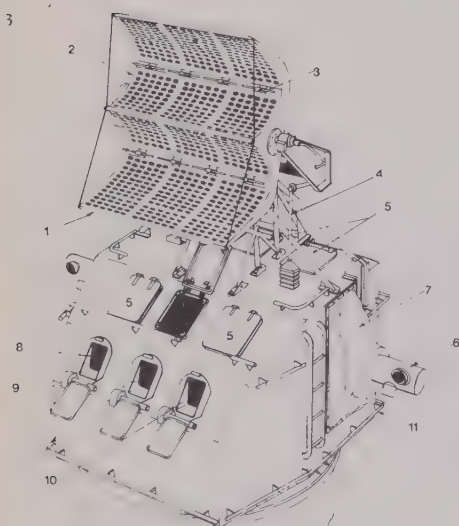
- 1 Range talker
- 2 Rangefinder operator
- 3 Illumination control officer
- 4 Talker
- 5 Control officer
- 6 Pointer
- 7 Trainer



2 THE DIRECTOR MARK 37 (INTERNAL DETAILS)

Key

- 1 Shield
- 2 Range spot transmitter
- 3 Radar antenna mount
- 4 Slewing sight
- 5 Radar elevation indicator
- 6 Telescope
- 7 Elevation indicator
- 8 Telescope
- 9 Train indicator
- 10 Optical box shelf
- 11 Rangefinder
- 12 Rangefinder beam
- 13 Port closure handwheel
- 14 Carriage weldment
- 15 Blister for amplifier power assembly



3 THE DIRECTOR MARK 37

Key

- 1 Mk 4 radar antenna
- 2 Reflector
- 3 Dipoles
- 4 Cross-level connecting rod to radar antenna
- 5 Observation hatches
- 6 15ft rangefinder
- 7 Canvas weather cover over rangefinder slot
- 8 Trainer's telescope port
- 9 Pointer's telescope port
- 10 Control officer's sight port
- 11 Handrail
- 12 Elevation connecting rod to radar antenna
- 13 Rangefinder slot, allowing clearance for cross-level movement

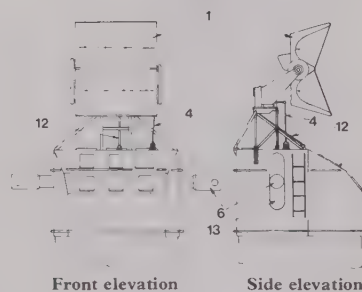
that errors increased as the range decreased, *ie* as angular rates increased. There was a proposal to incorporate acceleration factors for maneuvering aircraft.

systems which until very recently dominated 5in/54 fire control, Mk 67 and Mk 68. Mk 67 was, in effect, a redesigned Mk 37 incorporating a new Mk 47 electronic/electro-mechanical computer in place of the electro-mechanical Mk 1. It could, therefore, deal with higher-speed targets. However, only a few were produced, since a similar system modified to counter supersonic targets, Mk 68, soon appeared. Mk 68 remained standard until the appearance of an entirely new generation of systems in the 1960s (see Part IV).

Because it incorporated elements remote from the rotating director, Mk 37 was designated a 'gun fire control system' rather than a 'director'. This nomenclature would be of little moment except that after 1945 gun fire control systems continued to be designated in the 'director' series, but directors (*ie* sub-components) received their own mark numbers. Some caution is therefore necessary in following fire control development by 'mark number' series.

Early Light Antiaircraft Control Systems

Directors were not developed for automatic weapons before 1940, partly because they were not considered necessary (the weapons were aimed through a combination of ring sights and tracer fire) and partly because funds were not available, but in 1940 the Bureau of Ordnance was able to invite its major fire control contractors to propose light antiaircraft directors, resulting in Mk 44 through 49, none of which was entirely successful. Approaches ranged from the 'dummy gun' of Mk 44 to complex, power-operated systems which were similar in principle to the 5in directors. Mk 44 itself was no more than a gun sight carried off the mount to permit remote control of the quadruple 1.1in, for much the same reason that director control had originally been applied to secondary battery guns. That is, simply by moving the sighting and control function away from the noise and smoke of the gun mount proper, accuracy could be improved – the director could be sited much better than the gun it controlled. Moreover, one director could (at least in theory) concentrate the fire of several gun mounts.



Front elevation

Side elevation



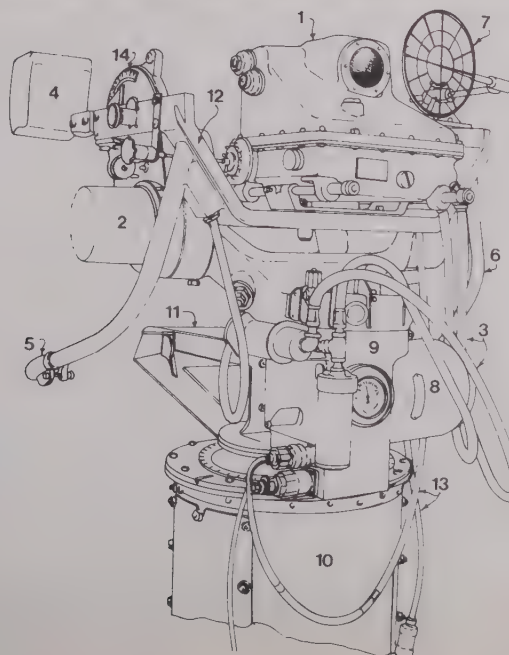
Successful light AA control systems had a rather different origin. All were 'relative-rate' types, in which the director, tracking a target, measures target motion, which is then fed into a computer to aim guns. Gyros in the director are used for the measurement, and the short range of the weapon simplifies computation very considerably, for a very fast fire control solution. Relative-rate systems were rejected for longer-range fire because very high precision was needed: roughness in gyro motion would have led to excessive errors. In effect, the computer in a linear-rate system smooths out the observed data to overcome such random motion – which might include some jinking by the airplane itself. The general principle of measurement of target motion by gyro applied, in World War Two, not only to shipboard fire control, but also to the family of airborne fire control systems which replaced the earlier simple sights.

The first of the relative-rate systems was the Mk 14 gun sight, developed at MIT by Dr Charles Draper, who later became important in missile inertial guidance development. Since the guns fired at very short range, Draper could



1 The most successful US attempt at an automatic-weapon director was also one of the simplest – the Mk 51. Here two of them, as yet without their splinter shields, are visible atop pedestals on the reconstructed destroyer *Dorwin* (at Mare Island, 30 November 1943), controlling a pair of twin Bofors guns in a typical destroyer arrangement. Note, too, the fuze-setter on the left-hand side of No 3 5in/38 gun abaft the automatic weapons. By the end of World War Two, the Mk 51 had developed into a radar-equipped blind-fire director, Mk 63, the radar dish being carried on the gun mount proper.

2 Through the war, there were attempts to develop directors for automatic anti-aircraft weapons. This is one of the more elaborate, a Mk 49 with a Mk 19 radar, aboard the battleship *New Jersey*, 29 October 1943
US National Archives



3 THE DIRECTOR MARK 51

Key

- 1 Mk 14 gyro gun sight
- 2 Elevation synchro unit
- 3 Air hoses
- 4 Counterbalance weights
- 5 Right handle with firing key
- 6 Left handlebar
- 7 Open ring sight
- 8 Power unit motor
- 9 Air power unit
- 10 Pedestal
- 11 Body rest
- 12 Sight bracket
- 13 Electricity cables
- 14 Elevation scale

afford to use a relatively crude system, and this simplicity was the key to its success. His sight calculated the lead angle on an airplane, which, approximately, was the observed angular rate of motion of the target multiplied by a function of present and advanced range. Without a rangefinder at the gun, and operating at short range, Draper approximated both ranges by a single figure (which would have in any case to be estimated). He used two gyros, one to measure vertical and the other lateral rate, damping them to overcome the instabilities which had plagued earlier relative-rate systems. The computing sight itself was fixed to the gun, but as it operated, its optical line of sight was moved by the gyros, so that the operator had to move his gun (in fact to lead his target) to compensate.

The Mark 51 Director

Dr Draper first proposed his 'disturbed line of sight' device in 1940 as a secret project for the Sperry Gyroscope Company, and it was first shown to senior BuOrd representatives in May 1941, just as alternative approaches to light fire control were showing severe problems. Tests followed at Dahlgren in July, and by October 2500 had been ordered. Not only did Draper solve the problem of effective control of individual 20mm mounts; he also solved the 1.1in/40mm fire control problem at the same time, since his gun sight could be mounted on a 'dummy gun' director linked to a multiple gun mount. Of twelve pilot models ordered on 30 June 1941, four were designated in August for mounting on dummy guns which became the primary wartime light weapon director, Mk 51. Its original 'barber chair' design was not successful, but a very simple substitute, with handlebar control and synchro transmitters, was adopted. The first order, for 1000, was placed in January 1942, even before the system had been tested, and in all 14,000 were manufactured, as well as about 85,000 Gun Sights Mark 14.

In service, Mk 51 was adapted to control 3in and 5in guns for ships which could not take heavier directors. In many cases, too, it was cross-connected to 5in/38 or 5in/25 guns to permit them to come into action more quickly against short-range targets. There was strong sentiment in the Fleet to provide each 5in gun with its own Mk 51, to permit ships to counter saturation attacks. After 1945 the Bureau of Ordnance commented that, since it generally took four 5in/38 to destroy an incoming target, such dispersion of the anti-aircraft battery would be useless.

The Mark 52 Director

Wartime development of the Draper sight led to a new director, Mk 52, built around a new Mk 15 gun sight, which included a telescopic sight for more accurate tracking, for reduced sight damping and for faster solution. Since the sight was ready before the new director, it was incorporated in a modified Mk 51 (Mod 3). Although it could not provide a very great improvement (since range remained an operator estimate), it did greatly advance target pickup, identification and tracking in confused situations. BuOrd had assigned its Mk 51 Mod 3 directors to 3in and 5in batteries, and was unprepared for Fleet demands for 40mm directors with the new sight. A reversal in priorities took time, and only about 200 had reached the Fleet by the end of the war. In fact, the tele-

scopic sight had been designed for combination with a range-only radar in a new Mk 52 director. The radar itself did not generate a precise enough beam for blind fire, but merely by providing accurate range it did greatly improve the accuracy of the system. There was one major problem: the radar operator, below decks, had to 'gate' a radar signal corresponding to the target the sight operator, above, was tracking.* Even so, Mk 52 was mass-produced, particularly for destroyer escorts for which no alternative lightweight system was available.

The Marks 63 and 64 (GUNAR) Directors

The final development of the Draper system was its adaptation to blind fire, *ie* to full radar control, in the Mk 63. Draper had tried for blind fire in an intermediate Mk 58, in which a radar dish on the director was able to displace from the line of the sight of the director proper to provide a radar analog of sight's optics. The antenna had to be much enlarged to gain angular accuracy, and it proved too heavy for the small director. In Mk 63, therefore, the radar was mounted on the gun mount; Mk 63 is characteristic of many postwar 40mm and 3in/50 mounts. The director itself did not have to bear the weight or the wind-loading associated with a large enough dish. To overcome the problem of misdesignation, the radar display was projected into the field of view of the sight, a feature unique among wartime sights. Mk 63 was first tested in June 1944, and BuOrd later considered it 'as accurate as any system in existence at the end of the war on evasively maneuvering targets within 4000 yards range. This short range accuracy together with hardness and light weight made the Mk 63 well adapted to cope with daylight kamikaze attacks. It weighed 4500 pounds complete, the lightest of all blind firing systems produced during the war or in design stage at the war's end.'

Mk 63 was a prominent element of the antikamikaze rearmament in progress in 1945. Few, however, saw action. The first was installed aboard the new carrier *Bon Homme Richard* in November 1944, only five months after the acceptance of the prototype. The other early installations were aboard the new destroyer *Purdy* and the refitted cruisers *Mobile* and *Oakland*. The system first entered action at Okinawa, and shared with Mk 57 the distinction of being the only blind-firing machine gun controls available before the end of the war.

Probably the chief defect of Mk 63, from a blind fire point of view, was its inability to acquire targets, using its very narrow-beam tracking radar. That is, a target might be detected by a search radar with a beam about 20° (and without any elevation indication); the Mk 34 radar of the Mk 63 system had a beam only 3° wide. A TACU (Target Acquisition Control Unit) was devised to nod the antenna through 20° in the vertical (10° each way), and the entire gun carriage could turn to search in bearing.

Despite the success of the 'disturbed line of sight' systems, a 1945 Pacific Fleet Board on Ordnance Lessons of World War Two leaned against them, given the inherent difficulties in fitting them with radar: 'any gun director which does not have radar control in both pointing and range is already obsolete... Even though the Mk 63 may operate satisfactorily, the arrangement is nevertheless illogical and

awkward.'

Mk 64 began as a developed Mk 63 with all components moved to the gun itself; a single mount director was, after all, no more than an extension of the sights on the gun. In this system the line of sight was displaced by remote control through a prism system in the sight telescope. The Bureau of Ordnance decided that it was not a director at all, and instead christened it GUNAR. GUNARs did appear on several ships postwar, but it appears that they proved too complex to be popular, and they did not last.

The Mark 57 Director

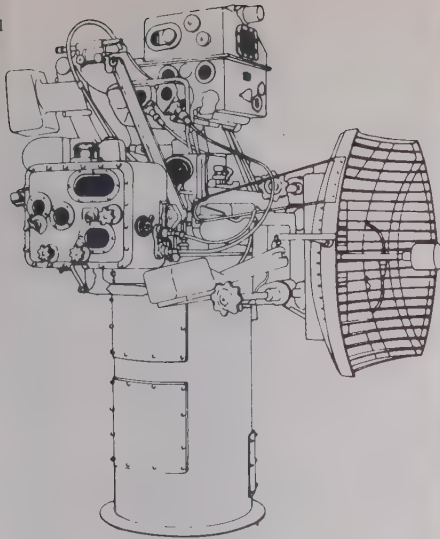
Beside Dr Draper at MIT, the other major Navy fire control development group was led by Dr Merle A Tuve at Johns Hopkins University (Applied Physics Laboratory, or APL). Its first task was the VT fuze, but in February 1943 it began to study light anti-aircraft fire control. Mk 57, a group concentration director, was the result. It carried rate gyros similar to those in the Draper sights, but employed a fixed line of sight. Gyro data was fed into a below-decks computer, which controlled the guns. Because the computer (which was Mk 16, showing how far matters had progressed since the Mk 1 of the Mk 37 fire control system) was located below decks, it could be large enough to incorporate ballistics for different guns, in this case 40mm and 5in/38. In most Mk 57s a switch selected one or the other, but in a late model (with Computer Mark 33) both could be developed simultaneously. It was even a simple matter to modify the system to control other guns: for example, it took only six weeks to prepare a Mk 57 for shipboard installation, to control 6in/47 guns. Moreover, since the director employed an 'undisturbed line of sight', it could be made relatively massive and could easily accommodate a blind-fire radar. Indeed, Mk 57 was planned from the first as a radar system.

Tests were brief, and 450 were ordered in March 1944, deliveries beginning that October. The first ships fitted were the battleship *Missouri* and the large cruisers *Alaska* and *Guam*. Target acquisition was a problem in blind fire, but unfortunately no TACU had been developed by the end of the war. Mk 61 was a power-driven Mk 57 employing automatic radar tracking and a TACU, in effect a perfected version of the very austere Mk 51/57 series. It was too late for the war and was not produced postwar, as funding for conventional air defense systems was cut back.

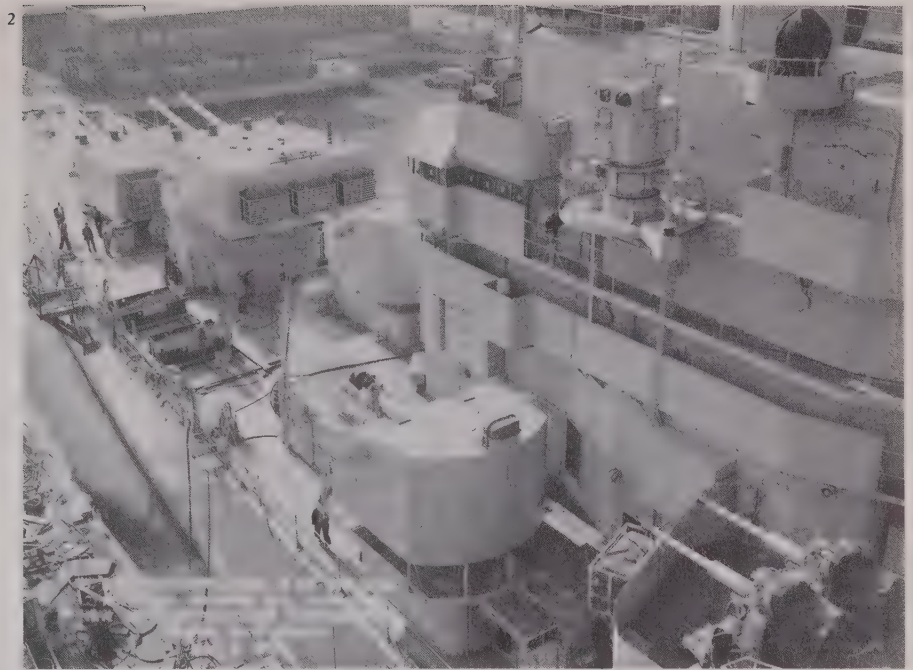
The Mark 56 Director

Mk 37 and the Draper/Tuve series were, in effect, the ends of a spectrum of director capabilities. The only other major wartime anti-aircraft control system, Mk 56, lay between them. It began as an MIT development, a full blind-fire director capable of air and surface fire, to weigh no more than 6000lb, and thus to be the primary director of small ships such as destroyer escorts, which required effective night surface fire control for ASW. At first, therefore, it was seen as little more than a radar

*'Gating' meant placing electronic markers around the radar 'blip' representing the target, so that the radar could be assigned to track that target rather than others it might detect. The display was an A-scope, showing range only, and 'gating' consisted of adjusting a pair of vertical, electronically generated lines (gates) around the spike representing the target.



1 THE DIRECTOR MARK 52
Note Mk 26 fire control radar



2 The Mk 56 director was the culmination of the series of US radar-equipped anti-aircraft fire control systems developed during World War Two. This one is shown aboard the converted missile cruiser *Canberra*, May 1956. The rear is visible, the Mk 35 radar being turned towards the ship's superstructure. In the triple 8in/55 turrets forward, note that both turret rangefinders have been removed to save weight. Each turret carries five periscopes: at the front are three for pointer's sights to control the three separate guns in elevation and one (to their right) for the turret trainer; at the rear is a periscope for the turret officer, for general lookout purposes, for picking up targets, for estimating their range, course and speed, and for spotting the fall of shell. Each turret has, in addition, on its left-hand side, a separate projection housing a checker's telescope, a feature not found in earlier US 8in/55 mounts. The stereo rangefinder originally installed in these turrets had a 26ft 6in base line (coincidence type in No 1 turret, stereo in Nos 2 and 3) and was effective between 2500 and 50,000yds. US enclosed 5in mounts of World War Two design also had a separate checker's sight, generally sharing the same optical system as the pointer; note the paired sights in the twin 5in/38 in the foreground, and the hood at the rear for a slewing sight to engage high-speed targets locally.

mount, target acquisition being achieved by spiral scan of the radar over a 12° cone. Admiral King demanded that optics be added, since radar would be unable to track very fast close-in targets. Mk 56 grew very rapidly in complexity, and development was not nearly complete when the end of the war closed the MIT Radiation Laboratory. It had, however, been chosen for several new ships, and General Electric completed work on it. As finalized, Mk 56 was a dual-ballistic system, which could issue simultaneous gun and fuze-setting orders to two different batteries of different types, such as 3in/50 and 5in/38. It was also considered very fast, capable of producing a fire control solution within two seconds of beginning to track. Postwar, it was installed aboard many ships refitted with 3in/50 batteries, from destroyers up through *Iowa* class battleships (which got the directors, but not the guns).

Reclassification

With so wide a range of anti-aircraft fire control available at the end of the war, the Bureau of Ordnance adopted a new classification in which major long-range dual-purpose directors such as Mk 37 became Class One, the new intermediate type became Class Two, and the Mk 57/63 became Class Three. Mk 52 became Class Four, and Mk 51 Class Five. At that time Class Two was envisaged as a means of achieving control of groups of heavy machine guns by quadrants. In September 1945, for example, the Chief of Naval Operations ordered that the number of such groups should not exceed twelve for a *Midway* class carrier, eight for an *Essex*, six for a battleship or large cruiser (17,000 tons), four for a light carrier or a conventional cruiser, and two for a destroyer escort. Each heavy machine gun mount would have its own Mk 51, which might be connected to a 5in as a secondary control; but there would be no more Mk 51s specifically for 5in control.

In November, a second CNO letter discussed the basis for anti-aircraft fire control installations. It was assumed that four 5in

guns, or six 3in, or twelve 40mm, were the basic unit capable of effective fire against a single airplane. Each such group would be provided with a primary director:

... for widely separated mounts on the bow and stern, a primary control at or near the mount should be provided in addition. For large combatant vessels, it is highly desirable that the battery installation be of such capacity as to provide reasonably effective fire against two targets in each quadrant.

In considering quantity of control provided, due weight shall be given to provision of alternate control facilities in case of material casualty. In ships with two calibers of AA battery (power-driven) the directors of one caliber should be capable of simultaneous control of the other caliber in case of casualty. In addition each director should be capable of controlling the guns of adjacent groups as a standby measure.

As secondary control for all AA batteries (power-driven) provision should be made for local control of each mount by optical means, and, if possible, by radar. While electronics have proven their ability to give the best fire control solutions, yet there always remains a considerable degree of the probability of the solutions being nullified due either to counter measures, material or power failure. For this reason, it is considered that secondary control for all AA batteries (power-driven) should be provided for local control of each mount, by optical means and, if possible, by radar.

The control of the primary anti-aircraft battery requires, as a basic feature, directors on the centerline, fore and aft. Where quadrant control is required, this is to mean specifically two directors on the centerline and one on each side.

This policy could not always be carried through, but generally it meant that primary directors would be Class Two or better, with Class Three at or near mounts for local control; Classes Four and Five were to be discarded. Carriers were to have Class One directors fore and aft of their islands for primary control; in destroyers, fire control was to be by a Class One director forward, and a Class Two unit aft.

6. The VT fuze

Effectiveness

Probably the most spectacular wartime anti-aircraft artillery development was the proximity, or variable time (VT) fuze, in effect a small radar carried by a shell, exploding the shell when it came within lethal range of an airplane. VT operation was important because it compensated for many of the errors of prediction inherent in conventional time-fuze operation, *ie* it was no longer necessary for the fire control system to predict nearly so precisely the moment at which shell and airplane would meet. Most wartime naval use of VT ammunition was by 5in AA guns; the 3in gun was chosen for the 1945 antkamikaze program because it was the smallest caliber then suited to VT operation. Since World War Two, however, VTs as small as 40mm have entered service.

Since time-fuze effectiveness depends upon the precise estimation of range, conventional anti-aircraft fire lost much of its potency at long ranges, at which the same percentage error might bring the shell out of lethal range of its target. Moreover, statistical errors in the operation of the time fuze itself became more severe at longer ranges. A VT fuze, on the other hand, was accurate (in burst timing) virtually independent of its range, so that the performance of VT batteries declined only with decreased fire control accuracy at longer range. For example, RPB (rounds per bird) curves were drawn on the basis of combat experience. Those based on combat between 1943 and the first third of 1944 showed 60 rounds per airplane at 2000–4000yds and 100 at 8000–10,000; it was easier to kill an airplane at short range, but only by a ratio of about 1.7. At night, short-range killing power remained about constant (65 rounds per bird), whereas at longer ranges the RPB rose to 240, reflecting inaccuracies inherent in the Mk 4 fire control radar then in use. BuOrd analysts speculated that its error, probably constant in angular terms (mils), increased proportionately with range.

From a technical point of view, the great achievement of the VT fuze team was a combination of extremely rugged electronic tubes and careful miniaturization, the fuze being designed to burst the shell when its target lay within the cone of fragments, about 55° back from the nose of the shell. In effect, the radio transmitter in the nose of the shell acts as a continuous-wave radar: it detects a target when the reflections from the latter, interfering with the outgoing pulses, set up a 'ripple pulse' strong enough to trip an amplifying firing circuit. This technique of bursting a shell by doppler effect – by the difference in frequency between outgoing and returning signals – was understood as early as January 1941.

Ruggedness was very much another matter. A typical 5in/38 shell experienced an acceleration of 20,000g on firing, and spun at up to 475 revolutions per second. Moreover, the device had to be handled on a 'wooden round' basis, *ie* without any special measures. This kind of treatment is relatively rare, even now, in guided missiles, but VT fuzes had to be fired in

such numbers that special maintenance and checkout were entirely out of the question – and the VT fuze was a relatively complex electronic mechanism in its day. Typically, the shock of firing was used to break a glass ampule containing an electrolyte and the spin of the shell moved it into a small wet battery, to begin fuze operation. A firing condenser was charged within $\frac{1}{4}$ – $\frac{1}{2}$ second after firing, *ie* within about 300–500yds of the muzzle. A mercury safety switch also had to be opened to arm the shell. The antenna pattern was specially adapted to the shell burst pattern, and most shells were set to explode about 70ft from their targets. The signal pattern around the shell was symmetrical, so that below a certain altitude VT fuzes might burst against the surface rather than against aircraft flying over them. This problem has continued to the present in some missiles, and is the subject of continuing work on fuzing problems for low-altitude attack.

The VT fuzes were greatly superior to time fuzes. During 1943, of 36,370 rounds of 5in fired, a quarter were VT-fuzed, but 51 percent of all aircraft shot down were credited to the VT rounds, showing an advantage over time fuzes of 3.1 to 1. BuOrd estimated that later wartime improvements in the fuze probably increased this ratio to about 4 to 1. There were also theoretical analyses of fuze advantages, based on alternative levels of fire control accuracy: (i) a CEP of 100ft (half of all rounds pass through a circle centered on the target with a radius of 100ft) and (ii) a CEP of 200ft. With smaller shooting errors the VT fuze shows increased advantages:

Advantage ratio of VT fuze (i)	Advantage ratio of VT fuze (ii)	Percentage normal bursts (of VT fuzes)
6	4	70
5	3	60
4	2.5	50

BuOrd recommended that three-quarters of 5in and 3in rounds fired against aircraft be VT-fuzed; time-fuzed bursts near the target remained useful as a means of pointing out the target to other ships and to automatic weapons, in deterring the attack, in influencing its accuracy, and in disclosing gross fire control inaccuracies. The VT rounds, however, would be responsible for most of the aircraft destroyed.

VT-fuzing made the 5in gun a worthwhile competitor to the contact-fuzed (but much faster-firing) 40mm gun. The lethal area for the latter is only about 60ft², since the projectile must actually hit in order to detonate. By way of contrast, a 5in shell was considered lethal at 60–70ft, with an effective lethal areal of about 3000ft²; the VT shell has about 50 times the lethal area of the 40mm, which fires about six times as fast, for a net ratio of about 8.3, assuming only 70 percent normal bursts by VT rounds. These figures are only approximate, assuming as they do similar fire control accuracies and similar lethal effects within the burst areas. However, they do begin to explain the demise of the 40mm and even the 3in/50 post-

war, and the continued production of 5in dual-purpose weapons. Moreover, these estimates do not take into account the greater range of the 5in, which would considerably increase the length of time during which it could keep the approaching airplane under fire: no 40mm gun could be effective out to 8000yds. However, the BuOrd official history had to admit that

...at short ranges...the automatic 40mm and 20mm guns have a special value in certain tactical situations which larger guns using VT fuzes cannot equal. An outstanding example... was the suicide attacks by Japanese bombers [which] usually attempted to use islands or ships as screens against FD [Mk 4, 5in fire control] radars and then come in at great speed from short distances. Under such special circumstances fast firing and easily maneuverable automatic weapons have a distinct advantage over more cumbersome weapons and, in fact, action reports show that they accounted for by far the largest number of Japanese suicide planes.

Although the VT fuze was originally developed as a naval anti-aircraft weapon, it was also used extensively by the Army, both in land artillery and against aircraft and V-1 missiles in Europe.

Development

The concept of a proximity fuze was known well before World War Two: it was suggested by Admiral Blandy of BuOrd (then a junior officer) in 1925, and Robert Millikan, a prominent physicist, proposed one to the Navy in 1938. The British began work on alternative radio and photoelectric proximity fuzes for their 3in AA rocket in 1939, believing that components rugged enough to withstand the shock of firing could not be developed in time to be used during the war. BuOrd informally asked NDRC to develop a proximity AA fuze on 12 August 1940 at a meeting of the National Academy of Sciences; Dr Merle A Tuve of Johns Hopkins University was soon named to head Section T of Division A (armor and ordnance) of the NDRC. Alternative systems under consideration included a photoelectric fuze, a pulse fuze (ground-controlled), and an acoustic fuze, a special subsection of Section T being responsible for rugged components.

By May 1941 there was a preliminary design for a self-contained radio proximity fuze, and in August 1941 Dr Vannevar Bush, director of ORSD, suggested to J D Hunsacker, Navy coordinator of research and development, that contracts for production be negotiated, although the fuze was not yet fully developed. Cdr W S Parsons, who was later involved in the nuclear project, stated at the time that any delay in bringing VT fuzes into action would be extremely costly: that it would be equivalent to the loss of a battleship every three months, or a cruiser a month, of 150 men per day. A production contract was signed in December, although it did not take effect for nearly a year. Even so, the rate at which the revolutionary weapon was developed is impressive by modern standards.

The first fully successful test firing from a naval 5in gun took place in June 1941, and emphasis soon shifted to improved reliability, whence the alternative 'normal burst' percentages in the table of advantages above. The 50 percent reliability level was first exceeded in a production batch at the end of January 1942, and that April shells were first test-fired against an airplane, a Taylor Cub suspended beneath a Navy barrage balloon at Parris Island, South Carolina. The next step was a full live test: the new cruiser *Cleveland* shot down two drones simulating torpedo-bombers, in each case with fewer than ten rounds, on 12 August 1942. Volume production of the new Mk 32 VT fuze began in November 1942 and it saw action for the first time aboard the light cruiser *Helena* on 4 January 1943, against Japanese dive-bombers – a target originally considered far beyond the powers of large-caliber antiaircraft guns.

The original VT Fuze Mark 32 replaced the earlier Mk 18 time fuze, increasing effectiveness by a factor of about three. Wartime development was directed towards increased reliability and shelf-life, and also towards extension to other weapons, including British ones (under Lend-Lease). Mk 32 Mod 40 (begun in December 1942 and placed in service in June 1944) incorporated a 'wave suppression' feature permitting its use against low fliers. Mk 33 (October 1942–September 1943) was an equivalent of Mk 32 for use in the British 4.5in AA gun. Mk 40 (December 1943–September 1944) incorporated both a permanent battery (to overcome inadequate shelf-life) and 'wave suppression', and was first used in Mk 32 Mod 30. Mk 41 was a British fuze. Mk 45 (September 1943–December 1944) was a smaller fuze suitable for the 3in/50 and also for the Army 90mm and the British 3.7in AA guns; some of its versions were designed for protection

against electronic countermeasures. It was adapted for the 5in/38 (Mk 53) as a reduced-size equivalent of Mk 32/40, for British weapons (Mk 56), and for the 3in/50 (Mk 58). Mk 47, begun in June 1943, was intended specifically for the new 6in/47 dual-purpose gun. Mk 59 was a Mk 45-size fuze for the 5in/54 (July 1944–September 1945), and Mk 60 was a Mk 45-size fuze for the British. Finally, Mk 170 was a VT rocket fuze for the Army T38 rocket and Mk 173 was a VT fuze for the Navy high-capacity spin-stabilized rocket (5in). Development since 1945 has been extensive, but this list indicates just how rapidly the VT fuze concept spread in wartime; it does not even include the wide range of purely Army fuzes.

As for Section T, it became the Applied Physics Laboratory of Johns Hopkins University, the leading postwar Navy developer of surface-to-air guided weapons (Project 'Bumblebee').

7. Fighters in fleet air defense

Tactics

The primary tactic for active fighter defense of ships at sea, the combat air patrol (CAP), dates back to the earliest days of carrier operations, as a close relative to the standing patrols operated over the Western Front on land during World War One. However, the carrier could not hope to put up (nor to sustain) so powerful a force, given her very limited resources. Moreover, before World War Two the US Navy generally operated its carriers singly, largely because of its view of their vulnerability to detection and attack. That in turn greatly limited the size of combat air patrols available, either to protect the carrier or to defend a surface fleet, which would generally operate some considerable distance from the carrier. Independent carrier operations began with the appearance of the two large carriers, *Lexington* and *Saratoga*, in 1929. At first they were no more than a means of utilizing the superior speed of the carriers, compared to that of the Battle Fleet. However, it was soon observed that, once located, a carrier was as good as sunk. It followed that the best defenses of the carrier were evasion and earliest detection of the opposing carrier(s). A carrier tightly tied to a battle fleet which it was screening was much too easy to locate and to attack. On the other hand, several carrier functions, quite aside from air defense, were essential to that fleet: scouting, patrols against surface ships, and ASW patrols.

By the late interwar period, carrier tactics appear to have envisaged a combination of independent task force operations (one carrier plus, often, three cruisers and several destroyers) and Battle Line screening, the carrier retiring to a considerable distance (about 75nm) when action was imminent or enemy aircraft were nearby. Without radar,

there was some question as to how those potential attackers might be detected. Special formations provided one solution. For example, Fleet Tactical Instructions (FTP 142) issued in 1934 included a formation to be taken when air attack was considered possible. Destroyers were distributed along a circle, spaced to assure detection of large aircraft formations. Hopefully enough would be available to permit effective warning at 75–100nm. Carriers were to be located within a series of concentric screens so that their aircraft might be launched immediately upon receipt of information of the approach of hostile aircraft, and also so that an air patrol might be maintained if desired.

In fact there was widespread suspicion that combat air patrols over heavily armed surface ships might well be counterproductive, that many friendly fighters would actually be shot down. Even a carrier operating independently would find it difficult to launch and retrieve her combat air patrol within a tight formation, as she turned into the wind for extended periods. It appears, too, that at least until about 1939 there was considerable overoptimism as to the value of antiaircraft guns. There could be no realistic tests of their fire until the introduction of drone targets, which first appeared in 1939. Without any realization of the low effectiveness of the guns, it was natural for the Fleet to emphasize them. That was not to say that carriers were deemphasized, but rather that the carriers and carrier aviators preferred to develop their offensive role.

The evolution of fleet tactics was reflected in the annual and semiannual Fleet Problems (exercises). Carrier firepower and vulnerability were constant themes. For example, the Commander, Aircraft Squadrons, Scouting Fleet

(who had served as commander of 'Black' aircraft squadrons) wrote in 1930, after Fleet Problem X, that 'opposing carriers within a strategical area are like blindfolded men armed with daggers in a ring. There is apt to be sudden destruction to one or both. If the bandage over the eyes of one is removed the other is doomed. If the location of the enemy carrier is made known by air, surface or submarine contacts or by radio compass bearing or otherwise, a decisive advantage is obtained.' Scouting squadrons, but not fighter squadrons, were therefore enlarged, and carrier tactics reemphasized the value of evasion. In later Problem critiques, it was observed that map exercises almost always began with carrier-to-carrier engagements (often destroying both) and that the 'private war' of the carriers was beginning to take precedence, at least in carrier commanders' eyes, over the overall missions of their fleets, such as the successful transport of an expeditionary force across the Pacific.

No scouting triumph could protect a carrier from land-based aircraft, particularly if she disclosed her position by striking a land target. Although the early carrier operations in Fleet Problems often included attacks on the Panama Canal, as well as on West Coast cities, by the mid-1930s many carrier strike force commanders were recommending against such operations, at least as long as carriers were armed entirely with high-performance, short-range aircraft. Many stated that attacks of this type would risk the loss of all or most of the carrier's aircraft as well, quite possibly, as the carrier herself. After Problem XIV (1933), Captain C A Blakely of the *Lexington* wrote that

It was our intention to launch our planes about an hour and a half before dawn . . . we were willing to

launch from maximum distance that the planes could reach and return to the carrier with sufficient fuel to retrace their flight to the coast and intern at Sebastopol if they failed to effect rendezvous. Thus the maximum launching position was fixed at 125 miles and the rendezvous at 75 miles from San Francisco.

These distances to some may seem aggressive, to others conservative. They are prudently aggressive peace time radii, whose length in war time with present planes cannot be increased by more than 10 or 15 miles, if we wish to give flight task group commanders any assurance of having a reasonable amount of fuel on hand to search for and effect a new rendezvous which the carrier may be forced to specify during the absence of the squadrons, because of the presence of the enemy or other circumstances...

Our squadron commanders and their pilots are willing to risk their lives in the cause of their country, but in return they do ask a reasonable chance of getting back of their carrier after their mission has been accomplished. In peace time, insofar as is possible, this is provided; so, too, must it be provided in war. Therefore, if we expect to execute successful raids against shore bases, well-defended by a vigilant enemy, we must provide special carrier planes for the purpose and not expect planes of high performance but short radius to do the work...

Short radius planes can get in and deliver a raid on the enemy but plane and aviator may be sacrificed. To attempt to save the aviator by [a] carrier standing in close to a well-defended enemy's shore will, in most cases, result in [the] destruction of both carrier and planes... if it can be avoided, fleet carriers and fleet planes [should] not be used, but in lieu thereof converted merchantmen of high speed, equipped with long-range bombers that can be launched from 350 miles and recovered at not less than 250 miles from the enemy's coast...

Captain Blakely had particularly in mind the threat of heavy enemy ships, which in the Problem had destroyed his own, before she could discover their presence by means of her own scouts. However, the major difficulty was ease of discovery by patrols which would necessarily be dense near an enemy base. It seems notable that Captain Blakely did not see more powerful carrier defensive forces (other than, perhaps, a screen of fast battleships) as a solution to the problem of vulnerability: like his predecessors, he saw his ship as immensely powerful yet also quite vulnerable. He recommended converted merchantmen for the strikes on shore targets because he considered fleet carriers far too valuable to risk in such secondary operations. Ironically, his own ship would first enter combat in World War Two in exactly the type of strike he so opposed.

Four years later, Rear Admiral F J Horne (Commander, Aircraft, Battle Force) wrote of Problem XVIII (1937) that

Friendly aircraft continuously face the hazard of antiaircraft fire from their own surface craft. In the planning for BLACK participation in Fleet Problem XVIII, Commander, Aircraft, Battle Force particularly stressed recognition procedures. During the conduct of the Problem itself and at least while carriers were with BLACK main body it is believed that some progress was made both by aircraft and by surface vessels in the application of prescribed recognition procedures. BLACK carrier aircraft with few exceptions did return in non-attack formation at low altitudes within prearranged bearings. However, when WHITE carrier aircraft contacted BLACK main body it appeared that some BLACK surface ships presumed them to be friendly due mainly to the fact that they had become used to distinguishing

between landplanes and patrol planes in the three days which preceded... Commander, Aircraft, Battle Force has been informed by the Bureau of Aeronautics that there is some hope of developing a pyrotechnic device which will make a visible recognition signal and that another method, not named, is under development...

IFF would, however, continue to be a serious issue in fleet air defense through World War Two and well beyond. The 'other method not named' was a very early electronic IFF system, then under development by the Naval Research Laboratory.

Admiral Horne continued:

While carriers operating within a screen of heavy gunned ships, including antiaircraft batteries, are given fair protection against daylight attacks by enemy aircraft or surface vessels, such operations are most difficult except under very favorable conditions and the dangers of dawn and dusk attacks by enemy aircraft are increased once the enemy has located this formation. To launch aircraft from within a fleet formation in war before daylight would be highly dangerous because of the close proximity of other darkened ships and to wait until dark to recover aircraft would require the carriers to take up their positions in the formation well after dark with the consequent risk of collision. Therefore, the carriers cannot provide their own protection against enemy aircraft attack during the two critical periods when such attacks are most to be expected. Further, certain lights must be shown while launching and recovering aircraft during darkness and thus the carriers would be an easy target to locate should the enemy make a pre-dawn or after dark attack against the fleet formation...

The present carrier complements of aircraft were drawn up with the idea of providing, first, an adequate number of scouts to locate objectives, second, the greatest possible power to strike at these objectives when located. The number of aircraft in the complement of our carriers represents the practical maximum that can be carried and operated effectively for *offensive* missions. These *offensive* aircraft complements do not lend themselves to *defensive* missions. It is difficult to maintain continuous daylight operations involving only a portion of the total complement, particularly where such operations require multiplicity of task assignments. In fact, this type of operation with present aircraft complements is so arduous that in Fleet Problem XVIII the conclusion of the problem found pilots and deck personnel exhausted. If carrier service with the Main Body is considered essential, a carrier with a special complement of aircraft types should be so detailed. The number of aircraft carried should be less than that at present and proportionately the number of personnel for planes and for the carrier flight deck should be greater.

Horne was referring not only to combat air patrol, but to the customary patrols against enemy surface craft and submarines (the latter considered quite essential), and to scouting operations. In each case, a relatively small number of aircraft had to be maintained aloft continuously. By way of contrast, an offensive carrier would maintain limited patrols, but would launch a massive (deck-load) strike on her objective. Admiral Horne listed the patrols a carrier operating with the 'main body' (Battle Line) had to maintain:

Inner air patrol - an invaluable service, very effective against submarines. Relatively few aircraft are required at any one time, but they may require relief at any moment depending upon contacts since they must be rearmed at once. A very difficult patrol for present carriers to maintain.

Outer air patrol - of questionable value considering the difficulty of maintenance. Arduous and very exhausting if long continued. It seems probable that this patrol cannot equal in effectiveness the ability of screening vessels in detecting enemy aircraft. If maintained in force as an aerial attack group, it requires an excessive number of aircraft.

Combat patrol - a high patrol over our own forces, that should be abolished *except when used by carriers themselves* under conditions of unlimited ceiling and high visibility and when they are operating alone. Used over a large formation it is open to the very serious objection of being fired upon by our own ships.

Fleet Problem XVIII again proved that evasive movements at high speed are a carrier's best protection against air attack and the old, oft repeated lesson - a carrier tied down to a slow formation is quite certain to be put out of action.

Commander, Aircraft, Battle Force invites particular attention to the last comment above, and to other comments which explain in particular detail the serious objections, from a carrier viewpoint, of operations close to a slow Main Body. There is nothing new in either the comments or the objections - yet plans and orders continue to be issued which foredoom carriers to certain loss before they can strike one telling blow.

Consider the *primary* mission of Aircraft, United States Fleet:

'To obtain and maintain control of the air in the Theatre of Naval operations.'

This mission cannot be accomplished if a multiplicity of lesser, *defensive* missions are assigned which, by their very nature, rapidly dissipate the energies and strength of the air arm. *Once an enemy carrier is within striking distance of our fleet no security remains until it - its squadrons - or both, are destroyed*, and our carriers, if with the Main Body, are at a tremendous initial disadvantage in conducting the necessary operations.

Offensive carrier operations at a distance from our Main Body do reduce the strength of that Main Body. Under this condition, the Main Body may be, for the time being, without aircraft services - even the important services of anti-submarine patrols and air scouts - if battleship and cruiser based aircraft cannot operate. It is a gamble for the Fleet Commander who detaches carriers in this manner but he is playing for high stakes. It is no gamble, on the other hand, if they are kept with the Main Body for their certain loss is only a matter of time - and usually a short time at that.

In 1939, Rear Admiral E J King, who three years later would become Chief of Naval Operations, commanded Aircraft, Battle Force. In discussing Fleet Problem XX, he too emphasized the need to use surface antiaircraft fire to defend the carrier:

Those who are charged with carrier air operations should continue to place special emphasis on the fact that carriers are often called on and expected to perform too many air jobs at one time. The extract from Commander Escort Detachment Operation Plan 5W39-E which follows is a striking example of the numerous and varied tasks sometimes assigned to carriers:

- Locate and destroy enemy aircraft in air prior to their reaching the convoy;
- Scout with aircraft a sector 140 to 290 true plus sweeps in rear semi-circle;
- Maintain Combat Air Patrol;
- Maintain aerial pickets;
- Locate and destroy enemy carrier;
- Locate and destroy enemy cruisers;
- Provide air spot for Cruiser Division 7 if cruiser-based aircraft cannot fly.

Note the institution of the aerial pickets to provide warning of incoming air attacks, a development which would assume much greater

importance within a year. Like Admiral Horne, King considered much of the effort wasted, a dissipation of the valuable offensive power of the relatively few carriers available. Moreover, he could not generally operate more than one carrier together, given requirements to maneuver independently, as well as the hope of evasion. If a carrier located was very nearly a carrier destroyed, it was far better to split up the carrier force. However, a single carrier had only limited resources to provide a powerful combat air patrol, although two carriers (or more) might be protected together by a patrol little more powerful than that required for one.

King himself emphasized non-air protection of the carriers:

Throughout Fleet Problem XX every opportunity was seized to afford carriers the antiaircraft protection of accompanying vessels. To show what can be done, and is being done, by carriers in defense against air attack by means other than Combat Air Patrol there are enclosed Plates I and II, showing two such plans, one used while the Raiding Force was operating as such, the other when the battleships were so disposed as to aid carrier air defense.

Particular attention is requested to the formidable antiaircraft batteries, the close screening, and to the fact that the carriers were free to maneuver to one flank [ie to launch and recover aircraft by leaving the formation].

Combat Air Patrols were maintained over and around the WHITE Main Body during daylight hours from the start to the finish of the Problem.

It is desired to place special emphasis on the uses of 'Combat Air Patrol'. Each carrier has but one fighting squadron and needs that primarily for her own defense. It is, in fact, an essential part of her own antiaircraft battery. No fighters – no flight deck, no flight deck – no fighters – nor any of the other three squadrons.

Commander, Battle Force – Rear Admiral E C Kalbfus – disagreed: 'Combat air patrols . . . constitute the best, if not the only, defense against bombing attacks from extreme altitudes, but no reasonable concentration of fighters can be depended upon to intercept all enemy air offensives'.

There was also considerable debate as to how surface antiaircraft fire might best be coordinated among surface ships, and how their own fire control might best be adjusted to take account of evasive maneuvering. It is not clear, in retrospect, to what extent various other commanders shared Admiral King's optimism concerning heavy surface fire. Indeed, he would soon begin his own study of Navy antiaircraft fire, with distressing results. The results of drone practices must also have begun to make a considerable impression.

In any case, there was a great change of heart by the time of the next (and last) Fleet Problem, number XXI of 1940. In the fall of 1939, the General Board asked the Bureaus, the fleet commanders and the carrier commanders to what extent the next carrier, which would become the *Essex*, should operate more than the current 72 aircraft (four 18-plane squadrons). It was generally agreed that up to 81 aircraft should be operable at one time from a somewhat enlarged flight deck, and that the extra nine should be fighters. However, there was some hope that, by using a hangar-deck (athwartships) catapult, up to five full squadrons (two of fighters) could be operated efficiently. So great was the need for fighters that not only was the new *Essex* designed from

the first for five squadrons, but in addition standard carrier air groups were enlarged to five, and the number of fighter squadrons doubled.

These changes were reflected in a critique of Problem XXI by Admiral Blakely, the outgoing Commander, Aircraft, Battle Force (May 1940):

The ability of the carrier to alter the caliber of its defensive or offensive weapons by changing its embarked squadrons – that is, by embarking other types of squadrons than those normally carried in her group – should receive more general recognition than it has been accorded in the past . . . In Part II, for example, an improved complement for the *Yorktown* would have been a fighting squadron in place of the horizontal bombers (and torpedo) squadron of TBDs. A third fighting squadron would not only have eased the load on the fighting squadrons and made possible the maintenance of a full one-squadron combat patrol for a longer period of time, but would also have provided an extra fighting squadron in reserve which would have materially increased the defensive power of the combat air patrol, and at the same time provide sufficient striking force for attack.

On the other hand when the carrier is to be used effectively in company with another carrier the fighting squadrons might readily be replaced by bombing squadrons and the fighting squadrons be placed on the defensive carrier, particularly if the offensive carrier may expect to receive a measure of aircraft protection from the defensive carrier. While there is a natural reaction against placing all of our 'eggs in one basket' and risking the loss of a large part of one type of airplane by the loss of one carrier we will soon have a sufficient number of carriers with the fleet to warrant a greater concentration of types in order to obtain the resulting marked increase in the flexibility in the carrier's operations. This became particularly evident in the operation of a five-squadron group such as now on the *Yorktown*. While there is ample room on these carriers to operate a five-squadron group, it becomes increasingly difficult to provide a particular squadron for a special task if required on short notice. Where multiplicity of tasks is anticipated of the carrier it would be preferable to avoid overcrowding the carrier and to provide a special complement of only fighters and scouts such as has been proposed for the *Ranger* and *Wasp*. Carried out to a logical limit this plan would require organization of additional squadrons of all types to meet all the special tasks required of carriers in war.

Fleet commanders must realize that although carrier aircraft can perform a variety of tasks for the fleet they cannot be ready to perform *all* of these tasks on a moments notice. In using a five-squadron complement these difficulties are naturally increased. However, when all the carrier aircraft are equipped for catapulting and more catapults are provided, as in the latest carriers, the operation of a five-squadron complement will be improved. It would appear that whatever loss in flexibility results from the larger complements would be compensated for to a large degree by the presence of an additional squadron. The (tremendous) advantage of this additional squadron can be appreciated when it is realized that if all four of our large carriers are increased to a five-squadron complement we would have the equivalent of one additional carrier in the fleet (which in dollars and cents alone is a matter of approximately \$30,000,000) . . .

I find in some recent tactical publications statements raising considerable doubt as to the effectiveness or even the usefulness at all of a combat air patrol. I believe this situation is somewhat changed at the present time and that the fleet can expect that it will be the exception rather than the rule if bombing attacks reach the fleet unmolested when adequate aerial pickets and combat air patrol

are in the air. I believe this is due in part to a better realization of the fact that a combat air patrol, to be effective, must have considerable strength, at least one squadron and preferably two or three squadrons, dependent upon the aircraft opposition expected; but the improvement is probably more directly due to the greater emphasis placed on the training of aerial pickets and the better appreciation of their importance in detecting early approach of enemy aircraft. (Every opportunity offered during the year has been taken to utilize as large a number of fighters as possible together as a combat patrol to oppose bombing attacks. It is through such training that the mutual co-ordination necessary for an effective combat patrol is developed.) The program recently proposed and now underway in part to increase the number of fighting squadrons in the fleet should aid in providing sufficient fighting squadrons for an adequate defense of the fleet.

Increasing reliance on airborne antiaircraft search aircraft (aerial pickets) shows in the radically altered Fleet antiaircraft disposition adopted in 1940, in FTP 188, successor to FTP 142. Here the only even moderately distant screen was a 'sound' (ASW) screen of destroyers steaming ahead of the fleet, about 11nm from fleet center. Cruisers were spread around a circle about 8nm from fleet center, and carriers about 6nm out, to give them some freedom to maneuver. Early warning from the surface was entirely abandoned, at least in principle. In part, the rise of the aerial pickets was due to the realization that really high altitude raids would not be visible from the surface; there was real fear that a fleet, entirely unaware that it was being attacked, would suddenly find itself the target of heavy bombs dropped in patterns.

Aerial pickets could provide effective warning of incoming air attacks out to about 24nm from fleet center, and the combat air patrol orbiting over its carrier could not engage an enemy at sufficient range to deny him a good chance of damaging a carrier, particularly if it was available only in small numbers. Later practice, with larger CAPs (as in Admiral Blakely's comments) placed the CAP in sections 10–15 miles from fleet center, to permit earlier engagement. Even so, it was impossible, without much earlier warning, to concentrate CAP to meet an incoming mass raid, even if all the attackers came from one direction. Moreover, fighter control was generally by an airborne officer, who could not see the whole of a rapidly developing battle and so could not use all his aircraft most efficiently.

By 1940 a standard CAP doctrine, which would form the basis for wartime development, had evolved. No raid was to be permitted to arrive unopposed, even though it was conceded that in most cases CAP would be unable to destroy all raiding aircraft: any opposition at all might effectively disrupt a raid. This applied particularly to high-altitude bombers depending upon disciplined pattern bombing. CAP fighters would orbit at high altitude, and they would engage at maximum possible range.

Fighter Control: the Combat Information Center

Although the performance and armament of individual fighter aircraft improved dramatically between 1940 and 1945, the most important development was in effective use of the fighters: fighter control. Radar made it possible to detect raids at great distances and, probably more importantly, to form a usable picture of

the evolving air situation, so that assignment of CAP fighters to particular raids could be made intelligently, by a fighter director team on a carrier or some other warship, out of the melee aloft. Radar also promised (somewhat over-optimistically) the solution to the identification problem which had plagued prewar exercises. The control techniques and concepts evolved in wartime shaped postwar development, and even four decades later retain some validity.

In 1940 Admiral Blakely remarked that 'we have now in Europe a full scale laboratory test of aircraft tactics from which we hope to obtain valuable observations and thus judge the merits and effectiveness of our own accepted tactics. We all realize that our planes can be greatly improved and that of necessity this must come in the not too distant future...' In particular, in the fall of 1940 the United States, including its Navy, began a very free exchange of information with the British, who were actually fighting the equivalent of a CAP battle, the Battle of Britain. In their system, radars provided early warning, and radar and other data was all collated in filter centers. Plots of the developing air battle permitted fighter controllers, sitting in the filter centers, to use their resources most efficiently. Similar practices carried over into the British Fleet. Carriers were fighter direction ships; the Royal Navy claimed that an experienced fighter direction officer (FDO) could control three groups of interceptors, vectoring them to engage bombers as much as 30nm out. British fighter control practice, including the technique of designating raids by numbers and vectors, became standard US doctrine; the ship-board equivalent of the filter center was the Combat Information Center, or CIC.

The carrier *Yorktown* appears to have been the first US ship to practice radar-guided intercepts, as reported by her captain in March 1941. Her FDO suffered a lack of trained plotters and the absence of any centralized Radar Plot; he had to work through battle telephones connected to Air Plot, Conn, Flag Plot, and Sky Control. Even so, *Yorktown's* experience showed the potential of radar fighter control, as well as the need for a centralized radar plot with a trained plotting team, in other words a CIC. The Secretary of the Navy approved a proposal for such an installation in July 1941, in the new carrier *Hornet*: it would be 'the brains of the organization which protects the fleet or ships from air attack', and would be accessible to the Chart House, Air Plot, Flag Plot, and to the radar control room where the radar set itself was located. It would be fitted out with remote radio outlets and receivers, intra-ship telephones, bearing indicators, a status board to show fighter patrols, and a large plotting board to show the evolving battle.

Tactically, the issue of air control by more than one carrier in a fleet was not to be resolved for some considerable time, and, although IFF systems were fitted during 1942, IFF remained a problem through the war. Even so, the new organization could be effective. For example, *Lexington* was attacked by a large raid in February 1942. Detected at 76nm at an altitude estimated as 8000ft, it was intercepted at 11,000 by a CAP sent out half an hour after detection. Five of nine attackers were shot down before they could come within range. However, while this battle was proceeding, a second large raid was detected, coming from the opposite direction; only two fighters were

available to intercept it, and the carrier survived only by evading the bombs dropped on her. One reason for the failure of the CAP in the second raid was the tendency of the first CAP group to pursue the retiring bombers, rather than staying to protect the carrier against possible subsequent raids.

CIC failures at the Battle of the Coral Sea were blamed for the loss of the *Lexington*. Many were human errors: failure of members of the plotting team to use symbols consistently, and therefore to distinguish properly between friendly and enemy aircraft; failure of the FDO to identify himself or use standardized commands; failure of the FDO to place his CAP high enough to intercept one of the major raids; and failure to provide sufficient CAP aircraft. The task force commander remarked that 'it would appear that the advantage which we possess with our radar and fighter director system was not exploited to the fullest extent'; the carrier group commander added that 'the value of our combat patrols is in direct proportion to the efficiency of our fighter directors'.

The captain of the surviving carrier, *Yorktown*, considered his radar plot inadequate, either to use the information provided by the fleet's radars or even to make full use of his own. He wanted it enlarged, isolated so as 'to be free from spectator interference or from noise interference from other activities', but to 'be contiguous with Air Plot and [to] have means for actual physical, conversational communications with Air Plot'. It would need two separate plots, one for search, the other for tracking, as well as an adequate status board showing fighter patrols and the general tactical situation. Because *Yorktown's* one radar had been out of action during the battle, her captain and CinCPac recommended that all carriers be fitted with two search radars; CinCPac also recommended that the standard fighter complement be thirty-six, a change already strongly supported in the Fleet two years earlier.

Lack of accurate height information on incoming raids was a matter of considerable concern, as CAP aircraft might be vectored to meet a raid they could not actually engage, as it would be too far above or below them. In the absence of a reliable height-finding radar, a 'stacking' doctrine for CAP was evolved: in one version the main body of the CAP flew at the estimated raid altitude, with one division (four aircraft) 5000ft above, and one section (two fighters) 5000ft below. In theory, this problem could be solved in part by noting the distances at which an approaching raid 'faded' from the radar screen, and comparing them to a chart showing the characteristic fading pattern of the radar. However, beginning in 1943, US carriers received special height-finding radars, SM and then SP; postwar they were replaced by SPS-8 and then by the current SPS-30. Even raid bearing could be in error, given the relatively wide beams of the standard US long-range search radars. By late 1942, special tactical doctrines had been evolved specifically to overcome CIC direction errors. For example, CAP fighters could orbit along the expected path of approach of a raid, on the theory that they would be more likely to sight it than if they were directed to the farthest possible point of intercept. Missing that intercept, they would find themselves in a tail chase heading in towards the carrier, generally catching up too late.

In effect, then, CIC was to direct CAP into the path of a raid, but the CAP fighters themselves assumed an important burden of re-acquiring an incoming raid. After the Gilberts invasion (November 1943) new fighter control instructions were issued: CAP leaders were to stack their fighters 'so as to insure visual contact at the earliest moment and to provide a high cover if deemed necessary'. The orbit athwart the line of approach of the raid was abandoned in favor of one to one side and above, the fighters to be directed onto the flank of the raid, for maximum tactical advantage. That in turn required very precise tracking of a raid, in bearing and in altitude. However, as ranges increased, relatively small angular errors in radar information became more significant – an error of 2°, which was not very much in a broad-beam radar such as SC-2 or SK, amounted to seven miles at a range of 100. Nor could even a pencil-beam set such as SP give accurate altitude data at such a range. These problems became particularly important as the Japanese adopted small-raid tactics late in the war, attempting to saturate CIC and its CAP.

As carriers began to work together, further difficulties developed. A director in one found it difficult to control pilots from another carrier; commanders suggested that one carrier be loaded entirely with fighters and charged with force fighter defense. Several thought that would be the ideal use for the new *Independence* class light carriers, one light carrier providing CAP for two *Essexes*, to form a three-carrier task group. Pressure mounted for a common fighter control doctrine and vocabulary, and for effective IFF; CinCPac commented late in 1942 that 'our fighter direction both in practice and in action against small groups has been good but fighter direction against a number of enemy groups with our own planes in the air [in numbers] is a problem not yet solved'.

In November 1942, CinCPac renamed the radar control organization aboard ship a Combat Information Center (CIC) and called for the establishment of a CIC aboard every warship. It was to have direct communication with all radar and fire control (including fighter control) stations, with all lookouts, and with ship control; it was to be kept informed of changes in the tactical situation, and it was to have radio facilities on the fighter control and warning radio nets. CIC was to have initial control of all ship radars, and was to broadcast raid information whenever the ship was acting as radar guard or fighter direction ship. Prewar and early-war doctrine for radar silence (to avoid disclosure of ship position) was abandoned, as warning of incoming raids was considered far more important. There were also radio improvements. The original fighter control radio frequency was so low that it could be intercepted at a great distance, and there was fear that practice use (which was essential) would permit Japanese aircraft to home on the carrier. Later higher-frequency radios had much shorter ranges, and in addition could accommodate more channels, so reducing radio confusion.

The CIC was useful for functions other than fighter control. For example, in destroyers, its surface plot permitted much more efficient operation in the night torpedo battles in the Solomons. In particular, effective CIC plotting could permit the identification of US and Japanese ships from their tracks, even in the

Radar made possible the deck-launched interceptor (DLI), since it could detect an incoming raid in time for a high-performance airplane to get from the flight deck out to a useful interception range. The first carrier interceptor to be designed specifically for this role was the Grumman F8F Bearcat, essentially the minimum airframe which could fit around an R-2800 engine. It was so compact that postwar attempts to fit the Bearcat with night-fighter radar failed: the radar pod, quite acceptable in a Hellcat or a Corsair, added far too much drag. More recently the value of the DLI has come into question, as the speed of incoming attackers and the range at which they can drop their missiles increases. That is, in defending the Fleet against a force of Soviet missile-bearing bombers, the fighters are intended primarily to destroy the bombers before they can launch their missiles, which latter are much more difficult targets. Higher missile speeds and longer ranges reduce the time available for the DLI.



absence of effective IFF. It could allow an officer in tactical command (OTC) to unravel the complexity of a night action, at least with some assurance. However, CIC development was paced by the requirements of air rather than surface warfare.

Through 1943 the carriers did not engage large enemy air forces, and the development of fighter direction shifted to smaller ships, which controlled land-based aircraft, and to shore installations, for example on Guadalcanal. In some cases cruisers controlled CAP sections contributed by distant carriers. Destroyers, particularly those escorting carriers, often acted as FDO ships, with two FDOs and three or four radar operators and plotters. Equipment was still primitive; many ships did not even have radars with PPI displays, and many of the IFF systems were nondirectional, so that friendly and enemy echoes at the same range (but at different bearings) could not be discriminated.

By the latter part of 1943 enough new carriers were in service for them to be combined into large task forces. *Essex* class CICs were equipped with a large vertical (summary) plotting board as well as two smaller plotting tables for controlling individual interceptions, and large status boards, plus PPI repeaters which brought radar data directly into the CIC. In addition, in the late summer of 1943 the Fleet received a new four-channel VHF radio: separate channels could now be assigned to communication among CICs in a task force, between the FDO and his fighters, and between Air Plot and other patrol and strike groups. Given the short range inherent in VHF radio, continuous practice at sea and continuous intra-force contact was possible. These advances were first tried out in the raids on Marcus Island and on Wake, in February 1944. There were some problems: for example, the inter-CIC frequency was the same as the inter-plane, and the OTC wanted additional channels. Even so, every plane (bogey) approaching the task force was successfully intercepted. Other lessons learned included the need for CICs and FDOs aboard cruisers which might be furnished with their own CAPs (eg to protect a bombardment force) and the great value of the experimental height-finding radar (CXBL, a prototype SM) aboard the *Lexington*. It was effective against low fliers, although its narrow beam often failed to pick up high-flying aircraft. The *Independence*, with 24 fighters aboard, came close to the 'duty carrier' concept, providing most of the CAP for the Marcus raid; the commander of the task force recommended an all-fighter air group for this class.

The Battle of the Philippine Sea in June 1944 was the great triumph of fighter direction, as it had been developed since 1941 to counter massive high-altitude attacks. Admiral Mitscher, commanding Task Force 58, remarked that 'four major raids were each hit at ranges of some 50 to 60 miles from the carriers, and each time with sufficient altitude advantage to our fighters. It was the first time that a major enemy air blow has been made on our forces without the loss of or serious damage to at least one of our carriers. It proved that the long and costly efforts in research, training, and the practical application of radar have not been in vain...' Of 33 interceptions initiated as a result of radar or visual contacts, 28 were completed successfully, resulting in the destruction of 141 enemy planes. One of the most important factors in the success of fighter direction during this phase was the instantaneous reinforcement of standing combat air patrols. Whenever one division of the standing two-division combat air patrol was committed to an interception, eight more fighters were immediately launched if another bogey contact appeared on the radars.

The Japanese fleet made contact with Task Force 58 well before it had been detected, and by prewar rules should have triumphed; however, the CIC/CAP preserved the task force and its vulnerable carriers, and the Japanese naval air arm was decimated. In effect, radar fighter direction had invalidated prewar concepts of carrier warfare. Some of the attacking aircraft did manage to penetrate the CAP screen, but they were ineffective; the defending fighters just could not deal with the sheer number of targets with which they were presented, and only the low individual lethality of the Japanese aircraft saved the force from severe damage. Moreover, the task force itself had used its heavy fighter and attack aircraft complement to destroy much of the shore-based Japanese air force which might otherwise have contributed heavily to the air battle. Although such 'air blanket' tactics were not part of air control, they reduced the load on CIC/CAP by reducing the total air effort the Japanese could mount. They were the functional equivalent of prewar concepts of preemptive attack on an enemy carrier, and they and the island assaults presaged a major

shift in carrier operations, towards exactly those attacks on land targets which prewar carrier commanders had regarded as largely suicidal. Fighter control did not become a major fixture of such operations until Vietnam, when it made a major contribution to the success of US air attacks (see Part IV).

The Kamikaze Problem

In the fall of 1944, the Japanese changed tactics. In view of the success of the CIC/CAP combination that June, they concluded that in future they would have to saturate the CICs by attacking singly, from different directions and at different altitudes, presenting too many individual 'raids' for the plotters to handle. Such raids would suffer a high mortality rate, and they were rational only if each one which penetrated successfully was extremely lethal – as conventional bombers and torpedo-planes usually were not. This explains the genesis of the suicide attacker, or kamikaze, who might well disable or even sink a carrier with a single hit. The combination of numerous raiders and high individual lethality carried over postwar to Soviet cruise missile tactics: in effect, any attacker which penetrates the screen carries a very high cost to the defense. He may still be splashed by short-range weapons – and indeed much more lethal short-range defenses were a major antikamikaze measure – but that is at best a tactic of desperation. In 1945 the major burden lay on the CAP. Carrier fighter complements were enormously increased, both for the preemptive fighter-bomber strikes on kamikaze bases, and to strengthen CAP patrols. For example, in the sweeps against Luzon in the fall of 1944, the fleet carriers *Wasp* and *Essex* both flew all-fighter groups, of 91 aircraft each. The next spring, the standard *Essex* air group included one double-strength fighter squadron (36 aircraft) and a double-strength fighter-bomber squadron (36 aircraft) as well as reduced attack squadrons.

Task Force 58 described kamikaze attacks off Okinawa:

Rarely have the enemy attacks been so cleverly executed and made with such reckless determination. These attacks were generally by single or few aircraft making their approaches with radical changes in course and altitude, dispersing when intercepted and using cloud cover to every

advantage. They tailed our friendlies home, used decoy planes, and came in at any altitude or on the water. Only once during the entire operation did the enemy attack in the old orthodox fashion. Here a raid of 32 Bettys with 16 fighters as cover stacked 14–18,000 ft was annihilated 60 miles from this force. Fighter Director teams and radar personnel operating in this task force were well trained and experienced and every effort was made to increase efficiency by practice and experience. Never before, however, have the limitations of our present equipment become so pronounced, and the enemy, fully aware of these limitations gained by experience and other means, made every effort to attack this force under the cloak of these limitations and with quite effective results.

Long-Range Pickets

As perceived by the task force, the fundamental limitation was human: the Japanese were swamping the CIC plotters, posing a problem that would not be overcome for a decade (see Part IV). Existing radar was limited in its low- and high-altitude coverage, the latter making 'snooper' operations possible (as well as near-vertical dives onto the task force). Even when low fliers were detected, the defending fighters generally could make only a single pass. Although radars could detect large formations at impressive ranges, their performance declined drastically against single aircraft, particularly when the latter maneuvered radically. Moreover, the Japanese were beginning to use countermeasures, such as 'window', with considerable effect.

Several tactical countermeasures were introduced by the Pacific Fleet. Certain destroyers were designated 'radar pickets', to extend outward the fleet's radar cover. For example, in the Gilberts operation, the destroyer *Kimberley* steamed 30,000 yds in the van. At Kwajalein the next spring, a radar screen was placed ten miles beyond the sound (ASW) screen, and steaming to the Marianas the task force placed radar pickets ten miles from fleet center at night as insurance against air attack. Since only the carriers then had pencil-beam radars (SM and SP) capable of detecting low fliers, the radar pickets were an important counter to existing Japanese low-level torpedo attack tactics. The *Kimberley* combined early warning with fighter direction; at Saipan, at night, radar picket/fighter director destroyers were used to protect the amphibious force anchorage. Although they had only two-dimensional air search radars, they were able to use their fire control sets to estimate raid altitude and so to facilitate interceptions. Saipan was the first operation in which night fighters (controlled by the destroyers) protected the anchorage.

The radar picket destroyers marked an attempt to decentralize air control. The force fighter director, generally aboard a carrier, was responsible for fighter direction as well as warnings and alerts; the team on the destroyer could concentrate on interception. In fast task force operations from early 1945 on, a radar picket line in the direction of the expected threat became standard. For example, off Tokyo in January, Task Force 58 stationed two pickets and six other destroyers forty miles closer to the objective, stationing a 16-fighter CAP over this force. Of eight enemy aircraft shot down by the destroyers' CAP, four were trying to tail a US strike home. Within a few months, the picket destroyers had been given the particular function ('Tomcat') of assuring that all aircraft returning to the carriers were friendly. Plans were also being made to equip

specialized destroyer radar pickets with SP height-finding radars.

In effect, a radar picket destroyer had as its main battery not its guns or its torpedo tubes, but rather the CAP section above it. Its radars were the outward symbol of this change (the SP and its tripod actually replacing a bank of torpedo tubes) but the central internal facility, not at all evident to the casual observer, was the CIC. The introduction of the specialized picket thus symbolized the ascendancy of the carrier, which supplied the CAP and for which the picket had been called into existence, as well as the modern tendency for military efficiency to depend more on electronic sophistication than on visible weapons.

Pickets were both extremely effective and intensively attacked off Okinawa, and proposals were made to provide submarine pickets, which could submerge to evade such attack. They materialized postwar, and for about twenty years destroyer radar pickets were a constant fixture of US carrier task force operations. They survive in the form of major air control facilities aboard major fleet escorts such as missile cruisers.

The large amphibious flagships (AGCs) also contributed to wartime fighter control; they were equipped with carrier-quality radars and CICs. In addition, they provided an amphibious force commander with radio links to the beach. At first the two functions were separated; for example, in the Sicilian landings, *Ancon* carried the invasion commander and his staff, but Army aircraft (the CAP) were controlled by another ship, *Monrovia*. At Salerno, however, the fighter control team moved to *Ancon*, and permanent fighter control arrangements were recommended. The specially built command ships, such as *Blue Ridge*, were designed from the first with CICs, although initially they did not have height-finding radars. They appeared at Kwajalein in January 1944, and *Blue Ridge* carried out her first fighter control operations at Saipan that June. Generally the flagship was not so much concerned with fighter control as with effective positioning of radar picket ships which would themselves handle interceptions; the OTC aboard the flagship was supplied with a running commentary of the raid, and his staff could coordinate operations by the pickets. Even more than in the case of the destroyers, the AGC was a CIC whose weapons were aboard other platforms, on the beach, and in the air. Nonetheless, that CIC cannot be divorced from any discussion of the evolution of US naval weapons. Its development paralleled that of the carrier CIC, from a small cramped compartment on the bridge to much larger spaces, and ultimately to combination with height-finding radars (SP was first installed in November 1944, on the *Eldorado*, which carried the amphibious commander to Iwo Jima in the following February). By that time air activity had become so intense that several channels were needed for the fighter net alone, and many ships had begun to receive ten-channel radios. For example, at Okinawa, CAP over the objective varied from 56 to 76 fighters, plus five 2-fighter CAPs for the radar picket destroyers.

Several times during the war there were attempts to streamline the usual radar/radio fighter control procedures to take account of the threat of close-range aircraft. A parallel effort in gunnery resulted in the proliferation of Mk 51 directors for individual gun control.

In fighter control, there were proposals for visual fighter director officers stationed aloft, plotting close-in aircraft and carrying out their own interceptions. Japanese use of low-level tactics, to come in under radar coverage, made visual fighter control particularly attractive from the summer of 1944 onwards. Often look-outs were the first to detect such aircraft. In addition, the usual high-altitude CAPs could not hope to intercept them. One proposal called for the usual low-altitude antisubmarine patrol to double as an anti-low-flier patrol, vectored in by the visual FDO aloft; in April 1944, for example, the patrols were strengthened by single fighters designated 'anti-snoopers'. This practice, which was moderately successful, continued through the Leyte invasion that October. However, it was soon learned that the CIC could use lookout reports quite as effectively as could a single officer aloft, if not much more so, and visual fighter direction doctrine evolved back towards the use of CIC for all fighter control. Again, the key was that CIC was sufficiently isolated from the battle to maintain effective control: at Lingayen Gulf, aloft FDOs trying to control CAP sections used a 'clock' code with reference to their ships – which were maneuvering so radically that the fighters were completely confused.

The aloft directors always saw approaching aircraft positioned in relation to the current heading of their ships – which was changing from moment to moment. Fighters, however, required direction with relation to compass headings, since they were certainly not maneuvering radically in concert with any particular ship. Thus a bogey described as approaching from 'six o'clock', ie from dead ahead of a ship, might a few moments later shift to 'twelve o'clock', ie to dead astern, merely due to changes in the heading of the observing ship. On the other hand, radar displays could be 'stabilized' with respect to a compass heading, so that CIC commands to fighters could be given in terms of coordinates fixed to the earth. The entire issue of appropriate coordinates in terms of which to control air and sea forces in motion became more and more important as the control of forces dispersed over a wide area became more centralized. For example, accurate navigation, ie accurate means of placing ships and aircraft with respect to standard coordinates fixed in the earth, became more and more essential. In modern formations linked by NTDS, the problem is to make sure the coordinate system centered in one ship matches one generated by another, so that confusion is minimized; this is sometimes referred to as the 'grid-lock' problem.

Night Fighters

The other major feature of wartime fighter operations was night fighter control. As on land, the night fighter radar was not a long-range search set; rather, it bridged a gap between a controlled intercept, which might place the fighter within a few miles of its target, and gunfire range of the target proper. Thus, although wartime night-fighter radars were listed in a search (APS) series, postwar types were classified as gunnery radars (APG). Compared to land operations by night fighters, carrier night operations placed special emphasis on simplicity, since two-seat aircraft of fighter performance generally could not operate from US carriers (the postwar Grumman Tigercat – F7F – was a major

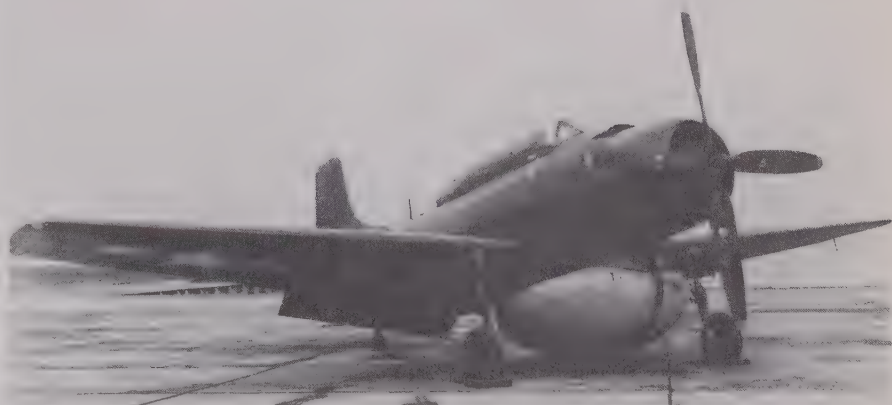
exception). Therefore the fighter pilot had both to fly his airplane and to operate his radar – which, moreover, had to have a minimum effect on aircraft performance.

The need for carrier night fighters became critical as the Japanese, unable to destroy carrier task forces in daylight attacks, sought to operate when the carrier fighters could not. During December 1943, for example, over 90 percent of all Japanese attacks came at night. The first US counter was a radar-equipped torpedo-bomber (TBF-1C, fitted with a surface search radar, ASB) which was to guide two conventional Hellcats into an intercept. This combination, flown from the *Enterprise*, actually shot down two or three aircraft on 26 November 1943, breaking up a torpedo attack; however, one of the two Hellcats was also lost, probably to friendly fire. Meanwhile, a better solution was being assembled, in the form of a lightweight single-seat radar, APS-6, which a Hellcat or Corsair could carry on one wing. The latter was initially selected, becoming operational in the Solomons (VF(N)-75) in September 1943. In the late spring of that year, a Hellcat installation, better suited to the fast carriers, was tested, and in January 1944 both the Corsairs and the Hellcats (F6F-3N) appeared in small detachments aboard the fast carriers, initially aboard *Enterprise* and *Intrepid*.

These aircraft were not entirely successful at first. On 26 February *Intrepid* vectored a *Yorktown* night fighter against a bogey but missed, and *Intrepid* herself was torpedoed. The carrier night fighters were more successful during the Marianas invasion, *Enterprise* fighters shooting down three in one night. During the summer of 1944 it was decided to form four-fighter detachments for each carrier, and also to designate particular ships night carriers, their air groups composed entirely of night fighters and torpedo-bombers. *Independence* was the first, entering combat in October, as Japanese dusk and night air activity intensified against the fast carriers operating off Formosa. In December, *Enterprise* became the second night carrier, and she and *Independence* formed a night carrier task group. The task force commander, Admiral Mitscher, considered the night carriers extraordinarily useful, as they released the others for daylight duties. Even so, *Independence* reverted to day operations in February, and there were suggestions that the single remaining night carrier could not cover an entire task force. Moreover, *Enterprise* was out of action for much of the spring of 1945 due to battle damage. Admiral Mitscher ultimately proposed that each large carrier operate six night fighters and six night torpedo-bombers. Indeed, task force successes against Japanese night attacks at the time were primarily credited to the small night fighter sections distributed among the carriers.

Postwar Directions

From a future point of view, these detachments were the first of the special-purpose fighters which continued to operate from fast carriers postwar, until all naval fighters were equipped with radar and long-range weapons. Given a limited number of carriers, and the distinct possibility that one might be put out of action, the task force and its successors could not afford excessive specialization in one carrier; better to distribute air defense assets more evenly through the Fleet, relying on the



1 Carrier radar could vector a fighter into range of a target in day, or into airborne radar range at night. The US Navy developed several single-seat carrier night fighters; this is an F4U-5N Corsair, at Patuxent River, 19 June 1949, showing its APS-19 radar pod and flash suppressors on its four 20mm cannon. Later jet night fighters had much larger radars, partly because higher speeds required longer intercept ranges, and partly because they were designed for 'collision course' rather than 'tail chase' tactics, requiring in themselves longer radar ranges.

2 'Cadillac', or Airborne Early Warning (AEW), was another element of carrier contribution to fleet air defense: an airborne APS-20 radar which could detect both low fliers and surface ships well beyond the horizons of shipboard sets. The radar picture was transmitted down to the carrier CIC for aircraft control. This is an airborne early warning version of the Skyraider, an AD-1W, at Patuxent River, 7 January 1948. The original AEW aircraft was a converted Avenger, and the first Skyraiders to be used in the AEW role were AD-3Ws.

3 A large land-based airplane could carry not only the 'Cadillac' radar (APS-20) but also a compact CIC by means of which it could itself control defensive aircraft. In 1945 the Navy acquired several Boeing Flying Fortresses as PB-1Ws, one of which is illustrated, with the standard APS-20 radar under its belly. In Korea several were tested with additional radars on top of their fuselages, leading to the development of the Lockheed 'Warning Star' Constellation conversion of the 1950s, with a large-antenna APS-20 below and an APS-45 height-finder above the fuselage. Some of the latter aircraft operated as airborne control posts in Vietnam; they were the ancestors of the present AWACS. In addition, airborne CICs eventually went aboard carriers (as in the case of the Grumman E-2 Hawkeye). In theory, the land-based Cadillac had sufficient endurance to fly out and loiter over or near the Fleet, even though it was not nearly so integral to the Fleet as was the carrier-based airplane. This PB-1W was at Patuxent River, 25 May 1949.

US National Archives

existing CIC organization and modified night fighters.

At the end of the war efforts were in train to overcome the major deficiencies of task force air defense. 'Zenith search' radars promised high-altitude coverage, at least directly overhead, which would suffice if such radars were placed aboard radar picket ships. At the other end of the scale, airborne radars would improve low-flier detection ('Cadillac' – see Part IV). Both carrier-borne Avengers and Flying Fortresses operating from land bases were to be

used; the latter would accommodate their own CIC teams. The British had already equipped a Wellington with a new radar, VHF radio and a radio altimeter, to vector a Mosquito against German bombers carrying flying bombs. Had the war continued, 'Cadillac' was to have become operational aboard four fast carriers in the fall of 1945.

For the longer term, there were demands for better radars and better IFF; a report by the Chief of Naval Operations placed particular emphasis on improved radar display for better

decision-making in CICs: 'The display of information was slow, complicated, and incomplete, rendering it difficult for the human mind to grasp the entire situation rapidly or correctly and resulting in the inability to handle more than a few raids simultaneously. Weak communications prevented information from being properly collected or disseminated either internally aboard ships or externally between ships of a force.' The solution, over a decade later, was NTDS (see Part IV).

8. Fighter weapons

Guns

The Navy procured its aircraft machine guns from the Army; its standard weapons from the 1930s through most of World War Two were the Browning 0.30- and 0.50-caliber air-cooled guns, M1919A2 and M2. In 1935 the 0.30 was credited with a cyclic rate of 1100 rounds per minute and with a muzzle velocity of 2900ft/sec; corresponding figures for the 0.50 were 600 and 2700, and most Army and Navy fighters combined the two. By 1941 each had undergone about a 50 percent improvement in cyclic rate, with further improvements in muzzle velocity. In view of the growing armor protection of foreign aircraft, little further work was done on the 0.30, but in 1943–45 the cyclic rate of the 0.50 was increased from 850 to 1200 rounds per minute, and the introduction of a new Stellite barrel liner greatly increased barrel-life, the resulting weapon being designated M3. In 1945 it remained the principal US naval aircraft gun. However, from 1939 onwards, attempts were made to achieve greater firepower.*

The first of these was the 0.60-caliber machine gun, development of which began in 1939 based on the German Mauser MG 151. Its muzzle velocity, 3600ft/sec, was superior to that of any existing or projected aircraft gun. By December 1941, the 0.60 design was complete, and a prototype was being built. Work on various prototypes continued through the war, and late in 1943 Rock Island arsenal was commissioned to manufacture over 5000 for the Army and Navy. However, the 20mm gun was adopted instead; the official histories do not say why, but standardization with ship-board guns must have been an important consideration.

Moreover, the 20mm gun already existed in prototype form in the United States. A French Hispano-Suiza (Birkgt) Aircraft Cannon, Type 404, was purchased and tested by the Army at Aberdeen in 1937; patent rights were obtained, and several prototypes – none entirely successful – were produced between 1939 and 1941. Muzzle velocity and cyclic rate approached that of the 0.50, and the 20mm round carried an explosive charge which could disintegrate an airplane even with a very short burst. Efforts therefore continued, and early in 1942 the gun, now designated AN-M2, was specified for the

new SB2C dive-bomber. Production began in 1943, and the gun entered service early the following year. It also replaced (or partially replaced) the six 0.50-caliber machine guns of the Hellcat and Corsair, and became the standard postwar fighter weapon. By the end of the war it had advanced to a cyclic rate of 750 rounds per minute and a muzzle velocity of 2800ft/sec, both close to 0.50-caliber figures; in this form it was designated M3 (T31).

Another wartime weapon development is of interest primarily for its postwar successors: the gun container, later the gun pod. In mid-1943 BuOrd developed a series of pods, complete with gun, charger, ammunition and firing mechanism, which could be carried underwing by most naval aircraft. Single and twin versions were planned for the 0.50, 0.60 and 20mm weapons. Mk 1 (one 0.50, January 1944) was developed for the SC-1 scout float-plane; it could be jettisoned in an emergency to reduce weight, and it was also suitable for aircraft such as the Helldiver and Bearcat. The twin 0.50 Mk 2, developed by Douglas, entered service in May 1944. Mk 3 (one 20mm) was too late to see combat service, and interest appears to have lapsed postwar. Moreover, it is not clear to what extent any of the gun containers entered combat.

Gun Sights

Aircraft gun sights enjoyed major improvement during the war. Sight evolution began with a ring and post, allowing the gunner considerable eye freedom, *ie* the ability to see well beyond his immediate target. However, it was crude at best, and it presented focusing problems, being superseded, as in surface gunnery, by a telescopic sight. In 1941 most fighters and dive-bombers had Aircraft Telescope Mark 3, although the new Wildcat had the Army M2A reflector sight with strafing reticle or the M2AN modification which provided a 35mil radius ring to estimate deflection (the telescope severely limited a pilot's field of view, which could be fatal in a crowded sky). The reflector sight, in a sense a predecessor of the current head-up display, projected a pattern of rings, in effect, into the eye of the pilot, so that he saw them floating in space ahead of him, bore-sighted with his guns. The first US Navy reflector sight, the

Illuminated Sight Mark 7, was in limited production in 1941, but the contemporary British sight was superior, the British having begun work on such systems some years earlier. It was adapted for US production as the Mk 8, serving through the war, and even being adapted for low-level bombing and as the basis of the Mk 30 torpedo director. Mk 9 was an equivalent turret or free gun sight. During the war, NDRC developed an Illuminated Sight Mark 14 ('fly's eye') with Kodak; it provided, in effect, unlimited eye freedom and aperture through the use of nested lenses. It was specified for some new aircraft as the only sight which could meet the eye-to-sight distance requirements they entailed.

None of these sights really solved the air gunnery problem, which was to compute the 'lead', or deflection needed to compensate for the speeds of plane and target. BuOrd had tried as early as 1937 to develop a gyro-stabilized lead-computing sight for the Brewster F2A fighter, but the result had been far too bulky. In 1941 the Bureau received a British lead-computing sight, but rejected it because it provided no means of estimating the range, and could not be used at night. However, an improved version was adopted in October 1942 as Mk 18. The gunner fed in a range estimate by framing his target within a circle of 'pips', and fed rate information into the system by tracking the target with his sight, as in the 20mm Gun Sight Mark 14. Own-aircraft speed and altitude were entered on dials. Production began in 1943, complicated to some extent by large Army orders. An analogous lead-computing sight for fighter pilots was developed in interim form as Mk 21, and then as Mk 23 (1945). The BuOrd history notes that 'naval pilots received the sight with something less than enthusiasm. The illuminated sight already in use had the virtue of being familiar, and the need for a lead-computing sight was less urgent than it had been earlier in the war. Moreover, the task of performing both sighting and ranging operations was more difficult for pilots than

*The 1945 Pacific Fleet evaluation credited the 0.50 with winning the Pacific air war, but cautioned that its success had been due to Japanese reluctance to install adequate armor or self-sealing tanks.



for gunners.' This particular problem would not really be solved until the advent of ranging radars. The simple illuminated sight remained in production after the end of the war for night fighters, in a modified Mk 20 form, which included provision for the pilot to select the most appropriate sight pattern at the time of attack.

During World War Two about 85,000 Mk 8 sights were produced, a quarter of them for the Army. Of 7800 Mk 21 computing sights for fighters, all but 86 went to the Army, and the 10,000 Mk 23s manufactured were never sent into combat; the illuminated sight remained standard until well after the war. One problem was clearly the complexity of the computing sight. Early in the war an alternative was sought in the form of a simplified turret sight. For a bomber gunner, the target would generally be attacking head-on, and the only compensation required would be for bomber speed, which adds a component to the velocity of the bullets. Two sights, Mk 17 and 25, were developed and tested during 1944, but they did not enter service in view of the success of the computing sights.

A computing sight was inherently very flexible: in 1945 BuOrd developed Mk 23 Mod 1, which could control rockets as well as fighter guns, solving for such variables as gravity drop and for about three-quarters of the windage. Several other sights then under development could solve only for gravity drop. These programs made it evident that an integrated Pilot's Universal Sighting System (PUSS), which became Aircraft Fire Control System Mark 1, could control guns, bombs and rockets. Within a few years a considerable AFCS program was in train, although relatively few of its fruits saw service. Mk 2 was a gyro lead-computing sight for guns and for 5in HVAR rockets; Mk 3 was similar, but did not incorporate Bomb Director Mark 1. Mk 4, 'Pneumatic PUSS', employed a pneumatic computer. It was generally similar to Mk 2 but with a different disposition of its control units. Mk 5, another universal fire control system, again incorporated Bomb Director Mark 1 (see Part V).

Mk 6, the only really successful AFCS, was a fixture of the first generation of Navy jet fighters, similar to Mk 5 except for the elimination of the bomb director; these aircraft (at least at first) were not considered suitable as fighter-

bombers, although Mk 6 could fire air-to-ground rockets and, in Mod 3, air-to-air rockets. In service it was often combined with an APG-30 range-only radar. Mk 7, for the Vought Cutlass interceptor, was replaced in fact by a Mk 6. Mk 8 was designed for a night fighter armed with guns and missiles, employing the APG-37 radar; it could also direct visual employment of guns, rockets, bombs and special weapons against ground targets, in dive- or toss-bombing. Mod 1 used the APQ-50 radar, and it appears that Mk 8 was intended for the Douglas Skynight or a successor. Mk 10 was a fighter AFCS built around the basic computing mechanism of Gun Sight Mark 23, altitude and temperature corrections being applied to the computed lead, with range (to 2000yds) via an APG-18 radar, and altitudes up to 30,000ft; own-plane speed could be up to 500kts, target speed up to 315, and guns were to be the wartime 0.60 (1947).

With Mk 9, ground attack was once more emphasized; it was functionally but not physically equivalent to Mk 1 and 4, and some of its features ended up in Mk 11, for the Douglas A2D Skyshark (1947); this latter also had an APG-30 ranging radar. Mk 15, also for the Skyshark, was similar but incorporated a later bomb director (Mk 3) which permitted toss-bombing as well as rocket-firing; it was suitable for radar range input.

Mks 12 and 13 were to control the complex defensive battery of the large P5Y flying boat, and Mk 14 was for gunner-operated systems for a remote control turret (1949), using a periscope, with automatic data entry into its computer; it was intended ultimately to receive a range-only radar for range and range rate. Mk 18 (1950), similar to Gun Sight Mark 18, was for manned turrets.

The remaining systems were for fighters. Mk 16 (1949) could fire air-to-air HVAR, 2.75in aircraft rockets and 5in HPAG rockets; it could track at 3000yds, release at 1500, and fire from a pursuit course, using a reticle sight. Mod 5 was linked to the fighter radar. Mk 17 was an optical lead-computing sight for fixed forward guns (air-to-air and air-to-ground) as well as air-to-ground rockets; it used radar for air-to-air ranging (January 1951). Mk 21 was a lead-computing air-to-air and air-to-ground system for guns and rockets; it became the

This Convair Privateer (PB4Y-2, actually the prototype) symbolized the extent to which heavy naval aircraft were protected by power turrets by the end of World War Two. The bow and tail turrets were Erco 250SH: there were also Erco 250TH waist powered blisters, each with twin 0.50-caliber guns. The waist mounts could fire below as well: at maximum deflection their fire converged at a point 30ft below the belly of the Privateer. The deck turrets were Martin types. Privateers were extensively equipped for ECM: reading from the nose aft, the radomes housed an APA-17 HF/DF, an AS-124/APR intercept receiver (300-1000mc/s), and an AS-67/APQ-2B for a jammer. The bulge below the fuselage under the engines houses an APS-15 surface search radar. Many Privateers also had an APG-15 ball to control their tail guns, and in many cases there was a third small radome on the lower forward side of the fuselage, abaft the two shown, housing an AS-125/APR countermeasures receiving antenna (1000-3000mc/s range). Privateers continued in the ECM 'ferret' role through the Korean War.

BuAer E-10 fire control system. Mk 22 (November 1953) was more elaborate, with an APG-48 radar, an AAG-3 infrared receiver, and a Mk 18 gun sight.

Gun Turrets

It seems appropriate to end by summarizing the development of powered turrets for patrol bombers, since the Navy preceded the Army in this field. Prior to the war, defensive guns were flexibly mounted 0.30-caliber machine guns, on scuff or post mounts, whether aboard carrier or patrol aircraft. The first Navy flexible 0.50-caliber mount appeared in 1934, but not until 1937, with the advent of the Martin Mariner (PBM), was there a large enough US aircraft to carry a power turret. At the same time, the four-engine Sikorsky XPBS-1 carried the first US tail turret, a hand-operated 0.50, with another in the nose.

For most of the war, turrets were developed as part of larger aircraft projects, and there were no separate 'universal' turret programs, although particular types were interchanged between aircraft. Thus Martin developed its 150SH series for the Mariner and the later XPB2M, the latter including, for the first time, side and tail as well as nose and deck installations (August 1938). A year later Curtiss developed its 150CH-1 turret for the Helldiver, and Vought produced a similar turret for its abortive Seawolf (TBU/TBY) torpedo-bomber. In each case, the numerical part of the turret designation indicated the number of guns and their caliber; Grumman's equivalent

was the 150SE electric (vice hydraulic) turret of its Avenger (1940). In 1940, too, Erco produced the first US twin 0.50-caliber turret for the unsuccessful Boeing XPBB; its X150TH was the first US streamlined turret. In June 1941 Douglas developed a remote fire control system for its 150RE turret for the XSB2D-1 dive-bomber; it was a predecessor of the system in the Army A-26 light bomber, and work was halted to avoid conflict with the Army effort. A year later Emerson produced the first US quadruple turret (450SH) for the tail of the abortive Consolidated PB3Y patrol bomber; it was too heavy for any other plane. A twin 20mm turret for its bow, 220SH, was intended primarily for strafing.

BuAer decided late in 1941 to coordinate turret design, buying the turrets from their manufacturers and supplying them directly to the aircraft companies. For example, the Martin turret of the PBM-3C was also installed in the Consolidated PB2Y-3 in 1942. Erco's 250SH-1 ball turret, originally developed for the Boeing PBB, was tested in the summer of 1942 on Navy Liberators (PB4Y-1) and proved extremely successful. It was, in effect, the first 'universal' turret. Erco later made the streamlined blister turrets of the PB4Y-2 Privateer (250TH), which were unique in US service in that they totally enclosed the gunners, moving independently of the airplane, unlike the blister mounts on Catalinas and Flying Fortresses. This latter mount had originally been designed for the abortive PB3Y (September 1943); in 1945 Erco was working on a twin 20mm turret, 220TH, to replace it,

and Martin had a contract pending for a twin 20mm deck turret (220CH-1A), also a replacement for the existing 0.50-caliber unit. Emerson had a contract for a 20mm nose strafing turret at this time, continued postwar (220SE-101, May 1945).

In December 1942 Emerson received a contract for a universal nose, deck or tail turret light enough for carrier dive- and torpedo-bombers (250CH). It was unusual in that its two guns were independently mounted, driven and controlled, so that when one fouled the tail of the airplane the other could continue to fire while the first was elevated out of the way; the effective area of fire would increase by 10 to 20 percent. Although it was scheduled as a standard installation for all Navy aircraft, production problems caused cancellation. Other wartime general turret contracts included a Martin lead-computing sight controlled turret (250CE-12A, March 1944); Martin turrets with stabilized drives, sights and radar controls (220CH and 260CH, August 1944); and an Erco strafing turret (450SH, September 1944) which was canceled due to preference for the 20mm gun in this role. At the end of the war Emerson was working on the first turret to use 'aided tracking' (250SE-1) for the new Martin Mercator (P4M) patrol bomber, while Sperry's 220SH for the Lockheed Neptune (P2V) had been rejected as too cramped.

Relatively few new powered turrets were developed postwar. The large Convair P5Y flying boat was to have had a system of remote-controlled 20mm turrets, four on the hull sides

and one in the tail, but it never entered mass production. The land-based Neptune and Mercator were defensively armed, the former initially (P2V-1) with twin 0.50-caliber guns in a hand-operated nose mount, and power-operated upper and tail turrets. In the P2V-5, the tail battery was two 20mm cannon; the parallel Martin P4M Mercator had twin 20mm nose and tail turrets (M-24) and a twin 0.50-caliber upper turret (M-2). Other aircraft had unmanned radar-controlled twin 20mm tail turrets: the Martin P5M and P6M flying boats (the latter with an Aero X-23B), and the carrier-based A2J and A3D (Skywarrior) attack bombers. Ultimately the P2V exchanged its tail turret for a magnetic anomaly detector (MAD) for ASW, and the Skywarrior exchanged its Aero-21B for increased ECM equipment an squared-off tail.

After the Skywarrior, the Navy shifted to speed as a means of self-defense, in the North American A3J (later redesignated A-5) Vigilante, and then stealth (by low-altitude flight) in the Grumman A-6 Intruder. The current standard land-based ASW patrol plane, the P-3 Orion, is entirely unarmed – a situation not entirely satisfactory if, as some believe, the Soviet Yak-36 ('Forger') VTOL fighter has been designed specifically to destroy P-3s attempting to prosecute ASW barriers in Soviet submarine operating areas. It is, therefore, possible that patrol plane armament will return during the 1980s. However, if that happens it will be missiles, not guns, for self-protection.

Part III

Underwater ordnance



The huge SQS-26 is typical of modern US bow sonar installations; this one, aboard the *Willis A Lee* in 1966, was one of the first fitted with a rubber dome for improved sound transmission and therefore for much improved long-range performance. Earlier installations had incorporated thin steel 'windows' and reportedly had shown poor performance, particularly at the bottom-bounce and

convergence-zone ranges for which SQS-26 had specifically been designed. At sea, the entire dome is flooded, the transducer inside transmitting power to the water in the dome and the pressure waves passing through the flexible rubber of the dome itself. Such a dome adds several hundred tons to the displacement of a destroyer.

1. Introduction

Underwater ordnance embraces the two disparate areas of antiship and antisubmarine warfare, but both use much the same technology and therefore cannot easily be separated from a weapon point of view. Moreover, there is almost a clean chronological break between US interest in the two warfare areas, so weapons and techniques devised for one have later become available to the other. Except for a brief period during World War One, US naval efforts in undersea ordnance prior to about 1940 were largely concentrated on antiship attack by mine and torpedo. As in the case of the Royal Navy, the extent of the German submarine threat proved a considerable shock, to the extent that new laboratories had to be created to devise the means to meet it. By mid-war, some of the technology they had developed was being employed by American submarines operating against Japanese shipping in the Pacific, some ASW sensors and weapons leading directly to antiship (or pro-submarine) equipment.

After 1945 US naval strategy shifted once more. The only future opponent in view, the Soviet Union, presented very few worthwhile ship targets, but had the potential to fight a new Battle of the Atlantic, using the advanced German technology she had captured at the end of World War Two. Antiship efforts waned as ASW took priority, a position it retains more than three decades later. There is, in 1983, increased interest in antiship operations, as the Soviet surface fleet is more and more in evidence, but generally that is interest in antiship weapons which will not unduly interfere with ASW operations.

Unlike projectile weapons, undersea weapons rely almost entirely on the force of their explosion for their effect. That is, given a sufficiently large charge, it is entirely irrelevant (from the point of view of its effect) how it arrives at its target: by swimmer, by self-propelled torpedo, by the approach of the target itself (as in a mine), or by being dropped or pushed by a small boat. Moreover, weight for weight, underwater explosives are the most efficient way of sinking a ship. They achieve their destructive power either by contact (leading to flooding as well as to shock damage) or by standoff explosion (leading to shock damage and in some cases to whipping so severe that a ship can be broken in half). Because the effect depends almost entirely on the size of the charge, undersea weapons can, in theory, permit the destruction of the largest ships at minimal cost and effort. The Italian and British X-craft attacks during World War Two were a particularly dramatic illustration: a small submarine or manned torpedo could drop a charge large enough to sink a battleship. Against this, the X-craft was usable only in very limited circumstances, whereas the battleship was far more flexible. Classically, however, underwater weapons have promised the most minimal naval powers the possibility of countering the massive investments their enemies made in capital ships. Their counters

might be useless on the open ocean, but such powers have been far more interested in coast defense – as was the United States before the late 1890s.

Thus underwater weapons were always the traditional weapons of the small power. As early as 1776, an American, David Bushnell, attempted to attack British warships with underwater explosives, first by submarine (using an early equivalent of a limpet mine) and then by floating mine. During the American Civil War, the Confederates made extensive use of mines (Farragut's 'damn the torpedoes' actually refers to these early mines). Probably their greatest success was the destruction of the monitor *Tecumseh*, mined at Mobile Bay on 5 August 1864. Both sides also used spar torpedoes – charges held away from small craft on long spars. The Confederates used such a charge, carried by a small submersible, to sink the Union screw sloop *Housatonic* on 17 February 1864. For its part, the Union Navy employed a picket boat carrying a spar torpedo to sink the Confederate armored ram *Albemarle*, in hiding up the Roanoke River, on 27 October 1864.

The *Albemarle* attack was significant to the US Navy because it was made under the jurisdiction of Admiral David Dixon Porter, who after the Civil War became Admiral of the Navy, exerting enormous influence on a long series of civilian administrators, for whom he embodied the professional views of the Navy. He was the only senior naval officer, and there was no organization comparable to the Office of the Chief of Naval Operations or even to the General Board. Porter had not planned the attack – that had been the work of a young naval officer, Lt W B Cushing – but Porter had approved it and had apparently been deeply impressed by the results. He became an enthusiastic supporter of torpedo warfare, as it was then understood.

With the Navy steeply in decline after 1865, torpedoes were attractive as inexpensive ways to counterbalance the threat of any foreign naval attack. Indeed, they were probably the only US naval weapon which progressed significantly between the Civil War and the beginning of the New Navy in the early 1880s. Thus, despite the general financial problems of the Navy, Porter was nonetheless able to establish the Naval Torpedo Station at Newport, Rhode Island, in 1869. It developed American torpedoes up to World War Two, and lost its influence largely as a result of the disastrous performance of the magnetic exploders it had developed prewar. In addition, it was responsible for mine development until the end of World War One, when a separate Mine Building was established at the Washington Navy Yard (Naval Gun Factory), the ancestor of the present Naval Ordnance Laboratory at White Oak.

Originally the Army was responsible for mines, that is, for coast and harbor defense. Newport was concerned more with the existing spar torpedoes, and with the development of a

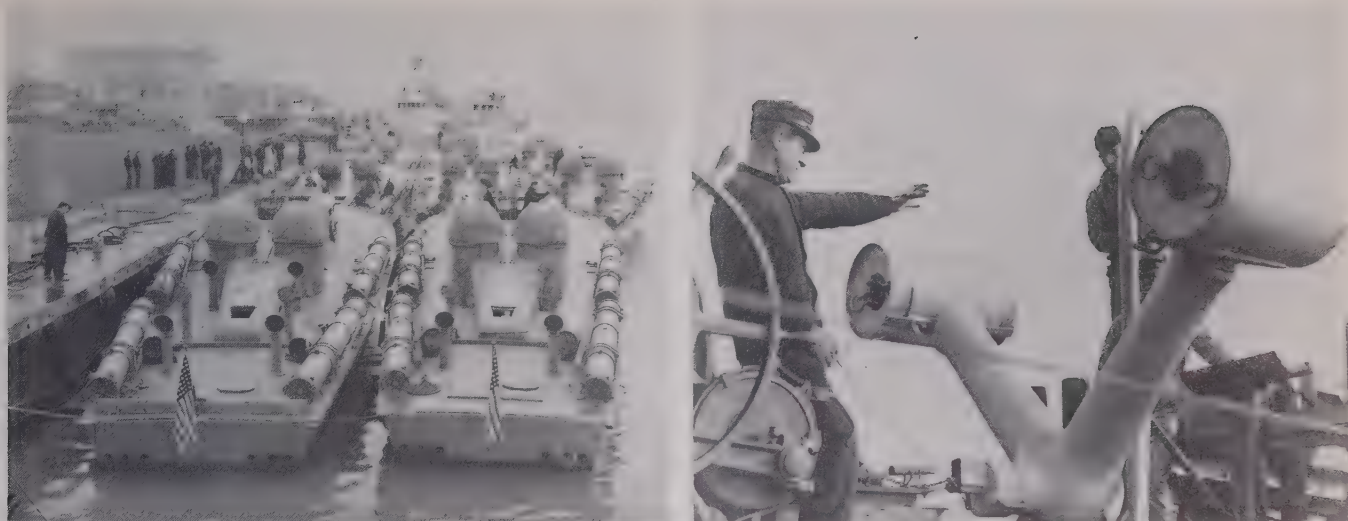
self-propelled torpedo comparable, perhaps, to the Whitehead 'automobile' torpedo which had first been demonstrated at Fiume in 1866. In fact, the United States unsuccessfully negotiated to obtain the Whitehead patents for what became the modern torpedo in 1869, and again in 1873, but chose instead to develop a series of domestic designs. One of them, the flywheel-propelled Howell torpedo, actually entered service, but it was replaced by Whiteheads and their successors after successful patent negotiations begun in 1891.

Even though the United States Navy had no satisfactory torpedo before about 1890, it showed strong interest in torpedo-bearing craft, particularly for coast defense. Until the Spanish-American War, the assumption seems to have been that American naval forces would be unlikely to encounter enemy torpedo boats, which were essentially coastal craft, whereas American torpedo craft would be effective against any enemy capital ships attempting to operate off the US coast. One of the shocks of the Spanish-American War was the Spanish success in bringing destroyers to Cuba to operate with the Spanish cruiser fleet. As a result, the United States began a crash program of destroyer construction.

Over the next decade, improvements in torpedo performance strongly affected US Battle Line tactics and battleship design: the threat of the torpedo drove up the expected battle range. At the same time, interest in mine warfare increased to the point that mine depot ships were requested in the annual budget, and two elderly cruisers were actually converted in 1912–13. The other major element of undersea warfare, the submarine, was considered primarily as a coast defense weapon, an inexpensive device which could, for example, secure the Philippines against the far superior Japanese Navy. Submarines continued to be an essential element of Philippine defense down to 1941, but their special feature before 1914 was that they were considered only a very minor threat to American shipping, given their natural limitations.

World War One changed that view entirely, and forced the United States into an emergency ASW program. The submarine threat was sufficiently novel and sufficiently severe that the civilian Naval Consulting Board, led by Thomas Edison, was convened to suggest solutions. It developed, among other devices, a variety of hydrophones, as well as the concept of the North Sea mine barrage. Other ASW weapons and tactics, such as the use of depth charges, were taken over from the Royal Navy.

After 1918, interest in ASW rapidly waned. To some extent, it appeared that the German U-boat offensive had been a special and unusual case, that its defeat by the convoy system and other tactics had been so complete as to demonstrate that any such offensive would be extremely unprofitable in the future. To some extent, too, there appears to have been a rather naive belief (not limited to the US Navy) that the general condemnation of German wartime



practice would serve to deter any future enemy. Moreover, the Navy as an organization found itself far more comfortable returning to traditional fleet-versus-fleet concerns. For example, it continued to develop submarines, but saw them primarily as warships capable of operation in forward areas under nominal enemy sea control. Underwater ordnance development was concentrated in more effective, longer-range torpedoes, and the US Navy adopted carrier torpedo-bombers as a major strike weapon. Mine development was largely limited to the conservation and improvement of the large surviving stock of World War One mines.

From an ASW point of view, the most important development was sonar, an active submarine detector effective at relatively short range, and operating at 'supersonic' frequencies, *ie* at frequencies above the usual aural range. Tests repeatedly showed that sonar did not solve the antisubmarine screening problem, but it does not appear that much effort went into ASW (including ASW tactics) prior to the outbreak of World War Two. There was just too little money, and the Navy was primarily concerned, for most of the inter-war period, with the strategic problem of war with Japan. Indeed, it was correct in its belief, that war in the Pacific would involve relatively little ASW: the Japanese, unlike the Germans, used their submarines more or less according to prewar ideas, as warships fighting other warships.

As American involvement in World War Two became inevitable, ASW once more became paramount. As in World War One, new laboratories were established to devise new weapons and tactics. Examples included the Under Sea Laboratory at New London (USL), the Harvard Under Sea Laboratory, and the torpedo program at the Ordnance Research Laboratory at Pennsylvania State University. There was also the Naval Research Laboratory (NRL), itself a result of the recommendations of the Naval Consulting Board; and there were the efforts of a great number of existing industrial organizations, such as Bell Telephone Laboratories (Western Electric). There were also new attempts at operational analysis, which led, after World War Two, to the formation of the Center for Naval Analyses, with its Operational Evaluation Group. A separate naval organization, the Tenth Fleet,

was ultimately established specifically to administer antisubmarine warfare.

From a weapons point of view, these developments meant that a great variety of unconventional ASW sensors and weapons were developed, many of them in parallel, and many of them ancestors of postwar systems. Examples included magnetic anomaly detectors (MAD), sonobuoys, airborne infrared detectors, and 'sniffers'. With the failure of Newport's torpedoes, several companies began to develop their own, and some of the non-Navy torpedoes saw action during the war, both in pro- and in antisubmarine operations. At the same time, the expanding role of operations analysts made for a much more theoretical approach to the effectiveness of antisubmarine weapons than had previously obtained, an approach which explains some of the postwar attempts to overcome the threat posed by fast, deep-diving submarines.

The United States ended World War Two with a very large and efficient (and obsolescent) submarine force, with an extensive (and also largely obsolescent) ASW organization, and with a probable future enemy who presented very few surface ship targets for air, submarine or surface-ship torpedoes. Antiship weapons therefore went into an inevitable decline, while the threat of the submarine increased very considerably. Existing forces were considered obsolescent in view of the development of advanced submarines, examples of which both the Western Allies and the Soviets had captured in 1945. At first, American experts tended to believe that within a few years the entire Soviet submarine fleet would consist of the new Type XXI or some equivalent, and hence that all American ASW ships and aircraft would have to be replaced on an urgent basis – entirely impractical, incidentally, given the peacetime budget. New projects such as Weapon Alfa were placed in production before evaluation, and for a time the mass conversion of existing *Fletcher* class destroyers for ASW was planned.

In fact Soviet progress was much slower than the alarmists expected, and from 1950 onwards US policy was to buy as much ASW improvement as possible at minimum expense, utilizing existing hulls (including the DEs, which had been considered too slow), while using available funds for research and deve-

1 Early motor torpedo boats carried destroyer-type torpedoes, whose gyros had to be lined up before launch, in heavy tubes. These boats are shown visiting the Washington Navy Yard late in 1940 or early in 1941. Note the absence of the heavy gun batteries later carried: they have only paired, aircraft-type, power-operated twin 0.50s.

2 The depth charge was the first effective surface ship ASW weapon: here a chief petty officer prepares to fire two of them from a Y-gun in 1918.

lopment against the inevitable modernization and enlargement of the Soviet submarine fleet. Thus the advent of a new generation of ASW sensors and weapons, such as the SQS-23 sonar and ASROC, coincided with the maturation of the threat, about 1960, when the Soviets not only had the submarines (primarily 'Whiskies') but also began operating them in the open oceans.

Two decades later, US undersea weapon development remains concentrated on ASW, although there is an increased interest in antiship weapons. Given the economics of even an expanded defense budget, however, such interest is generally manifested in improvements of existing ASW-oriented weapons to gain antiship potential; the best example is the Mk 48 torpedo. The submarines now benefit, too, from missile development (see Part VI), so that they can employ Harpoon and Tomahawk missiles at long range.

2. Antisubmarine strategy and tactics

'Covering' Strategies

There are always two principal options in ASW: wide-area hunting, or concentration of forces in areas in which the submarines must of necessity operate, *ie* a 'covering' strategy. The second case includes, but is by no means restricted to, convoy escort. The relative value of these alternatives depends upon effective sensor range, *ie* upon the extent to which a submarine can capitalize on its effective invisibility. The economics of the two strategies are very different. The forces needed to execute wide-area search and attack are proportional to the size of the enemy submarine fleet. The forces needed for the covering strategy, on the other hand, are proportional to the areas to be covered. In the convoy case, for example, the forces are proportional to the number of convoys at sea at any one time. However, the covering concept also embraces barrier operations in which the issue is geographical. Generally the balance between the alternative strategies depends upon effective sensor range and platform cost.

Barriers are a good example. In theory, a barrier thrown across the route by which submarines must exit to their patrol areas can enormously reduce the load on ASW forces in those areas. In World War One, German submarines had to pass through either the English Channel or the North Sea east of Scotland en route to their operational areas in the Atlantic. The US Navy planted thousands of mines along the Northern route as an ASW measure. Although each mine had an effective sensing range of not more than 100ft, each was so inexpensive that a dense barrier could be laid; it was hoped, in fact, that a submarine would have no more than one chance in three of passing through undamaged. The current CAPTOR (Encapsulated Torpedo) mine is intended to have much the same effect; it trades off a much longer mine sensing (and attacking) radius against greater unit mine cost.

Similarly, the current US submarine barrier strategy for closing the Greenland-Iceland-UK (GIUK) Gap to Soviet submarines is rational in view of the long ranges claimed for modern US passive submarine sonars. SUBROC was designed to exploit this performance, with a reported range of about 30-40nm (*ie* first convergence zone); however, because it is nuclear, a wartime barrier might well have to be prosecuted instead with non-nuclear torpedoes such as Mk 48, which have slightly smaller ranges.* A submarine can probably be expected to patrol a sector 60nm wide; ten submarines can hope to control a 600nm barrier. However, were the same submarines to be limited to World War Two-type detection and attack ranges of perhaps 2000yds (one nautical mile, or 2nm per submarine station), 300 would be needed. In fact, US ASW strategy of the early 1950s envisaged the mass production of ASW submarines which would

operate immediately off Soviet submarine bases, benefiting from very greatly reduced geographical areas to be covered.

Air ASW in both World Wars very often involved a covering strategy, aircraft having a relatively long range of detection against a surfaced submarine. They could, therefore, cover large operational areas – against surfaced submarines. Tactically, before the advent of the snorkel, submarines were largely immobile *except* when surfaced, so that the presence of aircraft drastically reduced their effectiveness, even though relatively few submarines (particularly in World War One) fell victim to air attack. It followed that, with the advent of snorkel-equipped submarines which could operate continuously submerged, aircraft lost much of their search capability. Indeed, much of the air ASW effort since 1944 has been devoted to restoring the search range of aircraft against fully submerged or snorkeling submarines. Very long-range sonobuoys are a step in this direction. Current airborne radars, such as the APS-116 of the S-3A, are considered effective against exposed periscopes, and snorkels are easy radar targets by comparison. Other techniques have also been tried: 'sniffers' and a variety of nonacoustic attempts to detect submerged submarines or their trails.†

Convoy is the prototypical covering tactic. It was founded on sensor inadequacy: in neither World War was there any effective and reliable means of searching the whole ocean for submarines. Moreover, the object of ASW was much more to protect shipping than to destroy submarines as such. ASW forces were therefore concentrated at the submarine targets, the merchant ships; any submarine attacking a convoy would be announcing its presence and inviting counterattack. It may be noted that the chief surface ship ASW sensor of World War Two, the searchlight sonar, was much more a means of maintaining contact with a submarine already detected (*eg* by its own act of attack) than of searching: its probability of initial (unalerted) detection was quite low.

All of the covering tactics have in common that they are tactics of deterrence and of harassment. They reduce submarine effectiveness by increasing the risk to a submarine attempting to operate efficiently: most barriers can be defeated, but only at a cost in the net level of forces passed through. Either several boats must be sacrificed to get one through, or individual submarines must move much more cautiously, and hence spend much less time on offensive patrol after penetration. Convoy tactics tended to deter individual submarine commanders from attacking, although they could sometimes be overcome by concentrations of submarines in 'wolf-packs'.

Offensive Antisubmarine Warfare
Hunting – offensive ASW – is an alternative. If

there is some means of detecting individual submarines at a great distance, then it may be profitable to dispatch attackers. Generally the wide-area system provides an approximate location (datum). The hunter must carry out its own limited-area search (called localization) to reacquire the target and then to refine its location to the point of an attack. There is, then, a premium on how fast the hunter can reach the datum, as delays allow the submarine more time to move from its original position, enlarging the area which the hunter must search. Thus offensive ASW is almost always airborne ASW. Originally that meant a combination of shore-based and carrier-based aircraft, the latter filling a mid-ocean 'gap' left by the relatively short range of the former. With the advent of the P-3 Orion, the US Navy ceased to operate 'filler' ASW carrier groups and transferred its ASW carriers (CVS) to the support of fast attack carriers; however, the Royal Navy continues to operate its V/STOL carriers in the offensive ASW role.

Historically, there have been three major long-range submarine location systems. The first was radio direction-finding (DF). Particularly during World War Two, the German submarine fleet was under central control, not least to permit the U-boat commander ashore to form 'wolf-packs' to attack convoys. Such control required two-way communication, as the U-boat Command had to know the status (*eg* number of torpedoes, level of fuel remaining) of individual boats, not to mention their success in locating convoys in their approximate area. Even in World War One, submarines had to report regularly to their shore organization. At the same time, the commander of U-boats ashore had to transmit orders to his boats. Direction-finding was tried in World War One, but only with limited success, partly because existing short-range sensors were inadequate to follow up the long-

*To fire her torpedoes, a submarine would have to stalk her adversary, maneuvering to come within range and remaining in the area while guiding her torpedoes. For example, at 40kts a homing torpedo would require half an hour to cover the 20nm to its target, and the latter might well evade upon hearing torpedo propeller noises, so that the torpedo prosecution of an approaching submarine might well be a lengthy process. In consequence the barrier might be saturated by several submarines approaching at once in a limited sector. This problem largely explains recent US interest in a non-nuclear successor to SUBROC, the ASW Stand-Off Weapon (SOW), which also reportedly reaches to two convergence zones.

†'Autocycclus' or 'sniffer' is a means of detecting snorkel exhaust products; it has become less and less effective in recent years due to the proliferation of diesel-powered merchant ships (which produce similar exhaust products) and also due to industrial pollution near coasts (which, again, can confuse it).

range (but imprecise) detection it made possible. In World War Two, the Germans again used radio, and the submarines used high-frequency sets amenable to accurate DF.

The Germans were well aware of the vulnerability inherent in submarine radio emissions, but believed that the necessary equipment was far too massive for shipboard installation; land DF stations had inadequate accuracy at ranges beyond about 300nm. The great Allied technological surprise was shipboard HF/DF (high-frequency direction-finding), which permitted convoy escorts to run down U-boats over the horizon, as they made their contact reports. These particular trailing U-boats were essential to the wolf-pack system as it then functioned, since they arranged the rendezvous of the pack before a night surface attack. If they were forced to dive, they could no longer maintain a station on a convoy.

HF/DF lost much of its value by late in the war, as the Germans introduced a countermeasure of their own, 'Kurier'. It was a 'burst' transmitter, compressing a report into a signal so short that existing systems could not acquire and track it. However, by that time Britain and the United States were benefiting from the other major wartime wide-area system, codebreaking ('Ultra', or 'Z').

The other end of the German command signal system was the series of orders sent by the commander of U-boats ashore, ranging from setting up patrol lines of U-boats to counter specific convoys to signals setting up fueling rendezvous with special 'milch cow' submarines. In December 1942 the British broke the Triton U-boat code, and it became possible for the Allies to anticipate German U-boat movements, assigning offensive ASW forces to hunt U-boats in the very limited areas thus indicated. Refueling rendezvous were particularly useful, because they were set up so far in advance that hunting groups built around escort carriers could generally reach them in time, even taking into account the delays inherent in codebreaking. 'Ultra' was central to the hunter-killer tactics adopted by the US Navy: such tactics had, indeed, been opposed by Admiral King (as 'hunting needles in a very large haystack') prior to the Triton break. Given 'Ultra', the United States freed almost all its escort carriers from convoy escort duty, using them instead for search and strike operations on the basis of intelligence data.

The significance of 'Ultra' is shown by U-boat sinkings: throughout World War Two, the United States Navy was credited with the sinking of 174 U-boats. In a postwar analysis, 'Ultra' was credited with 63 of them, and another 30 were considered indirect results of 'Ultra' data. The first US use of such inform-

ation was an attack by the escort carrier *Bogue* and her consorts on the 'Trutz' group of U-boats early in June 1943.

Aircraft were an essential element of both wide-area systems (DF and 'Ultra'), as they alone could run down contacts at very long ranges. DF contacts were generally fleeting in nature, so that it was unlikely that contact positions would be updated during flight. By way of contrast, 'Ultra' gave projected future enemy positions at particular times; given navigational inaccuracies, such data had to be considered no more than the beginning points of searches which might have to cover relatively large areas in a short time. Delays in exploiting a contact merely enlarged the area to be searched: only aircraft could exploit the full range inherent in the wide-area systems. That is why, for example, escort carriers in the Atlantic were fitted with HF/DF. It is also why the Allied navies faced so depressing an ASW future after 1945: the Germans had found a counter to HF/DF in 'Kurier,' and it seemed unlikely that the good fortune represented by 'Ultra' would necessarily be repeated. At the same time, the effective range of airborne sensors – ie of the devices used to permit the airplane to reacquire contact and then convert that contact into an attack – was shrinking radically, as submarines would be able to operate fully submerged, showing only their snorkels. These severe problems were a major stimulus to postwar research and development; for example, much attention went into direction-finders effective against short radio transmissions, and also into snorkel-detection radars.

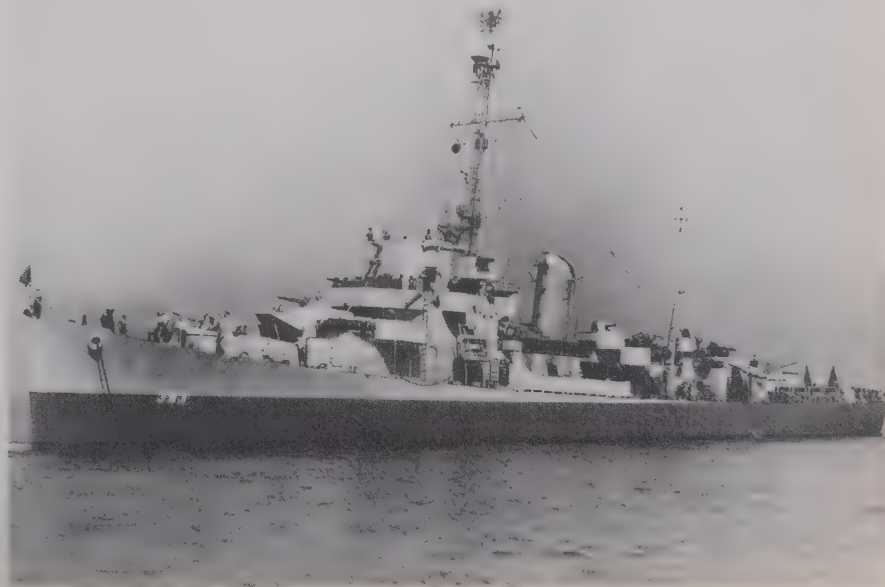
SOSUS

The modern successor to the wartime long-range systems is SOSUS (Sound Surveillance System), a network of ocean-floor hydrophones operated by the US Navy. All submarines emit sounds, and SOSUS is able to distinguish them, some fraction of the time, from background noises. The existence and capability of SOSUS is responsible for the current predominance of long-range shore-based patrol planes in the US ASW inventory:

the aircraft follow up SOSUS contacts, acting as 'pouncers'. It should be emphasized that SOSUS does not provide its operators with a complete picture of the position of all submarines in the ocean areas under surveillance at all times. Rather, any submarine operating in a SOSUS area has some finite probability of registering its position, and over the length of a submarine patrol that probability may become quite substantial. Given advances in airborne sensors, particularly sonobuoys, a long-range patrol plane has a good chance of following up a SOSUS contact, searching the area of uncertainty about the datum supplied by the system, and attacking. To some considerable extent, a combination of effective airborne detection range, SOSUS detection range and aircraft speed determine the fraction of the ocean which can be covered by shore-based, as opposed to sea-based, aircraft. Thus the P-2 Neptune appears in retrospect to have been incapable of covering the entire North Atlantic, which accounts for the formation of special ASW task groups to operate in mid-ocean. The P-3 Orion, however, particularly in its newer variants, appears to solve this problem. After it appeared, the ASW carriers were reassigned to the direct support of attack carrier forces.

Reliance on long-range shore-based aircraft emphasizes the value of bases along both coasts of the Atlantic Ocean. The limit on effective range of such an airplane is not fuel load, but a combination of its speed and its ability to search an area of uncertainty defined by (i) the inaccuracy of the initial contact and (ii) the time delay between that contact and the arrival of the airplane at the original datum. To some extent, too, the early SOSUS could not itself cover the mid-Atlantic and hunting forces had to rely instead on the 'flaming datum', ie on reports from sinking ships. A submarine would be quite aware that it had created such a datum, and so would be sure to flee; that datum would become 'stale' more quickly than would a SOSUS or DF 'fix' of which the submarine commander might be unaware. The P2V-5 cruised at 156kts, and had a rated combat radius, with four torpedoes, of only 860nm. In the last Neptune, the P2V-7 or P-2H, these

HF/DF, or high-frequency direction-finding, was the longest-range submarine detector of World War Two. The destroyer escort *Haverfield*, shown on 1 May 1944, had hers atop a stub mainmast; others carried their HF/DF antennas at the fore, in place of an air search radar. HF/DF was effective because German submarines had to communicate with each other and with their commander ashore in France, always using HF radio. The Allies' ability to break the German code used by the shore-based U-boat command to control vessels at sea was also vital, often allowing hunter-killer groups to concentrate near expected U-boat positions. HF/DF was also fitted to escort carriers operating in the ASW role in the Atlantic.



figures increased, but only to 174kts and 1050nm, with a search on station of three hours; during the 6-hour flight to the datum and the 3-hour loiter there, a 15kt submarine could cover 135nm. Comparable figures for the P-3A Orion were 308kts and 1400nm, again with a 3-hour search; but that meant that the P-3 could reach a datum a thousand miles from its base in only three and a quarter hours.

SOSUS began in the fall of 1950 with a research contract to Western Electric for what was then termed Project 'Caesar': a very long-range low-frequency array. The first model was installed at Sandy Hook in May 1951, followed by a deep-water (200-fathom) array off Eleuthra (40 hydrophones) in April 1952. In June, the Chief of Naval Operations ordered six stations for the Atlantic, with full readiness in December 1956; the Pacific chain followed in March 1958. Two stations, Eleuthra and Bermuda, were ready for an ASW exercise (ASDEX 54-1) in the late spring of 1954; they and the new ASW submarine K-1 transmitted data to the new SOSUS center at Norfolk. Aircraft equipped with passive sonobuoys functioned as pouncers, achieving a 90 percent detection rate on snorkeling submarines.

All of the hunting tactics require some measure of cooperation by the submarine: it must generate some signature distinguishable at a great distance. All also have in common the objective of direct destruction of the submarine. In an antishipping war that is attrition: if a pure hunting strategy is adopted, the assumption is that attrition will be so rapid that the (presumably high) initial loss rate of merchant ships will be tolerable. Hunting is also, however, the strategy most appropriate to countering missile-firing strategic submarines, which are difficult to exclude from their inherently large operational areas, particularly early in a war. Presumably the Soviet effort to develop ballistic missile submarines, such as the 'Delta' class, which can fire from Soviet-controlled waters, is a testimony to the efficacy of the SOSUS/pouncer combination operating in the open ocean.

Sensor Development

Historically, the balance between hunting and covering tactics has been dictated by sensor development. Offensive ASW has always been attractive both emotionally and economically, but until World War Two it was quite impractical. Convoy tactics predominated at the end of World War One because there was no effective long-range submarine detector. A submarine attacking a convoy announced its presence by the wake of its torpedo, which gave a visual clue to submarine location. Escorts could then saturate the indicated area with depth charges, making up in numbers of weapons for their inability to locate the submarine precisely. Their great need was for some means of locating a submarine after its approximate location had become known from the track of its torpedo. Such a system would not be a submarine 'detector', in that it would not have to alert the escorts to the appearance of all submarines nearby; rather, it need only function after the escorts had been alerted.

No such system then existed. The principal sensors available were hydrophones (*ie* passive sonar) and eyesight. Submarines could be detected passively at a range of several miles, but only if the detecting ship hove-to with her

engines stopped. Even the direction to a submarine could be measured, using arrays of hydrophones mounted on destroyer and sub-chaser hulls, or towed by aircraft and airships. However, all such systems were blinded to some extent by general shipping noise (particularly near a convoy) and by self-noise, and all could be countered by submarine silencing. By 1918 they were limited to barrier duty, as what would now be called 'sprint-and-drift' operations in support of convoys were impractical. On the other hand, a seaplane, alighting on the water, could also use hydrophones. The latter experiment was the earliest attempt to allow an airplane to penetrate the surface of the water; its World War Two successor was the sonobuoy.

The human eye should not be discounted. At the least, raising it well above the surface aboard an airplane greatly increased its effective range against a surfaced submarine. In the absence of aircraft, the submarine, with a low silhouette, would not be visible to ships at over a few miles' range. It could therefore operate largely on the surface, submerging only to attack or, briefly, to evade surface ships happening across its path. Aircraft were a very different matter, as they could attack and sink any submarine they happened upon. In very clear water, as in the Mediterranean, even submerged submarines were visible from the air – as a number of British submarines discovered, to their cost, in World War Two. Purely visual ASW patrol, particularly ahead of naval formations, remained an important tactic through World War Two.

The Weapons Problem

Tactically, the principal ASW weapon was the depth charge. A torpedo track indicated where the submarine had been a few minutes earlier, and an effective counterattack required saturation of the area in which the submarine was most likely to be found. That required a combination of high speed (to get there as fast as possible, and thus to minimize the area of uncertainty) and saturation of the widest possible area (hence the adoption of such depth charge throwers as the Y-gun). Since great precision was extremely unlikely, the depth charge was a proximity weapon, fuzed to explode at a set depth, and capable (in theory) of damaging a submarine at some considerable distance, perhaps 40ft. That in turn made the depth charge quite large and difficult to handle, given the small size of the average ASW ship. In particular, throwers such as Y-guns could not be reloaded during a single attack, so that to throw several charges to any great distance required multiple Y-guns, which in turn would require considerable centerline space on the attacking ship. Conventional depth charge tracks, on the other hand, took up space not generally required for any other purpose, and in addition could fire several charges in quick succession. Standard depth charge patterns therefore emphasized the line of charges dropped astern. Moreover, postwar destroyer designs generally made provision for small depth charge tracks – but not for projectors (Y-guns). In the late 1930s, an alternative projector, the K-gun, was developed to overcome the space requirements of the Y-gun, and it could be fitted alongside a ship's superstructure. Given this relaxation, pattern size and complexity could rise, typical World War Two installations consisting of six

or even eight K-guns, as well as the traditional stern tracks.

There were also mine barriers: the North Sea Barrage, as well as one across the Straits of Dover, one across the Irish Channel (British, which sank ten submarines), and proposed barriers across the Straits of Otranto (Adriatic Sea) and between islands in the Aegean. The North Sea Barrage, the principal US effort, was proposed early in May 1917, but was originally rejected in view of British failures to block such wide areas of sea. However, the Bureau of Ordnance continued studies, and encouraged inventors to devise a mine antenna whose effective length would correspond to the lethal range of the mine, estimated at 75–100ft with a 300lb charge of TNT. The project was finally approved at an Allied naval conference in September 1917, as U-boat sinkings of merchant ships were so great that almost any workable project would have been welcomed. In all, about 56,000 US and about 16,000 British mines were planted, accounting for at least six U-boats. The entire barrier was about 250nm long, joining Northern Scotland to Norway. Because it was never completed, its effectiveness could never fully be assessed. Moreover, the sheer size of the barrier precluded patrols which would have prevented U-boats from passing over it on the surface.

The principal interwar innovation was active sonar, using ultrasonic (then called 'supersonic') pulses to achieve useful beam definition with projectors limited in size by ship dimensions. Prewar and wartime sonars were 'searchlights', useful more for maintaining contact with a submerged submarine than for searching for one in the first place, so that the World War One image of a submarine first revealing itself by its attack remained valid. However, sonar permitted ASW ships to achieve much greater precision in their attacks, and to gain and maintain contact with an evading submarine with much greater confidence, and for a much longer time, through several successive attacks. Even so, sonar was not the panacea it had been thought by some (particularly in the Royal Navy) prewar.

Weapons were a particular problem. Depth charges sank relatively slowly, and as a ship accelerated to drop her charges over the estimated position of a submarine, she lost sonar contact, since the sonar beam projected down at an angle. There were tactical and technical solutions; for example, faster-sinking depth charges (Mk 9) and proximity-fuzed depth charges (Mk 14) were developed. The United States did not, however, follow the Royal Navy in introducing an ultra-heavy (Mk X one-ton) depth charge to combat very deep submarines. Alternatively, the blind area under a ship could be eliminated entirely by provision of a tilting sonar (QGB, for 'maintenance of close contact'). Tactically, one ship could coach another into position to attack, keeping the submarine under observation throughout.

Ahead-Throwing Weapons

Ahead-throwing weapons (Mousetrap, and the British Hedgehog and Squid) were a more radical solution. They could be fired from a ship while she remained in sonar contact with the submarine, for far more precise fire control. Hedgehog, the most successful in US service, was a British-designed spigot mortar firing a submarine-size circular or elliptical pattern. Each charge had to be limited in weight, given



1 The destroyer *Blakely* shows her hydrophones in this drydock view, May 1919. They were installed in the two blisters just above her keel, visible on either side of her bow, and were aboard several US destroyers of this period. Listening at sonic (rather than the later supersonic) frequencies, they were relatively ineffective, and plans to fit all destroyers with such equipment were never implemented.

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2, 3 The K-gun reduced the centerline space required to fire depth charges off to one side, but it still required considerable space for davits to hoist charges up onto the thrower. In early US installations (the ones shown are aboard a destroyer and, with the crew loading, aboard *PC-548*) the depth charges were stowed around the thrower, their arbors resting in upright tubes fixed to the deck, and the charges fixed to the arbors by chains. Later a 'roller loader' was devised, in which the charges for a thrower could be rolled down alongside it, the arbors being loaded separately into the K-gun. Note the chamber into which a firing charge was loaded.



4 Hedgehog was the first ahead-throwing weapon, the first ASW weapon which could be fired while the firing ship remained in sonar contact with the target. It was a spigot mortar, the spigots being played to produce a circular pattern to counter target movement while the bombs were in flight or were sinking. The motors at the front of the mount could tilt the spigots to compensate for ship roll; the plate aft is a blast shield. This one is aboard the South Korean frigate *Apnok* (formerly the US *PF-48*), 21 December 1950.

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the need for numbers to maintain a full lethal pattern; that in turn required contact-fuzing. The British Squid (and its postwar successor, Limbo) represented an alternative approach; a small number of large depth-fuzed projectiles, aimed with the aid of a depth-determining sonar, Type 147. The US Navy tested Squid in 1944 (aboard USS *Asheville*) and postwar considered adopting it or Limbo. Instead it developed its own depth charge projector, 'Weapon A' ('Alfa' or 'Able', depending upon the phonetic code in use), with a range of about 900yds, compared to perhaps 250 for Hedgehog. The new charges were fast-sinking, and were depth-fuzed with the aid of a special fire control sonar (SQG series). An alternative 'Weapon B' was to have replaced the Mouse-traps of small ASW vessels, but theoretical evaluation showed that its projectiles would have been ineffective.

Airborne Antisubmarine Warfare

Air attack was the other major element of wartime ASW. As in World War One, the mere presence of aircraft tended to keep submarines down, so that an airplane in company with a convoy could often prevent U-boats from shadowing it on the surface – as they had to, given their limited underwater high-speed endurance. Aircraft could also make high-speed transits to operating areas difficult, as they did in the Bay of Biscay. Finally, aircraft were the best means of following up long-range detections by HF/DF and codebreaking, since they could arrive at a datum far more quickly than could ships. Radar extended air operations to night attacks on surfaced submarines attempting to recharge their batteries. However, such operations in turn required a powerful searchlight by means of which the submarine could be identified and attacked: it was an early example of the need for 'classification' sensors to complement the detectors. One of the major problems in ASW is the presence of very large numbers of false targets, generally outnumbering the real ones. The problem extends to sonar as well as to aircraft radar; in World War Two the great majority of surface ASW attacks were on false targets, and target classification has been a major theme of sonar development, separating submarines from whales or schools of fish or wrecks. Visual identification falls into this category, as does current US use of magnetic anomaly detection.

It might be argued that firing a weapon will often permit a quick differentiation of false from real targets, particularly since homing torpedoes are unlikely to be attracted to non-submarines. However, current ASW forces are extremely weapon-limited: many ships have only the six lightweight torpedoes they carry in their tubes, and firing doctrine is undoubtedly two torpedoes per attack. Similarly, many ships were built without ASROC reloads. Again, the design of the ASROC launcher strongly suggests that the standard doctrine is to fire a pair of weapons, unless nuclear ASROC is used. In either case, there is little re-

serve against what is likely to be a very strong temptation, in wartime, to fire first and ask questions later. Certainly that was World War Two experience.

As in World War One, attempts were made to provide aircraft (both heavier-than-air and blimps, the latter valuable for their ability to loiter) with some means of conducting underwater searches. The first was MAD (Magnetic Anomaly Detector), a magnetometer which could (in theory) detect the presence of a mass of metal underwater. In 1941 the British were already investigating magnetic detection, but they had achieved ranges of only about 200ft, which were inadequate. The American approach was to improve systems already in use for prospecting, using magnetometers. The US ASQ-1 was credited with a range of about 600ft, and about 400 were installed between 1941 and 1944. Many contacts were made, but classification was a serious problem, as most of the contacts (off the US coast) were wrecks.* Sonobuoys were originally introduced to permit effective classification, which is the opposite of the current (and postwar) sequence; in 1942, when the proposal was first made, the long range inherent in the sonobuoy was largely unsuspected. Another consequence of MAD use was the need for a weapon which an airplane could drop exactly over a MAD contact, ie exactly over a spot it was passing. The solution was the retro-bomb, in which a rocket charge balanced off the forward motion of the airplane dropping the bomb.

Aircraft were far too fast to trail permanent sonars; ultimately they dropped expendable ones, a postwar writer remarking that the trend of US airborne ASW sensor development had been to invest the sophistication in the fixed data processor aboard the airplane, while seeking low cost in the greatest possible number of sonobuoys. Blimps, on the other hand, were low and slow enough to tow sensors on or under the sea surface. Although no towed sonar was deployed in wartime, postwar there was ATERE, the Airship Towed Echo Ranging Equipment, or AQS-1. It was employed both by blimps and by some surface ships. Proposals for a hydrofoil sub-chaser (PCH) included the use of an auxiliary sonar which might be towed while the PCH operated at high speed, and the blimp sonar was

proposed in this context; a more powerful sonar (SQS-20) was to have been used when the PCH rode on its hull. This high-speed towed unit should be distinguished from 'dipping' sonars typically operated by helicopters, which are intended for use only when the latter are hovering.

The sonobuoy had first been proposed by the Royal Navy. Dr P M S Blackett had suggested it in May 1941 as a means by which convoys could detect submarines trailing them. His 'detector buoy' would be dropped astern, and would radio its data to the convoy. As in the case of the proximity fuze, it was brought to the attention of the US government, as the British did not have the resources to develop it. RCA developed a US model, but it was not adopted. However, it formed the basis for the aircraft-launched sonobuoy, revived in 1942 at the suggestion of Admiral Rosendahl, the blimp commander. In tests on 7 March, a blimp (*K-5*) heard the submarine *S-20* at up to 3nm. At first Navy interest was slight, but the Army, which shared ASW responsibility (using land-based aircraft), was enthusiastic. The first prototypes were dropped (unsuccessfully) from an Army B-18 on 18 July 1942: they broke up on impact. However, there was a successful drop on 25 July, and sonobuoys were being used operationally by August. The resulting CRT-1 was credited with a 3.5nm range against a cavitating target.

ASW in World War Two

At the outbreak of war, the standard air weapon against submarines was a ship-type Mk 6 depth charge, fitted with a flight adapter; wartime successors were developed. However, there were also ASW rockets, effective against a surfaced submarine, and there was the Mk 24 mine (homing torpedo), 'Fido'. The rockets countered the standard submarine tactic of diving upon sighting an airplane, since they could reach the submarine far sooner than could conventional bombs. 'Fido' could reach the submarine even after it had submerged. Its development was assigned top priority in

*Apparently, the great wartime MAD success was the air barrier across the Straits of Gibraltar.



Before the advent of the dive-bomber, the torpedo was the principal carrier antiship weapon. However, it imposed very severe limits on the airplane carrying it. Here a standard US Navy torpedo-bomber of the late 1920s, a Martin T4M, drops a Mk VII Mod 2A in Newport Harbor in 1928 – at a speed of only 90kts and an altitude of about 50ft. Similar (though hardly so severe) restrictions helped doom the US torpedo-bombers at Midway.



At first patrol aircraft carried adapted shipboard depth charges, but quite soon specialized aircraft types were evolved. This is a Mk 17 (325lb), the standard wartime aircraft depth bomb, being removed from a bomb rack aboard an SOC scout plane on the cruiser *Philadelphia*, 2 July 1942.

US National Archives

August 1942, and it was service tested on 1 February 1943. Since it had a low speed (12kts) and a short effective range, it was subject to tactical countermeasures: it was expected that it would last no more than six months in combat, even though special security measures were taken. For example, aircraft were permitted only to attack individual U-boats with 'Fido', never groups (one of which might survive to report its existence). In addition, 'Fido' was distributed to both British and US forces for simultaneous introduction. In fact, it survived the war with its security intact. The first Mk 24 success was by a British Liberator, defending Convoy HX 237, on 12 May 1943; the US Navy followed with a sinking by the escort carrier *Santee* in July.

The combination of aircraft and shipborne weapons reached peak effectiveness in 1943–44. By that time codebreaking and HF/DF had combined to increase enormously the effective Allied detection range, and command arrangements in both the United States and Britain had become sufficiently unified (eg with the departure of the Army Air Force from US ASW) to permit efficient wide-area operations. Since submarines had to spend a large fraction of their time on the surface, they presented large radar targets, which could be detected at long range, making for efficient air search even by relatively small (eg carrier-based) aircraft.

Matters began to worsen with the introduction of the snorkel in 1944. Now submarines no longer had to surface at all; air search lost much of its former efficiency, as radars could detect snorkels only at short range. For example, the large APS-20 airborne early warning radar, which could detect a surfaced submarine at well over 100nm, was limited to a search width of about 26 against a snorkel. Wartime radars were considered much worse: the S-band APS-3A (installed aboard the PV-2 Harpoon) was credited with a search width of only 1nm and the X-band APS-15A (PB4Y) one of just 2nm. The postwar APS-33 (P2V-3 Neptune) was credited with only six. In effect, then, long-range air search was no longer practicable

(APS-20 did not enter service until well after 1945), and visual search regained much of its importance, as occasionally puffs of snorkel exhaust could be seen at a considerable range. Binoculars were distributed to air crews.

In a typical operation, an RAF Coastal Command Liberator of No 86 Squadron, using X-band radar, detected a snorkeling submarine on 20 March 1945. It dropped a five-buoy pattern in a three-mile square. The buoys were omnidirectional, but they could narrow the search area; one reported noise, and in addition there was a further radar contact. Two Mk 24 torpedoes were dropped, and after six minutes noises (presumably from their explosions) were heard. Postwar it was learned that *U-905* had been sunk. On 25 April, just before the end of the war in the Atlantic, a US Navy Liberator of VP-103 sank *U-1107* in a similar manner. Aircraft could still detect and kill submarines, particularly if their homing weapons and sonobuoys were improved to match the newer U-boats; but they had lost that wide-area search capability which had been one of their greatest assets.

Snorkel and 'Kurier' were sharply reducing the effectiveness of the surface escorts also. Moreover, the new German torpedoes markedly reduced the value of their searchlight sonars, as they considerably expanded the areas the escorts had to search following a sinking. Prior to the advent of the snorkel, the Germans attacked primarily at night, on the surface. Given short torpedo ranges, they had to be fairly close to the convoy, and an escort could begin her search at the last submarine radar position. Submarines attacking in daytime, submerged, left the wakes of their torpedoes as starting positions. Submerged operations with electric (wakeless) torpedoes overcame both possibilities. Long-range pattern-runners could be fired from well beyond the escort screen without loss of hitting probability. Moreover, in 1943 the Germans introduced an antiescort homing torpedo, T-5 (GNAT). Although its existence had been known for some time (thanks to Allied codebreaking), and although a countermeasure, 'Foxer', was available, GNAT did

make surface ASW forces uncomfortably aware of the submarine's potential for counterattack. That potential contributed considerably to the development of standoff weapons of increased range, both wartime (eg Weapon Alfa) and postwar.

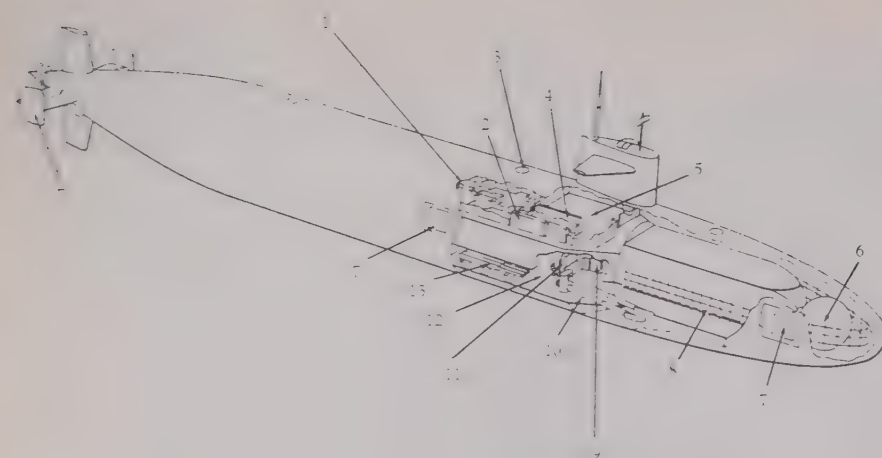
The only major surface ship improvement in sight was the scanning sonar, which greatly increased the probability of detecting a submarine in the first place, though not the range of detection or the probability of maintaining contact once the submarine had been found. It was useful as a search sensor, but its initial detection range was no more than 2000yds; a submarine could detect a surface ship at 18,000. Indeed, in 1946 there was considerable enthusiasm for moving sonars onto helicopters, which could dip them and 'ping' without fear of being torpedoed. This development was held back largely by the immature state of helicopter development at the time, but it illustrates contemporary concerns.

The new generation of U-boats approaching operational service at the end of the war were further cause for alarm, as they were clearly the prototypes for a new generation of Soviet submarines. Type XXI was streamlined for much higher underwater speed; with its greatly increased battery capacity it could sustain an underwater speed of 15.2kts (greater than the surface speed of many escorts in anything approaching rough weather) for over an hour, quite long enough to emerge from any screen. It was also extremely quiet, equivalent at its maximum speed to a US wartime fleet submarine at 8kts, and fading into background noise when operating on its special quiet motor at 5kts (with an endurance of 72 hours). In prospect was the Walter-powered Type XXVI, credited with a speed of 25kts, sustained for ten hours (the Soviets had captured the Walter factory in 1945). Even Type XXVI would have to refuel, but in 1946 the US Navy looked nervously towards a nuclear submarine capable of shadowing and overtaking convoys entirely submerged, never piercing the surface with even a periscope, firing very long-range, pattern-running torpedoes from well outside the screen, and thus essentially immune from wartime ASW measures. Economics alone would prohibit the expansion of convoy screens to match the range of its torpedoes, since there was no hope (at the time) of any radical improvement in sonar range given the high frequencies, and consequent propagation properties, of sonars then in use or in prospect.

New Technologies

American attention therefore turned to a new strategic approach. The new technologies available were nuclear weapons and a large shipboard passive sonar array, GHG, which had been captured from the Germans. Since convoy screens could not effectively counter the new submarines, the latter would have to be kept out of the North Atlantic as efficiently as possible. Aircraft could mine their approach routes and might also be able to destroy their

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MAJOR COMPONENTS OF A SUBMARINE COMBAT SYSTEM

Key

- 1 Sonar control center
- 2 Digital computer
- 3 Loading hatch
- 4 Attack console
- 5 Attack control center
- 6 Spherical sonar
- 7 Hydrophone arrays (PUFFS)
- 8 Conformal sonar
- 9 Torpedo room
- 10 Torpedo tubes
- 11 Weapon control console
- 12 Weapon control center
- 13 Missile and torpedo stowage

bases: nuclear weapons would be effective even against concrete submarine pens. For example, the design and construction of the super-carrier *United States* was justified partly on ASW grounds.

The other major barrier concept was the SSK, the killer submarine. It appeared that the GHG array would permit a quiet submarine to detect and track another, particularly if the latter were snorkeling, at 20,000yds. Submarine listening range might also be extended by trailing a hydrophone well below the submarine. The SSKs, operating deep in enemy-controlled waters, would be armed with homing torpedoes, and it was hoped that they would engage enemy submarines as they emerged from their bases, transiting at high speed either on the surface or using their snorkels. Given the (still) relatively short range of the sonar, and the size of the area to be covered, projected wartime requirements for such submarines were huge. For example, in a 1948 General Board study, a total of 250 were needed to counter a projected Soviet 1951 fleet of 356 submarines, including 26 Type XXIs: 19 for training, and another 231 to cover 77 patrol stations, including 56 between the North Cape and Spitzbergen.

Escort carriers would have to support the surface escorts, whose value had declined sharply. Aircraft could lay sonobuoy barriers around a moving force or a fixed area, preventing submarines from penetrating undetected, at ranges well beyond escort sonar range. Although sonobuoys were as yet quite primitive, they had the great advantage over surface ship sonars of distance from self-noise, so that in 1948 nine buoys sufficed to cover a 30-mile line. Land-based search aircraft, on the other hand, were far less useful, since it was more difficult for them to cooperate with moving convoys at sea. They could, however, set up barriers, and their mere presence would keep submarines down. Moreover, a new generation of snorkel-detection radars promised to return to them at least some fraction of their wartime area-search capability.

The Soviet Threat

Perhaps the principal issue of early postwar US ASW development was the immediacy of the problem, *ie* the balance to be struck between long-term research and emergency procurement to meet an existing threat. From 1946 to 1950 forecasts of the continued value of exist-

ing (wartime) ASW weapons and tactics tended to be extremely pessimistic, the Soviets being credited (incorrectly, as it turned out) with very large near-term submarine forces of advanced type. Despite very tight Navy budgets, advanced weapons such as Weapon Alfa were bought before operational evaluation, and plans were laid for massive increases in advanced ASW forces upon mobilization. For example, the 'Guppy' conversions of existing fleet submarines were designed to facilitate later conversion to SSK configuration. Conversions of *Fletcher* class destroyers to escort destroyers (DDE) were intended as prototypes for conversion of the entire class; in peacetime, the bulk of these ships were to have been placed in reserve after conversion pending mobilization.

Only in 1949 was the situation reviewed and the alarm found somewhat premature. Admiral F S Low, wartime commander of the Tenth (ASW) Fleet, reported to the CNO in April 1950 that the Soviets had not as yet succeeded in integrating German ideas and developments into their forces. For example, there were as yet only 82 Soviet long-range submarines, of which only 13 were snorkel types: four Type XXIs, two Type IXCs, five Type VIICs, and eight of a new 'B' type, presumably the first of the 'Whiskey' class. As a current threat this was unimpressive, although the Soviets were building at a rate of twenty to thirty boats per year, and might soon accelerate.* The question was whether, given limited funds, the United States should mass-produce existing weapons and sensors, or whether instead funds should go into a combination of research and development and improvement of existing forces to a level commensurate with the current threat. Surely the threat, when it did mature, would be beyond the reach of existing systems, yet some modest expenditure on current ships and aircraft would suffice for the current level. Low also considered some of the existing ASW ships and systems ill-conceived, due to the emergency nature of their development.

Thus, he recommended curtailment of the *Fletcher* DDE program; one such conversion was canceled in favor of a fast underwater target, which became the research submarine *Albacore*. Given the low current level of the Soviet submarine fleet, a relatively simple improvement, the provision of twin Hedgehogs aboard destroyers and other escorts, was of great value, as was the provision of short-

range scanning sonar in place of the wartime searchlight equipment. Low also drew attention to the mobilization resource represented by the reserve fleet, including destroyer escorts which had been discounted as too slow to be effective against Type XXI submarines.

Admiral Low also called for some re-direction of priorities. He considered helicopters valuable sonar platforms, as they might be able to keep long-range torpedoes out of a convoy. However, convoy operations remained low on his list of priorities, after mining and bombing of submarine bases, although above HUK operations which, in the absence of HF/DF and codebreaking, were unlikely to be successful. There was still some hope that aircraft might regain their ability to conduct wide-area search, and Low suggested efforts in infrared detection.

Meanwhile, a committee of scientists produced Project 'Hartwell', an attempt to determine the ASW requirements of a war in which the Soviets might have 200-300 Type XXI submarines, and would be willing to use nuclear weapons against ships and ports, as well as large numbers of mines. In effect, the Hartwell report, which came just over four months after Low's, was a look into the future he was buying by deferring present production of advanced ASW weapons. Its recommendations included strong support for what would become SOSUS and for other advanced passive sensors such as 'Jezebel'; for underwater nuclear weapons (which, it was hoped, might have a kill radius as great as a mile); for the SSK concept (which, in 1950, promised detection ranges as great as 100nm on a snorkeling submarine); and for new methods of airborne submarine detection, such as infrared wake detection and long-range MAD by paramagnetic resonance. As in other reports of this time, the helicopter with its dipping sonar showed great promise. Finally, there appeared to be some hope of resurrecting the wartime HUK concept, since it appeared that the 'Kurier' problem might be solvable, at least in large land installations. SOSUS, the very long-range fixed hydrophone system, would have much the same effect, providing long-range

*However, it should be noted that in 1948 a Soviet Admiral spoke of plans to build 1200 submarines, a figure widely accepted at the time as a concrete Soviet goal.

detections which aircraft could fly out to prosecute.

Within a few years, the position of the surface ships had improved considerably, as the Naval Research Laboratory discovered that a combination of much lower frequency and much higher power could increase sonar range spectacularly, to about 10,000yds in fact. SQS-4 and similar sonars made possible reliable long-range submarine detection; in January 1956 the Destroyer Force of the Atlantic Fleet reported an average of 60 percent detections of submarines attempting to penetrate screens in convoy and HUK exercises; even the fast *Nautilus* was detected 63 percent of the time in a July 1955 exercise, while the tracking ship operated at 25kts. However, the faster the submarine, the less effective were ballistic weapons such as Hedgehog and Weapon Alfa. For example, on 31 firing runs against the maneuverable *Albacore*, the destroyer *Sarsfield* made only one hit. Thus the new sonars had to be combined with longer-range standoff weapons such as RAT, or with destroyer-launched atomic weapons, which would make up in kill radius for errors and blind time inherent in their operation.

In 1956 the commander of the Atlantic Destroyer Force envisaged a potential Soviet 24kt submarine as an important threat within three years; the existing lightweight torpedo (the conventional warhead of the prospective RAT weapon), Mk 43, had a speed of only 21kts. An EX-2 torpedo, which would become Mk 44, was more promising, with a speed of 30kts (necessary to counter the 1960 threat of a 24kt submarine); it could replace Mk 43 as a RAT weapon), Mk 43, had a speed of only improvement over Weapon Alfa, with a range of 1000-5000 rather than 900yds. Unfortunately, the Soviets could be expected to go further, probably to a 30kt nuclear submarine, in the slightly more distant future. That would require greater sonar range, probably about 20,000yds, and a standoff weapon to match. In fact, it seemed likely that such a sensor could be developed, given detections at 27,000yds with an experimental SQS-5 sonar already in existence. The thermal layer remained a problem, particularly in operations against the newer, deeper-diving submarines, and the future seemed to hold solutions in the form of 'bottom-bounce' operation and variable-depth sonar (VDS). There was, then, in 1956, none of the extreme pessimism which had surrounded surface ship operations a decade earlier. Within a few years a reliable 10,000yd sonar would appear in the form of SQS-23, and then a 20,000yd type, SQS-26, with bottom-bounce and even, theoretically, convergence-zone capability. Advances in sonar brought advances in standoff weapons: the 5000yd RAT was compatible with SQS-4, but the 10,000yd SQS-23 was specified for the newer ASROC, which also incorporated a nuclear depth charge. Extended-range versions of ASROC were often proposed for SQS-26. There was also a small ASW drone helicopter, DASH, an alternative means of delivering a homing torpedo at a distance without the ship impact of ASROC or RAT; it was conceived by the Atlantic Destroyer Force.

In an ASW guide issued in September 1957 the Atlantic Destroyer Force claimed that one

modern destroyer (with SQS-4 but without RAT) could neutralize a medium-speed (eg Type XXI) submarine, and that a surface attack unit (SAU) of two could be certain of a kill; against the two-ship SAU a conventional modern submarine armed with conventional torpedoes and antiescort torpedoes of less than 25kts could be destroyed with an acceptable loss rate. However, it was essential that the existing rate of one damaging attack in three be improved sharply. At this time screening doctrine was based on achieving a very high probability of detection by spacing the escorts within assured sonar range of each other, and a combination of inner and outer screens was recommended to improve the chance of detecting a penetrating submarine. That in turn required large numbers of escorts or much longer reliable sonar ranges, particularly as the screen had to spread out to counter longer submarine attack ranges. This problem remains acute, as the submarines now can attack with missiles from much greater ranges. The 1957 handbook commented that normally the size of the area which had to be protected would exceed that which could be protected with existing forces: 'experience showed that many so-called adequate screens have been penetrated by undetected submarines' due, for example, to deteriorating conditions, or to poorly performing equipment or personnel. It is only fair to remark that ASW system performance always varies greatly from one occasion to another, as it depends so critically on transient ocean conditions. The issue, then, is generally long-term attrition rather than individual events. However, as the number of high-value units (such as carriers) falls, such statistical attrition becomes less and less satisfactory as a guarantee of the survivability of sufficient such units in the face of submarine attack.

The thermal layer was a particular problem; a 5000 or 10,000yd sonar performance referred to detections in the (surface) layer, and below that layer ranges often shrank to 1000 or 2000yds. In standard Fleet screening tactics,

1 A torpedo-bearing ASROC missile is fired by the destroyer *Brinkley Bass*, 1972. Note that only one 2-cell section of the 'pepperbox' launcher elevates to fire. Unlike the earlier RAT, the ASROC missile drops its payload at a predetermined time, for greater flexibility in range; RAT actually dove into the water.

2 RAT was the first major US standoff ASW weapon, in effect an earlier and more austere equivalent of ASROC. Its rocket carried a Mk 43 torpedo, compared to the Mk 44 or Mk 46 of ASROC. In operation, ASROC is range-controlled by rocket motor cutoff, whereas the RAT motor fired until burnout. The spent rocket dropped away, the torpedo (as in ASROC) being lowered by parachute. The destroyer *De Haven* (about July 1958), shows the extremely austere launcher planned for installation aboard most existing destroyers. RAT was typically paired with the SQS-4 sonar, and had a nominal range of 5000yds (compared to 10,000 for the SQS-23/ASROC combination). It was abandoned largely because of its excessive dispersion, plus the low performance of its homing torpedo.



an inner screen was intended to detect submarines below the layer, and within them there would be pouncers to attack using the existing short-range weapons. Such tactics required large numbers, and they also made for a tight formation, to keep down the size of the outer screen. Neither consideration was attractive in a period of rising individual ship cost and increasing threat of Soviet nuclear attack on formations at sea. In the late 1950s, then, task forces began to spread out to reduce the consequences of single nuclear hits. At the same time the destroyers began to receive much longer-range sonars and weapons (ASROC, DASH, SQS-23). In addition, long-range sonars were installed aboard major fleet units (such as light missile cruisers) which were not expected to prosecute submarine contacts, but which were expected to improve considerably the overall probability of detection of the force. To some extent, too, these cruisers could attack submarines by controlling DASH torpedo-carrying drones launched by destroyers in the force. Even some carriers, both ASW and attack, were fitted with bow sonars.

In 1957 the Atlantic Destroyer Force saw aircraft, either land- or carrier-based, as a means of detecting patrolling and transiting submarines, providing intelligence as to their location, and also detection and localization. However, they would have only a limited ability to attack, given their restricted weapon loads. Ships, on the other hand, could remain with a submarine to exhaustion and kill. In a typical hunter-killer operation, a carrier might operate with six to eight destroyers; her aircraft would search for submarines offensively, and then a two-ship SAU would be despatched to rendezvous with them, while they tried to localize and kill the submarine. Initial detection would probably be by visual or radar sighting, possibly by MAD or ECM; localization would probably be by ECM. Operating within 50nm of the forces it was supporting, a single HUK group could, it was hoped, support three convoys at once.

Meanwhile the other elements of US ASW were also changing. As submarine sonar improved, SSK operations further from Soviet ports became practicable; submarines could cover longer patrol lines with relatively small numbers. For a time, the submarine was conceived of as a sort of 'super sonobuoy', vectoring in patrol aircraft to attack well beyond its own weapon range. However, from about 1957 onwards improved submarine weapons began to appear: first long-range homing torpedoes, then a wire-guided nuclear torpedo (ASTOR, Mk 45), and then a ballistic missile, SUBROC, reportedly with a range of 35-40nm. In consequence, although the practicality of mining Soviet ports or of attacking the Soviet bases with nuclear weapons waned, the increased efficiency of the ASW barrier more than made up the difference.

Moreover, from the late 1950s, SOSUS began to restore to the ASW forces the kind of wide-area detection of submarines they had enjoyed during World War Two. Land-based aircraft could cover much of the Atlantic, and the ASW task forces originally created for convoy support could be reassigned to cover the mid-Atlantic. In effect, the balance of effort went towards a strategy of attrition. Unlike a convoy strategy, it could be activated at the outbreak of war, since the Navy would have sufficient numbers of active ships and aircraft

to make it work. Convoy operations, while still contemplated, would require the activation of numerous reserve ships. To this end, destroyers and destroyer escorts in the reserve ('mothball') fleet were modernized to a limited extent, and plans drawn for more extensive modernization upon mobilization.

However, at the outbreak of war convoy operations would be limited to vital formations, the loss of which would be unacceptable. Despite improvements to the attrition forces (which improvements continued into the 1960s and 1970s), such escort operations were actually more demanding than they had been in the early 1950s - that is, with advances in the Soviet submarine force, including the appearance of nuclear submarines, speed ceased to be a full protection for task forces and other major naval formations. Fast nuclear submarines, supported by air reconnaissance, could maneuver into position to fire very long-range (reportedly nuclear) torpedoes, perhaps from well outside the sonar screen. In consequence, from the mid-1950s onwards, ships designed for fast task force escort had to incorporate into their designs not only anti-air but also antisubmarine weapons. Perhaps the culmination of this trend was the DX/DXG study of 1968, which concluded that, of the six escorts required by each carrier group, three might be restricted to ASW only, the others requiring both ASW and AAW weapons.

Economics drove this evolution more and more from about 1959 onwards. That year a massive destroyer modernisation program (FRAM) was begun to rehabilitate an already ageing force. New construction was clearly indicated, but equally clearly out of the question, at least on a ship-for-ship basis. At the same time, it was made clear that major rehabilitation of the existing destroyer escorts was impossible, that only the largest war-built destroyers could accommodate a useful sensor and weapon, either SQS-4/variable-depth sonar/DASH in a FRAM II or SQS-23/ASROC in a FRAM I. Most of the existing escort force was not rehabilitated, and would have to pass from the list. The surviving numbers did not approach traditional convoy requirements of five to eight ships per convoy.

In its effort to formulate LRO-59, the 1959 long-range planning study, the Long Range Objectives Group (Op-93) found that, under realistic budgetary conditions, it would be impossible to build enough escorts to convoy merchant ships while still meeting other essential ASW requirements in a two-ocean war, during the prospective FY69-FY74 time period. It looked at a variety of alternatives, including giant convoys which would reduce the ratio of escorts to merchant ships, as well as the potential for much longer-range submarine detectors. In February 1959 it asked the Bureau of Ships to investigate the possibilities of inexpensive escorts, which it defined as the minimum platforms capable of supporting an SQS-26 sonar and a means (generally a helicopter) of prosecuting its contacts. Even relatively inexpensive submarines (such as *Threshers* with *Skate*-class power plants) were considered. The results were, at best, unimpressive, and the report of the study makes it clear that convoy operations would no longer be economical in the face of the rising cost of naval shipbuilding.

At this time, too, the decision was made to apply the SSK mission to all submarines, *ie* to

concentrate the submarine force in barrier operations. The FY58 attack submarine, the *Thresher* class, was designed to accommodate a very large passive-active bow sonar (BQQ-2), torpedo tubes being relocated amidships to clear it. BQQ-2 was roughly equivalent to the contemporary SQS-26, and its associated weapon was SUBROC.

Aircraft development produced the P-3 Orion, capable of covering the entire North Atlantic. As it replaced the shorter-range P-2 Neptune, ASW carrier groups could be reassigned to direct fleet support - which had become more critical with the growth of the Soviet nuclear submarine fleet, and then with the appearance of long-range submarine-launched missiles. By the early 1970s, too, the ASW carriers remaining in service were sufficiently expensive to operate (due to their age) that efforts were made to eliminate them in favor of ASW detachments aboard attack carriers. Although such detachments might, at least in theory, provide useful cover for the carrier battle groups, they could not help fill the mid-ocean gaps formerly filled by the specialized carriers, as in wartime the attack carriers would be badly needed elsewhere.

As for the ASW ships, the tacit decision favoring unit quality over quantity equated to the introduction of the most powerful of all American sonars, SQS-26, capable not only of long-range direct-path search, but also of bottom-bounce and convergence-zone operation. In the latter case, precision would be far too poor to permit direct attack, a point not realized for some time. By the mid-1960s, however, there was growing interest in a light helicopter which might go out to the convergence zone, reacquire a target, and then classify and attack it. In 1966 this was proposed as LAAV, the Light Airborne Attack Vehicle; later it became LAMPS, the Light Airborne Multi-Purpose System, to add antimissile ('Styx') defense and so to become politically more palatable. To some considerable extent, too, LAAV/LAMPS was a response to the combination of the abject failure of DASH (which finally disappeared in 1969) and to the continuing need for a long-range attack system to match sonar range. LAMPS became even more important with the advent of longer-range ASW detectors, such as the towed array, in the 1970s.

Current Strategy

All of these developments took several years to materialize, and the net evolution was so slow that it was not even recognized. However, in 1983 it is clear that convoy operations have very largely been discarded, and that the United States has designed its ASW forces largely to fight a war of attrition in the Atlantic and Pacific. There are, to be sure, considerable problems. For example, SOSUS coverage is geographically limited and subject to wartime attack, including sabotage. Thus, the absence of friendly states along the Indian Ocean littoral (not to mention sound conditions in the Indian Ocean) may severely limit the ability of the United States to prosecute ASW there. Offensive operations in particular would be difficult, and resort would have to be made to convoying.

Since convoying is in any case indicated for essential formations (such as carrier battle groups) there remains considerable potential - in quality, but not in quantity - within the US Navy. Much of it is concentrated in sweeps

ahead of the moving formation. That is, given weapon range and target and submarine speed, a submarine must lie within a well-defined area ahead of a formation if it is to be able to attack, and the faster the formation, the narrower this area. Moreover, if the force is equipped with passive detectors usable even at high speed, the submarine cannot afford to move very fast, and it is even more confined – if indeed it can enter the firing area at all. The high speed of the *Los Angeles* class attack submarines was, thus, justified at least partly by the carrier battle group escort mission. A submarine moving far ahead of the group is not subject to erroneous attack by friendly forces, but can detect and engage enemy submarines moving into position to attack. Similarly, a P-3 laying fields of long-range sonobuoys ahead of the formation can often detect and attack submarines moving into position.

The solutions become less effective if it becomes necessary to abandon the war of attrition in the North Atlantic due, say, to the destruction of SOSUS. To some extent SOSUS survivability is to be assured by the existence of mobile SOSUS towed arrays (SURTASS) aboard specialized ships. To some extent, too, the P-3s can sanitize sea areas ahead of fast convoys, and they can sink submarines in those areas. However, there appears to be increasing fear that old-style convoy warfare will again become necessary, and that inexpensive escorts will be required. A recent (and now discarded) Navy response to this problem was the FFX, the minimum platform capable of supporting a towed array passive sonar and a helicopter to prosecute its contacts. The towed array itself is a tactical equivalent of the SOSUS fixed array, and it permits long-range detection of sub-

marine sounds while the ship towing it moves at speed; towed arrays are planned for many other US frigates and destroyers.

The current US ASW strategy, then, is a combination of point defense of high-value formations (carrier battle groups, military convoys, underway replenishment groups), offensive area search, and barriers. The need for military convoys at the outset of a war is reduced by a major program of prepositioning of land and air force materiel overseas, including 'prepositioning of material configured in unit sets' (POMCUS). In an emergency, troops would be flown overseas to match up with their POMCUS equipment, the annual REFORGER (reinforcement of Germany) exercises testing the concept. In principle, then, attrition of Soviet submarines in the North Atlantic could proceed for some time before it became necessary to protect essential resupply and reinforcement shipping.

There would be considerable emphasis on long-run attrition of submarines which would have to transit to and from the sea lanes over huge distances to resupply with weapons. Uncertainties would include weapon shortages on both sides and the submarines' ability to place themselves efficiently in the way of shipping targets. For example, a British analyst of World War One operations recently remarked that one value of convoys in 1917–18 was that they could be routed clear of U-boat concentrations revealed by codebreaking; with the oceans relatively empty, reconnaissance became more and more critical to the submarines. The same would probably be true in a future ASW war. Soviet ability to maintain satellite coverage of the open seas would be critical, and the destruction of those satellites might, in future,

be a key NATO ASW tactic. In the absence of satellites, the Soviets would have to rely on a combination of shore-based DF stations of their own, and on reporting by their own submarines – as the Germans did during World War Two.

The current US ASW arsenal is ageing. It still reflects the concepts of the early 1960s: after about 1964, more and more money went into operations in Vietnam and into new platform production. There were new sensors: principally the towed arrays and a new generation of sonobuoys. However, the weapons have not been replaced. The Mk 46 lightweight torpedo remains the principal short-range ship-launched weapon, the non-nuclear warhead of ASROC, and the principal airborne ASW weapon, despite attempts to develop a new deeper-diving replacement. A longer-range ASROC, which might match the capabilities of the SQS-26, has been proposed many times since the early 1960s, but it has never appeared. Nor is there as yet a non-nuclear replacement for SUBROC, even though US nuclear release policy is considerably more restrictive than it was in the early 1960s.

In 1983, it is by no means clear what the next generation of ASW concepts will be. The prospect of restoring wide-area sensing from the air or from space – of 'rendering the ocean transparent' – continues to be seductive, but also continues to be less than feasible, given current understanding of the oceans. Advanced computer technology might conceivably permit the multiplication of remote, automatic ASW platforms and hunting weapons, but any such concept lies well in the future. To a very limited extent, the CAPTOR mine barrier typifies such concepts.

3. Mines

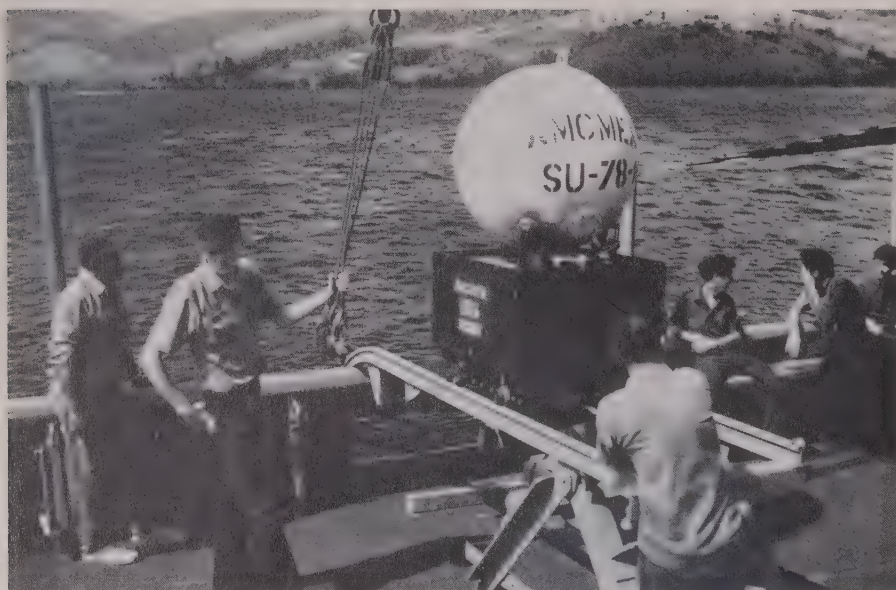
Developments up to World War One

Through the nineteenth century mine warfare was an Army prerogative, controlled mines being planted for coast defense. There were indications of Navy interest late in the century, but it appears that the success of Russian naval mines in the Russo-Japanese War first made them really popular within the Navy. In 1907, Congress was asked for a mine depot ship, which finally materialized in 1912 as the elderly cruiser *San Francisco*. She was soon followed by a second old cruiser, *Baltimore*. Work at Newport proceeded on both anchored (naval defense) mines and on drifting mines. The latter had reportedly been dropped by the Russian fleet as it fled engagements, and the specter of numbers of mines drifting down upon a pursuing fleet was a popular naval problem. In addition, countermines were developed for rapid clearance of enemy minefields.

The US Navy did not as yet have any ability to design its own mines; for example, its Naval Defense Mine Mark II was a French Sauter-Harle type. As of late 1914, however, progress in equipping the mine force had been substantial. The *San Francisco* was in service with a complete outfit of Mk II mines and had practiced laying them; four tugs had been provided with temporary sweeping outfits, and the Destroyer Flotilla had five sets of light sweeps. Laying and sweeping had been practiced in Pensacola Bay (by *San Francisco* and the tugs) in November and December 1913, and sweeping trials by destroyers followed at Culebra (Panama) in January and February 1914. The old gunboat *Dubuque* was fitted as a minelayer and instructional ship, and six old torpedo boats fitted as permanent sweepers. A Mine Division was formed in the Fleet, and all battleships were fitted for sweeping, with six gunboats to follow. Portable minelaying tracks

for one destroyer division in each fleet were to be placed aboard tenders, and tracks were authorized for eleven cruisers.

Given this kind of enthusiasm in 1914, it was not surprising that the US Navy proposed a mine barrage as an anti-U-boat measure in 1917. Existing mine technology was inadequate, because existing mine sensors had a very short range. Thus mines would have had to be planted very densely, so much so that the explosion of one might well countermine much of a field. For example, the Naval Defense Mine Mark 3, a Vickers type, employed a horizontal lever carrying a cork float; it was expected that contact with a ship would move the mine case relative to the float and trigger the mine – at a range of, at most, a foot or two. This type had proved ineffective during the early part of World War One, and had been replaced by the classic 'horned' mine (eg US Mk 5) in which each horn contained acid. Contact



The first major US production mine was the Mk 6 devised for the North Sea Barrage of World War One; it was also the longest-lived, shown here awaiting launch from a fleet tug (*Ute*, ATF-76) in Philippine waters in January 1978. Note the absence of the conventional 'horns'; Mk 6 detects its target by means of a pair of wire 'antennas' which it deploys. Note, too, that although the US Navy no longer has dedicated minelaying ships, it retains a considerable mining capability in the form of miscellaneous surface ships, submarines and aircraft.

with the horn broke open the acid container, permitting the acid to energize a battery and explode the mine. Again, effective range was very short, far shorter than the range at which the mine charge could damage its target.

For the North Sea Barrage an entirely new mechanism, the 'K device', was developed. A copper antenna extended upward from the mine to a float just below the surface, connected through a relay to a copper plate on the outside of the mine. Seawater acted as the electrolyte of a battery which would be formed when a steel ship hull approached the antenna; current running down the antenna operated the relay and activated the mine exploder. In consequence the Mk 6 mine could cover a considerable horizontal as well as vertical area.*

It formed a bridge between contact and influence mines. The latter operate at a distance from a ship, damaging it by shock rather than by blowing a hole in its hull. Since shock damage extends over a larger area of the ship, and is physically more difficult to counter, it can be argued that, pound for pound, an influence mine is more effective than a contact one. Moreover, it has a much larger effective area than the contact mine, so a field need not be as dense. Although a ship produces many signatures, there are three classic ones: magnetic, acoustic and pressure. The pressure wave produced by a ship can also be described as a zero-frequency acoustic field, so the last two are closely related. Most magnetic mines are inherently bottom mines because they measure changes in the local magnetic field relative to the earth's field: were they moored, they would explode due to changes in local field as they rose and fell with the tide. Similarly, a pressure mine measures the pressure head on the bottom. Acoustic mines are inherently moorable, and it is possible to build moored

magnetic mines as well, in which the mine measures the total field around it, adding it up in such a way that mine motion does not change that total. This development made possible both moored magnetic mines and magnetic depth charges, the latter introduced at the end of World War Two.

World War Two

All three influence mechanisms were used by the United States during World War Two, although the pressure mine was withheld until very late in the war for fear of compromising it: it was deemed virtually impossible to sweep. In fact the Germans had developed a very similar mine, and they withheld theirs for similar reasons: pressure mines first appeared in combat off the invasion beaches of Europe. Generally they were provided with auxiliary magnetic sensors, so that waves could not set them off; US pressure-magnetic mines were heavily used in the air mining campaign against Japan at the end of the war.

Operationally, the United States laid both defensive and offensive fields during World War Two, the latter beginning with destroyer operations in the Solomons in August 1942, against the 'Tokyo Express'. For example, a field laid in May 1943 accounted for three Japanese destroyers within a few hours. All fleet submarines were capable of laying Mk 10 and Mk 12 mines, although the *Argonaut*, which had been designed specifically for minelaying, was used instead as a submarine transport. The first submarine fields were laid in October and November 1942 in Southeast Asian waters, blocking the Hainan Strait and the approaches to Bangkok.

In 1943 the Seventh Fleet developed a new mine stowage system, by which a submarine could load eleven mines at the cost of only three torpedoes, retaining 21 of what the submarine force considered by far its primary offensive weapon. The result was a series of small fields in Southeast Asian waters; other submarines laid mines in Japanese home waters. In each case the fields proved very effective; it was later claimed that a total of 421 mines in 21 fields sank 27 ships and damaged 27 more, or one for every eight mines. Another fifteen fields, however, appear to have produced no casualties at all.

Air mining produced the most dramatic results. The first offensive fields were planted in the Solomons between March 1943 and February 1944, by Avengers and Venturas, each capable of carrying only a single mine. In March 1944, carrier aircraft (Avengers) closed the harbor at Palau by mining all its outlets, then sank all 32 ships in the harbor with bombs and torpedoes. Later the major naval base at Truk was closed by mining.

In each case, naval minelaying aircraft were limited to small capacities. However, as early as 1942 the Navy had discussed with the Army Air Force the possibility of minelaying by heavy bombers. In August 1944, B-29s based in Ceylon mined the approaches to Palembang, Sumatra, proving their suitability for a mine-laying campaign. Although the Army preferred to devote its aircraft to conventional bombing, they proved extremely effective in the mining role. For example, between January and March 1945 B-29s closed the approaches to Singapore, Saigon and Camranh Bay by magnetic mining.

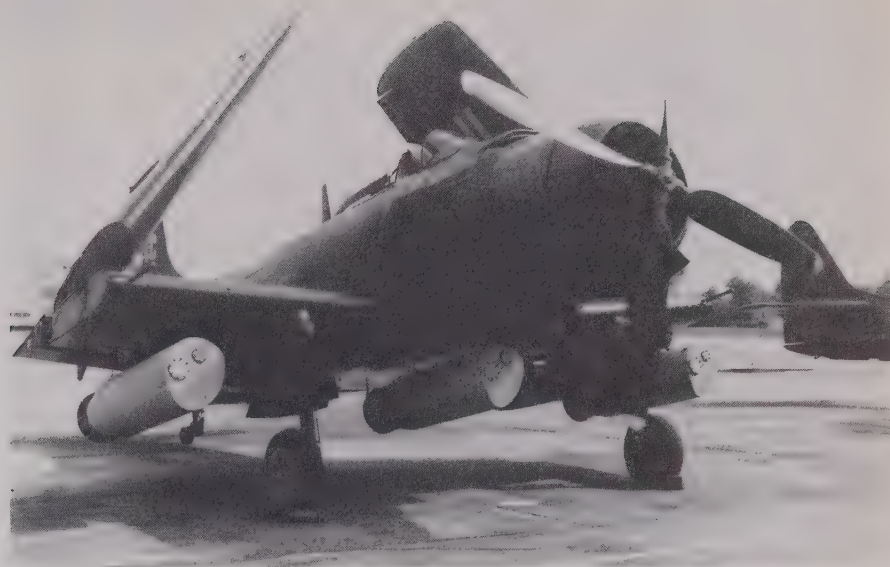
However, the ultimate mining campaign was the 'starvation campaign' directed against Japan proper, and designed to stop shipping between the home islands and between the islands and the mainland. In 1944, for example, Japan obtained 80 percent of her oil, 88 percent of her iron ore and ingots, 24 percent of her coal and 20 percent of her fuel by sea from outside Japan. Within the country, 75 percent of all traffic was by water. Admiral Nimitz proposed a mining campaign against this traffic in November 1944; it began in April 1945. At that time Japan possessed about 1.8 million tons of merchant ships of 1000 tons or more. Mk 25, 26 and 36 mines were used, with a combination of magnetic, acoustic and pressure exploders. It was believed that the high-frequency acoustic exploder had been compromised, but that the Japanese would be unable to sweep low-frequency and pressure mines, both of which would become available in May. About 100 Army B-29s at Tinian were available as minelayers, capable of carrying twelve 1000lb, or seven 2000lb mines. In all, 12,135 mines were planted in Japanese and Korean waters, and 1.4 million tons of Japanese shipping, nearly the entire surviving Japanese merchant fleet, was sunk or severely damaged: 670 ships, including 65 warships. Much of the Japanese merchant marine had already been destroyed by US submarines, but the mining campaign entirely disrupted the economy of the home islands, closing port area after port area.

Quickstrike

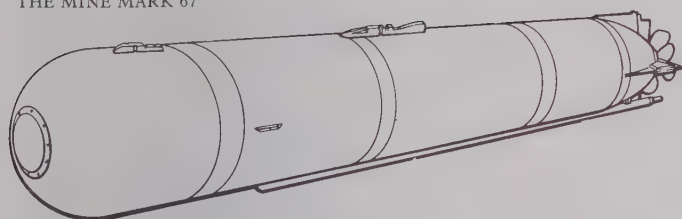
Postwar, US interest in mining shifted gradually to ASW mine warfare, in line with US postwar ASW strategy. The P6M jet seaplane bomber, for example, was described as a heavy mining aircraft, although it could also function as a nuclear bomber. A new series of modular mines (Mk 50 series) was developed. However, there were barriers to the creation of large mine stocks. Mines become obsolete, and they are massive; opportunities for their use require large numbers, but they are not frequent. In the 1950s and 1960s, therefore, efforts turned to means of modifying existing standard bombs to mine operation. In particular, the Naval

*In modern terms, the 'K' device exploited the Underwater Electric Potential (UEP) effect.

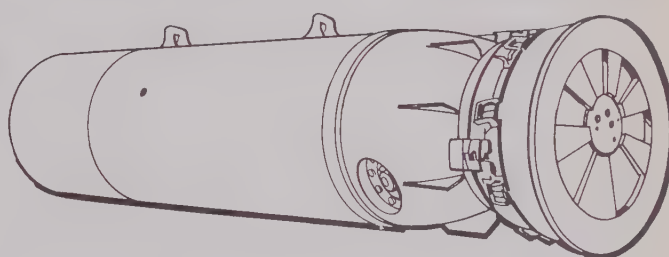
The principal US mines of World War Two were air-laid, like these Mk 25 Mod 2s beneath the wings of an AD-2 Skyraider at Patuxent River, June 1949.



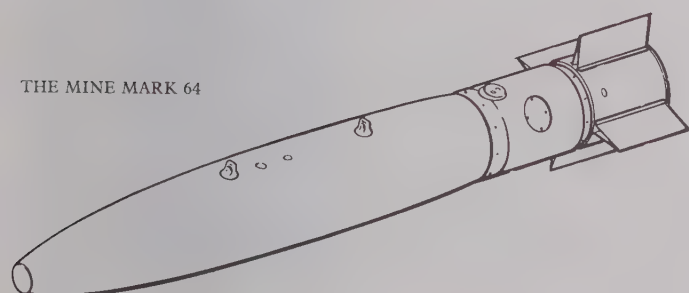
THE MINE MARK 67



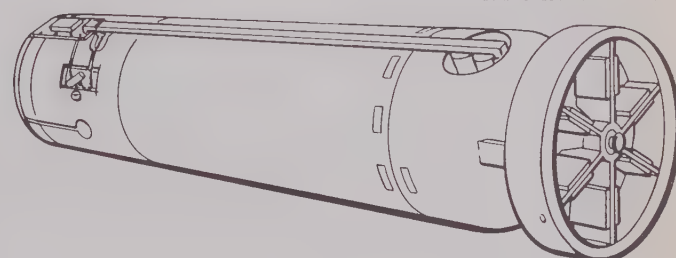
THE MINE MARK 56



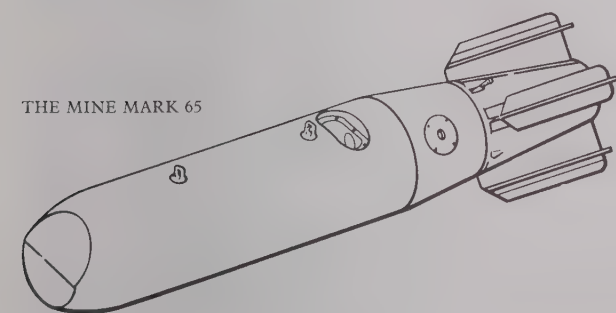
THE MINE MARK 64



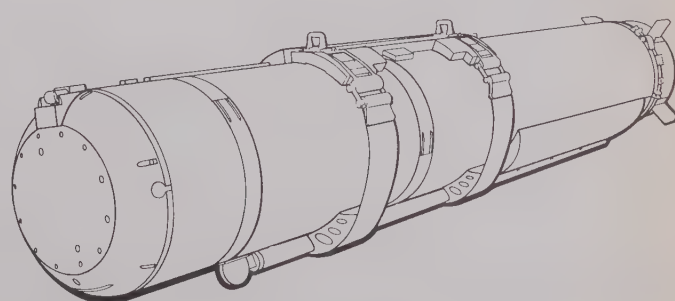
THE MINE MARK 57



THE MINE MARK 65



THE MINE MARK 60



Ordnance Laboratory developed a thin-film magnetometer which was robust enough to be dropped without a parachute.

The Navy developed a series of modification kits for standard bombs which turned them into 'destructors', shallow-water bottom mines. In some cases these bomb-mines were actually used on land during the Vietnam War. Postwar, they were to have been replaced by a new series, the 'Quickstrike' mines.

The mining of Haiphong harbor compromised the existing family of Navy mines, to the extent that procurement of new ones was suspended while development of a new family proceeded. Two new influence mechanisms, one of them magnetic/seismic/pressure, were reportedly developed, and operationally evaluated during FY78, with modified versions (with ship counters) scheduled for evaluation during FY81. They were to be employed in

conjunction with the new family of shallow-water mines, Quickstrike and the Submarine Launched Mobile Mine (EX-67, converted from a Mk 37 torpedo); the latter permits a submarine in relatively deep water to mine shallower water in which she cannot safely operate.

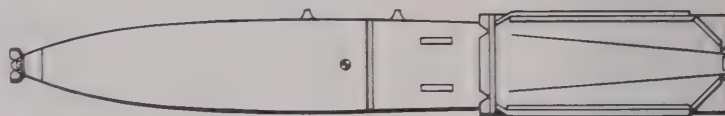
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PRAM and CAPTOR

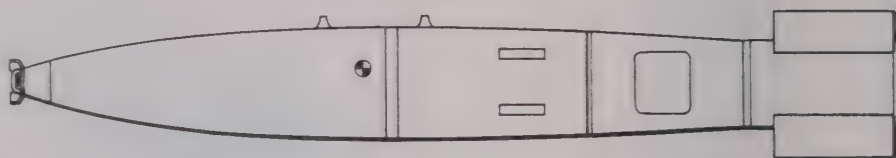
Complementing these shallow-water weapons is an intermediate-water-depth mine, currently represented by PRAM (Propelled Rapid-Ascent Mine), a rocket-propelled (rising) moored mine (EX-68) triggered by the presence of a ship target a considerable distance above – hence the need for very rapid ascent. Exploratory development began in the late 1960s, with the objective a 2000lb mine with a 500lb warhead which would be propelled to the surface by rocket. In combination with Quickstrike and the SLMM, it would complete the Navy port-closing requirement. The PRAM program encountered



THE DESTROYER MARK 36



THE DESTROYER MARK 40



THE DESTROYER MARK 46

1 An A-7 of Attack Squadron 94, aboard the *USS Intrepid*, is loaded with mine- 2000lb-class Mk 36s for the mining of Haiphong Harbor, May 1972

2 Mine Mark 36, a World War Two-developed bottom mine, loaded on an A-7A, April 1966. It was part of the A-7 test program.



problems with OMB Circular A-109, and it was canceled in September 1978. The IWD requirement survives in a more recent Medium Depth Mine (MDM) program; a PRAM-like weapon remains an attractive solution.

PRAM is related in concept to CAPTOR, a deep-water mine which launches a Mk 46 Mod 4 torpedo when it is triggered by a passing submarine. In principle, CAPTOR should be able to control large ocean areas, and should contribute greatly to the standard US submarine barrier strategy; one major issue is how rapidly it can be laid. Another is reliability: although the FY78-80 budgets funded 1810 of these Mk 60 mines, procurement was suspended in FY81. CAPTOR became operational in 1979 after an unusually protracted developmental career. A Tentative Specific Operational Requirement was issued in November 1962, and the name CAPTOR was selected for a Specific Operational Requirement of May 1964; it was hoped that the new weapon would reduce mine barrier costs by a factor of 100, numbers by a factor as great as 400. CAPTOR was to be launched from sub-

marines, surface ships and aircraft, and was to have had a long operational life (six months is the reported figure). Goodyear was chosen as the contractor, and the mine was technically evaluated beginning in February 1974, operational evaluation following in June. Reliability and, probably, lethality issues delayed production and then suspended it in 1980; there is some considerable question, for example, whether the 96lb warhead of a Mk 46 torpedo can sufficiently damage a Soviet double-hulled submarine. However, the DoD FY82 program included 400 CAPTORs; officially, tests have 'demonstrated that recent modifications have corrected its performance deficiencies'. Supporters of the Mk 46 argue that although it might well fail to sink a Soviet submarine, the damage it would inflict would probably cause the submarine to abort its mission.

Mines are at once the least expensive and the most obscure of underwater weapons. The United States used them extensively and very successfully in both World Wars and then in Vietnam, yet the US Navy is generally

described as suffering from a lack of mine-consciousness. One reason why is that mines seem, somehow, 'defensive'; another is the absence of platforms dedicated to their laying. Currently, the US Navy plans to lay its mines with naval aircraft, with submarines, perhaps with Air Force B-52s – but not with specialized minelayers. Thus the mine force and the mine warfare establishment tend to be largely invisible – but the record suggests that invisibility may be somewhat deceptive. At present, however the US Navy's greatest mine warfare problem is its lack of adequate mine countermeasures. It can be argued that the low estate of mine countermeasures is an indirect consequence of the relative lack of US Navy interest in offensive mine warfare.

4. Torpedoes

Early Torpedoes

The self-propelled torpedo was invented by Robert Whitehead in 1866. For the next five decades, the principal issues in its design were stability (ultimately by means of a gyro), speed and range. The higher the speed, the less the chance that a target might be able to evade, either by accident or by design. Once the modern 'steam' torpedo had been developed, by World War One, effort turned to an extension of torpedo-launching platforms (to aircraft and motor torpedo boats), to improved performance by means of exotic propulsion (in the US case, hydrogen peroxide), and into increased lethality (again, in the US Navy, by means of the magnetic exploder). World War Two marked another redirection, to wakeless (electric) propulsion, and to homing and other sophisticated forms of guidance. The torpedoes developed during and just after World War Two are the direct ancestors of those in service over three decades later.

Although the US Navy did not buy the Whitehead patent in 1869, Newport tried to develop an equivalent 'fish torpedo' of its own between 1871 and 1874. It suffered from an underdeveloped US industrial base, which could not equal European air flask and torpedo hull construction. Newport was able to achieve good depth-keeping, the subject of the celebrated Whitehead 'secret', but it appears to have provided its weapon with far too little fin area to achieve accuracy. The 'fish torpedo' was dropped in favor of a long series of abortive (and relatively exotic) weapons, while the first US service torpedo, the Howell, was developed. Unlike the Whitehead, which was propelled by a small piston engine driven by compressed air, the Howell was driven by a 132lb flywheel, spun up to 10,000rpm by a small steam turbine mounted on the torpedo tube. Development was completed in 1889, and for almost a decade the Howell armed US battleships. It was even considered a serious rival to the Whitehead in the international market. For example, it was simpler and cheaper than the Whitehead, required no (potentially explosive) air flask, and could steer a straighter course, since its heavy flywheel acted as a gyroscope.

Ultimately, however the Howell was limited in range by the strength of its flywheel, whereas the Whitehead could benefit from enlargement or strengthening of its air flask. Negotiations for the Whitehead were opened by the E W Bliss company in 1891, the first 100 Whitehead Mk 1 (45cm x 3.55m) torpedoes being ordered the next year. Compared to the Howell, they were much better depth-keepers, but on the other hand they were relatively inaccurate in course-keeping.

That defect was soon eliminated through the introduction of a gyroscope, Howell suing in 1898 for infringement of his own steering mechanism patent. However, the Obry gyro (in the Whitehead torpedo) was distinguished by the court. At first, it was considered defective in that it ran down faster than did the torpedo

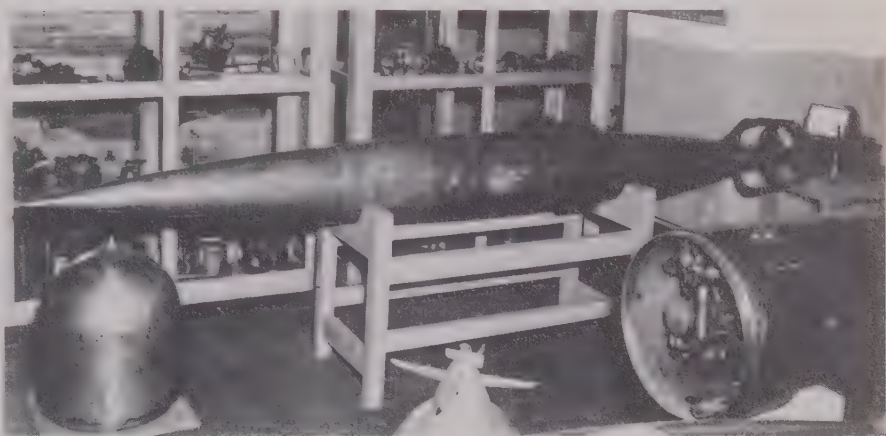
engine. Moreover, it merely assured that the torpedo would follow a straight path from its tube. From 1910 onwards, however, US torpedoes (beginning with the Whitehead Mk 5 and the Bliss-Leavitt Mk 2) were designed for curved fire, *ie* to take a new course upon emerging from the tube. Gradually the permissible angle was increased, so that torpedo-fire, even from fixed tubes, became quite flexible; this technique was further developed in the 1930s, as will be discussed in a moment.

The first major improvement to the Whitehead engine was a heater for the air fed into it; the last US Whitehead, Mk 5, was classified as a 'hot runner'. It achieved a range of 4000yds at 27kts, a factor of five improvement over earlier Whiteheads. The next step was a new engine: in 1904, F M Leavitt, a Bliss engineer, developed a turbine torpedo, which became the Bliss-Leavitt Mk 1 and superseded the piston-engined Whitehead in US service. Its engine

was set perpendicular to the propeller shaft, to avoid torque, but even so its single propeller tended to roll the torpedo. The solution was a two-stage turbine driving contrarotating propellers, an arrangement retained through World War Two. The final major propulsion development of the period was the 'steam' torpedo (Bliss-Leavitt Mk 7). In order to accept

1 Torpedoes were one of the few areas of technology which the US Navy kept fully alive during the 'dark ages' between the end of the Civil War and 1883: it was a possible 'equalizer' against the great sea powers. This is the 'fish torpedo' of 1873, presumably a copy of the Whitehead torpedo of the time, the first air-driven torpedo manufactured by the Torpedo Station at Newport.

2 The Howell torpedo was driven by a flywheel, and was unusual in having twin screws. This late production example is shown on the deck of the experimental torpedo boat *Stiletto* in 1896, by which time the United States had purchased the rights to the more conventional Whitehead torpedo.



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higher combustion temperatures in the air heater, water was mixed with the air and fuel. It flashed into steam, which accompanied the hot air through the turbine. Although hot air remained the dominant ingredient, such systems were called steam torpedoes.

Delivery Vehicles

By the 1920s, steam systems had reached their limits in range and speed, and the Fleet was able to debate the resulting tradeoffs for various roles: cruisers, destroyers, submarines and torpedo planes. The submarine force correctly assumed that most of its attacks would be executed at short range, probably no more than 2000yds. A range of up to 6000yds at maximum speed (45kts) was desirable, as it would permit the submarine to reach a zig-zagging target without imposing unusual restrictions on the firing ship. Moreover, it was argued that at such a speed the torpedo, set at 30ft, would be about 400yds ahead of its trail of bubbles when the latter broke the surface. The other major submarine role would be attacks on heavily screened warships; for this, maximum range (consistent with submarine visual range, about 10,000yds) was needed. As the limit on output was 1350 horsepower-minutes, long-range speed was restricted to 34 or 35kts, which was the lowest value guaranteeing a reasonable chance of hitting.

For cruisers and destroyers, the General Board argued in 1928 that night attacks would be at short range, about 6000yds. In daylight,

however, these ships would fire at the maximum possible range; 15,500yds was possible at 27kts. The Board argued further that destroyer and cruiser formations would often attack at about 27kts, and that tactics would be simplified if the torpedo speed were made the same as the ship speed. However, the Destroyer Force considered the low speed inadequate in a daylight attack on a battle line, given the speed of modern capital ships. The General Board argued that the provision of three speeds made for inefficiency at the intermediate speed, 35kts, which was the most valuable in daylight; that elimination of the low speed and provision of special 35kt gearing would increase range from 9500 to 10,500yds. However, the daylight range of 14,000 or 15,000yds was still considered desirable at this speed. It would require an increase of 70 percent in turbine speed, or else a new type of propulsion: pure oxygen was suggested (1932). It would roughly double torpedo range, to 19,000yds at 35kts. At the time, it appeared that existing torpedoes could be converted to oxygen operation; tests were underway at Newport. The Board considered oxygen preferable to the Destroyer Force proposal that the standard 21in torpedo be abandoned in favor of a 24in weapon.

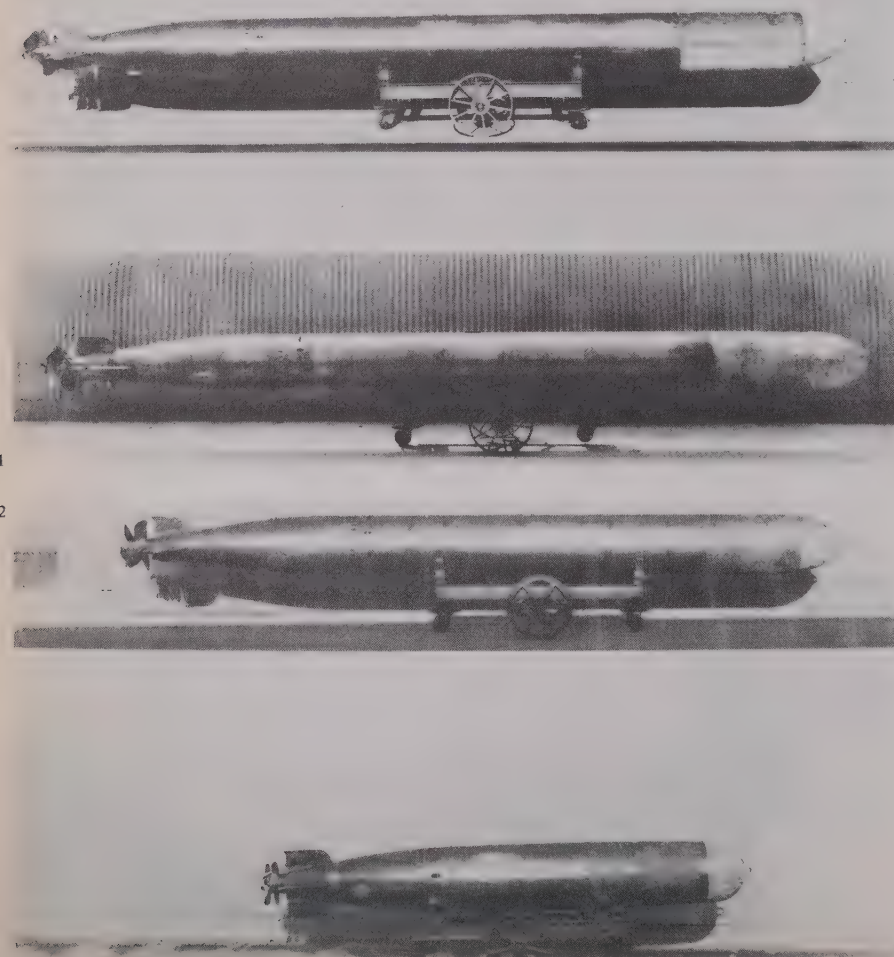
Ultimately, funds did not permit any radical change. The best that could be done was to use better forgings for the torpedo air flasks, thus reducing overall torpedo weight. Moreover, BuOrd reported that its work on oxygen power

showed primarily that much more remained to be done – and that funds would not suffice to develop both it and the new aircraft torpedo (Mk 13). All it could propose for a new destroyer torpedo was an increase in length over that of Mk 12; the latter had been limited to 271.06in by the size of submarine torpedo tubes. Another 5.5in would buy 100lb more warhead. The result was Mk 15, the last US destroyer torpedo.*

A major non-torpedo improvement of the interwar period was 'curved ahead fire'. The United States built a large number of destroyers with banks of torpedo tubes on both beams, and in theory they could not, therefore, fire all of their tubes at a single target. However, the gyros of the torpedoes could be set to turn them towards the centerline of the destroyer, so that torpedoes fired from both beams could emerge on parallel courses dead ahead. It appears that this tactic originated in the 1930s, although documentation is sparse; it did give the US Navy the capability to fire up to sixteen torpedoes from a single destroyer. Developed relatively secretly, curved ahead fire does not appear to have survived in destroyer tactical doctrine during World War Two, perhaps because of the relative unreliability of torpedoes fired at large gyro angles.

For aircraft, on the other hand, the primary consideration was the capacity of the airplane, which limited the torpedo to about 2000lb. Work on a specialized aircraft torpedo (Project 'G-6') began in February 1925, with the goals of a 4000yd range at 35kts and a 350lb warhead, within a length of 18ft (216in) and a diameter of 21in; launch speed was to be 140mph at 40ft. However, in 1926 G-6 was discontinued in favor of modifying the existing Mk 7 torpedo, which had been dropped successfully two years earlier (at about 110mph at 32ft). By this time, however, the Bureau of Aeronautics was convinced that the torpedo would be its primary antiship weapon; Project G-6 was revived in 1927, to permit production of a new torpedo before stocks of the Mk 7 were exhausted. By 1929, Ordnance looked toward a maximum length of 13ft 6in (162in), a diameter, unlimited by existing tubes, of 23in, and a weight of 1700lb, for a range of 7000yds at a minimum speed of 30kts, with a 400lb warhead. The torpedo was designated Mk 13 in August 1930, but from that October through the following July work again stopped, as the future of the torpedo-bomber came into question. It appeared that dive-bombers would wholly supplant it, and the new carrier *Ranger*

*One consequence of torpedo development was that, with heavier warheads, tubes became unbalanced and often jammed during World War Two.

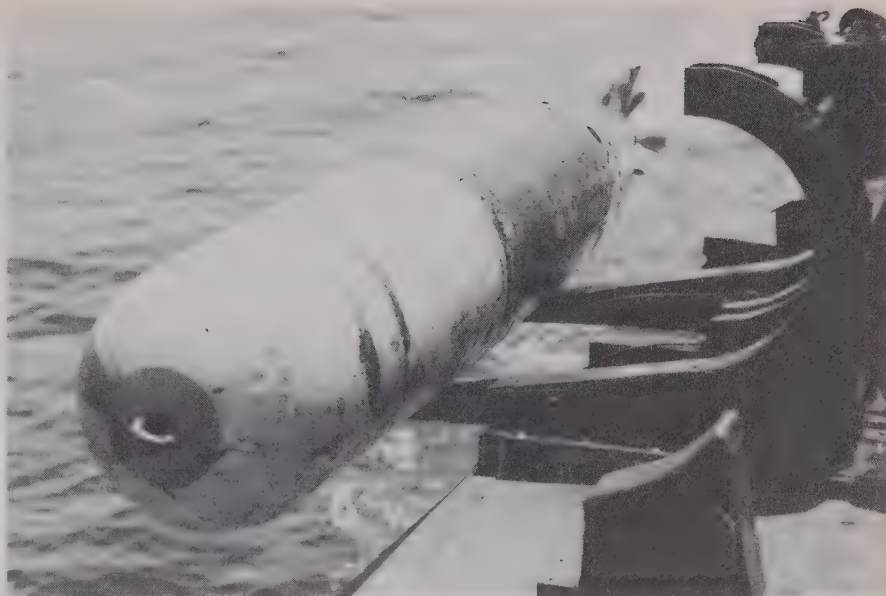


1 Destroyer torpedoes at Newport: the upper one is a Mk 15 Mod 3, the type developed between wars; the lower type, the hydrogen peroxide Mk 17 Mod 1, was used only very briefly, after the war. Mk 15 was the third of a family: the Mk 13 aerial torpedo and the Mk 14 submarine torpedo were contemporaries.

2 The other two members of the interwar family were the Mk 14 submarine torpedo (at top, 20ft 6in long compared to 24ft for the destroyer weapon) and the Mk 13 aerial torpedo, the latter much shorter but also somewhat fatter, with a 22.4in diameter.

Once the PT-boats had adopted aircraft torpedoes, they could dispense with the heavy weight of the earlier torpedo tubes. This Mk 13 was launched from a PT-boat off Rendova in January 1944; it was shorter than the earlier type, and its reduced weight (plus the weight-saving in the tubes) made possible the addition of considerable other armament. A similar 'poor boy' type of launcher was devised postwar for the Mk 32 acoustic homing torpedo, which could not be launched from a conventional tube because its tailfins were so much larger than its body.

US Navy, by courtesy of Norman Polmar



was designed without torpedo stowage. BuAer itself wanted to replace Mk 13 with a lighter (1000lb) weapon suitable for use by bombers (with a range of 2000yds at 30kts, and capable of launch at about 140mph at 50ft). Mk 13 was saved by the impracticality of this scheme, and its development continued, resulting in a 2216lb weapon with a 600lb warhead and a range of 6300yds at 33.5kts. Its primary deficiency, at the outbreak of World War Two, was the speed and the altitude limitation it imposed on torpedo aircraft, making them vulnerable – as demonstrated at Midway.

The solution was to fit stabilizers, drag rings and shroud rings which slowed the torpedo sufficiently to permit it to be dropped from high altitude (2400 *vs* an original limit of 50ft) and at high speed (410 *vs* 110kts). As a result the torpedo regained some of the popularity among air crews which it had lost in the disaster at Midway. A review of war experience showed a total of 1287 attacks, of which 40 percent (514) resulted in hits, including 50 percent hits on battleships and carriers (322 attacks, including Midway), 31 percent on destroyers (179 attacks), and 41 percent (out of 445 attacks) on merchant ships.

Propulsion

American attempts to achieve greater torpedo performance by alternative forms of propulsion began in 1915, with a contract to Westinghouse to develop solid or gaseous fuels for propulsion. The project was transferred to the Naval Research Laboratory in 1926, and the following year NRL recommended that emphasis be switched to development of an oxygen torpedo, in which oxygen would replace air in the combustion chamber. Development was authorized in 1929, and a torpedo was actually run at Newport two years later. However, it appears that the problem of supplying oxygen to ships killed it.

At the same time, NRL tried various chemical reactions to provide increased energy for torpedo propulsion, selecting 'Navol' (hydrogen peroxide) in 1934. Three years later a Mk 10 torpedo with a Navol power plant had its range increased by about 275 percent, from 3500 to 9500yds. BuOrd, suitably impressed, asked NRL to apply Navol to the standard submarine torpedo, Mk 14, which made 16,500yds at 46kts (compared to the standard 4500). Production of Navol Mk 14s began at Newport in 1940, and design of a 16,000yd, 50kt destroyer weapon (with a 600lb warhead) was authorized as Mk 17.

However, the outbreak of war intervened, and the need for submarine (Mk 14) and aircraft (Mk 13) torpedoes was so great that the Navol project lapsed until 1943. Navol itself was not available in great enough quantities, and a new plant for its production had to be built; meanwhile Newport began design of a Navol submarine torpedo, Mk 16, essentially a

Navol version of Mk 14, with a range of 7000yds at 46kts (later changed to 11,000 in a Mod 1 version, 1944). Both Mk 16 and Mk 17 were produced in modest numbers, but neither was used in combat. The former remained in submarine service as late as 1975, although the older Mk 14 outlasted it. As for the latter, it did enter destroyer service, but was abandoned about 1950, due in part to its great weight and also in part to declining interest in destroyer torpedo attack against surface targets.

Warheads

The other major line of development in antiship torpedoes was in their lethality. At first this meant heavier warheads, the weight of explosive rising from about 140lb in the first Whitehead to 600lb or more in World War Two types. In addition, more potent explosives were employed. The earliest weapons used wet guncotton; it was replaced by TNT and then, during World War Two, by a new explosive, Torpex (TPX), in 1943. Torpex in turn was replaced by HBX in the 1940s, then by H-6 in the 1960s and by PBX in the 1970s. Torpex, HBX and H-6 were all TNT with additives to increase their explosive power or to improve their long-term stability. Very approximately, 1.9lb of wet guncotton was equivalent to 1lb of TNT or to 0.5lb of Torpex, TNT replacing guncotton in about 1913.

The other means of advancing lethality was an improvement in the efficiency with which that weight of explosive was used. In World War Two that meant a magnetic exploder permitting an under-the-keel attack. Such an explosion is generally more lethal than a contact burst against the side of a ship; it affects a much larger portion of the ship and can, in favorable cases, break a ship in half. Moreover, an under-the-keel explosion maintains its lethality with much greater tolerance for poor aim than does a conventional contact explosion. All of these considerations were well understood as early as World War One, and in 1922 BuOrd proposed the development of a magnetic influence torpedo pistol. A magnetic mine was under development (abortively, as it turned out) at the same time. Project G-53 was begun, and carried out, under maximum secrecy.

Initially, progress was very rapid; as early as 1924 Newport reported that it was ready for a live test, and requested a battleship for the purpose. BuOrd refused on safety grounds, but ultimately the obsolete submarine *L-8* was provided. It was blown in half on 8 May 1926, giving the United States what was thought at the time to be a vast advance in torpedo effectiveness. A new exploder, Mk VI, was developed by Newport and manufactured in great secrecy by General Electric. Indeed, secrecy was probably its undoing. For example, once it had been perfected (in theory) it was never tested against a live target. It was manufactured, but not installed, a new Mk V contact exploder being substituted.

Both Britain and Germany came to similar conclusions about the value of an influence exploder between wars, and both experienced numerous failures early in World War Two. However, although US observers in Britain reported these problems (and their solution, reversion to a contact exploder), BuOrd made no tests of its own. The war experience which followed might most favorably be described as dismal. Not only did the Mk VI fail to perform, but in addition it turned out that the Mk 14 torpedo tended to run very deep. In combat, perfect shots often struck Japanese ships squarely and then failed to explode; grazing shots, on the other hand, often operated as designed.

In retrospect the torpedo scandal appears to have been the result of peacetime economy measures: torpedoes were not expended in tests. For example, on 20 June 1942 a Mk 14 was fired into a net at Frenchman's Bay, an Australian submarine base. It was the first depth-keeping test of a weapon, over 800 of which had been fired (often unsuccessfully) in combat. Set for 10ft, it hit the net at 25. Further tests showed similar failures, but BuOrd refused to accept these results for a time. Ultimately it was conceded that Mk 14 should be expected to run about 10ft deeper than set. However, the exploder remained unsuspected.

The exploder problem was actually twofold. First, the untested magnetic exploder proved unreliable, and by early 1943 many submarine commanders wanted it deactivated. At times,

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too, it did work, and the advance in lethality it promised was extremely attractive. Work therefore continued to improve it, but in view of its failures it was finally ordered deactivated in December 1943. Even then the Mk 14 had problems: its backup contact exploder was also unreliable. Tests showed that when it hit at a perfect 90° to the target, it was so badly crushed as to fail; at 45°, on the other hand, only about half the exploders were duds. Again, the problem was a lack of peacetime testing.*

These experiences prejudiced the Submarine Force against magnetic exploders and under-the-keel hits, a prejudice still evident over three decades later. The problem of peacetime testing is, if anything, somewhat aggravated by the higher unit cost of current torpedoes, although targets are much more frequently destroyed than before World War Two.

The lethality issue has returned with the appearance of lightweight ASW torpedoes such as Mk 43, 44 and 46. Each is very limited in size by the requirement for air and missile launch; each must attack Soviet submarines of heavy double-hull construction. One possible improvement is the use of a shaped charge, but that is likely to be effective only if it can be exploded at right angles to its target. Since this cannot generally be guaranteed for the torpedo as a whole, it is possible that a shaped-charge torpedo of the future will have a swiveling warhead – whose weight will subtract from the weight available for the explosive proper. Another factor in future torpedo development is the need for greater speed and range to counter faster, deeper-diving submarines; again the weight available for the lethal charge will tend to shrink.

Wakeless Torpedoes

Through 1940, then, American torpedo development concentrated on speed, range and explosive effect. From that time onwards, another need of the submarine – invisibility – also had to be taken into consideration: the United States developed an electric, *ie* wakeless, torpedo. Sperry began work on such a weapon as early as July 1915 (90lb without warhead, 7.25 × 72in, 3800yds at 25kts), but its project ended in 1918. Germany had developed its own electric torpedo during World War One, and Newport worked sporadically on its own (which became Mk 20) for the next quarter-century, aiming at a range of 3500yds at 33kts, with a 500lb warhead. With the outbreak of war, and with widespread successful use of electric torpedoes by German submarines, the project gained priority. A German torpedo (G7e) captured by the Royal Navy in 1941 aboard *U-570*, was to be copied by Westinghouse as the Mk 18; the Royal Navy made its own copy as its Mk 11. Westinghouse produced a prototype in the remarkable time of fifteen weeks, and the first six production torpedoes were delivered within six months of the original contract. Besides wakelessness, the electric torpedo required only about 70 percent as much labor in manufacture as a conventional steam type.

Mk 18 was extremely popular with the submariners, its use rising from 30 percent of all war shots in 1944 to 65 percent in 1945. However, postwar analysis showed that the greater speed of the steam torpedo made for more hits. Against merchant ships, steam torpedoes made

1.17 times as many hits, and against destroyers and escorts the factor was 2.5. In only about 8 percent of all cases did Japanese merchant ships spot the wakes of oncoming torpedoes and evade. In addition, the storage battery of the Mk 18 evolved hydrogen gas, which had to be purged periodically. In at least one case (*USS Flying Fish*) a battery fire melted the contents of the torpedo warhead, the explosive running down into the tube. Mk 18 was credited with sinking about a million tons of Japanese shipping, about a fifth of the total submarine score, but by 1950 it had been discarded in favor of the more conventional Mk 14 and 16, which survived into the 1970s.

Early Homing Torpedoes

Homing, both passive and active, was the principal wartime torpedo development. Work began in December 1941 at Harvard, Bell Labs and General Electric in response to a Navy request for a slow, air-launched, antisubmarine torpedo, quiet enough to home passively (acoustically). A speed of 12kts was the lowest which would suffice against a fast evading submarine underwater: in theory the torpedo would be dropped on a submarine which had just submerged after spotting an attacking airplane. It would, in effect, replace the air-dropped depth charge. Since, unlike the latter, it could be expected actually to hit the submarine, it could have relatively small warhead (100lb). A 5–15-minute running time was specified, drop speed being 125kts (144mph) at 250ft. The resulting weapon was designated Mine Mark 24, apparently for security reasons; some writers suggest rather that the mine designation was chosen because much of the development was carried out by the mine, rather than the Navy torpedo, organization. US forces used 142 in combat, sinking 31 submarines and damaging another 15, for a 32 percent success rate. Other Allied forces, principally British, expended another 204 (37 sinkings, 18 U-boats damaged), for a success rate of 27 percent. By way of comparison, air-dropped depth charges were successful 9.5 percent of the time.

Torpedo Mark 27 was a lengthened Mk 24 intended for submarine use against escorts, principally for self-defense. Its passive operation required quiet launching, so that it was designed to swim out of a flooded torpedo tube under its own power. Of 106 fired in combat in 1944–45, 33 hit (24 ships were sunk, another 9 damaged); it was estimated that a single Mk 27 was equivalent in hitting effectiveness against escorts to a salvo of conventional torpedoes. The final US submarine design of World War Two, the fleet submarine of 1945, incorporated external broadside tubes for 19in antiescort torpedoes, presumably Mk 27s.

In effect, Mk 27 was a US equivalent of the German T-5 antiescort homing torpedo, which the Allies termed GNAT (German Naval Acoustic Torpedo) – and which was known, due to codebreaking, before its introduction into service. Presumably the success of Mk 27 was due in part to its surprise, as the Japanese had no equivalent of Foxer.

The success of Mk 24 led to further projects in the spring of 1943. One, based on Mk 13, was an air-launched homing torpedo (Mk 21); it entered limited service postwar as the payload of the Petrel missile. Another was a passive-homing submarine torpedo. Three versions were based on the Mk 18: Mk 28 (20kts), Mk 29

(25kts), and Mk 31 (28kts). Mk 18, itself an emergency product, was not inherently very quiet, and only Mk 28 was available for combat tests in 1945. Of sixteen fired, five (31 percent) hit. The faster versions required redesign, and were themselves inferior to a homing version of the faster, quieter Mk 20 electric torpedo developed by Newport. Using a new lightweight high-speed electric motor, it could achieve 39kts, and was quiet enough to steer acoustically at 37 – at which speed it was quieter than Mk 31 at 28 kts.

Finally, a homing torpedo was evolved from Mk 24 for ship use against submarines – Mk 32. It incorporated active homing ('pinging') rather than a passive system; a similar guidance system was proposed for an antiship version of Mk 18, which was completed too late to be tested. Mk 32 was the direct ancestor of modern lightweight shipborne torpedoes. In 1942 it was envisaged as a powered, homing depth charge, compatible with shipboard sonars. It would glide downwards at a small fixed angle, steering a tight circle and 'pinging'. Its speed was considered sufficient to attack a submarine running as deep as 400ft, although it was inadequate against a Type XXI submarine. Moreover, it could replace Mine Mark 24 as an air-launched weapon, its active homing system overcoming the noisemaking decoys which might counter the earlier torpedo. Tests in 1944 showed an unexpected problem: as the torpedo came within 50ft of its target, there was insufficient time for it to receive its own echoes, and sometimes it turned away before impact. Circuit modifications were indicated, but so urgent was the need that it was ordered into production at once. However, the project ended in 1945 with only ten built, resuming in 1951. Mk 32 then became a standard destroyer weapon, usually launched by Torpedo Launching System Mark 2, which tossed it over the side. In a few cases, however, it was rolled from a stern track, showing its origins as a homing depth charge. Conventional tubes were impractical because its tail fins were much wider than its body.

Postwar Programs

A total of fifteen torpedoes were in development in 1945: six straight-runners (Mks 16, 17, 19, 20, 25 and 26) and nine homers, passive and active (Mks 21, 22, 29, 30, 31, 32, 33, 34 and 35). Only six were included in the BuOrd postwar program, and only three entered service: the Navol Mk 16, the lightweight Mk 32, and the air-launched Mk 34. In addition, Mk 27 was issued as an interim weapon, with Mk 32 and 34. Within a few years, three other torpedoes had been recognized as 'ultimate' types: Mk 35, Mk 37 and the lightweight Mk 43, the direct ancestor of the current Mk 44 and 46. Mk 34 was an improved Mk 24 using magnetostrictive rather than crystal hydrophones, and provided with two batteries in a parallel/series arrangement which allowed it two speeds, a long-endurance low speed for search and a high speed (17kts) for attack. It served through 1958.

Mk 35 began as a 'universal' (air, submarine and destroyer) passive/active homer, derived

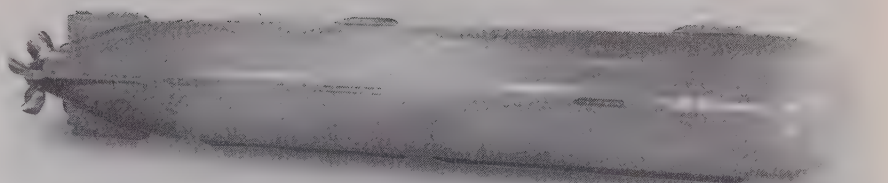
*Mk 14 was criticized for its prominent wake (which allowed targets to evade) and for the fact that in at least one wartime case it sank the submarine which fired it by making a circular run.

from work on Mk 24, 32 and 33. Its air-launch requirement was discarded in 1948, and Mk 41 developed instead as the ultimate payload for Petrel. Physically Mk 35 was to be based on the air-launched Mk 13. Meanwhile a new submarine defensive torpedo, Mk 37, was under development. Plans originally called for it to incorporate a decoy, either an echo-repeater or a noisemaker; a feature was to be provided whereby the torpedo would cease to be a decoy and attack the ASW ship tracking it when the target's noise level reached a preset value. Mk 38 would be the complementary offensive target-seeking torpedo, with a range of at least 10,000yds (compared to 3000 for Mk 37). In addition, there was under development, about 1948, a specialized antiescort torpedo (SOB), which was to lure and destroy ASW ships. It was to simulate a submarine, to operate at low speed (4-11kts) but with a long run (15,000yds) and a very heavy warhead (877lb, compared to about 300 for Mk 35 and 37).

In practice Mk 35 and 37 were very similar and were developed in parallel, one with a cast and the other with a welded aluminium hull. In addition, Mk 37 alone incorporated the Harvard Underwater Sound Laboratory/ Ordnance Research Laboratory homing panel which sought doppler returns to avoid homing on false targets. Although some Mk 35s were produced, it was Mk 37 which entered large-scale production, equipping both submarines and surface ships from about 1956 onwards. Mods 0 and 3 were standard submarine torpedoes; Mods 1 and 2 were wire-guided.

Originally, Mk 35 was considered the 'ultimate' surface ship weapon against fast, deep-diving submarines, far more important than projectors such as Weapon Alfa. Its existence (in experimental form) explains the presence of torpedo tubes aboard such postwar ASW ships as the *Fletcher* and *Gearing* class conversions. However, a decade of labor and \$90 million failed to make it work, and its changing fortunes explain much of the appearance and disappearance of torpedo tubes aboard American destroyers of the postwar Navy. Mk 37, the submarine weapon, was pressed into service as a substitute. It was the only really long-range ASW weapon which could be fitted to a destroyer or even to a destroyer escort at minimum cost in space and weight. For example, tubes capable of firing Mk 37 torpedoes were fitted to FRAM II destroyers which were not given ASROC; they supplemented DASH.

In effect, then, the free-running Mk 37 was considered appropriate to the SQS-4/VDS sonar of such ships, with an effective range of about 8000yds. Free-running itself was inappropriate to really long sonar ranges, because the torpedo had to be launched into the neighborhood of the target before its (relatively short-range) seeker could function. Its run-out, preset, was 'dead time' during which a target could maneuver and thus escape the acquisition 'footprint' of the torpedo. Hence the wire guidance of the Mod 1, a system first tested on a modified Mk 27 (Mk 39). Wire guidance proved most amenable to fixed bow or stern torpedo tubes, but was not successfully applied to surface ship installations, although there were several attempts to develop suitable wire stowage and dispensers: Mod 1 was above all a submarine weapon.

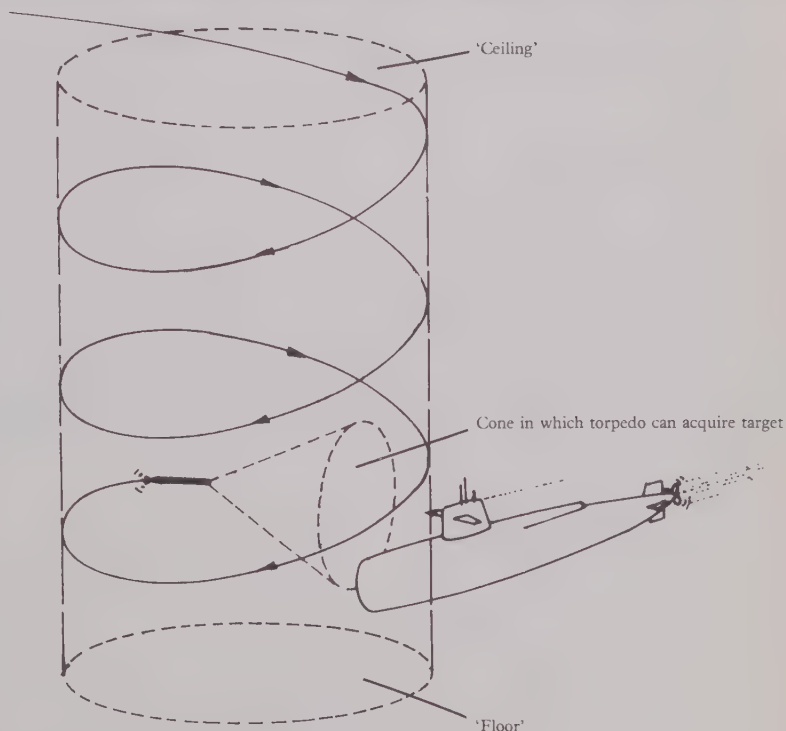


1

2



3



1 A modern submarine-launched ASW torpedo, this Mk 37 is smaller than the standard torpedo tube and thus requires studs along its surface to fit the tube. It is also very short: two Mk 37s can be carried, for example, for each Mk 48, and so a submarine with four tubes and, say, stowage for twenty Mk 48s might carry up to forty-four Mark 37s – or up to forty-four of a new half-length torpedo, which might duplicate Mk 48 performance with new propulsion technology. This example is not wire-guided and so does not show the characteristic wire dispenser under one of the vertical fins.

2 Petrel was a torpedo-carrying missile, developed for use against surface ships and canceled soon after it entered service because the primary Soviet naval threat was underwater. Here two are carried by a Neptune in April 1956 tests; note that, unlike most ASW versions of this airplane, this missile version has a relatively small surface-search radar.

US National Archives

3 TYPICAL HOMING TORPEDO PATH



By the early 1950s there was a serious question whether a torpedo might be made both fast enough and quiet enough to home effectively on very fast (eg nuclear) submarines. One alternative was a torpedo with a nuclear warhead, whose lethal radius would be great enough to make up for very considerable sonar fire control errors. Several projects were canceled; in 1956 a scientific panel, 'Nobska' (better known for its support of what became Polaris), strongly advocated the immediate development of a nuclear nonhoming torpedo. Mk 45, ASTOR (Anti-Submarine Torpedo), was the result, entering service in 1959. It was never entirely successful, as it appeared just as the submarine community was becoming more and more committed to wholly passive operation. In those circumstances it was difficult to find the range precisely enough to fire ASTOR. With the appearance of Mk 48, ASTOR was withdrawn from service, and the torpedo bodies converted to conventional operation (as 'freedom torpedoes') for sale abroad. ASTOR thus had the distinction of being the first US nuclear weapon to be withdrawn in favor of a conventional one.

BuOrd soon began to consider a new heavy torpedo, which was first designated EX-10 and then Mk 48; feasibility studies began in September 1957, with an Operational Requirement issued in November 1960, looking towards entry into service by 1967. Mk 48 is much longer and heavier than Mk 37, and has four times the range (about 35,000 vs 9000 yds), about twice the speed (reportedly over 50 kts), can dive much deeper (2500 vs 1000 ft) and can acquire its target at a much greater range (4000 vs 700 ft, according to recent Congressional testimony). It was provided with wire mid-course guidance applicable to its range, which was always described as appropriate to the SQS-26 sonar: indeed, most of the SQS-26-equipped ships of the early 1960s were originally designed (and, in some cases, built) with Mk 48-firing tubes set into their transom sterns, tubes suitable for wire guidance. Al-

though EX-10 was intended to operate against both surface and submerged targets (and thus caused the purely antisurface Mk 47 to be canceled), the ASW mission was emphasized.

Mk 48 development was urgent because of the inadequacy of the existing Mk 37, which in the mid-1960s was credited with only a 0.1 effectiveness against a submarine exceeding 20 kts. On the other hand, as proposed, Mk 48 promised an effectiveness of up to 0.4, even against submarines making up to 35 kts, at depths as great as 2500 ft. In the fall of 1964, Secretary of Defense McNamara was briefed on system tests aboard the nuclear submarine *Permit* in the Pacific, and the program was accelerated; Mk 48 entered service in 1971. The principal issue in its development was propulsion, to provide the extreme range and speed desired. Mod 0, developed directly from the Navy RETORC II (Research Torpedo Configuration) program by Penn State University and Westinghouse, used a turbine, but in 1967 Gould developed a piston (swashplate) engine, and a new homing panel; its Mod 1 was selected in favor of the Westinghouse Mod 2, a redesigned Mod 0. Mod 3 adds a two-way (rather than one-way) wire communication link, TELCOM, so that the torpedo can transmit its sonar data back to the submarine for processing; it is a torpedo equivalent of the track-via-missile guidance system of Typhon, the Soviet SA-10/SA-N-6, and the US Patriot. There were also Acoustic Homing Improvement modifications (Ordalts) to existing torpedoes to improve their performance against low-doppler and surface targets. The current version, Mod 4, incorporates TELCOM as well as a fire-and-forget mode, useful if the torpedo's self-noise blanks out the submarine's passive sonar. A pilot production contract was awarded in October 1970, followed by a shoot-off between Mk 1 and 2 in June 1971, with Clevite (Gould) being awarded a prime contract that July. Mod 3 appeared in 1973. In November 1978 the Navy issued a Request for Proposals for a new ADCAP (Advanced Capa-

ASTOR, the Mk 45 torpedo, was a wire-guided undersea nuclear missile. It had the great advantage of overcoming those sonar countermeasures, such as anechoic coatings, which might confuse a homing torpedo. However, it had no means of homing or even of fuzing against a nearby object, so that the launching submarine had to detonate it within a lethal distance of its target. That in turn required very accurate ranging, and many submariners found this requirement excessive, inimical to their passive mode of operation. The conventional (high explosive) Mk 48 replaced it, and surviving Mark 45s were converted into 'Freedom Torpedoes' for sale abroad. Note the shroud ring around the propeller, for quieter running, so as to avoid alarming a target. Although there were many projects for Navy nuclear torpedoes, ASTOR probably owed its existence to the deliberations of the 'Nobska' Committee, which reported in 1957 that, pending great improvements in sensors, nuclear weapons with very large lethal ranges were probably the best interim counter to a Soviet nuclear submarine threat.

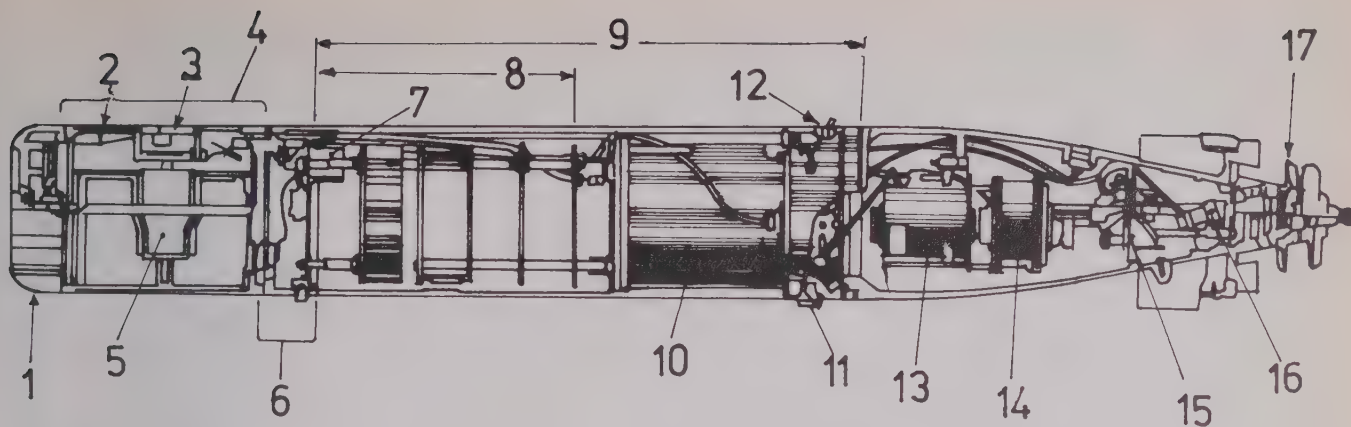
bility) version, Mod 5; the following August Hughes was selected to develop a new guidance system to cope with fast, deep-diving submarines; the existing Gould swashplate motor was to be retained. Specific improvements include a stronger shell and more fuel, reduced self-noise, and greater sensitivity in passive operation. There will also be a higher-powered active sonar, electronically steered to reduce maneuvering by the torpedo. First deliveries of test torpedoes were scheduled for December 1980, with production in 1984-85 after a DSARC II (Defense Systems Acquisition Review Council) decision scheduled for March 1982. Mk 48 procurement continues, 144 having been requested in the Amended (Reagan Administration) FY82 budget, and previous plans to terminate production having been abandoned.

It is a very large torpedo, and submarine stowage space is very limited. Although the precise figure is classified, it has been suggested that as few as twenty weapons can be stowed per submarine. Drawings of submarine weapon stowage suggest that two Mk 37s can probably be stowed in each Mk 48 position; but the Mk 37 is entirely inadequate against modern submarines. Gould has, however, proposed a half-length Mk 48, exploiting new technology to achieve much the same performance in a much smaller volume. At the time of writing this option was not yet being pursued.

Lightweight Torpedoes

Since 1945 lightweight torpedoes have been the other major stream of US development. Mk 24 and 32 were the first in this series, but both had large diameters. In 1942, however, the Brush Development Company of Cleveland produced a 10in diameter Mine Mark 30 as an alternative to Mk 24. Interest in very light ASW torpedoes increased postwar with the development of sonar-carrying helicopters, which could lift only very limited loads. Thus in 1950 the maximum torpedo weight was set at 350 lb, far below that of Mk 35 and 41; the new weapon would have the same active homing system as the heavier ones, but much reduced performance would be accepted. The existence of Mine Mark 30 (265 lb) seems to have shown that such a project was feasible, the resulting Mk 43 being of very nearly the same configuration. Two competitive versions, both electrically powered, were developed.

Mk 44 was the next generation, limited to 450 lb; work (on what was then designated EX-2A/2B) began in January 1953. Ex-2B was selected for production as Mk 44 in 1956, be-



THE TORPEDO MARK 44

Key

- 1 Nose section (acoustic sensor)
- 2 Fuzing line
- 3 Fuze cover

- 4 Warhead
- 5 Fuze
- 6 Coupling section
- 7 Gyro
- 8 Guidance panel
- 9 Power section
- 10 Battery

- 11 Scoop
- 12 Safety valve
- 13 Electric motor
- 14 Power train
- 15 Steering drive
- 16 Side yoke
- 17 Propeller

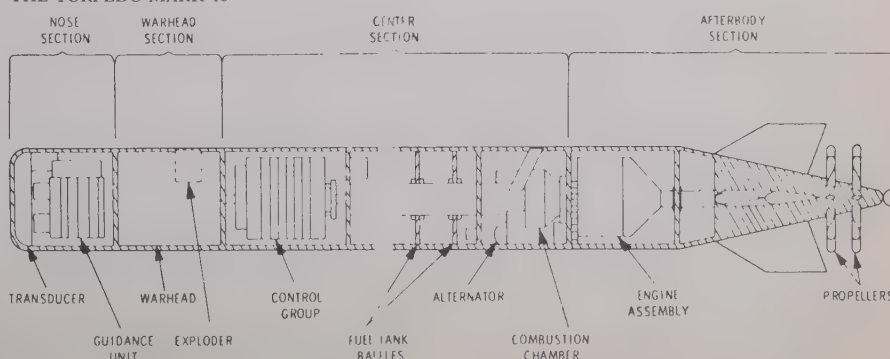
coming the payload for ASROC and the standard ship and aircraft ASW torpedo. Like Mk 43, it was electrically powered, and it used pure active homing. Mk 44 could be set to run out before searching, thus avoiding acoustic interference from the launching ship. It was also much faster than Mk 43 (30 *vs* 15 or 21kts).^{*} Even so, it did not match the potential of nuclear submarines, and in December 1956 feasibility studies of a more powerful lightweight torpedo, which became Mk 46, began. An Operational Requirement was issued in November 1960, production beginning in 1963 (Mod 0).

Mk 46 achieved about twice the range of Mk 44, could dive much more deeply, and could run out at 45kts – which performance required a new type of propulsion, a solid fuel powering a swashplate engine. It could also be launched at up to 500kts. However, the solid fuel engine created maintenance difficulties, and for a time a return to battery propulsion was considered. Instead, in Mod 1, a liquid (Otto) monopropellant was used, with a cam engine. Mod 2 was designed to provide Helicopter Attack Tactical System (HATS) capability, one sonar helicopter vectoring in another to attack. Mod 0, evaluated in 1964, incorporated a REVEL acoustic panel, one of three tested. Mod 1, with simplified steering, was tested in 1966, although its first production contract had been awarded the previous year. Production ended under the FY69 program. Mod 2 prototypes were tested in 1968–69, with Honeywell (second source after Aerojet-General on Mods 0 and 1) prime contractor. No production was authorized in FY70 and 71, however, but in FY72 the line reopened with a British order for 950 torpedoes. Meanwhile, in October 1972 a Near-Term Improvement Program (NEARTIP) was begun, the resulting Mod 5 entering service in FY79. The torpedo transducer was overhauled, new guidance and control groups were fitted, as well as a new afterbody cable and a two-speed valve and hardware. Some new torpedoes were manufactured to NEARTIP standards. In this series, Mod 4



The Mk 32 triple lightweight torpedo tube is now standard, not only in the US Navy but also in most Allied navies employing the Mk 44 and 46 lightweight ASW torpedoes; here one is fired from the *Newman K Petty*, June 1967. The tubes in turn limit any future lightweight torpedo and thus are a considerable factor in the development of the ALWT. Except for the twin enclosed tubes in the *Knox* class, all US lightweight tubes are of this Mk 32 type.

THE TORPEDO MARK 46



^{*}As a rule of thumb, a homing torpedo should be about 50 percent faster than its target, so that Mk 44 could usefully counter a 20kt submarine.

was the specialized CAPTOR payload, built to Mod 5 standards. Mk 46 is a very small torpedo, necessarily with a small warhead. In recent years it has been criticized as insufficiently lethal, damaging rather than killing its targets.

The general depression in ASW research and development during the late 1960s and early 1970s left Mk 46 frozen as the only available US lightweight torpedo, while Soviet submarine development proceeded apace. A new program, for an Advanced Light Weight Torpedo (ALWT) or Mark XX (designations EX-50 and -51 appear to have been reserved in fact) began with a Technical Assessment Phase (February 1972 through September 1978), the two competitors being McDonnell Douglas and Honeywell. Honeywell's Mk 50 (Barracuda) was selected in 1982, for operational evaluation in FY86. In view of the rather long wait until such a weapon would replace the ageing Mk 46, there have been proposals that the United States buy the Marconi Stingray torpedo instead; the Royal Navy would drop its ongoing heavy torpedo program in favor of Mk 48 Mod 5. As of this

writing, Marconi claims that Stingray is the first torpedo to substitute software for hard-wiring in its signal processor, permitting rapid reprogramming to meet a changing threat, and that it is particularly effective in shallow water. Stingray was evaluated at a DSARC meeting in July 1979 and rejected partly on the basis of cost, then estimated at \$440,000 for a Stingray, \$180,000 for the existing Mk 46, and \$250,000 for an ALWT; there was also a hint that the US Navy considered its speed inadequate, as 1981 Congressional testimony indicated that the British were proposing new means of increasing that speed. Thus it seems unlikely that, despite delays in the ALWT program, the US Navy will be willing to buy the Marconi torpedo.

In 1981, the Defense Advanced Research Projects Agency (DARPA) was pursuing a new torpedo program, REGAL (Remotely Guided Autonomous Lightweight torpedo), in which the torpedo and a lightweight acoustic array are launched together, separating upon entry into the water. The array, presumably representative of the same technology which has produced the tactical towed array (TACTASS)

and the strategic towed array (and, for that matter SOSUS), is used to acquire a submarine at relatively long range, guiding in the torpedo. Guidance and control software were tested in FY80, followed by a series of fully autonomous sea runs during FY81 to evaluate REGAL performance as a function of the sensor-target-torpedo geometry, weapon speed and maneuverability, and target range at the point of handover from the nearly stationary array to sensors aboard the moving torpedo. The FY82 test program was to come closer to realistic target conditions in sea runs, and a new 'brassboard' sensor was to have been tested. In 1981 planning called for a final demonstration series in FY83, at which time the developed technology would be handed over to the Navy for incorporation in the existing SOW and ALWT programs.

5. Antisubmarine projectiles

Types of Projectiles

There are two major classes of ASW projectiles: proximity and contact weapons. The former, typified by the depth charge, must be large enough to damage a submarine even at a considerable miss distance. Nuclear depth charges, such as ASROC and SUBROC warheads, achieve the greatest lethal radii. Contact weapons, such as Hedgehog projectiles, can be much smaller, but must either be guided into their targets (as in homing torpedoes) or else used in very large numbers (as in a Hedgehog). A homing torpedo is an intermediate case, since (in theory) its effective homing volume may be comparable to the lethal volume of a large proximity weapon. Thus Mk 44 and 46 lightweight torpedoes appear in many cases as alternatives to nuclear depth charges. Similarly, the Mk 48 homing torpedo has replaced the Mk 45 nuclear torpedo. In each case, some guidance mechanism carries the torpedo or nuclear weapon into the vicinity of the target and then activates it; the torpedo searches, the weapon merely bursts. One might add that the greatest virtue of the nuclear depth charge is its relative immunity to countermeasures.

The 'Blind Time' Problem

'Blind Time' has always been a major issue in the efficacy of ASW weapons: the projectile does not approach the presumed location of the submarine for some considerable time after it is launched, if only due to the density of water. How much safety that time buys for an evading submarine depends upon the depth to which the submarine can dive, how fast and how maneuverable it is, and also upon the lethal radius (or volume) of the weapon, which in turn depends upon the strength of the submarine itself. As for the latter factor, the

history of submarine warfare in both World Wars was one of underestimation of the depth performance and survivability of submarines. For example, the deeper the submarine, the more difficult it was to maintain contact using a conventional sonar, and also the more difficult it was to perform effective fire control. During World War Two, it was realized that the use of hydrostatic (depth-fuzed) depth charges was roughly analogous to the use of time-fuzed anti-aircraft shells, and proximity (magnetic and then acoustic-fuzed) depth charges were developed. Their effectiveness was increased by streamlining for faster sinking rates.

For a destroyer dropping depth charges, the effect of blind time was, if anything, increased by the ability of the submarine to detect her acceleration toward the attack area; once the destroyer was committed, the submarine could evade. Such tactics could be very effective in World War One, when the destroyer's only indication of submarine position was a surface trace, such as a disappearing periscope or the end of a torpedo track; on the other hand, most submarines did not dive very deeply. In World War Two, the two-ship attack was called 'creeping', precisely because the attacking destroyer avoided accelerating, to avoid giving the game away. However, a destroyer making a single-ship attack had to accelerate because she would lose sonar contact with a submarine as she approached; the more slowly she attacked, the staler the last contact would become.

The traditional solution to the blind time problem was to saturate an area with charges, using, in many cases, a pattern of bursts in layout and in depth calculated to maximize the probability that the submarine would not escape. At first depth charges were simply rolled from the stern, but the British devised a

Thornycroft Projector which permitted a ship to barrage the area around her. It fired one charge at a time, and had the defect of considerable recoil forces. In 1917 the US Navy was already experimenting with a nonrecoiling aircraft weapon, the Davis Gun, and Cdr A J Stone, formerly of the General Ordnance Company of Groton, Connecticut, proposed to apply the same principle to a depth charge projector. The result was the Y-gun, which fired off two depth charges in opposite directions at the same time. Work began in November 1917, although a formal order was not received until 8 December; the first was delivered two days later, and 947 were produced in wartime for destroyers and sub-chasers.

Projectors and Tracks

There still remained the problem of 'dead time' between a visual sighting and the destroyer's arrival in the presumed vicinity of a submarine. Visual ranges were long, and a submarine could go some considerable time in the interim - hence, it would appear, the development of the 8in/23 Mk 7 ASW howitzer, interchangeable with a standard destroyer 4in gun, and firing a special small-diameter Mk 5 depth charge. Work stopped in 1921 due to limited funding. It might be added that the value of very long-range ASW projectors such as the howitzer waned with the advent of sonar as the primary ASW attack sensor, since sonar was relatively short-ranged. The value of large barrages remained, and with it the Y-gun.

The chief defect of the Y-gun was that it occupied precious centerline space, and so could be mounted (if at all) only in very limited quantities. Generally only one was provided, and the weight of the charges precluded reloading during an attack. Thus a ship was

limited to two (or, in very rare cases, four) charges abeam, plus as many as could be rolled off the stern. Since the throwers were the main countermeasure against evasion by the submarine, they were valuable. In 1936 BuOrd devised a one-charge thrower, the K-gun (Projector Mark 6), accepting its recoil in large ships such as destroyers. It could, then, be accommodated alongside a ship's superstructure. Typical wartime installations called for four or six in a destroyer, although destroyer escorts had eight. Roller racks alongside accommodated three or four depth charges, depending upon the installation. For example, destroyer escorts had the four-charge rack; many destroyers had the three-charge type, as did most ships of smaller size, such as large minesweepers.

Projector Mark 6 did not enter service until mid-1941. Like the Y-gun, it required a separate arbor which had to be inserted before a depth charge could be loaded, and which fell into the sea independently of the depth charge. It appeared to be wasted weight, and a Mk 9, in which the arbor was part of the K-gun, was developed beginning in November 1942. In August 1944 it was tested aboard the ASW experimental frigate *Asheville*, but the weight-saving proved illusory and Mk 9 was never adopted, Mk 6 remaining postwar.

The classical means of launching depth charges was the stern rail. Although the first World War One installations were no more than a pair of stern slings, an eight-charge track (Mk 1) was designed in 1918, with deliveries beginning in April. Mk 2 was a lighter-weight, five-charge track for smaller ships, such as subchasers; the war ended before it could be placed in production. Many World War One destroyers had, in addition to their eight-charge rails, five-charge extensions, for a total of thirteen standard-size (300lb) charges. Postwar, however, these long tracks were too intrusive on destroyer quarterdecks, and the new destroyers of the 1930s were designed rather to accommodate a pair of five-charge tracks cut down from the original Mk 1 and designated Mk 1 Mod 1. The alternate load was three 600lb charges (or, in a Mk 1, six 600lb *vs* eight 300lb). Revisions in depth charge track design produced Mk 3 (eight charges) and Mk 6 (five). For smaller ships there were lightweight aluminum tracks: Mk 4 (four 300lb) and Mk 5 (seven 300lb). Finally, with the delivery of ships to Britain under Lend-Lease, there was a requirement for tracks which could accommodate both British and US charges: Mk 9, for four to twelve 300lb or three to eight 600lb charges. Its capacity decreased by two 300lb for each step in Mod number from 0 to 4. Production began in September 1942, and by 1945 it was the most widely used track in the service.

As in World War One, flexibility was achieved partly by the design of the depth charge track extensions: Mk 1, for use with Mk 1, five 300lb charges; Mk 1 Mod 1 (the portion of Mk 1 remaining when it was cut down to

form Mk 1 Mod 1), three charges; Mk 3, for use with Mk 3, ten 300lb or seven 600lb; Mk 3 Mod 1, three 300lb or two 600lb; Mk 3 Mod 2 (the remainder of the Mk 3 extension), seven 300lb or five 600lb; and Mk 7, two 300lb, for use with Mk 7. *Fletcher* and *Sumner* class destroyers, particularly restricted in fantail area, had no magazine stowage for depth charges. They therefore received a pair of eight-charge tracks, with two five-charge stowage racks inside them, for a total of 26 charges aft. For the other destroyers, the original level of five depth charges per track was increased, at least in the Atlantic, to seven in 1941, and later to eight or even twelve. In 1944, for example, destroyer escorts down to PCEs had pairs of twelve-charge tracks; PCs had eight; PCSs seven; SCs (110ft) five; large minesweepers seven; and YMSs (136ft) four. Destroyers were limited to seven- or eight-charge tracks, with ten-charge tracks in the larger units.

Depth Charges

The depth charge itself was introduced by the Royal Navy in 1916. In February 1917 the Bureau of Ordnance began production of a Mk 1 with 50lb of explosive, which was clearly far too small; the Royal Navy was already using 300lb. By the fall of 1917, Mk 2, a British depth charge with a US-designed hydrostatic fuze, was ready. It could be set as deep as 200ft; as the U-boats improved, maximum depth was increased to 300ft. The final wartime development was Mk 4 (745lb, of which 600 was explosive), the first of which were sent overseas in September 1918.

Relatively little work was done on depth charges for much of the interwar period. However, in 1936 a Special Board on Naval Ordnance showed by mathematical analysis that, for a given depth charge track, the 600lb charge would always be more effective than the 300, even when the smaller number (six rather than eight) of the former were taken into account; this reduced capacity was a consequence of the greater diameter of the larger charge. On the other hand, no projector for the 600lb charge ever entered service, so that US doctrine at the outbreak of war was to restrict 600lb charges to stern tracks, using the 300lb type on throwers.

Also at this time, faster-sinking equivalents of Mk 3 and 4, Mk 6 and 7, were designed; Mk 5 had been the special howitzer round.

The submarines of World War Two operated at greater depths than their forebears, particularly when evading depth-charging. Thus in August 1942 a new depth pistol, effective to 600ft, was issued. Even it was considered insufficient, and work proceeded on a pistol effective at up to 1000ft. However, the greater the depth, the greater the dead time for a given sinking rate: efforts to develop a faster-sinking weapon produced, first, lead-weighted versions of Mk 6 and 7 (for about a 50 percent improvement over their 8 and 9ft/sec) and then the teardrop-shaped Mk 9. The latter sank at 14.5ft/sec, and was designed to spin so as to maintain a stable underwater trajectory. On the other hand, in order to fit existing tracks, it had to sacrifice weight and explosive content.

Mk 9 development began early in 1941 on the basis of British reports that German submarines were being tested at depths greater than 300ft. Studies showed that existing depth charges were unlikely to achieve kills below that depth due to dead time, and BuShips began work on depth-finding sonars and on means of maintaining contact with very deep submarines. Mk 9 was the weapon element of this system, entering service in the spring of 1943. Even it did not sink fast enough; BuShips wanted 25ft/sec. The Naval Ordnance Laboratory added 10lb of lead, set the tail fins at 3° rather than at 20°, and made other minor changes, to achieve 22.7ft/sec in its Mod 2 version of Mk 9. Later versions were strengthened to avoid damage in carrying and launching. Mk 9 was the major wartime depth charge, since the proximity-fuzed weapons never became available in comparable quantities.

The first such project was Mk 8, aluminum-cased and magnetic-fuzed; it was considered 14 times as lethal as Mk 6, 7 times as lethal as Mk 9 Mod 1, and 5.5 times as lethal as the faster-sinking Mk 9 Mod 2. Lead-weighted, it sank much faster than Mk 7, at 11.2ft/sec. The fuze was set to explode about 20–25ft from a submarine. Work began in the fall of 1941, with the first units issued in the spring of 1943. They proved unreliable, and Mk 8 was first issued in



The destroyer escort *Edward C. Daly*, refitting at Mare Island, shows both the new teardrop-shaped Mk 9 depth charge and also the effect of roller-loading: note the stowage of arbors under each thrower, rather than under each charge. Economy of space was particularly important in a DE, with eight K-guns (rather than the four or six of a destroyer) concentrated aft.

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quantity, to Atlantic destroyer escorts, in 1944. The official BuOrd history notes that Mk 8 required considerable maintenance aboard ship, which was practical aboard a destroyer escort but not aboard a cargo ship moving stocks of Mk 8s through the Pacific. Moreover, in 1945, it appeared that the level of maintenance required would be beyond the capacity of the peacetime Navy. All Mk 8 magnetic pistols were ordered deactivated at the end of the war; one reason this was acceptable was the availability of a much better proximity depth charge, Mk 14.

Mk 14, the ultimate wartime depth charge, was teardropped (23ft/sec), stable in its underwater trajectory, and fitted with an RCA-developed doppler acoustic fuze. Preliminary characteristics, based on the Mk 9 charge, were set by the Naval Ordnance Laboratory in October 1943, sea trials following in the fall of 1944. However, the war ended before any could be issued to the Fleet. Production post-war appears to have been on a relatively small scale. In addition, there was a postwar Mk 16 depth charge, heavier than Mk 14, and produced both in hydrostatic (Mod 0) and acoustic (Mod 1) versions. It cannot have been manufactured on any substantial scale.

Besides these conventional weapons, there was a cluster depth charge, consisting of six Mousetrap warheads fired together from a K-gun and then dispersing in mid-air. Details of its operational use are not available.

Hedgehog

The most radical advance in shipboard ASW weapons was the long-range projector, or ahead-throwing weapon: Hedgehog and Mousetrap. Hedgehog was a British invention, a spigot mortar throwing 24 charges ahead of a ship in a circular or elliptical pattern. In its US wartime form, as Projector Mark 10 or 11, it could be roll-stabilized – that is, the rolling of a ship in itself would throw off the direction in which a Hedgehog barrage would go, unless the projector were isolated from that motion. In addition, the stabilizer could be used to aim the Hedgehog pattern some distance off dead

ahead. However, ship agility still limited the competence of Hedgehog to deal with a rapidly maneuvering submarine; for example, Weapons Able (Alfa) and Baker, conceived in 1945, were trainable, as were the later Hedgehogs.

Initial US interest in Hedgehog was discouraged by the Admiralty's own low opinion of the weapon, which was clumsy and generally displaced a gun mount aboard a destroyer. However, it reduced by two-thirds the blind, or dead, time associated with a depth charge attack, and, because its projectiles were contact-fuzed, it did not cause the post-attack noise associated with depth charges. Work on a US version, A/S Projector Mark 10, began early in 1942. It employed a degree of sophistication new in ASW weapons: a target designation transmitter and a target train transmitter, both based on British prototypes. Production began late in 1942, primarily for destroyer escorts and large minesweepers, as smaller craft could not bear the 40-ton recoil of the spigot mortar. From the first, Hedgehog was considered at least twice as effective as a depth charge barrage; late-war figures were as high as nine times as effective. However, at the end of the war Hedgehog was criticized for its inadequate fire control system and also its great weight.

Mousetrap

Given the value of long-range ahead-thrown weapons, it was natural to seek an equivalent to Hedgehog suited to such lesser craft as the 173ft PC and the 110ft SC. This was Mousetrap, a rocket throwing a Hedgehog charge but without recoil. It was an NDRC project, begun in March 1942 with the objectives of a range of 200yds and a dispersion among four or six rockets of about 20ft on striking the water. In theory this performance would allow for effective fire control, yet spread a lethal pattern about a submarine, as in Hedgehog; the charge was to be about 40lb, in an 80lb rocket. However, NDRC hoped to gain increased range and payload compared to the British weapon. In fact, the 85lb rocket first designed was difficult to handle on a pitching deck, and NDRC went

to a direct copy of the Hedgehog round, in weight and shape.

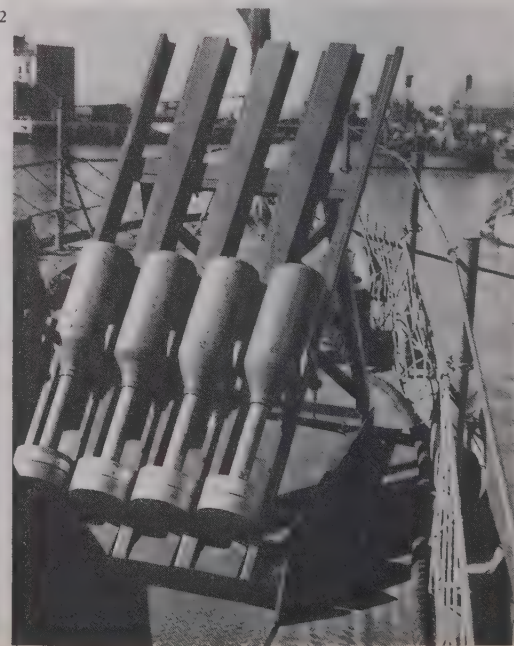
The codename 'Mousetrap' (A/S Projector Mark 20) was taken from the shape of the launcher, four steel rails spread slightly apart and raised to a fixed angle to give maximum range. Later a second set of rails was added, to form Mk 22. Both were very extensively used, from twelve *Benson* class destroyers (1944) down to small Coast Guard craft. Mousetrap was less effective than Hedgehog, given its design limitations: no roll stabilization, a smaller (and less dense) pattern, and no adjustment in range. For example, the paired Mk 22 experimentally installed aboard twelve Atlantic Fleet destroyers in 1944 were all removed as ineffective. However, it continued in service aboard small craft, as a much better alternative to depth charging.

Squid

One other wartime projector requires mention: the British Squid, which the US Navy considered twice for adoption. Squid fired a triangular pattern of three depth-fuzed charges, each much larger than a Hedgehog charge and thus possessing a lethal radius of about 21ft, comparable to that of a depth charge. Moreover, it benefited from the addition of a depth-determining sonar, which greatly reduced the error in depth from which standard depth charges suffered. In 1944 USS *Asheville* was refitted to test it, and a decade later the destroyer escort *Dealey* was completed with Squid, although all of her sisterships had Weapon Alfa.

1 A pattern of foam indicates where Hedgehog bombs have struck; these were fired by the frigate *Moberly* off Block Island, 6 May 1945, in a series of attacks which sank *U-853*, the last German submarine sunk by US warships in World War Two.

2 For small craft, the alternative to Hedgehog was a rocket-propelled (and therefore recoilless) Mousetrap, fired from racks (whence its name) in the bows, as in this view of a 110ft subchaser, *SC-724*. Unfortunately it could not be stabilized, nor could the racks be splayed to produce anything like the Hedgehog pattern; Mousetrap proved relatively ineffective. *US National Archives*



Weapon	Fuze	Number	Lethal Radius (ft)	Probable Effectiveness (percent)
Depth charge	Depth	9	21	6
Depth charge	Proximity	9	21	24
Hedgehog	Contact	24	Contact	28
Mousetrap	Contact	16	Contact	17
Squid	Depth	3	21	16
	Depth	6	21	26

Comparison of Wartime ASW Weapons

In 1946 the US Operational Evaluation Group published a summary entitled *Antisubmarine Warfare in World War Two*, which evaluated various weapons and tactics. For the major weapons, it found Hedgehog (Mk 10) and the British dual-Squid the most effective, as the accompanying table suggests.

The net effectiveness of a Hedgehog ship was increased because such a ship would find it easier to regain contact after the attack. Training was also an important consideration. For example, on a per barrage basis, Hedgehog attacks in the second half of 1943 (by the Royal Navy) were only 7.5 percent successful, but this figure rose to 23 percent in the first quarter of 1945, approaching the theoretical limit. On the other hand, Squid exceeded expectations, achieving 33.3 percent success with dual-Squid attacks in the second half of 1944, and 62 percent in the first quarter of 1945. These improvements did not correlate with major changes in sonar, except for the depth-determining gear associated with Squid.

Hedgehog was designed with the wartime Type VII U-boat in mind. Its blind time, unlike that for a depth charge, included time of flight: for a depth of about 200ft, that might be about 18 seconds at a standard range of 283yds, during which the U-boat could move about 100yds. There were two alternative patterns: an ellipse allowing for a 195ft error in deflection or 168ft in range; or a circle with a 134ft radius. Type VII had a length of about 218ft and a beam of about 20; the contact charges (30lb of TNT each) were spaced about 34ft apart. Hedgehog was considerably less effective against a faster, deeper-diving submarine such as Type XXI, which might sustain 15kts (500yds/min) while operating more deeply submerged than Type VII, greatly increasing blind time. For example, a postwar ASW study equated blind time with a 'radial probable error' (RPE) to be expected of an evasive submarine, at various speeds and depths. At 6kts and 150ft, for example, a Hedgehog would experience an RPE of 150ft; at the same depth but 20kts that figure would more than double, to 330ft. For fast-sinking depth charges (14ft/sec compared to 25ft/sec for Hedgehog, and 38 for the later Weapon Alfa), the corresponding figures were 190 and 510ft. With an RPE of 200ft, Hedgehog was credited with a 20 percent chance of killing a fast submarine; but this figure fell to only about 6 percent at a more realistic RPE of 400ft. As an interim solution, two Hedgehogs could fire together, with kill probabilities rising to, respectively, 34 and 12 percent; there would be some slight improvement if tighter patterns, about 100ft in diameter, were used.

The streamlined depth charge was useful because it could reach a submarine at 150ft in less than 11 seconds; if the submarine were evading at 6kts, it could only move about 35yds in that time, and a depth charge pattern would

probably cover a much larger range of error. However, the same submarine at 600ft would be able to move up to 140yds, well over its own length, in the sinking time of the charge. In fact, for a single-ship attack, blind time would be far greater, since the ship would lose contact at a range equal to about one-third submarine depth, and its own acceleration towards the point of attack would warn the submarine to begin its evasion. Hence the development of 'creeping' attacks, in which the attacking ship would not accelerate at all, and would be coached in by a second ship. Delays in achieving a fire control solution also added significant amounts of blind time, although it could be assumed that the submarine would not evade while the fire control system sought a solution. Thus depth charges retained a diminishing value during World War Two, a value heavily discounted by the advent of Type XXI: at 15kts and 600ft depth, such a submarine would move up to 350yds, over three times its length, while the charges sank. The faster-sinking Weapon Alfa could, however, reach 600ft in 15.8 rather than about 43 seconds, equating to about 130yds of submarine travel.

Postwar anti-Type XXI measures included much enlarged depth charge patterns, to overcome large RPEs: at a depth of 400ft even a 6kt submarine showed a 420ft RPE, and at 20kts the RPE was too large to be worth calculating. With a 200ft RPE (ie under the most favourable circumstances) a standard wartime-type 9-charge pattern (six K-guns) would have about a 20 percent chance of sinking a wartime German Type VII submarine; the 19-charge pattern then in prospect aboard some special ASW ships (fourteen K-guns) would improve that to almost one chance in three. Hedgehog would do much better. However, if the RPE were doubled, matters would worsen very considerably: nine depth charges would have less than a 10 percent chance of success, and nineteen less than 20 percent. Moreover, these figures assumed the use of influence-fuzed charges. With the wartime depth-fuzed type, the chance of success of a 9-charge (RPE 200ft) attack was less than 5 percent, and with nineteen charges only about 6. With a 400ft RPE these figures fell to, respectively, 1 and 3 percent. Depth charges were of limited (but certainly not negligible) value, and they gradually disappeared from US service during the 1950s.

At the end, their significance was as a means of prompt attack against a nearby submarine which might suddenly appear, well within Hedgehog range, and they could only be discarded with the development of lightweight short-range homing torpedoes, which could fulfill the same function and which began, in fact, as powered, intelligent depth charges. One major attempt to improve depth charge performance postwar was the careful analysis of larger and larger patterns; to achieve them, all of a ship's projectors had to fire in an exact

sequence. This was done by a timing device, an intervalometer, which could fire K-guns and drop charges automatically.

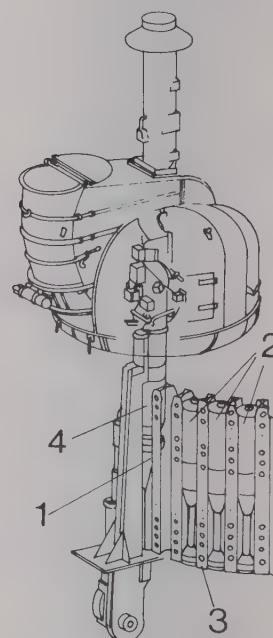
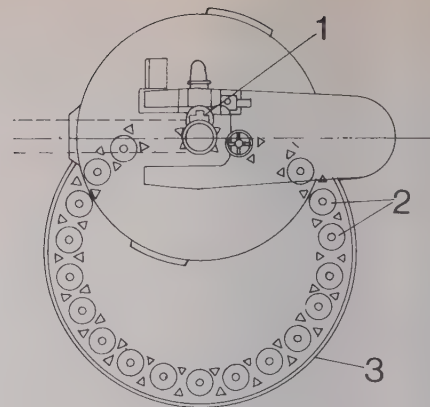
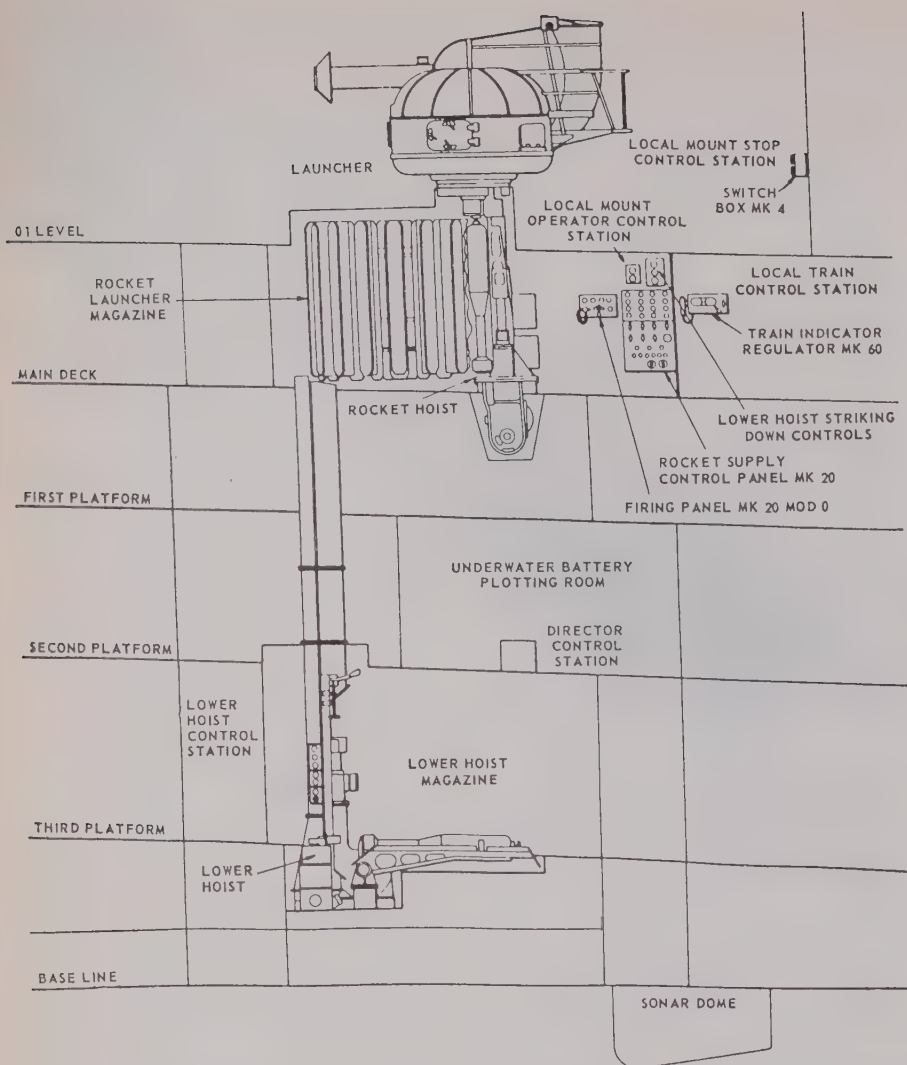
Postwar Projectors

War experience is reflected in the design of the major postwar US projector, Weapon Alfa (Rocket Launcher Mark 108). In April 1945 the Chief of the Bureau of Ordnance specified a program for the 'ultimate' armament and control equipment for ASW ships. He looked towards improved effectiveness for Hedgehog and Mousetrap through an increased sinking rate and a more powerful explosive charge. In addition, two new weapons, 'A' and 'B', were to be developed. Both would have ranges of 400–800yds, would train over a 360° arc (firing over the arc between 140° to port and 140° to starboard), and both would be able to elevate above deck (probably to 45° above the horizontal) for a combination of stabilization and range variation. Fuzing would be both influence and time (depth), the latter requiring a rapid means of fuze-setting, and a high rate of fire would be aimed at, to produce a lethal pattern. A sinking rate of 40ft/sec was desirable, and the two differed only in charge and therefore in size: 250lb of explosive for 'A', which became Able/Alfa, and 50lb for 'B' (Baker). 'Weapon B' was considered a natural successor to the wartime Hedgehog, whereas 'Weapon A' would require a specialized installation, and would probably displace a gun mount. Postwar theoretical evaluation showed that 'Weapon B' was unlikely to defeat a fast submarine, and it was abandoned. 'Weapon A', however, was built on an emergency basis as counter to fast Soviet submarines, alongside the new generation of ASW homing torpedoes. It materialized in 1949 as an automatic rocket launcher, suffering throughout its career from mechanical complexity and, therefore, from unreliability. Even so, it was a primary weapon of American destroyer ASW conversions, as well as of the *Dealey* class destroyer escorts, having been adopted to some extent in preference to the British Limbo.

A trainable Hedgehog was developed postwar as an interim ASW weapon. Mk 14 was mounted on a quadruple 40mm Bofors mounting, and appeared aboard converted destroyers. Its successor, Mk 15, was fully stabilized and so represented a considerable improvement over wartime types, in that it could finally overcome the limited maneuverability of a ship in an attack. Ironically, Mk 14 was originally conceived by the Operational Development Force as a means of studying the tactics and possibilities of small contact weapons such as 'Weapon B', rather than as a useful weapon in its own right; it first appeared in 1947. Deliveries of the more sophisticated Mk 15 began late in 1948.

Moreover, by 1948 the mass installation of ahead-throwing weapons (Mks 10, 11, 14 or 15, and Mk 108 rocket launchers for Weapon Alfa) was being considered for all ships assigned to ASW, quite beyond those of special design or specially modified; in an emergency Mk 15 would have replaced the torpedo tubes of Atlantic Fleet destroyers. Two years later the installation of a pair of Mk 10 or 11 Hedgehogs on the 01 level (forward) of all destroyers was approved; many destroyer escorts were also so modified. Advanced Hedgehogs were also planned: Mk 16, firing 36 charges, and suited to a more powerful rocket with a range 100yds

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THE 12.75in ROCKET LAUNCHER MARK 108 (WEAPON ALFA)

- Key**
- 1 Hoist lifter
 - 2 12.75in rockets
 - 3 Ready-service ring
 - 4 Tube assembly

greater; Mk 17, based on a 5in/38 mount, and firing 61 charges; and X-4, combining a Hedgehog with a conventional 5in gun mount, to provide a trainable projector even where deck space was at a minimum. None of these devices ever completed development, X-4 being canceled in 1956 after having been considered, briefly, for the new generation of fast task force escorts, which became the *Dewey* class.

Terne III was the last US weapon of this class. Developed by the Norwegian Defense Research Establishment with US assistance (under the Mutual Weapons Development Program), it was tested at Key West in September 1958, and formed part of ASW Weapon System Mark 1, installed aboard the destroyer escorts *Charles Berry* and *McMorris* at Long Beach in 1961; it was removed in 1964. Rocket-Thrown Depth Charge Mark 3 (Terne) was similar in overall performance to Weapon Alfa, with a minimum range of 400yds, a maximum of 920, and minimum and maximum depths of 50 and 700ft; it was designed to combat Type XXI-like submarines. It could be fired singly, or in a pattern of six; in the latter case the launcher aimed the weapons 20yds apart in a line perpendicular to target course. Time (depth) or proximity (doppler) fuzing could be selected, and it appears that a lethal distance of 20ft was expected. Fire control required both the usual SQS-31 or -32 sonar (a modified SQS-4), but also a searchlight sonar

(SQA-16) slaved in azimuth to the primary one, effective at up to 3000yds, and at depression angles between 5° and 35°, for depths up to 1000ft.

RAT and ASROC

The next stage was a homing torpedo which would be effective at a much greater standoff range, since it could make up for very great blind-time errors. In November 1945, for example, the Pacific Fleet called for a weapon propelled through the air to a range of 15,000yds, then homing at a speed 5kts 'in excess of highest known or estimated submarine speed'. It was to be controlled by a fire control system effective at 15,000yds, fed by a sonar capable of detecting submarines down to midget size at 35,000. These figures are still impressive almost forty years later. They suggest the extent to which the submarine threat had seized Navy imaginations at the end of World War Two.

Steps were actually taken to provide the weapon end of this system. The First ASW Conference (April 1946) recommended the development of some means of air-launching Mk 35 torpedoes from surface ships. BuOrd's response was a subsonic, torpedo-bearing missile, initially designated Kingfisher E and then Grebe, X-SUM-N-2. Within two years it had been reoriented towards carrying a lighter weapon, Mk 41 or possibly Mk 34. Both short- and long-range versions were envisaged:

5000-8000yds with a rocket booster alone, and 5000-40,000yds (20nm) by powered flight after rocket-booster takeoff. Grebe was canceled in 1950, Admiral Low pointing out that no existing sonar corresponded to its range; prototypes had already flown. However, the idea soon reemerged, given improvements both in existing and in projected sonars (such as SQS-4).

At a conference on thrown antisubmarine weapons in March 1951 a need for ranges up to 3000yds was stated: under favorable conditions, fire control sonar range might well be that great, with even better expected in the future. Existing weapons were, however, limited to less than 1000yds (750 for Weapon Alfa, 1000 for the British Limbo). Optional systems included a longer-range Alfa, a new seven-charge weapon with rapid reloading (35lb charges, with a range of 1500yds) for large patterns; and a rocket-thrown lightweight

torpedo, using the Mk 43 then being developed for aircraft use. A range of 3000yds was considered quite practicable. It was the only viable solution for such ranges, given the blind-time problem. Moreover, the rocket-thrown torpedo would have considerable advantages over existing long-range torpedoes. For example, a 27kt torpedo would require 3.3 minutes to cover 3000yds, during which time a 15kt target would move 1670. The slow (12kt) homing torpedoes would not even catch a 16kt target unless they were fortunate enough to approach from its bow. Given a rocket, an air time of under a minute was considered desirable.

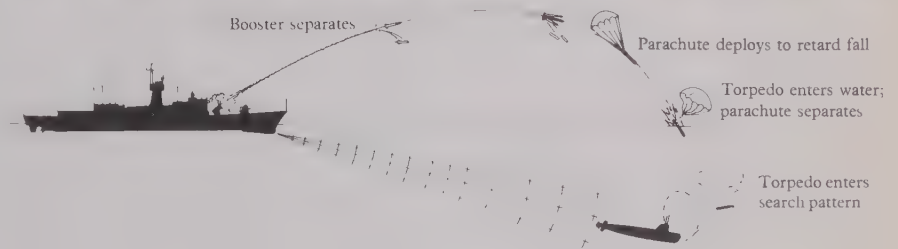
The Naval Ordnance Test Station (NOTS) made a feasibility study of the RAT 'A' rocket-thrown Torpedo (Mine) Mark 24, and tests in 1952-53 were successful, leading to a 1953 proposal for RAT (Rocket-Assisted Torpedo), with a Mk 43 Mod 0 (later Mod 1) as the payload. From the first, the RAT program emphasized simplicity, using a launcher which could be mounted atop a standard twin 5in/38 gun house; alternatively, a simple twin launcher could replace a twin 3in/50. The design range of this RAT 'B' was 1500-5000yds, consistent with both the capabilities of the SQS-4 sonar and the effective search volume of the Mk 43 torpedo, given the blind time inherent in weapon speed and range. By 1956, then, the Atlantic Fleet Destroyer Force was calling for RAT and its Mk 110 launcher (with ten reloads) to replace all existing Hedgehogs; plans required it to be installed in the FY57 missile destroyer (*Charles F Adams* class), with ASROC (RAT 'C') replacing it from FY58 onwards.

As evaluated aboard the destroyer *Sarsfield* in 1957, RAT was considered effective at 1500-3000yds against an 11kt submarine at 400ft; it actually exceeded the capacity of the ship sonar. It was expected that, although the Mk 43 Mod 4 was limited to 11kt targets, a Mod 6 would be effective against 16kt submarines at up to 600ft. However, RAT accuracy turned out to be too poor to place the torpedoes within lethal distance of the submarine, and the system was abandoned in favor of RAT 'C', carrying a Mk 44 (EX-2) 30kt homing torpedo to 1000-10,000yds. This weapon was soon combined with another concept, the rocket-thrown nuclear depth charge, which had been proposed by the Naval Ordnance Laboratory in March 1953 as a depth charge fired from a JATO (jet-assisted takeoff) booster atop a Talos booster.

The combination torpedo/depth charge weapon, ASROC, was by 1955 a 10,000yd ballistic rocket fired from a twelve-round 'pepperbox' launcher comparable in size to a twin 5in/38 mount. It was always paired with a 10,000yd sonar, SQS-23, in the proposed ship Characteristics of the period. With the failure of RAT, the ASROC fin area had to be increased considerably, and the number per launcher reduced to eight. ASROC was later upgraded by the substitution of a Mk 46 for the earlier Mk 44 torpedo. In consequence, the US Navy achieved a uniformity of ASW weapons, which could all be upgraded through improvements in the standard lightweight torpedo: the ship-launched short-range torpedo which replaced the depth charge; the air-launched homing weapon; and the ship-launched stand-off weapon. In 1983, a vertically-launched variant of ASROC, VLA, was being developed for the new vertical launcher.



Airframe separates from torpedo



1 The trainable Hedgehog was developed initially as a means of testing a proposed 'Weapon Baker', but soon became a major postwar ASW weapon. This Mk 15 is shown aboard the experimental destroyer *Sarsfield*, 2 August 1955, with a wartime-type Mk 11 alongside the bridge, in the foreground. Mk 15 was both stabilized and power-driven, and it was installed aboard many converted escort destroyers (DDE). The submarine in the background is the nuclear *Nautilus*, an example of what made Hedgehog and its brethren obsolete.

December 1950. Twenty prototypes were built before the program ended in 1953. One was refurbished in 1972, apparently in connection with tactical cruise missile studies.

3 LAUNCH PROFILE OF ASROC

2 Grebe (SUM-N-2) was the first US attempt to develop a standoff ASW missile. This prototype (presumably marked as an AA target for security) is in position for launching, wings as yet still folded. The long pitot tube protrudes from the torpedo (or a fairing representing the torpedo) beneath the airframe proper. The photograph was taken at the Naval Aviation Ordnance Test Station, Chincoteague, Virginia, 6

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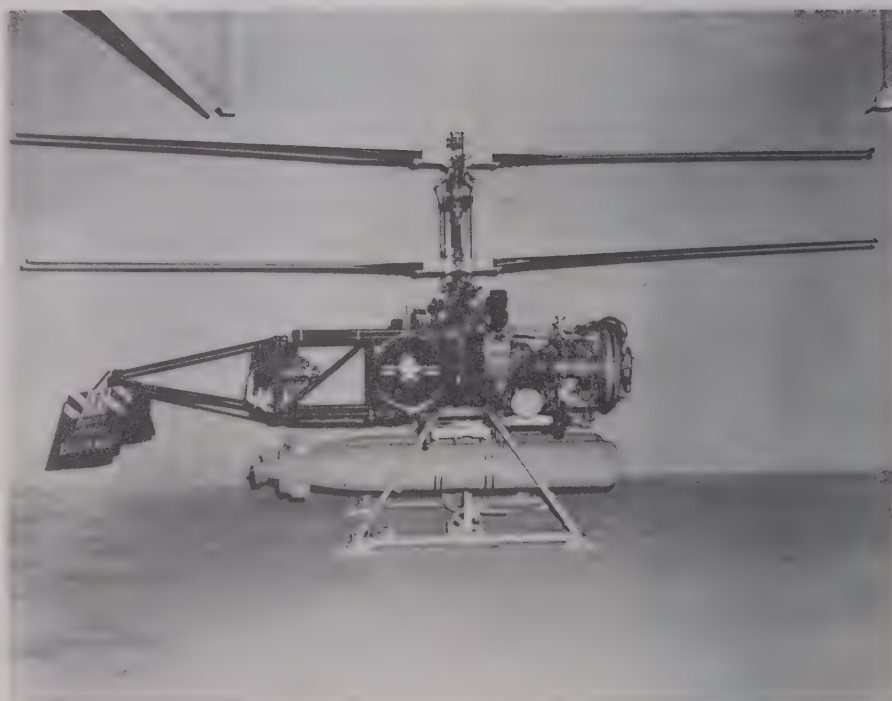


1 An ASROC (depth charge version) sits on the launcher portion of the Mk 26 system at China Lake in this June 1973 photograph. Note that the hinged forward part of the launch rail is lined up with the rear, to give the missile greater stability as it gains speed. The missile is unguided, so that accuracy of launch determines its accuracy at the far end of the trajectory. For a guided missile, on the other hand, the shorter the launch rail the less energy is lost through friction as the missile accelerates: thus in firing AA missiles the forward portion of the launch arm hinges away from the rear rails.



2 The ASROC installation of the newly refitted FRAM I destroyer *Herbert J. Thomas* shows arrangements for reloading. The small box at left contains a disassembled loader which, when set up, was seated on the fitting between the control cab and the ASROC 'pepperbox' in the foreground. The rounds themselves were carried on the right; the circles just visible in the bulkhead are blowout ports to vent gases from the accidental explosion of ASROC motors. The windowed structure was a control cab for ASROC reloading (but not firing). Even ships without reloads aboard carried such reloading arrangements, presumably for replenishment at sea.

3 The Remotely Piloted Vehicle (RPV) is not a new concept: the DASH ASW drone helicopter was developed from 1958 onwards. This DSN-3 could carry two lightweight (Mk 44) homing torpedoes or a nuclear depth charge. It did not prove sufficiently reliable in service, and very fortunately proposals to abandon ASROC entirely in its favor were not carried through. Even so, when the DASH program died, FRAM II destroyers armed with the drone were left with no effective long-range ASW weapon. In Vietnam, a version called 'Snoopy DASH' was used successfully for artillery spotting, using a commercial television camera on board. In its heyday, DASH control facilities were provided for missile cruisers with long-range (SQS-23) sonars, allowing them to control ASW attacks without paying any price in drone support facilities.



DASH

ASROC was deployed in the early 1960s aboard new construction and aboard FRAM I destroyer conversions. As expected, it required massive changes and therefore could not be fitted to many existing destroyers and destroyer escorts. This problem had actually been foreseen, at least in the Atlantic Fleet Destroyer Force, as early as 1956. The proposed solution was a small antisubmarine helicopter, a drone which could be operated in any weather and which would impose only the minimum cost on the ship carrying it. The first experiments employed a small Bell helicopter flying from the fantail of the large destroyer *Mitscher* (February 1957), with similar opera-

tions following from six other destroyers. The next step was to use a drone helicopter, a variant of the existing HTK-1 training craft which was already being developed under a joint Army-Navy program (begun in 1955). The HTK-1 drone was demonstrated aboard USS *Mitscher* in May 1957.

Designed for training, the Kaman HTK-1 had a negligible payload, and so the Navy sought a helicopter which could carry one or, better, two homing torpedoes out to a sonar contact. After a competition, it ordered a drone version of the Gyrodyne ultralight helicopter (Rotorcycle, YRON-1), which had originally been intended for observation and liaison work for the Marines. This DSN-1 (later

redesignated QH-50) drone first landed at sea (with a pilot aboard) on the *Mitscher*, 1 July 1960; on 7 December 1960 a successful drone takeoff was made from the converted *Fletcher* class destroyer *Hazelwood*.

By this time the program was designated DASH (Drone Anti-Submarine Helicopter) and great things were expected of it, to the extent that all FRAM destroyers were to have DASH capability. At one point there was even talk of discarding ASROC altogether, as DASH appeared to have a similar potential. However, the rocket was retained for very bad weather, a decision which proved fortunate. It might be noted, too, that DASH was hardly the minimum system originally conceived by the Atlantic Fleet destroyer men: it usually required a substantial helipad as well as a hangar for two drones.

The minimum DASH installation comprised an SQS-32 sonar for target detection and tracking; SPS-10 (search) and Mk 25 (fire control) radars; and radios and signal converters to transform radar and sonar signals into a form suited to display on a single consolidated console in the destroyer CIC. One remarkable lapse in the system design was the lack of any feedback from helicopter to operator. For example, it was entirely possible for an inexperienced DASH operator to flip the drone on its back and then fly it into his ship while trying to land it. This lack of feedback was a major cause of the DASH disaster. Another was bureaucratic. DASH was a Bureau of Aeronautics project, but it had to operate within a BuShips environment and, moreover, had no flight crew and no shipboard constituency. Reportedly, some captains preferred to order their drones flown into the sea rather than operate them; reportedly, too, DASH landings could often be hair-raising at best, due to the lack of feedback. Sometimes, too, destroyer radar signals interfered with drone control, with unfortunate results.

A DASH specification issued in May 1958 called for a control system capable of putting the drone within 200yds of a plotted submarine position at a range of 10,000yds (or 400 at 20,000). Performance would include a cruising speed of 80kts, an endurance of at least 25 minutes, and the capability to hover for at least 20 percent of total endurance time. Other requirements were quick reaction (launch within 30 seconds) and low signature on approach to the target area. A single Mk 43 torpedo would be carried. DSN-1 was not quite up to these standards. On operational evaluation off Key West in February-March 1961 it made 38 attacks on a radar reflector at ranges out to 9080yds, plus nine dummy weapon drops against a submarine at ranges out to 14,540. Unfortunately, it was unable to lift even a single Mk 43 under the high temperature and high humidity it encountered. Moreover, its low reliability made quick response unlikely.

DSN-1 was only an interim drone pending production of a more powerful turbine model, which would carry two Mk 44 or one Mk 46 torpedoes, or a single nuclear depth charge. This DSN-3 (QH-50C; DSN-2 was a development model) first flew in January 1962; on 7 January 1963 USS *Buck* became the first DASH ship to complete Ship Qualification Trials. Although operational evaluation aboard USS *Hugh Purvis* showed further reliability problems, DASH proceeded rapidly in view of the enormous investment already made in ship

conversions. Even some nonconverted ships, such as missile cruisers, were fitted for DASH control, on the theory that they could use other ships' drones to prosecute their own sonar contacts. In fact, nearly all the FRAM destroyers were ready for DASH long before the system could be considered mature. In 1970 the GAO, trying to explain the failure of the DASH project, described it as a seven-year program telescoped into three.

Through the 1960s there were periodic efforts to overcome the problems of DASH, but none quite succeeded. Of 746 drones built, over half were lost at sea: by 1968, one DASH was lost, on average, for every 80 hours of flight. DoD turned down a Navy request for \$31 million to continue DASH production through FY68, at which time about one hundred ships flew the drones. Two years later only half remained, mostly FRAM IIs which had no other quick-reaction long-range weapon system, and no long-range ASW weapon at all beyond the Mk 37 torpedo.

Yet helicopter weapon delivery did make sense. The Royal Navy built what amounted to a manned DASH (which it called MATCH) and operated it from many frigates, long before it adopted its own equivalent of ASROC (Ikara). The Japanese Navy bought 17 drones and lost none at all. A spotter version, 'Snoopy DASH', proved effective in Vietnam, carrying a television camera. In addition, it is not entirely clear whether the failure rate of the drones should have been unacceptable. For example, in February 1967 Gyrodyne claimed that a 150-hour mean time before failure, as then observed, would make DASH quite competitive with ASROC; indeed, this figure actually exceeded the required level of 40 failures in a thousand 51-minute flights (*ie* one failure every 21.25 hours) which had led to the selection of DASH in the first place. That is, a \$100,000 DASH good for 150 hours (154 flights) would cost about \$650 per attack, whereas a single ASROC booster then cost \$5000. The problem was that such wartime rates bore little relation to expectations of peacetime training rates in a force supported by peacetime production. It was as though the loss rate of bombers in peacetime exercises was equated to the combat loss rate. The statements that 'DASH is more economical than ASROC' and that 'loss rates are unacceptably high' were actually entirely consistent.

DASH was limited, too, in that it was generally impossible to correlate sonar and radar range data, given the refraction of sound in water. At longer ranges, moreover, the drone was difficult to track on radar. Thus the inherent range capacity of the drone was largely wasted, even when it was operated from a ship with a very long-range sonar such as SQS-26. One attempted solution was a buoy, LORELI, which DASH could drop and which could provide a simultaneous radar and sonar reference point. However, even with LORELI, DASH could not accommodate any sensor suite which might permit it to acquire a submarine contact at a great range. Given the convergence zone capability hoped for in the SQS-26, and the diffuse character of contacts at that range, such a sensor seemed (and seems) essential for any long-range weapon carrier; DASH was insufficient. The current LAMPS helicopter is probably the minimum platform required, if the target is to be acquired and then attacked at very long range.

Interest in a manned helicopter capability aboard destroyers considerably predated LAMPS. During the Berlin crisis, fleet commanders requested manned helicopters as an interim ASW measure pending the availability of sufficient DASH; they also wanted the DASH program expedited. In addition, by early 1962 the Long Range Objectives Group was proposing the construction of about 29 helicopter-carrying ASW destroyers (which later became Project 'Seahawk') by 1970. This project in turn was based on a 'Patrol Escort' or PE which Op-93 had proposed in 1959. The PE was to have been a broad-beamed ocean escort carrying six HSS-1 helicopters, and intended specifically to shadow Soviet submarines (presumably primarily missile-carriers) for 'cold war coercion'. It was rejected at the time as less efficient than conventional DASH-carrying ocean escorts in the more conventional ASW roles it would generally have to fill. However, renewed Op-93 interest in helicopter escorts may have resulted in an Operational Requirement for a lightweight manned ASW helicopter, which was being framed in March 1962.

SUBROC

In the 1960s, ASROC was by far the best surface-ship standoff weapon available, but even so it was a very limited one. Originally, it had pushed sonar development out to 10,000yd direct-path range, but by the late 1950s SQS-26, with perhaps twice that range (particularly using bottom-bounce) was in prospect.* Longer-range versions of ASROC (variously designated ERA, for Extended-Range ASROC, and LASROC, for Long-range ASROC) were proposed from about 1962 onwards, but they were never funded; in 1983 ASROC remains a limited weapon and extensions of range remain unfulfilled operational requirements.

Contemporary with SQS-23/ASROC was a dramatic increase in submarine sonar detection range, to the point where a torpedo would no longer be able to exploit it properly. In 1956 the Nobska Committee, which also recommended accelerated development of what became *Polaris* (see Part VI), suggested the extensive use of nuclear weapons in ASW, particularly in nuclear torpedoes (ASTOR, Mk 45) and in a submarine-launched nuclear missile, which became SUBROC.

The SUBROC concept actually originated within BuOrd about 1953, as part of the ALIEX study which followed ALIAS ('Betty' nuclear depth bomb). In the spring of 1955 the commander of the Pacific *Regulus* submarines, Cdr J D Miller (SubDiv 51), proposed a solid-fuel, torpedo-tube-launched bombardment missile. A more elaborate proposal, submitted by the missile officer of the *Tunny* that December, looked toward antiship applications, but the SubPac and Pacific Fleet staffs were more interested in shore bombardment: it would make every submarine an SSG. OpNav issued an Operational Requirement (AS-08701) for a Submerged-

*It appears, however, that for quite some time SQS-26 did not fulfill its developers' hopes. It was so powerful that it suffered unduly from reverberation, and considerable detailed sonar dome (including the advent of the rubber dome) and electronics work was required; at first, it did not provide significantly better performance than the much smaller SQS-23.

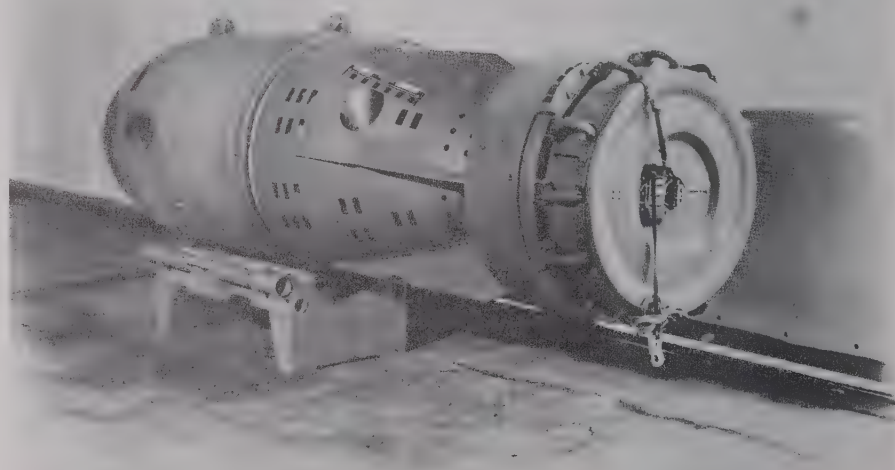
III. UNDERWATER ORDNANCE

Launch Missile System in April 1956. Like other naval bombardment projects of the time, this one was nominally ASW-oriented, although at first BuOrd expected that it would be useless against submerged submarines in view of insufficient underwater fire control ranges. Development began early in 1958, funds becoming available with the cancellation of the Triton SSM. The shore bombardment function survived with provision in the warhead for an airburst fuze.

SUBROC was certainly the most futuristic weapon of its day, launched underwater, rocket-propelled to its target, and guided through its flight by an inertial system to assure accuracy. It benefited considerably from its high speed, which greatly reduced system blind time, and it is usually credited with a range of about 35–40nm, *ie* about first convergence zone. Development began in June 1958, and it was service-approved in July 1966; production was completed in 1972. A torpedo-carrying version of SUBROC, to a 1962 Operational Requirement, was never developed, although it did lead to a proposed Submarine Tactical Missile, STAM (see Part VI). STAM was largely an anti-surface-ship weapon; during the development of the nuclear SUBROC just such use was contemplated, and SUBROC-type weapons formed an important element of the projected antiship threat, against which US defensive systems were designed. Ironically, the Soviets did copy SUBROC (as SS-N-15), but the parallel anti-surface-ship threat was the more conventional submerged-launch SS-N-7 ('Charlie' class submarines).

SOW

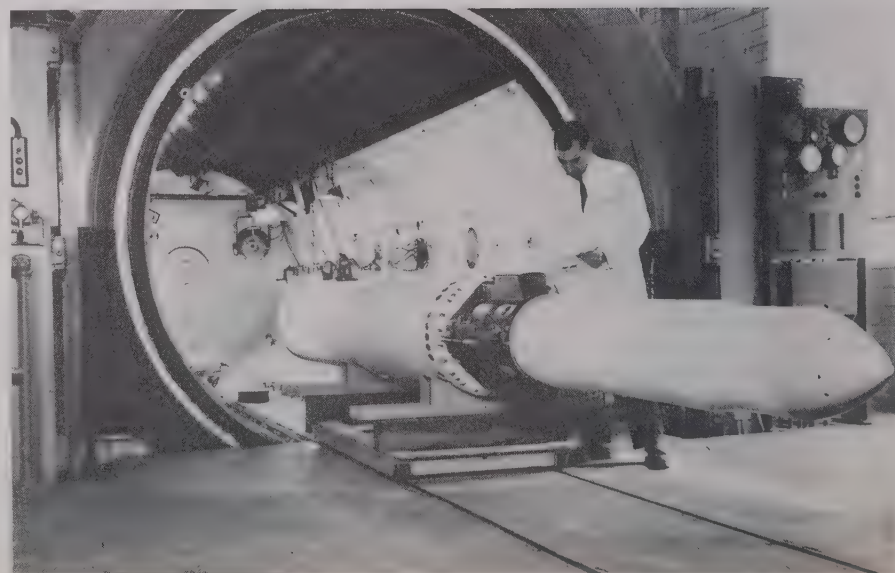
By the late 1970s SUBROC was ageing. Perhaps most importantly, it was not compatible with the emerging digital fire control systems, and there was no willingness to redesign it. Proposals for a new Stand-Off Weapon (SOW) were solicited, with alternative torpedo and depth charge payloads to be considered from the outset. The advantage of the former would be much increased willingness, on the part of the US government, to permit its use; without some conventional (non-nuclear) option, the submarine will generally be unable to exploit its excellent sonar per-



1 Nuclear depth bombs were developed even before nuclear torpedoes and ASROC; this is an HSS-1 (H-34) helicopter with a 'Lulu' (Mk 101) at its side, January 1961. 'Lulu' represented a considerable advance on the earlier 'Betty', which was far too large for most aircraft to carry; indeed, the Grumman S2F (S-2) had to have its bomb bay bulged for the purpose. Lulu in turn was succeeded by a depth bomb version of the Mk 57 bomb, 'Hotpoint' (Mk 105), also known as 'Little Lulu'.

2 A rear view of the 'Betty' nuclear depth bomb, equipped with a Mk 1 Mod 0 afterbody, a Mk 19 Mod 0 release mechanism, and a Mk 22 Mod 0 parachute pack. Gross weight was 1243lb.
Atomic Museum, Albuquerque

3 SUBROC, the submarine-launched ballistic rocket with a nuclear payload, was developed in parallel with ASROC and ASTOR, and is associated with long-range submarine sonars such as BQQ-2. It is not compatible with the new digital fire control systems and is being phased out of service in favor of the Mk 48 torpedo and, hopefully, the new ASW Stand-Off Weapon (SOW). Here one emerges from the pressure chamber at the Naval Ordnance Laboratory, White Oak, October 1964.



formance in anything short of nuclear war. Alternatively, it will have to waste considerable time approaching to within torpedo range of a target, reducing greatly the saturation level which can defeat a submarine barrier of which it is an element. In the case of SUBROC, the homing torpedo version fell foul of skepticism that the weapon would hit within the torpedo's lethal search volume. Perhaps as importantly, it was perceived by some as a rival for funding for what became Mk 48.

Boeing and Gould were awarded the SOW development contract in May 1981, after a competition with General Dynamics, Good-year and McDonnell Douglas. It employs an encapsulated solid-fuel rocket which ignites after reaching the surface. General Dynamics proposed a derivative of its Tomahawk cruise missile, which would be able to capitalize on its relatively long endurance by dropping sonobuoys to localize a submarine before attacking with a torpedo or depth charge. McDonnell

Douglas proposed an integral rocket-ramjet for high-speed, long-range cruise operation with minimum blind time; it was also surface-ship compatible, presumably as an ASROC replacement. From time to time during the 1970s a torpedo-armed Harpoon derivative, Tarpon, was also proposed for the latter role.

6. Sonar systems

Aspects of Sonar Design and Performance

Sonar performance effectively limits the performance of almost all ASW systems. Apart from some nonacoustic sensors, most of which (like MAD) operate only at very short range, ASW depends on active and passive sonars. Optimism and pessimism seem often to be functions, not of weapon characteristics, but rather of the state of sonar development – it was the short range and poor detection probability of existing sonars which so depressed the ASW community just after World War Two. The advent of SQS-26 was responsible for a new round of optimism, and its failure quite to live up to expectations appears to have been profoundly depressing in the late 1960s. More recently, the towed array has been greeted as the single most important ASW development of the 1970s, a statement justified on grounds of the tactical possibilities it presents. In a larger sense, SOSUS and its capabilities have dominated US ASW thinking at least since the mid-1950s, to the extent that US many ASW forces are designed very largely to prosecute SOSUS contacts. Those forces appear to use much of the low-frequency technology which makes SOSUS practicable.

Sensitivity to inherent SOSUS vulnerability has led to a variety of possible alternative wide-area acoustic detection systems. The recent success of towed arrays offers the first prospect of achieving this goal. An earlier approach, the former air-dropped Mobile Surveillance System (MSS) survives as the Rapidly Deployable Surveillance System (RDSS), although its operational future is uncertain. The more ambitious Surveillance Towed Array Sensor System (SURTASS) seems much close to fruition. These mobile systems also offer the possibility of SOSUS-like coverage in areas such as the Indian Ocean, which will not, for political or for physical reasons, support the current fixed arrays.

Sonar systems are generally divided into passive and active ones, the passive ones having been developed first. They depend upon the submarine to supply a signal, and so can (at least in theory) be defeated by aggressive silencing. On the other hand, they do not warn

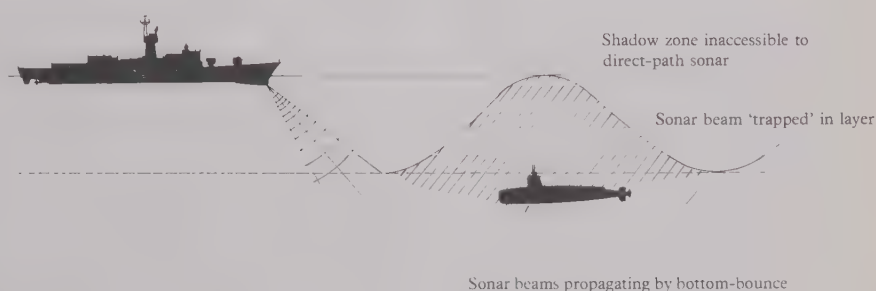
the submarine of their presence and cannot be used as a beacon for attack. Successful passive sonar operation requires that the system be able to distinguish a relatively faint noise from the surrounding noise of the sea and, often more importantly, from the self-noise of the platform. In these respects a submarine is generally a better platform than a surface ship at the noisy interface between air and water; moreover, submarines have traditionally been more concerned to avoid detection than have their surface counterparts.

Active sonars are distinguished by their frequencies, by their pulse patterns, by their beam forms, by their scanning systems, and by their power levels. Very generally, the lower the frequency, the longer the sonar range, for a given power level. However, sonar wavelength is inversely proportional to frequency, and the

size of the sonar beam is proportional to the size of the sonar in wavelengths: the lower the frequency, for a given size of sonar, the more diffuse the beam and the less the power level projected onto a target at a great distance. Scanning is a major issue because sound travels relatively slowly in water, *ie* there is a considerable time lapse between the sonar's 'ping' and the return of an echo. If the sonar operator must wait for a 'ping' to return before trying an alternative direction, he will search very slowly and, if his ship is moving at any substantial speed, his chance of detecting a submarine will be relatively small. Such 'searchlight' operation was standard until after World War Two.

The alternative to the searchlight was a 'scanning' sonar, such as QHB. In such a system, a 'ping' is sent simultaneously in all directions. The sonar receiver samples all

LAYER DEPTH AND 'BOTTOM-BOUNCE'



MULTIPLE REFLECTIONS IN SHALLOW WATER
Not to scale



directions constantly (or at least very rapidly), and thus the probability of initial detection rises. In addition, a scanning sonar does not have to rotate physically and so can be made considerably larger than a searchlight, for a better-defined beam. However, the classical scanning sonar suffers from low power in any one direction. The next step, therefore, is RDT, Rotating Directional Transmission, in which the elements of the sonar transducer are used to produce a succession of intense beams. In some systems the reception pattern is tri-axial, *ie* three beams rotate to allow for a higher search rate, or for shorter pulses. The greater the sonar range, the longer the interval between 'pings', since it is generally impossible for the system to distinguish between an echo returning from a very distant target and the echo of a subsequent 'ping' returning from a closer one. The keying ('pinging') rate is therefore proportional to the range expected; hence the common observation in accounts of submarines undergoing attack that the attacking destroyer switched from the 'long' (range) scale to a short-range attack scale, at which the more frequent 'pings' would make for better detection of submarine maneuvers.

Another major issue in sonar beam shape is the inclination of the sonar beam. The shape of most US World War Two sonars was such that a wide cone under the ship was blind: a submarine was generally lost to (sonar) view as it came within a range about equal to three times its depth. Since such loss of contact generally occurred just at the moment of attack, efforts were made to overcome it, under the designation MDC (Maintenance of Deep Contact) or MCC (Maintenance of Close Contact). In the late-war QGA sonar, the transducer tilted to maintain contact at short range. However, later MCC installations (such as Dual-MCC in many SQS-4s) employed coils which actually tilted the sonar beam without physical movement of the sonar transducer. Such systems (and, indeed the more advanced scanning sonars with RDT) are similar in principle to phased array radars.

Sonar power determines not only sonar range but also the extent to which a sonar can exploit alternative means of sound propagation. Short-range sonars employ the 'direct path', and are limited in principle to a range of about 20,000yds (and generally to far less) by the refraction of sound waves in the sea. At much higher powers, however, a sonar can actually use that refraction to gain considerable range. That is, its beam is bent down and then up, to concentrate near the surface in a 'convergence zone', a circular area around the ship a few miles wide. Just how far from the sonar the convergence zone (CZ) is depends upon sea conditions, *ie* upon the rate at which the speed of sound changes with depth, which in turn depends largely on the temperature profile of the sea. Further circular CZs are repeated at equal distances to form a series of rings around a ship. It is generally claimed that although range to a CZ target is very well defined, bearing is not, so that a target detected at CZ range cannot be attacked directly. However, the existence of SUBROC suggests otherwise, when the lethal radius of the weapon is large enough, as in this case of a nuclear warhead. Finally, in many cases high power and the ability to tilt the sonar beam provide a third propagation mode, 'bottom-bounce' (BB), in which the beam is sent steeply downwards to

reflect off the sea bottom. Both CZ and BB are reactions to the problem of the bending of sound beams by the temperature layers of the ocean, in particular the 'thermal layer'. A submarine under the layer can be detected by a direct-path sonar only at very short range, perhaps about 2000yds, because beams striking the layer at a glancing angle tend to reflect from it. However, a beam sent into the layer at the appropriate steep angle will pass through it to the bottom. SQS-26 was exciting because it appeared to incorporate sufficient power to achieve both BB and CZ operation. In fact, it was some considerable time before this potential was realized, partly because the original SQS-26 sonar domes imposed excessive power losses, and the steel 'windows' had to be replaced by rubber ones.

These surface-ship considerations apply equally to submarines. However, a deeply submerged submarine can often operate below the thermal layer and so can enjoy very great sonar ranges. Like the surface ship, it can employ BB and CZ sonar. It also has a unique mode of propagation in which the sonar beam reflects off the sea surface. Comparison of the time of return of a pulse by the three possible paths (surface reflection, direct and BB) can, for example, give the depth of the sonar target. Finally, in theory, a very deeply submerged sonar can exploit the 'deep channel' in which the refractive effect of the sea produces a kind of waveguide for sound. The deep channel is usually described as lying at about 4000ft, accessible to towed or dunked hydrophones. It appears that the Reliable Acoustic Path (RAP) sonar proposed from time to time is an attempt to use the deep channel.

Sonar efficiency depends to a considerable extent on the size, shape, material and location of the dome surrounding the sonar. Through the beginning of World War Two, US destroyers employed no dome at all to shield their sonar transducers from flow noises. Although their magnetostrictive transducers were considerably more powerful than the quartz crystals of British asdics, effective range was far lower because the British had domes; the earliest effective US sonar domes were copied from British prototypes. By 1944, three classes of sonar dome were in US service: retractable 'fish' (ball- or torpedo-shaped) domes in sub-chasers and other small craft (WEA, QBE, JK-9/QBE and QCU sonars); retractable domes (QBF, QC and the submarine WFA) in destroyer escorts, PCs, PCEs, minesweepers (AM) and frigates (PF); and fixed or welded domes (QC series and QGA) for destroyers, fast transports (APD), small seaplane-tenders (AVD) and anti-aircraft cruisers (CL or CLAA).^{*} The earliest fixed (57.25in 'corrugated' type and 57in NRL type) and retractable (54.75in British type) domes had no baffles, *ie* no sound absorbers at the after end to keep the sonar from picking up propeller noises. All later types, and most of the 'fishes', did have such baffles, for improved performance. Wartime evolution included the development of better dome materials and 'windows' for sound transmission. All were fluid-filled, as the transducer had to make sound waves in a fluid medium for transmission into the surrounding sea. In almost all cases domes were free-flooding, but 'fishes' were fluid-filled and sealed.

A typical wartime retractable sonar dome was the Budd QBF dome, 50in long, 16in wide,

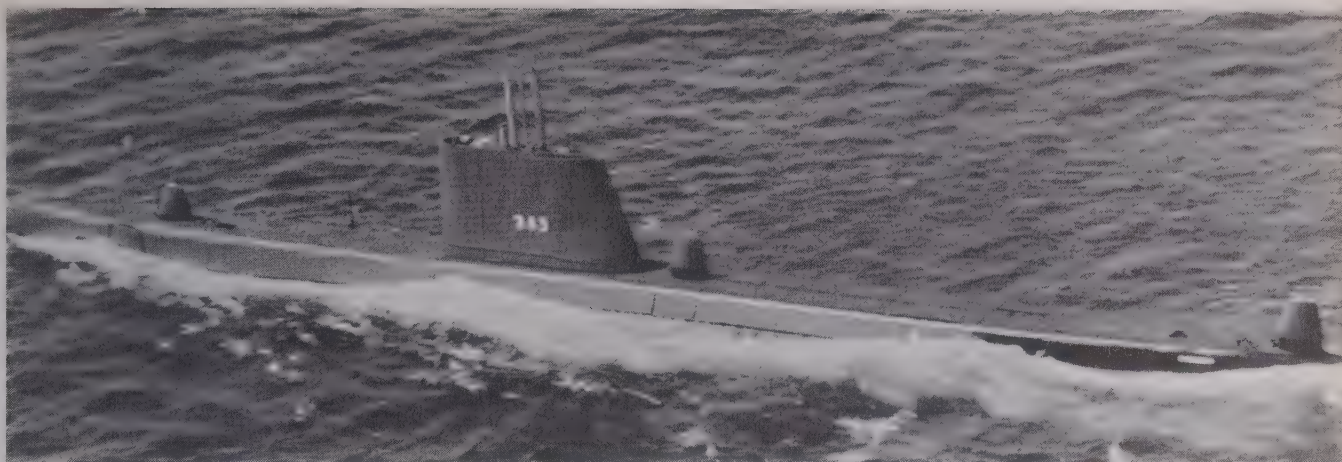
and 25 $\frac{3}{8}$ in deep, with a $\frac{1}{8}$ in expanded-steel body, and a steel 'window' 0.20in thick and 18in deep. For destroyers, Budd produced a 57in $\times$ 23in $\times$ 63.5in dome for QC-series sonars, made of 0.25in steel, with a 0.125in stainless steel window 26in deep. The *Sumner* and *Gearing* class destroyers received a new 100in dome, of improved form (and quietness), for their QGA sonars: it was 100in $\times$ 26in $\times$ 59.25in, with a 33in 'window' of 0.20in stainless steel, and a $\frac{1}{4}$ in body (with a 0.125in bottom). Postwar some *Sumners* and *Gearings* (and *Fletcher* class DDEs) were fitted with fixed 60in rubber domes.

The postwar progression to lower frequencies required ever larger sonar domes, so that low-frequency versions of SQS-4 had 154in domes (which were not retractable). SQS-26 has a 16ft diameter transducer in a 50ft $\times$ 18ft $\times$ 10ft dome. The water in such a dome makes a substantial contribution to ship displacement, and at very high power and long range the construction of the 'window' through which sonar signals pass becomes critical. For example, one of the major problems of early SQS-26 installations was excessive reflection of sound energy from the inside of the steel dome, a problem cured only when a more transmissive rubber dome was substituted. The latter is now standard, and has made a major contribution to realizing early hopes for very long-range (bottom-bounce and convergence-zone) performance in so powerful a sonar.

Postwar, sonar location was a major issue. The *Mitschers* experienced extremely poor sonar performance because their domes, well forward, were often covered by the screen of bubbles entrained by their bows. Later, SQS-23 and -26 sonars were often placed in bow domes to achieve better sonar performance, even at a considerable cost in seakeeping. In submarines, the bow was clearly the ideal sonar location. In SUBROC ships (*Thresher/Permit* and later classes) with very long-range sonars, so much volume was needed for the spherical sonar transducer that the torpedo tubes had to be moved out of the bow, in a direct tradeoff of sonar performance against weapon efficiency.

Perhaps the most extreme example of sonar placement for efficiency is a towed or dipped (variable-depth) sonar. A towed transducer makes use of the relatively quiet region well abaft a ship, even a noisy one; the towed (passive) array is the major current example. Dipping was originally a way of overcoming lost performance due to 'quenching', *ie* due to the movement of the sonar dome of a relatively small ship in and out of the water. However, it is also a way of moving a surface-ship sonar through the thermal layer, or at the least of filling the shadow zone under the ship. In US service, variable-depth sonars (VDS) appeared in two distinct forms; either as alternative transducers operating from the same signal generator and processor (stack) as the hull sonar, or as independent systems, such as SQS-35. The first experimental VDS systems were lowered from the hull on rigid telescopic rods, a system continued in the current SQQ-14 mine detector; later ones were suspended from cables. It may be noted that, to some

^{*}In fact installations varied, so that postwar most DEs had fixed domes, and in wartime many destroyers had retractable units.



considerable extent, a helicopter's dipping sonar is functionally a VDS equivalent.

Passive Sonar Systems

The earliest underwater detection systems were passive, and the submarine force continued to use passive systems such as JT through World War Two. However, most US sonar research went into active systems, and German achievements in large fixed passive array systems (GHG) were a considerable postwar surprise. Major submarine passive developments postwar included large arrays of hydrophones mounted conformally along submarine hulls to achieve very well-defined receiving beams and very long range; systems for passive rangefinding; PUFFS; and submarine towed arrays. The principal development in passive rangefinding was the perception that, if a submarine measured the rate at which the bearing of a target changed as she (the submarine) maneuvered in a set pattern, she could calculate target range. The result would not be precise, and it would depend for its accuracy on constant target course and speed, but it was still extremely useful. Supplemented by a single 'ping' for precise ranging, it might well suffice – and would certainly help the submarine avoid detection by her target.

PUFFS, originally the Passive Underwater Fire Control Feasibility Study, is a shorter-range triangulation device employing three passive sonars mounted along the length of the submarine. As the sound wave from a target strikes the submarine, the differences in time of arrival between bow, midships and stern sensors are measured and compared to yield both direction and range. The longer the submarine, the more accurate the estimate. PUFFS was developed in 1955, when a sonobuoy ranging calculation system of similar type, CODAR, was also being devised. CODAR ultimately proved ineffective, partly because it was difficult to associate the same part of a given sound wave received by widely separated sonobuoys. Matters were much simpler aboard a submarine, operating, in any case, at shorter range, and PUFFS remains more than two decades after its introduction.

For a submarine, perhaps the greatest problem of sonar operation is the 'baffle' astern: propeller noise makes it impossible for any submarine sonar system to operate within some fixed angle of dead astern. Good submarine practice is usually to 'clear baffles' by zigzagging, so that the stern arc is covered from

time to time by fixed hull sonars. However, a sonar towed astern can accomplish the same task without requiring any radical maneuvers. Moreover, the towed sonar can be extremely long, so that its beam(s) can be very narrow, very precise. The theory of the towed array is just that; with modern technology individual hydrophones can be made quite compact, so that a linear array of them can have little drag. The submarine towed array was originally developed for ballistic missile submarines, in particular need of advanced warning of approaching threats, but it was also applied to attack submarines.

One of the great advantages of the towed array was the low level of flow noise associated with it: it could operate effectively even at quite considerable speed, even at a speed beyond that at which a hull sonar could be effective. From the late 1960s onwards, projects for surface-ship towed arrays were mooted, either for surveillance of enemy ocean areas (ie as a kind of mini-SOSUS) or for tactical ASW. In the latter role the towed array suggested revolutionary possibilities. A ship operating it could steam at high speed, so much so that any submarine trying to attack the formation it was screening would have to move very fast, ie to generate sufficient noise to be detected, even at one or more convergence zones. Given a helicopter to refine that detection to the point of attack, the towed-array ship might largely solve the ASW problems of a surface force. At least that is the current (1983) view prevalent in the US surface warfare community.

Signal processing is so important an element of sonar performance, both active and passive, that it deserves mention here, even though details are generally classified. Many current sonar systems are equipped with DIMUS (Digital Multiple-Beam Steering), in which a large fixed sonar array can be steered electronically. It is the sonar equivalent of electronic steering of radar arrays such as SPY-1, and is particularly significant for the large passive submarine array sonars, such as BQQ-5. Early scanning sonars used mechanical devices to switch among reception beams, and these mechanisms were themselves sources of internal noise. Purely electronic operation, then, becomes an important means of improving sonar operation through improvement of the signal-to-noise ratio. More generally, signal processing often determines the effective range of a sonar, since it can determine the signal-to-noise ratio which the sonar can

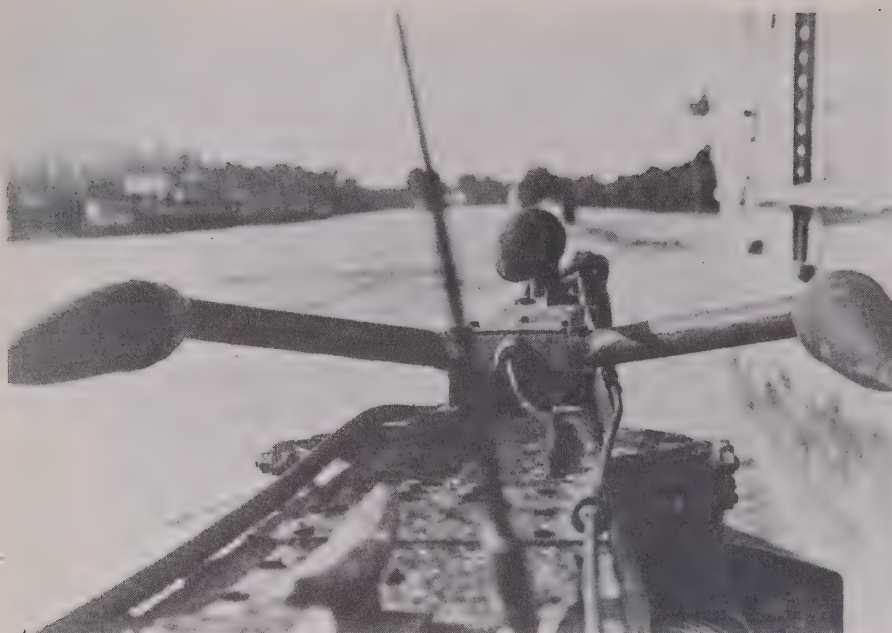
The Guppy submarine *Clamagore* shows the characteristic triplet of sonar domes of a PUFFS passive fire control system in this February 1967 photograph. The same type of system is installed on current attack submarines, but it now incorporates flush, hull-mounted hydrophones.

accept. Thus effective sonar ranges, particularly for exotic modes of propagation, often depend as much on processing sophistication as on sheer signal power level and beam-width. The extension of SQS-23 from direct-path to limited convergence-zone and bottom-bounce operation is a major case in point, achieved without major (or at least apparent) changes to ships carrying this sonar.

US sonar development began before World War One with the work of the Submarine Signal Company, formed in 1901. Its steam-operated underwater bells, operating at 1215 cycles, could be heard at 10nm; by 1912 there were bells along the coasts of the United States, Canada, the British Isles, France, Portugal, Italy, Brazil, Chile, even China, supplementing the system of lighthouses. Two years later Professor R A Fessenden succeeded in developing an oscillator, which could be keyed, for underwater signaling. He detected echoes, and proposed underwater ranging on obstacles such as icebergs; such a system was actually tested aboard the Coast Guard cutter *Miami*. As a staff member of the Submarine Signal Company, Fessenden was available to provide sound devices for the Navy during World War One.

The Naval Consulting Board set up a Subcommittee on Submarine Detection in February 1917, two months before US entry into the war. Fessenden detectors were placed aboard the destroyers *Aylwin* and *Calhoun*, but performance was insufficient. Submarine Signal then devised a very sensitive microphone for passive detection. It was, however, subject to self-noise, and had to be suspended from a float attached to a long cable, to eliminate such noises as the water lapping against the ship's hull. The result became known as the drifter set.

The other two major experimental stations were Nahant (a joint venture of Submarine Signal, General Electric and Western Electric) and New London (the Naval Experimental Station). Nahant devised the C-tube, a pair of 3in rubber spheres set 5ft apart on an inverted T-pipe, which could be turned until the sounds were equalized and the bearing of the sound source known. Ultimately six or more spheres



were used at each end of the 'T', for greater sensitivity. The next step was to modify the drifter set to incorporate this direction-finding system. The 'compensator', an indicator of the angle of incidence of a sound wave striking a line of microphones, was designated the K-tube. Three microphones were arranged in an equilateral triangle, two being used simultaneously, with their outputs connected to two earphones. Instead of rotating the microphones, as in the C-tube, air lines were used to compensate for the difference in time of arrival of sound at the two; when the two earphones matched, an operator could read off the bearing of the sound received. Such compensation of the different elements of a fixed array to obtain (in effect) a moving beam is the basis of large fixed array sonar systems, although in those devices the compensation is electrical.

In practice it was found that the directional (binaural) devices were more effective than the omnidirectional microphones in picking up a new sound, although the latter could hold a fading sound out to a considerable distance. The C-tube, for example, was credited with a range of 1000–8000yds, with an observation time (in sprint-and-drift operation) of about 90 seconds and a bearing accuracy better than 5°. The K-tube was considered effective as an initial submarine detector, but could not be operated by a moving vessel, *ie* it could not be used in hunting. To overcome this defect, Nahant developed in April 1918 the OS-tube, which could be towed and which could, under some conditions, detect submarines while a ship was underway or, with its engine shut down, while it still had some way on. It was considered an improvement on the performance and weight of the British 'Nash fish'.

Readings were typically taken from one to two minutes after a sub-chaser's power had been shut down. A 4 or 5kt submarine could be heard at 1–5nm and surface ships at 8–15nm, and direction-finding accuracy was generally better than 10°. The OS device consisted of a steel spreader towing three K-tube fish in the form of an equilateral triangle, 4ft on a side. A total of 210 were built, compared to 1020 C-tubes.

Nahant also produced the OK-tube, which

combined the qualities of the drifter and the OS-tube, consisting of a metal streamline spreader with a metal float, supporting the three K-tubes. A lightweight version for airships could follow a submarine at about 1000yds while the airship flew at 4 or 5kts overhead. Another variant was the Y-tube, for submarines, consisting of three rubber fish (K-tubes) rigidly connected. It was first tested on the bows of the submarine *G-1*, on 27 and 29 March 1918. The standard installation was a pair of Y-tubes, one for the submarine's deck (for submerged operation only) and one for the keel, which could be used when the submarine was surfaced. About 80 complete sets, plus 25 for deck installation only, were built. The Delta-tube was devised in December 1917 for water or oil tank installation aboard destroyers. It consisted of a steel spider supporting three K-tubes; about 100 were built. Presumably the water or oil tank had much the role of the later sonar dome, permitting sea sounds to enter the sound detector. Finally there were devices such as the PB-tube, which could be used by a seaplane drifting on the water. Like the others, it employed three K-tubes (in its case, suspended separately from three rings on the bow of the seaplane).

New London pursued an entirely different approach, the MV-tube. Proposed in July 1917, it ultimately consisted of twelve carbon button-type microphones in a blister on each bow of a ship, feeding sound through phased circuits to a compensator, which could measure bearing to within a few degrees. MV-tube installations continued postwar, and to some considerable extent eliminated the need for towed devices. Even so, they could not overcome the need to shut down shipboard noise sources when searching.

Probably the last of the wartime passive systems was a quartet of Fessenden oscillators located in the forepeak tank of each of two destroyers. Each was screened from the others to detect only a single quadrant. By pairing the oscillators, an operator could measure target bearing.

These passive systems were more than ASW systems. Postwar experiments showed that they could detect surface ships even when the

These hydrophone 'ears' aboard the submarine *K-5* (1919) formed a Y-tube, consisting of three rubber 'fish' (K-tube units) spaced 4ft apart at the vertices of a triangle; each K-unit in turn enclosed a microphone listening at one end of a brass tube with a rubber cap. All three were connected to a compensator which could, in effect, rotate the beam along which the Y-tube listened without physical rotation of the 'tube'. A triple K-tube on a special spar was first tested aboard the submarine *G-1* on 27 and 29 March 1918, and the Y-tube itself was adopted the next month, submarines generally being fitted with deck and keel outfits (the latter for use while on the surface) and the compensator being connected to either deck or keel unit. General Electric built about 80 complete sets at Lynn, Massachusetts, as well as 25 Y-tubes for deck installation (*ie* for use only when submerged).

listening destroyer was steaming. On this basis the *Omaha* class light cruisers were fitted with MV-tubes for their surface scouting role.

Active Sonar Systems

The major development in ASW at the end of World War I was active sonar. As developed before World War II by the US Navy it was generally termed 'supersonic', *ie* operating at frequencies above those heard by the ear (at or above 15 kilocycles). Such operation avoided much of the ocean noise (which is at lower frequencies), and permitted relatively small transducers to project narrow beams. It was also claimed that signal amplification was simpler at supersonic frequencies. The basis of the earliest sonars was a quartz steel transducer, employing the piezoelectric property of quartz crystals to transform an oscillating electric current into supersonic waves. It was devised in 1917 by a French physicist, Paul Langevin, who saw it not as a submarine detector, but rather as a means of underwater telegraphy, secure from enemy interception because of its supersonic frequency.

In the summer of 1918, American officers of the ASW section of the Headquarters of US Naval Forces in Europe saw a demonstration of the Langevin apparatus on a ship at Toulon, including the pursuit and (theoretical) destruction of a 'tame' submarine. By October 1918 Langevin was detecting submarines at 1000 and 2000yds and communicating underwater at 8000. A working model of his detector was at sea, but it did not see action before the end of the war. At that time the Allied ASW Committee was dissolved, but Britain, France and the United States continued their work. The Royal Navy, for example, obtained echoes from a submerged submarine as early as 1921. In American tests (using a sandwich of nine quartz plates) echoes were received at up to 1000–1200yds and submarines were detected in fog at up to 1000. The detection project, which was referred to as 'supersonics' (*ie* as above the frequency range of humans), was assigned to the Naval Research Laboratory in 1925, two Eagle boats (*PE-35* and *PE-58*) being assigned in 1927, and brought from the West to the East Coast.

The first US active sonar, QA, appeared at sea in 1927. Its transducer consisted of quartz slabs between steel discs about 16in in diameter, the entire assembly being about 4in thick. It could emit 1/4-second pulses ('pings') at 15–20 kilocycles, and was effective at speeds of 3–4kts. The power level was 20 watts, and by 1930 such equipment was giving a bearing accuracy of 1° and a range accuracy of a few yards at 4000yds. A 1930 Bureau of Engineering report claimed that the Eagles had detected 'S' class submarines in 15 fathoms, abeam, at

up to 4200yds on a choppy day. However, the smaller sonar target presented by the bow of such a submarine reduced average detection range to 1500yds. A smaller submarine had a smaller target cross-section, and so could be detected only at shorter ranges (about 75 per cent of S-boat range on an O-boat). Tests also showed that a submarine at 8kts produced a wake which was detectable out to 1000yds astern, and which could be distinguished from the submarine proper. In other tests, an S-boat attacking an Eagle boat was detected (at 1600–2800yds) on six of seven passes, the seventh being missed because the sonar was switched to a loudspeaker rather than to the headphones previously used.

QA was first installed in the submarines S-49 and S-50 in the spring of 1927, the transceiver protruding above deck using a periscope. At about the same time the two Eagle boats were fitted with amidships wells for retractable transducers at the Norfolk Navy Yard. The larger and more modern submarines V-1 and V-2 were fitted in November and December 1929, the destroyers *Southard* and *Hovey* following in March and May 1930. Plans for FY31 included one heavy and one light cruiser, with more to follow. At the time sonar functions included mine detection (at up to 800yds) and it was hoped that torpedoes might be detected during their runs. However, there was no indication, at least at this time, that the US Navy expected heavy-ship sonars (passively) to detect incoming air raids or nearby ships, both of which functions seem to have been envisaged by the Germans and the Japanese a decade later.

In 1929 NRL produced a new transducer employing rochelle salts, which were far more sensitive than quartz crystals. It was first employed in a submarine listening system, JK, which was considered superior to the wartime SC, and which was mounted topside on all submarines. In a few cases it was supplemented with a small 'pinging' transmitter for underwater communications; sometimes there was an underwater telephone as well. JK increased effective passive detection range to about 5nm. The same transducer technology led to a new sonar, QB, in 1931. It operated at much the same power level and frequency range as did QA, and was mounted aboard all new submarines, generally protruding from their bottoms to permit its use when they were surfaced. NRL and Goodyear devised a rubber dome for QB, reducing the turbulence around it and permitting operation at 10 rather than the previous 5kts.

Finally, in 1934 a third type of transducer, a magnetostrictive type, was introduced. It consisted of hollow nickel alloy tubes, 3in long and $\frac{1}{2}$ in in diameter, wound with wire coils, which elongated or contracted with changes in current, moving a diaphragm. Magnetostriction sonars were designated QC and were standard aboard US destroyers at the outbreak of World War Two. The earliest version, ultimately designated QCA, operated at 24kc with a power output of 400W, well above the level achieved by QBs. By way of contrast, the Royal Navy continued to use quartz crystals in its asdics, as the US Navy learned when contact was resumed in 1941; however, unlike the US Navy, it had devised a permanent sonar dome permitting operation at high speed. For example, a 6 November 1941 report on the state of ASW weapons and devices claimed that

without a dome sonar was worthless above 15kts and that passive detection was impossible for a submarine speed below 3kts. However, a contact made at 15kts could be held to 20. With the British-type dome, search speeds of 20–24kts were expected, although these latter figures proved overoptimistic.

Systems Allocation in World War Two

Although some prewar US cruisers were fitted with sonars, this practice ceased in the late 1930s, the sole major exception being the *Atlanta* class, in which sonar was considered useful for submarine warning, to allow the Task Force to evade. However, by 1945 these ships were deemed too valuable to risk in a screen or in a hunter-killer group; a November 1945 Pacific Fleet sonar report described their presence as 'detrimental to efficient AS search by the destroyers. In cruising dispositions actually used during the later part of the war they have been moved in from the 7000 yard circle to the 4500 yard circle where their AA usefulness is at its best.'

US sonar installation policy, as promulgated by the General Board in 1938, called for two sonars per destroyer, and one for lesser craft. In fact many early war destroyers had both units, but the urgency of the destroyer escort program, and the relatively low rate of production of sonars, required that the policy be revised, half of the units earmarked for destroyers going instead to DEs. Submarines generally had one passive device (J series) as well as a combined ranging and sounding set, such as WCA or WFA. Wartime development of the standard QB and QC sets produced console equivalents in, respectively, QJ and QG series. In each case, successive sets were designated by letter suffixes, as in QBF and QCJ. QGA was probably the most advanced of these searchlight sonars, operating on two frequencies to achieve both accurate bearings for attack (30kc, for a narrow beam) and long range (14kc) in a new 100in streamlined dome which was expected to permit detection at up to 30kts (with the destroyer rigged for quiet running) and attack at 18–20; previous figures had been, respectively, 17–18 and 12–15kts. The high-frequency transducer tilted to maintain contact at short range.

A 1944 table of sonar assignments to surface ships shows QGA in the new 2200-ton destroyers, with a QC or QG (other than QGA) retractable-dome sonar in other destroyers, DEs, minesweepers, 173ft PCs and PCEs. Some DEs had QBF, as did the *Tacoma* class frigates, in retractable domes. However, the light transports (APD, converted from old destroyers) and the light seaplane tenders (AVD and AVP) all had QCJ or QCL in a fixed dome. The 136ft minesweeper (YMS) and the 100ft sub-chaser had QCU or QCV, lightweight sets with about half the output of a destroyer sonar; the sub-chaser had QBE as an alternative. The 136ft sub-chaser (PCS) had WEA, a lightweight magnetostrictive sonar. Late in 1944 the Bureau of Ships announced a destroyer sonar modernization program intended to provide a single centerline-mounted retractable streamlined dome (QGB, QJB, or QGC/QGD) in all modern (*Farragut* and later classes) destroyers except for the *Summers* and *Gearings* (QGA). Particular attention was to be paid to sonar interference, ships operating together tuning their systems to alternative frequencies. For example, QGB ships would

share the frequencies 20, 22, 24 and 26kc, and QJB units would divide the range from 23.6 to 25.2kc in 500-cycle steps.

These 'single-beam' sonars were considered inadequate by the end of the war: a Pacific Fleet 'lessons learned' report of November 1945 held that they were vulnerable to standard sonar countermeasures. Fast submarines, such as the German Type XXI, could evade them, and 'the man-piloted torpedo is so small that echo-ranging on it with our modern heavy-weight equipment will not produce an echo because of the thinning out of the sound beam at the surface with a normal gradient'. The same report pressed for the development of effective torpedo detection (TD) equipment, noting that the early version in fleet service had already reportedly enabled at least two US fleet submarines to take timely evasive action.

As for existing sets, Type 147B was too heavy and uncompensated for roll and pitch errors; QDA, which was, was too heavy for installation in ASW ships. Destroyers and fleet minesweepers were to be modernized with QGB and QJB (except for QGA ships), and small ships with QCU: although US small combatants had done little damage to Japanese submarines, US submarines considered Japanese escorts and sub-chasers 'far more efficient, dangerous, and nasty than their DD's and large DE's'. Surely the US Navy could do as well, given better sonars and better offensive weapons.

All of the wartime single-beam sets were effective much more as attack aids than as search devices. Before the war, the commander of Destroyer Division 60, experimenting with sonar off San Diego, remarked that 'no dependence whatever can be placed upon defense sound screening . . . a cleverly handled submarine has two chances out of three to get through. On the other hand, once the submarine's presence and location are known, time permitting, her ultimate destruction can be made fairly simple.' It followed that the major wartime improvement to sonar was BDI (Bearing Deviation Indicator), which permitted a sonar operator to maintain contact with an evading submarine.

BDI was achieved by splitting the beam of the sonar, and comparing echoes from the two sub-beams, a technique analogous to the lobing used to improve the bearing accuracy of fire control radars. Another important wartime development was Maintenance of True Bearing (MTB), which stabilized the sonar display with respect to the compass rather than with respect to ship heading: a sonar operator aboard a maneuvering ship could plot submarine positions far more effectively if his equipment presented submarine positions undistorted by the effect of that maneuvering. Again, wartime radars showed a similar development in the form of the north-stabilized PPI display, which made it easier to understand an evolving air-sea battle from the Combat Information Center below decks than from the bridge.

It also appears that only in wartime were attack aids developed to translate sonar data into fire control data. The first was the 'chemical range recorder', a British invention which presented successive sonar echoes as horizontal traces on a moving paper strip. The position of the trace indicated range, and the trend in positions indicated target range rate for fire control. There were also two plots: a

III. UNDERWATER ORDNANCE

geographical plot to regain lost contact, essentially a modified DRT (dead-reckoning tracer); and a large-scale relative plot to conn the attacking ship into position, the Attack Plotter. Its inputs included target range and bearing from the sonar, and own-ship course and speed from the ship's gyro system and pitometer log. A late-war modification displayed the position of the second ship in a creeping attack. Target course projection was particularly important because contact would be lost as a ship approached the target: the sonars all had beams sloping downwards, so that at very short range the target would be *within* the upper edge of the beam. Indeed, this property of vanishing was used as a rough estimate of target depth (one-third of the range at which contact was lost) prior to the appearance of special depth-determining sonars such as the British Type 147 and the US QDA.

At the end of World War Two the Pacific Fleet considered the absence of an ASW fire control computer (to solve for submarine course, depth and speed, and automatically guide the attacker into firing position) the major gap in US ASW fire control technology. It was filled postwar, as the appendices show. In 1945 proposed limits were a target speed range of 0-30kts and depths of 0-600ft.

Scanning Sonar

The major new wartime sonar development, and the link to modern sonars, was scanning sonar. It employed a fixed transducer, a circular array of vertical 'staves' which could, together, emit a 'ping' in all directions at once. As receivers, the staves could be connected to form a sharp beam of receiving sensitivity, and this beam could be revolved rapidly (typically at 30-500 revolutions per second) to sample all directions. Each 'ping' was long enough to permit at least one complete revolution of the reception beam, so that the sonar would detect targets in every direction with equal probability, higher scan speeds (*ie* shorter 'pings') providing better resolution but lower average power and hence a lower probability of target detection. There were two wartime series, QH (for QHA, the submarine torpedo detection sonar, and QHB, the major early postwar destroyer sonar), and QK (crystal rather than magnetostrictive transducer, which was not produced in quantity). QH series sonars employed much the same technology as the QC/QG series, except that to achieve the same range performance they required about 20 times as much electrical power.

QH sonar development was carried out by the Harvard Undersea Laboratory (HUSL), the first model being demonstrated to the Navy aboard USS *Sardonyx* in February 1944. Early in 1944 BuShips asked NDRC to develop in addition a vertically mounted scanning sonar which would operate as a depth-finder in combination with a horizontal scanner, to form what it called the 'Type B' integrated sonar system. Vertical scanning made stabilization against roll and pitch particularly important; the system incorporated a stable element (as in fire control systems) and corrected for roll and pitch by a combination of the training system for the depth-finder and electrical phase shifts in the depth-listening circuits - as in a modern phased array radar. Such depth-finders became much more prominent after 1945 with increased interest in very deep-diving submarines, and integrated sonars (*ie* stabilized

units capable of depth-finding) were specified for the early ASW destroyers (DDEs). Another scanning system should be noted briefly: the QLA, a frequency-modulated, high-definition scanning sonar which permitted submarines to penetrate Japanese defensive minefields in home waters.

Passive Sonar in World War Two

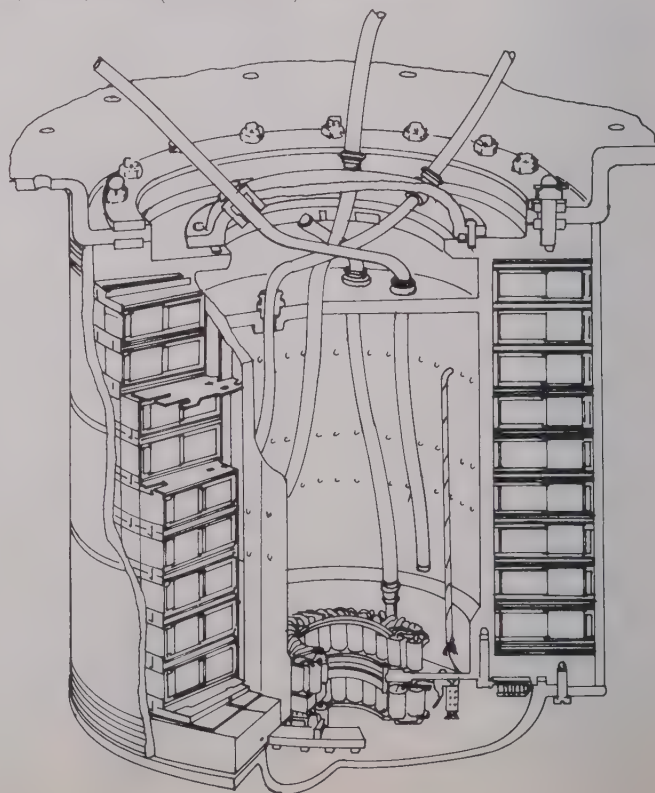
Wartime sonar development also embraced passive systems, beginning with simplified listening gear proposed in 1942 for use by small craft which, it was hoped, might be able to detect and localize submarines even though they could not themselves attack them (JP, a mechanically steered supersonic system).

As in the case of hull sonars, helicopter sonars progressed to scanning operation and to lower frequency, *ie* to greater size. This is an AQS-10A transducer being lowered by an SH-3A Sea King helicopter from the carrier *Hornet*, 24 January 1969. The stave construction (transducer elements arranged vertically) was typical of such hull sonars as SQS-4 and SQS-23.

US Navy, by courtesy of Norman Polmar



THE AN/SQS-4 SONAR SYSTEM (TRANSDUCER)



There were also sonobuoys (see below). Submarines combined sonic and supersonic systems, the latter often preferred because of reduced background noise and the possibility of better directionality. However, wartime research made the sonic band far more useful, and efforts were made to develop an effective sonic hydrophone. The other major wartime development in this area was the line hydrophone, giving good directionality in the sonic band. Effective wide-band amplifiers were also developed. Applications included torpedo detection on a passive basis. Postwar, the US Navy discovered that the Germans, too, had been working on sonic (*ie* relatively low-frequency) passive sonar, including torpedo detection and evasion systems; operational systems (called GHG, and consisting of arrays of hydrophones) were captured in 1945, to form the basis of many postwar systems.

Sonic systems for submarines became important in World War Two partly because, although supersonic equipment could detect the broad-band noise of propeller cavitation, the characteristic peaks which permit a submarine to identify a surface ship are in the sonic range. Moreover, lower-frequency sounds travel much further in water. In addition, the standard US submarine sonar was mounted below the keel, so that the submarine could not listen at any frequency while lying on the bottom. The patrol craft system, JP, was adapted to submarine topside use, with the secondary function of detecting submarine self-noise; in some cases it could detect surface ship propellers at 20,000yds, and destroyer auxiliary machinery at up to 1000. However, JP was rotated mechanically by hand, and it was believed that its effectiveness was sharply reduced by the structural transmission of vibration from submarine to hydrophone, as well as by waterborne noise from the machinery and even from the superstructure of the submarine. Improvements included continuous rotation and power training of the hydrophone, as well as a right-left indicator (RLI) system for more accurate bearings, and the incorporation of a supersonic converter to allow for either sonic or supersonic target tracking. JT was the ultimate result of this development.

Postwar, QHB became the standard destroyer sonar, since it was the only one with even a fair probability of detecting a fast

submarine. Considerable efforts were concentrated on a variety of high-definition 'attack' sonars (SQG series) in connection with the 'Weapon A' program. However, sonar range remained a problem: as late as 1948 NRL could offer no hope of any major extension. Tactically, that meant large numbers of escorts if submarines were to be prevented from penetrating to attack screened formations – hence the attractiveness of inexpensive sonar barrier devices such as sonobuoy screens and helicopters with dipping sonars. In fact, however, the immediate solution was a new generation of lower-frequency sonars.

Postwar Systems

SQS-4 was proposed in 1948 as a 14kc equivalent of QHB, with about double the effective range. It was later rated at 4500yds, although calibrated for 15,000. Wartime sonars such as QC or QHB were effective out to about 1500 or 2000yds. With RDT (tribeam), SQS-4 had a range as great as 8000yds against a submarine in the thermal layer. In later versions its frequency was as low as 8kc, and it was succeeded by the 5kc SQS-23, with an estimated range of 12,000yds under similar conditions (and generally described as a 10,000yd sonar). In 1955 NRL proposed yet another step down in frequency, to what became SQS-26, the largest US sonar, at 3.5kc. It was credited with a range of about 23,000yds on a shallow submarine (as designed), plus bottom-bounce and convergence-zone operation.

From the late 1950s on, there was increased interest in passive detection of submarines by surface ships, presumably because very fast submarines could begin to fire at the noise beacons of shipborne long-range sonars. Initial developments were described as PADLOC (Passive Detection and Localization) and, when applied to the existing SQS-23, as SQQ-23, the second 'Q' denoted multiple functions. SQQ-23s had a second sonar dome to house the passive transducer, but some recent conversions of existing SQS-23s have only a single dome. For many years SQQ-23 was known through the Fleet as the most effective passive submarine detector, far surpassing the larger SQS-26, particularly aboard a well-silenced ship.

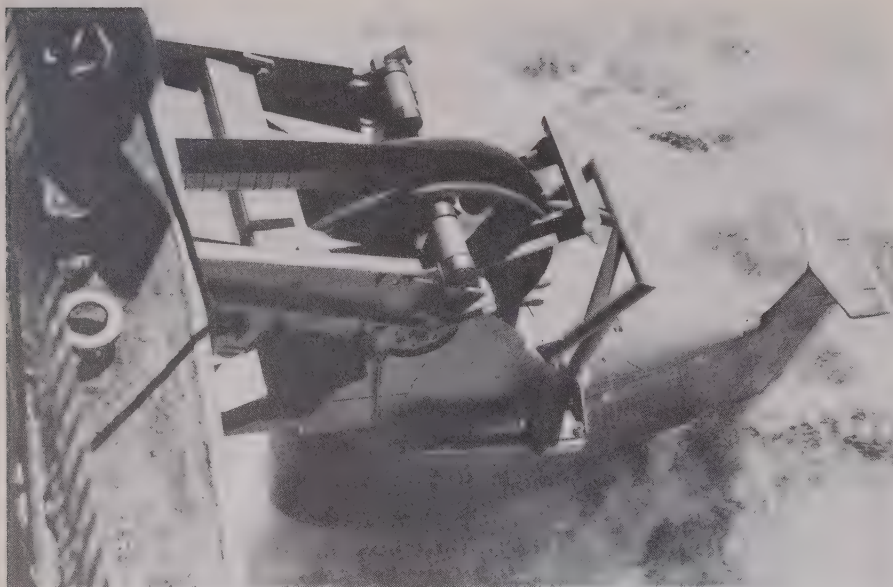
Several special sonar devices have appeared. ASPECT (Acoustic Short Pulse Classification

Technique) employs a series of very short pulses to resolve a target into parts which can be recognized by an observer. Since classification of sonar targets is a principal problem of sonar operation, ASPECT is, in theory, quite valuable. Without it, the chief classification technique is observation of target motion through the doppler effect. SDT (Steered Directional Transmission) allows an RDT sonar to track a target continuously. Four major modifications to SQS-23 have greatly improved its capability. TRAM (Test, Reliability and Maintenance) split the transmitter into two groups, either one of which could maintain operation, though at half power; Group A, for example drives elements 1, 2, 3, 8 and 9 of the ten (numbered downwards) in each stave. TRAM also adds Performance Monitoring Equipment (PME), and an 83-track tape recorder used to record and reproduce a sonar 'picture' for training and testing; a range and bearing test set; a transmitter test set; and SDT. The Modest Improvement Program (MIP) reduces scope clutter caused by reverberation, and adds a frequency-modulated (FM) transmission mode for better performance. The Long Range Addition (LORA) gives SQS-23 a convergence-zone capability similar to that of SQS-26. Finally, the Performance and Integration Retrofit (PAIR) adds the second transducer independent of the main one. It incorporates SQS-26 technology and achieves track-while-search capability; passive capability effective during active operation; a visual display of doppler; and computer-aided performance monitoring and casualty location.

Current surface ship sonars are SQS-23, SQS-26 (with SQS-53, a transistorized version), the SQS-35 independent VDS, and the small, direct-path SQS-56. The latter marks a retreat from the large active sonar, partly in view of the danger of beaconing, and partly in order to keep cost and complexity down in a ship largely oriented towards anti-aircraft operation, the patrol frigate (*Oliver Hazard Perry* class, FFG-7). To some extent, too, its

The destroyer *John W Thomason* shows the SQA-8 variable-depth sonar installation, rejected in favor of SQA-10. Note the top and bottom fins used to stabilize the towed 'fish' in depth as well as the relatively elaborate installation compared to SQA-10.





continued procurement reflects faith in passive towed arrays such as SQR-19.

Towed array development was inspired by the success of the passive SOSUS arrays, and experimental devices appear to have been under test as early as 1962. In 1967 a design project for a tactical surveillance ship (designated PR at the time by Op-93) included a towed array for submarine detection at minimal ship impact levels. Early work was done by Hughes. By the early 1970s an SQR-15T TASS (Tactical Towed Array Sonar) was being tested aboard two minesweepers, MSO-520 and -521, reclassified as 'miscellaneous auxiliaries' for these trials in 1973. A production SQR-18 escort array was procured under the FY76 and later programs, two prototypes having seen service earlier. It is towed from the 'fish' of the SQS-35 VDS, and is considered an interim system pending the introduction of the advanced SQR-19. The great merit of the towed array is that it permits reliable long-range submarine detection at great range (reportedly beyond the first convergence zone) even when moving at speed; the LAMPS III program is associated with towed array operations, as the LAMPS I was with SQS-26 convergence-zone operation. Towed array technology has also been applied to submarine sonar operations.

Submarine sonar suits have always been more complex than those of surface ships. In 1953 a standard fleet submarine of World War Two type had WCA (combined QC and JK supersonic passive sonar plus QB) in a 57in steel dome, plus a secure echo-sounder on her bottom. Topside was JT or JP, as well as QLA for mine detection. There were also DCDI (Depth Charge Direction Indicator) and DCRE (Depth Charge Range Estimator) for attack evasion, with sensors mounted on hull and superstructure; and self-noise level monitors (NLM) and cavitation indicators (CI) to permit the submarine to operate as quietly as possible. At the same level of technology, a typical 'Guppy' was more complex, with a large chin sonar dome containing a BQR-2 array (long-range passive detection), a bottom dome containing an underwater telephone (UQC-1), a torpedo detection sonar (QXB), and an active sonar (BQS-2 or QHB or SQS-

10). Topside sonar domes contained another BQS-2 forward, a BQC-1 emergency phone, and a combination of passive devices - BQR-3, a precision tracker (essentially JT in a sonar dome), and BQR-6, a vertical triangulation ranging sonar. Special ASW submarines (SSK) were even more elaborate, and more strongly oriented towards passive operation. Many had large domes forward containing the BQR-4 passive low-frequency system descended from the German GHG, with BQS-3 (a high-power, low-frequency, single-'ping' sonar) above it in the specially built SSKs and in the converted SSK-214. In SSK-214, the former fleet boat (USS *Grouper*), the BQR-4 array was arranged on the side of her conning tower. These submarines had a 60in rubber dome for their underhull combination of QXB, BQS-2 and UQC-1; it had a hoist. They also had fixed topside domes for a second BQS-2.

Active sonar range was comparable to that of contemporary surface-ship installations. For example, aboard a quiet submarine in the thermal layer, BQS-3 was credited with a range of about 10,000yds. Aboard a noisy, transiting submarine, SQS-4 (which was installed in several submarines) was credited with about 6000. However, BQR-2b, a 6ft diameter array of 3ft high line arrays, was credited with a range of 110,000yds when operated by a quiet submarine against a snorkeling target (but of only 13,000 when operated at 13kts). BQR-4a, a 10ft x 20ft conformal array of 8ft lines, was credited with ranges of, respectively, 160,000 and 20,000yds under similar circumstances. The existing BQR-3A (JT in dome) was considered capable of target classification at up to 18,000yds. These figures help to explain the popularity of passive systems in submarine-to-submarine ASW, particularly given the barrier tactics of the early 1950s, in which most targets would be noisy snorkelers. In 1956 the Navy Undersea Laboratory (USL) was proposing a 36ft x 24ft array of spot hydrophones for the 1958 nuclear submarine (*Skipjack*), with estimated ranges of 180,000 and 11,000yds. There were also a 5kc sonar, equivalent to SQS-23, which was expected to detect actively at about 20,000yds from a quiet submarine, and perhaps also to operate effectively at the convergence zone, *ie* at about 70,000yds. In passive

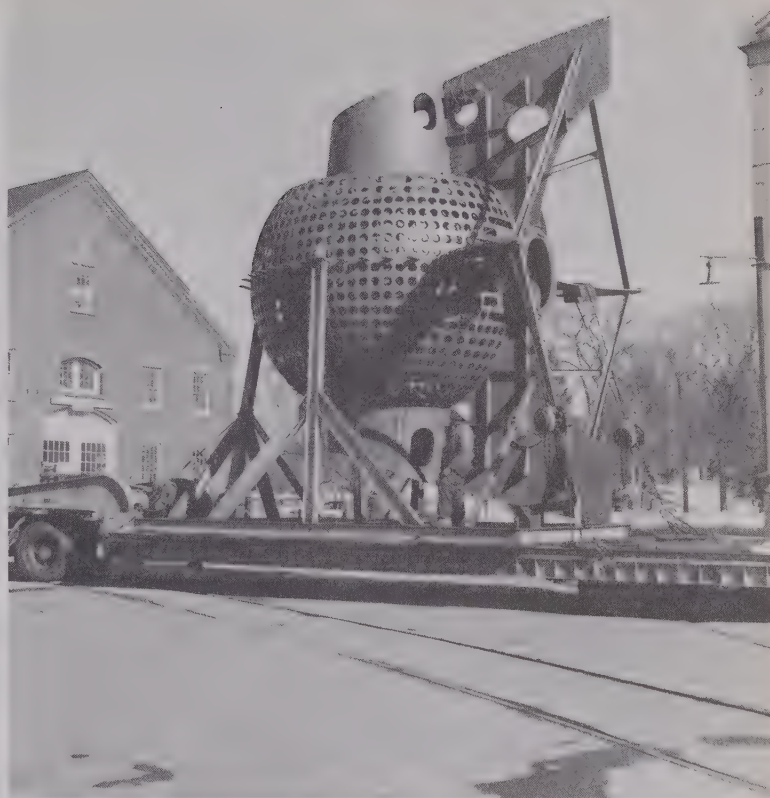
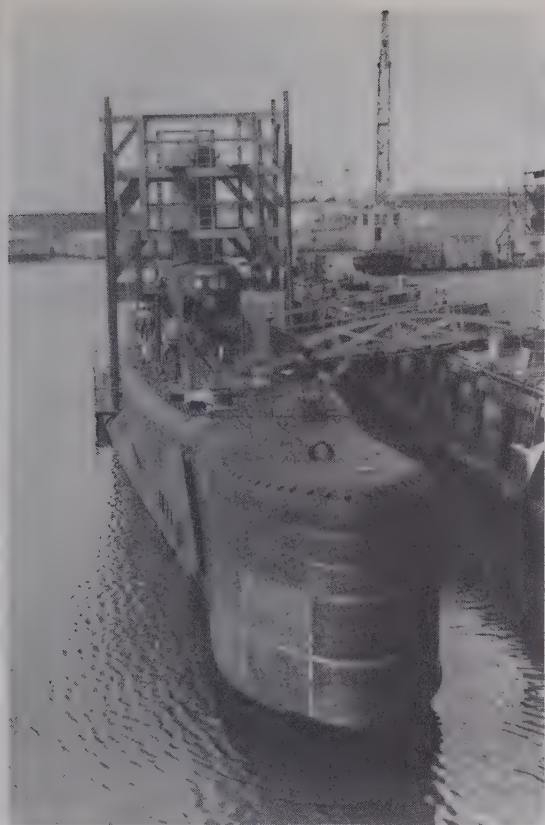
Many current US escorts are fitted with the SQS-35 Independent VDS, the 'fish' of which is shown; the hoist system is designated SQA-13. Typically it is fitted in *Knox* class frigates in a space originally reserved for fixed Mk 25 torpedo tubes, which would have fired an (abortive) surface version of the Mk 48 ASW torpedo. In many cases the SQS-35 'fish' is now used to trail a towed array passive sonar system. This 'fish' was photographed aboard USS *Valdez*, 5 August 1974, during a three-day precommissioning shakedown cruise. Note the small elevators on the upper fin of the 'fish,' to maneuver it in the water, and the relative simplicity of the hoist gear, compared to SQA-8 and -10.

operation at lower frequencies, it would detect targets at up to 170,000yds. All of these figures were predictions made about 1956 and should be considered indications of actual performance rather than the results of service tests. Even so, they indicate the rationale for weapon systems such as SUBROC (with a probable range of about 80,000yds).

Of the active submarine sonars, BQS-4 became operational about 1955 and remains in service in 1983 aboard older US submarines through the *Skipjack* class. In fact routine overhauls of *Skipjack* class submarines proved so expensive that major improvements could not be financed. Proposals for a new sonar suit for the latter were made in the late 1960s but were never fully funded. The *Tullibee*, intended originally as a nuclear SSK, introduced the large spherical bow array (active and passive) of BQQ-2, comprising BQS-6 and BQR-7 and installed on all subsequent US attack submarines. It was later upgraded to BQQ-5; BQQ-6 is an all-passive BQQ-5 for Trident submarines. The increased sonar range provided by the large bow array was considered important enough for it to replace the traditional bow torpedo tubes, and the latter were moved back to amidships. The only exceptions were ballistic missile submarines, which did not have the space to spare, and received a different sonar suit, BQS-4 plus (in the *Lafayette* class) the BQR-7 conformal array.

Sonobuoys

Sonobuoys are the principal airborne submarine detectors, the principal means by which ASW aircraft can overcome the opacity of the sea surface. Without them, aircraft are limited to a very short-range detector (MAD) and to whatever signatures a submarine may choose to project above the surface, principally the radar target of her periscope or snorkel, the electronic emissions she may make (subject to interception), and her snorkel exhaust, which can be picked up by a 'sniffer' such as the US AN/ASR-3. Each of these possibilities is sharply limited. For example a submarine can operate without exposing her periscope, relying entirely on passive sonar. Nuclear submarines need no snorkels, nor do they provide any exhaust that is as yet detectable. Moreover, air pollution largely negates the 'sniffer' when it is operated downwind of any large city, or indeed when it is operated near surface shipping. MAD can, in theory, be used as a search sensor, but its very short range makes it ineffective, particularly against deeply submerged submarines. There are a variety of possible nonacoustic signatures which may, in future, be observable from the air or even from space, but it appears that none of the technologies involved is nearly mature just now. That leaves aircraft with acoustic systems, but since conventional aircraft are incapable of



hovering, the acoustic systems they use must generally be expendable, ejected while the airplane flies overhead at a substantial speed, and monitored by radio. The US philosophy throughout has been to use multiple inexpensive sonobuoys, concentrating the cost of the system in the nonexpendable signal processor aboard the airplane monitoring them.

Both passive and active sonobuoys, using a variety of processing schemes, have been used. Probably the most exotic was 'Julie', in which a small practice depth charge produced a sound pulse which was received by several passive buoys, to provide submarine detection which in theory would be independent of submarine quieting, and indeed of submarine motion. It suffered from reverberation, and produced a pulse too broad-band in frequency to permit target classification by doppler. Ultimately 'Julie' was superseded by a low-frequency passive system (LOFAR), which employed much the same acoustic technology as SOSUS and which could achieve very great ranges even using small sonobuoys. LOFAR-based systems remain the basis of US airborne ASW in 1983. LOFAR ('Jezebel') was, in fact, so effective at very long range that it quite exceeded the capabilities of the aircraft carrying it. For example, in 1956 it was credited with a range of 30–100nm on a snorkeling submarine.

The earliest proposal for an expendable sonobuoy appears to have come from P M S Blackett of the Royal Navy, who in an 18 May 1941 memo proposed a 'detector buoy' to be dropped astern of convoys, in order to detect shadowing submarines. He hoped that it could be developed in the United States, as British capacity was overstretched. The NDRC contracted with RCA, which developed a prototype buoy. Tests showed that the concept was workable, but it was not pressed forward. However, with the entry of the United States

into World War Two, Navy blimps equipped with MAD gear found that they were attacking many wrecks, which they could not distinguish from live submarines. The Undersea Laboratory at New London proposed either a towed hydrophone or a passive sonobuoy, and Rear Admiral Rosendahl, commanding the blimps, sponsored tests which revived the convoy buoy concept. On 7 March 1942 the blimp *K-5* was able to hear the submarine *S-20* at up to 3nm. It seems ironic in retrospect that at first the sonobuoy was considered a classification aid, the MAD, as the primary search sensor; this order was soon reversed.

The first sonobuoy was AN/CRT-1, ordered by the Army in quantity in June 1942; operations began in August. These early buoys were color-coded for six distinct radio frequencies, with power limited to half a watt for line-of-sight operation. They used a 30ft deep hydrophone (a compromise between size and interference from wave noise) to listen omnidirectionally at all acoustic frequencies between 100 cycles and 10kc. In operation, an airplane would drop a sonobuoy pattern, listen to each buoy in turn, and then search around the one receiving the loudest acoustic signal from the submarine, MAD often being used to localize such a contact. NDRC was considering a directional buoy as early as August 1942, and the Army formally requested one in February 1943. It became AN/CRT-4, and was first tested at Fort Lauderdale in January and February 1945. It rotated its microphone through a full 360° every 12–20 minutes, depending on sea state, as a weighted fishline descended from it, giving an accuracy of about 11° in bearing. Although similar requirements were levied postwar, it appears that CRT-4 development had little impact at that time.

In 1946 the Navy began development of a family of sonobuoys: the directional SSQ-1

1 Although submarines have had sonars since the 1930s, very long-range detection of other submarines did not become practical until after World War Two, with the advent of the large German-designed GHG or BQR-4 low-frequency passive array. This one covers the bow of the ASW submarine (SSK) *Angler*, refitting at Philadelphia about 1962. The small sonar dome just forward of the gangway probably houses BQS-2, a high-frequency 'single-ping' searchlight sonar. Submariners prefer to operate passively, 'pinging' only to establish target range, whereas in many cases (at least in the past) a surface ship would 'ping' continuously to search.

2 Recent US nuclear submarines have spherical bow sonar domes for long (presumably convergence-zone) range, operating at low frequency; they probably correspond to the SQS-26 of the surface force. In the submarine case, there was a weapon, SUBROC, to match this range, whereas no surface convergence-zone missile has yet appeared. The submarine combination was considered so important that torpedo-tube salvo size was sacrificed in favor of sonar range, the usual six tubes being replaced by four amidships in the *Tullibee* and the *Thresher* and later classes. This sphere, not yet fitted with its hydrophones, was installed in the unfortunate *Thresher*. The steel supports at top and bottom fitted inside the submarine's pressure hull, and the circular opening led wiring into it. In operation, the volume around the transducer would be flooded, as in a surface-ship sonar.

III. UNDERWATER ORDNANCE

and the improved omnidirectional SSQ-2. The latter would be dropped in large numbers the former then used for cross-fixes. In fact both suffered from the failure of the first contractors to produce them. Both the first and the second contractors for SSQ-1 failed before Magnavox succeeded about 1954. Hazeltine, the second SSQ-2 contractor, was successful in 1950-51, and RCA was brought in as a second source. Sonobuoy production was considered so important that Hazeltine trained Sparton and Zenith, and RCA trained Magnavox and Hoffman Radio. SSQ-2B went into crash production, but although BuAer developed a much more reliable version it was not built. Both new systems operated at a new sonobuoy radio band, 162.25-173.5mc/s, rather than the wartime 67-72mc/s. Other features of postwar buoys included a radar beacon/transponder, much cheaper hydrophones (piezoceramics), rotochutes for descent, and better batteries.

The British, meanwhile, were working on their own directional sonobuoys. Given problems with SSQ-1, the Chief of Naval Operations authorized the purchase of an Americanized version of the British directional buoy as SSQ-20.

At about the same time an active 'pinging' buoy, SSQ-15, was developed; however, it was soon eclipsed by 'Julie' (explosive echo-ranging, or E²R), which became operational about 1957. Several specialized sonobuoys were developed specifically for this system, SSQ-23 being widely used. However, in practice, 'Julie' and its associated CODAR computer proved ineffective. SSQ-15 regained popularity as a reliable attack aid, albeit at relatively short range.

'Julie' was paralleled by 'Jezebel', the application of LOFAR (low frequency) technology to a sonobuoy system. At first 'Jezebel' was rejected in favor of 'Julie', as the latter was simpler. In addition, the very long range of a passive omnidirectional 'Jezebel' detection often made conversion to a shorter-range (and more precise) 'Julie' contact impossible. The solution was crash development of a directional LOFAR buoy, DIFAR; two DIFAR buoys could obtain a long-range (LOFAR) fix by cross-bearings. Because it used the same technology, 'Jezebel' was particularly well adapted as a SOSUS follow-up. That is, the same submarine signature detected by SOSUS could be matched against a 'Jezebel' detection. The first 'Jezebel' omnidirectional sonobuoy was SSQ-28 (1960), which was followed by SSQ-38 (1964) and then by SSQ-41 (1965) which combined the 'Julie' and 'Jezebel' functions. SSQ-53 (1969) was the DIFAR buoy, employed in the localization phase of an attack, after target detection by SSQ-41s.

As for the active buoys, GE proposed a miniaturized version of SSQ-15 as early as 1957, in the form of a simple 'pinger' (a noise source) to work with passive buoys. It was outmoded by 'Julie'. However, interest remained, and the SSQ-47 active buoy appeared about 1966, having been proposed by Sparton in 1959. In 1983 it is being replaced by a command-activated active buoy, CASS (SSQ-50) and by a directional command-activated active buoy (DICASS, SSQ-62), both of which can operate both passively and actively. Command activation saves battery use and provides for longer life at higher peak power, *ie* at longer effective range. CASS first appeared about 1964 but did not enter production until con-



siderably later, due in part to its early reliability problems; it was not certified for service until March 1974.

Aircraft acoustic operations also employ two specialized sonobuoys, an expendable bathythermograph (XBT, SSQ-36 or -56) to obtain a sound velocity profile and so to permit the prediction of sound propagation paths; and a noise monitor (SSQ-57), which permits a tactical coordinating officer to calculate optimum buoy placement in view of the level of background noise.

About 1960 the Navy began a long-range acoustic development program, concentrating on studies of sound propagation, in many cases at great depths. Sonobuoys reflecting this research are beginning to appear: SSQ-75, the Expendable Reliable Acoustic Path Sonobuoy (ERAPS), employing an active search sonar to seek targets below passive sonobuoy detection capabilities, in the deep sound channel; SSQ-77, the deep passive sonobuoy (vertical line array DIFAR system, or VLAD); and SSQ-79, the Passive Advanced Sonobuoy (PADS), also known as the Steered Vertical Line Array (SVLA), designed to overcome background noise in the horizontal plane. There is also a current effort to miniaturize all of the sonobuoys ('Dwarf').

1 For an airplane, expendable sonobuoys, active or passive, are the only effective means of penetrating the ocean surface. Here an SSQ-41 passive line hydrophone buoy is loaded into a chute, presumably aboard a P-3, in February 1974. The tapered top of the buoy contains a rotochute to lower it relatively gently to the sea surface, and virtually all US buoys are a standard size ('A' size) to fit standard racks and chutes. A P-3 can monitor 31 buoys simultaneously, and can carry a total of 87. The contemporary Grumman S-2 carrier-based ASW patrol aircraft carried its sonobuoys in its nacelles.

2 MAD, Magnetic Anomaly Detection, began as a search sensor but now functions almost exclusively as a means of confirming ('classifying') acoustic contacts, since MAD range is far shorter than that of the sonobuoys. These P-3s display the ASQ-81, isolated from most of the metal of the airplane in a tail 'stinger'. LAMPS helicopters use MAD to confirm the presence of a submarine as they make their attack passes; since they cannot lift a long tail boom, they trail their MAD pods. These patrol planes were photographed in Puerto Rico in February 1974.

Part IV

Fleet air defense after 1945

As the cost of the new technology began to be evident in the late 1950s, several expedients to provide the fleet with missile air defense at lower cost were examined. One was to save the cost of additional hulls by placing missile launchers on carriers: after all, given the range of the weapon, it did not really matter very much where in the task force it was located. This is the carrier *Constellation*, 17 April 1962; one of her SPG-55 guidance radars is visible, just forward of a missile launcher, on her port after sponson. Terrier was actually installed aboard the *Constellation*, *Kitty Hawk*, and *America*. It was planned for the nuclear *Enterprise*, but was deleted to save money; more recently it has been replaced by Sea Sparrow, indicating a change in the role of the carrier-launched defensive missile, from contributing to the area defense of the task force to defending the carrier herself against missiles leaking through other defenses. To some extent, too, installing Terrier on the carrier limited the carrier's ability to maintain the Combat Air Patrol which is a major part of task force air defense.



1. Introduction

For the US Navy, postwar fleet air defense development was largely bound up in an increasing degree of automation on many levels, as airborne threats became faster (*ie* reduced warning and decision time), more numerous and more lethal. Although the air forces engaged in the major battles of World War Two involved many more aircraft than would be encountered postwar, those aircraft generally attacked in only a few massive raids. By way of contrast, jet tactics often involved large numbers of individual attackers, approaching a task force or an individual ship on different bearings and at different altitudes. The kamikaze attack tactics of 1945 were an unpleasant foretaste of this type of saturation attack; much of the system development of the first two postwar decades was devoted to overcoming it. After 1965 the issue of decision time and speed became more important, as the threat of the antiship missile increased sharply. In particular, 'pop-up' weapons such as 'Styx' and the submarine-fired SS-N-7 do not appear at all until they are within about 30nm of their targets; even at a relatively low speed like Mach 1, a missile covers 30nm in about three minutes.

The combat organization of a wartime carrier task force responded to incoming air threats on two distinct levels. There was an outer defense by combat air patrol (CAP) fighters, controlled by a Combat Information Center (CIC). Attackers leaking through the fighters were opposed by shipborne guns, often controlled on a less centralized basis. Postwar development led to the automation of both functions, which gradually merged as the guns were replaced by increasingly powerful ship-to-air missiles. With their widespread deployment, a third level of defense came into existence – point defense – to deal with attackers penetrating both fighters and SAMs. In 1983, point defense is the major remaining anti-aircraft role of the shipboard gun, although many such weapons are very different, particularly in their control arrangements, from their predecessors.

Current US doctrine, then, divides the fleet air defense problem into an 'outer zone' or 'outer air battle' fought by aircraft, then an area surface-to-air missile zone or 'middle zone', and then an 'inner zone' of point defense ('hard-kill') weapons and countermeasures ('soft-kill' weapons, such as jammers, decoys and chaff rockets). The outer battle will be fought by fighters on CAP station, augmented if possible by deck-launched interceptors (DLI), and all vectored to attack by airborne early warning (AEW) aircraft. Given the difficulty of intercepting missiles as compared to bombers, a key objective in the outer zone is the destruction of missile-armed bombers before they can launch. To some extent the bombers can be forced to avoid launching at maximum range by electronic countermeasures which confuse the high-value target (such as a carrier) with escorting ships, and which can be defeated only by higher effective radar power on the

bomber, *ie* by closing with the target.

Bombers were the primary Soviet threat from the mid 1950s onwards, and the threat of saturation and long standoffs produced a generation of very long-range weapons with a relatively low rate of engagement, from Terrier through Typhon. However, with the advent of the 'Styx' surface-to-surface missile, Soviet weapons appeared which would never pass through the outer zone, and which would, therefore, be countered primarily by shipborne weapons. The submarine-launched SS-N-7 was particularly difficult to counter, given the lack of warning of its launching platform, a submerged 'Charlie' class submarine.

CIC automation for fighter control was instituted largely to overcome saturation. In 1948, for example, British experiments showed that a conventional manual vertical plot performed poorly when handling twelve tracks; with twenty 'the whole thing is practically hopeless'. Accuracy was soon lost; with twelve tracks, errors of 4 or 5nm (quite sufficient to ruin an interception) were common, and some tracks were lost entirely. Worse, low-level saturation was not apparent to those running the plot. Many US air defense exercises, primarily in the Sixth Fleet in the early 1950s, confirmed this grim analysis, and an October 1956 summary report on Fleet Air Defense Improvements (by the OEG) noted that 75 percent of all raids now arrived at the task force (in exercises) completely unopposed by fighters. Of these, 20 percent were never detected; only 75 percent of all detected 'bandits' were assigned CAP interceptors, and half of those closed 17nm or more between detection and CAP assignment. Worst of all, these exercises actually favored the defense.

Improvement depended, first, on better training for air defense teams, particularly CIC teams; tactics (such as better use of picket ships and aircraft) could also improve, and the OEG looked forward to the introduction of better long-range radars, such as SPS-17 (and its current successors, SPS-29, -37 and -43). Thus the first series of exercises, in 1951, gave an average detection range of only 40nm, rising to 60 in 1952, and 80 in 1953–54, largely due to improved use of pickets. For example, picket destroyers could detect incoming raiders at a median range of 50nm, and airborne early warning aircraft could do even better. SPS-17 aboard the carrier might, however, detect 85 percent of all targets at 20–40nm in from the 200nm horizon. The OEG believed that proper use of pickets and of task force radars would permit detection of all but 10 percent of attackers (jets at extreme altitude) at some range, even before the introduction of the new radar; the main body itself might detect 75 percent of all raiders at a median range of 53nm, compared with an average performance, in exercises, of 65 percent detection at over 55nm (50 percent at 80nm).

Given better detection, there remained the problem of CAP assignment, which much more closely tested CIC saturation. A great

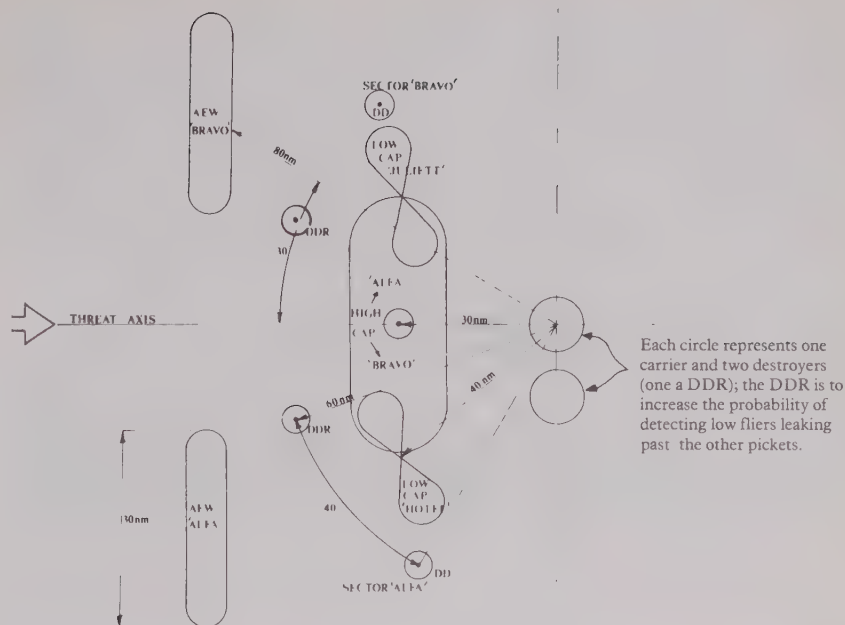
deal depended upon proper identification; in crowded areas, many of the unidentified aircraft (bogeys) were transients (13 percent) and even more were friendly (59 percent in a typical exercise); only 28 percent were hostile (bandits) which had to be intercepted, using the limited resources of the task force. However, in a typical exercise, nearly as much of CAP was assigned to misidentified friendly aircraft as to true bandits. In the last quarter of 1955 the Sixth Fleet steadily improved its CAP assignment performance, ultimately achieving a 90 percent assignment rate. However, it still suffered from delays in interception (which would have been extremely serious had the attackers been carrying Soviet-style standoff missiles), which were greatest at long range: on average an attacker closed 13nm between detection and assignment. If he was detected at 75nm, delays in CIC cost 20 more; if at 100nm, the gap was 32nm.

As in World War Two, IFF was a major issue. One of the great advantages of the new TACAN (Tactical Air Navigation) system was that it permitted aircraft to report their positions accurately and frequently, to avoid being taken for bandits. The OEG also strongly recommended that air defense be decentralized, with CAP sectors assigned to individual ships, with the flagship relieving any sector ship being saturated. Delays could be reduced even further if all air control ships were permitted to assign their CAPs to any bogey they detected without delay. In effect, these concepts were to carry over to the SAM control concepts developed about a decade later: if the pressure was to reduce decision time, that required that individual decision-makers be less burdened, that they predelegate much of their authority over some parts of the air defense problem. One other major advantage of TACAN was that it permitted a pilot to navigate himself towards a contact, using a small computer in his fighter. This reduced the burden of the CIC fighter control officers, who had only to broadcast the position of the incoming raiders.

Poor CIC performance showed in assignment of CAP fighters, *ie* of assignment of aircraft physically unable to counter some raids. Problems included limited control facilities, slow transfer of data, and lack of reliable height data. In more than half of all cases, there were height errors of 3000–30,000ft, the worst due to measurement of the altitude of the wrong radar target. If those were excluded, errors closer to 2600ft were encountered, and daylight fighter control was more practicable. However, that in turn required an automatic means of co-ordinating search radars with the heightfinders, which in 1956 was just becoming available. Air control by airborne early warning aircraft was a promising counter to low fliers. It appeared to the OEG that by eliminating impossible CAP assignments, the probability of 'tally-ho' (*ie* of intercept) of a high-flying jet could be increased to 50 percent. Elimination of gross altitude errors, or stacking CAP in alti-

AEW AND CAP STATIONS

A typical US disposition, showing stations for an air defense exercise in the Seventh Fleet, December 1956 (Task Group 77.4). In this exercise, CAP aircraft were FJ Furies (model not specified). High CAP aircraft cruised in the large 'racetrack' pattern shown to conserve fuel, while low-altitude CAP operated on the two stations shown. A more modern arrangement would include a SAM defense zone around the carrier, with aircraft operating zones beyond that. Current CAP practice, as reflected in Standard Aircraft Characteristics, is for CAPs to operate 150nm from the carrier and AEW aircraft 200nm (50 rather than 30nm 'racetrack'). This extension towards the incoming threat reflects considerable Soviet progress in air-to-surface missile technology, as the 1956 formation was designed against bomb and torpedo attack from short range.



The major development in postwar anti-aircraft warfare was automation, both aboard ship and in the weapons. This is the missile cruiser *Canberra* in January 1961; she was one of the first two US missile ships, and carried two Terrier launchers aft. The CXRX radar on her foremast was part of Target Designation System Mark 7, assigning the Terrier launchers aft to targets. Note that, in contrast to later missile ships, there was only a single fire control radar (SPQ-5 in this case) for each pair of launch rails. *Canberra* had SPS-29 amidships, just below her TACAN radome, and SPS-13, for long-range search and height-finding, aft; it was a smaller equivalent of the massive SPS-2 originally fitted to the fleet flagship *Northampton*.



tude, could cut existing tally-ho failures by as much as a quarter. Broadcast and TACAN tactics could allow earlier interception of raids, permit more efficient transfer of control, and overcome saturation. In all, it appeared that 90 percent of all raids could be tally-hoed; if two CAP sections were assigned to each, 90 percent could be splashed.

The manual CIC could just barely cope with the threat, if it was operated at peak efficiency with large numbers of fighters – and if the criterion for interception was a splash 20nm from task force center. However, by the late 1950s the Soviets had introduced long-range standoff weapons, which the fighters probably could not shoot down, and which could be fired from much more than 20nm. Moreover, the number of carriers was beginning to shrink as the cost per carrier and per airplane rose steadily. The fighters were receiving longer-range weapons (the OEG study was made in terms of a Fury carrying Sidewinder), but they required certain detection at greater ranges. In addition, the longer the weapon range the greater the emphasis on full target identi-

fication before weapon release could be permitted: to shoot down an airliner merely passing through a fleet air defense zone would be embarrassing, to say the least; to shoot down a friendly fighter or a returning attack bomber would be, perhaps, as bad.

NTDS, the Naval Tactical Data System, was brought about to solve this series of problems. It began as a form of electronic bookkeeping, a means of entering radar scope data in an electronic memory which would display to fighter control officers the overall shape of the battle, and which would be less subject than a manual plot to error and saturation. The Royal Navy first proposed its CDS (Comprehensive Display System) about 1949; a CDS was set up by the Naval Research Laboratory at Chesapeake Bay in 1951–52, and demonstrated to numerous US, British and Canadian officers. It was fed by three simulated shipboard radars, an air early warning terminal, and the new Mk X IFF system; displays were provided for the flag officer, captain, CIC officer, detectors, trackers, analyzers, fighter direction officers, super-

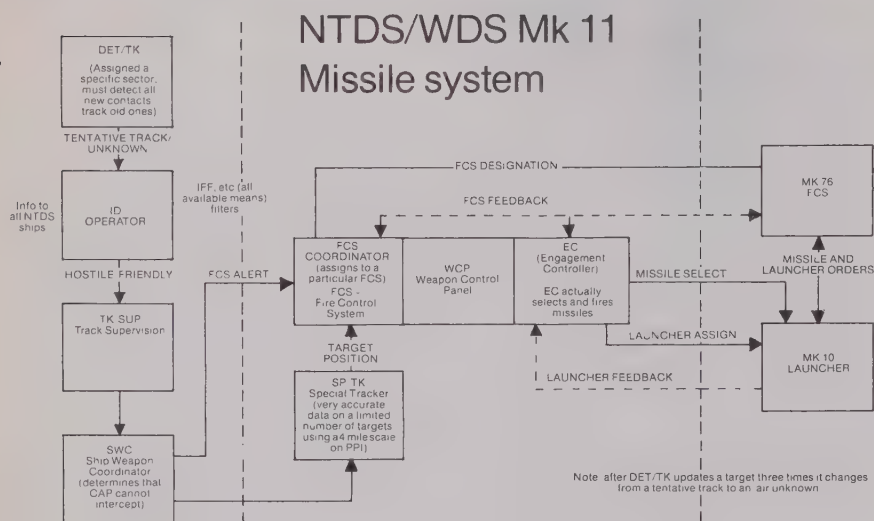
visors and gunnery liaison officers. Track number, plan-position (range and bearing), height, raid size and identity were stored, as in a manual CIC. For example, height could be stored as low, medium or high; identity as friendly or hostile, action taken or no action taken, own aircraft or other, homing, or emergency; and numbers as single, few, or many. The detectors transferred data from their radar scopes to the data store; there was not yet, in the 1950s, any way for a radar automatically to detect a target and then to convert that decision into numerical data suitable for computer processing. Indeed, that development did not come until the late 1960s, long after the introduction of NTDS. Trackers separate from the detectors updated the position data of existing raids, again by reference to their own radar scopes; their work load was automatically equalized. The analyzer stored raid identity, height and size.

CDS was bulky and relatively unreliable, but it showed the value of CIC automation. NRL developed improved techniques for data-handling, and in 1953 produced the Electronic



Fleet air defense originally required a combination of fighters and surface-launched weapons; until shipboard missiles reached maturity, fighters were the only real counter to bombers with standoff weapons. Radar picket destroyers for CAP control were, therefore, an extremely important aspect of the fleet air defense system; *Furber* is shown in September 1961, as the air control function was beginning to pass to a combination of missile ships (which had the requisite radars and CICs) and to airborne CICs such as the Grumman E-1B and E-2. She shows the usual picket combination of TACAN, to orient the CAP to her position for effective control, just forward of her second funnel; an SPS-8 height-finder aft; and a long-range two-dimensional air search radar, on her foremast. This particular set was SPS-31, in effect the prototype of the current standard SPS-40, although rather different in appearance. The bar below it is an IFF antenna, representing another essential air control function. The ubiquitous triple Mk 32 torpedo tube can be seen under canvas abeam the second funnel, with Hedgehog abeam the bridge, and a single depth charge track aft. The small shield on the fantail protects a 'Fanfare' towed torpedo countermeasure, a descendant of the wartime 'Foxer'.

NTDS/WDS MARK 11 (TYPICAL AUTOMATED AIR ENGAGEMENT)



Key

DET/TK:

Detector/Tracker console (assigned a specific sector) – must detect all new contacts and track old ones; after target is updated three times it changes from a tentative track to an 'air unknown'.

ID OPERATOR:

IFF etc (all available means); relays information to all NTDS ships

TK/SUP

Track Supervisor – determines that no other ship in the formation holds this contact

SWC:

Ship Weapons Coordinator – determines that CAP cannot intercept

SP/TK:

Special Tracker – very accurate data on a limited number of targets, using a 4-mile scale on PPI

FCS:

Fire Control System Coordinator – assigns to a particular FCS

WCP:

Weapon Control Panel

EC:

Engagement Controller – actually selects and fires the missiles

Data System (EDS), which permitted not only data-handling but also automatic interchange of data within a task force. The first model was tested at Chesapeake Bay in 1953. In 1955 the Department of Defense established Project 'Lamplight', looking towards solutions for Navy participation in Continental Air Defense (ie antibomber defense using radar picket ships). The final Lamplight report recommended EDS installation, and the Navy bought twenty, installing them aboard the frigate *Willis A Lee* in 1956, then aboard four radar picket destroyers (1959), and ultimately aboard missile cruisers, which had a major task force air defense role. One important EDS feature, continued in NTDS, was a means of taking data directly from the radar scope (PPI): the operator simply touched the electrically excited conducting glass plate over the PPI with his contact, to enter data, and the system confirmed entry by displaying a dot of its own on the PPI scope. EDS circuits also estimated target velocity from successive data, and projected forward estimated target tracks to aid in tracking. The Naval Research Laboratory history claims that, with this technique, an operator could track up to eight targets, rather

than two as in CDS. Moreover, since raid velocity was now automatically stored, it could be used automatically to aid in computing aircraft interception tracks – and so to reduce the number of 'impossible' CAP assignments.

The next step was the transition to digital electronics, permitting much more efficient storage and use of data, as well as coding of the ship-to-ship data exchange. NRL devised a digital coded data link, HICAPCOM (High Capacity Communications), and in 1956 the Navy contracted for a digital successor to EDS, the present NTDS, using a HICAPCOM data link. It was first tested aboard the carrier *Oriskany* and the missile frigates *King* and *Mahan*, which operated in company in July 1962, the first equipment having gone to sea the previous year. As currently used, NTDS is generally linked automatically to airborne radars such as that of the E-2, using an Airborne Tactical Data System (ATDS). In addition, as radars have been devised which automatically detect and track targets (such as later versions of the SPS-48), they have been integrated directly into NTDS, reducing the errors inherent in operator manual data entry.

NTDS was severely tested during the

Vietnam War, when single missile ships were stationed in the Gulf of Tonkin as air control ships for strikes over North Vietnam. These PIRAZ (Positive Identification Radar Advisory Zone) ships controlled all US strike aircraft – Navy, Marine and Air Force – and also monitored North Vietnamese air activity; however, the bulk of the aircraft they detected were neutrals, such as Japanese airliners en route for Indonesia. Air traffic density often exceeded that in the US Eastern air corridor between New York and Washington, and neither the neutrals nor the North Vietnamese were identifying themselves on the US IFF system. Identification, then, could only be by examination of the way a particular radar track developed; it was essential that tracks be distinguished properly. That there were no tragic errors is a tribute to the system, only two decades after twelve tracks at once had hopelessly overloaded a CIC. USS *Chicago* (CG-11) was the first PIRAZ ship (June 1966); she was followed by most of the available NTDS missile cruisers and destroyers, including the nuclear-powered *Long Beach*. Although some of these ships actually fired their missiles at North Vietnamese aircraft, in many cases they

made a larger contribution to the air war by controlling friendly fighters to successful interceptions. One enlisted air controller, who was decorated for it, claimed twelve successes by Air Force fighters.

The other major strain in automation was applied initially to short-range air defense. In 1945 BuOrd asked Bell Laboratories to study the saturation problem in ship air defense, under the designation Mk 65 (fire control system). The contract looked toward the anticipated conditions of 1960, when aircraft speeds might be expected to reach Mach 2.5 (1500kts) and when saturation might be an even worse problem than in 1945, particularly given very short warning times. Bell concluded that the existing CIC, as used to control and coordinate shipboard guns, was inefficient; the radars feeding it were not precise enough to permit rapid handover to fire control radars, and weapon assignment to incoming threats was not nearly fast enough. Its solution, evolved over about a decade, was, first, to interpose a high data rate, precision search radar between the long-range search systems and the fire control radars, for quicker handover. This new radar, better matched to the short ranges of the guns, would have to scan very rapidly over the entire hemisphere surrounding the ship.

Internally, it would be necessary to evaluate incoming targets so that weapons could be assigned to them on a logical basis. Bell recommended development of a suitable control system, the heart of which was a coordinated display showing target positions, targets being tracked, and targets under fire. It appeared, too, that the decision process involved could be automated to achieve the most efficient threat evaluation. Bell made its first report, 'Naval AA', in July 1947, and the Navy approved construction of a land version of a Threat Evaluator and Weapon Assigner (TEWA). An alternative automated version was to be called an ATEWA. Incoming threats were ranked according to speed, closing time, proximity to individual gun directors, and gun arcs of fire; the land version, which could handle ten simulated target tracks was tested at Bell Laboratories between 1949 and 1951, operating four simulated directors. In 1953 the experimental command cruiser *Northampton* was fitted with the first operational system, Target Designation System Mark 3, which employed ten radar and four optical channels and automated the decision process and also the assignment of guns to particular directors. Its radar was the unsuccessful SPS-3 'hemispheric scanner'.

With the development of missiles, decision time limits were somewhat relaxed. In Target Designation System Mark 7, for the first two missile cruisers (*Boston* and *Canberra*), threat evaluation and weapon assignment was automatic for guns, but manual for missiles. In subsequent missile ships, entirely manual operation was adopted, the key value of the Bell studies being in the display making decisions quicker and more effective. Designation Equipment Mark 9 was installed aboard the *Cleveland* class Terrier conversions as well as aboard *Dewey* class frigates; Weapon Designation Equipment Mark 1 was fitted to Tartar destroyers and frigates, eleven of which had the new SPS-42 frequency-scanning radar with digital input directly to NTDS. Weapon Designation Equipment Marks 3, 4 and 8 went

to later Terrier ships. Except for *Boston* and *Canberra*, which had the last of the mechanically scanning precision search radars (CXRX, or SPS-27), all of these ships were fitted with frequency-scanning radars (SPS-39 and -42). The early Talos cruisers had Weapons Direction (or Designation) Systems Mark 2, and the Talos/Tartar ships had Mk 6.

The next step was to combine Weapon Direction Equipment (or System) with NTDS, a step first taken in the cruiser *Long Beach*. Her NTDS could maintain up to 128 target tracks, and could provide twelve targets for her WDS Mk 6; in effect, the WDS was submerged within the larger automated CIC, at about the same time that missile ranges began to approximate CAP ranges from the task force center. From the *Wainwright* (CG-28) onwards, US missile frigates (cruisers) were built with NTDS facilities, and a major modification program extended NTDS to all earlier missile frigates, generally involving the addition of a large deck house amidships. The cruisers *Albany* and *Chicago* were also refitted with NTDS; one reason for the retirement of the earlier Talos cruiser/flagships was that they did not have the internal space required for such an installation.

Even the combination of NTDS and a semi-automatic WDS was not nearly fast enough to meet the 'pop-up' (short-range antiship) missile threat; a New Threat Upgrade (NTU) program was begun in 1968. It concentrated on reducing the reaction time of the existing missile systems to below one minute from initial detection to engagement. The problem was not the limited performance of the existing missiles, but rather the time lost before they could be fired. Radar detection of low-flying targets was difficult in view of the extreme clutter to be expected. To overcome this problem, radar detection was automated, and the outputs of all shipboard radars, including some of the fire control radars, was to be correlated by a single system, such as NTDS. In particular, the link between the high-data-rate radars (eg SPS-52) and the WDE/WDS was to be broken; such radars would contribute on the same basis as the long-range two-dimensional types. Other purely electronic counters to clutter would also be installed. Together, these measures would speed detection and tracking of a threat, and they would minimize false alarms due to clutter and ECM. Perhaps as importantly, with radar data entered automatically into a computer, the characteristics of incoming radar targets could be compared with a standardized set of antiship missile characteristics, so that possible threats could be identified and automatically ranked – as Bell Labs had proposed in its 1947 report on ATEWA.

Given the combination of very few false alarms and a high probability of detection, it was reasonable to ask the OTC to delegate his authority to begin an engagement; he could allow the computer-based combat system to decide to engage what it identified as an incoming threat. Criteria for judgment were predetermined; there was not nearly enough time for much more. The OTC was allowed only to veto an ongoing engagement. In fact much more could be done: for example, as soon as a possible target was detected, fire control calculations could begin, even if the shipboard computer had not yet identified it as a threat. Such parallel processing could greatly reduce

delays, if there was enough shipboard computer capacity to overcome possible saturation in a crowded area.

In hardware terms, the symbol of the NTU development is AN/SYS-1, an integrated automatic detection and tracking device which can tie together the radars of a Tartar destroyer; the analogous system for cruisers is AN/SYS-2, and both are entering service in numbers as this is written. The *Perry* class missile frigates are the first ships to have a combat system designed with NTU principles in mind, ie with the inherent capability to counter low-flying antiship missiles. From an external point of view, full correlation of all shipboard radars (including fire control radars) should reduce the number of separate systems required for a given level of coverage. Computer handling of radar data should in itself increase precision, since the visual display on a radar scope rather understates the amount of information the radar can provide, for example by showing a 'blip' larger than that which would correspond precisely to the returning radar pulse.

Both NTDS and the NTU/SYS-1 programs are symptomatic of a major trend in fleet air defense since 1945 – the emphasis on systems aspects of the problem, rather than on the performance of the individual weapons. For example, many ships currently carry versions of the Standard Missile which have essentially the same engine and airframe. However, effective system performance depends upon the combination of radars, computers and fire control devices in the system as a whole. The Standard Missile fired by an Aegis ship is said to enjoy approximately a 60 percent range advantage over a Standard Missile fired by a Tartar D ship, because the former can program its weapon to fly a more energy-efficient flight profile. A ship equipped with SYS-1 should be able to handle appreciably more targets than one without, and indeed should enjoy a much higher probability of successful target detection in the first place. Similarly, a carrier equipped with NTDS can handle far more interceptions (ie far more individual targets) than can one without, even though both ships may have identical numbers of identical fighters aboard.

A second important issue is the balance between shipboard weapons and airborne ones. As the range of the former increased, the dividing line between short-range (shipboard) and long-range (airborne) weapons became less and less meaningful. Indeed, from time to time tradeoffs were proposed between carrier fighters (which crowded out carrier offensive aircraft) and long-range fleet defense missiles such as Talos and Typhon. From the mid 1950s on there have been proposals for a sort of merger – 'Forward Pass' – which uses the ships to carry massive, very long range missiles, but directs them from radar picket aircraft such as the Grumman E-2 Hawkeye. Forward Pass epitomizes US postwar air defense development, since it emphasizes the role of the radar (aboard the airplane) and of the communications and control system (linking airplane and ship); no one platform can be identified with the entire system. Thus far Forward Pass has never been adopted, in view of the fragility of the communications links on which it would have to depend.

A related major feature of postwar naval air defense is the attempt to extend fleet radar



coverage through the use of airborne pickets (airborne early warning, or AEW, aircraft). Initially, they were developed as a means of improved surface (antiship) search, but this project ('Cadillac') received considerably increased emphasis from 1944 onwards as a means of overcoming low-flying kamikazes. 'Cadillac' materialized in 1945 in the form of APS-20 radars slung under modified TBM Avengers and then under modified Flying Fortresses (PB) which were large enough to accommodate fighter control teams and which were sometimes referred to as flying CICs. Similar installations were later made in modified Super Constellations (WV-2s); for example the OEG study of 1956 envisaged such an airplane orbiting directly over the center of the task force. The carrier-based Avengers were succeeded by Skyraiders (AD-5W) and then by the Grumman Tracer (WF-2, later E-1B) and Hawkeye (E-2) which had greatly superior radars and which could accommodate fighter controllers. The current ATDS is an airborne adjunct to NTDS, carried aboard an E-2 which orbits several hundred miles from the carrier, in the direction of the expected threat.

The single theme which overlies all discussions of fleet air defense after 1945 is the severity of the threat. The guided bomb, as demonstrated by the Germans in 1943, brought the bomber out from the range of existing antiaircraft guns, and thus increased the load on fleet fighters. It also greatly increased the lethality of the individual attacker, which Pacific War experience suggested could very often penetrate a screen unopposed. In 1946, US officers considered the missile-carrying radar-guided bomber, (which could strike in weather precluding fighter flying) the principal threat to the fast carrier task force. Moreover, it was known that the Soviets had captured the relevant German technology. In fact not only had they obtained it, they had made it the subject of a crash program, reportedly led by the son of the head of the Secret Police. By 1956 the first Soviet bomber-launched, long-range antiship missiles were in service, and by the end of the decade the force of jet bombers armed with such weapons was considered by many within the US Navy the only effective Soviet counter to fast task forces.

The second great wartime air threat was the kamikaze. Off Okinawa kamikazes attacked in

such numbers that carrier fighters could not shoot them all down; fleet air defenses were saturated with individual targets, each of which carried enough explosive to do great damage. Moreover, unlike a conventional attacker, the kamikaze pilot was not deterred by a heavy barrage: he wanted to die. In fact, if he got close enough, even if his wings and control surfaces were destroyed, he would still succeed in crashing into his target. There was no postwar expectation of a repeat performance by the most probable enemy, the Soviet Union, but the issue of saturation continued to haunt air defense. As long as a single aircraft attacking alone could inflict fatal damage (eg by means of a standoff bomb or a nuclear weapon) then the attacking force would profit by splitting up its attacks and thus forcing the defense to deal with the maximum number of threats. NTDS was the attempt to resolve this problem, and both Aegis and Phoenix are attempts to overcome saturation. The other issue, that even a damaged attacker might 'go ballistic' and still inflict severe or fatal damage, made it essential that postwar air defense weapons achieve a much higher level of lethality than had been accepted before 1945. This particularly applied to the point defense weapons developed from the early 1960s onwards.

Nuclear weapons only made matters much worse, as a single hit or near-miss could certainly destroy a carrier and, quite possibly, some of her consorts. Again, it was necessary to destroy every attacker well beyond lethal range, and task force formations had to open up to reduce the consequences of a hit on any single ship. Defensive weapons had to have sufficient range to maintain continuous coverage in the larger formations. At first it appeared that nuclear weapons would be so scarce that few if any would become available for attacks on rapidly moving task forces – which would not be very easy to locate in the first place. However, by the early 1950s US nuclear production sufficed to permit the extensive deployment of tactical nuclear weapons, including nuclear air defense weapons; the Soviets were assumed to have a similar arsenal. Moreover, by the mid-1950s there were hydrogen bombs with yields as great as a hundred times those of the first nuclear weapons, and consequently with lethal distances about five times greater.

The nuclear threat in some ways corres-



1 Less well known than the Super Constellations conversion was the early warning version of the Neptune patrol bomber, the P2V-3W, an example of which is shown (20 June 1950). There was also an early warning version of the contemporary Mercator. Both had the APS-20 radar in belly radomes, but they could not accommodate the height-finding APS-45 of the Constellation. Moreover, the APS-20 proved useful as a periscope or snorkel detector, most Neptunes carrying it for ASW rather than for air control.

2 The interior of an E-2C Hawkeye shows several intercept operators at their consoles. The man in the foreground is using a light pen to manipulate the symbols on his display; there are four separate intercept control stations in the airplane. Almost as much as the capacity of the computer or the data rate of the APS-120 radar, the number of such stations determines the extent to which a single E-2C can deal with large numbers of airborne targets simultaneously.

Grumman

ponded to that of the guided missile carrier, in that a very fast bomber at high altitude could project its weapon some considerable distance, simply by virtue of the momentum it provided. Such a bomb would not be particularly accurate, but on the other hand it would not have to be.

Existing fleet air defense systems could not cope with these threats. The fighters of 1945 were unable to land under some weather conditions, and so BuAer made a major effort to develop bad-weather landing aids (Carrier Controlled Approach or CCA), leading ultimately to the current automated All-Weather Landing System. The prospective generation of jet fighters had such short endurance that they would probably have to be held on deck awaiting warning of an incoming attacker; moreover, given the high speeds to be expected, they would have sharply reduced time to attack that bomber. Major efforts therefore went into improving fighter lethality, first through improvements in guns, then through unguided rockets, and ultimately through guided missiles. Fighter designers sought increased endurance, which in turn required larger aircraft with more fuel tankage – which required more powerful carrier catapults and much increased carrier aviation fuel stowage. There were also programs designed to

increase early warning range, through either an airborne picket or the use of special radar picket destroyers or submarines. Only since the early 1960s has carrier bad-weather performance sufficed to permit full dependence on airborne pickets.

The balance between shipborne and air-borne weapons continued to shift throughout the postwar period, given variations in the rate at which each system evolved. However, the urgency of the air defense problem never relaxed. For example, in May 1955 the Senior Member of the Ad Hoc Committee to Study Long Range Naval Shipbuilding Plans and Progress, Vice Admiral T C Combs, DCNO (Air), wrote to the CNO that

The defense of the Fleet against air attack appears to be the most critical single area in present and prospective capabilities, and thus the area deserving priority of attention in balancing the ship program against requirements. The primary areas requiring improvement are surface-to-air fire power and radar for warning and for fighter control . . .

The air defense problem is posed by present and immediate future Soviet capabilities of attack at high subsonic speeds and altitudes up to 40,000 or more feet, using nuclear as well as conventional weapons. While adequate solution of the conventional weapons defense problem may be within the outer fringe of present capabilities, solution of the nuclear weapons defense problem is not. Nuclear weapons make successful attacks possible from altitudes and weapons release ranges beyond the effective hitting range of antiaircraft gunfire. Enemy nuclear weapons use would considerably increase the necessity for the pre-release attrition of attackers in order to assure the security of a naval force, while simultaneously the higher approach speeds considerably reduce the time available to fighters to inflict this attrition. Cognizance must also be taken of the reduced fighter capabilities in present and future task forces, compared with those available in later stages of World War Two, and of the lower number of firing runs to be expected per airborne fighter.

It becomes increasingly clear that as of now, and in the future as well, the fighters alone (unless used in inordinate numbers) cannot control the principal threat – nuclear attack – while the gun will be virtually out of the battle in such attacks. It is thus essential that surface-to-air missile fire in considerable volume be available at the earliest possible opportunity.

In reaching this conclusion the limitations of these missiles, and the probability that their performance may be less than optimum for several years, have been considered. It is evident that the limitations affecting defense against low altitude attack must be lifted in time, by improved guidance, use of nuclear warheads, pointer fire, etc. Similar solutions give promise of making both Terrier and Talos useful as dual-purpose, surface-to-surface weapons, with greater range and lethality than present main batteries on destroyers and cruisers.

While these limitations and various operational deficiencies are being remedied, the enemy nuclear threat will year by year be growing in magnitude to the point (600-knot bombers at 60,000 feet, plus air-to-surface missiles) where successful surface fire solution is wholly dependent on the missile. As missiles and missile launching systems surmount their present limitations and become fully operational they should completely replace the present major anti-aircraft batteries of the Fleet. We will not accomplish this until after 1970 even if we place full missile batteries in every new construction vessel whose primary tasks require participation in nuclear air defense.

In the interim the question remains of how we can place a respectable missile capability in at least

our carrier striking forces by 1960, despite funds limitations. By that year Soviet nuclear plenty, and advanced delivery capabilities, will be most probable.

In assessing 1960 striking force requirements . . . the best single measure is number of missile launchers available to each task group considered as a whole. During the transition to missiles, formations must in any event continuously adapt to a growing number of launchers per task group, thus initially type of ship and position in disposition is not the controlling factor, so long as the ship has adequate stability, guidance equipment, and missile stowage. The important thing initially is to get the maximum number of effective launchers in the Fleet. To this end some specialization in individual ships can be accepted . . .

Consistent with its technical progress, the Talos missile should be introduced in adequate proportions. It will have the first nuclear A/A capability. Its long range will be valuable with any warhead to break up attack coordination at a distance, and ultimately essential to defeat missile carriers before they reach the drop point. Two Talos launchers per attack carrier task group, preferably in separate ships, are considered a minimum requirement for 1960.

To meet these requirements, several courses are open. The least promising, because of ship limitations, conversion costs, and short hull life remaining, appears to be conversion of existing destroyers. This is not recommended. The frigate construction program offers an excellent opportunity . . . to place maximum missile capability in a class of ships intended primarily for striking force screen employment. A program of austere CL conversion offers an additional and economical means of accelerating missile introduction, and the only feasible means of placing an appreciable number of Talos missile launchers in service by 1960 . . .

Thus far, only the carrier task force has been considered. A recent Op-60 study indicates that surface-to-air missile ship requirements for ASW forces, for underway replenishment groups, and for the defense of merchant shipping are very high even for a war in 1955–56. Amphibious force defense must also be considered. Granting the primary importance of striking force requirements, it would appear that immediate steps to meet these additional requirements should be taken if at all possible on a not-to-interfere basis, and at moderate cost. It is possible that destroyers will be acceptable platforms for partial Terrier installations, and therefore it would seem indicated that all such new construction ships incorporate a Terrier battery aft at the earliest date it can be demonstrated technically practicable. Whatever may be the ultimately desirable proportion of DDG to DD in the Fleet, we can be sure that two years' production confined solely to DDG, in comparison with the present DD inventories, will not exceed this proportion. Plain DD's or DDG's incorporating a smaller, shorter-range Terrier when developed, can be added to program in later years if requisite for long-term balance.

Associated with the accelerated introduction of missiles, and of vital importance to Fleet air defense, is the provision of increased warning and control range. While airborne early warning may be developed to assist in this problem, it appears that the continuing first charge on AEW resources should be low altitude warning, not otherwise readily achievable . . .

Once missile ships reach the Fleet in numbers, and the surface anti-aircraft zone can be extended to 50 or more miles, it becomes obvious that the full effectiveness of fighters will be contingent on ability to intercept at ranges of 100 miles or more. This cannot be accomplished against high altitude jet attack with present ship radar. Furthermore, it appears that development of ship radar is sufficiently slow to restrict the growth potential of missile batteries.

It appears possible that by 1960, in ships converted under the FY 58 program, Talos ranges up to 100 miles may be achieved – provided warning ranges approaching 200 miles can be attained.

Current information indicates that by 1957 early warning ranges of 250 miles against Mach 1 targets up to 60,000 feet could be obtained, if adequate priority were given to the provision of necessary equipment. For the 1960–62 period there is a requirement for a long range air search radar with characteristics which will provide detection on guided missile targets ($\frac{1}{4}$ square meter – Mach 3) at 300 miles to 100,000 ft altitude. The present state of the art appears to make this requirement possible. It is also indicated that well within this period precision height-finding and control information could be provided out to 125 miles, again assuming an adequate priority is assigned to the early provision of such equipment . . .

Priority should be given to Talos cruisers, which should be configured for the dual mission of serving also as task force air defense centers, with capacity for controlling fighter intercepts and coordinating the anti-aircraft fire of the force. A minimum requirement for 1960 would appear to be one such ship per carrier task group, or five for the Navy as a whole . . . The 200-mile air search capability should also be installed, if at all possible, in frigates of the FY 57 program, to enable them to act as distant pickets, extending task group detection well beyond 200 miles, and permitting radar silence in the main body when desired . . .

These conclusions were reflected in actual programs. Thus Tartar, far better suited than the heavier Terrier to a destroyer, was ordered into production to arm the FY57 and later destroyers of the *Charles F Adams* class, although the first test vehicle did not fly until November 1956; the first control test vehicle flew at the Naval Ordnance Test Station in July 1957, and the missile prototype only in August 1958 – after the nameship of the class had been laid down. As for the light cruiser/task force air defense centers, they received the first of the computerized CICs, EDS, as well as the advanced height-finding radars advocated in the May 1955 letter.

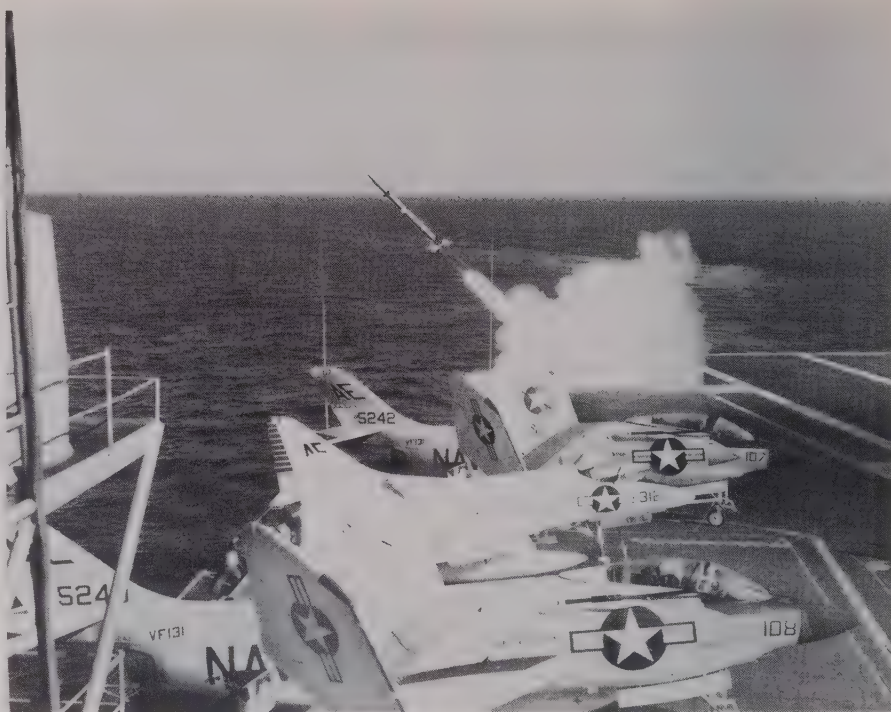
The major missiles of the postwar period, particularly the 'Bumblebee' series of shipboard weapons (Talos, Terrier and Tartar) were begun at the end of World War Two to meet the guided bomb/kamikaze threat. Ironically, all of them became operational in the latter half of the 1950s, just as the Soviets put into service the lineal descendants of the standoff weapons which had inspired them in the first place.

By that time the major perceived future threat was saturation: existing missiles such as Sparrow and Terrier required a single dedicated radar from firing to explosion, and hand-over from one target to the next was relatively slow. In the shipboard field, saturation led to a proposal for a new missile system, Typhon, combining new aerodynamic and electronic technology to overcome both saturation and the great unit cost of the first generation of missile ships. It ultimately perished of premature technology, but many of its central concepts were realized two decades later in Aegis, which will be the primary shipboard fleet air defense system of the 1980s.

As for the interceptors, it soon became evident that any fighter armed with short-range weapons would have no more than one or two passes per bomber, and indeed probably would make only one or two passes per engagement. Thus unless fighter weapon ranges were

drastically increased, the number of targets the fighter force might engage would be limited (at best) to the number of fighters on station in position near the direction of the incoming raid. By the late 1950s it was clear that higher fighter performance would not materially change matters, although it might permit some fighters initially orbiting away from the raid axis to enter the battle early enough to have some effect. Several studies suggested that the solution would be to abandon the search for higher fighter performance, transferring the performance requirement to the air-to-air missile. An advanced fire control system might then permit a single fighter to engage several attackers almost simultaneously. This was the origin of the current Phoenix/AWG-9 system, which is descended from an earlier Eagle-Missileer project, and is generally credited with the ability to engage six targets simultaneously.

Although it originated as a supersonic test vehicle for Talos components, Terrier entered service first. Here, in April 1962, both major components of the fleet air defense system of the time come together, as the carrier *Constellation* fires a Terrier with Demon all-weather missile-armed interceptors in the foreground. The missile is of the early wing-controlled configuration.



2. Wartime and early postwar missile programs

Gorgon

An important issue in the development of US air defense weapons was the wartime and postwar rivalry between the Bureaus of Aeronautics (BuAer) and Ordnance (BuOrd). The earliest guided missile proposals emanated from BuAer as projects for pilotless aircraft (P/A); BuOrd referred to its missiles, which were generally closer to rockets, as 'special weapons', a term later transferred to nuclear weapons. BuAer feelings towards the new missiles were ambiguous. Clearly they were weapons of the future, but on the other hand they required no pilots and were therefore rather unattractive to an aviator agency. On the other hand, BuOrd saw the missiles as the natural successors to its guns and, moreover, feared that if it lost control over missiles it would become the Bureau of Obsolete Ordnance. To some extent the efforts of the two Bureaus were coordinated in the early postwar period by the creation of a Deputy Chief of Naval Operations for Guided Missiles, and by an agreement that BuAer would continue to develop winged weapons whereas BuOrd would gain control over rockets and rocket-like devices.

The origin of interest in anti-aircraft weapons in the two agencies also differed. With BuAer, there had long been interest in a variety of small pilotless piston aircraft to be used as target drones. In 1937 Cdr D S Fahrney proposed that a drone be developed for a variety of mili-

tary tasks, including the interception of bomber formations and attack on ground targets. It would be surface-launched, like an airplane. The design of such an 'aerial torpedo' began in the BuAer Preliminary Airplane Design Section in mid-1940, and was completed in February 1941. It was a mid-wing monoplane powered by a 170hp engine and capable of 243mph. This was far too low a performance, and the project was dropped pending the development of a more satisfactory power source. That was the jet or rocket engine. In May 1943 Fahrney and Ivan Driggs of the Preliminary Design Section proposed an 'aerial ram' which would be powered by a 9.5in Westinghouse jet engine. It would weigh 661lb, would fly at 510mph, and could be air- or surface-launched. An alternative version, powered by a 19in jet engine, would weigh a ton and would be surface-launched only. Development of this weapon, now known as Gorgon, was formally begun on 19 July 1943; it was to be small – capable of air launch – and its primary mission would be to destroy large enemy aircraft by explosion, either contact or proximity. A secondary mission was attack on light surface craft. Gorgon would be command-guided, using either an RCA-developed FM radio homer or an infrared seeker. No one seems to have realized at first that guidance and homing would be a far greater problem than mere airframe design, or that much of the Gorgon program would be directed towards

improvements in propulsion. For example, in October 1943 a liquid rocket developed by the Naval Experimental Station, Annapolis, was specified as an alternative power plant. There were also two alternative configurations, a canard (Gorgon II) and a conventional one (Gorgon III), engine alternatives being designated by suffix letters ('A' for rocket, 'B' for turbojet, and 'C' for a 14in pulsejet).

Gorgon was not a very high priority project, and in retrospect seems to have been more a means of developing a new and promising technology than a means of winning the war at hand. Thus in the fall of 1943 a major impetus to its development was the report that the Germans were developing their own surface-to-air missiles. Gorgon itself was designated primarily an anti-aircraft weapon as of October 1943, but very little work was done on the guidance requirements peculiar to such a weapon. Rather, existing systems, primarily suited to air-to-ground use, were to be incorporated: television (in which the weapon was 'flown' by a remote pilot), the Pelican/D radar homer, a heat-seeker, and an RCA 'supersniffer'.

After a long period of development, the Bureau in March 1945 ordered a television-guided Gorgon expended in an attack on a TD3R-1 assault drone to test the feasibility of such guidance; however, the experimenters had to admit that television was entirely unworkable, given the very high speed of the missile and the sluggishness of the guidance

system. Gorgon could fly as much as 18–20nm in about two minutes of controllable flight, but no existing guidance system was effective over that distance. It appeared in 1945 that the only chance of success was to use a radar night fighter to guide the missile to within radar homing range (about 2nm) of its target, then release it. The Gorgon air-to-air missile project then died, leaving BuAer with a legacy of experience in missile and homing system development.

Gorgon also illustrated the primary choices available in anti-aircraft missile guidance, either air- or surface-launched; command, command plus terminal, and fire-and-forget. In a command system such as the television guidance originally proposed, the missile is flown under positive control for its entire trajectory. All computation is done on the ground; on the other hand, the greater the range, the more difficult it is for the ground computer or pilot to bring the missile into contact with its target. Thus an alternative is command guidance with terminal homing, which relaxes the requirement on the positive controller. This was the radar system proposed just before the entire project died. Finally, there are fire-and-forget missiles in which the missile itself homes on a target designated to it by the launcher; there is no load on the missile controller beyond the decision to attack one or another specific target. Infrared guidance would have worked that way, and Sidewinder is a modern example. Postwar development included an important compromise solution, semiactive radar homing, in which the missile guides itself towards radar energy reflected from a target; the radar illuminator on the ground (or in the launching airplane) must remain pointed at the target and, moreover, often furnishes a reference signal permitting more efficient navigation on the part of the airborne missile.

Lark and 'Little Joe'

Although Gorgon was unrelated to any specific wartime emergency, the same could not be said of the next series of weapons. In September 1943 the Germans introduced guided bombs and rockets by means of which a bomber could attack warships from well beyond their effective anti-aircraft range. By May of the following year the Office of Scientific Research and Development (OSRD) and the Joint Committee on New Weapons (JNW) were looking for countermeasures; JNW formed a Guided Missile Subcommittee on 22 June 1944. Both BuAer and BuOrd proposed surface-to-air missiles, although in the event only the BuOrd project, 'Bumblebee', resulted in a family of postwar missiles.

The BuAer project, 'Lark', originated with a memorandum from Cdr Grayson Merrill, head of the Special Design Branch, to the Aviation Design Research Branch (5 September 1944). He saw the target as an evasive bomber approaching at 400mph at 30,000ft, dropping its weapons at or beyond 20,000yds. The countermeasure was to be usable from a battleship or even a light cruiser, and it was envisaged as weighing a total of 1300lb, with a 150lb warhead, 11ft long, with an 8ft span and a 15in diameter, and a speed of 650mph. Subsonic speed was selected specifically to get Lark into action before the end of the war, although by November 1944 it was clear that not even a crash program would be effective.

Almost simultaneously BuOrd decided to

assign its surface-to-air weapon to the successful organization which had developed the proximity (VT) fuze, the Applied Physics Lab (APL) of Johns Hopkins University, which has had a dominant role in US naval SAM development ever since. Its director, Dr Merle A Tuve, proposed a ramjet engine to gain range, speed and altitude in a compact airframe. The CNO approved, and Project 'Bumblebee' was formally begun on 4 December 1944. Its products all received names beginning with 'T', after its head's name: Talos, Terrier, Tartar and Typhon. They would form the postwar missile defense of the US fleet, but for the moment they competed with equivalent BuAer projects such as Lark.

This competition was not resolved until after the end of the war. A Navy Jet Propelled Missiles Board, convened by the Office of the CNO in February 1945, recommended that both programs be pressed ahead on a crash basis; the VCNO, endorsing the Board's report, referred specifically to the kamikaze problem as a major incentive for missile development. This encouraged the Naval Air Material Unit (NAMU) to propose an extremely austere missile, 'Little Joe', as an interim substitute for Lark. Essentially it was a JATO unit with wings (canard configuration), radio command control, and a 100lb GP bomb with a VT fuze. The Little Joe design was proposed on 10 May, approved by BuAer on the 30th, and flown on 20 July 1945, only 86 days after its conception. However, it was a relatively primitive weapon and was canceled as inadequate in December 1946.

Meteor, Oriole and 'Super Lark'

The missile program continued to gain momentum postwar because both Bureaus recognized missiles as the weapons of the future. Although it was not yet clear what enemies the United States would have to face, all of the services pursued technology development; they could not go wrong if they backed the new weapons. Some confusion resulted. For example, in November 1945

BuOrd awarded MIT a missile development contract, Project 'Meteor', as insurance against the failure of 'Bumblebee'. Both surface-to-air and air-to-air weapons were envisaged, and at first the MIT program was concerned more with component development than with any particular missile. Although 'Meteor' did not lead to any viable weapon, a backup project for its air-to-air component did lead to a Naval Ordnance Test Station project, which ultimately became the very successful Sidewinder. This latter missile was approved by BuOrd in March 1947, shortly after the basic Meteor began its flight tests. At the same time, however, BuAer had its own ideas about air-to-air weapons.

Immediately after the war, then, there was some considerable confusion as to the type or types of missile the United States Navy required for fleet air defense. BuAer looked towards the development of a family of new weapons in the first five postwar years, 1945–1950, and convened a Board under Cdr Merrill to study 'Pilotless Aircraft For Fleet Use in 1950'. It called for a series of sixteen 1-year study programs (some of which are described in Part VI), including three surface-to-air and two air-to-air: P/A IV (antisnooper, long- and medium-range, by NAMU, Fairchild and Convair); P/A XII (antiferret, medium- and short-range, by Fairchild and Convair); P/A III (antikamikaze, by NAMU); P/A XI (patrol aircraft use, short-range, by

The Navy's first postwar anti-aircraft guided missile, Lark (Fairchild XSAM-N-2), is shown in a test launching at Point Mugu, April 1949. Although Lark did not lead directly to an operational weapon, it provided extremely valuable experience in the development of beam-riding guidance. The diamond-shaped structure at the tail contained two rocket boosters, angled out to either side, and both wings and tail were cruciform. Lark was abandoned in part because it was subsonic (Mach 0.85); it was propelled by a twin-chambered, liquid-fuel rocket engine, incorporating a large (400lb thrust) chamber which operated only when Lark slowed below a set velocity, and a small (220lb) sustainer, total firing time being up to 260 seconds. Lark was used as a Control Test Vehicle, CTV-N-9, postwar.



NAMU and McDonnell); and P/A XV (carrier aircraft use, short-range, by McDonnell). In other contexts the Board defined P/A XV as capable of up to 17nm, and P/A XI as capable of up to 35. In addition, there was an ongoing study of a standard 5in aircraft rocket fitted with a radar seeker, for short-range, air-to-air use. It became P/A XVI, and ultimately Sparrow, the standard long-range fleet air defense missile until the mid-1970s and, now, the standard short-range surface defense weapon. Of the more ambitious projects, the tightness of postwar budgets killed all but Lark (P/A IV and XII). Martin showed such promise in developing P/A VIII and XIII (ASM and SSM) that it was assigned its own air-to-air missile, 'Oriole', in March 1947. Oriole, unlike its ultimate competitor, Sparrow, employed active (fire-and-forget) radar homing and thus involved greater system complexity. As funds shrank and the threat against which the weapons were designed accelerated, only crash projects promising immediate results could be pursued, and Oriole died. Lark was also a postwar casualty, in its case of a decision dividing up the postwar missile program, in 1948. Clearly the original subsonic Lark would be inadequate, but a supersonic follow-on, 'Super Lark', was also discarded. Lark became a test vehicle, and the work done on it was transferred to 'Bumblebee'.

Sparrow was a principal benefactor of the fund shrinkage, and is interesting in retrospect as a project begun with only the most limited expectations, and yet developed to meet rather exacting specifications. It began as a guided derivative of the standard aircraft rocket,

similar in theory to a British project, 'Long Shot', and designated 'Hot Shot'. At first it was to be effective at up to 2000yds, fast enough to overtake a Mach 1 target. Given experience in beam-riding in the 'Lark' project, BuAer decided quite early to provide Hotshot with such guidance, looking towards target interception between 350 and 2000yds, using a dedicated tracking radar feeding target data into a computer which would direct a second, guidance, beam. Sperry, an electronics corporation, was selected as the prime contractor, in an unusual step which recognized the primacy of electronics in a missile project; the letter of intent was issued in December 1946. The next March Sperry indicated that the 5in airframe would not be large enough to accommodate radar and control equipment and to make full use of the guidance system; a new airframe was to be developed by Douglas, and the project was renamed Sparrow. By 1950, it was envisaged as a supersonic weapon with a range of up to 5.5nm at up to 50,000ft. It was to be complemented by 'Meteor', defined in 1946 as an air-to-air program with a range of up to 25nm.

The wartime technology base from which these weapons grew included the standard guidance system of the first generation of US air-to-air and air-to-surface missiles, beam-riding, developed by the Naval Research Lab. Although initially it appeared that any beam-riding system would require two radars, one of them tracking the target and the other generating the beam, in fact it was possible for a single radar to track a target and position a beam directed at it. Ultimately Talos was unique in having the paired systems, and that permitted it to fly a more efficient trajectory.

One of the striking features of the US naval missile program, in fact, was the parallelism between air-to-air and surface-to-air guidance systems: beam-riding in the first generation, then the much simpler semiactive homing, ultimately the combination of command and semiactive reflected in Aegis and Phoenix.

The one important exception was Sidewinder, the fire-and-forget infrared homing weapon developed by what became the Naval Weapons Center, China Lake. Infrared homing had the essential virtue of eliminating reliance on the launching airplane, a virtue for which it traded relatively short range and (at that time) an inability to home on anything but the tailpipe of its target. On the other hand, it was developed very rapidly, so that it entered service simultaneously with Sparrow. Moreover, it could be fired by a standard day fighter, whereas Sparrow required a dedicated fleet air defense interceptor with a heavy special-purpose beam-generating or illuminating radar. The virtues of autonomous operation were obvious from the beginning of the missile program, and in fact several missiles were designed for active (self-contained) radar guidance. However, it proved impossible to package sufficient power (at a sufficiently short wavelength) in a missile of reasonable dimensions, and even in 1983 Sidewinder is the sole fire-and-forget air-to-air weapon in the Navy's inventory. There is, to be sure, hope of an autonomous Sparrow successor, AMRAAM, for the mid- to late-1980s.

3. The '3-T' program and its successors

Talos

Talos, the long-range ramjet, was the principal objective of the wartime 'Bumblebee' program, although the latter remained a technology-development effort until 1946. Given the lack of any existing base of ramjet expertise, it was approached in stages. The first was a Burner Test Vehicle (BTV), Cobra, an 18in ramjet, followed by a Ramjet Test Vehicle (RTV), and then by an Experimental Prototype Missile (XPM), which it was hoped (in 1946) would provide a tactical weapon as early as 1948. In the event, XPM was developed into Talos proper, while a Supersonic Test Vehicle (STV) became an interim surface-to-air missile, Terrier, benefiting (with the Army Nike) from an OSD-ordered acceleration of the national missile program in 1949.

As originally visualized, XPM would be a missile to train the fleet in handling and in tactical employment. It would also be used for tests, and so would include some features, such as telemetry, not common to most weapons.

Both initial and ultimate forms were envisaged, boosted by a single rocket to Mach 1.7, and carrying a 300lb warhead to between 20,000 and 40,000yds (ie up to 20nm). Both would fly at Mach 2; the initial version would operate from 6° (2°) above the horizon to 20,000ft (ultimately 60,000ft), and would be a pure beam-rider; the ultimate weapon would add homing, since it would carry only a conventional warhead with a limited lethal radius. As actually built, Talos combined the two: it rode a beam which was programmed to fly it along an efficient trajectory, until it neared its target, when a semiactive seeker took over. As a result, Talos often hit its targets from overhead, achieving tactical surprise in some cases in Vietnam.

As early as September 1946, after the flight of an 18in RTV, BuOrd felt sufficient confidence in the program to enlarge it to include a long-range (400nm) surface-to-surface weapon (Triton, see Part VI). Booster problems delayed the program, and a variety of

control test vehicles were used; subsonic beam-riding roll-stabilized flight was achieved in January 1947, along a fixed beam; flight along a slowly moving beam followed in June. In July, a 'breadboard' seeker in an airplane was successfully tested. Effort then shifted to the Supersonic Test Vehicle (STV), which on 24 March 1948 made the first successful supersonic beam-riding flight (STV-2); in December it was fired successfully from a zero-length launcher. STV-3 was soon redesignated 'Terrier', but the lessons learned from it were of great value for the Talos program. A 6in ramjet flew to 60,000ft in September 1949, and a pretactical Talos in 1950, a prototype (RTV-N-6a3) flying in March 1951. Talos itself was designated SAM-N-6, the earlier Lark being SAM-N-2 (KAQ) and SAM-N-4 (KAY), designations in parentheses being those applied in July 1947.

The first full Talos (X-SAM-N-6) flew in October 1952, and the same month another, a test vehicle (RTV-N-6a4), made its first

1 USS *Dewey* was the first US missile frigate; in 1975 she was redesignated a missile destroyer, a measure of the general growth of all ship categories. Her two Terrier launch rails aft were associated with a pair of SPQ-5 beam-rider guidance radars, which were themselves closely related to the SPG-49 tracking radar developed for Talos, indicating how unified the '3-T' program was. SPQ-5 was later replaced by SPG-55, which was more reliable and which could provide illumination for semiactive homing as well as a guidance beam.

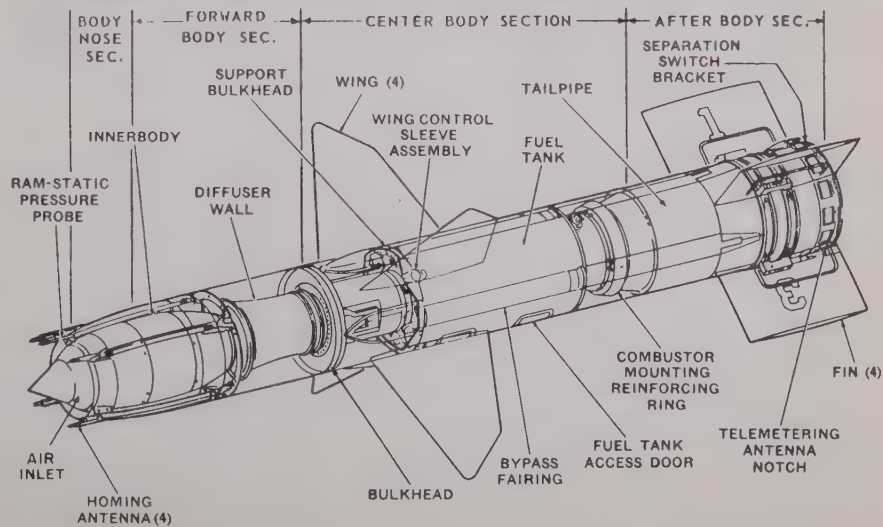
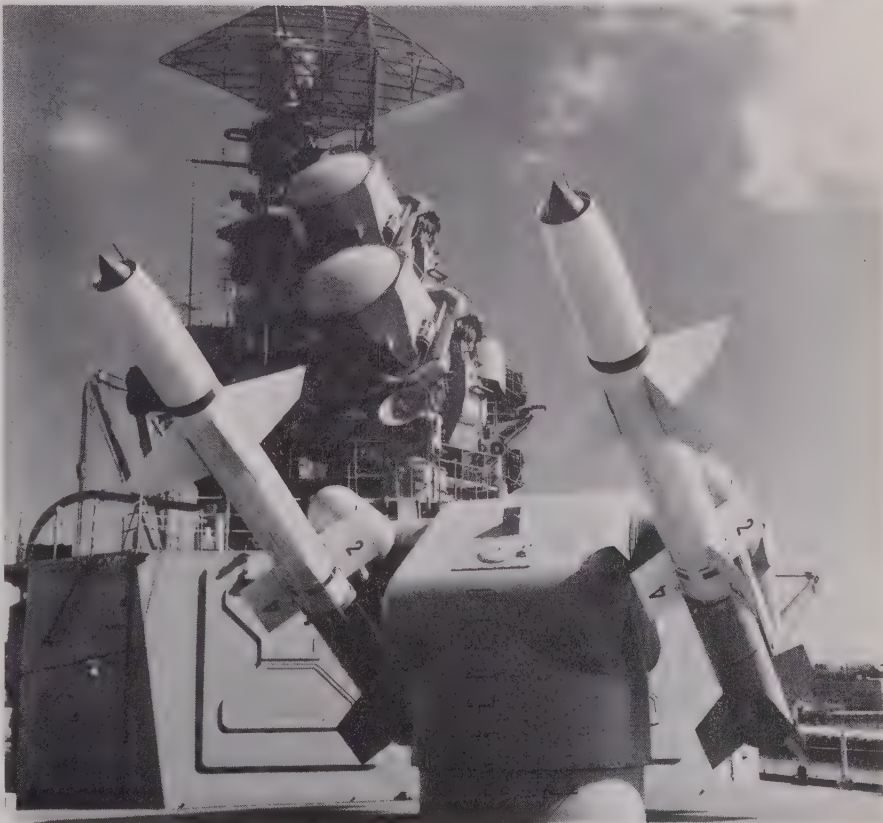
2 Talos was the weapon originally envisaged by Project 'Bumblebee'; here two are shown on their launcher aboard the missile cruiser *Little Rock*, November 1960. They lack the four-pronged nose antenna (interferometer) of homing weapons and are therefore probably either unguided training rounds or nuclear (nonhoming) rounds). The single nose probe is a static pressure probe. The large lens radars are SPG-49s for target tracking, whilst the small dish below them, SPW-2, projected the guidance beam. Another SPW-2 is hidden by the upper SPG-49. The large diamond-shaped radar is SPS-2, for very long-range air search and monopulse height-finding. Missile magazine blast doors are visible behind the launcher.

3 MAJOR SECTIONS AND COMPONENTS OF TALOS MISSILE

successful homing intercept. A successful collision with a QB-17 drone followed (at 28nm) in May 1954; Talos demonstrated its surface-to-surface missile capability in March 1956. In November, a SAM-N-6b succeeded in intercepting a target at 100,000yds (71ft miss distance), and one with a warhead destroyed a drone in March 1957. BuOrd evaluation aboard the first Talos cruiser, the *Galveston*, began in May 1957, the missile entering service about a decade after the initially predicted date.

From 1957 until 1979, Talos was certainly the most impressive US shipboard missile. In Vietnam it also showed that it was an effective one. During that long period of development, Talos operational requirements were considerably increased. Thus, as of December 1950, Talos was required to reach targets at 60,000ft and at a range up to 100,000yds (50nm); its primary targets would be incoming aircraft carrying guided missiles, at ranges out to 70,000yds. A miss distance of 70ft (300lb warhead) was acceptable, and service test was rather optimistically predicted for June 1953. In fact a Talos missile with these characteristics, SAM-N-6b (often referred to simply as '6b'), entered service only in March 1959. It employed pulse-radar semiactive terminal homing, and was accompanied by a nonhoming nuclear version, 6bW.

The next version of the missile, 6bl, rather dramatically doubled effective range, and also introduced a continuous-rod warhead with a greater lethal radius, 100ft. A nuclear version, 6bW1, had a similar performance, and was designated RIM-8D under the later (1962) designation system. It became operational in November 1960, the non-nuclear equivalent preceding it in October. Both presented logistical problems, since ships generally had to carry at least some nuclear Talos but were very unlikely to fire them except in dire circumstances. RIM-8E (6cl), the 'unified' Talos, solved this problem by allowing for an interchangeable warhead. It also introduced CW semiactive terminal homing, for better low-altitude performance (down to 50ft) and could fly at up to 80,000ft. The nuclear warhead was



1 CONTINUOUS-WAVE (CW) ILLUMINATION
(TALOS)2 A tail-controlled Terrier is shown at the commissioning of the missile frigate (now cruiser) *Gridley*, January 1970.3 The original Terrier was wing- rather than tail-controlled. Here one is launched from the test ship *Norton Sound*, 20 May 1958. In later versions, the long-span wings were replaced by narrow ones running much of the length of the missile, which had the great advantage of requiring no manual insertion at flight time. Although such finning was quite acceptable in Terrier, the same missile airframe was to be used for Tartar, for which no manual operations at all were possible.

said to guarantee severe damage against a battleship at maximum direct range, which explains why Talos was not considered an effective very long-range antiship missile, using any non-nuclear warhead. RIM-8E entered service in December 1962, and marked the last major performance advance in the program. There was already a successor program, Typhon, and major energies could no longer be diverted to Talos improvements; money spent on Talos went instead into improvements in its reliability. RIM-8G, an improved beam-rider, became operational in September 1966; the last surface-to-air version, RIM-8J, had improved guidance. An antiradar homing version (see Part VI) entered service in June 1968, as RGM-8H.

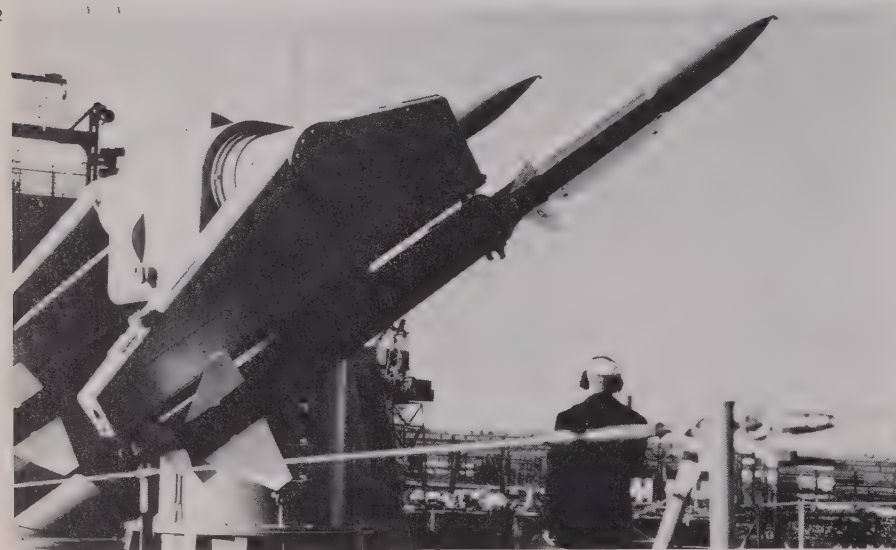
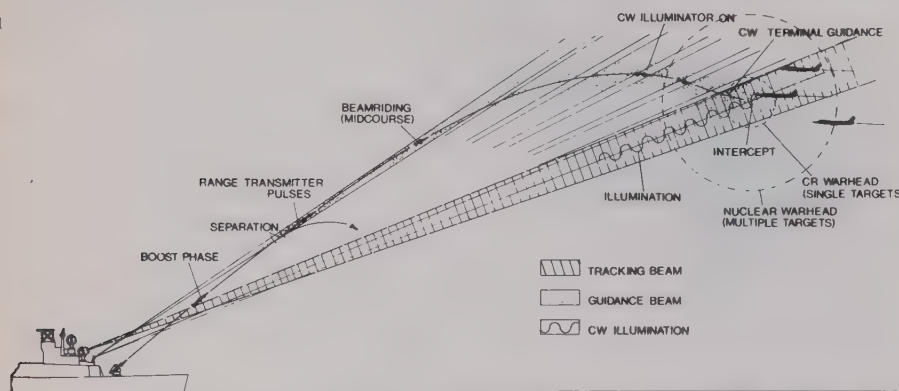
Talos suffered (and, ultimately, died) because it was too large to permit widespread

installation. Of all of the missile ships built as such from the mid-1950s onwards, only the nuclear cruiser *Long Beach* was large enough to take a Talos launcher. To modern eyes it is remarkable that there was little consideration of an appropriate Talos platform before 1954; even then a variety of specially built cruisers were considered, before anything beyond an austere cruiser conversion was rejected on cost grounds. The three *Clevelands* converted to Talos cruisers were, at least at first, topheavy and, at best, badly overcrowded. They certainly had no space or weight for growth features like NTDS. Three *Baltimore* class cruiser conversions were far more satisfactory, but that program was canceled in view of the impending availability of a far better missile, Typhon. In the event, with Typhon canceled in 1964, there was no interest in further Talos conversions: the reliability of the entire '3-T' series was considered so poor that any money spent on them went into improving it rather than into new platforms. Meanwhile Talos began to suffer from the problems inherent in any system based on the tube technology of the late 1940s. For example, its main guidance radar, SPG-49, had the transmitter tightly packed into the rear of the antenna (and thus extremely difficult to maintain) because, in the late 1940s, the power which could be passed through a rotary joint was more limited than it was later on. However, a project to develop a new guidance radar, SPG-61, foundered because by 1970 there were so few Talos ships on which to mount it. Similarly, any funding which might have been sought to convert Talos to a digital system would have been denied given the small number of installations.

Probably the final blow was the new emphasis on much shorter-range defensive missiles to counter the short-range 'pop-up' threat. Talos was a very long range weapon, relatively slow to respond, given the long warning time its operators could expect. The newer missile ships could be operated by a fraction of the crew of a Talos cruiser, and in 1979 the last Talos ship, *Oklahoma City*, was retired. *Long Beach* and the surviving *Baltimore* conversions, which had been scheduled to operate Talos as late as 1985, had their magazines sealed and, at least in the case of the *Long Beach*, their launchers removed. Surviving Talos missiles were expended as targets for the new Aegis system. The last operational Talos missile was fired by the cruiser *Oklahoma City* on 7 May 1979 off Poro Point, at the Republic of the Philippines Missile Range. However, *Oklahoma City* continued to fire Talos missiles as targets for other ship and aircraft missile systems, particularly Aegis, until her decommissioning at the end of 1979.

Terrier

Although it was developed from Talos technology, Terrier actually preceded the larger missile into service. Developed under great pressure, it suffered badly in reliability. However, the intensity of the need is illustrated by the willingness of the General Board to accept an interim missile system aboard the cruiser *Wichita*, even though each of the three launchers contemplated was to have had a rate of fire of no more than one round every 30 minutes (1948). Compared to Talos, the rocket-propelled Terrier was far more compact, and was small enough to go aboard a large destroyer or missile frigate. This was



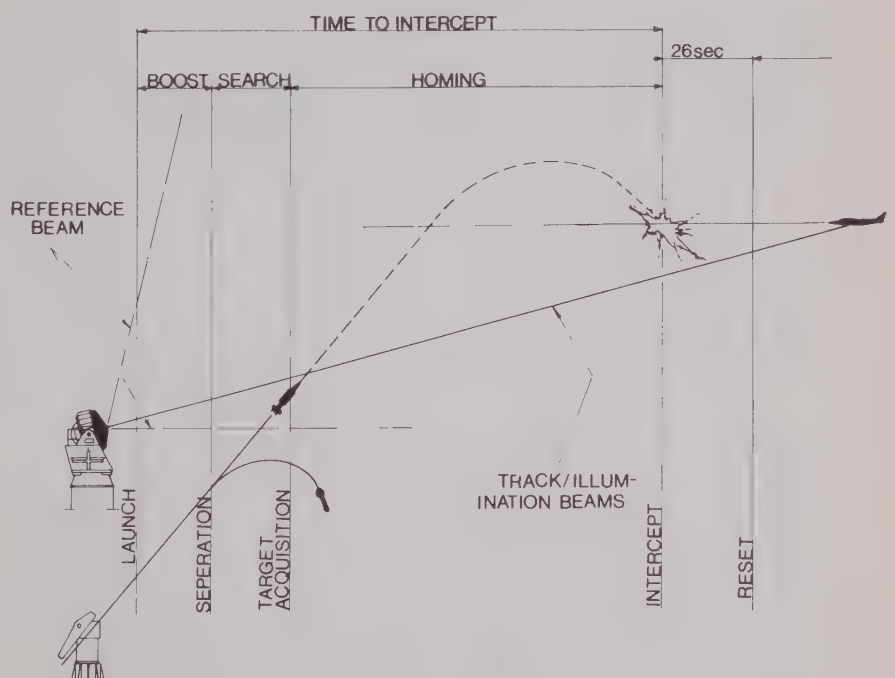
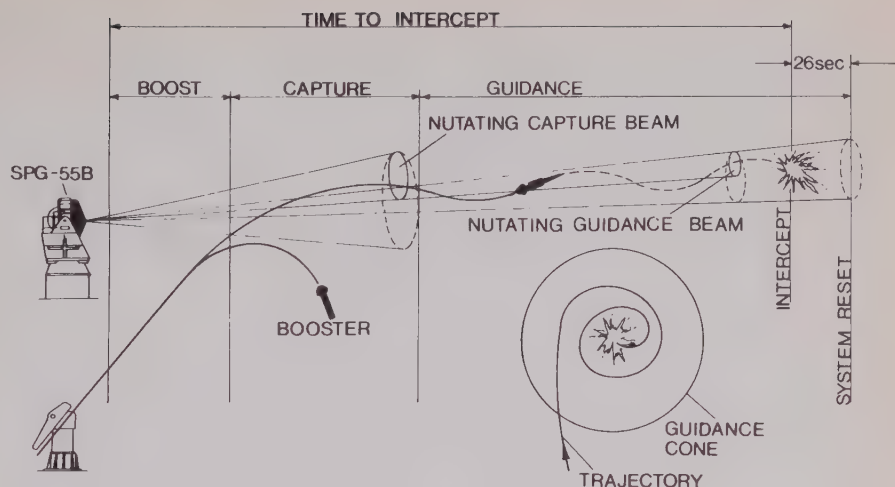
fortunate from the point of view of the longevity of the system: postwar shipbuilding budgets generally could not buy cruiser-size warships, but they could (and did) buy fast escorts (missile frigates) for the new carriers, and these escorts were generally Terrier-armed.

Terrier began as the Talos Supersonic Test Vehicle (STV-3), and Convair was assigned to produce the first lot of tactical missiles in the fall of 1949. However, flight tests in 1950 were considered deficient, while the missile design was frozen due to the outbreak of the Korean War, in hopes of obtaining an operational weapon at the earliest date. It was redesignated SAM-N-7 in 1951. A program reappraisal found the design itself deficient, difficult to produce in numbers, and with poor storage life. Terrier was, therefore, redesigned and simplified, its components grouped in sections for easier maintenance (*eg* hydraulic, electronic). It did not complete its Operational Evaluation until June 1955, when the cruiser *Boston* was nearly complete.

By way of contrast, early progress was impressive: in October 1949, STV-3 beam-ride for 54 seconds, more than double its performance of March 1948. A dual launch against a drone was achieved in October 1950, and in April 1951 a Terrier of Lot 1A detonated its smoke-puff warhead at the point of interception. That September Terrier was successfully launched from shipboard (presumably from the ex-seaplane tender *Norton Sound*), and Lot 3 Terriers destroyed two Hellcat drones at China Lake in May 1952. The first Terrier with a live warhead destroyed a drone in April 1953, and a ship-launched Terrier (Lot 4) destroyed a Hellcat in May. Meanwhile the old battleship *Mississippi* was converted into a Terrier test platform, firing its first missile in July 1953. A direct hit on a drone followed in August, and a Hellcat was destroyed by a high explosive salvo of Terriers in June 1954. Operational Evaluation aboard the *Mississippi* began that July.

Terrier evolution was gradual, one component at a time being varied. The major elements were the guidance method (beam-riding or semiactive homing), the means of control (wing or tail), and the engine. The original missile was designated BW-0, with a range of 20,000yds (10nm), a minimum range of 3nm, and effective between 5000 and 50,000ft. Its targets were to be aircraft at speeds of up to 600mph and at altitudes of up to 40,000ft; it flew at Mach 1.8. The 218lb controlled-fragmentation warhead was expected to be lethal at about 65ft, and as of 1950 studies were underway to increase the warhead size to 275lb and to improve range through use of a higher-impulse motor. The original booster burned for 2.5 seconds, after which a sustainer maintained flight speed for another 20 or more.

Terrier BW-1 was reengineered but showed no great performance improvement. A Terrier Improvement Program, begun about 1953, considered several changes: tail (T) control to overcome targets maneuvering at supersonic speed; a solid-propellant auxiliary power system to increase flight time; an improved autopilot; and an improved rocket engine (suffix -3; -2 was an improved motor without a new booster, and was not used) for higher speed and greater range. Tail control (STV-4) was first demonstrated completely successfully in July 1954, in a high-altitude flight. In



October the first wingless, tail-controlled Terrier flew successfully. Within two years a new model, BT-3, had appeared, aboard the *Cleveland* class missile conversions. BT-3A, later designated RIM-2D, was designed to achieve surface-to-surface performance without prejudice to its surface-to-air effectiveness. It had a longer-burning charge for its auxiliary power system, and an end-burning sustainer, which doubled missile range, to about 20nm. BT-3A (N) was a nuclear equivalent.

The next step was semiactive homing, which had great advantages against low-flying targets. By this time Tartar was being developed in modular fashion from Terrier, and both had very similar seekers. Since Tartar was a much shorter-range missile, X-band (subject to greater loss in rain) was chosen for it; Terrier would home on C-band. Later, as Tartar range increased, this distinction became less meaningful. The prototype CW-homing Terrier was XHW-1, emphasizing the gradual character of evolution. From the first, however, production of an HT-3 (RIM-2E) was planned, this weapon reportedly achieving a 30 percent improvement in SSPK compared to earlier

1 FLIGHT SEQUENCE OF TERRIER BEAM-RIDING MISSILE (ANTIAIRCRAFT MODE)

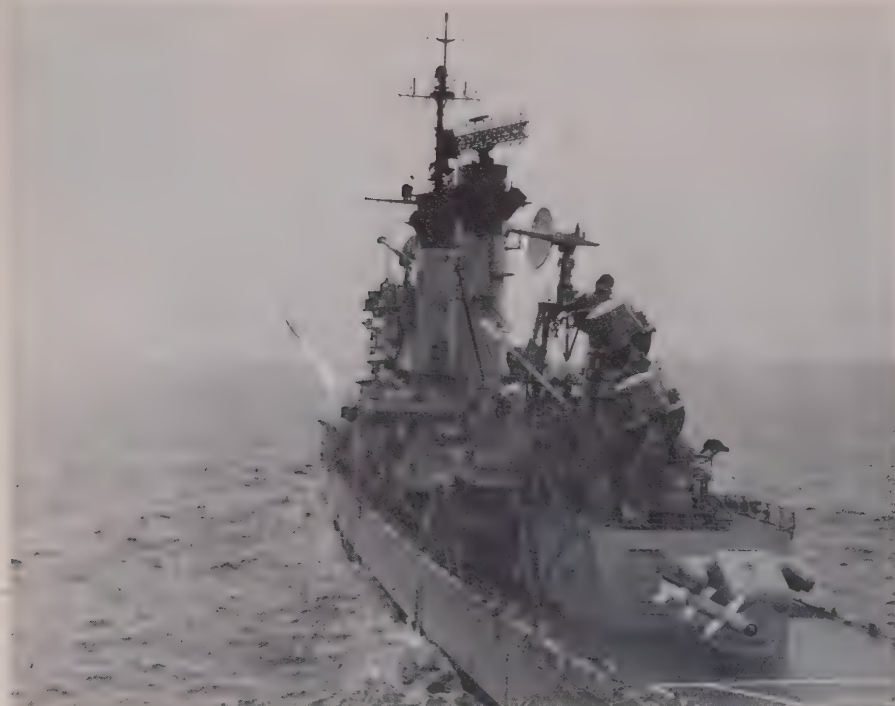
System reset is where computer automatically adjusts system if manual reset has not been performed.

2 FLIGHT SEQUENCE OF TERRIER/STANDARD SEMIACTIVE HOMING MISSILE (ANTIAIRCRAFT MODE)

After target acquisition, missile follows 'up and over' trajectory while maintaining constant collision angle. Computer automatically resets system if manual reset has not been performed.

versions, thanks to its better guidance. The last HT-3s had a new sustainer and power supply, which again doubled missile range, presumably to 40nm; they were designated RIM-2F. The greater complexity of the semiactive homing feature showed in the higher cost of RIM-3E and -2F - about \$75,600 in FY66, compared to \$57,600 for RIM-2C/D (FY60). Boosters accounted for only a very small portion of total missile cost: in FY66, an RIM-24 Tartar, essentially a Terrier missile with a different motor, cost about \$74,300.

Terrier production ended in 1966, about 8000 having been built; RIM-2 was succeeded



The *Columbus* (CG-12) fires a Tartar missile, in a photo taken in the early 1960s.

by the externally similar Standard Missile I (ER), RIM-67A. Internal changes must have been considerable: in FY73, the last year of procurement, SM-1(ER) cost about \$154,700 each, far more than RIM-2F, even taking inflation into account.

Tartar

As early as 1952 APL began to consider replacing its beam-riding guidance system with semi-active homing, which would improve effectiveness against low fliers, and which would also reduce the load on the launching ship. There was already a 1951 requirement for a missile system compact enough to replace a 5in/38 mount on a one-for-one basis, and a single-stage version of the tail-guided Terrier appeared suitable. Tail control was important because the relatively small tail fins could be folded against the missile, making for compact stowage and obviating the finning crew needed in a standard Terrier installation. APL submitted its proposal in 1955, and that May received a development contract for what would become Tartar. Deployment in the fleet was considered so important that the design of a Tartar destroyer was undertaken at once, and the ship incorporated in the FY57 program well before Tartar itself had flown in any form.

Tartar was conceived as a shorter-range equivalent of Terrier, effective between 2000 and 15,000yds, against low- and medium-altitude high-speed aircraft. As early as May 1957, a requirement for an Improved Tartar was issued, calling for range increased to 25,000yds, and maximum altitude to 65,000ft (from 50,000); in each case minimum altitude was 50ft, showing the value of semiactive homing. Even this was not the end of the improvement program. In 1959 TRIP (the Tartar Reliability Improvement Program) was begun (FY60). It sought lower cost and transistorization, but above all a reduction in weight by about 100lb (compared to Improved Tartar), an increase in range to 25nm, and of maximum altitude to 80,000ft. The TRIP missile thus ex-

ceeded the performance of Terrier HT3, although it was about half the size of the earlier weapon. However, in 1961 the longer-burning auxiliary power plant and sustainer were about to redress this particular balance, in RIM-2F. Even so, it is remarkable that within a few years Tartar progressed from a point defense weapon, with a range of about 7.5nm, to an effective area defense missile; late-model Tartars were generally credited with an effective range of 17.5nm. The small size and rapid launch rate inherent in the single-stage Tartar made it particularly attractive as a replacement for Terrier, even in major fleet escorts such as the *California* class nuclear cruisers. The Tartar system in these ships was the digital Tartar D, so named because it employed the higher-powered SPG-51D guidance radar.

Tartar development was very rapid, partly because it shared so many Terrier components. There was some initial delay due to competition from the Army Hawk system; for a short period in October 1955, the Defense Department froze its funds. However, a control test vehicle flew successfully at China Lake in July 1957, and the full Tartar prototype flew there in August 1958. Given the pressure behind service introduction, the disappointment which followed must have been particularly embarrassing. Technical Evaluation was completed aboard the first Tartar destroyer (*Charles F Adams*) in February 1961, with Operational Evaluation scheduled for the following May. However, it began late, and it had to be ended unsuccessfully in November, due to recurring difficulties in maintenance, particularly in the fire control system. However, in view of its performance potential, the Navy had already designated Tartar the principal future destroyer and frigate weapon, as early as 1958. Moreover, it was not possible to stop building Tartar destroyers. The program proceeded, Improved Tartar undergoing evaluation aboard the destroyer *Sampson* in 1962-63. It incorporated an HT-3 seeker, an improved

motor, and had improved lethality, specified SSPK being 0.5, with overall readiness for a twin-arm launcher with two illuminators being specified (rather optimistically) as 0.85. A search radar range of 60nm with altitude coverage to 100,000ft was required for successful operation, and missile coverage diagrams of the time appear to show an effective range of about 32,000yds (16nm).

Surface-to-surface capability was always a major factor in the Tartar program. The destroyers *Henry B Wilson* and *Lynde McCormick* each fired four against the former escort carrier *Makassar Strait* in October 1961 and January 1962, scoring two hits at 15,000-20,000yds; the continuous-rod warheads caused considerable damage. The only modification to the production Tartar used were slight changes in the speedgate. Even this change would not have been needed in an Improved Tartar, and no shipboard modifications were necessary. Further work planned for the FY64 program included development of a blast-fragmentation warhead, and modification of the Tartar fuze to incorporate a time-delay permitting penetration before explosion. Given these successes, it is somewhat surprising that Tartar antisurface potential was not widely publicized at the time of the *Eilat* sinking; a high supersonic Tartar would certainly have been much more difficult to stop than a subsonic weapon such as the Soviet 'Styx'. The capability was really there: Tartar surface-to-surface capability figured in a German decision to mount the missile aboard a planned class of frigates in the 1960s.

Although Tartar funding was sharply reduced in favor of Typhon, development of many of the TRIP features continued as part of the Typhon (Medium Range) program; these features later appeared in the Standard Missile I (Medium Range), which replaced Tartar. Unlike its predecessors, Tartar had no SAM-N designation: the Navy referred to it as Missile Mark 15 in a BuOrd series. Later it became RIM-24A in the unified Defense Department series.

Typhon

In 1958 APL became concerned about the ease with which existing 'Bumblebee' series systems could be saturated by mass attacks. Each missile required the attention of a dedicated beam-generator or illuminator throughout its flight, and no increase in the rate of missile fire could overcome saturation. Its solution was a combination of command and homing guidance, which eventually led to Aegis. In 1958 that meant track-via-missile guidance, in which radar signals were received by the missile but processed on shipboard, using the greater computer capacity available there. This relay system was later chosen for the US Army Patriot and the Soviet SA-10/SA-N-6. The new system also employed a massive, electronically scanned guidance radar, SPG-59, capable of tracking both targets and numerous defensive missiles. The program began as 'Super-Talos'/'Super-Tartar'; there was no Terrier successor since TRIP had shown that a Tartar-size missile could achieve Terrier performance. However, there was

some confusion with existing Tartar and Talos improvement programs, and the new APL missile became Typhon (Long Range) and Typhon (Medium Range). Ironically, it was also a response to the rising cost of missile ships. A single ship capable of engaging many targets simultaneously might replace several of the earlier ones. It could also be considerably smaller, if the long-range missile were reduced from Talos to Terrier size, thanks to more sophisticated aerodynamics and a better ramjet. A Tartar airframe was attractive for the shorter-range component of the system, since its automated launcher made a high rate of fire possible. In fact, Typhon was an early demonstration of the dictum that electronics cost dominates the cost of modern warships: the radar and fire control systems of the Typhon ships made them both expensive and, ultimately, rather large, at least as compared to existing Terrier and Tartar frigates.

As it was conceived in the early 1960s, Typhon was directed against the air and missile threat of the 1970 era; it was intended to provide

... defense in depth when operating in a heavy electronic countermeasure environment against air and submarine-launched missiles and high performance bombers... Although differences will necessarily exist in the two [long- and medium-range] missiles, in launching and handling facilities and in launch-trajectory computer programs, the two missiles will be capable of control from the same shipboard weapon control system. The unified weapon control system incorporates a fixed-array multi-element tracking and guidance radar to provide the high power needed for target acquisition and illumination for long-range missile intercepts and the beam agility required for multiple target engagements.

The proposed Weapons Direction System Mark 9 was closely integrated with NTDS, as might be expected.

Targets were expected to include Mach 3 bombers and missiles, generally at very high altitude; Mach 4 gravity bombs or short-range rockets; and surface ships ranging from torpedo boats to heavy cruisers and large merchant ships. In an optimum (energy-efficient) trajectory the long-range missile would have a range of 200nm; its maximum line-of-sight range was 110nm at 95,000ft, and its minimum range 6000yds (minimum altitude 50ft). Similar figures for the medium-range missile based on the Tartar airframe were 40nm for the command-guided trajectory, or 25nm at 50,000ft for line-of-sight homing; minimum range was 3000yds. Altitude limits were 50-90,000ft. Both missiles would have alternative nuclear and conventional warheads.

System performance was best expressed in terms of the number of targets which could be tracked and engaged simultaneously. There were alternative large- and small-ship versions, which could track 400 (120) targets at a 4-second data rate and 10 (10) at a 1-second data rate, *ie* with much higher precision. Up to 20 missiles could be controlled simultaneously in midcourse flight, but only 10 (with none midcourse) in terminal homing.

The long-range missile, thus, had double the range of Talos in about half the weight, and it cruised at Mach 4, compared to Mach 2.5 for the earlier weapon. However, its warhead was also only about half as heavy as that of Talos, at 150lb (50ft lethal radius). The smaller missile, with a range comparable to that of Tartar (*eg*

14nm on a line-of-sight trajectory at minimum altitude, or 20nm up-and-over), flew at Mach 1.25-4.0, compared to about Mach 2 for Tartar. Both missiles could operate in any one of three guidance modes: semiactive homing, passive homing or command, with missile guidance data processed aboard ship.

All of this was very impressive, but also very expensive; there would obviously be very few Typhon ships in the Navy's future. Secretary of Defense McNamara moved Typhon in and out of the shipbuilding program before finally canceling it in December 1963. In his Draft Presidential Memorandum on FY65-FY69 Fleet Air Defense Forces, he admitted that although Typhon was probably less expensive than the existing '3-T' ('Bumblebee') on a per-kill basis, he considered it far too expensive on a ship-for-ship basis; for example, the five-year cost for a rather austere Typhon DLG was 3.6 times the cost of a Tartar DDG, and each Typhon ship would of necessity become a prime target. He suspected further that, since over half of the cost of the system had been spent to overcome countermeasures,

... it should be possible to develop a new system with the high rate of fire of Typhon, but lower (though substantial) counter-ECM capability. With such a system, we would avoid the weight, size, and cost penalties associated with Typhon while obtaining what could be, for practical purposes, similar and adequate effectiveness...

The concentration of so much of the air defense capability of a task force in one or two Typhon ships, 'the citadel concept', makes those ships an attractive target. One radiation-homing missile could put a larger part of the missile ship force out of action due to the concentration in fewer ships and the use of a single radar in Typhon...

Similarly, concentration of capability in one or a few ships means that a malfunction or breakdown of a single system is more serious. There is concern over whether Typhon can be reliably operated in a sea-borne environment. The complexity of missile systems and our experiences of low reliability and readiness calls into question a system which implies great dependence on a few ships.

Defense of the formation against submarine attack requires numbers of ships. On one hand, when the widely dispersed formation is employed, more ships and more contacts add to the confusion of the submarine. On the other hand, the short range of sonars under many conditions ... means that large numbers of ships must be employed if tight conventional ASW screens are to be realized,

and the number required increases with increasing distance between the screens and the ships being protected. This issue would be less sharply defined if we could be assured of reliable long-range sonars and ASW weapons. However, it is often in the areas of high carrier hazard that sonar effectiveness diminishes...

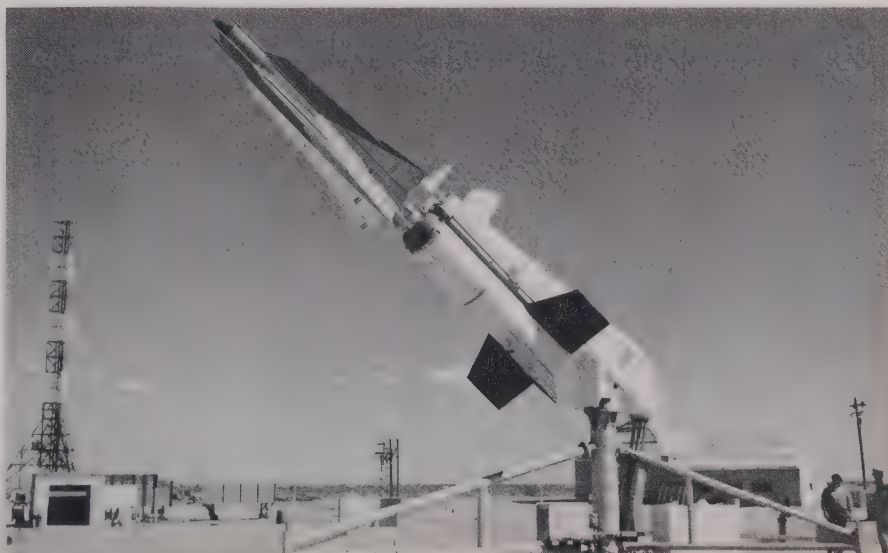
In effect, then, Typhon stood convicted of the many crimes of its '3-T' predecessors; the simpler system McNamara proposed became ASMS and then Aegis. At the same time, most of the money earmarked for Typhon was spent instead on a program to cure the unreliability of the existing missiles, a program which certainly proved its value in combat a few years later in Vietnam.

The '3-T Get Well' Program and the Standard Missile

The great defect of the 'Bumblebee' missiles was always their reliability, not their theoretical performance.* In 1962, for example, a

*In a 19 December 1963 Draft Presidential Memorandum on Fleet Air Defense for FY65-FY69 (which recommended the cancellation of Typhon and of the proposed Tartar destroyer conversion program), OSD listed what it described as Navy projections of single-shot kill probabilities: 0.48 for Talos, 0.40 for Tartar, 0.42 for semiactive homing Terrier, and 0.34 for beam-riding Terrier, in each case presumably against a standard high-altitude target. OSD noted that advances in fighter capability, particularly with the introduction of the APG-59 pulse-doppler radar in late-model Phantoms, would greatly reduce the number of enemy aircraft subject to surface missile fire in an attack on the fleet, and that even at the (relatively low) SSPKs proposed there would be more than enough missiles to handle realistic attacks. The F-4B was considered at least twice as effective as the earlier F-8E Crusader in this regard, although aircraft SSPK figures (as undoubtedly overoptimistically estimated at the time) were not given.

All three of the '3-T' missiles were to have been replaced by a new Typhon series, the Long Range variant of which (illustrated) was to have had Talos or better performance within Terrier dimensions. It incorporated new ramjet technology. The first prototype is shown at White Sands Missile Range, 23 March 1961, just before firing. Although the missile proved quite successful aerodynamically, the entire Typhon program failed as a result of overoptimism concerning its massive fire control radar, SPG-59. Aegis is its descendant.



IV. FLEET AIR DEFENSE AFTER 1945

sample of six Tartar ships reported 30 percent readiness, where a figure of 90 percent seemed possible. The United States had by then invested \$4.4 billion in missile-ship construction and conversion, and another \$2 billion in missile research and development, and procurement. Seventy-one missile ships had been authorized: 3 carriers with Terrier, 12 cruisers, 30 missile frigates, 23 Tartar destroyers, and 3 Tartar destroyer escorts, as well as several planned destroyer and frigate conversions and further Tartar escorts. Given the low availability of this force, Secretary of Defense McNamara refused to approve further new missile ships: the fleet would benefit more if defects in the existing types were resolved. In particular, a large new missile destroyer planned for the FY66 program was abandoned, and the number of *Forrest Sherman* class destroyers to be converted to Tartar ships cut from eighteen to four, and the number of *Mitscher* class frigates from four to two; a Terrier conversion planned for the large frigate *Norfolk* was also canceled, Secretary McNamara remarking that by FY66, when it was planned, the Terrier system would be quite obsolete, making conversion futile.

In September 1962 the CNO established a Long Term RDT&E Program for Surface to Air Missile Systems:

The rapidly increasing number of missile ships in the Fleet and the serious problems which have been associated with their introduction make it

imperative that the Navy establish an orderly Long Term Plan which takes into account the logistic, maintenance, and training problems of the Fleet as well as the technical opportunities presented by scientific progress. In the past, it was necessary to pursue increased performance as vigorously as possible in order to obtain weapons of sufficient capability to meet the air threat. Today, when performing as designed, our latest surface-to-air missile systems can handle any known aircraft; the principal problem being unreliability centered in the fire control systems and the search radars rather than in the missiles themselves. It is also economically impossible to scrap all our existing systems at once and replace them even with optimum equipment... The updating of the Surface-to-Air weapons systems of the Fleet must be done on a deliberate basis taking into account the value of the existing installation, the cost of a new installation, and the remaining life of the ships involved...

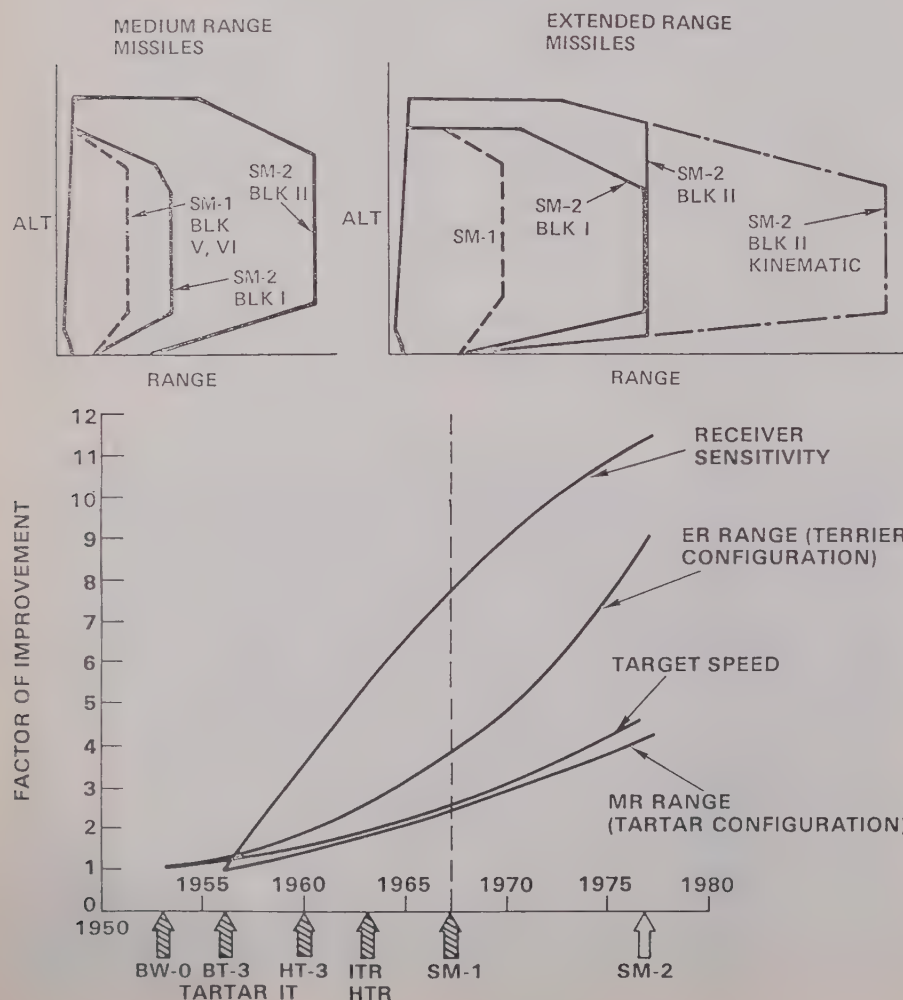
First priority...is accorded to those steps necessary to make our existing Terrier, Talos, and Tartar systems reliably meet the specifications to which they were built... A holiday is declared from anti-air performance extensions of the Terrier, Talos, and Tartar missiles: the range, speed, altitude, maneuverability, etc envelopes offered by the Terrier BT-3A and HT-3, the Talos 6c1, and the Improved Tartar are considered adequate. It is intended that this holiday shall be continued at least through FY65...

The principal Phase I effort shall be directed toward exploiting the full versatility of our Surface-to-Air systems by increasing their target capacity, reducing their reaction time, and developing their Surface-to-Surface capability...

A vigorous effort shall be directed towards developing more flexible and standardized fire control systems for SAM ships. The use of multi-purpose digital computers and digital data transmission shall be exploited, and the integration into the weapon systems of high performance 3-D radars, such as the SPS-48, shall be considered part of the program.

At the same time a new point defense missile, Mauler, was to be pressed forward, as well as a naval version of the Army Redeye, to provide even the smallest craft with effective self-defense. Submarines were to be provided with an effective defense against ASW helicopters, in a system then called SUBAD. Typhon was the next phase, with a more limited system, Cerberus, suitable for installation in existing Terrier missile frigates. For the more distant future, as Phase III, the plan envisaged the design of a new generation of surface-to-air missiles, Medusa, capable of defeating not only aircraft and tactical missiles but also ICBMs. Another new missile, Harpoon (not the one ultimately developed) would combine a helicopter radar platform with a very long-range, over-horizon, antiaircraft missile, to attack aircraft at 300nm and surface ships at 400; it was an extension of the earlier Forward Pass concept.

Of the whole imaginative program, only the improvement of the '3-T' missiles was ever really accomplished; Mauler was replaced by Sea Sparrow after the Army had to abandon it. The others were victims of advanced



STANDARD MISSILE INTERCEPT ENVELOPES

BLK: Block

General Dynamics

STANDARD MISSILE PERFORMANCE EVOLUTION

BW: Beam-riding/Wing-guided Terrier
BT: Beam/Tail Terrier
HT: Homing/Tail Terrier
IT: Improved Tartar
ITR: Improved Tartar Retrofits
HTR: Homing Tartar Retrofits
SM: Standard Missile

General Dynamics

technology and the expense of the Vietnam War. To some extent, too, Typhon fell victim to the skepticism engendered by the failure of the existing '3-T' missiles: one critic wrote that he could not understand the need for greatly increased raid-handling capacity when the existing systems could not yet meet the threats (already dated) for which they had been designed.

The problem was the explosive growth of the Navy missile force, which itself was a response to the gravity of the air defense problem. The first four missile ships were commissioned in 1956-58; twenty-six more followed in the next three years. In December 1961 the Assistant Secretary of the Navy for R&D reported on what he called the critical status of the Navy's Surface Missile Systems (SMS) and recommended drastic action. The Bureau of Naval Weapons established an Assistant Chief for Surface Missile Systems the following February, and on 20 July 1962 the Secretary of the Navy established a Special Navy Task Force for Surface Missile Systems. Bell Laboratories became a consultant to the Bureau of Naval Weapons in September 1962, as part of a proposed SMS 'get well' program. It included both ship modernization and the design and production of a new Standard Missile, which, in two versions, replaced both Tartar and Terrier.

The Fleet Air Defense Missile Systems Improvement Program began with \$274.1 million, authorized on 13 November 1962, and continued through FY66, with a total expenditure of about \$340 million, some of which had originally been allocated to Typhon. Another \$108 million was spent on a SAM Improvement Program in FY63-65, leading to development of a new Standard Missile. It was based on the original TRIP concept of 1959, and achieved so high a level of interchangeability of components that the two missiles involved came to differ only in motor, duration of power supply and autopilot setting. The Tartar successor incorporated the more powerful TRIP motor, which had also powered the Typhon (Medium Range) missile; it was designated Standard (Medium Range), or RIM-66A. As in TRIP, effective range is 25nm. Terrier was replaced by Standard (Extended Range), RIM-67A, reportedly effective at 40nm, which matches the range of late-model RIM-2F Terriers. Altitude capability is reportedly 50,000ft for RIM-66A and 80,000 for RIM-67A, but the former figure seems pessimistic. Standard Missile was developed by General Dynamics (Pomona), which had built Terrier and Tartar, between 1963 and 1966, a \$120.7 million production contract being signed in March 1967. Ship fittings began the following year.

The Standard Missile had several reliability improvements: it was all-electric with all-solid-state electronics; the elimination of hydraulic power for control surfaces and of high voltage power (for vacuum tube electronics) reduced warmup time from the former 26 seconds (for ITR, Improved Tartar Retrofit) to 1 second. In addition, shipboard checkout was eliminated, the Standard Missile being shipped as a 'wooden round' with a three-year no-test cycle, after which it is returned to the factory. It also incorporated a single sideband receiver for improved resistance to ECM and clutter rejection, as well as 'doppler offset' to improve multiple target discrimination. An increase to

19 guidance channels (*vs* 12 in ITR) reduces radio interference among nearby ships. The adaptive autopilot increases reliability, requiring no ram air and permitting the use of nonlinear electric actuators to move control surfaces; these latter have fewer parts for improved storage and handling. RIM-66B introduced a new Mk 56 dual-thrust rocket motor (DTRM) in place of the earlier Mk 27, for 45 percent greater intercept range and 25 percent greater intercept altitude. Both RIM-66A and -66B are described as Standard Missile I (SM-1) (Medium Range); RIM-66C, SM-2(MR), is the Aegis system missile described below. The others in the series were surface-to-surface weapons: RGM-66D, Standard ARM; RGM-66E, Standard ARM adapted to an ASROC launcher; and RGM-66F, Standard Active. RIM-67A is SM-1 (Extended Range), the Terrier successor; there is also an SM-2(ER) which extends the effective range of existing Terrier ships through the CG/SM-2 program.

Standard Missile development has been incremental, often through 'block' changes which are not reflected in special designations. For example, SM-1(MR) Block VI adds the SM-2 Block I monopulse seeker, for better countermeasures resistance, as well as a new proximity fuze (Target Detecting Device Mark 45 Mod 4) but retains guidance section interchangeability with Block V. Block VII and SM-2(MR) Block II are 10in longer than earlier Standard Missiles, with a new dual-thrust rocket motor which increases peak velocity by about 33 percent, for higher effective intercept altitude, improved maneuverability, and a range increase to match Aegis weapon system capability. A new dual-initiated warhead gives greater fragment velocity and density for higher closing rates, *ie* against faster incoming targets. SM-2 also has a coupled autopilot, for improved maneuverability against a diving and weaving target, and a Digital Fast Fourier Transform (FFT) signal processor for improved acquisition and tracking, and for improved performance in the presence of intense standoff jamming. The corresponding improvement in SM(ER) is a regainer Mk12 booster, which also adds about a Mach number in velocity. In the case of SM-2(ER), the added peak velocity give a kinematic range outside the current limits of the Aegis fire control system, but it does improve weapon performance against higher-performance targets.

The SM-2 system uses an autopilot to direct the missiles along most of its flight path, homing only near the target. In Terrier and Tartar ships the SM-2 autopilot will operate on the basis of settings at launch, whereas in the Aegis system the autopilot is commanded in flight, the ship radar tracking both missile and target. Air search radars aboard earlier missile ships are not precise enough for that task, and therefore do not track the missile at all.

The war in Vietnam was a test of the '3-T' improvement program. Both Terrier and Talos were fired in combat, and an air-launched ARM variant of Standard was extensively used as well; Tartar and Standard (MR) appear not to have been fired in combat. The cruiser *Long Beach* engaged seven MiGs overland during 1967-68, shooting down two of them at a range reported as 65 miles. However, most air kills by cruisers on the PIRAZ station off the Vietnamese coast were by Navy and Air Force aircraft directed by the ships, some air controllers making substantial scores. Perhaps

the peak of Talos operation was the assignment of the cruiser *Chicago* as primary air cover for the mining of Haiphong harbor. She shot down one intruding MiG and drove another away. There were two major Terrier actions reported. The missile frigate (later redesignated cruiser) *Biddle* (on PIRAZ duty) fought off air attacks by five MiGs against Task Force 77 during the night of 19 July 1972, shooting one down with a two-missile salvo at about 35,000yds. She was also credited with another kill (presumably at another time) and with directing thirteen successful fighter interceptions. The other major reported Terrier action was by the missile frigate (cruiser) *Sterret*, which shot down the first North Vietnamese MiG to attempt to attack US ships in the Tonkin Gulf, 19 April 1972, while operating with the missile cruiser *Oklahoma City* and the FRAM destroyer *Higbee*, the latter being severely damaged by an aircraft bomb. During this action *Sterret* reported having shot down a 'Styx' missile in the world's first example of missile *vs* missile combat. One MiG was shot down at about 10,000yds and another at about 30,000. During her Vietnam deployment, *Sterret* was credited with six MiG-21s and two MiG-17s, some of the former being air intercepts by friendly fighters. No total of MiGs shot down by US warships in Vietnam has yet been published, nor are there complete figures on assisted interceptions. Such data would give some indication of the balance between shipborne weapons and shipborne sensors in fleet air defense.

The 'get well' program involved considerable modifications to existing Terrier ships, including provision for homing rather than beam-riding missiles in early missile frigates. Improvements began under the FY66 program; they generally involved installation of the SPG-55B guidance radar (in some cases in place of the early SPQ-5) and of NTDS and the associated Weapon Direction System Mark 11. In addition, existing SPS-39 short-range three-dimensional radars were replaced by longer-range SPS-48s. The *Cleveland* class missile cruisers were too cramped for such improvements, and as such were effectively doomed. Improvements were possible in the two oldest missile cruisers, *Boston* and *Canberra*, but they were ultimately dropped from the modernisation program. That left the missile frigates and the cruiser *Long Beach*; the Talos ships were also to be modernized. They received SPS-48, a digital fire control computer, and NTDS, as well as the improved SPG-51B guidance radar for their Tartar secondary batteries. A new SPG-61 fire control radar was proposed, to replace the unreliable SPG-49, and the new weapon control system would be an NTDS/Mk 11 WDS type scaled to Talos requirements. In fact only *Albany* was modified fully (SCB-002); *Chicago* received NTDS during an early refit but it was not combined with the digital fire control system contemplated in the AAW Modernisation Program. *Columbus* never received NTDS and was the first of the three big *Baltimore* class Talos cruisers to be retired, in 1975.

The *Leahy* and *Farragut* class missile frigate AAW Modernization Program was funded in FY66-74, the nuclear *Bainbridge* in FY74, and *Albany*, the prototype *Baltimore* Talos cruiser, in FY66. That left the *Adams* class destroyers, which were a substantial fraction of the missile force, but which were considered relatively in-



A Standard Missile II (Extended Range), ready to fire from the *Wainwright*, February 1981.
General Dynamics

effective, lacking NTDS. They were provided with the Standard Missile, but no major modernisation was contemplated until the mid-1970s. In 1983 the DDG Upgrade program combines AAW Modernisation with the NTU Program. It is considered too expensive to be extended to all destroyers, but it does include a destroyer Tactical Data System (TDS) which can connect to NTDS Links 11 and 14 (in effect a small-ship NTDS) and which is integrated with a digital Weapon Direction System Mark 13 in place of the old analog Mk 4; there is also the integrated automatic target detector and tracker, SYS-1, and the SPS-52B radar replaces the older, unreliable SPS-39A. A new Mk 86 fire control system adds a third guidance channel to the two represented by the SPG-51 illuminators aft. In 1981 the refit of DDG-15-24 was planned, funded under an Operation and Maintenance rather than a Shipbuilding and Conversion (SCN) account; *Tattnall* was the first, at Philadelphia. The originally planned DDG-2 class AAW Modernisation program encountered both OSD and Congressional opposition on the ground of its very high cost (about \$200 million, or the cost of a new FFG-7 class frigate); moreover, it would not have made the ships fully adequate to face projected Soviet threats, since they still would have been subject to saturation attack.

Aegis

Even as he canceled Typhon, Secretary McNamara approved a small effort to develop a new antisaturation missile system, employing newer technology to fit it into a smaller ship. At first he envisaged the development of an entirely new missile, but by 1966 improvements in the Tartar and Terrier missiles had

encouraged him to approve a 'building block' approach in which a modified version of the existing weapon would be mated to a new fire control system. At the time he appears to have envisaged backfits to existing and future missile ships, since he approved the construction of two Tartar D missile destroyers for FY67; they would be the last conventional missile ships, before the introduction of the new system, then called ASMS (Advanced Surface Missile System). In fact ASMS emerged more than a decade later as Aegis, delayed in large part, it would appear, by uncertainty as to its platform. As this is written, Aegis will not become operational until 1984, a full two decades after its conception.

Like Typhon, Aegis employs a combination of command and homing guidance. Command midcourse guidance reduces sharply the length of time the missile requires the attentions of a dedicated illuminator, so that a small number of illuminators can control a large number of missiles. Early ASMS proposals envisaged the development of an active homing missile, which would require even less illuminator time and which would be better adapted to a violently maneuvering target, but this approach was rejected on cost and complexity grounds. Phoenix, which is somewhat similar in overall concept, and which was designed at about the same time, does employ an active seeker for terminal guidance. Effective midcourse guidance in turn requires effective tracking of both targets and defensive missiles, at a high data rate; Aegis substitutes a planar phased array radar, SPY-1A, for the massive SPG-59 of Typhon, and rejects track-via-missile in favor of a simple command-controlled autopilot combined with semiautonomous terminal homing. Early versions employed Tartar-type tracking illuminators, but SPY-1A tracking accuracy is such that the radar can direct (slave) illuminators which have no tracking capability of their own. Indeed, there have been suggestions that it is so precise that it can direct missiles provided with their own active short-range seekers into the acquisition 'baskets' of those seekers, thus increasing further the number of simultaneous interceptions possible.

The new DDG-51 missile destroyer, scheduled for first delivery in 1989, is to have a modified SPY-1D radar and three (rather than four, as in CG-47) SPG-62 illuminators. Later units will have illuminators described officially as 'agile-beam', suggesting a phased array capable of extremely fast slewing from target to target. They will also have the vertical missile launcher specified for late versions of the Aegis cruiser. In fact, current plans call for a modular weapon system in which a 32-element launcher can be substituted for a modularized light-weight 5in/54 gun; the current design shows one 64-weapon launcher aft, and two separate 32-element spots forward, one of them normally accommodating the gun.

Given a high rate of target handling, Aegis required a very fast-firing missile launcher, which in turn implied a single-stage folding-fin missile similar to Tartar. Early Aegis ship designs employed the existing Mk 13 single-arm Tartar launcher, but later the twin-arm Mk 26, which has the flexibility to handle a wider variety of weapons, was substituted. Later Aegis cruisers will have the Mark 41 Vertical Launching System, with an even higher rate of fire, and capable of firing

weapons as large as Tomahawk. The flexibility of the Mk 26 and Mk 41 launchers is considered important because the range inherent in an Aegis fire control and radar system exceeds that of the Standard Missile, at least in its current configuration.

Command guidance in itself increases missile range, because it permits the missile to fly a more energy-efficient flight trajectory. As in the case of Typhon, Aegis extends the range of a Tartar-size missile by 60 percent, presumably to 40nm. Applied to SM-1(ER), Aegis guidance is said to more than double missile range, presumably to over 80nm, which approaches Talos range performance. Further improvements are in progress, since the existing weapons are considered inadequate against very high-altitude supersonic missiles. Improvements in the SM-2 Block II program include a higher power propulsion system for greater speed and altitude (and, incidentally, about twice the range in the MR Block II version), autopilot modifications to improve midcourse stability and terminal manoeuvrability, ECCM, and improved warhead lethality to assure a kill against a very rapidly passing target. There is also an ongoing nuclear warhead program (W-81), to enable an SM-2 missile to counter a nuclear-armed antiship missile. It is argued that a conventional warhead, fired during the dive of such a weapon, would merely cause it to tumble, but would not destroy or disable it: this is a modern equivalent of the old kamikaze problem. The nuclear SM-2 program suffered badly under the Carter Administration, as the Arms Control and Disarmament Agency claimed that it approached ABM capability and was therefore illegal; it is likely to prosper under the Reagan Administration, given greater interest in carrier task force survivability in a general war.

Throughout the Aegis program, there have been complaints that the Standard Missile airframe is fundamentally limited, particularly in maneuvering energy at long range, and there have been proposals for alternative approaches. For example, the Mk 26 launching system was chosen in part because it permitted much greater flexibility in missile configuration than did its Mk 13 predecessor. For a time there was considerable interest in a low-volume ramjet or rocket-ramjet missile, which would have been powered (and therefore highly maneuverable) throughout its trajectory. In the early 1970s the Army Patriot, which has much greater acceleration than the Standard Missile, was proposed as a means of better exploiting the radar envelope and multiple-targeting capability inherent in the Aegis system. However, it ran afoul of the enormous 'sunk' costs represented by existing missile ships, whose magazines and launchers would have required total replacement.

Although Aegis ships are not to be designed to fire SM-2 (ER), this missile is still valuable; existing Terrier ships are to be modified to provide it with the necessary midcourse guidance. They will, therefore, increase considerably their ability to handle multiple targets. In this CG/SM-2 system, Missile Fire Control System Mark 76 Mod 9 provides the command uplink through the SPG-55B fire control radar, and the downlink is provided by a shipboard installation called SYR-1. This system was first tested in the missile destroyer (former frigate) *Dewey* in 1978, and it is to be extended

to all twenty missile cruisers of the *Leahy* and *Belknap* classes. Some accounts include the former missile frigates of the *Dewey* class and the Tartar D frigates of the *California* and

Virginia classes. SM-2 (ER) entered service in 1980, and all of the upgraded ships were to receive it by 1991; steps were also being taken to advance this date to 1988.

4. Point defense

The Basic Point Defense Missile System (BPDMS)

The history of the US Navy's surface missile program is marked by constant attempts to reduce the minimum size of the ship compatible with missile protection. From the mid-1950s onwards the design of a missile system to protect smaller ships was an operational requirement, although in practice such systems were not practicable until the mid-1960s. About 1959 the Navy became interested in a new Army system, Mauler, as a tentative replacement for existing 3in and 40mm air defense guns. Formal Studies began in 1962, a Specific Operational Requirement being issued in March. The Bureau of Naval Weapons wanted to begin Sea Mauler development in FY64, but the basic Army missile was as yet not mature enough, and the program began to slip. In March 1964 a shorter-range interim system, based on the existing Sparrow III air-to-air missile, was proposed; it would operate in all weather and would be able to react quickly to incoming threats. This Basic Point Defense Missile System was first tested aboard *LST-1158* in May and June 1965, before transfer to the *Norton Sound*. It had been briefed in August 1964 and approved for validation tests; Puget Sound Navy Yard fabricated the experimental

launcher, designing an eight-round box, while the Naval Materiel Command and Raytheon built the illuminator. At the time of the first validation tests, a system lifetime of eight to ten years was projected, but BuWeps had a much more sophisticated 'ultimate' system in mind.

Alternative interim systems included Redeye, a hand-held low-velocity weapon; the Army Shillelagh antitank missile; the British Seacat; Chaparral, a surface version of the air-to-air Sidewinder; Chaparral with an advanced seeker; and Sparrow. Sparrow had the highest kill probability per engagement, and was also capable of handling a head-on target, which the infrared systems could not. Its nearest rival was the British Seacat, but it was considerably faster and had a higher single-shot kill probability. Mauler was better against a tail-chase or crossing target, and it was smaller and lighter; it also came closest to the requirement of medium altitude against a supersonic target. However, it involved considerable (excessive as it turned out) technical risk. As of June 1964 it was expected that the Mauler development program would be completed in April 1965, but it was canceled instead that December, replaced in the Army by the much less capable Chaparral; Sea Mauler (RIM-46), which had been tested aboard the *Norton Sound*, died at the same time. That left only Sparrow, as the

basis for subsequent versions of the Point Defense Missile System.

An engineering development model of Sea Sparrow, employing a repackaged F-4

1 The Army Mauler system was originally to have been the standard Navy point defense weapon; here one is shown aboard the test ship *Norton Sound* on 14 June 1966, well after the program itself had been canceled. Surplus Sea Mauler missiles were proposed to test some of the technology suggested for the Advanced Point Defense Missile System program two years later. Equipment in the background appears to be an extemporized box launcher and a Sea Sparrow director. The equipment above the Mauler box launcher is its acquisition and guidance radar: Mauler was an entirely self-contained unit, which was one of its attractions.

2 All three elements of the Basic Point Defense Missile System appear in this March 1977 photograph taken aboard the command ship *Blue Ridge*: the missile, emerging from its box launcher, and the simple handlebar director which controls it. There are two separate antennas, a 2ft parabolic dish transmitting CW illumination and movable in elevation, and, on the right, a 2ft flat-plate planar array (electronically conically scanned) to receive the reflected radiation. The operator sees an error signal in his eyepiece, and he maneuvers the director to keep it centered, achieving continuous target illumination. Errors inherent in such a 'man in the loop' operation are tolerable partly because the Sparrow itself is semiactive. The BPDMS radar director (Mk 76 of the Mk 115 fire control system) is a modified World War Two Mk 63 handlebar director.



illuminator, was mounted aboard the carrier *Enterprise* in August 1966. Production deliveries began in October 1967, under the FY68 program. These systems were extremely austere. They employed a modified eight-round ASROC 'box' launcher atop of modified 3in/50 twin mount (Mk 25 system). Information from CIC was used to direct a hand-controlled radar illuminator and system reaction time was a major problem. The targets were to be aircraft and ships, particularly missile boats, and Sea Sparrow performance was reportedly quite impressive, given its size and weight: a range of 8-12nm, and a maximum altitude of 50,000ft, quite comparable to figures for early Tartars not too long before. The first missile, derived from the contemporary AIM-7E air-to-air round, was designated RIM-7E-5, a reconfigured type for shipboard use being designated RIM-7H; there was also RIM-7F, derived from the air-to-air AIM-7F. All were considered deficient against the low-flying cruise missiles which began to be the major threat almost from the origin of the system; they also required fuzing and ECCM improvements.

Basic Point Defense System performance was always considered limited, and from time to time attempts were made to refit existing BPDMS installations. In 1979 Frequency Engineering Laboratories of Farmingdale, which supported the system, proposed a modification in which the illuminator would be automated, for faster system response. However, it did not provide for a missile performance improvement (through adaptation of the RIM-7M, for example) or a basic radar upgrade (eg solid state *vs* vacuum tubes) or for refurbishment of the launchers themselves, which had not been very robust to begin with. In 1981 the Navy announced that all 72 existing BPDMS systems in the Fleet would be replaced by the Phalanx close-in defensive gun during the period from 1981 through August 1987 (ie by the end of FY88). The ground cited was cost-effectiveness. There was, moreover, no existing 'hot' production line for the successor point defense system, NATO Sea Sparrow, and in 1983 there is no future point defense missile system clearly in prospect.

Two approaches to a solution to Sea Sparrow missile deficiencies were taken. Under the FY75 program a Sea Sparrow Improvement Program was begun. In Block I the new RIM-7F was to be given low-altitude guidance and fuzing capability to correct its deficiencies against cruise missiles flying at altitudes below 50ft. The Contractor Test Phase was concluded with firings from the frigate *Downes*, ending on 29 September 1976. Block II (ECCM improvements) ended when RIM-7F was discarded in favor of a ship-launched version of the new AIM-7M, with its monopulse seeker. In view of the urgency of the cruise missile program, all existing Sea Sparrow are now being replaced by RIM-7M.

NATO Sea Sparrow and IPDMS

NATO Sea Sparrow is the successor to the Basic Point Defense Missile System, developed initially in cooperation with Denmark, Italy and Norway under a Memorandum of Agreement signed in 1968; the Netherlands joined in May 1970, Belgium that June, and West Germany in February 1977. As in many other recent missile systems, the principal difference from the basic system

is in fire control: NATO Sea Sparrow operates automatically from target acquisition through engagement. Its missile (RIM-7H-5) has folding fins to fit a more compact launcher (Mk 29) and its director is remotely controlled by the ship's combat system. Further improvement is achieved not so much through better missile performance as through improved target acquisition: the Improved Point Defense Missile System (IPDMS) incorporates the Hughes Target Acquisition System (TAS) Mk 23. The TAS combines an L-band pulse doppler radar with an IFF system, automatically ranks threats and begins engagements. It can track 54 targets simultaneously. IPDMS has been in production since 1973, and the TAS was tested aboard the frigate *Downes* in 1975.

The Advanced Point Defense Missile System (APDMS)

In the mid-1960s the Navy began to draft characteristics for a Sea Sparrow successor, tentatively designated the Advanced Point Defense Missile System. About \$1 million was spent on a 14-month Concept Formulation study in 1966-67, looking at various alternative concepts, including guns and unguided rockets. However, it soon became clear that a guided missile would be needed. The major changes, compared to BPDMS, would have been automation and a much hotter missile; Sparrow was considered too slow, and had too small a warhead to destroy a missile far enough from the target ship. This study was reported about 1 May 1967.

Meanwhile, a NATO Naval Armaments Group had revised interallied R&D procedures, and needed a test case; Admiral Michaelis, OP-72, thought that Sea Sparrow would be a good example, and NATO Sea Sparrow was the result. It was a natural competitor to the emerging Advanced Point Defense Missile System (APDMS), and incorporated as many APDMS features as possible; in effect the founding members of the NATO Sea Sparrow group bought the APDMS package except for the missile itself and the Target Acquisition Set (which became the Hughes Mk 23). The US system, IPDMS, incorporated the TAS and thus could be considered APDMS except for the missile.

Only a conceptual design for the APDMS missile was ever formulated, but it suggests what would have been required. As sketched by Naval Ordnance Systems Command, it looked like a short Standard Missile, and at Mach 2.5 was very fast, with a 150lb double-rod warhead, a 10in diameter, and a weight of about 825lb. It required a dual-mode seeker since radar could not be depended upon to burn through jamming at close range. The second seeker mode, infrared, would not be available under some conditions, but it was the best the developers could do. Since the big mosaic IR seeker would fill most of the nose of the missile, semiactive homing had to be by means of a four-prong interferometer (reminiscent of the Talos configuration, adopted in that missile to permit an uncluttered air intake). The seeker was to stare rather than to scan (as in more conventional types) and so to engage cruise missiles head-on, acquiring them at 7-8nm and intercepting them at 5. Semiactive radar homing would overcome dependence on detailed threat characteristics. Within the program office, there was considerable unhappiness as to the

sheer size of what was, after all, a very short-range weapon. There was also a bureaucratic problem, in that a large Sea Sparrow community naturally resented the development of an alternative weapon. The APDMS group went so far as to design a NATO Sea Sparrow launcher large enough to accommodate its conceptual missile, weighing about 38,000lb rather than the 23,000 ultimately accepted. When the APDMS project was terminated in the fall of 1968, one of the first effects was the shrinkage of the launcher, which effectively killed any option other than Sea Sparrow.

The TAS concept was a major product of the APDMS exercise. IR was wanted to permit operation under electronic silence and ECM conditions, and the unit proposed was that which had originally been developed as a search/tracker for the F-14. Hughes later expanded the radar envelope (which had been envisaged as up to 20nm) towards conventional search performance, and the IR feature was ultimately abandoned.

The General Dynamics RAM was also a by-product of the APDMS exercise. Although no contractor proposals were ever solicited, the contractors did demand a briefing, and they made a variety of proposals of their own. General Dynamics still had 25 Mauler airframes left over from that program, and offered them with Block 4 Redeye IR seekers and interferometers; but they had too small a warhead for the APDMS mission. The same concepts have reemerged in RAM, but with an ARM radar seeker rather than a semiactive system, because the small interferometer in the RAM missile has insufficient gain for semi-active homing.

Sea Chaparral

With the failure of Mauler, the Army turned to a surface-launched version of the existing Sidewinder (AIM-9D), Chaparral (MIM-72); the latter had already been proposed by China Lake, with tracking and sea trials as early as October and December 1963, presumably in connection with the early BPDMS studies. As in the air-to-air mode, Sidewinder had the great virtue of simplicity; the issue was the extent to which it could engage incoming targets. China Lake was quite optimistic: 'Should the target be a large bomber or the speed be supersonic, adequate IR signals would exist for ranges to seven miles with the current seeker, and the forward hemisphere firing envelopes would be limited by visual acquisition to about four miles. The primary limitation on the forward hemisphere firing envelope against subsonic targets is the IR seeker...' A range of about 4.3nm and an altitude limit of about 50,000ft were claimed. Modifications to the existing missile were relatively minor. The seeker was altered to permit delayed (post-launch) target acquisition, and drag was reduced to make up for the absence of an initial boost by the launching airplane: for example, two of the four rear wings were replaced by thinner low-drag non-rolleron types. Four AIM-9Ds were mounted on a modified Army M45 machine gun mount or, alternatively, on a modified twin 40mm mount for naval use; both types were sent to sea aboard the LSD *Fort Marion*, achieving a high simulated kill rate even when operated only by the ship's personnel, after a week of familiarization and four hours of practice. The first actual test

firing appears to have been the destruction of an outbound (tail-aspect) QF-9A (Panther) drone on 20 September 1963.

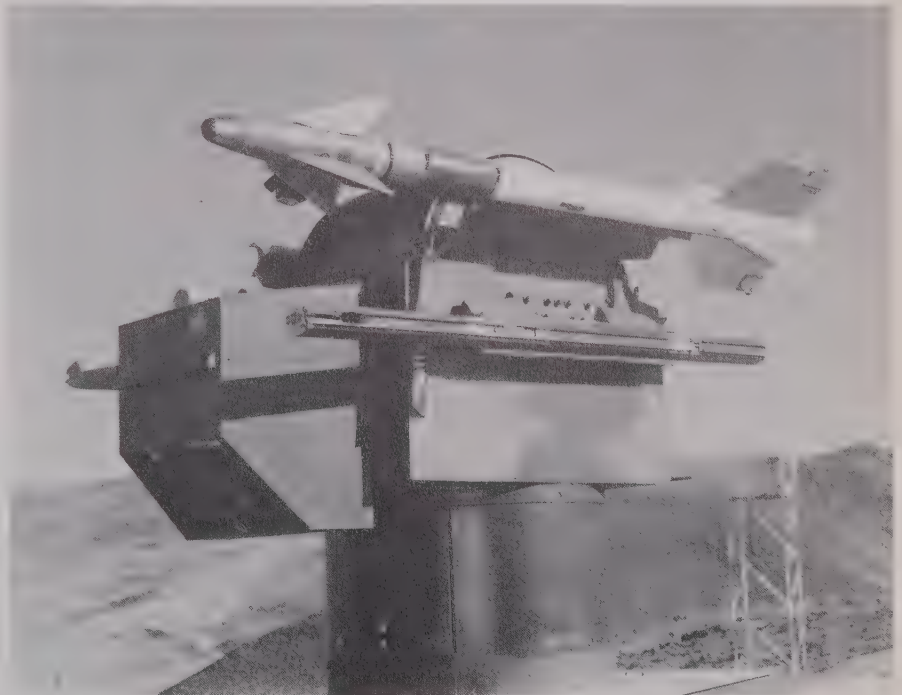
Clearly it was preferable to fire at outbound targets which would present the greatest IR signature; however, with the delay module in the missile guidance system, it could also be fired at a crossing or inbound target when the target filled a standard ring sight; the missile would begin to home later, as it picked up the 'glint' of the target. Moreover, China Lake claimed, in 1964, that an improved seeker would permit Sidewinder to home head-on against single-engine, subsonic jets at very useful ranges, a capability later demonstrated by the air-launched missile.

The Navy preferred the more powerful Sea Sparrow, but Sea Sparrow was a far larger and heavier system than a sea-based version of Chaparral would have been. By 1971 the cruise missile threat had become so urgent that emergency measures were being proposed and adopted. On 30 August 1971 the CNO, Admiral Zumwalt, approved an Op-93 proposal that the destroyer *Lawrence* be modified as an Anti-Ship Missile Defense (ASMD) test platform under the FY72 program. She received a special suit of weapons, including Chaparral and the even smaller Army hand-held Redeye IR homing missile, an IR search and track system, a CW threat warning radar (which shared the SPS-10 antenna), IR shielding for her funnels, a chaff mortar, and a flamethrower on her fantail (as an IR decoy). Her 'Hip-Pocket' ESM system used a computerized threat library for warning, providing an alarm automatically to the CIC. The CW warning radar used interrupted CW signals to achieve high average illumination in sea clutter, with doppler signal processing, detecting targets on the basis of their high incoming velocity. Once a target was detected, FM could be superimposed on the CW signal to measure its range. A multiscan display,

showing the past history (track) of a target enhanced the value of the existing SPS-39 rapid-scan radar: past scans were repeated in rapid succession so that a moving target appeared as a series of flashing lights on a line of residual light on the radar scope. Chaparral itself was to be used in an independent mode at least some of the time.

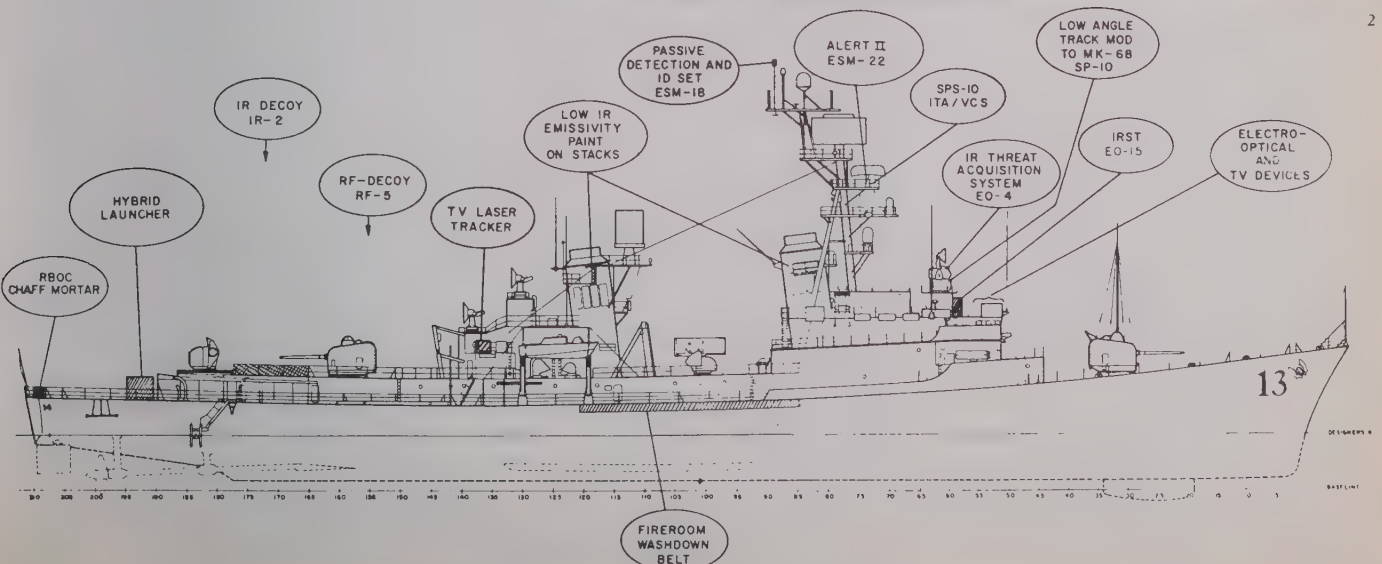
'Hip-Pocket' was evaluated in February-June 1972, and a 'Hip-Pocket II' plan authorized that September: this time the test-ships were *Hoel* (DDG-13, Pacific) and *Coontz* (DLG-9, Atlantic); there was also an ASW suite developed by NUSC San Diego. The DDG system included an ALERT II ESM apparatus (H-, I- and J-bands), sharing the antenna mount; a Passive Engagement System (PES) which automatically recognized incoming threats and showed their direction in the CIC; a Shipboard Infrared Surveillance System (SISS); a Dual-Spectrum Imaging Sensor (DSIS) for improved target detection

and identification; an IR Threat Acquisition and Verification System (ITAVS); an active-passive range-gated TV camera (including a laser for ranging and dusk/night operation); and a low-light-level antibloom television. The existing SPG-53 (Mk 68 GFCS) fire control radar was modified for better low-angle tracking, and the SPS-10 surface search system was given an incoming target alarm and video clutter suppression; it reacted to threats closing at Mach 0.5-3.0. The primary new weapon was a Hybrid Missile System consisting of a modified Chaparral launcher, a TV/laser tracker, and Hornet (laser guided), Chaparral (passive IR) and dual-mode Redeye (passive radar homing added) missiles. There were also passive defenses against IR and radar homing missiles: special low-emissivity paint, a 'fire-room' shield spraying the ship's side with seawater to reduce IR emissions, rapid-bloom chaff (RBOC), an IR decoy, and a variety of detectors of laser designators.



1 An MIM-72 Chaparral missile, loaded for test-firing at China Lake, January 1977.

2 'HIP-POCKET II' EQUIPMENT LOCATIONS ABOARD USS HOEL (DDG-13)



The DLG was to test active gun defense by Army-type Vulcan Air Defense Guns (VADS). Gun 1 was operator-controlled, target range being supplied by sound-powered phone. It had a stabilized lead-computing sight. Gun 2 was a VADS controlled by a modified Mk 68 gun fire control system. In addition, the ship was fitted with a 3-barrel XM-197 20mm gun on a pintle (Mk 10) mount, in effect a modern equivalent of the World War Two Oerlikon, and an austere NTDS (Link 11) receiver was installed. Of all of the 'Hip-Pocket II' equipment, only the SPS-10 radar modifications were service-approved, to remain after the experiments.

By no means were all of these measures taken, but the range of ideas suggests the urgency of the problem. It was significant at the time that Sea Sparrow could not be mounted on existing FRAM destroyers, which were exposed to possible North Vietnamese fighter and even missile attack; indeed, the destroyer *Higbee* was bombed by a MiG in April 1972. She was hit on her after gun mount, and the bomb exploded in the upper ammunition handling room, destroying it and the mount, as well as the magazine sprinkling system and the after part of the ship's fire main. Sea Chaparral was the only missile system available for such ships, and it was first tested on the destroyer *Floyd B Parks* (installed 15 May 1972, removed 14 March 1973). Eight other FRAMs were fitted: *Mason* (3 September 1972-6 July 1972), *Orleck* (1 October 1972-18 June 1973), *Anderson* (30 October 1972-1 October 1973), *Bausell* (10 October 1972-9 October 1973), *Henderson* (26 October 1972-30 June 1973), *Mackenzie* (30 October 1972-4 August 1973), *Tucker* (30 October 1972-18 June 1973), and *Gurke* (30 October 1972-9 October 1973). Missiles were removed as ships returned from Southeast Asia, and the system was not considered anything but interim. However, it was adopted by Taiwan, aboard three ex-US *Fletcher* class destroyers, replacing a twin 40mm gun mount.

The Shipboard Intermediate Range Combat System (SIRCS)

Apart from Mauler, US Navy small-ship defensive missile development in the 1960s was largely reactive, using existing systems developed for very different purposes. The Shipboard Intermediate Range Combat System (SIRCS) program was an attempt to plan ahead for the intense threat to be expected by about 1990. Although it was canceled (by Congressional order) in 1979, the concepts developed during the SIRCS competition will undoubtedly contribute to whatever system ultimately replaces Sea Sparrow. In 1976 the Navy funded competitive studies by RCA/Martin-Marietta, McDonnell Douglas/Sperry, and Raytheon/Lockheed/Univac; reportedly the threat against which SIRCS was designed was simultaneous attack by up to four missiles against a small ship (1000 tons) or up to fourteen against a large one; SIRCS was also to provide effective surface-to-surface fire.

The initial concept studies were completed by 1978, but Congress was skeptical at best. In the FY77 budget the Navy asked for \$16 million and received only \$2 million; it was told to modernize the existing missile systems. Later, concern was expressed that two new missiles (SIRCS and AMRAAM) were being

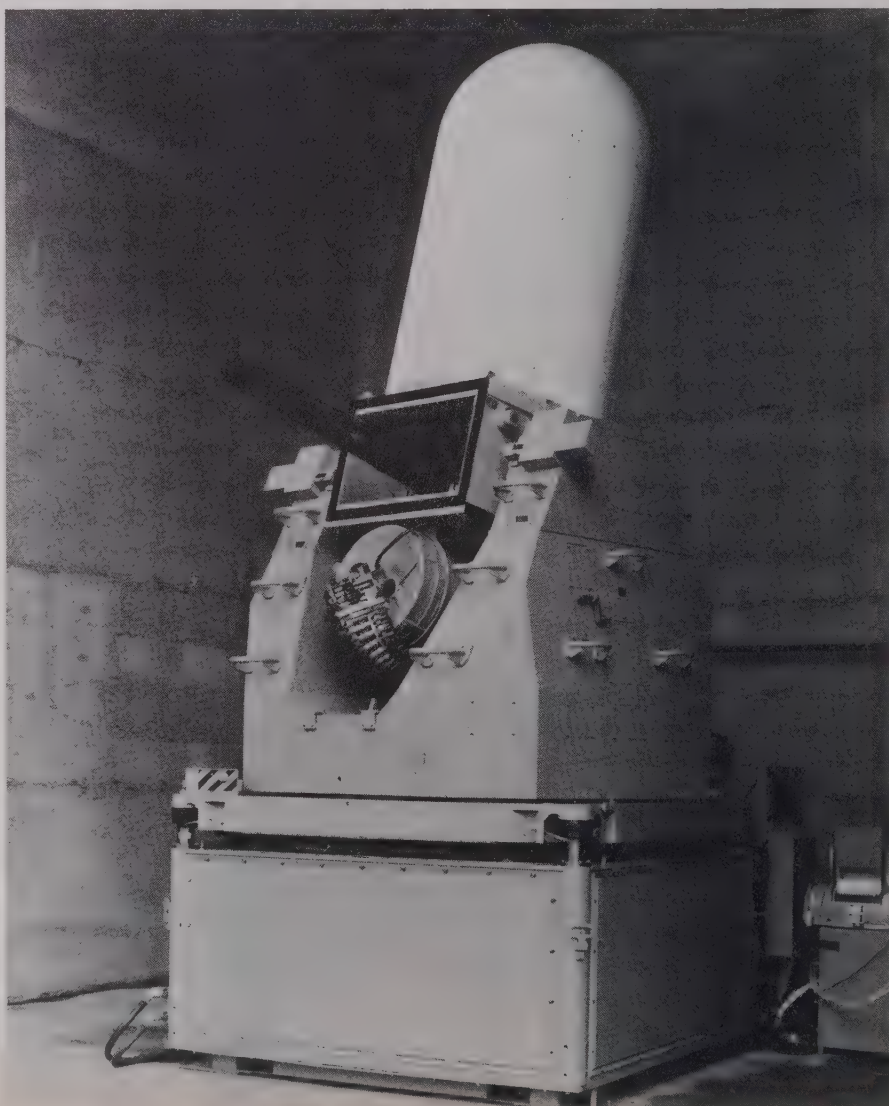
developed simultaneously to replace the former single Sparrow family. There was also some controversy as to the extent to which the SIRCS program adhered to a new policy, reflected in Office of Management and Budget (OMB) Circular A-109, calling for the customer to set only performance requirements, allowing for the widest possible competition. Finally the entire effort was abandoned; in 1980-81 the surface-to-air development program concentrated on relatively long-range (Aegis and the proposed DDGX suit, which will probably be a downgraded Aegis) and on close-in defense at less than Sea Sparrow range, by RAM (see below). As a private venture, Raytheon is continuing development of Sea Sparrow, including a vertical launch capability and new acquisition radars; it is conceivable that this niche will be filled, as in the case of Tartar/Terrier/Standard, by modernized forms of the existing weapon.

Phalanx

Fleet air defense is based on attrition of attackers by defense in depth: first with fleet fighters, then with missile systems of progressively decreasing range. In the 1960s Sea Sparrow was the shortest-range acceptable system, and the Navy sought some simpler, lighter system which could destroy attackers leaking through it. The Phalanx gun system was the

response to a requirement first stated by the Chief of Naval Operations in the mid-1960s. A feasibility contract was awarded to General Dynamics Pomona Division in 1969 for a new gun fire control concept which had been developed there: closed-loop spotting. Although work began under a Quick Reaction Contract (QRC), the type normally used to rush ECM systems into service, Phalanx did not in fact enter service for another eleven years, due in part to Congressional skepticism as to its capability (particularly reliability) in an extremely demanding role. It must defend ships too small to accommodate even Sea Sparrow, and it must also protect important units (which do have other antimissile systems) against 'leakers'. In both cases, the incoming missile must be destroyed far enough out to prevent it from 'going ballistic' and crashing into the target ship despite damage. Yet Phalanx must not waste ammunition by engaging while other, longer-range systems can still be effective. It is, therefore, effective between about 1500 and 500yds.

Phalanx, the Close-In Weapon System, is the heir to the 20mm and 40mm guns of World War Two: it will be mounted in very small numbers, but (at least in theory) should enjoy very high lethality. The drum beneath the gun should suffice for several engagements, and the radome above the gun carries both search and fire control antennas.



Design requirements are for high individual round lethality and for very fast reaction with a high probability of hitting. Pomona chose the proven M61 Gatling gun to achieve a very high rate of fire, but developed a new round, using high kinetic energy to destroy or prematurely burst the incoming warhead. A subcaliber projectile of the densest available material, depleted uranium, strikes the cruise missile with nearly all of its initial velocity of about 3600ft/sec. Its high speed also simplifies fire control, since the trajectory is very flat. This concept has long been known in antitank warfare, and reportedly the Mk 149 round was originally developed for air-to-ground attack.

The other major element of the Phalanx system is a closed-loop spotting fire control which greatly improves accuracy while cutting reaction time. The system radar tracks both outgoing bursts of fire and the incoming target; high velocity and very flat trajectories make such spotting worthwhile, and the angular error between fire and target can be measured and used to correct the next burst. Accuracy increases as the target approaches, with maximum lethality reported at about 500yds. Closed-loop operation refers to the use of such spotting data *before* the burst arrives at the target area. In more conventional (open-loop) systems a round or burst is fired and no correction is assessed until it has hit or missed – which in the case of Phalanx would waste much of its very short available time.

The Phalanx Close-In Weapon System (CIWS) consists of a pair of radar antennas (search and track) sharing a common Ku-band transmitter, mounted atop the housing of an M61A1 20mm Gatling gun, below which is a thousand-round magazine, reportedly estimated to be sufficient to destroy five targets. The entire assembly moves as a unit, engaging diving as well as sea-skimming missiles. Normally it operates automatically, detecting and engaging incoming aircraft or missiles unless a ceasefire button is pressed; the concept matches that of the New Threat Upgrade. Alternatively, it can accept target designation or, under the control of another fire control system, its gun can engage small craft. Elevation limits are +80° and -25°, with elevation at up to 86° per second, and train at 100°. Claimed reliability is very high, as it must be in so important a weapon: it showed 188 hours between failures in its final Operational Evaluation.

Development has been, unfortunately, extremely protracted. Closed-loop spotting was demonstrated at the White Sands Missile Range in 1970, and at the same time the lethality of the uranium round was proven. Full-scale engineering development was approved in 1970, and in 1971 simulated threat missiles were successfully destroyed. A prototype went to sea aboard the frigate *King* in 1973. However, skepticism remained; in 1975 a Phalanx prototype was installed aboard the hulk of the former destroyer *Cunningham* and missiles fired against it. All, including a Wall-eye, were destroyed in time to save the ship. An Operational Suitability Model mounted aboard the destroyer *Bigelow* in 1976 proved its capability in the presence of intense jamming, and succeeded in distinguishing small missile-like targets against nearby islands. Meanwhile, dramatic improvements in reliability were claimed. Phalanx was approved for service use in 1977, and a production contract signed that

December; the first units were installed in the spring of 1980 aboard the carriers *Enterprise* and *America* (three each). Ultimately each carrier will have three, each major amphibious ship and missile cruiser (or large missile destroyer) two, and each *Perry* class frigate one.

RAM

Although the Phalanx program was begun in 1969, interest in a new short-range lightweight missile for ASMD remained strong. After the Sea Chaparral experience, a new ASMD missile program (dual-mode Redeye, with radar/IR seekers) was begun under the FY74 program. Congress was skeptical of the value of so small a missile (2.75in, about 18lb) and directed the Navy to evaluate the adequacy of a 5in weapon, *ie* one about the size of a Sidewinder (about ten times as heavy). Thus the program was redirected to Advanced Development (rather than Engineering Development) in the FY75 budget, with concept validation due in FY76 and pilot production in 1978. A production decision would have followed in 1980, and the system might have entered service in 1981. However, Congress halved funding in FY78, partly because of apparent competition with SIRCS. The system may have been saved only because it was not solely a US project: in July 1976 West Germany signed a Memorandum of Understanding sharing development costs; later Denmark joined the consortium. A contract for a 50-month program of full-scale engineering development was signed with General Dynamics in June 1979 for what had become the RAM (RIM-116A) missile.

RAM derives its name from its configuration: it is a Rolling Airframe Missile, emerging spinning from its launcher, after which fins extend. Guidance is entirely passive, to permit rapid engagement of multiple targets. RAM and the current generation of US ESM sensors were conceived roughly simultaneously, and all are designed to exploit the active seekers of incoming antiship cruise missiles. RAM itself uses a two-antenna radar interferometer (reminiscent of the Talos system) for initial guidance, and the radar seeker points its infrared seeker at the target. When the latter picks up the 'glint' of the incoming missile, the radar seeker is switched off in its favor, as IR is considerably more precise.

RAM design is greatly simplified by the decision to roll the missile; only a single guidance channel is needed, since the same command, at one instant in the roll, causes the missile to pitch; at another instant, with the two fins vertical, it causes the missile to turn. Similarly, two rather than four interferometer antennas are required. The missile passive seeker is very broad-band, and it is informed by the ship fire control system of the frequency of the target radar at the time of firing. The initial missile spin is reportedly achieved by rifling the launcher tube; fins do not extend until after the missile emerges.

Missile development was simplified by the use of off-the-shelf components. The dual-mode guidance system had already been tested in the abortive dual-mode Redeye, and RAM is to use as its IR portion the seeker under production for the Army Stinger missile, the replacement for Redeye. It also employs the Sidewinder motor, fuze and warhead, and in this sense is a direct descendant of Sea

Chaparral. Even the proposed launchers will use existing components: RAM will be fired either from the two upper cells of a Sea Sparrow launcher (five missiles each) or from a new EX-31 24-tube launcher on the Phalanx gun mount. As in the case of Phalanx, RAM is described as a close-in or backup system; presumably its range will approximately match that claimed for Chaparral in 1963, since the current Sidewinder motor has not changed much since the AIM-9D.

5. Surface-to-air missile launchers

The reliability and launch rate of the missile launch systems have a major impact on the efficacy of the surface-to-air missile systems as a whole, and the weapons themselves show design features adopted to permit faster and more efficient launching. From the first, guided missiles presented the Bureau of Ordnance with unique problems. They were much larger (but also lighter) than the shells they replaced; they also represented a much greater explosive hazard on a pound-for-pound basis. They also were far less reliable, so that checkout and even overhaul facilities were required within the missile stowage and loading system. Until quite recently, for example, means of disposing of and then replacing dud missiles on the launcher had a considerable impact on launcher design. Moreover, the sheer size of the missile meant that even a cruiser would not be able to carry very many, and that arrangements for rapid replenishment at sea would be mandatory; such arrangements

in turn sometimes dictated missile magazine configuration.

The complexity of the weapons seemed at first to dictate that they would be stowed knocked-down, with relatively few available as complete ready-service rounds. Such arrangements survived in the Talos systems of the converted *Cleveland* class missile cruisers, although not in the Terrier systems, which had originally been developed in parallel. Even in the case of Talos, the goal of full service readiness was eventually adopted, in the *Baltimore* class (SCB-173) conversions.

Terrier Launchers

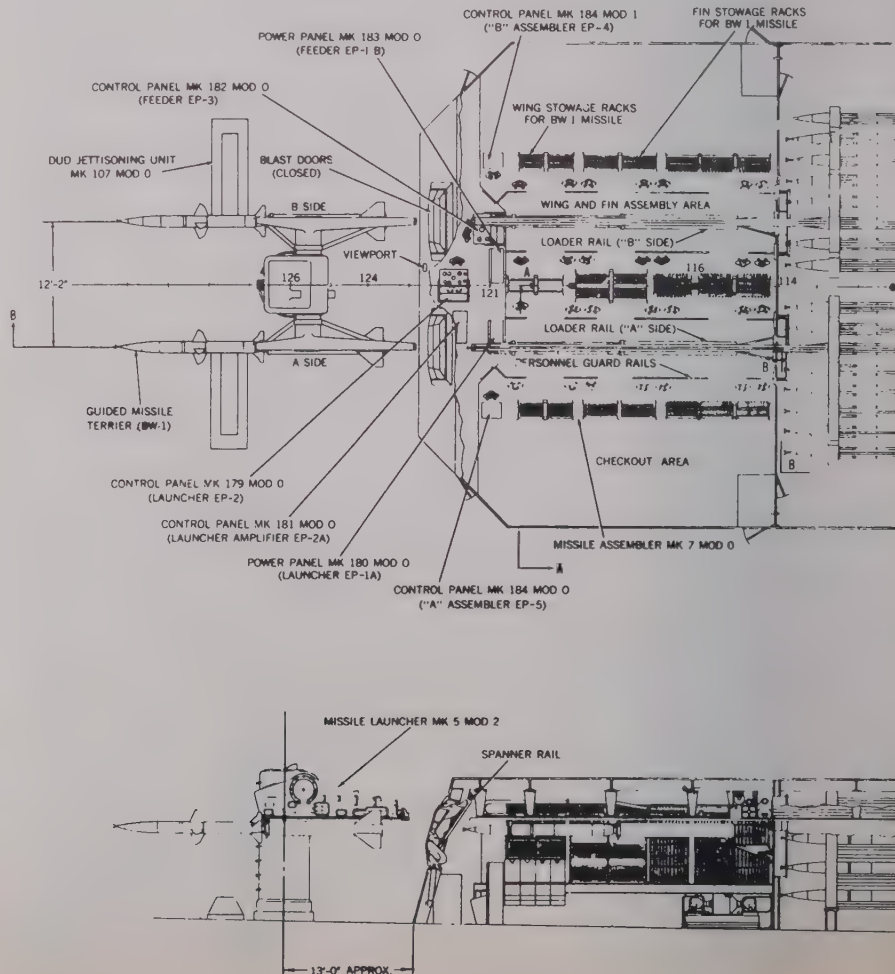
Terrier launching system evolution began with studies by APL for arrangements for what was then called the STV missile, to be installed aboard the heavy cruiser *Wichita* (1948). Both vertical and horizontal assembly schemes were considered, the boosters and the missiles proper being stowed separately. In the vertical

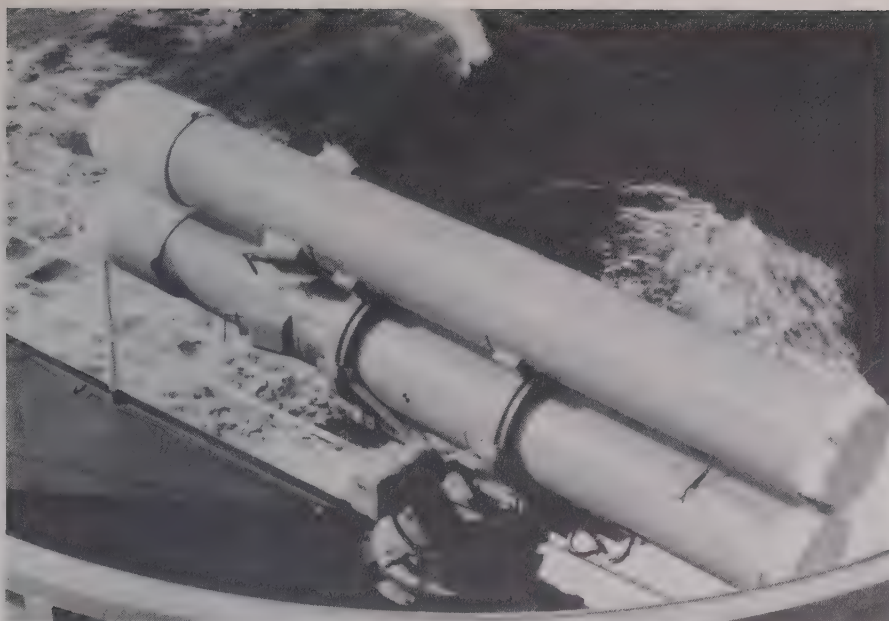
scheme the warheads were to be stowed low in the ship, and separate sections stowed between main and second and between second and third decks. Complete missiles would be assembled in 'a large ready service ring comparable in general dimension to the present portion of the turrets below the turret armor box'. The missiles would then be rammed upward onto the launcher which would be in the vertical position – as in fact was the case in the system adopted for the first US missile cruiser, *Boston*. The alternate horizontal scheme envisaged stowage of components below decks, with hoists or elevators leading to 'an assembly space on the main deck such as a low height hangar or large clear open superstructure deck house with loading from this assembly area into a launcher on the main deck or surmounted on top of this added deck house'. At this time the planned conversion called for three launchers, one in place of each of three main battery turrets, with 100 missiles (most of them stowed

1 THE MISSILE LAUNCHING SYSTEM MARK 4 MOD 0

FMC Corporation

2 THE MISSILE LAUNCHING SYSTEM MARK 9 (TERRIER) - CLEVELAND CLASS CONVERSIONS





broken down) each. Assembly was hardly trivial: a 25 January 1950 BuShips memorandum notes that

... Terrier, in its present configuration and component breakdown, requires one-half day for assembly. A development goal is to re-engineer components to decrease assembly and check-out time to approximately 5 minutes. It is hoped to attain this within 2 years but no information is available as to what the individual component breakdown will be at that time. As regards the launcher, BuOrd does not have 'a line on paper'... No decision has yet been made as to whether the launcher will accommodate 2 or 3 missiles. If a 3 missile launcher is chosen, it is not believed that the 18 months' period set up by BuOrd would be at all possible.

Meanwhile, the Terrier program had a very high priority, and a cruiser conversion was included in the FY51 program.

By the fall of 1950 the *Baltimore* class cruiser *Macon* had been substituted for the smaller *Wichita*, and initial plans called for four launchers and 400 missiles, with ten ready-service rounds for the end launchers and sixteen for each of the two superfiring ones. By this time a horizontal loading scheme had been adopted, consisting of a launcher, loader and assembly area. The launcher itself was to be 12ft long, and 12ft from launch rail to launch rail. The loader, in an adjacent 48ft x 40ft x 12ft compartment, was to have two shuttles carrying three missiles each, indexing athwartships to the loading rails. It was to be fed from an assembly area (68ft x 40ft x 12ft) with six rails athwartship, carrying two missiles per rail, and fed from below with boosters and other components. The entire design was predicated on a 45-second sustained rate of fire per salvo, with an ultimate goal of 30 seconds. Although this horizontal arrangement was ultimately discarded for Terrier, it appears to have been the basis for the austere Talos arrangement in the *Cleveland* conversions.

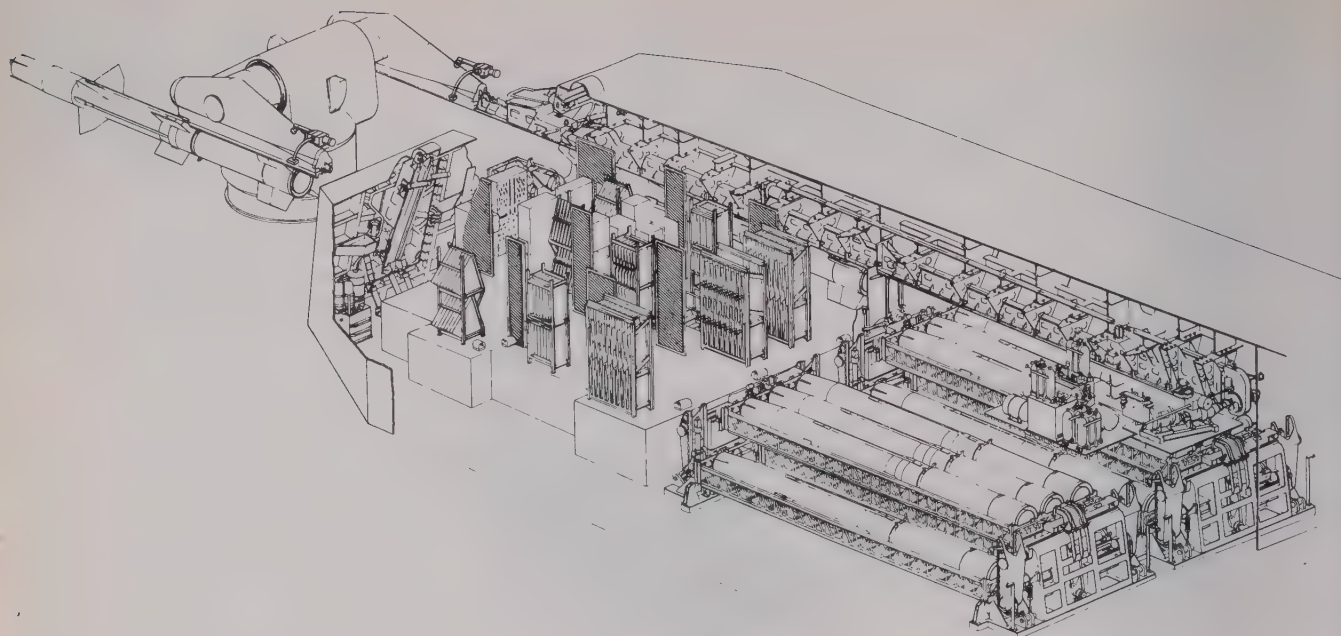
Meanwhile the urgency of the Terrier program grew, studies being undertaken for conversion of the incomplete large cruiser *Hawaii* as well as the *Macon*, and of austere schemes for launching systems which would be located entirely above the weather deck; Terrier was being advertised as capable of a 75 percent kill probability with two salvos against a 600kt target, with a 20,000yd range at 40,000ft altitude. The General Board turned to a partial conversion of a heavy cruiser, with only the after 8in turret removed and two twin missile launchers with 120 missiles replacing it. This proposal became the basis for the *Boston* conversion. It appears that the final load of 72



1 Not a weapon per se, but certainly an important addition to the defensive power of the fleet, is the chaff rocket launcher; this is a Mk 44 aboard the amphibious transport *Coronado*, March 1978. The earliest chaff rockets were modified air-to-ground Zunis, still in their original pods; this was the next step, followed by the current RBOC series.

2 The Super-RBOC (Rapid-Bloom Offboard Chaff) system is the current standard US radar decoy; there is also a combined radar-infrared flare decoy to counter missiles with combined homing systems. Here a launcher is shown under evaluation aboard the missile cruiser *Leahy*, August 1977.

3 Chaff rocket (CHAFFROC) launching from a two-tube Mk 44 launcher, January 1974. Note the blast shield and the ULQ-6 deceptive/jamming ECM system on the framework above, a standard feature of US warships.

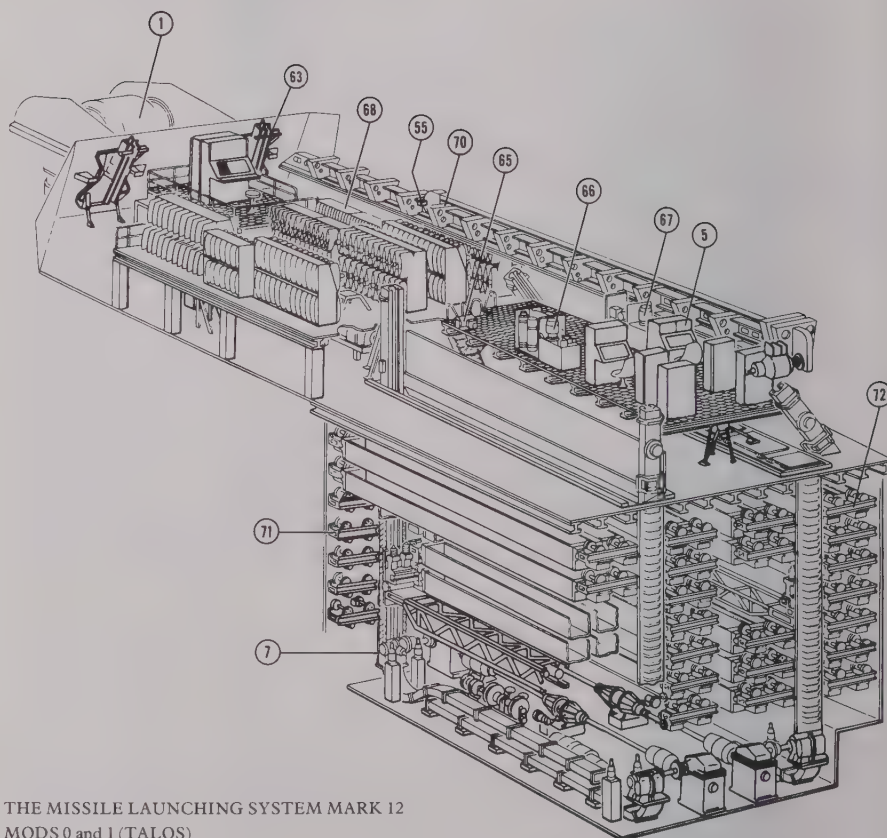


THE MISSILE LAUNCHING SYSTEM MARK 7
MOD 0 (TALOS)

missiles per launcher was chosen on the basis on an expected 20 percent dud rate, so that 60 good missiles per launcher were equated with a total load of 72.

During 1950 vertical missile stowage began to gain ground. Although 'it is slightly less flexible in the handling of duds, it possesses the particular advantages of handling the missiles in attitudes far less susceptible to damage from shock, vibration and ship motion, of being within the protective envelope, and elimination of separate hoist and rammer mechanisms (less handling and less equipment). The restrictions of below decks spaces require more cramped mechanical features, but it is considered that these can be developed', according to a June 1950 BuShips internal report on the cruiser conversion project. Matters were somewhat simplified when it became evident, in July, that missiles could be stowed without their fins, since the stabilizers, wings and control surfaces of both Talos and Terrier could be 'installed in about 15 seconds and immediately prior to ramming on the launcher. If this is done the size of elevators, the assembly space, and the method of handling can possibly be simplified, improved, and made more compact.' By this time the high loading density possible in a vertical system was becoming more and more attractive. Moreover, 'the present concept of a ready service loading ring is only a step toward an ultimate aim of continuous supply from stowage to launcher at a uniform rate commensurate with the firing rate... The number of missiles on the ring (ready service) will depend on the lot (particularly the finalized wing arrangement) chosen.'

By August 1950 it had been decided that wings and fins would be inserted just prior to launch, which made the high-density vertical-stowage vertical-lift system extremely attractive; 'BuShips stated that preliminary study indicated that the component stowage in compartments outboard of the ready service compartment appeared impracticable and



THE MISSILE LAUNCHING SYSTEM MARK 12
MODS 0 and 1 (TALOS)

expressed the opinion that outboard bulkheads of this ready service compartment could be moved further outboard, with the probability that the entire allowance of missiles could be stowed in the one space. BuShips will immediately exploit this idea' (Minutes of second BuOrd/BuShips/APL Macon Terrier working group, 1 August 1950). Meanwhile APL was establishing firm limits on missile and fin size, much earlier than had been expected.

The result was known popularly as the 'Coca-Cola machine', since missiles were

stowed vertically, much like soda bottles in contemporary vending machines. They could be overhauled in a horizontal deck space, reached via a tilting portion of the rammer which otherwise brought them up to the launcher itself. Booster and missile were struck below separately and mated in the magazine space, then placed on a conveyor belt or ready-service ring. Since only the heavy cruisers had sufficient hull depth to accommodate vertical Terriers, all other Terrier launching systems were horizontal, with multiple horizontal twenty-missile storage rings (Mk 10 system) or

with conveyor arrangements analogous to those originally proposed for the heavy cruiser conversion (*Cleveland* CLGs). The latter had the advantage of relative simplicity, accepting greater length but avoiding a penetration of the cruiser's main deck aft. In each case a large space was needed for finning, just before the missile was rammed onto the launcher.

Talos and Tartar Launchers

As for Talos, it was always considered much too large for vertical stowage. The Bureau of Ordnance appears to have envisaged from the first horizontal stowage below decks, with rounds held side by side and brought up by

elevators through protective deck doors. They would all be ready-service, as in the case of Terrier. In fact only the final Talos cruisers were so arranged. The *Cleveland* conversions carried all of their missiles above deck, and most were not assembled in stowage. Their designs thus accepted the disadvantages of limited sustained fire as well as the topweight associated with the protection of large deck-houses containing the missiles.

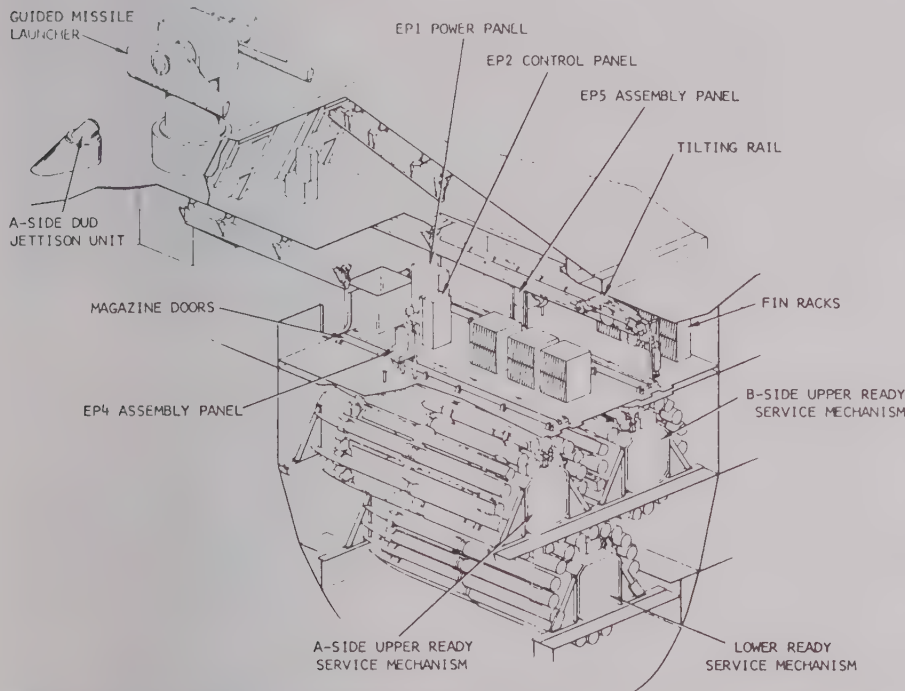
All of these systems required relatively large crews, if only for finning. When the Tartar missile system was developed for destroyers, automation was a major consideration. Unlike Terrier, Tartar had relatively small control

bins, which could be made to fold for stowage. Again, given its short length, it could be stowed vertically. That was particularly the case since there was no need for a long finning space between magazine and launcher. From a ship design point of view, vertical stowage was attractive because it limited demands on centerline length, always in short supply aboard destroyers. The result was a series of small canister launching systems: the twin-arm Mk 11, the single-arm Mk 13, and the limited-capacity single-arm Mk 22. Reportedly the single-arm system was devised to achieve higher reliability than the twin-arm Mk 11 without any loss in rate of fire; typical figures are one salvo of two weapons every 20 seconds in a Mk 11 *vs* one missile every ten seconds in a Mk 13.

The chief defect of the compact launchers is lack of flexibility in missile size; Mk 13, for example, could not accommodate the slightly larger Typhon (MR) missile which, even so, had been based on Tartar. Moreover, missiles in the automated launchers were difficult to service. This was not too important given the expected (but not always achieved) high reliability, but it did preclude the use of nuclear warheads, as the latter always had to be open to access for release. The nuclear problem was a major reason for the rejection of the Mk 13 launcher in the Aegis system. From a magazine load-out point of view, the Mk 13 can accommodate Harpoon but it cannot accommodate ASROC, which is why the *Perry* class frigates do not have the latter capability: there is not enough centerline length to provide both ASROC and a SAM launcher aboard them. In Terrier ships, similar considerations of centerline length made it attractive to develop a three-storage-ring version of Mk 10 (Mods 7 and 8) which accommodates up to 20 ASROCs on alternate positions of the two upper storage rings, for *Belknap* and *Truxtun* class missile cruisers.

Current Systems

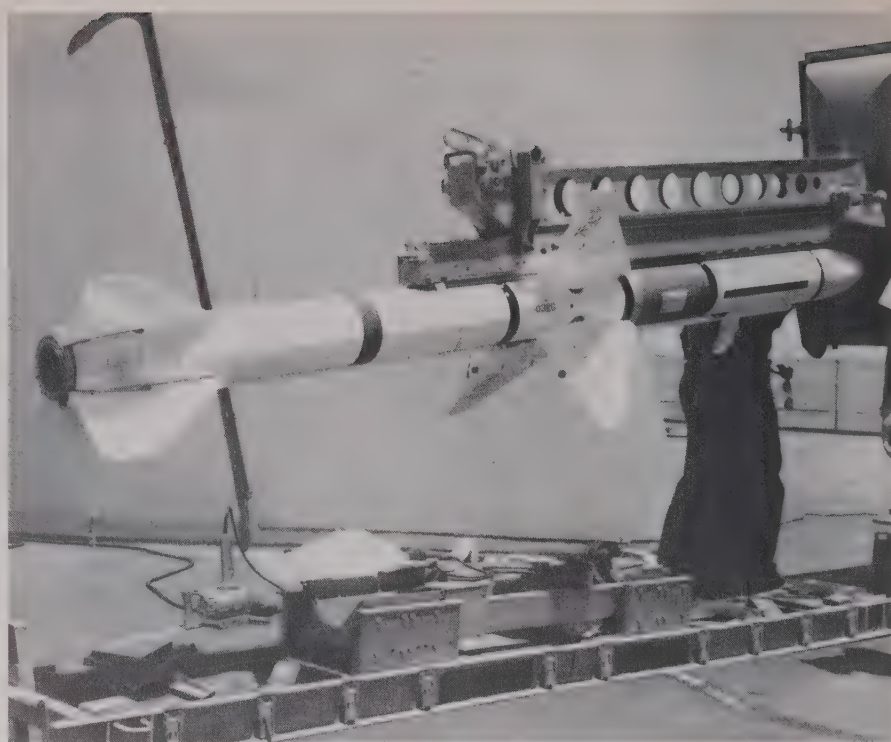
The current Mk 26 family of launchers was developed specifically to provide a high rate of fire combined with flexibility in missile size, for the Aegis system and for a variety of other recent missile ships. It returns to the 'coke-bottle' conveyor belt arrangement of the *Boston*, but, like Tartar systems, makes no provision for manual finning. A rate of fire of two rounds every ten seconds, *ie* equivalent to two Mk 13s, has been reported, and both ASROC and the Standard Missile (MR) can be accommodated, with an ultimate weight limit set at 2200lb for an AAW missile and 1500lb for an ASW missile (length of 200in and diameter of 14.75); these figures compare to 1500lb and 186.45in $\times$ 13.5in for Mark 13 Mod 4 as in the *Perry* class. The arms of the Mk 26 extend



1 THE MISSILE LAUNCHING SYSTEM MARK 10 MOD 7 (ASROC)

2 A Standard Missile, externally identical to a long line of Tartars, is shown being fired from a Mk 26 launcher aboard the test ship *Norton Sound*, 10 October 1973. Note that, in contrast with the launcher configuration to fire ASROC, the forward part of each launch rail is pivoted away from the accelerating missile, for minimum energy loss due to friction. Standard is descended from Tartar through a variety of improvement programs and also through the abortive Typhon (Medium Range), which used a slightly modified Tartar airframe.

Unlike the large-ship defensive missile systems, Sea Sparrow is hand-loaded: it depends upon missiles already in place on the launcher to last through an engagement. Here one is loaded into the NATO Sea Sparrow box launcher (Mk 29) aboard the replenishment ship *Kansas City*, late in 1978. Note the hinges in the missile wings, allowing them to fold so that Sparrow can fit within the launcher, and the cropped tailfins. The loader is not part of the Mk 29, and must be rigged before reloading.



considerably further forward than do those of earlier systems, to support ASROC missiles as they are launched. Because they are guided, Standard Missiles (AAW) do not require much support at the beginning of their trajectories, and in fact the forward part of the launch rail pivots away from the missile at launch time. An ASROC, however, is ballistic, and its accuracy depends upon the extent to which it follows the appropriate trajectory at the beginning of its flight, as it accelerates: hence the longer launch arm. In the Mk 10 Terrier-ASROC combined launcher, special adapter rails are brought onto the launcher with the missile, and withdrawn into the magazine after firing. The Mk 26 fires much more rapidly, in part because no special adapter is needed for ASROC.

Mk 26 is to be succeeded by a much simpler launching system, the Mk 41 Vertical Launching System (VLS), consisting of a series of simple vertical tubes. A rate of fire of one round per second is claimed, compatible with the engagement rate now envisaged for Aegis and for follow-on systems. Moreover, VLS is even more flexible than the Mk 26, accommodating anything up to a Tomahawk strategic cruise missile of torpedo-tube dimensions; current canister limits are 2500lb and 220in × 22in. The integral strikedown

system is expected to load ten canisters per hour, which is comparable with that claimed for Mk 26 (which also has an integral strikedown beam).

Mark 41 is typical of a new species of launchers in which ready-service stowage is identical with launcher loading; other examples are the box launchers of Sea Sparrow. Box launchers carry more rounds per unit weight and are inherently more reliable than

mechanical units such as Mk 26 (although in the case of Mk 41 there may be problems associated with proper missile blast door operation under some conditions). However, small boxes, such as the Mk 25 of Sea Sparrow, are relatively difficult to reload; NATO Sea Sparrow often incorporates a mechanical loader. In theory, the box carries enough weapons to last out an entire engagement, and the slow reloading rate can be accepted.

6. Shipboard guns

Guided Projectiles

From about 1955 onwards, there was a determined effort to eliminate the surface gun from fleet air defense, to the point that missile cruisers such as the *Long Beach* and *Albany* were designed entirely without guns. However, guns have important virtues in short-range defense. They can provide a great volume of fire at a relatively low cost per projectile, with considerable lethality. For example, reportedly a Mk 42 5in/54 gun with its fairly antiquated Mk 68 fire control system has a 17 percent chance of killing an incoming 'Styx' or 'Shaddock'. Presumably the newer Mk 86, as in the *Spruance* class, can do considerably better. However, there has been criticism of the Mk 86 system for poor reliability. Guidance should make a great difference to gun anti-air effectiveness, just as in the antisurface case (see Part I); for example, it appears that guns were retained in the Aegis cruiser (CG-47, *Ticonderoga*) partly for the contribution they can make to air defense.

As noted in Part I, Cannon-Launched

Guided Projectiles (CLGP) were originally considered primarily a means of improving the accuracy of surface-to-surface fire, which remains the motivation for the semiactive laser guidance program. Surface targets do not, in any case, have distinctive signatures suitable for the seekers of guided shells. Aircraft and missiles are, as the variety of IR missile programs shows, quite distinctive infrared targets, even when viewed head-on. A program therefore began to develop an Infra-Red Guided Projectile (IRGP), a fire-and-forget weapon with a rocket motor to boost it. However, the IRGP was deleted from the FY81 budget request due to tightness of funds, leaving the fleet without a useful mid-range anti-aircraft weapon suitable for the large number of existing 5in/54 mounts. The impact on fleet anti-air capability was rather less, since in most cases a laser-guided shell would be the weapon of choice. However, the IRGP was useful for cases in which a 'hot' target lay over the horizon or beyond some obstruction to the laser line of sight.

Work did continue on more conventional weapons and fire control systems. In 1961 the CNO issued an Operational Requirement for a new fire control system, which became Mk 86. It included a track-while-scan pulse compression radar coupled to a computer, and SOR 12-04 (February 1963) established a requirement for an improved surface-to-surface fire control system for new-construction destroyers and missile frigates (later cruisers). Revisions added anti-aircraft gun and missile illumination (CWI) capabilities; in 1972 requirements for electro-optical sensors (to overcome severe jamming) and guided projectile illumination were added. Lockheed Electronics won the Mk 86 contract, and service approval was granted in January 1973 following the completion of Operational Test and Evaluation the previous October. Installations were somewhat restricted because of the availability of a rival fire control system, the Dutch-designed Sperry Mk 92.

This latter system originated with the (then) Naval Ordnance Systems Command's 1970

Foreign Ordnance Review. A Dutch Signaal system had already been tested aboard fast gunboats as the US Mk 86, and a similar (but more capable) unit became Mk 92 (WM 28). The version installed in the *Perry* class frigates incorporates both gun and missile (Standard) fire control, and is linked to a secondary antenna (STIR) which provides a second missile control channel. Less capable versions appear in the US PHM (*Pegasus* class) and the new *Bear* class Coast Guard cutters. Compared to Mk 86, Mk 92 is considerably less capable, but it is also much lighter and less expensive. Given the availability of both, it appears that in the near term further fire control development will be restricted to the addition of shell-guidance capability, as in the combination of Seafire and the Mk 86 (see Part I).

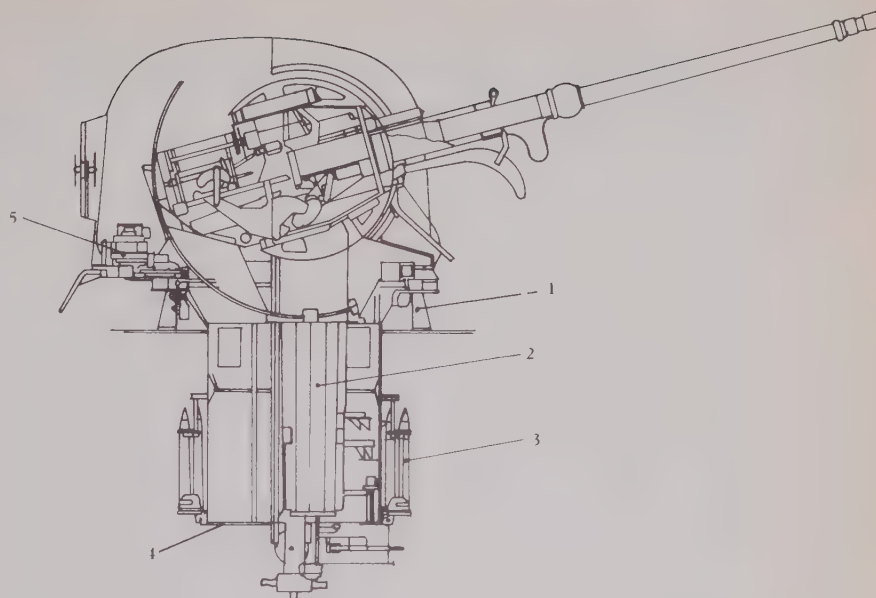
The 3in/62 Gun

The Mk 75 3in/62 gun is the only really post-war US naval gun, since the lightweight 5in/54 can be traced back to a World War Two family of weapons (see Part II). Like the Mk 92 which controls it, the 3in/62 was bought as the result of a review of foreign (and, in this case, domestic) ordnance capable of quick reaction against low-flying aircraft at relatively short range; it was, then, almost a contemporary of the Phalanx system, with, however, a rather longer effective range. It preceded the introduction of guided shells, which it cannot fire: current technology can fit a seeker into the 3in shell diameter, but not enough explosive power to make the result worthwhile.

The decision to procure the Italian-designed 3in/62 dates back to the origins of the *Perry* class frigate, about 1971. Alternative AAW and ASW versions of the same basic ship were to have been built, with the ASW variant capable of self-defense against supersonic aircraft or small numbers of incoming antiship missiles, without paying the price of a long-range defensive missile system. Candidate defensive weapons included Sea Sparrow, the existing 5in/54, the Italian OTO-Melara 76/62 (which became the Mk 75), an OTO-Melara 35mm gun then under design, and CIWS (Phalanx). An air defense study showed that the combination of Standard Missile and the Dutch-designed Mk 87 fire control system (with CW injection for missile control and separate tracking and illuminating radar) with the 35mm gun was significantly more effective than Sea Sparrow, and that the much more expensive and much heavier combination of Tartar D, a 5in/54 lightweight gun and CIWS would be only marginally better. The existing 76/62 lightweight gun was considered a useful backup for the 35mm gun, and in the event it was adopted instead; the US version is manufactured under license by Northern Ordnance.

Light Antiaircraft Guns

A number of light antiaircraft guns have also been developed within the last decade, although none has as yet appeared aboard US warships. The closest was the Emerlec twin 30mm gun, part of the armament of the US-designed Coastal Patrol and Interdiction Craft (CPIC). The EX-74 mounting carries two Oerlikon 30mm cannon, with an operator in a cab between them; it can be controlled either remotely or locally. Although no current US warship employs it, the EX-74 has been exported to Greece, Nigeria, South Korea and Taiwan. The other current US light weapons



THE MARK 75 3in/62 GUN

Key

- 1 Training base
- 2 Shell hoist
- 3 Shell ring
- 4 Revolving platform
- 5 Training motor

appear to have been developed more as private ventures, although they have been given Navy experimental mark numbers. They include Mk 77 (7.62mm Gatling gun), EX-80 (Hip-Pocket II for ASMD, with a Vulcan, a stabilized computing sight, and manual operation), EX-83 (an unmanned mount carrying a 30mm GAU-8/A antitank Vulcan aircraft cannon, as in the Fairchild A-10, by General Electric), and EX-84 (a low-profile 'universal' mount for a wide range of guns and missiles such as Stinger, to be mounted aboard small craft; it was developed by General Electric). EX-80 and -83 were attempts to achieve some useful ASMD performance without the complexity of Phalanx, relying on external fire control systems. It is difficult to see, however, how they are likely to compete effectively with Phalanx, whose closed-loop spotting system is claimed to be an order of magnitude more effective than earlier types; ASMD is just too marginal for the capability represented by Phalanx to be shaved away aboard any ship large enough to accommodate the necessary external fire control system.

In April 1980 the Royal Netherlands Navy selected the EX-83 mount over an earlier SEM-30 with four Mauser cannon; it is to fire tungsten rather than depleted-uranium rounds, but even so will enjoy about four times the kinetic energy of the 20mm Phalanx rounds at 1000yds. Fire control will be by the Dutch Signaal 'Goalkeeper' system, which is considered better than Phalanx because its surveillance radar can operate throughout the engagement, whereas the Phalanx radar tilts in elevation while firing. Goalkeeper also reportedly incorporates an advanced form of closed-loop tracking: Phalanx operates in steps (presumably corresponding to bursts of fire) whereas Goalkeeper operates more continuously; a typical Goalkeeper/EX-83 burst lasts three seconds and uses 190 rounds. Plans call for delivery of two prototypes in the winter of 1982-83, for land firing trials in the second half of 1983, and Dutch service introduction in 1985. EX-83 was a private GE development, carried out partly because of controversy as to whether the 20mm rounds fired by Phalanx could actually defeat the projected 1990s threat; test firing began in 1976. In 1979,

however, the Navy was willing to pay for an advanced prototyping program, and in 1981 sea trials were carried out aboard the destroyer *Merrill*. The mount was controlled by a standard Lockheed Mk 86 fire control system, slightly modified for additional antimissile capability (detection and threat assessment) and with a limited closed-loop tracking capability. Other EX-83 systems currently under consideration by GE include the combination of the mount with a phased array radar which would permit simultaneous tracking of closely spaced targets.

7. Fighters in fleet air defense

Postwar Trends

World War Two established the day fighter as the dominant outer layer of fleet air defense; evolution since then has been towards all-weather capability at longer and longer ranges not only from fleet center but from the fighter itself. In 1945 most carriers accommodated a limited night fighter detachment, and operated primarily in daylight; attacks in darkness or, worse, in very bad weather, were the greatest threat, since the fewest aircraft would be available to counter them. By 1945 there was hope of 'true all-weather operation through radar-guided landing, and a specially designed night fighter, the F3D Skyknight, was a fixture of the early postwar BuAer program. It was true that during the war the Navy had employed single-seat night fighters with considerable success, but, like the Air Force, BuAer believed that an airplane with a dedicated radar operator could be far more effective. Of course, it would have to sacrifice performance, and thus the carrier would still be able to accommodate only very limited numbers. During the five postwar years BuAer developed a new single-seat night fighter, a version of the twin-engine McDonnell Banshee, as insurance against the failure of the F3D, but the first flight tests of the latter in 1948 seemed to show that it had been a success. Meanwhile, existing night fighters were not well liked. For example, the very clean Bearcat, the standard early postwar fighter, was far too slow when equipped with an APS-19 interception radar, and plans to employ it had to be dropped in favour of continued use of the larger and heavier Corsair. The much faster Tigercat was judged too flimsy for carrier service.

Fighter weapons were a matter of some concern. The only ones in existence in 1945 were guns such as the wartime 20mm Hispano. BuAer analysts felt that it was only marginally adequate, at least as currently mounted. At a classified symposium in January 1947 they presented the Bureau's future programs. One issue was the combination of fighter speed and firepower: future fighters would have, it was thought, a much smaller speed advantage over the bombers they engaged. In World War Two, for example, a Hellcat engaging a Privateer would have a speed advantage in level flight of about 100mph and a 'never exceed' (*ie* flutter-limited) speed advantage of about 200mph; it could therefore choose its sector for attack, make deflection runs, and generally oppose six guns to the bomber's four in such a sector. However, the future bomber would probably fly at 550-600mph, the fighter at 600-650 – but his 'never exceed' speed limit would be very close to his level speed, and he would therefore not be able to make effective deflection runs. The only practicable approaches would be from ahead or astern, and attacks from ahead were dismissed 'because of

the extremely short time to sight and fire. I do not believe the ahead run will be effective against high-speed targets until homing air-to-air missiles are available.' However, in a stern attack, the bomber would enjoy a great advantage 'because of the difference in air resistance caused by relative bullet velocities over a considerably greater range than that of the fighter... at 20,000ft, the fire of the bomber will be effective from 1100 to 2000 yards while the fighter must close to within 1000 yards before his bullets can damage the bomber.' In each case, 20mm guns were assumed.

The BuAer Armament Division concluded that some means had to be found to permit the fighter to engage the bomber from above, below or the side; it developed an automatic gunlaying turret for installation in nose or tail, with radar ranging and direction. Such a weapon, it was hoped, would force the bomber designer to disperse his weapons to provide 'all around' fire, and would both reduce tail fire and slow the bomber down. In fact, however, work proceeded in a very different direction, towards batteries of unguided air-to-air rockets which permitted a fighter to attack a large bomber at a greater range, over a much shorter time interval. CIC development began to emphasize that fighters in a CAP near a bomber stream approaching the task force would be able to make only a single firing pass (or, at most, two), so that the lethality of those passes would have to improve. The 2.75in Folding-Fin Aircraft Rocket (FFAR) for Navy and Air Force interceptors must have entered development about 1948, since by 1949 an air-to-air fire control system controlling it had been designed for the Vought Cutlass. It was a major weapon of the fighters of the early 1950s, such as the Douglas Skyray and the Vought Crusader, which carried them in an internal rocket pack. Both also retained their conventional 20mm cannon.

As for the specialist night fighters, the F3D proved unsuited to carrier operations; a standard detachment entered combat for the first time in Korea, aboard the carrier *Lake Champlain* (June 1953). They tended to nose down when fired from their catapults, resulting in runaway catapult shots which disabled the catapults for about ten days. After six days of operations, they were transferred ashore. That left the single-pilot Banshee, the success of which proved once again that a single pilot with a good interception radar, directed by a competent CIC, could be quite effective at night. Meanwhile, the much faster McDonnell Demon (F3H, later F-3), originally bought as a deck-launched interceptor, was reordered as an all-weather fleet fighter. It became the major missile platform of the late 1950s and early 1960s, since it had the long range to fly a useful CAP as well as the size to accommodate the fire control radar of the Sparrow I system.

The McDonnell F-4 Phantom II

Analysis certainly showed that a homing missile with reasonable reliability was far superior to the salvo of unguided rockets previously envisaged. A 1954 analysis of fighter-to-fighter combat envisaged two masses of aircraft approaching at speeds as high as Mach 1.5. A great deal would depend upon air search radar range, if the long range of the missile were to be used adequately. If radar range were 10-15nm, and tail warning radar range 6nm, then the missile fighters could detect at 10, turn to fire (as escape would be impossible), fire, obtain hits within 6 seconds, and evade. Surviving rocket fighters would return that fire within a second or two. If Sparrow overall kill probability were 0.52 for a salvo of two (assuming an 80 percent chance of detection and correct firing, and a salvo kill probability of 0.65), it would be opposed by an overall rocket fighter kill probability of only 0.17. That is, the rocket fighter, too, would have, say, an 80 percent chance of shooting properly, but there would be only 48 percent of the rocket fighters left after the missile salvo, and the kill probability of a salvo of 72 FFARs was estimated at only 45 percent: $0.8 \times 0.48 \times 0.45$ is only 0.17. In fact the rocket fighters would do even worse, since they would have to sight very accurately at a range of about 1000yds, at a very high closing rate. In addition, the figures cited assumed a very reliable rocket fire control system, which was unlikely. In other words, fighters equipped even with the relatively unreliable Sparrow, as it was understood in 1954, might well achieve a kill rate of better than 5 to 1 against fighters armed with the next best weapon. That these concepts avoided the IFF problems which plagued Sparrow in Vietnam was of course unsuspected; what counted was the value of long range.

The Phantom was the result. As fighter size and power increased, the penalty of all-weather missile capability became less and less pronounced. It was certainly desirable to merge the day and all-weather fighter complements, if only to simplify logistics; the all-Phantom fighter group replaced a mixture of Demons and Crusaders, the latter in many cases capable of limited all-weather operation. The Phantom was particularly well liked at first because it brought back the specialist radar operator, who was needed for its massive intercept radar. It should be noted, however, that the F8U-3 Crusader, which competed directly with the Phantom, employed only a single pilot to control three (rather than four) Sparrows, using a high degree of automation. It did not have the radar dish diameter of the Phantom, and it can be argued that the dedicated operator himself is a major factor in effective radar range. Sparrow and the IR-homing day fighter weapon, Sidewinder, entered fleet service almost simultaneously, in 1956. Although both

had much longer ranges than guns or unguided rockets, they still required a fighter to make a full run on each target it engaged. The greater the number of raiders, and the higher their speed, the fewer each fighter could engage with its short-range weapons. Bell Laboratories (Naval Interceptor Project) began studies of this problem in the early 1950s, and in 1955 suggested a much longer range missile, which became Eagle and then the current Phoenix. Cornell Aeronautical Laboratories (CAL) contributed heavily, as did the Naval Air Development Center. The basic concept was to transfer high performance from the fighter to its missile, providing the fighter with both a very long range radar and a missile to match. In 1957, CAL proposed a turboprop fighter with an airborne early warning radar, looking much like an E-2 but carrying 6 missiles for a 7-hour endurance or 16 for a 4.8-hour flight; it called the concept 'Bogey Buster'. Conventional deck-launched interceptors were rejected because they could not hope to meet raiders in time to act, unless radar warning from airborne radar aircraft were extremely good at extreme range. In that case, a deck-launched fighter with a high dash speed might make a difference.

The Grumman F-14 Tomcat

A major advantage of the good radar in the long-range fighter would be an ability to correct CIC vectoring errors, always a major problem in fighter operations. Against mass raids, control was complex. For example, a 100-plane raid might be killed by 220 missiles (90 percent reliability assumed for two-missile salvos) – but only if the effects of hits were continuously observed, and sufficient time were available for each target to receive up to nine successive shots (which, fortunately, would be needed only about 0.4 percent of the time). That in turn required a relatively long-range missile, which each fighter would fire as

the raiding stream passed it, and CAL debated the merits of providing each fighter with its own picture of the raid as a whole, giving each fighter a specific zone of responsibilities. The most important lessons, however, were the value of good radars and very long ranges. They carried over into the Eagle missile project (see below), which was to have been combined with a relatively low-performance fleet air defense fighter (the Douglas F6D Missileer).

The most important objection to the Bell/CAL concepts was the low performance of the fleet air defense fighter. A carrier has only a limited air group, and much of her mission is power projection, *ie* the seizure and use of air superiority over the objective area. Long-range fighters would not help in so confused a situation; the carrier would have to accommodate the old mix of high-performance (air superiority) and fleet air defense (all-weather missile-carrying) aircraft. Both Eagle and its slow fighter were canceled in 1960, and the project transferred to a new missile, Phoenix, which was to have been carried by a supersonic fighter. One advantage of the faster airplane, it would appear, was that the missile would, in effect, be given a boost at launch and so would be able to dispense with the heavy booster planned for Eagle. Range performance was also somewhat less than that claimed initially for Eagle.

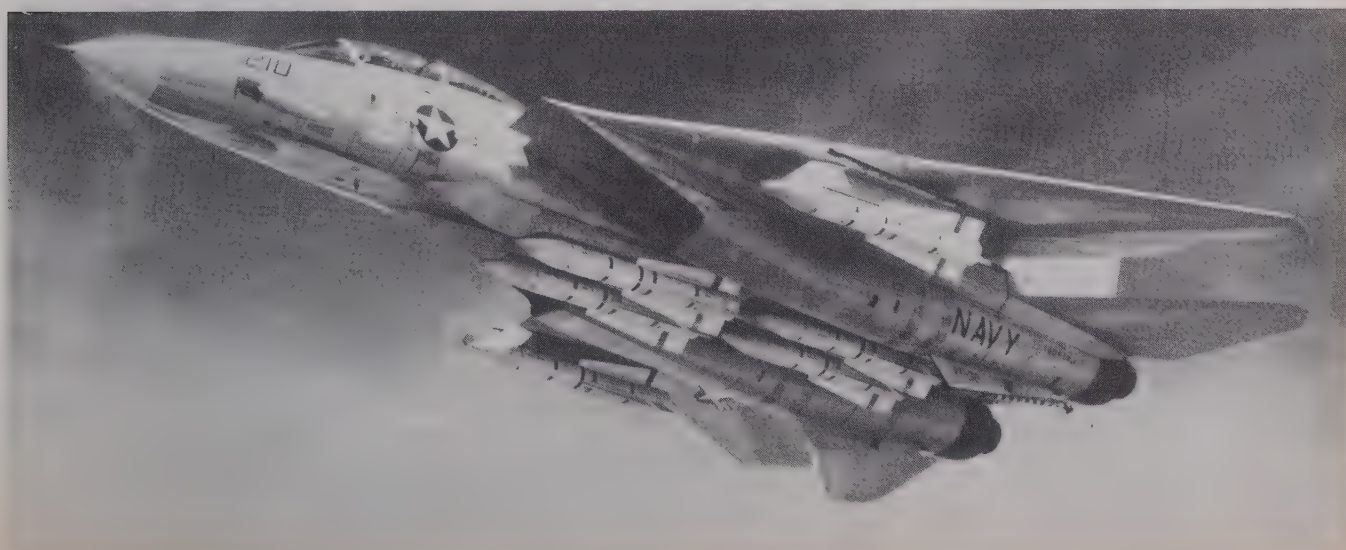
The result of all of this evolution is the F-14/Phoenix combination, designed to engage air targets at extreme range. There is some suspicion that, as in Vietnam, the lack of positive identification of those targets may make engagement difficult, and improved IFF remains a major issue in fleet air defense. Although identification might seem relatively easy in a 'pure' fleet air defense environment, in which fighters were opposing enemy bombers at a great distance, even then the long reach of their missiles might make for some confusion between defenders and attackers. This would be particularly the case for CAP fighters far from the direction of the raid, trying to fire across much of the defended air space. Matters are even worse near or over land, in which friendly and hostile aircraft cannot possibly be distinguished by the direction in which they are flying and, moreover, in which battle damage may prevent friendly aircraft from operating their IFF sets.

In 1983 the United States is developing JTIDS, the Joint Tactical Information Distribution System, which is supposed to provide both tactical data links *and* automatic navigation (as in TACAN) and identification. The Navy variant employs Distributed Time Division Multiple Access (DTDMA), which should have a higher system capacity than the TDMA being employed in Air Force AWACS (E-3A) aircraft. In principle JTIDS enjoys great security by means of its encrypted digital data transmission via a frequency-hopping spread-spectrum radio; it should be both intercept- and jam-resistant. However, it has suffered from very protracted development, having been formed by OSD from parallel

A US Navy crew prepares to load a Sparrow missile on to an F-4 Phantom at the Pacific Missile Test Center, Point Mugu, February 1981.
General Dynamics



The Grumman F-14 can, in theory, engage six separate incoming targets with Phoenix missiles at ranges of about 100 miles; here one is shown carrying a full complement of weapons, although in practice the fuel requirements of CAP operation will generally limit the missile load to four. The F-14 also has a 20mm Vulcan rotary cannon in its nose. This VF-32 Tomcat was photographed in September 1980.



IV. FLEET AIR DEFENSE AFTER 1945

- 1 The APG-65 radar of the F-18 fighter/attack bomber was designed for a combination of versatility, light weight and easy maintenance. From left to right, the three equipment racks behind the antenna (which can pull out for maintenance) are a receiver-exciter (the radar proper) which contains the analog-to-digital converter; a radar data processor with a 250,000-word (16-bit) bulk storage memory; and a fully software-programmable signal processor which can execute 7.2 million operations per second. Under the three racks is a liquid-cooled radar transmitter, containing a software-programmable, gridded, travelling-wave tube amplifier. The low-sidelobe planar array antenna uses direct electric drive in place of the hydraulics of earlier systems. Not visible here is the network of waveguides in the back of it. The entire radar weighs 340lb excluding the rack, and occupies 4.5ft³, excluding the antenna. By way of comparison, the APG-63 of the F-15, which is not software-programmable, weighs 483lb (9ft³).
McDonnell Douglas



- 2 The F-18 Hornet shows a modern cockpit arrangement with a combination of a head-up display (HUD) and two video monitors. Increasingly, conventional dials are being replaced, throughout the aircraft industry, with television-like displays which can, if necessary, show dial-like pictures. However, they can also show only those parts of a dial which the pilot needs, and they can show alternative pictures, such as the radar PPI or a television camera view, as here.
McDonnell Douglas

Service programs in 1974, and it is still some years from fruition.

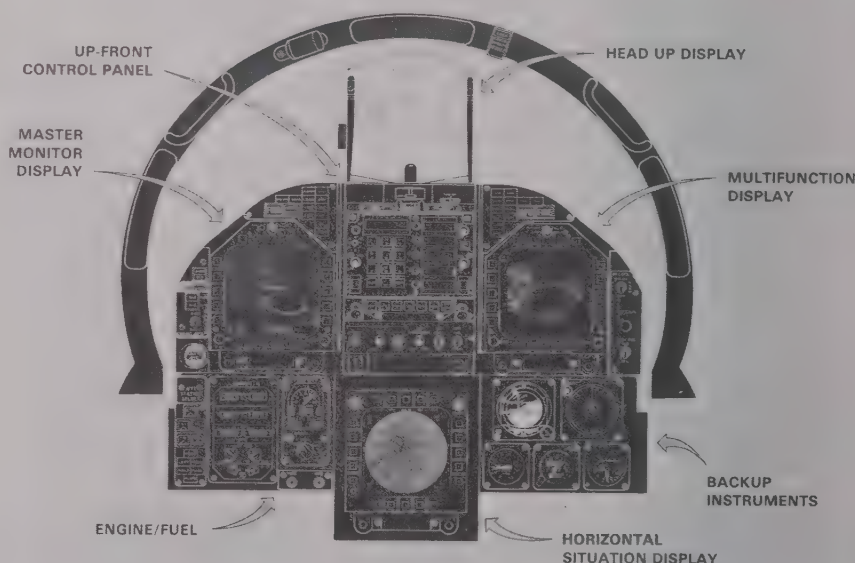
The F-14 itself is unusual in that it combines the long-range interceptor role (Phoenix) with significant close-in air combat capability (Sidewinder and an internal cannon); it can also carry the medium-range Sparrow. In the design stage, it was claimed that improved engine technology would provide both the loiter capability of the fleet air defense fighter and the high power of the dogfighter, and that variable-geometry wings would give the F-14 considerable superiority in the latter role. However, the advanced engine then planned did not materialize, and the F-14 is still powered by the TF-30 turbofan originally specified for only the first batches; there is a strong possibility that late aircraft (F-14D) will be powered by a new F101 engine originally conceived for the Air Force B-1 bomber. Moreover, the combination of roles, partly driven by limited air group size aboard carriers, made for an extremely expensive airplane, roughly \$40 million per F-14 without missiles in 1981 dollars.

The McDonnell Douglas F-18 Hornet

Thus there was an attempt to obtain a less expensive air superiority fighter in the form of the F-18 Hornet, the first carrier single-seat fighter since the Crusader. The Hornet fires the Sparrow, and will fire the longer-range AMRAAM, but it cannot come close to the raid-handling performance the larger F-14 should represent. Moreover, it, too, has been compromised, having been designed to combine the air superiority and day attack missions with minimal equipment changes, on economy grounds. Nor is it inexpensive: with all of the automation required to permit a single pilot to operate it, an F-18 is not too much less expensive than a new F-14. However, it has smaller engines, and reportedly shows enormous benefits in terms of life-cycle cost.

The Navy sees the F-18 as a complement to, rather than as a competitor to, the larger F-14, but the full size of both programs remains uncertain. Current planning is to fit all large-deck carriers with F-14 support capability; hope-

F/A-18 HORNET COCKPIT



fully enough will be bought to arm an all-Tomcat fighter force. The Carter Administration had planned to equip only 9 of 12 large carriers with F-14s (with six operating F-18s). In current plans, the F-18 would replace the A-7 attack bomber, providing a 'swing' fighter force not entirely different from that operated by many of the fleet carriers in 1945; at that time they had both pure fighter and fighter-bomber squadrons, the latter replacing pure attack squadrons.

It is sometimes argued that even the F-14 sacrifices too much missile capability to achieve its somewhat limited dog-fighting or air superiority performance, that its load of six Phoenixes does not fully utilize the capacity of

the powerful AWG-9 fire control system. On this basis, there are proposals from time to time to place the fire control system (and more missiles) aboard a slower airplane, such as the S-3A or even a C-130, *ie* to resurrect the full spirit of the Bell Labs/CAL concepts of a quarter-century ago.

Meanwhile, another series of missiles has evolved for short-range air combat, *ie* for dog fighting: Sidewinder. These are now called 'within visual range' (WVR) as opposed to beyond visual range (BVR: Sparrow and Phoenix) weapons, and overcome the IFF problem by visual means, achieving a high kill probability at moderate ranges. In Vietnam, even Sidewinder was found deficient,

impossible to fire quickly enough or at some angles, and the old aircraft gun, largely discarded (like the ship gun) in favor of missiles, returned. Some aircraft, such as the Crusader,

retained the 20mm cannon of the past, having been designed just before the era of total reliance on guided weapons. In other cases, gunpods reminiscent of the gun containers of

World War Two (see Part II) were hung underwing. Finally the 20mm Vulcan cannon became standard aboard all Navy fighters, even including the F-14 Phoenix-carrier.

8. Air-to-air weapons

Sparrow

Sparrow is surely the longest-lived US air-to-air missile, having originated with a proposal for beam-riding guidance for the 5in HVAR, Project 'Hot Shot' (by analogy with a similar British concept, 'Long Shot'). The guidance system was that originally developed for the abortive BuAer Lark surface-to-air missile, and Sparrow was conceived as an interim short-range weapon (by comparison with the 17nm 'intermediate range' and the 35nm 'long range' of the P/A program). Recognizing that electronics and not airframe would determine the success of the missile, BuAer contracted with Sperry, which ultimately sub-contracted to Douglas for the airframe. In May 1946 Sperry was asked to submit a proposal for a weapon with a maximum range of not less than 2000yds, and a minimum of not over 1000ft, fast enough to intercept a Mach 1 target. It was expected that the airborne guidance system would require separate beam-generating and target-tracking radars.

By March 1947 Sperry reported that the original 5in airframe was not large enough for the guidance equipment proposed, nor could it make full use of the range capability of that system; instead, Douglas was assigned to develop the 8in airframe which became the basis for later developments. A weapon contract was let in May 1947, and the project formally was named Sparrow that July. Point Mugu Naval Air Missile Test Center was authorized in January 1948, specifically for the Sparrow program, and the first test flight (unpowered) followed that August. However, the first intercept, of a Hellcat drone by an F3D, was not made until 3 December 1952. Production had already begun (1951), presumably as part of the same accelerated program which yielded early versions of Terrier.

Sparrow I, AAM-N-2, entered fleet service in 1956 aboard Demons (F3H) and Cutlasses (F7U), four missiles generally being carried underwing. In this version, the guidance beam was generated by an APG-51B radar, a modified version of the standard night fighter gunnery set (APG-51A). The beam was slaved to an optical sight, which in turn required visual target identification: Sparrow could not be described as an all-weather missile. A new multipurpose radar, APQ-50, was proposed for the new F4H (Phantom); it would eliminate this requirement. Similarly, the existing APG-51 was modified to provide all-weather capability as the APQ-51 for both Sparrow I missile fighters. However, beam-riding was abandoned for Sparrow much as in Terrier: its low-altitude performance was considered unacceptable.



About 2000 Sparrow I (redesignated AIM-7A after 1962) were produced.

Two alternative replacement guidance systems were considered from 1955 on. Douglas developed Sparrow II (AAM-N-3), with an active radar seeker, for its lightweight F5D Skylance all-weather fighter, using an APQ-64 radar derived from the bulky APQ-50, the largest existing air-to-air system (with a range of about 20nm compared to 13 for APG-51B). BuAer withdrew in 1956, and Sparrow II was taken over by Canada as the main armament of the proposed CF-105 interceptor. Two years later the missile was canceled, and active homing did not reemerge in the US arsenal for another two decades.

Sparrow III, AAM-N-6, was the other alternative, using the same type of CW homing then being applied to Terrier and Tartar. Its APQ-72 radar, also based on APQ-50, provided target illumination. Raytheon managed the project, taking over Sparrow production facilities after the completion of the Sparrow I project in 1956. Deliveries began in January 1958 and deployment in August, the

Since the late 1950s, Sparrow has been the major US naval long-range air defense missile. Here it is shown test-fired from a Demon interceptor, 2 December 1959. Since 1974, Sparrow has been supplemented by (but not replaced by) Phoenix in the beyond-visual-range role.

first fighters being Demons with CW injection for their APG-51B radars. AAM-N-6 was succeeded in production by AAM-N-6a, designed for supersonic launch, in 1959; under the post-1962 designation system these missiles were, respectively, AIM-7C and -7D, -7B having been assigned to the abortive Sparrow II.

AIM-7D could home from the forward hemisphere, *ie* could accommodate very high closing rates, and it could home on a jammer. Its Thiokol storable liquid-fuel motor replaced the former Aerojet solid-fuel type, increasing effective range by about a third, and ceiling by ten percent to 30,000ft. Both AIM-7C and -7D had 65lb continuous-rod warheads, the double layer of folded rods forming a 56ft circle before separating; they were considered lethal out to about 125ft from the missile when it detonated.



Although most Sparrows appear identical externally, the series has seen very considerable evolution. This 1973 sketch compares AIM-7E with -7F, the latter having a much larger rocket engine and far more compact electronics, permitting movement of the warhead forward of the wings.

Fuzing was contact or proximity, but the latter mode suffered from ground clutter at low altitudes; it became 'desensitized', and required a very large target to cause it to explode.

Missile propulsion was by a single-stage rocket; in the -7D, for example, it weighed 130lb, and produced 15,000lb-seconds of thrust over 1.9 seconds, after which the missile coasted. Its total aerodynamic range therefore depended upon launch speed (in effect, the aircraft acted as a first stage); effective range depended, too, on the strength of the illuminating radar, since the missile had to be locked onto its target at the moment of launch. As in Tartar and Terrier, guidance was semiactive, the missile receiving both a front-end reflected signal and a rear-end reference signal, the latter directly from the antenna of the launching fighter. The doppler difference between the two was used for target tracking, the missile incorporating a speed (doppler) gate. That is, after launch, the gate swept a preset frequency band until it either locked onto a target or self-destructed. In the most favorable case, the gate was set in a narrow range using data on closing rate from the aircraft fire control system; when set in a much wider range, the missile would suffer from the presence of chaff or ground clutter.

AIM-7E entered production in 1963, with yet another motor, a 156lb Rocketdyne type which burned for 2.9 seconds and produced 22,100lb-seconds of thrust, increasing range yet again, by about 75 percent. In each case actual range depended upon launch speed, so these figures are no more than approximate. The warhead was the same continuous-rod type employed in -7C and -7D. In 1963, Raytheon credited Sparrow IIIB, presumably AIM-7E, with an effective intercept range, against a 5m² target at 50,000ft, of 16nm (launch at Mach 2), with a time of flight of 40 seconds; generally firing doctrine would be two missiles per target. Under some circumstances range would be closer to 20nm. About five years later, an Air Force study credited AIM-7E with a maximum range of 13nm on a fighter at high altitude (frontal attack); maximum

range in a stern attack was given as 3nm. Typical minimum ranges were 5000ft for a stern attack, or 12,000 head-on. Fuze-arming and time to make guidance corrections were the most important considerations.

These were not the limits inherent in the Sparrow airframe. In 1963 Raytheon proposed what it called 'Advanced Sparrow III' as an alternative to what became the Phoenix missile (then designated AAM-N-11). The principal barrier to very long range was insufficient CW illumination of the target: although the missile could track when it neared its target, it would be unable to lock-on at launch. Raytheon proposed a programmed flyout to permit launch at the aerodynamic launch limit, which itself would be increased by using a new dual-thrust (boost-sustain) motor (as in Tartar), burning for a total of 3.5 seconds with a total impulse of 30,800lb-seconds at a weight of 200lb. Flight times as great as 75 seconds would be possible, and ranges as great as 52nm. More typically, the missile would double -7E range to about 30nm. Other major changes included much more compact electronics, freeing space forward of the wings for a larger (90lb) warhead and for the enlarged rocket motor; weight would rise from the 398lb of -7D and the 435 of -7E to about 490lb. Much depended on the power of the illuminating radar; for example, even the Advanced Sparrow was limited by the 440 watts of the Phantom's APG-59 radar, whereas it was expected that the new fleet fighter (F-111B), with up to 1300w, would do much better. One unusual feature of the Advanced Sparrow was its compatibility with pulse-doppler, rather than CW illumination, radar, which would permit better low-altitude performance. Many of the proposed Advanced Sparrow features appeared about a decade later in AIM-7F.

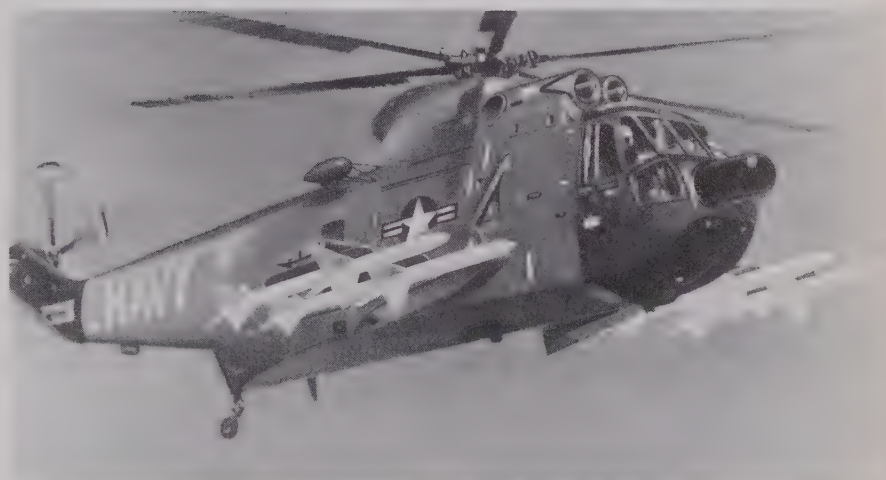
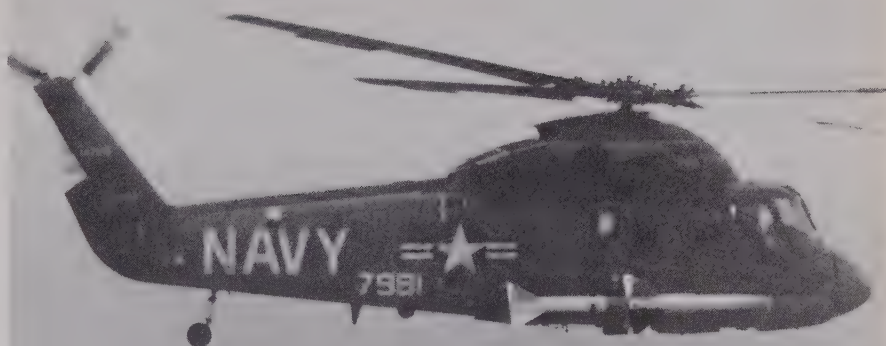
Meanwhile, AIM-7D and -7E fought the air war in Vietnam; about 7500 AIM-7D and 25,000 AIM-7E (as well as 2000 AIM-7C) were produced through 1973. Results in combat were disappointing technically and operationally. First, Sparrow had been designed to counter high-flying, slow-

maneuvering bombers, which the large fleet interceptors could engage at a considerable distance. It often could not deal with rapidly-maneuvering small targets at low altitude. For example, in April through December 1965 the Navy and the Air Force tested Sparrow against a variety of targets, including slow-flying aircraft (the theoretical limit was Mach 0.7; the targets flew at speeds down to 220kts). Of 59 missiles fired, only 31 percent were successful; another 18 percent failed due to the testing environment, giving a theoretical success rate of 49 percent. However, it was found that the system was virtually useless against fighters at low altitude; in 1967 the 366th Tactical Fighter Wing at Da Nang fired 21 Sparrows against MiGs below 8000ft without any hits. In fact, the missile was rarely successful against subsonic maneuvering targets or (fired in a dive) against nonmaneuvering targets as low as 5000ft. It appeared, too, that the considerable minimum range of the missile was a severe handicap.

Operationally, Sparrow's great range could not be used effectively. Most of the aircraft over North Vietnam at any one time were friendly, so it was natural that effective IFF was emphasized over long-range fighter combat. However, as in the past, IFF was never either completely reliable or completely trusted; it was too easy for an airplane to be damaged in combat to the extent of losing it. Tactics became distorted; in some cases one fighter would have almost to pull alongside a target to identify it, then fall back to fire or to permit a wingman to fire. Even so, some Sparrows were successful in combat, and the missile was not supplanted, as some suggested, by a short-range dogfight weapon such as a 'super-Sidewinder'. A modified version, AIM-7E-2, with a shorter minimum range, clipped wings for greater maneuverability, changes to the autopilot, and improved fuzing, was introduced in 1969 as a 'dogfight' missile. It was succeeded by AIM-7E-3, with an improved fuzing circuit and greater reliability, and by -7E-4, protected against the 'spillover' radiation of powerful fighter radars such as the AWG-9

1 At one time the LAMPS helicopter was proposed as an antiship missile defense platform, and some SH-2 Seasprites were actually flown with pairs of Sparrows, although without any guidance radars (which would tend to make the missiles ineffectual).

2 A 1973 drawing showing a Raytheon proposal for a full Sparrow weapon system, radar and all, to be carried by the SH-3 Sea King.



of the Tomcat. All of these changes, however, did not overcome Sparrow's basic problems, and Sidewinder and cannon remained more popular in Vietnam.

AIM-7D was a boost-glide missile, achieving a high initial velocity but suffering from high drag, heating, and a relatively short flight time; however, the initial boost was most valuable in a tail-chase. AIM-7E introduced instead a slower-burning pure sustaining motor, which made for lower but longer acceleration, lower drag and a longer period of powered flight. Such a motor was considered best to overcome gravity in a 'look-up' engagement, and it could provide sufficient velocity to maneuver at high altitudes. A sustainer motor was also considered best in head-on engagements. The next Sparrow, AIM-7F, development of which began officially in January 1972, attempted to combine the virtues of both systems in a new boost-sustain motor, with a total impulse of 31,000lb-seconds, resulting in a range reported variously as over 24nm and 38nm (AWG-9 in a pulse-doppler mode). A new seeker was more effective, particularly looking down into clutter and resolving multiple targets. It was also compatible with the new generation of pulse-doppler radars, such as the APG-65 of the F-18 Hornet. Guidance logic has also been modified: in the -7E the missile obtained target range by comparing the frequency-modulation (FM) ranging signal at its rear (reference) antenna with the time-delayed ranging signal reflected from the target; the frequency difference is proportional to target range. In AIM-7F range data is received at launch from the fighter fire control system, and the missile updates range by calculating target velocity (doppler); in both cases target speed is used to calculate target range and a speed-gate is used to lock-on to a specific target, rejecting such countermeasures as chaff clouds. In effect, AIM-7F seems to incorporate many of the features proposed for Advanced Sparrow over a decade earlier, with the sole exception of the programmed flyout. It was approved for production (DSARC III) on

1 October 1974, the first (FY75) award following on 31 October 1975, against a projected requirement for 6864 for the Navy and 5415 for the Air Force. A version with a new seeker, AIM-9G, appeared as a prototype only, about 1970.

Recent work has concentrated on the seeker and fuze, the former involving substitution of a monopulse seeker for the earlier conically scanning type, for better ECM resistance and improved accuracy at low altitudes. Fuze Operational Test and Evaluation was completed for AIM-7F in July 1975. Seeker development began that January, Raytheon being chosen over General Dynamics in August 1976; the monopulse variant entered production under the FY81 program as AIM-7M. There is no record of AIM-7J through -7L. The new missile incorporates a digital signal processor and a new fuze for better performance at low altitudes and in intense jamming. It was first fired, by an F-14, in April 1980. Production is by both Raytheon and General Dynamics, the latter having been chosen as a second (alternate) source in 1977. Sparrow will probably continue in production through the early 1980s, to be replaced in mid-decade by the projected AMRAAM.

Sidewinder

The other major US Navy air-to-air weapon of the 1950s and 1960s was Sidewinder, which will probably well outlast its longer-range counterpart in production. It was developed as an interim weapon by a team headed by Dr W B McLean at China Lake, essentially as an IR-guided 5in rocket. In 1951 Philco was given a contract for a seeker head based on the China Lake work; two years later, on 11 September 1953, the first round was fired successfully. Sidewinder I (AAM-N-7) entered Fleet service in May 1956. In September 1958 it became the first guided missile to shoot down an airplane in combat, as Chinese Nationalist pilots used it during the Formosa Straits crisis. At that time, too, a dud Sidewinder was brought home by a MiG it had failed to destroy, and the Soviets were able to copy it as AA-2 (Atoll).

Sidewinder design was marked by extreme simplicity, the missile having only about twenty moving parts and costing, about 1960, only \$3000. Control was by the four canard fins, the wings aft containing small bucket wheels (rollerons) which helped stabilize the missile gyroscopically. Operation was also extremely simple: the missile seeker sent an



1 A Sidewinder (probably AIM-9B or -9D) is loaded aboard an F-8 Crusader aboard the carrier *Ticonderoga* off Vietnam, 9 February 1967. Note the protective nose cover over the infrared seeker.



2 This dogfight test missile (ACV motor) appears to have been developed from the Sidewinder series, and was presumably part of the program which led to AIM-9L. The plates in the tailfins hold small, air-driven gyros. It differs externally from Sidewinders principally in lacking any IR seeker in its pointed nose. This photograph was taken at China Lake in January 1974.

audio signal to the pilot's headset when it sensed a strong enough heat source. Since its telescope was caged to the missile body until the pilot depressed his trigger, it could only be fired in stern chase, a serious limitation in dogfighting, but one not immediately perceived, since the Navy pilots considered large bombers their primary targets. The seeker could begin to follow its target after the trigger was pressed, but before the missile dropped free; there was also a delay before motor ignition to assure clean separation from the carrying airplane.

Sidewinder IA (redesignated AIM-9B after 1962) was the first operational version. Its seeker, uncooled and operating at relatively short wavelengths, was sensitive to sunlight, cloud edges, and the horizon, *ie* to much of the IR background. The 25lb blast-fragmentation warhead was lethal at up to 30ft, fired by either a contact or a VT fuze. Maximum range at high

altitude was about 2.6nm, achieved by a 4000lb thrust motor burning for about 2 seconds and accelerating the missile to Mach 1.7. Range decreased to about 4000ft at low altitude; both ranges are for co-speed stern attacks, the only type possible. Minimum launch range was about 3000ft, and mission duration about 20 seconds. The seeker had a field of view of 4°, and could tilt to follow a target over a total look angle of about 25°; tracking speed was 11° per second.

The Navy sought longer range, and, if possible, all-weather and all-aspect performance: it wanted to turn its day fighters, particularly the supersonic Crusader, into full fleet air defense platforms even without Sparrow-level radars. It therefore developed a new motor, which increased mission time to 60 seconds and range, reportedly, to 11.5nm, at a slight cost in size and weight. A continuous-rod

warhead replaced the earlier type, and a new seeker permitted better streamlining of the nose of the missile. The alternatives were semi-active homing (adapted to the APQ-94 radar of the limited all-weather version of the Crusader) and a liquid-nitrogen cooled seeker, with a smaller field of view, to reduce background noise (2.5°), a wider look angle, and a higher tracking rate (12° per second). The semiactive version was designated Sidewinder IB (AIM-9C) and the improved IR missile Sidewinder IC (AIM-9D). AIM-9D was credited with limited head-on capability, and could certainly execute stern attacks with greater deflection than could AIM-9B. As for the radar-guided AIM-9C, it saw relatively little service, partly (reportedly) because of insufficient awareness of its unique capabilities among Crusader pilots. For a time in Vietnam, the standard Crusader load was three AIM-9D and one -9C, but the -9Cs were not credited with any kills in action. Relatively few were built.

The Air Force found its AIM-9B ineffective in dogfighting; it is somewhat surprising in retrospect that tests against maneuvering targets were not even undertaken until 1964, when the missile's inability to handle them was demonstrated. Philco suggested a low-altitude performance (LAP) improvement retrofit program, which produced the short-range AIM-9E, with a thermoelectrically cooled seeker with a narrow field of view, a wider look angle, and faster tracking (16.5° per second). Similarly, in AIM-9G the Navy obtained an improved seeker with increased target acquisition capability. In the new SEAM (Sidewinder Expanded Acquisition Mode), the seeker was slaved to the fighter's radar as it scanned. AIM-9G was in turn superseded by -9H, with solid-state electronics, faster tracking, and double-delta control surfaces with great actuator power for increased maneuverability in dogfights. AIM-9H is also credited with limited all-weather capability, *ie* with the ability to track through haze and light cloud cover. Its seeker is forward biased, to hit aircraft forward, where they are most vulnerable. AIM-9H was the last purely Navy Sidewinder.

Meanwhile the Air Force rebuilt -9Bs and -9Es as AIM-9J, with partially solid-state electronics and double-delta wings with stronger actuators plus a longer-burning gas generator which extended mission duration to 40 seconds. However, in January 1971 both services agreed to a joint development program for AIM-9L, a weapon based on -9H but fully effective at all aspects, capable of engaging

violently maneuvering targets, and effective against high-speed aircraft even at medium range, with a new active-laser proximity fuze and a new annular blast-fragmentation warhead (which uses preformed fragments). These components were introduced into late-production AIM-9H missiles. The seeker employs the more sensitive indium antimonide in place of the earlier lead sulfide, and is sometimes described as operating in two colors, *ie* at two distinct infrared wavelengths, to improve its resistance to countermeasures. In 1980 it was claimed that modified signal processing and a change of reticle would give a 3-to-1 improvement in background discrimination; a 'Type II tracking loop' would improve tracking rate against low-signal targets, *eg* aircraft visible from ahead only by the 'glint' of the sun reflected from them.

Development of a follow-on AIM-9M with further seeker improvements and a cleaner-burning motor began in 1976. Guidance improvements are said to enhance its effectiveness by 50 percent against targets 'framed against hot desert backgrounds'. The Air Force retrofit series continues, meanwhile, with AIM-9P, examples of which may be either newly built or converted from existing stocks of AIM-9B/E/J. AIM-9N is the Foreign Military Sales equivalent of AIM-9P. Of the versions missing from this account, AIM-9A was the original Sidewinder, produced only in small numbers; -9F was the version of -9B built in Germany by Bodenseewerk, with a new guidance/control unit. AIM-9K was an alternative to AIM-9L developed by China Lake. During the Vietnam War, China Lake developed AGM-87A (Focus I), a Sidewinder slightly modified for night attacks against visible IR emitters such as truck headlights; it was quite successful during 1969-70.

Sidewinder was, and is being, produced in enormous numbers. About 80,900 of the original AIM-9B and earlier models were manufactured, about half by Philco and half by Raytheon; 15,000 more came from a European consortium. They were followed by 1000 each of AIM-9C and -9D, and then by 2120 AIM-9G; production of 7720 AIM-9H began in 1972, the missile entering service in 1973. Total production of AIM-9L is expected to be about 16,000, another 9000 being manufactured in Europe.

Eagle and Phoenix

The Eagle missile (AAM-N-10), the forerunner of the current Phoenix, was designed as a result of a 1955 Bell Labs study of fleet air defense, followed by a Naval Air Development Center (NADC) fleet air defense study the next year; in June 1956 an Operational Requirement for a very long-range missile was issued, and the CAL task force air defense study (July 1957) confirmed the value of such a weapon. Development Characteristics were issued in February 1958, and a Request for Proposals that March. Bendix was chosen in December 1958 as prime contractor; Grumman received a subcontract for the missile airframe, and Aerojet was to build the engine. A year later Douglas was chosen to build the specialized missile fighter which would carry it, the F6D Missileer.

Throughout, Eagle was designed against a projected 1965 threat dominated by standoff missile bombers; it would operate at the outer edge of the task force, attacking the bombers before they could release their weapons, driving off snoopers attempting to shadow the force, and also countering low fliers trying to penetrate task force air defenses. Individual Missileer fighters would be assigned to Airborne Early Warning aircraft (W2F, later redesignated as the Grumman E-2) which would operate 200nm from task force center, carrying 200nm radars; normally the Missileers would orbit about 150nm from task force center. Communication would be via the Airborne Tactical Data System and would not involve the ships of the task force proper, so that the latter would not necessarily have to break radio silence. The APQ-81 radar envisaged for the Missileer fighter was so powerful that it sufficed for the radar plane to supply only an initial vector or raid segment assignment; each fighter would handle its own final vectoring. Indeed, in an amphibious assault, it was expected that Missileers would operate as semi-AEW gap fillers to detect low fliers over land.

The missile itself was to destroy targets from sea level to 100,000ft, from Mach 1 to Mach 4, at ranges of up to 100nm in a clear environment, and up to 160nm in heavy jamming, using a combination of programmed (autopilot) flyout during initial boost, mid-course command guidance, and active terminal

guidance. Alternatively, the missile could home on a jammer, and in fact could engage a jammer at greater range than it could a more cooperative target. Full aerodynamic range in such a case might be as great as 200nm, although 160 was cited. Such missile performance demanded a very powerful fire control radar, APQ-81, which had been under development since 1956. It was a pulse-doppler, track-while-scan system, radiating an average power of 2kW (peak 20kW) through a 5ft dish (compared to the 32in which had been considered impressive in the Phantom a few years earlier); targets were to be velocity-tracked (with 0.9 probability of detection) at 120nm, and APQ-81 could, in theory, track sixteen targets at 80nm simultaneously. Thus the Missileer would be able to engage up to eight targets at once, tracking both targets and missiles to calculate midcourse guidance commands. Alternatively, it could engage even more if missile tracking could be time-shared.

The missile used boost-glide-boost-glide propulsion with a jettisonable initial booster accelerating it to Mach 3.5 while achieving flight control through four swiveling nozzles. The sustainer provided further acceleration to Mach 4.5, and command guidance permitted range extension through use of an up-and-over rather than a direct trajectory. It was expected that each missile would have as great as an 0.9 probability of destroying its target, using a large high-explosive warhead (nuclear warheads would also be available). Each missile fighter would carry at least six, launching them at Mach 0.7 and 35,000ft. Eagle appears, incidentally, to have been the first air-to-air missile to combine command guidance with terminal (10nm) active-radar homing; unlike Sparrow II, it would have been large enough to house a satisfactory seeker. The pulse-doppler seeker was adapted from that of Bomarc B, and APQ-81 was the first fighter track-while-scan radar, developed primarily by Westinghouse.

Missileer was canceled in December 1960, but the Eagle technology program continued, to form the basis of its functional successor, Phoenix (AAM-N-11, later AIM-54). Within a short time the new system had been begun under the stewardship of Hughes, which also developed its AWG-9 fire control system, the radar of which was based on the ASG-18 which Hughes developed for the F-12A interceptor



AIM-9L is the current version of the Sidewinder, with an IR seeker sensitive enough for all-aspect attacks and a longer-range rocket motor.

IV. FLEET AIR DEFENSE AFTER 1945

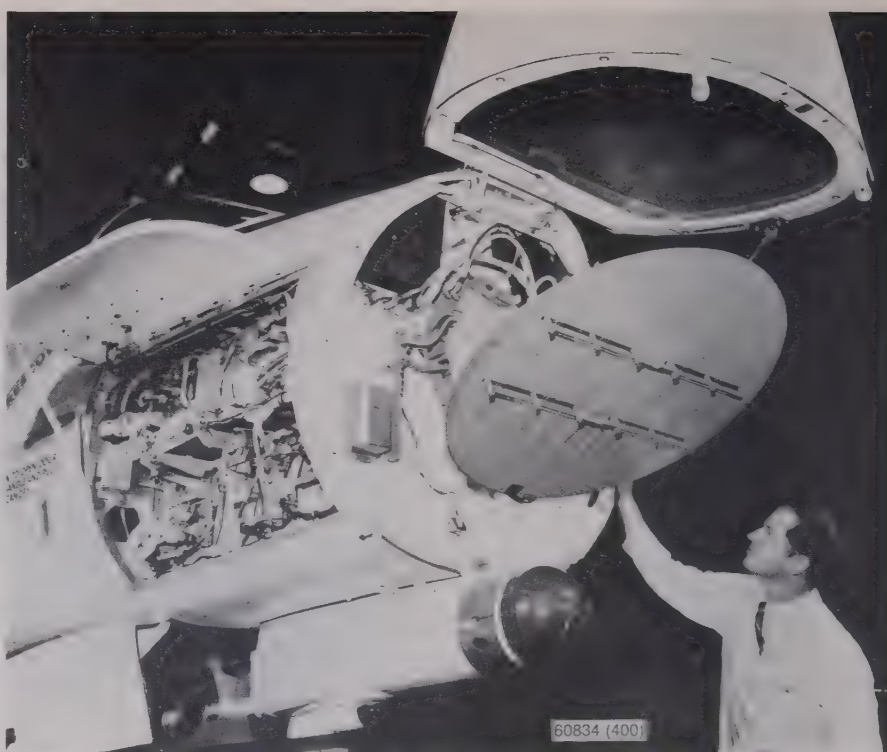
The AWG-9 airborne fire control system controls Phoenix long-range missiles, providing time-shared illumination for midcourse guidance; the missile itself has an active seeker for terminal homing. This early F-14 had both the large radar and, beneath it, an infrared detector for use in heavy ECM environments. The dipoles on the face of the AWG-9 radar are for IFF, the radar itself scanning electronically across the face of the planar array behind them.

program. The latter had originally been developed for the canceled F-108 long-range fighter, which had used a GAR-9 (AIM-47A) missile somewhat similar in concept to Eagle, except that it had used IR terminal homing (as in other variants of the Hughes Falcon series). GAR-9 was preserved by transfer to the F-12 program in 1959, and it is sometimes described as the immediate predecessor of the Hughes Phoenix. It should be noted that the reason for the December 1960 cancellation of the Eagle-Missileer program was the feeling on the part of then Secretary of Defense Gates that the incoming administration should have an opportunity to review it, rather than any feeling that a long-range multiple-kill system was not needed. Secretary McNamara merely decided to join two separate Service programs, the Hughes and Bendix long-range air-to-air missiles and existing Air Force and Navy tactical aircraft; the latter became the notorious TFX, or F-111.

Once again, the basic radar was a long-range, pulse-doppler, track-while-scan type, with a nominal (5m² target) velocity detection range of 115nm, and a tracking range of about 90nm. It has an alternate pulse mode for precision ranging, with a nominal range of 62nm (49nm for tracking), and can track 24 targets simultaneously in a TWS mode. However, as installed in the F-14, it is far more compact than the earlier APQ-81, with only a 32in planar antenna. Pulse-doppler power is great enough to permit AWG-9 to guide an AIM-7F missile up to 38nm, compared to 29nm in the pulse mode, and a more typically quoted range of 24nm for a standard F-4 radar. In the pulse mode, too, AIM-7E has a range of up to 18nm. Reportedly, target resolution in this latter mode is such that a Sidewinder (AIM-9G) can be fired 20nm in some cases, against a more typical maximum range of about 11nm.

Phoenix started as a somewhat more modest missile than Eagle, with a maximum range of 52nm. It could, therefore, employ semiactive homing for midcourse guidance, switching to active homing only in the terminal phase. Presumably the semiactive doppler system only brings the missile into the active seeker 'window', since illumination must be time-shared among several targets and several missiles airborne simultaneously. In practice, certainly F-14s equipped with AWG-9 and Phoenix have shown its multiple-target capability, hitting six drone targets almost simultaneously with six missiles, and engaging very high- and very low-altitude targets.

Demonstrated capabilities of the current AIM-54A include a maximum range of 72.5nm (80 for the new AIM-54C) and a minimum of 2.1 (2nm); a maximum speed of Mach 4.3 (5.0); a maximum launch altitude of 48,800ft (60,000ft); and a maximum missile altitude of 81,400ft (100,000ft). Some published descriptions of the missile suggest that there is a programmed flyout mode to counter standoff



jammers which the AWG-9 can detect but cannot effectively illuminate.

Hughes began flight-testing in 1965, flying Phoenixes aboard converted DA-3B Skywarriors and achieving an interception in September 1966. In March 1969 an F-111B (Navy version of TFX) successfully attacked two drones simultaneously, and from then on many multiple interceptions were made, including six out of six in 1973. The first F-14A was delivered in February 1970, and Phoenix deliveries began in 1973; AIM-54A production ended in 1981, with over 2000 missiles delivered. AIM-54B was a simplified version for easier production, with, for example, sheet-metal rather than honeycomb structure in the wings. It appears not to have been placed in production. However, the advanced AIM-54C, with improved ECCM capability and a new proximity fuze, is being placed in production. Meanwhile the earlier -54A was probably compromised by the Iranian revolution, Iran being the only foreign operator of the F-14 and its weapon system. Some modifications were made to the existing stock of missiles specifically to overcome the compromise problem.

Air-to-Air Missile Performance

The experience of air warfare in Vietnam showed that most of the theories of AAM per-

formance had been vastly overstated. For example, an investigation of Sidewinder and Sparrow failures suggested strongly that most missiles had been fired outside their launch envelopes. However, the appropriate aerodynamic criteria for the proper envelopes were, at best, extremely complex, far beyond the intuition of a pilot in combat. The table of single-shot kill probabilities (SSPK) which follows gives some indication of the problem. It has been compiled from 1980 Congressional testimony, and consists of alternative planning figures (*ie* expectations) as projected by the Navy, the Air Force and OSD. Only the OSD figures take into account altitude (low/high) and target type; the Navy and Air Force figures are presumably averages over the types of target each service expects to encounter. Thus the Navy would expect more docile, large targets (bombers), the Air Force small and more agile fighters. SEA figures are combat performance in Southeast Asia, where 604 Sparrows and 452 Sidewinders were fired in combat. No figures have been published of Israeli experience with the same weapons in the Middle East.

Phoenix and even Sparrow are relatively effective against the primary Navy target in the outer air battle, Soviet bombers flying at high altitude. The bombers are constrained to fly high in order to pick up their targets on their

	SEA	USN	USAF	OSD
Phoenix				0.10/0.35 (fighter) 0.37/0.70 (bomber) 0.05/0.15 (missile)
Sparrow	0.09	0.35	0.285	0.15/0.35 (fighter) 0.20/0.56 (bomber)
Sidewinder	0.18	0.50	0.285	0.15/0.30 (fighter) 0.20/0.40 (bomber)

own radars before releasing their weapons, and indeed the higher their altitude, the better the range those weapons will achieve. For example, on average an F-14 with four Phoenixes should be able to destroy almost three high-altitude bombers – but not even one missile. Combat in Vietnam was generally at relatively low altitude against fighters, where the OSD figures show the weapons were quite ineffective.

Advanced Air-to-Air Missiles

The longevity of Sparrow and Sidewinder has not been achieved without numerous attempts to replace them, particularly after the poor showing of AIM-7 and AIM-9B in dogfights in Vietnam. That all of these attempts have failed testifies to the flexibility of both weapons, as well as to the great advantages, not least from a logistical point of view, in evolutionary missile development. Some would, however, argue that the failure to find replacements is more an indication of US bureaucratic inertia (*eg* long lead-times from concept to decision) than of any inherent virtues in the weapons themselves.

The Air Force studied a short-range dogfight missile, AIM-82, in 1969 as an FX (F-15) weapon with all-aspect homing. Definition contracts were awarded in July 1970 to Hughes, Ford and General Dynamics (Pomona), but all were canceled that September, as improvements in Sidewinder appeared about

to achieve similar results. For its part, China Lake developed Agile, AIM-95, between 1971 and 1975. Control was entirely by thrust-vectoring, and it employed an IR seeker. Although unrelated to the Sidewinder series, it would have replaced AIM-9L. Agile became a joint services project after Congress instructed the Air Force to abandon its competitive AIM-82. For a time production in 1975 seemed likely, but that year Congress terminated both Agile and another Air Force project, CLAW (Close-range Attack Weapon, of Sidewinder size but with a much larger warhead). Agile had been developed specifically for large off-boresight angles, but Congress judged it both overexpensive and technically immature. CLAW was developed as a low-cost missile, about a quarter of the weight of Agile. Since both were intended to succeed a single missile system, Congress judged them duplicative and canceled both in favor of yet another new missile, ASRAAM. A joint project office was established in January 1979 but within a short time ASRAAM was assigned to European companies under a NATO 'family of weapons' agreement, the complementary AMRAAM going to the United States. ASRAAM is not expected to enter service before the 1990s.

The appearance of the Soviet 'Foxbat' (MiG-25) interceptor, with its extreme speed and altitude and its massive intercept radar, inspired two efforts to attack it with air-to-air

ARM missiles, Brazo and Seek Bat. Brazo was an ARM based on the Sparrow airframe, studied by Hughes and the Navy in 1972; in 1973 it was combined with the Air Force 'Pave Arm' program, and in 1974 firing tests were made with Sparrows fitted with broadband passive homing seekers, in look-down head-on and tail-on attacks on BQM-34A targets. Seek Bat (RIM-97) was an air-to-air modification of the Standard ARM (AGM-78), with a larger motor and an IR seeker in addition to its usual ARM seeker. Neither of these weapons entered production, presumably because they were far too specialized.

However, AMRAAM is a serious program to replace Sparrow. It will benefit from the continued development of compact active seekers, which in 1983 promises useful performance at K-band, *ie* with the resolution required in a Sparrow-size airframe. However, it is now clear, as it was not in Sparrow II days, that active homing is useful only in the terminal phase of missile flight. AMRAAM will have a programmed flyout, homing only when it approaches the predicted target location. Any fighter with a track-while-scan radar will then be capable of multiple target engagement; moreover, that engagement will be fire-and-forget, providing a relatively light fighter with the kind of flexibility now available only in the F-14. Raytheon and Hughes were the competitors, each building sixteen missiles for evaluation late in 1981 and service entry in 1986. Hughes won, its missile becoming AIM-120A. A related program is fighter radar improvement (including adding a Programmable Signal Processor, or PSP) for better resolution at long range, *ie* for better programming of the missile autopilot before launch. The missile itself, which is to be significantly smaller and lighter than Sparrow, will use a high-impulse motor for short flight times (and simpler fire control), all-digital electronics, and a strapdown inertial midcourse guidance system (for low cost, as in Harpoon).

Aircraft Guns

Two further aircraft guns were evolved by BuOrd postwar: the twin-barrel Mk 11, which appeared only in Gun Pod (successor to Gun Container) Mark 4, slung underwing; and the single-barrel Mk 12, which succeeded the 20mm M3 in the mid-1950s, aboard fighters such as the Douglas Skyray, the McDonnell



In the early 1970s, the Agile dogfight missile was developed at China Lake as an alternative to improved Sidewinders. It would appear that maneuverability was achieved by vectored thrust rather than by aerodynamic force, as in a Sidewinder. The Crusader carried four mock-up missiles; note that it could not carry pairs on its fuselage, as Sidewinders were generally carried. The mock-up view is dated November 1970, the missile view December 1973. The entire project was canceled in favor of an improved Sidewinder.



Hughes Aircraft was chosen as winner of the AMRAAM competition for a Sparrow III replacement on 11 December 1981. Here the Sparrow-size missile is shown aboard an F-16; it has also been tested for compatibility with the F-14 and will certainly arm the F-18. AMRAAM weighs about half as much as the Sparrow and has a similar configuration; it incorporates a programmable command-inertial autopilot like that of the Aegis SM-2, as well as an active terminal seeker, like the Phoenix, and is to have look-down/shoot-

down capability. In early tests, Hughes AMRAAM candidate missiles shot down two out of two QF-102 drones over White Sands; in the second test (23 November 1981) the missile was launched at 6000ft at Mach 0.75, at a range of 6 miles from a target flying at Mach 0.7 at 1000ft; the interception was so close that the drone was destroyed even though the missile had no warhead. The F-16 firing it was able to break immediately after launch.

Hughes

Demon and the Vought Crusader, as well as late models of the North American Fury (at least FJ-4). It was also mounted in the wing roots of Douglas Skyhawks. Carried by the Crusader, Mk 12 was the principal Navy 'dog-fighting' gun of the Vietnam War; indeed, its successes were partly responsible for the decision to include the Air Force-developed M61 Gatling gun in the armament of the first post-Vietnam Navy fighter, the Grumman F-14 Tomcat. However, the Phantom, the first Navy fighter to be designed entirely without internal guns, did not receive them in its final Navy version (F-4J).

In both postwar guns, the objective was a much higher rate of fire combined with a higher muzzle velocity, to make better use of the short firing intervals of very high speed dogfighting. Mk 11 was a revolver cannon, a distant descendant of the Mauser MG-213, examples of which were obtained by both the British and the Americans in 1945. As in a Gatling gun, the firing rate is increased by accomplishing the three major gun functions (ramming, firing and case ejection) simultaneously within a rapidly revolving structure, except that, unlike a Gatling, the barrel (or, in the case of the Mk 11, barrels) do not rotate.

The Naval Gun Factory rebuilt a captured MG-213 in 1945, and the Army Ordnance Corps and Armour Research Foundation produced a series of related weapons in the late 1940s, leading ultimately to the M39 of the North American F-100 series. Similarly, the British 30mm Aden cannon is descended from the MG-213. Frank R Marquardt, a naval technician, proposed an alternative approach to the revolver cannon in the late fall of 1945, drawings being delivered to the Naval Gun Factory in March 1947. The weapon, originally designated EX-4, was designated Mk 11 in December 1947, and was first test-fired in May 1949. By this time work was also proceeding on a 40mm, 3500ft/sec, high-cyclic-rate version, and a 30mm version was added in March 1952.

Neither proceeded very far, but the two-barrel 20mm Marquardt gun entered service, produced by Hughes.

Several unusual principals were tried out. For example, Marquardt tried at one time to balance the ramming strokes (and to shorten them, for higher speed) by loading the shell from the front of the cylinder, and the cartridge case from the rear. He also tried to use chemical energy (in the form of a 20mm primer firing) rather than mechanical to ram his rounds. Recoil rather than gas operation was chosen in order to make the gun suitable for a turret mounting, which would not be able to tolerate the release of large amounts of gun-generated gas to the rear. At the same time, Marquardt tried to make maximum use of gun recoil energy.

Mk 11 employs an eight-round revolving chamber with two barrels firing simultaneously, so that at any one time two rounds are being fired, two are being loaded and two cases are being ejected; two other chamber holes are being cooled by the passage of carbon dioxide after case ejection. The first models employed secondary cartridge cases (projectors), thin-walled containers with their own primers which literally shot the rounds into their appropriate chambers in lieu of conventional rammers. Later, however, more conventional chamber gas was used. Generally, Mk 11 employed gun recoil to spin its cylinder, that rotational motion later being used to return the firing barrels to battery. It was entirely self-contained, and saw considerable action in Vietnam as an underwing store.

During the late 1940s BuOrd also tested a gas-operated 20mm gun mechanism developed by the Shirgun Corporation of New York, which was to have an unusually low silhouette for wing mounting. It was never adopted, but is referred to in the appendices.

Mk 12, which did see considerable service, was a lineal descendant of the M3 Hispano-Suiza cannon of 1945. It differed in firing

electrically-primed ammunition, a lighter projectile, and in achieving both a higher muzzle velocity and a higher cyclic rate (3320ft/sec, 1000–1200 rounds per minute). As employed by Crusaders in Vietnam, it was also somewhat disappointing. Even before the war, Crusader pilots complained of poor accuracy, achieving about 12mils where other pilots (*eg* in Cougars) were achieving about 3; that meant a pattern of about 12yds at 1000, which was not sufficiently lethal. In addition, the Mk 12 reportedly jammed during dogfights, making the Sidewinder, rather than the gun, the weapon of choice under such circumstances.

Since that time the Navy has employed the Air Force-type M61 Gatling gun, which employs external power to fire 20mm rounds (3380ft/sec) at about 6000 rounds per minute, just under twice the rated cyclic rate of the Mk 11. It appears that Vietnam experience with missiles has confirmed the place of the gun in current Navy fighters, since the new F-18 as well as the F-14 has one.



Postwar Navy air-to-air gun development was conventional, except for the introduction of the twin 20mm gun pod, shown here as it was introduced under an A4D-2 Skyhawk, with the conventional 20mm Mk 12 cannon evident in the wing root above it. The long tube above the wing is the aerial refueling pipe, leading to a nose probe.

9. Future air defense systems

SOJS, SLAT and 'Thor'

In 1983 the primary air threats to the Fleet remain a combination of long-range air-to-surface missiles and short-range 'pop-up' weapons. In the former case the threat is considerably enhanced by special standoff jamming aircraft which may disable long-range fleet air defense systems such as Aegis; the Navy is seeking a means of dealing with them, tentatively called the Stand-Off Jammer Suppression System (SOJS). What little has been published suggests the use of a very long range surface-to-air missile, possibly guided by the airborne radar of an E-2, in an implementation of the 'Forward Pass' system first suggested by CAL in its fleet air defense study of July 1957.

The SOJS system was dropped by the Navy in 1981 with the declaration that the threat of the standoff jammer remained extremely important, but that a new technical approach was needed. However, there are continuing references to a Surface Launched Air Targeted (SLAT) weapon, at least partly because only through such a weapon can a new generation of V/STOL naval aircraft achieve long-range fleet air defense capability. In 1981 testimony, the Navy referred to the possibility of effective radar coverage as far from the fleet center as 500 or 600 miles, and a new SM-3 missile is sometimes mentioned in this connection. At present it is envisaged as a developed SM-2(MR) with a short booster (presumably with folding fins, for a high rate of fire and dense wage), but from time to time low-volume ramjets are also mentioned as candidate boosters.

For shorter ranges, there is continued interest in very high-velocity, high-acceleration weapons descended from anti-ballistic-missile technology. The program name 'Thor' is sometimes unofficially applied to a 'son of Sprint' missile which might be developed by Martin-Marietta, and which might be effective against any future Soviet naval ballistic missile (such as the abortive SS-N-13).

At the more conventional level, it seems likely that the development of antisaturation weapons and fire control systems will continue. The Aegis SPY-1 radar has shown a remarkable precision tracking capability, and it can handle many more targets than slaved illuminators. Some have suggested that the next stage is to provide the surface-to-air missile with a short-range active radar seeker of its own, using the large tracking radar to maneuver it into an intercept 'window'. The airborne Phoenix already employs just such a seeker, as will AMRAAM, and the IR-guided shell operates in the proposed mode, the gun itself directing it into the appropriate 'window'. It also seems likely that, with the advent of the more flexible Mk 26 and then Mk 41 launching systems, a new surface-to-air missile may be developed. For a time, it was proposed to substitute a blended rocket-ramjet

for the Standard Missile, to achieve in a single stage the long-range capability inherent in the Aegis system. Block II Standard (MR) Mk 2 has been described as sufficiently improved kinematically to achieve about the same range as Block I Standard (ER) Mk 2, *ie* about 70-80nm, and presumably its appearance has made immediate development of an entirely new missile unnecessary.

IFF remains a major issue in all naval air defense systems. In Vietnam, it crippled the long-range Sparrow missile, since the ratio of friendly to enemy aircraft was enormous, and accidental kills of friendly fighters were considered intolerable. The issue with regard to self-firing systems such as NTU/Standard and Phalanx is no less crucial. Antiship missiles represent so great a threat that the pressure for very rapid decisions is enormous, and IFF seems a distinctly secondary consideration. However, as SAM and AAM range increases, more and more nontargets enter the defended air space. Even to waste rounds on them is extremely dangerous, given the limited magazine space aboard all missile ships and aircraft. Additionally, the political consequences of an error would probably lead to restrictions of practice, in themselves devastating.

The Nuclear Standard Missile

The other major air defense issue of the next decade is the nuclear defensive weapon. Talos was always dual-capable, and Terrier has a nuclear warhead. Now Talos is gone, and only the rapidly ageing nuclear Terrier remains. However, to apply a nuclear warhead to the Standard Missile and thence to Aegis would be to remove a nuclear weapon from positive (*eg* beam-riding) control, and that would run against the US trend. The question is therefore asked whether *any* nuclear AAW missile is needed in future, particularly given a general reluctance on the part of the former Carter Administration to expand the nuclear arsenal.

Three arguments will probably assure the future of the nuclear variant of the Standard Mk 2 missile (W81 warhead). One is that a nuclear weapon can overcome the many forms of ECM which triumph by causing a weapon to miss just outside its lethal distance. The second is that the mere existence of nuclear missiles, which are very useful against mass attacks, can force an enemy to fly in open ('nuclear-scared') formations which in themselves reduce the saturation level to which the entire fleet air defense system is subjected. The third, possibly decisive, point is that only a nuclear weapon can achieve certain destruction of Soviet nuclear-armed high-flying antiship missiles such as the AS-6. Such weapons may fly at the upper limits of the SAM flight envelope, and may be vulnerable to engagement only near or during their terminal dives. In that case, mere destruction of the missile

airframe (as by a continuous-rod warhead) will leave an intact, tumbling nuclear bomb, capable of inflicting very severe damage.

Arguments against nuclear air defense occur on at least three levels. One is that such weapons will generally not be released early in a war, and therefore occupy valuable, and very limited, magazine space. From time to time it is suggested that a dual warhead, capable of exploding efficiently in a conventional mode when the nuclear material is removed, is worth developing for precisely this reason. A second major argument is that, even were they successful, the nuclear effects of friendly nuclear explosions would severely damage all Fleet electronics and so cancel out the systems involved. The only solution here is intensive hardening, and the uncertainty and thus the success of such hardening is a matter of considerable controversy. Finally, during the Carter Administration it was argued that nuclear Aegis would have considerable anti-ballistic missile capability, and therefore that it was illegal under the ABM Treaty. It seems unlikely that this particular argument will survive review by the Reagan Administration. There is, however, a widespread belief within the Navy that it is very much against US interests to initiate nuclear warfare at sea, since the United States has far more to lose in the form of very high value individual targets such as carriers; although defense against conventional weapons is quite plausible, the destruction of *every* incoming nuclear weapon (which might include nuclear-armed torpedoes) would seem far more difficult. For their part, the Soviets have long stated that they do not distinguish nuclear weapons from non-nuclear weapons nearly as clearly as do Westerners, and there is some ambiguity as to their willingness to use their own nuclear weapons at sea from the outset, against what they may regard as nuclear strike forces (*ie* carriers, and naval forces which they may consider cover for NATO SSBNs). The advent of nuclear-armed land attack missiles (Tomahawk) may well increase Soviet willingness to use nuclear weapons at sea, and there seems, in 1983, to be an increasing acceptance on the part of US naval officers that a future naval war may well become nuclear.

For the future, two major new systems have been mooted. One is a high-energy laser, to engage missiles at relatively short ranges but with great lethality and a very high target-handling rate. In 1983 it is by no means clear that such systems are feasible, given the problems of beam propagation through the dense lower atmosphere, as well as the difficulties of actually transmitting the laser energy into the target. However, it can be argued that some form of directed-energy weapon is the best conceivable answer to increasingly fast and maneuverable cruise missiles.

SIAM

The other new development is a weapon for submarine air defense. For many years aircraft have been effective ASW platforms largely because they alone have been immune to counterattack. Vickers did develop a short-range system (SLAM), but that required the submarine to come almost to the surface, a major disadvantage. It has been known for some time that submarines underwater can detect nearby aircraft, particularly low fliers, by the noise they put into the water. Recently Ford Aerospace has demonstrated a short-range SIAM (Self-Initiated Antiaircraft

Missile) which may be the forerunner of effective submarine self-defense weapons. Presumably sent to the surface in a buoy, SIAM would itself incorporate a search radar which would acquire the air target, then fire itself, lock-on, and home by means of dual-mode (IR/radar) signals. In its initial tests in the spring of 1981 it intercepted a QH-50 drone helicopter at 1500ft, two miles down range.

SIAM was first developed by the Defense Advanced Research Projects Agency (DARPA) at least partly as an anti-aircraft 'mine' which could be air-emplaced near Soviet and Warsaw Pact airfields to render

them inoperable, or which could be used to form an antihelicopter barrier. It is the successor to a long line of submarine air defense projects, including a submarine-launched version of Sidewinder, Subwinder. Indeed, as early as 1959 BuWeps was considering a long-range standoff ASW weapon precisely as a counter to future submarine (submerged) air defense systems. In 1980 SIAM (then called SUBADS, Submarine Air Defense System) was listed among long-term (10-20 year) naval air defense weapon systems.

CIC LAYOUT (FFG-7 CLASS) - CONDITION 1 STATIONS

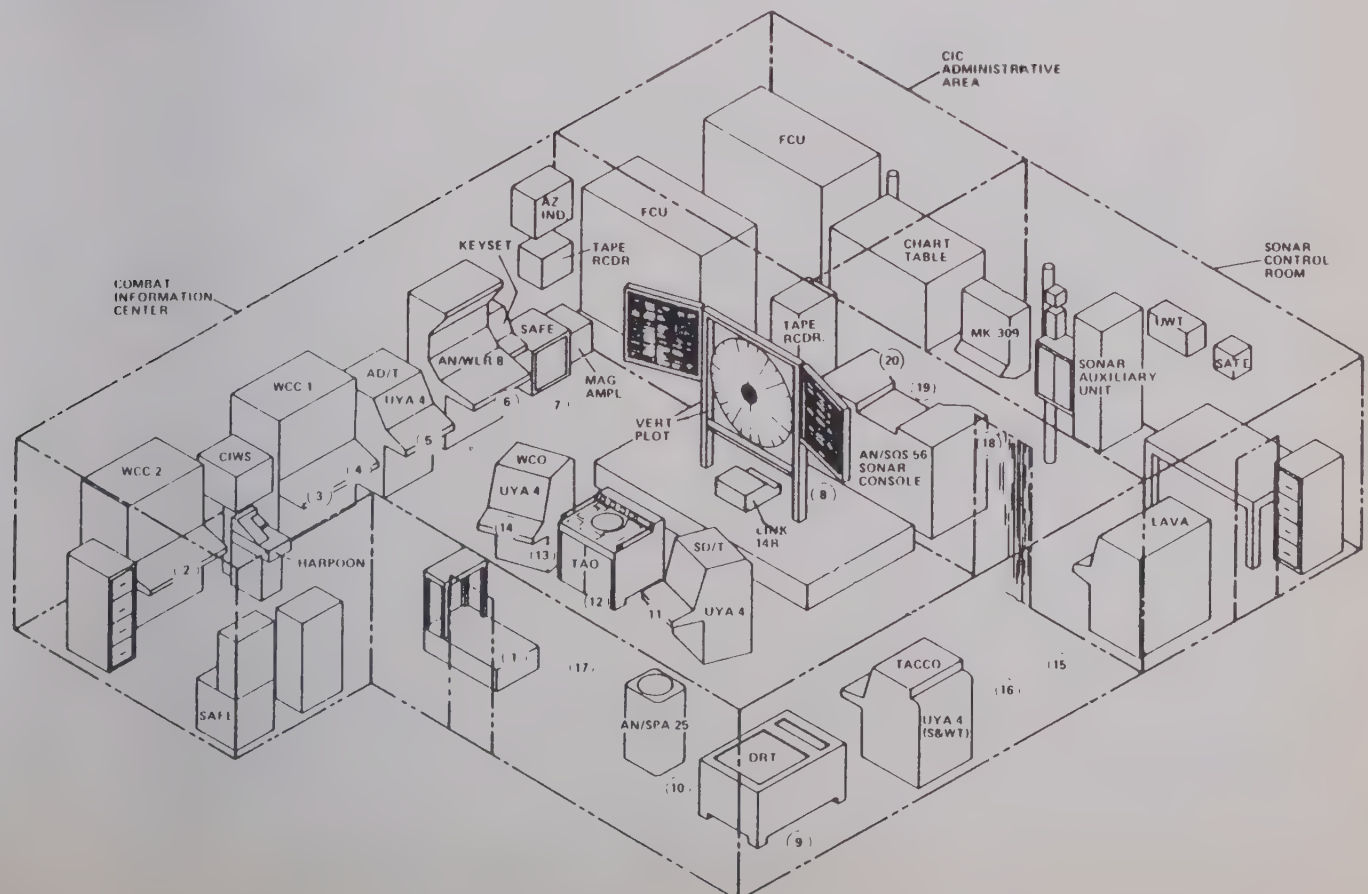
Key

- 1 Commanding Officer
- 2 WCC-2 Operator
- 3 WCC-1 Operator 2
- 4 WCC-1 Operator 1
- 5 Air Detector/Tracker
- 6 EW Operator
- 7 EW Supervisor
- 8 Vertical Plot/Link 14 Operator
- 9 DRT (Dead-Reckoning Tracer) Plotter (Surface/Subsurface)

- 10 ASW Attack Officer
- 11 Surface Detector/Tracker
- 12 CIC Supervisor
- 13 Evaluation/TAO
- 14 Weapons Control Officer
- 15 Radio Circuit Operator
- 16 Radio Circuit Operator
- 17 1 JV Talker
- 18 Sonar Supervisor
- 19 Sonar Track Operator
- 20 Sonar Information Officer

AD/T: Air Detector/Tracker
AN/SPA-25: Radar scope

AN/SQS-56: Ship's sonar
AN/WLR-8: ECM
CIWS: Phalanx
LAVA: LAMPS Data Processor
MK 309: Torpedo firing panel for Mk 46 torpedoes
SD/T: Surface Detector/Tracker
TAO: Tactical Action Officer (CIC Supervisor) - at Operational Summary Console (OpSum), which can combine displays of other consoles.
UYA-4: Computer console
VERT PLOT: Vertical (manual) Plot (classical CIC plot)
WCC: Weapon Control Console
WCO: Weapons Control Officer



Part V

Air-to-surface

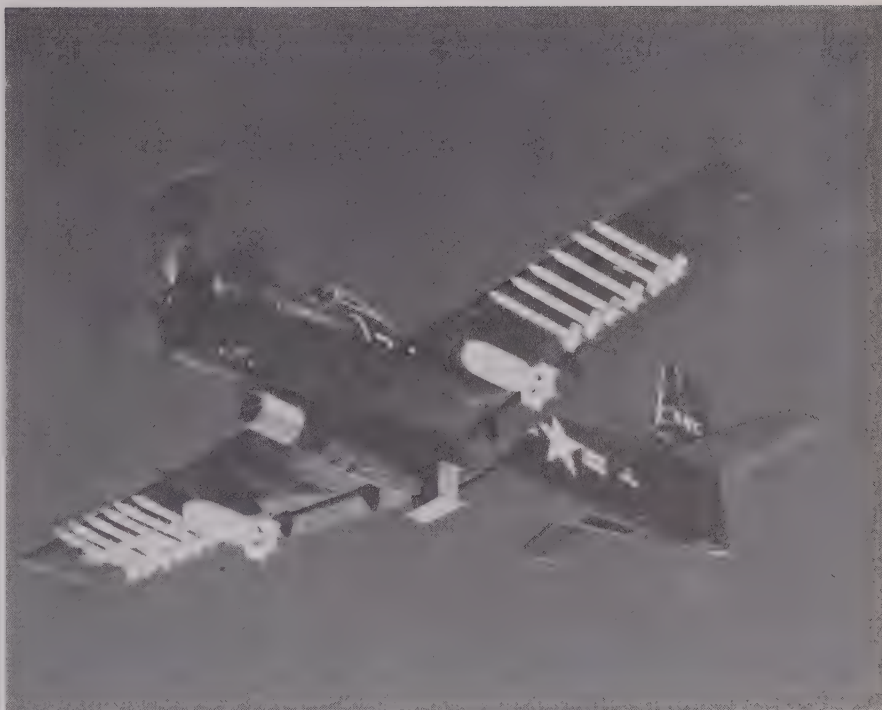
weapons



1. Introduction

Aircraft are extremely versatile weapon platforms, imposing few limitations on the details of the loads they carry beyond gross weight, some dimensions (both for carriage and for separation), and stresses imposed by some weapon delivery maneuvers (*eg* dive- and toss-bombing). In consequence improvements in the weapons themselves can often amount to modernisation of the entire air weapon system without major changes to the airplane. The substitution of guided ('smart') bombs for gravity ('iron') bombs is a case in point. It might be noted, too, that a similar consideration permits the effective modernisation of a carrier weapon system without major change to the ship element (*ie* the single largest element) of it.* Aircraft can also change their missions by changing their weapons, again generally without major airframe changes.† For example, the Avenger of World War Two functioned against shipping (as a torpedo-bomber), against ground targets (generally as a glide bomber), and against submarines (carrying sonobuoys, depth charges, rockets and homing torpedoes). Postwar it sometimes carried the Bat antiship guided missile. Tactical attack aircraft such as the Skyraider became strategic bombers when they exchanged their high explosive bombs for nuclear weapons. Conversely, the Skyhawk, designed as a nuclear bomber, fought very effectively in Vietnam armed with conventional weapons. Similarly, the Phantom, conceived as a long-range fleet air defense fighter with a secondary nuclear delivery role, became the principal US fighter-bomber in Vietnam, with an enormous load-carrying capacity.

Most naval aircraft carry their weapons externally, and external carriage in particular imposes limits on weapon weight and dimensions. Thus much of the airborne missile development of the last three decades can be seen as an attempt to build the widest variety of capabilities into packages within these limits, the size of the package defining tradeoffs between missile range, accuracy (guidance size and weight) and warhead size (lethality). The development of high-performance lightweight air-breathing engines, such as the small turbofans of cruise missiles and the new generation of blended rocket-ramjets, is particularly significant because it promises longer range without increases in weight or engine volume. That is, compared to a rocket, an air-breather should need far less fuel (since it need not carry its own oxidizer). Airborne weapon performance is also critically affected by the speed of the airplane at the time of release, since the airplane in effect acts as a first-stage booster for the missile, supplying it with considerable initial velocity. Given that initial boost, a missile need not have a high-thrust engine, and so can trade off acceleration for longer burn time and thus for longer range. Particularly in the case of air-to-air missiles, the mere ability to be launched at supersonic speed can amount to a considerable increase in effective range.



External and internal weapon carriage define different ranges of compromise. For a given weight of weapons, external carriage means a smaller and less complex airplane, but also an airplane afflicted by considerable drag when it is loaded. Weapon weights, particularly for weapons carried underwing, may also be strictly limited. On the other hand, internal carriage permits the use of much larger (less drag-limited) weapons, or, alternatively, permits an airplane to achieve very high speed while loaded. These considerations explain the use of internal bomb bays in the last prewar-designed generation of attack aircraft, the Curtiss SB2C Helldiver and the Grumman TBF Avenger. However, the generation produced at the end of the war, typified by the Douglas Skyraider, had such powerful engines that they could accept very large external loads. To have carried comparable loads internally would have required aircraft so large as to be unacceptable for carrier operation. Postwar, the need to continue to carry massive bomb loads externally led to the design of special low-drag bombs (Mk 80 series and M117). More recently, there has been considerable interest in low-drag (conformal) carriage of external stores, particularly for the Air Force F-15. Similar considerations explain the semi-buried arrangement adopted for Sparrow in the Phantom and for Phoenix in the F-14 Tomcat.

Postwar, the need to carry nuclear weapons mandated an internal bomb bay in the AJ (Savage) and in the A3D (Skywarrior). Both were conceived at a time when an atomic bomb was expected to weigh up to 10,000lb and to be very nearly spherical (*ie* to be an implosion weapon) and thus impossible to fit below the

An AD-2 Skyraider displays standard air-to-ground weapons of the early postwar period: a Mk 13 torpedo (with drag shroud and tailfins) under the center section, and 1000-pounders and 5in HVARs under the wings (September 1950).

US National Archives

body of any conventional carrier airplane, which would in any case be limited in height by the dimensions of hangar decks. Ironically, nuclear weapons soon shrank to the point of suitability for external carriage by fighter-bombers, but even then they created considerable drag. The North American A3J (later

*However, at present air wing costs entirely overshadow the cost of the carrier proper when both are projected over a 30-year life-cycle, including operation and maintenance as well as procurement. In such analyses the carrier is credited with two entire air wings (allowing for aircraft development), although the very high cost of new aircraft forces the Navy to keep some types in the Fleet for as long as ships used to serve, about 30 years. Even individual aircraft lifetimes have increased very greatly, as compared to earlier (and much less expensive) types.

†Pilot and aircrew training is a major barrier to aircraft mission flexibility, however, since training is generally more specialized than the airframe. This is particularly evident in the case of modern multirole aircraft such as the F/A-18 Hornet; the Air Force decided quite early on to dedicate its F-15s to air-to-air (air superiority) missions, and not to conduct *any* air-to-ground in F-15 squadrons. During World War Two, similar considerations showed in the distinction between pure fighter (VF) and fighter-bomber (VBF) squadrons, both flying the same type of aircraft.

A-5) Vigilante was designed to penetrate Soviet air defenses by flying supersonic at high altitude, and so could not afford such drag. Instead, it had an internal tunnel, out of which both the bomb and an auxiliary fuel tank were to have been ejected. The concept proved impractical, and in any case the Vigilante was soon converted into a long-range reconnaissance aircraft with a very secondary attack capability, but it showed the relationship between drag and external stores. It seems noteworthy that the Air Force, with a somewhat similar requirement for a supersonic bomber, was able (in the B-58 Hustler) to use an external weapon, but only at the cost of an extremely high undercarriage (unacceptable on a carrier); the B-58, too, ejected both a fuel tank and its weapon over the target.

Among current naval aircraft, only the ASW patrol types (S-3 and P-3) have internal bomb bays. In their case, fuselage volume is largely devoted to fuel and electronics, and the internal bay makes relatively little difference in the overall size and weight of the aircraft. It does reduce overall drag at a given weapon load, and so somewhat increases endurance; both aircraft carry underwing weapons as well.

Current weapon size and weight restrictions are suggested by the range of air weapons. Among bombs, the largest service type is the 2000lb Mk 84; no low-drag successor to the wartime 4000lb type, which some Skyraiders carried immediately postwar, ever appeared. Cluster weapons such as Rockeye are limited to well below 2000lb, although greater weights can be accommodated in multiple bomb racks, and many aircraft can take greater weights on their hard points. As for missiles, the abortive Condor was typical of the heavier ones, at 2130lb, with a length of 13ft 10in (166in) and a diameter of 17in. Indeed, most heavy missiles are considerably lighter, at about 1000lb: (Harpoon, for example, is launched at 1150lb, and is 151in long and 13.5in in diameter). Many underwing weapons fall into a 500lb class. For example, Sparrow weighs about 450lb at launch, is 144in long and 8in in diameter. The LAU-10/A Zuni rocket launcher weighs 533lb, is 140in long, and 14in in diameter, somewhat larger than the nineteen-rocket Aero-7D package launcher.

As for the earlier generation of naval aircraft, the design of the Mk 13 torpedo gives a good indication of the limits of the 1930s, when the single-engine torpedo-bomber was the largest available naval attack airplane. Its large bomb bay permitted it to carry the largest bombs of its day, the 2000lb general-purpose bomb and the 1600lb armor-piercing bomb. Neither could be used in a dive, the latter because a dive-bomber could not build up sufficient velocity for the bomb to penetrate armor.

As for dive-bombers, at first only very small bombs were used, as they could be carried underwing, outboard of the arc of the propeller. With the development of 'displacement gear', which could carry an underbody bomb clear of the propeller, much heavier weapons could be used. Thus by 1930 two classes of dive-bombers were envisaged: the scout, carrying a 500lb bomb, and the bomber proper, with a 1000lb weapon. In each case the airplane was expected to be able to abort an attack, *ie* to pull out of its dive with the bomb aboard. With the development of better engines the two classes merged in the late 1930s; aircraft such as the Douglas Dauntless (SBD) were designed both

to scout at long range and to carry the heavy bomb. However, they did not then have the bomb capacity assigned to the torpedo-bombers. Indeed, one reason the dive-bomber did not supplant the torpedo-plane (which was considered extremely vulnerable to anti-aircraft fire) was the latter's great bomb-carrying capacity; before their disaster at Midway, Douglas TBDs performed well as pure level bombers in the early carrier raids of World War Two.

Many of the aircraft of World War Two were stressed to carry the 2000lb bomb, but few could accommodate the next larger weapon (4000lb), which was used briefly postwar. A major exception was the huge (and abortive) Douglas TB2D bomber.

One major case of a weapon influenced by aircraft limitations deserves mention: the ASW homing torpedo. Lightweight torpedoes were originally developed in view of the very limited capacities of helicopters, which from 1946 onwards were seen as a major future ASW asset. In addition, their existence greatly simplified the design of ASW aircraft, permitting them to carry more torpedoes which in turn had a much better chance of killing their targets. For example, two torpedoes each with a 50 percent kill probability have a net kill probability of 75 percent, better than a single heavier torpedo which might have a net kill probability of perhaps 65 percent. In particular, the Grumman S2F Tracker was always weight-critical. It began as a single-package (both hunter and killer) design barely suited to operation from the standard ASW carrier, which in 1949 was the *Commencement Bay* class. Weight was at such a premium that the airplane could not be manned as it rode the elevator, and it could carry only one of the existing Mk 34 ASW torpedoes. Similarly, development of lightweight nuclear depth charges greatly extended the range of aircraft and helicopters which could deliver them.

Air weapon development reflected the evolution of the naval air mission. As envisaged before the United States entered World War One, naval aircraft were valuable principally for scouting and patrolling, and for spotting gunfire. Although Rear Admiral Bradley Fiske had patented an aerial torpedo as early as 1912, four years later the Bureau of Construction and Repair could certify only that existing aircraft could carry two 300lb weapons, whereas the Bureau of Ordnance felt that 1000lb was the lower limit. As for bombing, in 1916 the General Board opposed the development of heavy bombers in view of inaccuracies which would limit such aircraft to large land targets. A Cognizance Board had restricted the Navy to operations with the fleet; to scouting overseas; and to operations under the commandants of the naval districts and advanced bases – which would appear to have ruled out land targets as restricted to the Army. However, the existence of a Marine Corps with its own aircraft did keep the Navy, responsible for supplies for the Corps, legitimately involved in land operations.

In fact the primary naval aviation contribution to World War One was in ASW. Two tactics were proposed: patrol, to keep U-boats below the surface and so greatly to limit their mobility; and the bombing of U-boat bases, a tactic foreshadowing American post-World War Two concepts. The British first proposed the bombing offensive, and late in 1917 it was strongly endorsed by a new

American naval air planning section in London, which went so far as to favor bombing of U-boat pens even at the expense of the air escorts provided for convoys. A similar bombing offensive was proposed for the Adriatic, but had to be withdrawn in view of the cost of the German offensive planned for the same time. The import of these plans was Navy interest in heavy land-based bombers, and orders were placed for the largest available Allied bomber, the Italian Caproni. An independent Northern Bombing Force was formed, making its first raid (with one Caproni) on the night of 15 August 1918 against the pens at Ostend. Later, with the end of the war in sight, the Navy bombing unit was attached to the Royal Air Force for miscellaneous duty, which did not leave much legacy of purely Navy involvement in air operations.

Most of the naval effort went into patrolling with flying boats. Although few submarines were sighted and fewer attacked, these aircraft could carry bombs large enough to do noticeable damage. For example, the naval air station at Killingholme, which began operations in July 1918, was credited with sinking at least one and possibly two submarines. Seaplanes flying from the French base of Le Croisic between November 1917 and November 1918 were credited with spotting 27 submarines, attacking 25, and damaging 12. The most notable weapon development of this period was the Davis nonrecoil gun, a means of providing a relatively flimsy airplane with a powerful weapon. The Davis gun fired a load of bird-shot out of an auxiliary barrel to counter-balance the shell fired from its main barrel, and appears to have been successful.

From the point of view of the immediate future of the Navy, the experiences of observers with the Grand Fleet were probably most significant. They learned of experiments with aircraft carriers, and of plans for a mass torpedo strike on the German High Seas Fleet. Stanley Goodall, a British naval constructor on loan to the US Bureau of Construction and Repair, provided further details and helped to draft proposals for a US carrier. From a weapons point of view, the most effective weapon of carrier aircraft was clearly the torpedo – if a carrier-capable airplane could carry a heavy enough one. The carrier, moreover, was by far the most efficient way to operate aircraft in conjunction with the Battle Fleet. Its only rival, the catapult floatplane, was suitable (in theory) for fighter operation could not lift major offensive weapons, given its lack of underfuselage space.

As for heavy bombers, a Cognizance Board announced in August 1919 that Navy air missions were to include operation from coastal stations for convoy, reconnaissance and patrol, and from war vessels, bases and carriers for reconnaissance and spotting and for offensive operations against enemy vessels and naval bases. The latter clause certainly included the anti-U-boat bomber offensive of 1918. However, over the next decade the Army gradually became interested in the coast defense mission, while the Navy began to concentrate on a combination of carrier aircraft and long-range seaplanes, the latter suitable for forward basing. The Army Appropriation Act of 1920 specifically gave the Army control of land-based aircraft; the Navy was to limit its shore bases to requirements for experimentation, construction, training, maintenance,

repair and the support of fleet operations. In November 1929, however, the Navy announced that it would base torpedo-aircraft at Coco Solo in the Canal Zone and at Pearl Harbor. Army protests included a demand that the Navy procure no further land-based aircraft and that the Marine Corps air arm be restricted in size.

This development oriented the Navy further towards relatively lightweight antiship weapons. Admiral Pratt, the incoming Chief of Naval Operations, gave up coast defense in favor of active operations far from the United States, which would in theory forestall any coastal threat. The long-range seaplanes, now the only long-range naval aircraft, would operate from tenders, which would give them the mobility to accompany the Fleet overseas, although they might be based temporarily at Coco Solo or Pearl Harbor. In effect there were to be no permanent overseas air bases, which further emphasized the need for mobile forces such as seaplanes and carriers. The General Board regarded the new policy as surrender to the Army. The latter, for its part, began to dramatize its coast defense capability, culminating in the successful interception of the Italian liner *Rex* 776 miles out to sea on 12 May 1938 by Flying Fortresses.

By the late 1930s, then, the Navy air force was oriented towards a war with Japan, and its primary task was the destruction of the Japanese Fleet. The flying boats were strategic scouts, although their offensive function was emphasized by the transition from a 'P' (patrol) designation to a 'PB' (patrol bombing) one in such aircraft as the Catalina (PBY, originally P3Y). The need for tenders to assure their mobility in the Central and Western Pacific was emphasized by fleet exercises; like carriers, the tenders accommodated torpedoes and bombs for their aircraft. To some extent, too, the Navy experimented with large dirigibles for pure scouting, but had to abandon them after a series of disasters. It did, however, purchase some blimps which proved effective in ASW during World War Two. Their peculiar requirements for lightweight weapons and sensors led to such developments as MAD and sonobuoys. However, ASW was relatively insignificant in US naval doctrine until shortly before the outbreak of war in 1939.

Quite suddenly, then, the Navy had to provide effective neutrality patrols in the Atlantic, and clearly it would soon have to provide World War One-style ASW cover as well. Plans were drawn for a new class of coastal patrol seaplanes, but instead the Navy returned to the use of land-based patrol aircraft. Experience in Iceland showed that existing seaplanes were not always suitable, given the weather and icing of the North Atlantic, and the Navy requested and received Lockheed Hudsons originally built for the RAF; the first of these PBOs entered service with VP-82 in October 1941. During 1942 the Navy competed with a large Army coastal patrol organisation for, among other things, scarce long-range bombers. However, in July 1942 the two services agreed on the supply to the Navy of medium (B-25 and B-34) and heavy (B-24) bombers; in return the Army was

permitted to use the Renton (Washington) plant originally earmarked for seaplane production to build B-29s. In 1943, with the establishment of the Tenth Fleet, the Army finally abandoned coast defense (maritime patrol) operations, and the Navy was permitted to operate its own land-based air arm for patrol, scouting, and for ASW. Some Navy bombers, notably the PV-1s and -2s in the Aleutians, even bombed Japanese land targets.

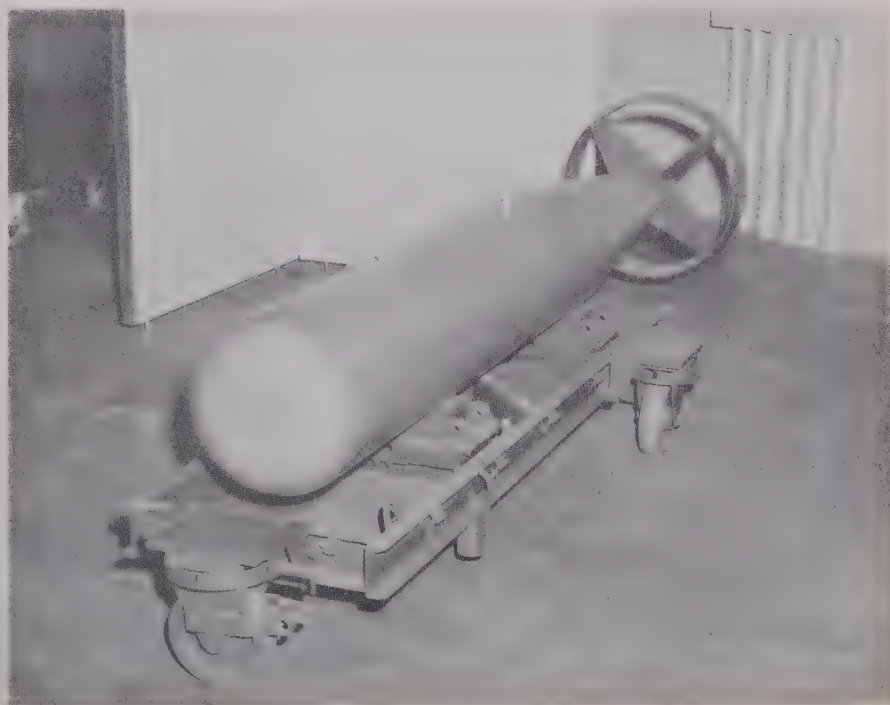
From a weapon point of view, the large land-based patrol bombers were very different from their carrier contemporaries. They could accommodate much more elaborate electronics, but on the other hand they tended to operate singly, and so could not use standard carrier air saturation tactics. They could also accommodate larger missiles than could carrier aircraft. The bombers were, therefore, the natural platforms for the wartime antiship Bat missile as well as for its postwar successor, Petrel. In ASW, they could carry the heaviest weapon and sensor loads, and always had to operate as single-package aircraft.

Operations in the Pacific gradually shifted from attacks against ships to attacks against land targets in support of amphibious operations, to attacks against strategic land targets such as Tokyo itself. At the beginning, the primary air weapons were bombs (largely for dive-bombing) and torpedoes, the latter initially unpopular because of the poor performance of the torpedo-bombers. However, from 1943 onwards the carriers found a diminishing supply of ship targets, whereas they were frequently assigned to attack Japanese-held islands. Aircraft bomb loads increased, and rockets were introduced against both sea and land targets. In some cases the assigned bomb loads proved insufficient, carrier pilots being reduced to using depth charges against buildings. However, there appears to have been very little interest within the Navy in the use of guided (standoff) bombs to overcome antiaircraft fire. The technology certainly existed, and indeed the Army Air

Force was using such weapons in combat in both Europe and the Far East. However, Navy guided weapon development was largely ship-oriented.

By January 1945 there was little left of the Japanese fleet and the US fast carriers struck Tokyo. There they discovered that their very limited bomb loads could do little damage compared to that the Army had done with B-29s. However, it was already becoming clear that the future role of the carrier would be in land attack. After all, the next most probable enemy, the Soviet Union, had no fleet worth sinking, apart from submarines. Over the final year of the war, interest among senior carrier and air officers turned to larger attack aircraft capable of carrying much heavier bombs, the figure of 8000lb appearing frequently. One explanation was the need to attack reinforced-concrete submarine pens, such as those constructed by the Germans. Only 'super-heavy' bombs, dropped from very high altitudes, seemed likely to be effective, as the British had recently shown. To some extent, too, interest in very large bombs can be construed, at least after the summer of 1945, as interest in nuclear weapons.

The Navy of 1945 was seeking a new mission. It no longer faced a major surface threat, although it did foresee a major future submarine threat, should the Soviets copy the German prototypes they had just seized. As for amphibious warfare, the Marines would be kept in existence, but there was considerable feeling that the mere existence of nuclear weapons would make future amphibious operations impossible. Nuclear weapons seemed the ultimate weapon, and the ultimate justification for the existence of the service. However, the Army Air Force was becoming the US Air Force, and the Navy must have feared that it would gain a nuclear monopoly. Certainly the Bureau of Aeronautics placed enormous stress, from late 1945 onwards, on developing a new class of long-range carrier bombers capable of delivering 10,000lb



A Mk 8 nuclear bomb, on display at the Atomic Museum, Albuquerque.
Atomic Museum, Albuquerque

weapons. The new carrier *United States* was designed specifically to support them, and was often advertised as the Navy's hope for its future.

Indeed, these projects appear to have enraged the nascent Air Force, which did succeed in having the new carrier canceled. However, the Navy retained authority to deliver nuclear weapons and with it a toehold in the coming form of warfare, strategic attack. At Key West in 1948 it had to agree not to form its own strategic air force, but it was able to retain for itself the right to attack inland targets, such as airfields, which might threaten fleet operations. The Air Force officially recognized the right and need for the Navy to participate in any all-out air campaign. Most importantly, the Navy explicitly retained its right to nuclear weapons – if it could develop the means to employ them.

As far as future weapon projects were concerned, the Navy of the late 1940s was simultaneously developing a wide range of surface-to-surface and air-to-surface missiles, most of which did not survive the tightening finances of the period. In the North American Savage (AJ) it had a nuclear bomber which could fly from existing *Midway* class carriers; at the same time it could expect to rebuild the wartime *Essex*s to take similar aircraft. However, it does not appear that there was any expectation that the size and weight of nuclear weapons would fall so precipitously that within a few years the issue of their delivery by special aircraft would largely disappear.

The Korean War changed both the Navy's funding and its concerns. Quite suddenly ground support became a major issue; losses to groundfire, for example, prompted the development of Bullpup. As an emergency measure, the Naval Weapons Center developed a new antitank rocket, ATAR. Meanwhile the very large carrier materialized as the *Forrestal*, and indeed the resources available for naval nuclear warfare increased as well. For example, with the weapons much smaller, it became possible for tactical attack aircraft to deliver them. The Skyraider could not escape fast enough from a burst, so its bombs were carried by a large rocket, Boar, which could deliver them at a distance. In addition, the Navy bought the Skyhawk, a light

day nuclear bomber. It appears in retrospect that the great expansion in defense funding prompted by the Korean War greatly reduced interservice rivalry, so that the Air Force no longer effectively opposed naval participation in US strategic strike power. That is, the Navy saw the carrier task force of the mid-1950s more and more as a long-range nuclear strike weapon. For example, there were suggestions that ground attack be relegated as a secondary role for the ASW carriers (CVS). Antiship attack appeared relatively unimportant, the only major antiship weapon of the 1950s being the Petrel missile-carried torpedo. It entered service in 1955 aboard patrol bombers which (in effect) were to counter the relatively weak wartime threat of Soviet surface raiders. Even they were considered a disproportionate investment, and the Petrel squadrons were converted to ASW operation within a year.

In 1955 the Chief of Naval Operations established a Long Range Objectives Group (LROG, within Op-93) to examine the requirements of the fleet over a 15-year period, taking into account probable technological and strategic developments. The LROG concluded that US-Soviet strategic war was becoming less and less likely, given the increasing size of the Soviet nuclear arsenal and consequent US self-deterrence. Moreover, within the time period the carrier would probably be superseded by naval missiles (such as Regulus II) as a strategic strike platform, particularly given the rise of surface-to-air missiles. However, limited wars around the Eurasian coast would become increasingly probable, and they would demand the flexibility inherent in carrier aircraft. The development of the Grumman A-6 Intruder (then designated A2F) was among the results of this particular study; at the time, it still appeared that nuclear weapons could be used in the limited warfare contemplated. However, the naval air and weapons establishment became more and more interested in guided weapons which might assure the survival of pilots operating against massed anti-aircraft missiles. The projects of this period included Corvus and the first of the 'smart' bombs, Walleye, as well as a variety of improved unguided munitions, such as Snakeye for very low-level delivery. Shrike was developed specifically to counter surface-to-air

missile systems, the emphasis on nonstrategic air warfare increasing towards the end of the 1950s.

Vietnam was the war the LROG had predicted, except that it was entirely non-nuclear. Most of the improved conventional weapons of the 1950s and early 1960s were employed in quantity, and developed in detail though not in concept. To some extent, too, the Navy employed some unconventional weapons, such as the shallow-water Destructor. Major air ordnance developments since the mid-1960s include increasing standardization between Air Force and Navy, the Navy adopting such Air Force-developed weapons as Maverick and the EOGB.

However, in some ways the most revolutionary recent development has been the re-emergence of the surface ship as a major naval air target, as symbolized by the advent of the specialized air-launched Harpoon missile. It was originally intended to counter surfaced submarines (time-urgent targets, since they might submerge before a patrol plane could reach them with more conventional weapons), as well as fast Soviet-built missile craft such as 'Komars'. The former class of targets was particularly important because the major Soviet submarine-launched anticarrier weapon of the 1960s and 1970s, the SSN-3 ('Shaddock'), required midcourse guidance from its launch platform, the latter having to remain at least awash for some considerable time after missile launch.

There was also interest, from the early 1960s onwards, in the antiship (particularly anti-'Komar') capability of standard air-to-air missiles. As described in Part IV, Sparrow III was tested in 1962 with encouraging results, in a project prompted by the export of 'Komar' class missile boats to Cuba. During the Vietnam War a Shrike antiradar missile was accidentally launched against the missile frigate (now cruiser) *Worden*, severely damaging her topside electronics and effectively disabling her for some considerable time. The extent of the damage so small a warhead was able to do encouraged Navy interest in 'soft' (antielelectronics) kills and in the use of antiradar missiles against warships. The new HARM antiradar missile is often described as an antiship weapon.

2. Bomb delivery

Level Bombing

Bombing tactics determine, to a great extent, both bombing accuracy and the survivability of the attack bomber. They also exert great influence on the choice of the bombs themselves. For example, dive-bombing requirements effectively precluded the use of large armor-piercing bombs. Snakeye, the retarded bomb, was developed to permit low-level bombing and thus to improve a pilot's chances by allowing him to avoid higher-altitude fire. Dive-bombing, the most characteristic US Navy bombing tactic of the 1930s, was originally evolved to improve accuracy, but it also made air defense far more difficult. Postwar, elaborate toss-bombing tactics were evolved to permit a low-flying attack bomber to avoid both enemy fire and the self-destructive effects of its own nuclear bomb.

The earliest technique was level bombing, exerting little strain on the airplane (and thus permitting it to deliver the heaviest load it could lift) but requiring a sophisticated bomb sight/computer to correct for windage and aircraft forward motion, and thus to calculate the appropriate moment of release. Against moving targets such as ships, level bombing had the additional disadvantage of a relatively lengthy time of flight (blind time), since the bomber generally remained at high altitude to avoid antiaircraft fire. Ships could often maneuver away from falling sticks of bombs. On the other hand, only a level bomber could provide an armor-piercing bomb with sufficient terminal velocity to permit it to penetrate much deck armor; given the defects inherent in high-altitude level bombing, a wartime solution to this problem was to accelerate the bomb with a rocket in its tail.

Navy interest in bomb sights dates from World War One; indeed, the Norden bomb sight of World War Two employed so extensively by strategic bombers, was a Navy system. Carl L Norden, who developed it from 1920 on, first became involved with naval ordnance through his work on the Sperry Aerial Torpedo (see Part VI). There was already a Mk 3 sight; the Bureau of Ordnance asked Norden to gyro-stabilize it. In June 1922 he was awarded a contract for a computing sight which he believed would permit a bomber to hit a moving ship; it used a timer to estimate the proper moment of release. The first was delivered in 1924, but the sight, Mk 11, was not accepted for service use until 1929. It was 50 percent more accurate than its predecessor, but it was too complex and required too long a steady approach prior to the attack. Mk 15, which appeared in 1931, and which was still the

standard ten years later, was an attempt to reduce the tactical limitations imposed by the timing device; the closing speed for attack could be established at any time during the run-in, although an airplane with Mk 15 had still to fly a steady course at a constant speed for the last fifteen or twenty seconds of its bombing run. Tests against the former cruiser *Pittsburgh* in 1931 proved the effectiveness of Mk 15, and the Army as well as the Navy placed orders.

In practice, fleet pilots found themselves making severe deflection errors. Norden devised the Stabilized Bombing Approach Equipment (SBAE), an autopilot which took over control of the airplane during the final run, using a gyro-stabilizer to achieve steady flight. Since the SBAE and the bomb sight were linked, the latter automatically had accurate values of aircraft course and speed. The steady run-in was required, first, to permit the bombardier to begin tracking his target through his sight; by continuing on the same course, the sight computer could, in effect, continue that tracking. Manual inputs were time of fall, based on airplane course and speed (from tables), and the trail, the distance behind the airplane that the bomb was expected to strike; airplane speed was automatically input. The sighting telescope was automatically lined up with the bomber's true course, and windage could also be input.

In 1941 the Norden bomb sight was considered the most sophisticated in the world, and its 'secret' was very closely guarded, particularly by its chief user, the Army Air Force. The bulk of production went to the Army, which ultimately received all but 6434 of the 43,292 produced between July 1939 and VJ-Day.

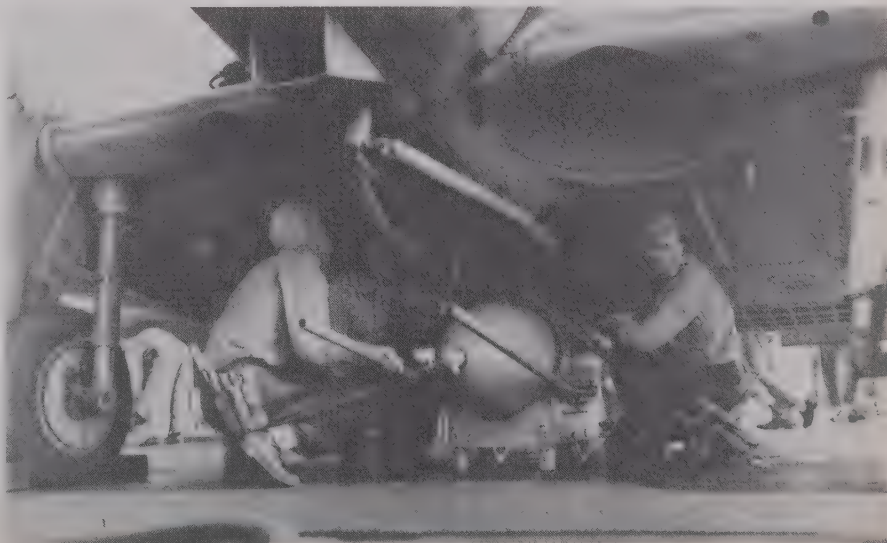
High-altitude bombing had severe drawbacks from the Navy's point of view; as early as

1932 a patrol squadron warned that this tactic would not be effective for antisubmarine patrol, best conducted at about 1000ft, since its minimum effective altitude was 1800. Norden did produce a low-altitude attachment, effective down to 500ft, for which a production contract was awarded in 1938, but it proved unpopular, many pilots believing that gun sights or the 'seaman's eye' would suffice. In fact the experience of ASW from 1941 on showed the urgency of the problem. One officer suggested that the swirl of a diving U-boat would make a useful sighting point, and that computation be based on the estimated course and speed of the submarine at the moment of diving; NDRC developed this concept into a small Mk 20 sight – which proved unsuccessful. In particular, the limits it placed on aircraft maneuverability were unacceptable. However, the Pacific Fleet suggested a very simple alternative, Mk 21 (the 'San Diego Sight'), consisting of an Illuminated Sight Mark 9 which could be set at any desired angle of depression. It proved an effective stopgap, far superior to the 'seaman's eye'.

NDRC looked to a more sophisticated alternative, exploiting gyros to measure angular velocity. The angle from airplane to target changed at an increasing rate during the run-in, reaching the vertical (and a maximum rate of change) as the bomber passed overhead. A gyro measured the rate of angular velocity, and was set to release bombs at the appropriate instant. The prototype of this Mk 23 sight appeared (as the NDRC BARB III) in 1944, and 300 had been produced by the end of the war. They appeared in most of the early post-war ASW attack aircraft. An alternative sight, developed by Eastman Kodak, was stabilized to eliminate the effects of aircraft maneuvers and operator jitters, appeared only at the end of the war (as Mk 25), and was not produced.

At the beginning of World War Two, the dive-bomber was by far the most effective US carrier-based weapon. Here crewman load a Douglas SBD Dauntless with a 500lb bomb aboard the carrier *Enterprise* supporting the Guadalcanal landings, 7 August 1942. The bomb is being lifted onto a 'crutch' which will carry it clear of the propeller arc as it is dropped. Note, too, the perforated dive brakes visible behind the crewman on the right, to limit speed in the dive and so to keep the trajectory controllable.

US National Archives



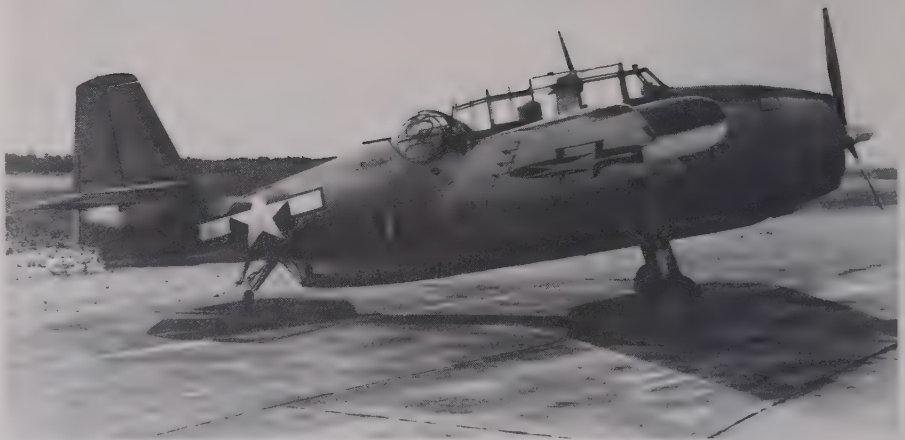
Dive-Bombing

The great and successful rival to level bombing was dive-bombing: the airplane itself was aimed at the target, diving at so high an angle that the bombs followed its path down into the target. No compensation for aircraft motion as such was needed, and the bomb was generally released at such low altitude that windage was no problem, nor was blind time. Thus the standard dive-bombing sight in use in 1941 was no more than a three-power telescope. The pilot lined up his target in its cross-hairs while keeping his aircraft level in the dive, using a device similar to a turn-and-bank indicator. The chief problem was a tendency for the telescope to fog during the long dive from about 7500ft to a release at 1500; in the later wartime dive-bombers, beginning with the SBD-5, reflector sights located entirely within a heated windshield were fitted.

Dive-bombing was not quite as simple as it appeared, since the bomb did not in fact quite follow the path of the airplane. Rather, the line of sight was a reference line, and the pilot had to compensate for the effect of gravity, which would drop his bomb out of its straight-line path. This deviation could be calculated, but the pilot could not be expected to do so during his dive. Instead, squadron doctrines were developed, specifying the factors (bomb type, dive angle, speed and altitude) with a point of aim and release for each.

There were attempts to design a more accurate sight for dive-bombing. During 1942 Norden developed an Aiming Angle Sight (Bomb Sight Mark 16), which was designed to permit bomb release above 5000ft without compromising accuracy; the simplified Mk 18 soon followed. Although tests in 1943 and 1944 were promising, both had to be rejected because of the requirements they placed upon the dive-bombing pilot. As in all of the other sights, the pilot was required to maintain a very steady course and speed merely to input into the sight the target position; there was (and could be) no independent target designator which the sight could track. Moreover, the pilot needed so much concentration to stay on target that he could not spare attention for instruments outside the gunsight he used for aiming. This particular problem has been solved only recently, with the advent of the head-up display (HUD).

The precise origins of dive-bombing are obscure. The Marines are credited with using it in Haiti in 1919, and the Army sank one of the German target destroyers by dive-bombing in 1921. By 1925 experiments had become so common that the CNO ordered it included in the following year's competitive exercises. At that time the only suitable airplane was the Vought VO, which could carry light bombs under its wings, outboard of its propeller, diving at a 45° angle from 1000 to 400ft. The tests were so successful that bomb racks were soon installed on the standard Navy fighters, the VE-7, FB and F6C. Indeed, the fighters and observation planes were so effective as extemporised dive-bombers that in March 1927 officers of the Bureau of Aeronautics reported that the Fleet saw no need for a specialized light dive-bomber. Exercises that October at Hampton Roads (VF-5S) showed that dive-bombers could easily hit targets towed at 20kts by destroyers, and that their speed, particularly the rapid rate at which they changed altitude, might well protect them from



antiaircraft fire. The obverse of this particular coin was the quick development of antiaircraft machine guns such as the quadruple 1.1 in (see Part II).

As a result of the October 1927 tests, BuAer began development of two new classes of dive-bombers, one to take a 500lb and one to take a 1000lb; in each case the bomber was to be stressed to be able to pull out of a dive still carrying its bomb. As of December 1928, both the F4B-1 fighter and the O2U-2 scout were capable of carrying either a single 500lb bomb or ten 30lb bombs underwing; most other carrier aircraft could carry five 30lb bombs.

However, difficulties were soon encountered. In a really steep dive, any bomb carried under the fuselage might well become entangled in the propeller or undercarriage of the bomber, yet any hope of dive-bombing with substantial weapons required exactly such carriage, and accuracy demanded the steepest possible dive. There were several incidents: a miniature (practice) bomb struck the propeller of the XF6C-4 fighter prototype; bombs struck landing gear, and one even lodged in the landing gear, falling to the carrier flight deck as the bomber landed. At first it appeared that dive angles could be restricted, but movies of actual practice runs showed that pilots generally miscalculated their diving angles by as much as 15–30°. The solution was a displacement gear, or bomb crutch. It swung the bomb clear of the propeller on a sort of trapeze; as an additional safety feature, the bomb was not armed until after it had left the airplane. The displacement gear encouraged the development of the heavy dive-bomber, since it was far too massive to be carried underwing. Dive-bombers carrying additional bombs, then, were restricted in numbers so that those weapons would not strike the propeller on their way down. Displacement gear entered service in 1931, and through the 1930s the dive-bomber gained prestige within the Navy. At first, indeed, it seemed destined to replace the torpedo-bomber entirely, and the carrier *Ranger* was completed without torpedo stowage.

Glide-Bombing

Torpedo-bombers could not be fitted with bomb crutches for dive-bombing, yet by the late 1930s the Bureau of Aeronautics considered level bombing inadequate. It turned to an intermediate tactic, glide-bombing. Where the dive-bomber approached its target at an angle of 70° or more, the glide-bomber

The TBM-1D Avenger (shown here at Patuxent River, 4 July 1944) had an ASD-1 radar permanently installed on one wing. Also designated AN/APS-3, it could detect a bomber at 8nm and a fighter at 5 – or a battleship at 50. It replaced the much simpler ASB, whose antennas were yagis, assemblies of dipoles under each wing. The ASD provided far greater precision, and the TBM-1D was the first Avenger variant fully suited to night attack.

might attack at 40 or 50. One advantage of glide-bombing was the elimination of the heavy and bulky SBAE, although an equivalent weight might have to be added to strengthen the airplane against the stress of the dive. As a result, BuAer at first abandoned its glide-bombing plans, although it did persuade BuOrd to produce a Mk 15 sight modified for glide-bombing, which became available in the fall of 1941.

In wartime, glide-bombing completely replaced horizontal bombing from 7000ft to 15,000ft. In experiments in July 1942 VT-6 (USS *Enterprise*) pilots dove from 6500ft to 2500ft at 45–60°, placing their bombs within 40ft of a moving target. BuAer refused to eliminate the Norden bomb sight from their aircraft, but glide-bombing became the standard attack tactic for aircraft not fitted with bomb crutches. Pilots generally found the SBAE useful as an automatic pilot for long flights; in 1944, Eastern Aircraft (then the primary builder of the Avenger torpedo-bomber) replaced the Norden sight with a simple automatic pilot. There was still a problem of strengthening, which had deterred BuAer from adopting glide-bombing for its torpedo-bombers prewar. Avengers dove at too shallow an angle (60° or less) to be struck by their own bombs, but they did disintegrate on occasion. However, to add 400–600lb to strengthen them beyond the possibility of structural failure was unacceptable; Grumman sought to find the weak points, and installed accelerometers to warn pilots of impending failure. However, the solution to the problem was to redesign the Avenger using higher-strength materials. Production of the new version, the TBM-4, was scheduled for August 1945, and was canceled due to the end of World War Two.

Glide-bombing was the principal tactic of fighter-bombers armed with bombs and rockets but not equipped with divebrakes. Similarly, modern jet fighter and attack aircraft are generally designed to glide-bomb. Their



By 1945 all attack aircraft had internal fittings for APS-4 radar, which could be carried as an underwing, bomb-shaped pod. This is an SBF-4E, a Fairchild-built Helldiver, at Patuxent River, 17 December 1945. Similar pods were often carried postwar by Skyraiders. The zero-length rocket stubs outboard of the pod (and visible on the other wing) were also standard by this time.

alternative is low-level horizontal bombing using delayed-action bombs or else retarded bombs whose own airbrakes slow them down so fast that they strike the ground well behind the bomber. Snakeye is the current type, although a Goodyear 'ballute' (balloon-chute) has been tested recently. The World War Two equivalent was a bomb with a retarding parachute, which would not stand up to modern airspeeds.

Toss-Bombing

Toss-bombing was developed in 1943 as an alternative to dive- or glide-bombing. It differed from earlier techniques in that the bombs were released during the pull-up from the dive, giving them an added velocity which could compensate for gravity and thus produce a straight-line trajectory; their line of fall would then correspond to the line of the dive or glide. Given an appropriate computer, the pilot had only to allow for wind and target motion, and he could bomb accurately from up to 6000ft in a 15-60° dive, yet achieve the accuracy of lower-altitude dive-bombing. The key to the technique was calculation of the precise moment of bomb release; in 1944 the rate of decrease of altitude (rather than range) was selected as the criterion, and the problem solved. The altimeter reading plus the dive angle (as measured by a gyro) automatically gave the range to the target, and a BuAer requirement for 500 toss-bombing equipments led, in August 1944, to Bomb Director Mark 1. The pilot dove at his target, pressing his release button when steady on course. After a short time (about one-sixth of the way to the target) the bomb director turned on a light indicating that it was ready, and that the pilot could pull up.

Although very few bomb directors had been delivered by the end of the war, and none had seen combat, BuAer considered them (and their computer, AN/ASG-10) a revolutionary development. Postwar it was redesigned to eliminate the gyro and thus permit greater tactical latitude, releasing bombs or rockets at up to 25,000ft, as Bomb Director Mark 3, which appeared in the Skyraider. Bomb Director Mark 2 was a radar precision-bombing system, initially designated Bomb Sight Mark 22, and developed by Norden using a Bell Laboratories K-band radar; however, the K-band radar could not penetrate water vapor, and had to be replaced by an X-

band set of lower definition. The entire system was too large for carrier aircraft, and a new attempt was made to design a computer which could be connected to their existing search radars, as Bomb Director Mark 4 (Bell Laboratories). In the event, neither was built. The last of the specialist bomb directors was Mk 5, developed postwar as the Radar Bombing System AN/ASB-1 for carrier-based strategic bombers (AJ Savage, A3D Skywarrior).

Towards the end of World War Two there appear to have been tests of toss-bombing as an air-to-air weapon. They were successful, and in November 1945 the Pacific Fleet recommended continued research. No combat tests were reported, however.

One other wartime bomb-delivery technique deserves mention: very low-level attack (masthead, skip or low-level bombing) in which the airplane approached at an angle of 30° or less, leveling out to drop its weapon, which might skip across water into a ship target. It was the principal mode of delivery for napalm and for fragmentation weapons; postwar some of the Naval Weapons Center 'Eye' series were designed with delays making them suitable for low-level attack.

Techniques since 1945

Postwar bombing development embraced two very different concerns. One was the strategic or tactical delivery of nuclear weapons, in which evasion of enemy defenses had to be combined with evasion of the effects of the bomb itself. The other was tactical delivery of conventional weapons, in which greater accuracy might buy reduced exposure to increasingly effective ground defenses. Although standoff weapons (such as Bullpup and Walleye) solved part of the latter problem, unguided bombs continued (and continue) to be important enough to require specialized bomb-aiming systems.

In the early 1950s it appeared that target defenses could be penetrated either at very high or at very low levels. The large carrier bombers typified the former approach. For example, the A3D-2 Skywarrior was designed to make its bombing run at about 41,000ft, flying for 15 minutes at normal thrust, including two for post-attack evasion and 8 for escape, leaving the target area at about 41,400ft. It employed a radar/visual bombing system, ASB-1 (Bomb Director Mark 5). Its successor, the A3J (A-5A) Vigilante, was

designed around a 'nonradiating' (inertial) navigational system, running in for the last 100nm at Mach 1.5 at 50,000ft. Total supersonic run-in was 155nm, climbing up from 40,000ft after acceleration to Mach 1.7. This mission profile required a dragless weapon, a bomb carried in a linear (internal) bomb bay. In 1959 the Bureau of Naval Weapons, successor to BuAer, looked towards a Mach 4 successor, which it provisionally designated AWS-202A, and which it hoped to introduce into fleet service in 1968, given a 1964 go-ahead. By that time enemy defenses would prohibit a direct flyover, and AWS-202 would fire a 200nm and 400nm standoff missile from 100,000ft, using a Vigilante-style linear bomb bay to minimize drag. Where the Skywarrior could attack at 1585nm (a 7.9-hour mission) and the Vigilante at 670 (cycle time 2.9 hours), AWS-202 was intended to strike at up to 1250nm, accelerating to its engine limit at 36,000ft, then climbing to 90,000, cruising towards its target at Mach 4, then firing and climbing to 100,000ft for the long glide home. By this time Regulus II and Polaris seemed far more attractive as deep-strike systems, and long-range strategic bombers were about to be phased out.

Loft- and lob-bombing were developed to permit safe low-level delivery of nuclear weapons; the alternative was a delay fuze. In loft delivery, the pilot finds an initial point (IP) between him and the target, and flies over it towards the target, pulling up and over at a computed point; the bomb continues upwards and arcs over towards the target. Lob-bombing was developed for attacks on targets whose precise location was unknown. The pilot flies directly over the target, then climbs, loops over, and drops his bomb in the loop, continuing away from the target. Again, the bomb climbs to a considerable altitude before dropping, delaying its explosion until the bomber is clear. Together, these and related techniques were described as 'low altitude bombing', and attack aircraft such as the A-4 Skyhawk were fitted with LABS, the Low Altitude Bombing System. Both techniques were quite accurate enough for nuclear delivery, but could not be used with conventional bombs.

Modern conventional bombing systems are all descended from Bomb Director Mark 1, in that they increasingly allow the airplane to follow through to attack a target the pilot designates. Many are angle-rate systems distantly related to Mk 23. Accuracy and effectiveness depend in large measure on the angular size of the field of view of the sight and of the 'pipper' (target designator) within it. The first important improvement, then, was a stabilized-recticle sight, which permitted a pilot to keep his eye on the target despite the motion of his airplane, which might be considerable in low-level flight. The next was a head-up display (HUD), symbols projected on the windshield, to permit a pilot to aim without refocusing his eyes. In each case, the weight of

V. AIR-TO-SURFACE WEAPONS

avionics electronics increases considerably. For example, the dorsal 'hump' in an A-4F houses added avionics including the bombing computer. The Air Force A-7D introduced a head-up display, which is also incorporated in the equivalent Navy A-7E.

The Grumman A-6 Intruder

Modern sophisticated blind bombing systems are typified by those developed for the A-6 Intruder. This airplane was originally designed primarily for all-weather interdiction and close air support, roles performed in Korea by Sky-raid. From the first, a computer, DIANE (Digital Integrated Attack Navigation Equipment), was to be used to sort out the appropriate ground targets from the returns of a search (APQ-92) and a track (APQ-88) radar. Navigation was entirely automatic, and the A-6 was designed specifically to fly at low altitude. Among other features, in revised form the A-6 avionics was intended to be able to track slow-moving land targets such as trucks. In addition,

it could attack a target using as its reference a radar reflective aim point up to about 8nm away.

Improved avionics has had a mixed reputation. When it works, it can markedly improve bombing accuracy, systems being rated by their design errors in mils (thousandths of a radian), 10mils being quite common. On the other hand, failures can be catastrophic, and on average an unreliable if sophisticated bombing system can be far worse than the simplest manual devices. For example, a 1968 OSD report noted that the at-target reliability, at that time, of the A-6A radars was only 40 per cent, and of the entire A-6A radar system, only 26 percent. Tests of visual aided bombing systems (employing ranging radar, gyro, analog computer, a fixed sight, and a dive approach at 10-50°) were showing CEPs *worse* than those obtained with 'iron sights' (in test) by 35-65 percent, at altitudes of 3000-7000ft. Errors in practice were up to 15mils in azimuth and 11 in elevation. A more elaborate radar system with a digital computer and a servoed sight was barely competitive with the 'iron sights', with median miss distances of 10mils in azimuth and 8.5 in elevation. By way of comparison, the 20mm aircraft cannon, with what the report characterized as 'rather poor ballistics', 'achieves 4-5mils CEP in multipass strafing, a

factor of 2-3 better than the most optimistic (untested) claims made for bombing systems'.

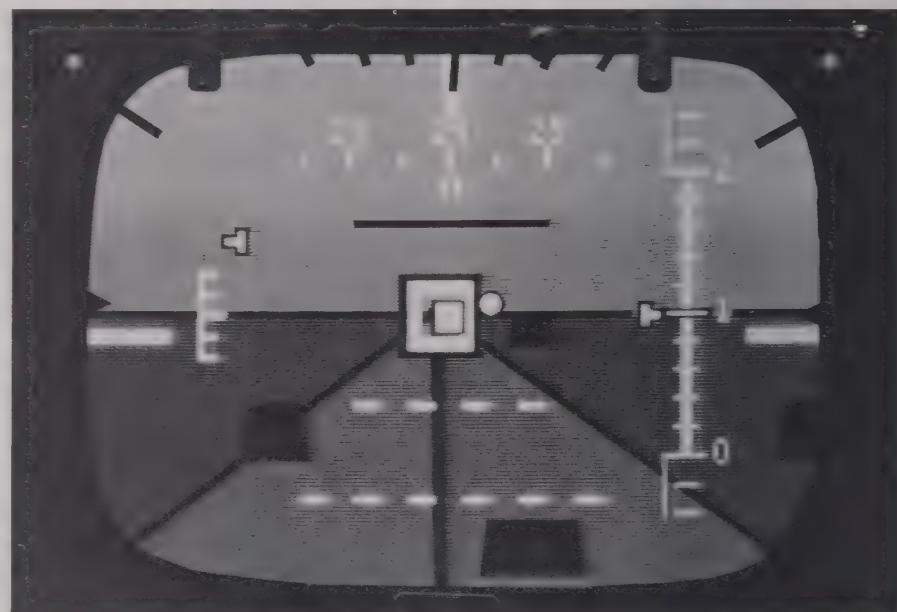
Blind bombing systems such as that in the A-6 were far worse, one problem being that

... CEPs for a given radar will vary by at least 5:1, depending on target difficulty ... results degrade by a factor of 3 to 5 from radar corner reflector tests to realistic target tests. In addition, tests of the same systems in the manual timer mode show negligible differences between automatic and manual modes (generally a slight edge for manual releases). All this points to the radar's inherent lack of resolution and inability to separate targets in strong clutter as being the limiting factor in blind bombing accuracy. In other words, the complexity and expense of the automatic release mechanization of the most modern systems is simply misplaced effort until the basic radar is significantly improved...

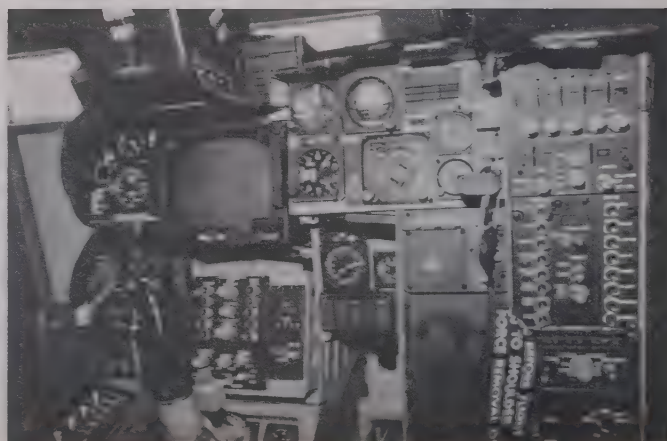
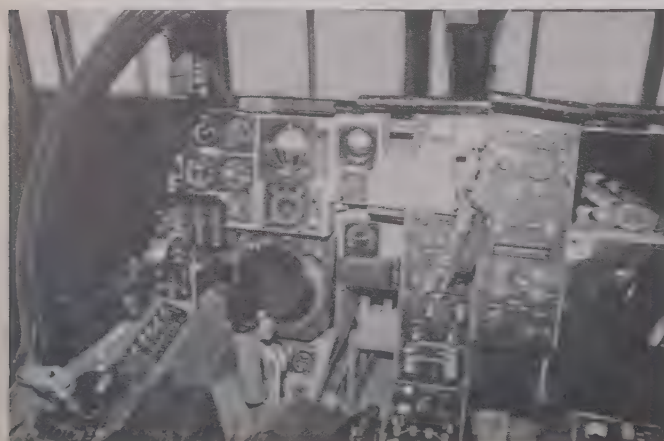
This explains the very considerable effort to improve the A-6 radar and to provide it with nonradar sensors (of higher resolution), such as those of the TRAM program.

In combat, it was estimated that an A-6A could achieve a 900ft CEP from an altitude of 1000ft against a good target, or one of 1500ft from 3000ft; however, against difficult radar targets at these altitudes, CEP was closer to 4800ft. Night attacks against Vietcong trucks were therefore disappointing. For example, between September and November 1967 the

- 1 The unique Grumman 'road in the sky' display is shown in its Contact Analog (CA) mode, as fitted in an A-6 Intruder. The lower half of the screen is the 'ground plane', with a horizon for reference and command heading lines at the bottom to indicate the flight path to the white dot which is the impact point symbol. The open square is a weapon-steering symbol and the white dot at the intersection of the flight path lines represents the target. The dark figures on the ground plane are 'perspective trapezoids' to give the pilot a three-dimensional effect. The white T-shaped objects in the 'sky' are 'bugs', that on the left indicating vertical speed along a scale of radar altitude and speed. Above and below the target are $\pm 10^\circ$ pitch lines, that above the target being blacked. The numbers above the display are a heading 'tape' with a double mark acting as a heading index. The area above the horizon is a 'sky plane', and in some cases it is filled with artificial 'clouds'. This entire display is an example of recent computer technology, since it replaces a pair of tapes, altitude and heading, and also provides an artificial forward view by means of which the airplane can be flown. In an alternative terrain contour mode (not shown), the computer provides an artificial indication of the shape of the terrain ahead of the airplane.
Grumman



- 2 Two views of Grumman A-6 cockpits suggest the simplification brought by the use of a digitally generated display. In one case the pilot must look at his radar-scope and at the same time scan a variety of electro-mechanical displays, including the complex heading indicator and artificial horizon at the upper left; in the other, the 'road in the sky' digital display dominates the instrument panel, with an optical sight above it. Most of the instruments in both cases are still the classical dials, often connected directly to measuring devices: Grumman had not yet made the transition to an all-digital cockpit, as in some modern airliners and, for that matter, the F-18.
Grumman



most successful A-6A squadron, VA-196, achieved only 0.6 truck claims per sortie, based on secondary explosions. Even that score could be attributed to recent improvements in the Airborne Moving Target Indicator (AMTI) of the A-6A, as the 1965 score was only 0.07 trucks per night sortie. Hopefully radar improvements in the decade and a half since have greatly improved matters. A 1980 review of naval aircraft radars emphasized the reliability improvements of the 1970s, in which the A-6 radars (APQ-85/92 and then APQ-148) had been replaced by APQ-156 (and the APG-53 of the A-4 had been replaced by an electro-optical sensor). However, there were still complaints of inadequate resolution.

As an indication of the current state of the art, the Grumman A-6E is fitted with a digital computer which processes data from sensors of aircraft angle of attack and acceleration; from a doppler (radar) navigation system (APN-153) and an inertial navigation system (ASN-31); from backup magnetic compass and vertical gyro indicators; and from the APQ-148 multirole radar system. The computer judges which navigational data are valid, and so to some extent can overcome reliability problems in individual elements of the system. It generates a display of steering commands 'and other data necessary to navigate to a target and deliver ordnance accurately without visual reference to the surface. When an attack is being executed, the computer performs certain additional calculations related to the attack profile and weapons selected by the crew and provides attack steering commands to the crew and, if an automatic release has been selected, weapon release signals to the armament control unit.' For example, in a nuclear attack, the computer can determine whether a given release path will be safe, given the blast and other effects of the weapon.*

The extent of backups is silent testimony to the reliability problems of the 1960s. For example, the angle of attack indicator is, according to the Navy manual for the aircraft, 'used only as a secondary means of determining aircraft flight path angle (measured from the horizon). Under normal circumstances the computer calculates flight path angle from the relationship between vertical velocity (baroinertial loop) and TAS [true air speed]'. The doppler navigational radar itself, the primary means of measuring ground speed, is considered effective between 40 and 50,000ft altitude, and from 80 to 800kts; it is stabilized against a 30° roll and against pitch between 17° nose up and 25° nose down. Pitch and roll in turn are supplied to the radar from another system (aircraft attitude reference system). In addition, the A-6E has an inertial navigation system, which in principle is entirely independent of external data; as in the case of a ballistic missile, it operates from accelerometers within the airplane. However, over a lengthy flight such a system is subject to drift. It also requires arrangements for proper alignment aboard the carrier prior to launch. Possibly the most important innovation in late-1960s and 1970s avionics was the incorporation of built-in test equipment (BITE) which permitted the aircrew to tell when particular elements were failing, so that they could turn on backup systems. Such equipment also permits relatively quick diagnosis of faults before flight, for much quicker repairs (generally by total replacement of the faulty element).

Radar operating modes in the A-6E are search (the basic mode), beacon, airborne moving target indication (AMTI), and terrain clearance for low level flight. Both pilot and bombardier/navigator were provided with alternative depressed-center PPI (radar map) and B-scan (distorted map) displays; radar range modes include displays at up to 150nm as well as much more detailed ones out to 75nm, and AMTI operation at short range (limits are 18, 22 and 27.5nm depending on the display mode). There are also two special distorted modes, ARE-60 (automatic range expansion - 60°) and ARE-30, in which the range between ±30° (or 15°) fills the width of the B-scan scope; these modes are used primarily for attack, the depressed-center PPI modes for navigation (with an azimuth sector scanned from 20° to 110°). Range in the ARE-60 mode is set at greater than or less than 18nm in the ARE-30 mode, and there is a 22-56nm range band selectable. These details suggest the complexity of a modern radar attack system, and the flexibility provided the aircrew.

The pilot's vertical display indicator has a unique 'contact analog' mode, in which a synthetic map of the terrain and the sky leading to the target (sometimes called a 'road in the sky' display) shows appropriate flight maneuvers to be made. A ground-stabilized horizon line indicates aircraft attitude, and there are 'ground texture' and 'cloud texture' elements on the scope, moving to indicate aircraft motion towards the artificial horizon; 'the sky is lighter than the ground and has white cloud texture elements [which] provide additional real-world reference. The clouds move when the aircraft attitude is changed in pitch or heading, and remain fixed when constant attitude is maintained.'

The A-6E weapon control system is of course far more complex than these notes suggest, and includes as well an optical sight as a backup to the radars. Like earlier variants of the A-6, the A-6E was fitted only with radar night attack sensors, which were inherently limited in resolution and so in accuracy. However, in the current TRAM (Target Recognition Attack Multisensor) modification, which first flew on 22 March 1974, optical and laser devices, of much finer resolution, were added in a special stabilized turret under the nose of the A-6E. The turret contains a forward-looking infrared sensor (FLIR) and a laser rangefinder/designator, so that a TRAM A-6E can drop laser-guided bombs. It also retains the radar ranging and tracking capability of earlier versions. 'The optimum technique is to acquire the target using the radar cursors to define it, thus making use of the longer range and wider field of view of the radar, and then...taking advantage of the FLIR and laser for target tracking and precise range and altitude measurement.' In 1981, about forty A-6Es (TRAM) were in service, and the Navy planned to use the TRAM configuration as the baseline for further A-6E improvements. (All A-6Es are to be modified to the TRAM configuration by 1984).

For some years Grumman and Norden were developing a radar-based All Weather Stand-off Attack Control System (AWSACS), incorporating a high-resolution, image-forming radar and high-speed digital radar signal processing to identify and track fixed and moving targets. The AWSACS radars were intended to provide midcourse and

terminal homing to a variety of missiles by means of transponder/command decoder; Harpoon and MRASM had been specifically mentioned in this context. The radar itself was a sophisticated synthetic aperture type which used velocity (doppler) data to achieve higher resolution; it had a 3ft dish, but the signal processing increased its virtual size by a factor of a hundred. Consequently, it would be able to provide detailed missile guidance information, even at considerable standoff range. AWSACS was originally a Grumman initiative, but was later supported by the Navy. It was, however, extremely expensive, and was canceled in 1982 as not affordable. In its place the Navy hoped to achieve 90 percent of AWSACS performance using F-18 radar techniques, presumably principally doppler beam-forming.

The LTV A-7 Corsair II

The LTV A-7E is typical of modern light day attack practice, and its weapon system indicates the extent to which computers already dominate attack performance. LTV claims that the head-up display and computer give the A-7E a level bombing laydown accuracy of 125-200ft (CEP), a dive-toss delivery accuracy between 8.1 and 9.6mils, and a strafing accuracy (20mm cannon and 2.75in rockets) of 8.2-9.5mils. Again, according to LTV, the typical performance of earlier systems was 15mils; the A-7E requires only half as many sorties to kill a medium target, such as a truck, as the 15mil system, and accordingly should suffer much lower attrition in combat. Even these figures are considerably less impressive than claims for precision-guided bombs, but the A-7E system is likely to be much more difficult to countermeasure successfully.

Like the A-6E, the A-7E incorporates a combination of doppler radar (to determine true airspeed and ground drift) and an inertial navigation system, as in the A-6. It also has a forward-looking radar (APQ-126) to obtain target range as a weapon system input, as well as high- or low-altitude ground mapping for target acquisition and navigation, low-altitude terrain-following (to minimize exposure to enemy fire), and low-altitude terrain clearance. Two cross-scan modes allow either simultaneous terrain-following and terrain avoidance or terrain-following and low-altitude mapping. In addition, the radar display can be used as the television display for a Walleye, as a Shrike (ARM) Integrated Display System (SIDS), or with a beacon for air-to-air rendezvous, as in aerial refueling.

Since there is only one crewman, information must be presented compactly and conveniently. Most of it is shown in a head-up display (HUD) in front of the pilot; LTV claims that 'flight information as presented in symbolic form and accuracy of the weapon delivery modes provided by the HUD are major factors in the operational effectiveness of the NAV/WD (Navigation/Weapon Delivery) system'. Finally, there is a projected map-display using aeronautical charts reduced to 35mm film, to assist the pilot in recognizing targets and in orienting himself with respect to

*These notes are taken from a July 1978 A-6E/A-6E TRAM/KA-6D flight manual.

the radar ground-map. As in the A-6, considerable attention is paid to backup modes of operation. For example, there are four navigation modes: doppler-inertial gyrocompass (DIG); doppler-inertial (DI); inertial; and doppler/air mass, with a progression from preferable to worst (but least dependent on aircraft internal avionics). Air mass data includes inputs from pressure and temperature indicators and a true airspeed indicator dependent on airflow past the aircraft. If it fails, the airplane can navigate on the basis of doppler and magnetic compass; if the doppler radar fails, it can operate on true airspeed, magnetic heading, and the last computed wind from storage. To a considerable extent the airplane is constantly evaluating the reliability of each system, choosing a backup mode by itself.

The weapon system is based on a digital computer (ASN-91) which can provide five computed attack modes: normal, normal offset, navigation-bombing, radar, and radar offset. Typically the pilot identifies his target, aims (overlying the target with the reticle of the HUD), designates the target (*ie* enters target location into the computer), and then follows HUD steering and solution cues (which are projected in space in the pilot's field of view) until bombs are automatically released. Except for the required steering in azimuth (heading),

the pilot can dive or climb, the system allowing for level, glide, toss, loft, and over-the-shoulder attacks; he can even change from one tactic to another during an attack without having to change switches. That is, the airplane itself can sense the flight path and compute an appropriate release point on the basis of a precise target location entered from the HUD reticle (which is aimed either by slewing or by steering the airplane) and from the forward-looking (ranging) radar; in some modern attack aircraft the radar ranging function is taken over by a laser, which, due to its narrower beam, can avoid the ambiguity of a radar. Offset modes are similar to the normal mode described, except that a prominent landmark is chosen as an aiming point and the range and bearing from that landmark (or 'initial point', IP) to the target fed into the computer. Navigation bombing is totally blind, the navigational system flying the airplane to preselected coordinates for release. In all modes, the computer compensates for wind. The symbols projected on the HUD are the same for all modes, although when rockets and guns are fired, the aiming reticle indicates the projected impact point. As in navigation, there is automatic reversion to backup modes when the system senses the failure of any of its components.

The HUD display itself shows everything the pilot needs to complete his run. For example, in normal mode the pilot can slew the reticle onto the target. His computer generates a bomb impact line and a projected flight line; the pilot then turns his airplane to put the flight path marker over the bomb fall line at the target. The bomb is automatically released when the 'solution cue' moves down to intersect the flight path marker (if the pilot is holding down the release-enable button on his stick) and a pullup anticipation cue moves up the bomb fall line. When it intersects with the flight path marker, pullup lights flash to tell the pilot to pull up (at 4g) to clear bomb blast or terrain. In a pure radar bombing mode the symbology matches that in visual bombing, but the pilot uses his radar display to identify the target. The aiming reticle on the HUD is slaved to the radar cursor and thus is automatically driven to the target location. When guns or rockets are used, the HUD shows the point of impact, and the pilot merely aims the airplane until the computed point of impact matches the target. In each case, the effect of the HUD is greatly to simplify the pilot's flying task, since he has few or no switches to manipulate, and merely flies the airplane as commanded by the computer-generated display before his eyes.

3. Bombs

Procurement

Although initially the Bureau of Ordnance supplied all Navy bombs, from the middle of World War One onwards it shared that responsibility to some extent with the Army (later, the Air Force). The two services formalized joint requirements through an Army-Navy Standardization Board formed early in 1941; its influence is reflected both in weapon and in electronics (the 'AN' series) designations. Generally, BuOrd-supplied weapons were given mark numbers (such as Mk 82), whereas the Army or Air Force weapons had 'M' numbers (such as M117). In some cases the letters 'AN' were prefixed to an 'M' designation to indicate dual-service use.

World War Two practice was for the Navy to develop all armor-piercing and depth bombs; the Army was responsible for general-purpose, fragmentation, chemical, incendiary, and semi-armor-piercing bombs. However, both before and after the war, the two services shared responsibilities on a more parallel basis. For example, the postwar low-drag bomb program included both Navy (Mks 81, 82, 83 and 84) and Air Force (M117 and M118) types.

Bomb Development through 1941

BuOrd began bomb development even before US entry into World War One. It was concerned with the support of a naval landing force against defending troops, and developed two light antipersonnel weapons. However, by

1916 ASW was clearly a more urgent priority, and the Bureau began work on a dual-action bomb, which would explode either on contact with a submarine or at a preset depth. It was reasoned that submarines could often be seen from aircraft even when submerged; moreover, the depth-charge effect of a bomb would make up for aiming errors in many cases. Two types were in service by September 1917, with a third (larger) one following.

US ASW bomb evolution paralleled that of the British, who began with a 65lb weapon, found it insufficient to damage a submarine, and then escalated to 100, 320 and 520lb bombs. By 1918, their large flying boats, comparable to those in US service, could carry four 230lb or two 520lb bombs. Similarly, the US Navy began with 163lb (117lb of explosives) and 270lb (217lb) bombs, copied the British 230lb weapons, and produced its own 216lb bomb. At the Armistice, a 520lb ASW bomb was under development.

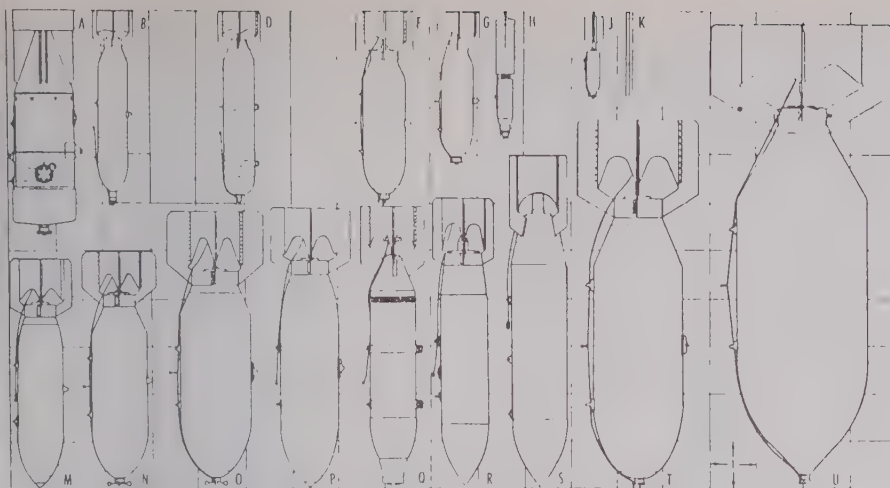
All of the ASW bombs had light cases, *ie* all had maximum explosive content. However, heavy-case bombs were also developed, to attack ships and shore installations. In particular, the Northern Bombing Project required large numbers of such weapons, beyond the Army's capacity to provide. BuOrd designed three types: 112lb (28lb of explosive), 250lb (111) and 550lb (180). The program was canceled at the end of the war, but fifty of each type were cast at the Naval Gun Factory for tests.

Both the Navy and the Marines operated light land-based aircraft, such as the DH4, in France, using Army bombs. Postwar, the Navy retained a range of Army-developed weapons, such as 17lb and 25lb fragmentation bombs, a 50lb demolition bomb, and a 100lb bomb.

In 1931 a BuOrd bomb list included a Navy 30lb fragmentation bomb as its lightest weapon, followed by the Army 50lb demolition weapon, Army and Navy 100-pounders, light-case 500-pounders, and light- and heavy-case 1000-pounders. By 1938 the 50lb demolition bomb had been abandoned, but there was a new heavy-case 500-pounder. Notes appended to the table commented that in general bombs could not be expected to reach their terminal velocities (about 900–1000ft/sec, or 614–682mph), as they would not be dropped from sufficient altitude: typically 19,000ft would be required. It was also considered inadvisable to bomb *below* 3000ft for the high-fragmentation heavy-case 1000lb bomb, or below 1500ft for light-case bombs, due to fragmentation envelopes and blast.

Armor-Piercing Bombs

The range of bombs developed prewar remained in service through the war, but there were also new categories. Even before the outbreak of war, existing armor-piercing shells had been adapted as bombs. They were considered unsatisfactory, due to their low explosive content, itself a consequence of the need to



TYPES OF AERIAL BOMBS (WORLD WAR TWO)

Key

- A Depth bomb, 325lb, flat nose
- B Gas bomb, 115lb
- D Chemical bomb, 100lb
- F GP bomb, 250lb
- G GP bomb, 100lb
- H Fragmentation bomb, 23lb
- J Fragmentation bomb, 20lb (for cluster)
- K Incendiary bomb, 4lb
- M SAP bomb, 500lb
- N GP bomb, 500lb
- O GP bomb, 1000lb
- P SAP bomb, 1000lb
- Q AP bomb, 1000lb
- R AP bomb, 1000lb
- S AP bomb, 1600lb
- T GP bomb, 2000lb
- U Light-case bomb, 4000lb

withstand the pressure and shock of firing. The first 1600lb Armor-Piercing Bomb Mark 1 was delivered in May 1942, with a charge of about 14 percent of its total weight. At first there were some difficulties in bomb suspension, because the design of the bomb made welding impossible, but these were overcome. More significantly, aircraft capable of carrying it were relatively scarce, and BuOrd had to develop a smaller AP bomb, Mk 33 (issued in October 1942), capable of defeating 5.8in of Class B (*ie* deck) armor, compared to 7.0in for Mk 1. These performances were generally checked by firing the bombs from guns against armor, at an angle of 30°. BuOrd considered the AP bomb the most effective air weapon against surface ships beside the torpedo. However, although it was stowed aboard all carriers, it never saw extensive use due to the lack of suitable targets.

Depth Bombs

Another major new weapon was the depth bomb. Although there was considerable use of dual-action ASW bombs during World War One, those weapons were abandoned postwar. In 1941, BuOrd had to develop flight adaptors for the existing Mk 6 naval depth charge, but it also pressed the development of a specialized aircraft depth bomb, the 325lb Mk 17, which became available in quantity by April 1942. A second, the 650lb Mk 29, appeared in May. Neither was entirely successful. Each was round-nosed and therefore had a tendency to ricochet, which was cured only by the addition of a flat-nosed attachment. Mk 29 had a weak tail and an unstable underwater trajectory, but its body was combined with a new tail to form Mk 37 (late 1942). Even this weapon was not considered satisfactory, partly because it was so powerful that its explosion sometimes destroyed the airplanes using it; Admiral King ordered its withdrawal. The lighter depth charge was successful; Mk 17 was succeeded by Mk 41, a flat-nosed version of about 350lb; by Mk 44, equivalent to Mk 17 but filled with Torpex rather than TNT; and by Mk 47, in effect a flat-nosed Mk 44. All had nose impact and athwartships hydrostatic (depth) fuzes, the latter a source of considerable trouble. In addition, airships had the Mk 52 7in, 100lb, fast-sinking contact depth bomb.

The wartime series was replaced late in the war by Mk 53 (330lb TNT) and 54 (354lb Torpex or HBX), both of which had nose contact and tail hydrostatic fuzes; Mk 54 remains the standard air-dropped depth charge more

than thirty years later. It has been supplemented but not supplanted by nuclear depth charges such as 'Betty', 'Lulu', and 'Little Lulu'.

Napalm and Antiaircraft Bombs

Napalm was a BuOrd development, differing from conventional incendiary bombs which were intended to start fires, using material in the target to sustain them. A napalm bomb, on the other hand, carries its own fuel. The first naval experiments were made by carrier crews in the Pacific, who secured a gasoline-laden practice bomb to a 100lb GP bomb and dropped the two together; the blast ignited and spread the gasoline. The result proved effective in the Marianas, and BuOrd sought to perfect it. It failed controlled tests at Dahlgren, but napalm, a fuel originally developed for flame throwers, was far more effective. Jettisonable fuel tanks were filled with gelled gasoline and equipped with igniters, capable of spreading flame over 20,000–30,000ft², and particularly effective against bunkers and caves. However, storage and safety in handling were major problems, and in large-scale tests in the spring of 1945 well over a quarter of the bombs were duds; napalm bombs were used in combat only at the end of the war.

The antiaircraft bomb was another BuOrd effort, intended to permit a fighter to fly over a bomber formation and attack it from above. The Mk 34 AA Bomb contained 2lb of TNT, enough to blow a 5–6ft hole in a bomber wing or fuselage. It was small enough to be carried in quantity, and the BuOrd bomb container dispersed twenty at a time to create a 150yd × 50yd lethal pattern. In practice the AA bomb was seldom if ever used as intended in combat, although it did prove useful as a supplement to strafing runs against troops and aircraft on the ground. AA Bomb Mark 32 was a lighter equivalent.

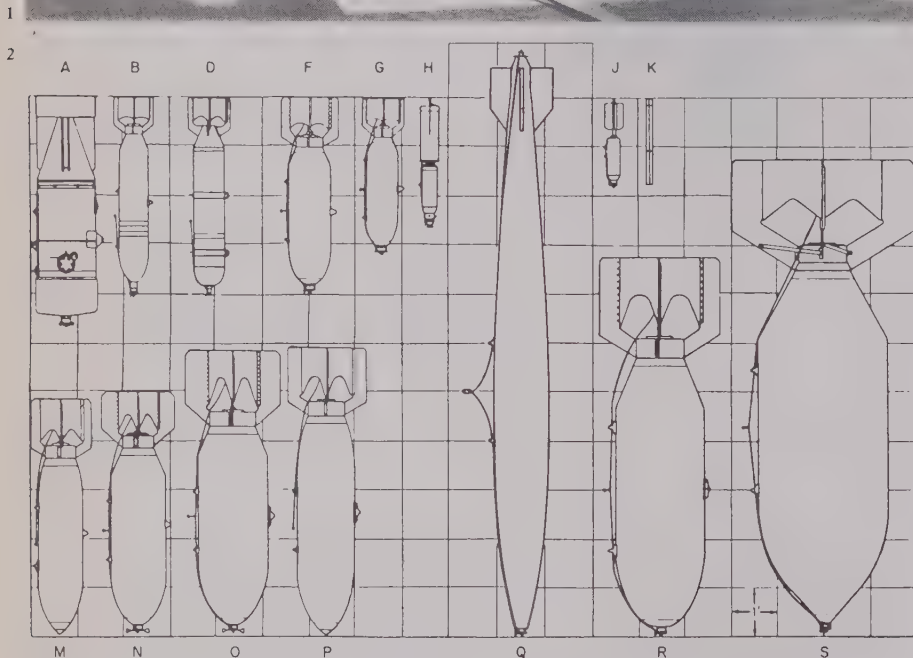
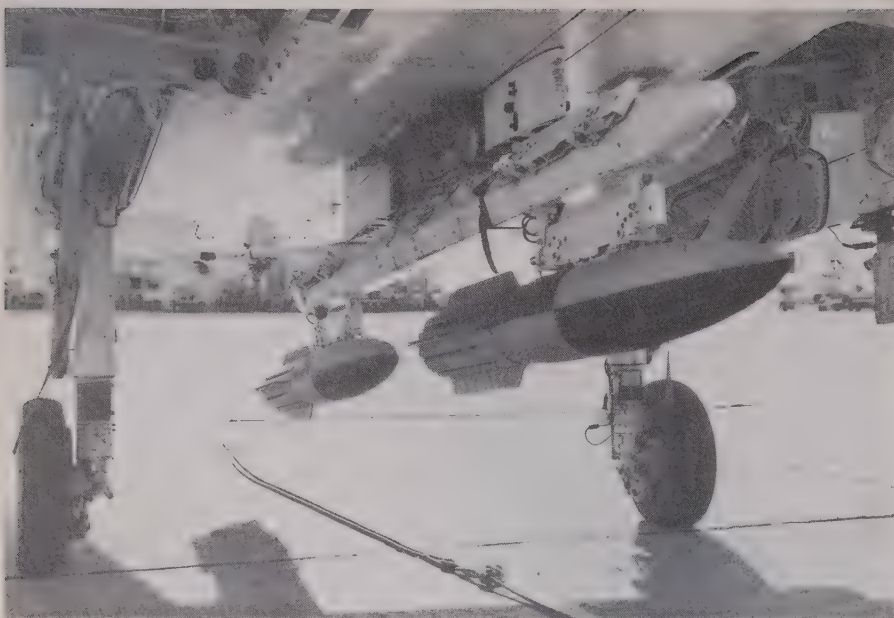
Other World War Two Developments

Late in 1943 BuOrd began the development of a range of bomb clusters, forerunners of an important class of modern freefall weapons. The program had high priority because existing Army clusters were not considered safe for catapult launching. Even so, it embraced non-airborne weapons: Bomb Cluster Mark 1 was six Hedgehog warheads banded together for launch from a K-gun. On the other hand, Cluster Adapter Mark 3 carried three bombs (100lb GP or incendiary, 90lb fragmentation

and 220 or 260lb fragmentation) and Cluster Adapter Mark 4 carried two of the same type of bombs. Cluster Adapter Mark 7, which was the size of a 250lb bomb, carried eight 20lb fragmentation bombs, using a spring to disperse them. Mk 8 carried this idea even further, consisting of a cylindrical shell with a four-vane tail, split along its length and hinged at the after end. When its fuze operated, it dispersed ninety M83 'Butterfly' fragmentation bombs assembled in nine wafers, ten bombs to a wafer. All of the cluster bombs dispersed their contents after release from an airplane. However, weapons could also be dispersed from a container which remained fixed to the airplane.

Only the 100lb incendiary and fragmentation cluster bombs were extensively used, as they came assembled. They were, however, criticized as too small; the 500lb size required shipboard assembly and so could not be used in great numbers. The 1945 Pacific Fleet Ordnance report called for 100, 500 and 1000lb clusters, prepackaged, with incendiary, fragmentation, 'Butterfly' fragmentation or special airfield neutralization loads.

The Army produced a wide variety of bombs in several series. M30 through M34 were demolition or general-purpose bombs of 100, 300, 600, 1100, and 2000lb, of which the Navy used only M30 and M34. A subsequent M40 series embraced M43 (500lb) and M44 (1000lb) as well as fragmentation bombs (23lb M40 and 20lb M41); M47 was an incendiary smoke bomb (100lb). All three were used by the Navy. The M50 series included a 1000lb AP bomb, M52, converted from an artillery shell; the 4000lb M56, the 250lb M57 GP bomb, and the 500 and 1000lb semi-armor-piercing M58 and M59. M60, M61, M62 and M63 were all armor-piercing bombs converted from artillery shells, and all were made obsolete by the advent of AP Bomb Mark 1 and Bomb Mark 33. M64, M65 and M66, which were carried on the Navy bomb inventory, were improved versions of M43, M44 and M34 to permit fuzing as depth bombs for ASW; it is not clear to what extent they were used as such by the Navy. M72 was a revision of M40 permitting carriage in individual racks; chemical bombs included M70 (115lb), M78 (500lb) and M79 (1000lb), the latter also serving as an incendiary, and adopted by both services. The M80 series consisted of fragment weapons: M81 (260lb), M82 (90lb), M83 (4lb 'Butterfly', copied from a German weapon first en-



1 Low-drag shapes were applied to bombs primarily to permit their carriage at very high speed. However, airplanes trying to drop them at very low altitude (eg to avoid missile fire) would be damaged or destroyed by their blast, as the bombs would continue just below the airplane dropping them. The answer appeared to be spring-loaded fins, which could rapidly convert a low-drag weapon on a bomb rack into a very high-drag bomb in flight: Snakeye is shown here ready for a test in February 1963, beneath a Skyhawk. Ironically, experience in Vietnam showed that low-altitude delivery might itself be hazardous, given the density of small-arms fire. More recently, Snakeye has been criticized as somewhat unreliable, and a successor is being developed – the Goodyear balloon-chute or ‘ballute’.

2 TYPES OF AERIAL BOMBS (POSTWAR)

Key

- A Depth bomb, 325lb, flat nose
- B Gas bomb, 115lb
- D Chemical bomb, 100lb
- F GP bomb, 250lb
- G GP bomb, 100lb
- H Fragmentation bomb, 23lb
- J Fragmentation bomb, 20lb (for cluster)
- K Incendiary bomb, 4lb
- M SAP bomb, 500lb
- N GP bomb, 500lb
- O GP bomb, 1000lb
- P SAP bomb, 1000lb
- Q Low-drag (GP) bomb, 1000lb
- R GP bomb, 2000lb
- S Light-case bomb, 4000lb

countered in numbers in North Africa), M86 (para-frag bomb, M82 plus a parachute), and M88 (260lb); M81 and M88 were specifically designed for dual-service use.

At the end of the war there was great interest in the use of VT-fuzed fragmentation bombs as a means of suppressing target AA fire, as well as against small craft. There was also a water-discriminating fuze (Mk 224), which would keep the bomb from exploding when it struck the water, so that it could follow an underwater trajectory and burst against a ship. It was not used in combat.

Streamlining and Retarded Bombs

Early postwar Navy bomb development was limited to low-drag (streamlined) bombs. They reportedly originated with a Douglas proposal (about 1946) to the Bureau of Aeronautics to revise the existing series of Navy bombs. BuAer wanted the results suitable for supersonic flight, with fineness (length to diameter) ratios of about 12, but such bombs would have been too long to fit existing aircraft. Douglas chose an Aero IA shape with an aspect ratio of 8.3, applying it to the 250lb (Mk 81), 500lb (Mk 82), 1000lb (Mk 83) and 2000lb (Mk 84) bombs, as well as to 150, 300 and 450-gallon fuel tanks. For its part the Air Force modified the existing 750lb bomb by applying a new streamlined tail, to produce the M117 Demolition Bomb (Mk 80 series weapons were described as ‘general-purpose’); it also produced a 3000lb M118. The Mk 80s had much thicker walls than did the Air Force bombs, and so produced their effects more by fragmentation than by blast. Although at least some were carried on the Navy inventory, it appears that the Navy did not use the M117 or M118 in combat in Vietnam.

In the late 1950s, perhaps as part of the general Navy shift towards limited war, the Naval Weapons Center (China Lake) began the development of a wide range of unguided non-nuclear weapons, most of which received ‘eye’ series code names. Snakeye was a fin retarder for Mk 81 and 82 bombs, permitting them to be carried at high speed, then dropped at very low altitude without destroying the bomber. It consumed a large fraction of the total program budget. However, even now it is somewhat unreliable, and Goodyear has proposed a new retarder program using its ‘ballute’ (balloon-parachute). Thus peacetime training, even with Snakeye, is often still conducted using the old 20° or 30° dive tactics, which do not endanger the bomber.

Ninety percent of the Navy bombs dropped in Vietnam were Mk 82, with Mk 83 accounting for most of the remainder. Bomb development did not quite cease during and after the Vietnam War, the major improvement being thermal protection against carrier fires. A non-coated Mk 82 would generally explode in about four minutes during a fuel fire; a coated Mk 82 would last at least nine minutes, and then burn instead of exploding. For the longer term, an Advanced General Purpose Bomb (AGPB) program was begun, seeking improved handling and storage capabilities, in light, medium, and heavy (approximately 500, 1000 and 2000lb) sizes: Vietnam showed the futility of the 250pdr. The light AGPB was to be a blast-fragmentation type for close air support, attacking troops, vehicles, supply dumps, light structures, hastily prepared bunkers and SAM sites, and fuzed for either instantaneous or

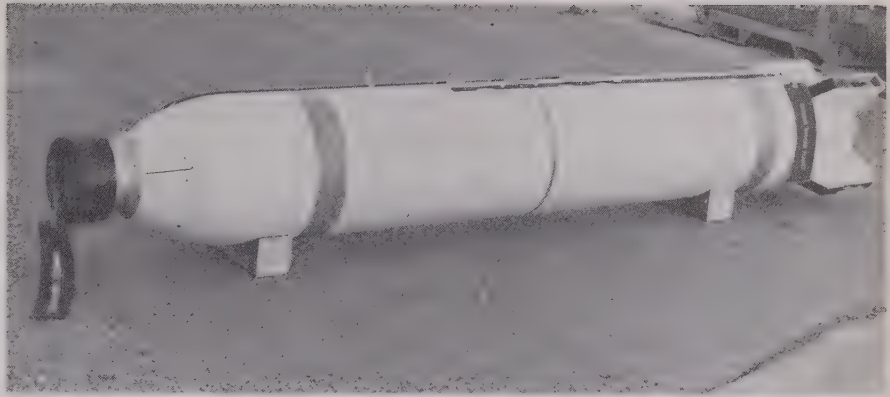
delayed explosion or for an air burst. The medium AGPB would be capable of moderate penetration, with either an instantaneous or a delayed fuze, and it would attack fortifications, buried ammunition dumps, or other moderately hard targets. Finally, the heavy AGPB would be a demolition weapon attacking bridges, roads and deep tunnels. The AGPB program continues in 1983 at a relatively low level of funding, partly because many of the Mk 80 series bombs survive, but also partly because of a widespread belief that guided bombs are the weapons of the future, particularly on the part of the Air Force.

The Air Force is buying very large quantities of Laser Guided Bomb (LGB) kits to retrofit older 'iron bombs' as PGMs, and has several very ambitious new PGM concepts in development. The Navy, with its Marine close support mission, tends to be more impressed by the need for area attack against ill-defined targets such as troops.

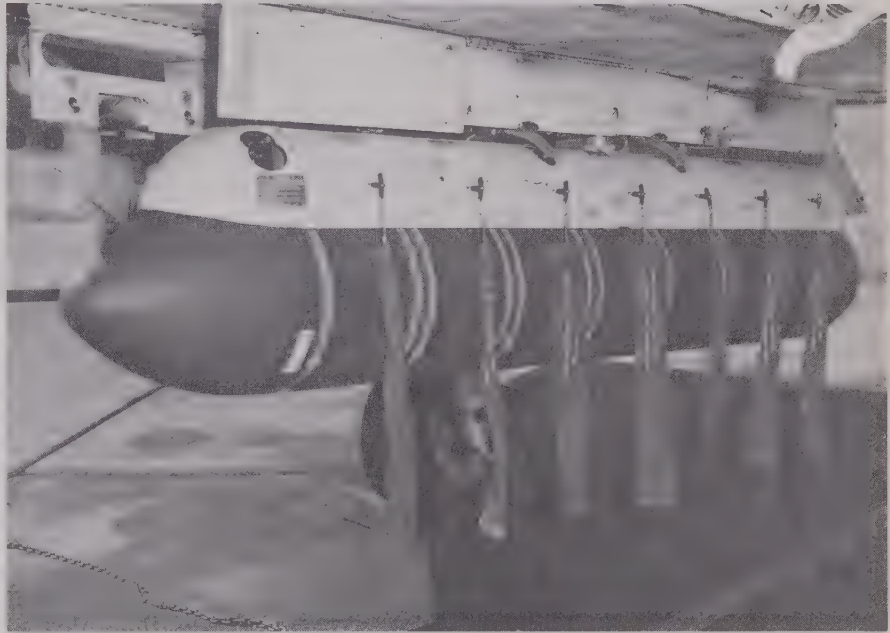
Cluster Bombs

Cluster bombs were particularly useful, because they enabled an airplane to make multiple kills of 'soft' targets on a single pass through what might be intense groundfire. Their development lapsed for the first postwar decade, but in 1956 the designation 'Mark 11' was applied to a 1720lb cluster of fifty-six 20lb M41A1 fragment bombs. Mk 12 (Rockeye I) was an antiarmor weapon carrying 96 bomblets in a 750lb case. It was not produced, but in 1963 development of Rockeye II (Mk 20) began. It entered production in 1967 and service in 1968, carrying 247 Mk 118 bomblets, each capable of penetrating tank armor using a shaped charge. In 1974 production of an improved version, APAM (Anti-Personnel/Anti-Materiel), began, the Rockeye dispenser carrying 717 target-discriminating bomblets: as each hits, the type of surface determines its reaction. Hard targets are blasted by instantaneously fuzed shaped charges, but a soft target activates a small rocket motor which tosses the bomblet into the air, where it bursts for fragmentation effect.

Cluster Bomb Mark 15 (Sadeye) employed a Universal Weapons Dispenser carrying 2100 bomblets, which could be dropped at high speed at moderately low altitude, set to burst well away from the bomber. Mk 17 (Gladeye) employed two separate time-delay cartridges in a canister, which would itself be carried on a standard strongback slung from a bomb rack. The strongback (dispenser) carried seven Gladeyes, each of them filled with 330 anti-personnel bombs (M40). Finally there was Padeye, Mk 23, carrying fifteen gas bomblets (BZ).



1



2



3

1 China Lake developed a variety of advanced unguided weapons during the late 1950s and early 1960s: this is Rockeye, a 500lb cluster weapon carrying 247 antitank bomblets. Note the Sidewinder-type 'rollerons' (air-driven gyros) in its tailfins, for stabilization.

2 Gladeye was a cylindrical canister containing 330 M40 antipersonnel bomblets with two separate time-delay cartridges; seven could be assembled, as shown, on a standard strongback slung from an aircraft bomb rack. This one was photographed at China Lake in October 1964.

3 Fuel-air explosives (FAE) have been a subject of interest to China Lake at least since 1966. They release a cloud of fuel, which vaporizes and is then exploded by bursters fired into it at the appropriate moment, to create a shock wave reminiscent of that of a small nuclear weapon, though of

course less intense and not nearly as sustained. FAE I (500lb) and FAE II (2000lb, also known as BLU-96/B) are shown under the wing of an A-7 at China Lake, July 1978. Reportedly Navy 500lb FAE weapons were employed in Vietnam from October 1970 onwards.

Fuel-Air Explosives

All of these weapons followed principles laid down in World War Two. Fuel-air explosives were something new. The typical weapon disperses a cloud of fuel, which forms an explosive vapor. When it reaches the appropriate density, detonators are ejected into it and fired, creating a shock wave reminiscent of that of a nuclear weapon. Weight for weight, fuel-air explosives are said to have about 2.7–5 times the destructive power of TNT per unit area, partly because they generally do not have to carry their own oxygen. Projected applications

include minefield clearance and attacks on bunkers and foxholes; there is some question of the efficacy of such weapons against targets that require precise placement of the explosive event or that are comparatively 'hard' (eg bunkers and aircraft shelters). China Lake exploded its first FAE charge as early as 1960, and the same organization began a formal Navy program in 1966. The Navy used a CBU-55B FAE cluster bomb in Vietnam, primarily for defoliation and mine clearance; each carries three 100lb canisters, which separate upon release and are lowered from parachutes. CBU-

72 was a CBU-55B modified for delivery by high-speed jets such as the A-4 and A-7, still using drogue chutes.

The other major recent naval bomb projects are also area weapons: Fireye, an incendiary, replacing the earlier Mk 79; Weteye, a chemical bomb, replacing the earlier Mk 94; and Deneye, a land mine (in alternative antivehicle and antipersonnel versions), which latter was not developed. Briteye was an improved parachute flare.

4. Rockets

Retrobombs

Rockets, both air and surface-launched, were a major armament innovation of World War Two. As in the case of self-propelled missiles, they promised great effectiveness per round on the basis of relatively few rounds, since most of the bulk of the weapon system was concentrated in its expendable portion. For an airplane, this proportion was ideal: a fighter, for example, could fire the equivalent of a destroyer salvo, although she could not repeat that feat without landing to reload. The overriding advantage of the rocket was its lack of recoil: it required no gun, and no heavy structure to absorb recoil energy. Accuracy, on the other hand, was generally less than that of a gun, although an aircraft rocket, benefiting from the additional speed imparted by the airplane, might approach gun accuracy. The US World War Two rocket program began with a series of proposals by Dr C N Hickman of Bell Laboratories to Dr F B Jewett, President of the National Academy of Sciences and a member of the NDRC, in June 1940. BuOrd requested a rocket-accelerated armor-piercing bomb for use by dive-bombers, which order started an NDRC Section. It flew its first test shot in September 1940. The greatest part of the work was done at CalTech.

The first US operational airborne rocket weapon was the retrobomb, conceived in 1942 as a complement to the existing MAD submarine detector. MAD had only a very short range, and so could detect a submarine only as the airplane carrying it flew directly overhead – from which position a depth charge would land many yards ahead of the submarine. A rocket, however, could cancel out the forward velocity of the airplane and land the bomb directly above its target. The retrobomb rocket was developed from Mousetrap, with the motor changed to increase velocity; first tests were carried out in May 1942, using a light wooden frame to simulate an airplane wing. Flight tests from a PBY-5A at the Mojave Anti-Aircraft Range (3 July 1942) showed 1.3 hits out of 10 rounds fired, on a submarine with dimensions of 300ft × 25ft. A complete launcher rail assembly, similar to that for the ship-launched Mousetrap, was assembled for the PBY, consisting of 24 rails fired in groups of eight to lay down a pattern 140ft in spread and 40ft in depth.

Several retrobombs were shipped for service tests in December 1942, and the next month three new motors were designed to permit alternative firing speeds: 205 (7V6), 200 (7V7), and 400 (7V8) miles per hour. In each case, the first digit was the rocket diameter, the 'V' signified 'vertical,' and the second digit was a modification number. A later series of retro-rockets, loaded with higher-density Torpex rather than TNT, was designated 7V11 through 7V13, and was standardized in May 1943. That summer two squadrons, VP-63 and VP-91, operated in the Atlantic with the retrobomb, claiming several kills until the Germans changed tactics and began to fight aircraft on the surface. Since retrobomb attacks required an airplane to fly at no more than 100–300ft over a submarine, the weapon was abandoned.

The Forward-Firing Aircraft Rocket

By that time interest had shifted to forward-firing aircraft rockets, still for ASW. Compared to ASW bombs, they sharply reduced the warning time a submarine enjoyed between the approach of an airplane and its attack, and were first used by the British, who employed a 3in fin-stabilized rocket with a solid steel head, to penetrate submarine pressure hulls. The British weapon entered service late in 1942, and early in June 1943 Admiral King asked BuOrd and BuAer to arrange for a corresponding NDRC project at high priority.

The rocket motor for the ASW rocket originated with another program, a CalTech anti-aircraft rocket. Although it had been relegated to low priority by 1943, work proceeded, and that spring a 3.25in rocket motor was test-fired. Just as the first field tests of an effective motor were conducted (15 May 1943) the Bureau of Ordnance requested the development of a long range (10,000yd) shore bombardment rocket, specifying a 3.25in motor and the solventless extruded ballistic CalTech was already developing; this weapon, with a 13lb smoke head, was soon under test. However, its performance closely matched that of the British air-launched ASW rocket. Thus work on a US equivalent was rapid, even before the official NDRC assignment (19 June 1943); indeed, rockets were fired from TBF (Avenger) wing sections the previous day, showing excessive damage to launch rails secured underwing. A rocket was, however, successfully air-fired late

in August; earlier that month the Bureau of Ordnance ordered production of 10,000 rounds per month for four to six months for service tests. A few days later CalTech was asked to provide 200 sets of launchers for Avengers, which would fly from escort carriers.

The rocket itself had a 3.5in solid steel head weighing 20lb, powered by a 3.5in motor; total weight was about 55lb, and total length about 55in. With a velocity of 1175ft/sec, it could penetrate the pressure hull of a submarine even after 50ft of travel through the water; later this figure was extended to 130ft. Although a rocket hit was not always fatal, it could generally damage a submarine sufficiently to keep it on the surface, vulnerable to follow-up attacks. The first US rocket attack was by aircraft from the carrier *Block Island*, January 11 1944; however, it was difficult to say whether rockets or depth charges were responsible for the sinking.

The first aircraft rocket launcher was a slotted rail similar to that used by the British, but built of dural to cut weight; four were mounted under each wing, and rockets could be fired singly, in pairs, or in salvo. The drag of these 72in rails cut an Avenger's speed by 17kts, and such a launcher was, therefore, unacceptable for use by fighter planes. It was found that accuracy did not suffer if the rails were cut down, and in the late spring of 1944 the 'zero-length' launcher replaced the rails consisting merely of a pair of posts attached to the wings; drag was reduced to 6–9kts. It was accepted as standard for all carrier-based aircraft in October 1944.

The 3.5in rocket was accurate enough to suggest use against ship and land targets, given an explosive warhead; however, it was too small to be useful. The 5in anti-aircraft shell was therefore modified for rocket propulsion, using the original 3.5in motor. Total weight increased to about 80lb and velocity fell to 710ft/sec. Development was straightforward, with firing tests in September 1943 and service use by the end of the year.

The High-Velocity Aircraft Rocket (HVAR)

Given recognition that rockets could be useful for purposes other than ASW, the next logical step was to regain the velocity of the original

3.5in weapon by means of a new motor; the first of these 5in motor rockets was test-fired in mid-December 1943. It was by far the most powerful rocket yet developed in the United States, and required some innovation in its design to deal with the very high internal temperatures involved, which might have caused motor blowout. Officially described as the 5in High-Velocity Aircraft Rocket (HVAR), it was named 'Holy Moses' during its first tests. It weighed 140lb, was 72in long, and attained 1375ft/sec.

Two major models were produced in World War Two, one with base and nose fuzes, the other with a base fuze only and a semi-armor-piercing head. Production and use continued postwar, and US ASW aircraft still carry an armor-piercing variant of the HVAR underwing. The other major postwar versions were a shaped-charge antitank rocket (HEAT) and a general-purpose type which could be fitted with a proximity fuze.

HVAR was shipped to Europe for its first combat; intended for use against German V-bomb sites, it was employed instead in the breakout at St Lo. Army experience was sufficiently encouraging that by the spring of 1945 Army fighters were being manufactured with HVAR launching posts. In principle the HVAR made the 5in rocket (with a 3.5in motor) obsolete, but the latter continued to be used in quantity in the Pacific until the end of the war because the HVAR was not available in sufficient quantity until the spring of 1945. The 5in rocket was first used by a Marine squadron, VMTB-134, in a strike on Rabaul, and through 1944 and 1945 was considered particularly effective against point targets, such as antiaircraft emplacements, ammunition dumps, oil storage, aircraft on the ground, small buildings, and ships. Rockets also sank one Japanese destroyer. They were particularly effective in ground support at Iwo Jima and Okinawa, against Japanese cave defenses.

'Tiny Tim'

In March 1944 CalTech showed theoretically that a major-caliber anti-shiping rocket could be fired from an aircraft. It was needed because existing airplanes were too fast to drop torpedoes, while skip-bombing exposed them to antiaircraft fire during a long run directly over the target. A rocket could be fired after a short run from 2000yds. The CNO, Admiral King, ordered such a development at the highest priority 'since the main strength and offensive striking power of naval aviation lies in the carrier based aircraft squadrons...'. The new weapon would be limited to 1000lb since existing carrier fighters had 1000-pound bomb racks; a diameter of 11.75in was selected so that commercially available steel tubing (oil well casing) might be used for the motor. It was also the diameter of a standard 500lb SAP bomb, which was selected as the warhead. CalTech already had a preliminary design ready, and was able to fire one from a ground launcher on 25 April 1944.

The chief problem in aircraft use was protection of the airplane from the blast of the heavy rocket motor. Initial tests showed that the rocket had to be at least 4ft from the airplane before it could safely be fired. In addition, if it were carried under the body of a fighter, it would have to be brought outside the propeller arc. A dive-bomber type displacement gear was

designed and built, but it was far too heavy and created too much drag. On the other hand, attempts to fire the heavy rocket directly from an airplane wing badly damaged one Helldiver. The solution ultimately adopted was to drop the rocket freely, letting it unreel a lanyard which would fire its motor when the rocket dropped far enough.

Development was fast, but not as fast as for some of the other rockets. On 28 June 1944, for example, it was put on an emergency basis as a counter to German V-weapon sites, and production of motors actually began before a launcher had been perfected. Several were fired from aircraft, generally with some damage to their carriers, and on 20 July the program was reduced from emergency status to high priority. Beside the SAP bomb warhead, an attempt was made to develop a specialized antishipping warhead which would travel a long, shallow, underwater trajectory; it would employ the water-discriminating fuze. This particular effort, somewhat similar to a British project called 'Long Tom', was pursued postwar, studies of warship vulnerability to such underwater hits being made as late as 1950.

By October 1944 the rocket, now called 'Tiny Tim', had been fired from Hellcats, Helldivers and Avengers; pilot-training followed in November and December. Tests showed that it could penetrate 3-4ft of reinforced concrete, and that its dispersion, only 5mils, made it

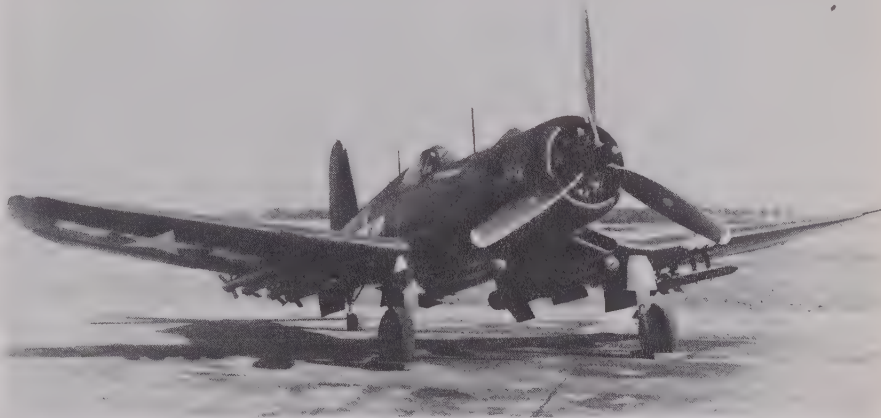
accurate to about 4000yds. At a weight of 1280lb, above that originally specified, and a length of 123in, somewhat longer than was convenient for carrier-handling, it achieved a velocity 810ft/sec above that of the launching airplane. A new version, shorter (by 10.6in) and lighter, was developed but not placed in production, in view of the urgency of bringing 'Tiny Tim' into service.

Even so, it almost missed the war. The carriers *Franklin* and *Intrepid* carried service test weapons to the Pacific, but the former was hit by a kamikaze before her rockets could be used in combat. Their sheer explosive bulk contributed to the subsequent damage. *Intrepid's* rockets were reportedly used at Okinawa, but results were not published.

As in the case of conventional bombs, conventional rocket development languished after 1945. China Lake became the primary rocket laboratory, developing an antitank

1 This F4U-1C Corsair illustrates the comparative sizes of 'Tiny Tim' and 5in air-launched rockets (Patuxent River, 31 January 1945). The muzzles of the six 0.50-caliber wing guns are covered by tape, which the bullets will pierce if the guns are fired in flight.

2 A Skyhawk fires 2.75in folding-fin aircraft rockets (FFAR) from an LAU-60/A pod; note the fins deploying as the rockets emerge.



rocket, essentially an enlarged HVAR, in only 23 days in 1950 in response to Korean War requirements. This 6.5in ATAR ('Ram') had a shaped-charge warhead large enough to penetrate 17in of Class A armor. It was withdrawn from service at the end of the war, presumably in favor of a HEAT version of the existing HVAR.

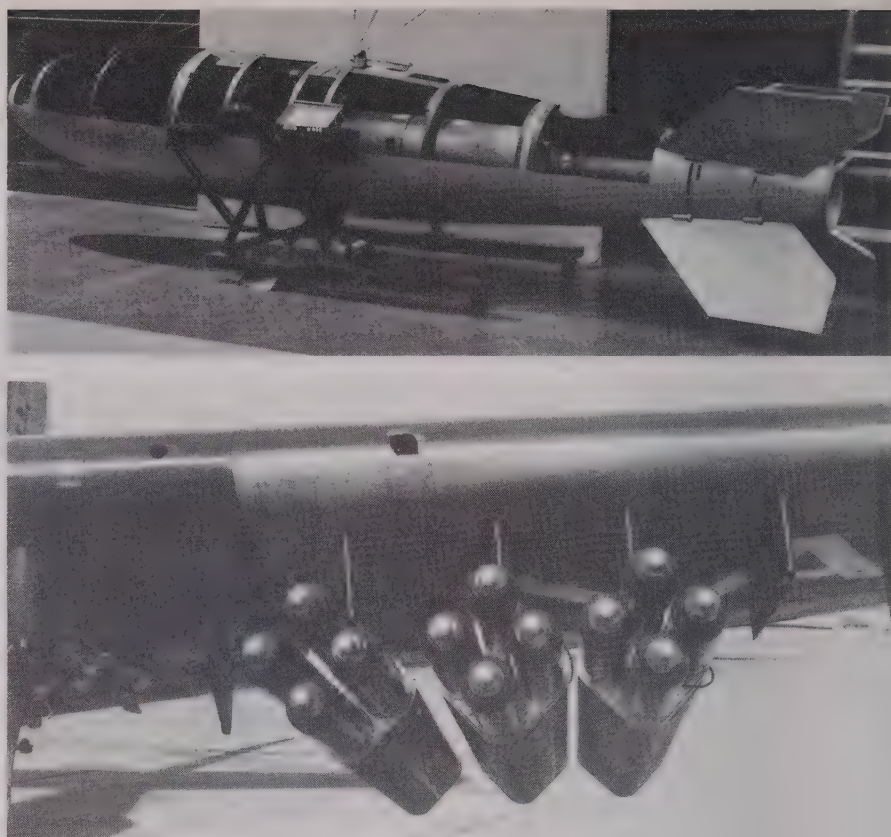
The Folding-Fin Aircraft Rocket (FFAR)

About 1950 China Lake produced the 2.75in FFAR (Folding-Fin Aircraft Rocket) primarily as an air-to-air weapon against large bombers: it appeared that a salvo of FFAR would be far more effective against a very large airplane than a stream of cannon shells. The 2.75in 'Mighty Mouse' was the sole armament of the Air Force F-86D interceptor; aboard Navy aircraft it was generally carried in expendable 7-rocket (Aero 6) or 19-rocket (Aero 7) launchers. The rocket weighed about 18lb, and its 800-900lb thrust engine accelerated it to 2300ft/sec (1570mph). Its destructive potential was originally compared to that of a 75mm shell. Although Mighty Mouse began as an air-to-air weapon, it has often been used for ground attack and so deserves a place among air-to-surface weapons. Warhead options are blast (HBX or Composition B) and armor-piercing (HEAT); one variant, Mk 13, was designed to spin slowly to reduce dispersion when launched by a slow-flying helicopter. Rocket length is 47.85in.

The next China Lake rocket development was BOAR (BuOrd Aircraft Rocket), which carried a Mk 7 nuclear weapon clear of a Skyraider attack bomber, saving the latter from self-destruction. Conceived as an interim weapon with a service lifetime of three years, it served instead from 1956 through 1963, after service tests in 1955. Burning for 3 seconds (15,000lb thrust), its motor accelerated the 2070lb BOAR (30.5in in diameter, 189in in length) to about Mach 1.

Zuni

HVAR production terminated in 1955, and in 1957 a new ground attack rocket, Zuni, was approved for service. Like the HVAR, it was 5in in diameter (110in long, 107lb, 2370ft/sec, ie about 1400kts); it was carried in two- or four-rocket reusable streamlined pods. Zuni was



designed for both air-to-air and air-to-ground use, and had two alternative warheads, general-purpose and shaped-charge; point detonation and proximity fuzes could be used, against targets ranging from pillboxes to aircraft. For example, fitted with a nose plug, the GP warhead was capable of delayed action. For air-to-air fire, the standard Zuni proximity fuze functioned at 40ft, at which distance the shaped-charge warhead was lethal.

Twenty-five years later, Zuni and Mighty Mouse continue as the standard Navy unguided aircraft rockets; no successors have been announced. Suggestions for modifications to exploit the reliability of this simple (if only modestly effective) weapon continue.

1 A sectioned BOAR free rocket on display at the National Atomic Museum, Albuquerque, 1980. BOAR was developed to permit slow attack aircraft, particularly the Skyraider, to deliver nuclear weapons at low altitude without destroying themselves with the resulting blast. The bomb itself filled the (now empty) nose cavity, and the large solid-fuel rocket motor is visible.

2 Quadruple Zuni (5in folding-fin) pods under the wing of a Skyraider, probably in the late 1950s.

5. Air-to-surface guided missiles

GLOMB

As in the surface-to-surface case, air-to-surface missiles had a somewhat uncertain career. They did have the bureaucratic advantage of operating with existing aircraft and indeed in some cases of enhancing the effectiveness of the primary naval air strike force, the carrier attack bomber. This became particularly important in 1944, when the naval missile program was reviewed from a decidedly carrier-oriented point

of view, and the Assault Drone program (see Part VI) suffered accordingly.

There were two quite separate wartime missile programs, administered by BuAer and by BuOrd; only the latter produced operational systems, some of which survived postwar. For its part, BuAer produced three separate weapons: GLOMB (glider-bomb), Gorgon and Gargoyle. GLOMB was proposed in December 1940 by Captain Fahrney as a means

of augmenting the bomb capacity of a carrier fighter, which he thought might tow a 15,000lb radio/television guided glider (as in the Assault Drone). Design work began at the Naval Aircraft Factory in April 1941, and the concept was tested in a series of converted training and troop gliders: the Taylorcraft LNT-1 (ex-Army TG-6), the Piper LNP (TG-8), the Aeronca LNR (TG-5), and the Waco LRW (CG-4A); the LNT was considered best for

tests. It could carry either a 2000lb bomb or stacked charges equivalent to about 3300lb. An August 1943 proposal called for a 3000lb glider capable of carrying 4000lb of explosives, which would have a 350nm radius of action when towed by a Hellcat. Three LNTs were authorized for destruction in tests, and in September bids from six firms were opened, contracts being negotiated with Piper (LBP) and with Taylor-Read (Gould) (LBE); Taylorcraft produced an LBT equivalent to the LBE. The LBP was to have carried a 4000lb bomb (2000lb in the LBT, canceled in October 1944). By 1944 the low performance inherent in the GLOMB was beginning to tell against the program, and LBE and LBP orders were cut from 100 each to 85 in November, with a further cut to 35 in February 1945. LBP was canceled entirely in June in view of landing difficulties when fully loaded, and LBE was canceled on 14 August 1945 after only four had been delivered. Admiral King wanted the program continued, in view of the success of the Bat radar-homing missile, but his request that three LBEs be converted for radar-homing had not been met by the end of the war. By that time the drag inherent in a GLOMB was clearly beyond that tolerable by the new generation of fast fighters.

Gorgon

Gorgon began as an air-to-air missile (see Part IV) but had considerable air-to-surface potential. Postwar, Gorgon IIC served as a control test vehicle (CTV-N-2), and was tested against ship targets with an active radar seeker; in one such test, in 1950, it homed from 9nm, descending at 5nm and striking the water 2500yds short. Gorgon IV, developed by Martin as an air-to-surface missile, was powered by a Marquardt ramjet slung beneath it. It began in 1945, and by 1949 had resulted in a propulsion test vehicle (PTV-N-2) and a target drone (KDM-1). The latter was renamed Plover, and was also developed as a chemical attack weapon. Gorgon V, in which the ramjet was replaced by an Edo X14A all-purpose aerosol generator, with guidance by programmed autopilot, angle of attack direction detector, and radio altimeter. Two of these 2400lb missiles could be carried by one airplane, dropped at 35,000ft and about Mach 0.95, to dive at 16° for 20nm, flying for another 5–11nm at 100–500ft. The spray run could cover a strip at least 5nm wide; in 1953, Gorgon V (X-ASM-N-5) was expected to become available late in 1955. It does not appear, however, to have entered service.

Gargoyle

Gargoyle was inspired by the success of German guided missiles such as the Hs 293 and the FX-1400 armor-piercing bomb. Lt Cdr Grayson Merrill, Head of the BuAer Special Design Branch, laid out requirements early in October 1943; he wanted a low wing, a butterfly tail, and a JATO rocket to accelerate the bomb and so to assure armor penetration. He envisaged Gargoyle as dropped by a diving bomber. Design Study 265, issued on 20 October, showed a missile carrying a 1600lb armor-piercing bomb, and capable of 585mph in a dive. Like the German weapon, it had a flare in its tail to facilitate radio/visual control. Gargoyle survived a Navy-wide review of missile programs because of its unique armor-piercing capability.

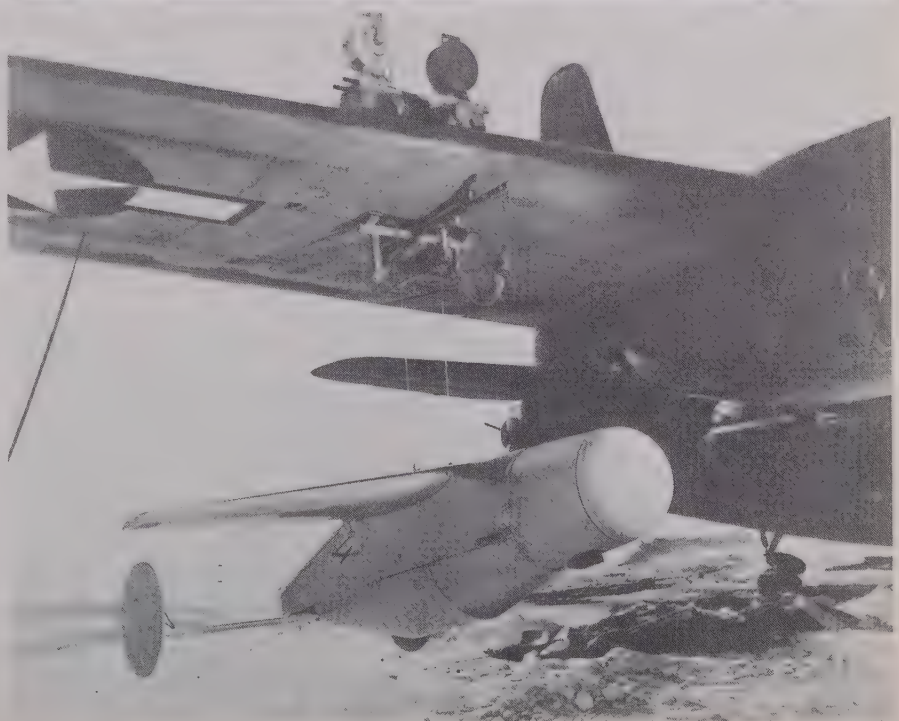
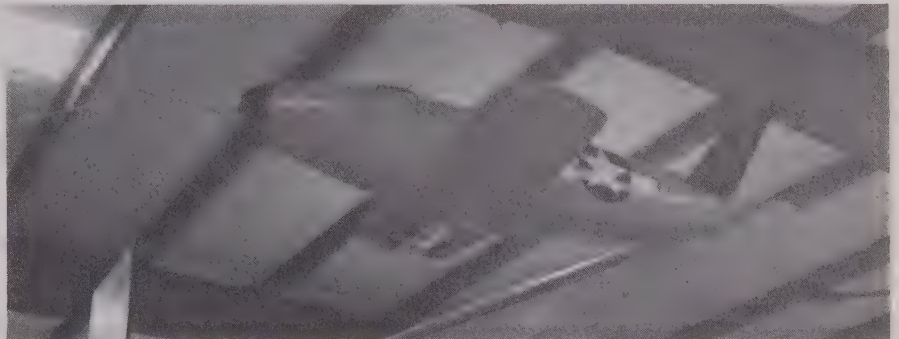
Preliminary design was completed by 1 May 1944; by this time the missile was to carry a 1000lb SAP or GP bomb, and was to incorporate a seeker in its nose. The rocket was to force it out ahead of a diving bomb to permit visual control, as well as to accelerate it for armor penetration. In April the COMINCH staff and the Bureaus of Aeronautics and Ordnance agreed on the basic concept; the seeker, as yet undeveloped, would be added later. The V-tail design simplified missile control, reducing the requirements a carrier airplane would have to meet. Gargoyle would be gyro-stabilized, with ailerons on its wings and 'ruddervators' on its tail. Four hundred were ordered for development and service testing. Gargoyle survived several Navy missile reviews because, unlike the Assault Drone, GLOMB, and parts of the Gorgon program, it was well suited to carrier aircraft, and did not require such massive alterations to its carrier that the latter would lose significant mission capability were the missile to fail. Moreover, by late in the war unguided weapons were proving so successful that only a very high degree of accuracy could justify a guided type.

As submitted to the CNO on 5 May 1944, Gargoyle cost only \$8900, and required only a 35lb radio aboard its airplane; its wing span was only 8ft 6in. It could penetrate any existing

armored deck, and was considered immune to anti-aircraft fire in view of its high diving speed. On 16 June Admiral King approved it as a steep-dive weapon, and McDonnell was selected to manufacture it as the LBD, suitable for all carrier aircraft other than the elderly SBD Dauntless. By this time terminal velocity was estimated at 700mph, and the missile was catapult-capable, an important consideration for its expected use. It just missed combat. The first five were delivered in January 1945, the first glide test (a failure) following on 9 March, and the first success on 21 May. The fourteenth was powered, and loaded to simulate a bomb. Production was authorized in July, but the project was cut back to developmental status

1 Gorgon II, at the Silver Hill facility, National Air and Space Museum, 1979.
Author

2 A Bat missile is shown being winched up onto the wing rack of a PB4Y-2 Privateer patrol bomber, December 1945. Bat was the first US Navy missile to be fired by aircraft in combat, in 1945; postwar it served as an interim weapon until a major ECCM deficiency was found in 1948, when it was retired. Although it was employed only by Privateers in combat, it was carried postwar by carrier aircraft, including at least Helldivers and Avengers.
US Navy, by courtesy of Norman Polmar



after VJ-Day, the first totally successful launch not occurring until 1 July 1946. The first 200 missiles were a 'developmental block', all completed by 16 May 1947, when McDonnell asked for authority to manufacture the next fifty ('production block') missiles. Instead, BuAer terminated production on 19 July, and on 8 December 1950 the Gargoyle project was officially canceled and the existing missiles scrapped.

The big postwar BuAer pilotless airplane program included two air-to-surface projects, P/A VIII, a short-range underwater plunger (Martin), and P/A XIV, a short-range above-water missile (Vought); neither appears to have been developed very far.

Bat

The wartime BuOrd air-to-surface missile program was more modest, and produced an operational weapon, Bat, in conjunction with the civilian NDRC. RCA, interested in television-homing weapons as early as 1937 (see Part VI), proposed a television glide bomb to the NDRC in August 1940; the latter began work in January 1941 on a missile with a 12ft span, capable of carrying a 2000lb bomb, and tentatively designated 'Dryden' after a prominent physicist. For test purposes the NDRC developed a two-thirds scale model, 'Robin'. In an April 1942 visit to the Radiation Laboratory, representatives of BuOrd were impressed with Army work on a radar-guided bomb, seeing it as a possible answer to German submarines then operating freely off the East Coast. A semiactive radar homing system was selected, with a gliding trajectory which would minimize sea returns. The alternative, a beam rider, was considered too inaccurate at long range, whereas the accuracy of a semiactive missile would increase as it neared the target; the same arguments were raised a decade later in Terrier/Tartar development (see Part IV).

The NDRC accepted this project on 17 June; soon it was being conducted in parallel with two other Navy requests: 'Moth', an antiradar missile, using rocket propulsion, ultimately turned over to the Army; and 'Falcon' (a scale model missile for antiaircraft use although one source describes it as a ship-to-ship rocket-powered radar homing missile using the 'Pelican' airframe). The ASW missile combined the 'Robin' airframe with a semiactive homer based on standard aircraft radars: it was called 'Pelican'. The radar seeker was tested aboard an SBN-1 trainer in March 1943, and in September Admiral King ordered the project expedited, a production rate of 300 per month being expected by October. The war load was a 325lb depth bomb or a 500lb GP bomb; a 'Dryden'-size airframe with the same seeker (which ultimately became Bat) could carry a 1000-pounder. The two versions would fit, respectively, standard 1000lb and 1500lb bomb racks. Admiral King approved the conversion of two PV-1 land-based attack squadrons, VB-152 and -153, on 24 January 1944. Their aircraft could carry two Mk IIs (1000lb) underwing and one Mk III (1500lb) under their fuselages, and used an APS-2 radar modified for tilt azimuth stabilization, becoming PV-1Ps. Initial tests failed because radar operators found it difficult to lock onto their targets; several missiles mis-homed. In addition, a converted PV-1 lost range due to the 1000lb of structural strengthening required around the belly hole cut for the Mk III mis-

sile; its combat radius was only 300nm without the missile, and 250 with it. Arguing that Japanese naval forces would not be likely to operate within so short a range of a permanent US naval base, and, incidentally, that PV-1s were in critically short supply, Admiral King terminated 'Pelican' in the fall of 1944. In one of its last tests, a night attack on 9 September, two out of four hit the moored hulk *James Longstreet*.

The active homing Bat was more successful. It began with the success of precision BTO (Bombing Through the Overcast) radars as surface search sets; in 1942 it appeared that a low angle of glide weapon could usefully employ just such radars, and the name 'Bat' described its homing mechanism. Originally developed as Bomb Mark 57, Bat was redesignated in a new SWOD (Special Weapon Ordnance Device) series as Mk 9, after its original designation had been compromised. Eleven had been dropped by early December 1944, with some considerable success. For example, on 22 December two were dropped against the target ship *Carisco*, a weak radar target only 180ft long, with a wooden superstructure: one, 30ft short, skipped into her stern; the other, 25ft short, showered her with debris. BuOrd reported the weapon combat-ready on 10 January 1945, after it achieved five hits out of ten dropped against the *Carisco*. It was estimated that three or four more would have struck a larger, more realistic target. Bat could be carried by all of the carrier bombers, as well as by the large new F7F Tigercat fighter. However, on 24 January Admiral King ruled that it would be primarily a weapon of opportunity for long-range patrol bombers; three squadrons of Privateers (VPB-109, 123 and 124) were converted. Carrier application was deferred, but an SB2C-1C was catapult-tested with a Bat.

VPB-109 was initially sent to Palawan in the Philippines, where it encountered poor conditions. For example, Bats dropped against a large freighter in a land-locked harbor locked onto returns from the land surrounding it. Transferred to Yontan on Okinawa, the squadron was more successful. As of 20 May it had expended a total of thirteen, of which five never had a chance due to operational errors. Of the remaining eight, three were direct hits, two were near-misses which inflicted damage, and only three failed entirely, in line with the original expectation of 40 percent successes. In a later mission against a 6000-ton tanker in the Tushima Strait, however, one Bat spun into the water and the other struck several ship lengths short.

The other two Bat squadrons arrived at Yontan at the end of May, when about forty undamaged Bats remained on the island. Results were mixed at best. For example, on 25 June a VPB-124 Privateer released its two Bats against a pair of destroyers tied up at a dock, but there was a mountain in the background, and the missiles homed on it instead. Pilots became unenthusiastic, particularly since Bat operation required flight at considerable altitude, where they were vulnerable to fighter attack. Even when the Bat detachment on Okinawa tried to convince them that the missile had not been used properly, all that they would agree to was to load two Privateers with Bats and hold them on alert, to attack targets which other aircraft (on patrol) might sight.

There were few Privateers available, and the squadrons considered diversion to Bat attacks wasteful. Even so, during July one VPB-124 airplane dropped two against a Japanese escort destroyer. One exploded a thousand yards short, but the other was believed to be either a hit or a near-miss. Visibility was poor, but the tail gunner of the accompanying aircraft saw a puff of smoke near the location of the ship; the Bat had last been seen on course into its target. In another attack, on two destroyers at a range of 6nm, one exploded in the turning circle of the destroyer as it evaded, and the other was not observed as it fell through the overcast. Heavy smoke did rise, and it appeared that the target had been hit. Nevertheless, in neither case do current records appear to show the loss of a Japanese destroyer or destroyer escort to Bat attack.

Bat was thus the only US Navy air-to-surface missile to enter combat, although Pelican (SWOD Mk 7 in its heavy version) came close. At the end of the war, contracts for 7000 Bats were canceled, leaving a total of 3000, most of which had already been produced. Of the latter, 2000 were retained as a war reserve, and another thousand modified to train three squadrons. Bat itself was redesignated ASM-N-2 in a new missile series. In tests against the target ship *Fleetwood*, Bat Mod 0 made seven hits and one miss, whilst Mod 1 made five hits out of six drops (three short skips and two direct hits).

Bat was extensively modified postwar, scoring up to 85 percent (with 15 percent component failures) against a pontoon barge in January 1948. However, four drops against a live target, the former battleship *Nevada*, on 30 July 1948, were failures. The operators locked on their missile radars at a range of about 13-15nm, and launched at 6.5-8nm. One, improperly armed, spun in and exploded when it hit the water. A second turned left a mile short of the target, striking the water 600yds left and 100yds over. The third dove noticeably a mile short, striking the water 750yds short of the ship. The fourth passed about 600ft over the target striking the water 1000yds beyond the ship. These disappointing results were attributed at the time to a combination of the sheer bulk of the target (which might overwhelm the missile radar) and to interference from other ship and aircraft radars. However, coming after so lengthy a development effort, they must have depressed advocates of fleet missiles. The entire program was canceled not long afterwards, as a simple but effective countermeasure to the missile had been discovered.

Dove

The other major wartime BuOrd missile program was 'Dove', an infrared homing bomb. It was originally an Army project ('Felix'), but early in 1944 Polaroid proposed a naval weapon, and Admiral King approved the project on 28 April. Dove was transferred to Eastman Kodak in July 1946, and the production of twenty prototypes was contracted for in 1949; BuOrd evaluation was completed in October 1952. However, Dove (then designated XASM-N-4) does not appear to have entered service. It was a homing head and special tail for a standard AN-M65 1000lb GP bomb, which could be dropped from unusually high altitude (8000-30,000ft) in view of its ability to correct for aiming errors as great as a

quarter-mile; 80 percent of bombs dropped were to fall within 60ft of a target. Horizontal, dive- or toss-bombing would be possible, and Dove was intended primarily for use against ships. However, it 'also may be of use against specially surveyed, isolated industrial installations', according to a 1950 Navy missile report.

Kingfisher

In August 1944 BuOrd proposed 'Kingfisher', an adaptation of Bat to carry a torpedo. Six variants were ultimately proposed. Kingfisher A (SWOD Mk 11) was a glider carrying a Mk 21 torpedo, an interim weapon against ships not effectively protected by fighters. It was not pursued postwar; BuOrd preferred a longer-range, powered weapon, Kingfisher C, which became Petrel (AUM-N-2, an air-to-underwater weapon). Kingfisher B was a lighter-weight glide weapon carrying a bomb-torpedo, and conceived as the ultimate anti-shipping air-to-surface missile, about two-thirds the weight of a Bat. Its unpowered weapon was similar to those developed by the Germans. Kingfisher D was conceived as a developed Kingfisher C, carrying a homing torpedo at higher speed (350 rather than 300kts). All four air-launched weapons were to have a

range of about 20nm. Finally, Kingfisher E was a surface-launched missile carrying a deep-diving homing torpedo, for use against deep-diving submarines. Conceived in 1946 and approved by the CNO on 5 February 1947, it became 'Grebe' (SUM-N-2; see Part III).

Kingfisher C was the only one of the original series to be pursued for long. In 1946 BuOrd proposed two more, 'Diver' (AUM-N-4) and 'Puffin' (AUM-N-6). Diver employed a proposed rocket torpedo whose motor could fire both in air and in water; the failure of the torpedo also killed the missile. Puffin was an air-launched, high-altitude, lightweight, powered missile carrying an unpowered plunge bomb. Approved on 5 February 1947, it was deferred indefinitely as of 1 October 1949; missile development was by McDonnell and the National Bureau of Standards (guidance). In effect, it would have been a powered equivalent of Kingfisher B, SWOD 21.

Like Bat, Kingfisher C (SWOD 15) was considered a weapon of opportunity for use by patrol bombers. It took priority over other Kingfisher projects, since 'research on this missile is considered basic to all other anti-surface(d) missiles of the Kingfisher type'. Launched at low altitude, it dove at about 15° until it pulled out at 200ft, flying until, 4500ft

from the target, it shut off power and dropped a Mk 21 torpedo. Guidance was by active pulsed X-band radar, and Petrei was considered effective against targets moving at up to 33kts. It was propelled at about 325kts by a turbojet. Operational Evaluation was completed in April 1956, and one squadron of specially configured Neptunes (P2V-6M) was planned for each coast: VP (HM)-13 (Atlantic, formerly VP-24) and VP (HM)-10 (formerly VP-17). They first received their weapons in, respectively, mid- and late-1956, but the following year these aircraft were transferred to the Reserves, beginning with VP-834 in November. In effect, then, US long-range antisurface raider capability was considered sufficiently secondary to be relegated to reservists. Even that was too high a priority: the phaseout of the missile began in January 1959, and Petrel was canceled entirely on 29 January in favor of concentration on airborne ASW; the special Neptunes were converted back to conventional configurations. There was just too little Soviet surface threat to be worthy of a specialized countermeasure, and far too much of a Soviet submarine threat to allow for the diversion of resources as valuable as Neptunes.

6. Tactical standoff missiles

Omar

With the Korean War, Navy attention turned to problems of ground attack. Missiles became attractive not so much as a means of securing great accuracy but rather as a means of striking from outside the reach of groundfire. Two systems, Omar and Bullpup, can be associated with this period. Omar, approved on 20 August 1951, was an abortive guided version of the standard 5in HVAR, designated ASM-N-6. It had an aft-looking light-sensing attachment, allowing it to ride a light beam projected by the launching airplane. Some Sidewinder components (servogenerator and roll-rate stabilizer) were to have been employed, but it appears that difficulties with the guidance system aborted it about 1953.

Bullpup

Bullpup, reminiscent of Gargoyle, was a much simpler and infinitely more successful weapon. Developed as ASM-N-7, it employed a joystick radio control, the operator observing a flare in the missile tail through his gunsight. Studies of means of reducing aircraft losses to groundfire began in 1951, with the formal BuAer study of the Bullpup concept in April–October 1952, an Operational Requirement issued in June 1953, and a Request for Proposals that August; the missile concept was approved by the Assistant Secretary of Defense for Research and Development on 15 March 1954, and a contract awarded to Martin on 30 April, fourteen proposals having been submitted. Bullpup carried a 250lb bomb inside a roll-stabilized airframe propelled at Mach 1.8

by a solid-fuel motor. It entered Fleet service in April 1959, the first missile having been delivered on 4 February 1955 and the first air launch attempted (unsuccessfully) on 4 April. A ground launch was successful on 6 May, and an air launch on 15 June. Bullpup A, ASM-N-7A, with a storable liquid-fuel motor for greater range, followed in 1960; in 1962 the first two versions were redesignated AGM -12A and -12B. Operational evaluation of Bullpup B (AGM-12C) began in January 1962, with Fleet

Bullpup (an AGM-12B is shown) was developed in the 1950s as a result of US experience in attacking heavily defended targets during the Korean War. Although it was considered obsolescent by the mid-1960s, it remained in use in Vietnam, and also armed P-3 maritime patrol aircraft, as until the advent of Harpoon it was the only available US antiship standoff weapon. This one was photographed slung from a Skyhawk at Point Mugu, California, April 1969.



V. AIR-TO-SURFACE WEAPONS

- 1 Bullpup B (AGM-12C) combined the Bullpup control surfaces and guidance system with a 1000lb (vs 250lb) warhead and a new liquid-fuel rocket. This one was photographed at Point Mugu missile range in October 1965.
- 2 Bulldog, AGM-83A, was the final development of the Bullpup series, an early Bullpup modified with a laser seeker replacing the earlier radio command guidance system. It was developed by China Lake for the Marines as a close support weapon; the laser-guided version of Maverick will be used instead. Here one is loaded onto a Skyhawk at China Lake, 13 October 1972.

introduction in 1964; it was enlarged to take a 1000lb SAP bomb and had larger wings and a liquid-fuel rocket for longer range (10 vs 8nm), but effective range remained limited by the guidance system. AGM-12D was an Air Force version with interchangeable nuclear and conventional warheads, and -12E, also for the Air Force, carried bomblets and was built only in very small numbers. An optical area correlation version of -12E was flown as Blue Eye (Air Force AGM-79A) but was canceled. Finally there was Bulldog, AGM-83A, a laser-guided version. It was terminated in 1971 due to its competition with Maverick; the Navy version of the latter incorporates its Mk 19 warhead.

Bullpup was built in huge numbers: 45,350 Bullpup A/Bs and 15,400 Bullpup Bs plus over 8000 Bullpup As built in Europe from 1963 onwards. It was carried not only by fighters and attack aircraft, but also by ASW patrol aircraft (P-3 Orion), as a prompt-attack weapon against surfaced submarines. It appears to have been too heavy for the earlier P-2 Neptune; in 1966 it was reported that existing SP-2Hs were soon to receive four French-built Nord AS-12 light-weight air-to-surface standoff missiles, two under each wing. However, that program was canceled.

Walleye

Bullpup's design placed severe limitations on maneuvers by a launching aircraft, and the need for its operator to observe its flight all the way to the target in itself limited its standoff range. Anything better required new technology, which was available by the early 1960s. Given a target contrasting sharply (visually) with its surroundings, a television camera could be 'gated' to remain pointed at the area of high contrast, and so to direct a homing missile. Not only could the pilot lock-on his missile before launch (LOBL) and then leave the area; in addition, the missile *gained* accuracy as it approached the target, since the image of the target expanded in its field of view, as in a semi-active radar-guided missile. With the guidance system already demonstrated, a Specific Operational Requirement for a television-guided glide bomb, Walleye, was issued in August 1962, looking towards development during FY66. The result, Walleye I, entered production in 1966 and service in 1967; production (by Martin) ended in 1970, after 4531 had been built. Walleye could be carried at up to Mach 1.9, at 35,000ft and was expected to be able to glide as much as 10nm on its large delta wings. Extreme accuracy has always been claimed for it, and Walleye was quite successful in combat in Southeast Asia. It was designated AGM-62A in the triservice system begun in 1962, and had an 825lb linear shaped-charge warhead; reportedly there is also a nuclear version.

Walleye was the first US electro-optical (EO/TV) or automatic television-guided

bomb. However, its warhead was not large enough to attack some 'hard' targets, and Hughes converted 1481 Walleye I to Walleye II configuration, with a 2000lb linear shaped-charge warhead and a seeker with a smaller 'gate', for greater accuracy. Walleye II also has a greater glide range. It was originally called 'Fat Albert', and Hughes reportedly built 529 new missiles in this configuration.

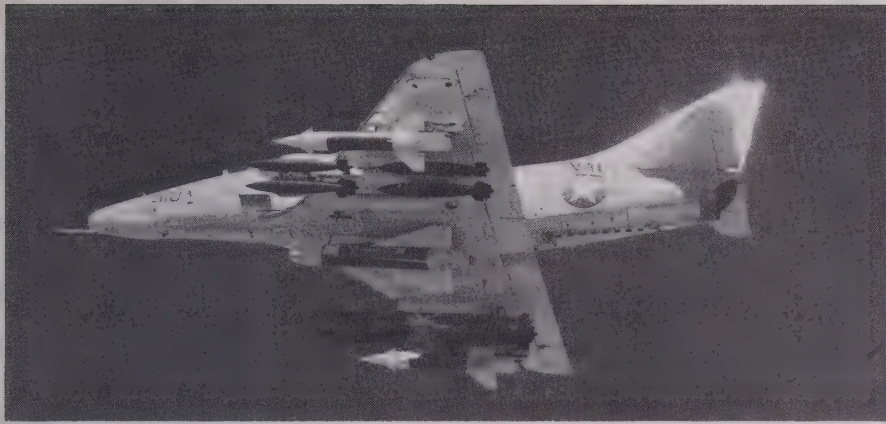
There were several other variations. An Extended Range (ER) Walleye had larger wings. However, LOBL was itself a range limitation, since the pilot of the launch aircraft had to be able to see the target on the missile's television before he could release it. If Walleye could be locked-on after launch (LOAL), then it could be dropped at greater standoff ranges, against targets not even visible at launch range. Glide range inherent in the missile, particularly in its ER version, made LOAL attractive. This in turn required a two-way data-link to the missile, somewhat similar to that already being developed for Condor (AGM-53), so that a pilot in a retiring aircraft could see the missile's television picture; the result was termed an Extended-Range Data-Link (ERDL) Walleye. Funding was approved in February 1971 and an initial production run undertaken between November 1972 and May 1973.

Three ERDL Walleye IIs were dropped in combat in Vietnam, another five being tested at China Lake, for a total of seven hits, all against targets invisible to the pilot at the time of

launch. Typically, a pilot could lock his Walleye onto some prominent reference point near the target, then steer it onto the correct reference point (using the data link and the television in the missile's nose) as he escaped. Alternatively, he could manually steer the missile until he locked it onto his final target. Given bad weather (as in Vietnam) it was sometimes best to transfer the data-link pod to a second aircraft closer to the target. Another Walleye improvement program was the addition of an imaging infrared (IIR) seeker, in effect an infrared television camera, to permit night attacks. In 1977 Hughes was given an R&D contract for a common IIR remote seeker for Night Walleye, as well as for the Air Force GBU-15 glide bomb and for a night attack version of the Air Force Maverick (AGM-65) missile.

Walleye was an extremely efficient weapon in terms of weight: in its first version, a total missile weight of 1125lb supported an 825lb warhead; in Walleye II the corresponding figures were 2400 and 2000, and the missile stood at the outer limits of fighter carrying capacity. It was also quite expensive, and production ended with the Vietnam War, although a considerable program of ERDL conversions followed: a total of 1400 Walleye I and 2400 Walleye II are reportedly planned. As Walleyes are expended, they are to be replaced by Air Force type guided bombs, presumably GBU-15 or HOBOS (Homing Optical Bomb-





1 Walleye was developed to overcome the defects of Bullpup; here an A-4F Skyhawk carries both weapons, as well as 500lb low-drag bombs on MERs underwing.



2 The original Walleye had to be locked-on to its target while still on the bomb rack, resulting in considerable exposure of the airplane to ground fire; one study suggested that a Walleye pass was up to four times as dangerous as an 'iron bomb' pass. One solution was the Extended Range Data Link (ERDL) missile, which could transmit a television picture back to the launching airplane via an underwing pod, seen here outboard of the Walleye I missile under an A-7, April 1978.

destroyed at somewhere between equal losses and half the losses when using Walleye (taking into account 4 times higher attrition per sortie for Walleye). The balance swings strongly in favor of the iron bomb when buildings as large or larger than 130×65 ft are considered (6 iron bomb A-4 sorties per building, according to JMEM) or when steel and concrete bridges are of interest.

Against hard bridges where a pier must be destroyed in order to drop a span, the Walleye results have been disappointing due to its inability to hold lock on the low contrast pier. Walleyes have registered three direct hits on the Thanh Hoa bridge; BDA shows the results to have been three bent girders. Other girder bridges have required 5-6 attempts per span destroyed due to lock-on difficulties, low contrast, lack of warhead effectiveness and lock-shifting to invulnerable girders...

In summary, it can be concluded that the Walleye is an excellent special purpose weapon for a restricted set of targets, namely, those targets that have high value, high contrast, are vulnerable to 1 or 2 Walleye impacts and are not heavily defended (or countermeasured). These limitations are reflected in the low SEA consumption rate (10-15 missiles per month) and recently reduced Service production requests.

An accompanying table shows Bullpup with a peacetime test CEP of 30ft, a peacetime squadron service CEP of 56ft, and a wartime combat CEP, as demonstrated, of 100-150ft. Walleye was credited by Navy pilots with 78 percent hits, by Air Force pilots with 49 percent, with a peacetime CEP of 10-15ft. The results for earlier guided air-to-surface weapons had been somewhat better: the German Hs 293 had a 15ft CEP when tested at 7km range, and 35ft in combat at 4-20km. The US 'Razon' guided bomb, which the report characterized as having 'unacceptable control dynamics', was nonetheless credited with a peacetime CEP of 60ft and a wartime figure of 170ft, in both cases when dropped from 15,000ft. Antiradar missiles, used in Vietnam, fared even worse. Shrike was credited with 14 percent hits in combat, but that was 'based on pilot claims for impacts in target area, not necessarily kills'. The longer-range Standard ARM was credited with only 6 percent hits, but a test squadron (VX-5) claimed a 20 percent success rate in 'suppression' kills.

Laser-Guided Bombs

The other major guided-bomb technology developed during the Vietnam War was laser guidance. Potentially, a laser is an ideal means of designating a target, even if the latter is so vaguely defined that an airborne observer may be unable to see it. Laser guidance was primarily an Air Force project, but developed its own hand-held designator: five were deployed in Vietnam in June 1972, for use by Phantoms, guiding a total of 372 Mk 83 bombs. In addition, two modified Philco-Ford Pave Knife

ing System, a conversion kit for Mk 80 series bombs).

Although they were very favorably advertised, precision air-to-surface weapons such as Walleye had considerable drawbacks. A 1968 OSD report, now declassified, observed that

Recently a school of thought has arisen in the avionics community that contends that bombing computers won't work well enough to be useful - consequently, accuracy must be built into the ordnance in the form of terminal guidance. Actually, there is a long and generally ignored history of air-to-ground missile development dating back to WW II... The American developments, which led to the first Bullpups, were radio-controlled pilot-steered glide bombs (later Bullpups added thrust, as in the Hs 293, to obtain reasonable standoff). The Hs 293 obtained good results against shipping and somewhat less satisfactory results in defended areas (the Henschel designers were realistic enough to realize that a separate missile operator was needed for missile control during the breakaway maneuver; this has not yet occurred to the Bullpup enthusiasts)... Bullpup [was] disappointing in combat... due to the highly vulnerable long straight flight path required for tracking up to impact...

There is no doubt that at least the simpler EO weapons will hit within 10-15ft CEP any *high contrast* target they can be locked onto. Whether the reliability of such weapons will ever exceed 80% is not obvious.

The difficulty of the pilot's lock-on task is not widely appreciated. The image, as in any airborne TV, has extremely poor resolution; the jitter in the

image due to both aircraft flexibility and electronic noise is remarkable. The pilot's task consists of rolling in and putting the piper on the target, switching to the TV screen to acquire the target, aligning the aircraft to center the target in the gate and then attempting to lock-on. This process generally takes 15 seconds as opposed to 6-8 seconds for iron sight combat drops. To make the task manageable, shallow dives (approximately 20°) are used. All this adds up to an extremely vulnerable approach tactic (attrition goes up exponentially with length of straight tracking flight). Combat results show the effect of poor resolution (despite the specially selected high contrast targets) and long tracking times: *average slant range at release is only 8900 feet; Walleye sorties take 4 times as many hits as iron bomb sorties... the pilot exposure in a Walleye release is as unacceptable as during a Bullpup release.*

The targets most frequently selected in SEA [Southeast Asia] have been large buildings and bridges. The large buildings with interior contrast windows are ideal for lock-on; unfortunately, it takes quite a few 800 lb warheads to destroy a large building such as a power plant; single detonations of Walleye inside the windows of large buildings have not shown any destruction of roofs or walls in the available BDA [Bomb Damage Assessment]. Results against soft wooden bridges have been excellent; a two aircraft attack has been generally sufficient. This compares with the JMEM [Joint Munitions Effectiveness Manual] prediction of 20 A-4 sorties (using 500 lb bombs) on the somewhat harder truss bridge (combat results are slightly better than JMEM prediction). We can therefore peg the comparison in aircraft lost per soft bridge

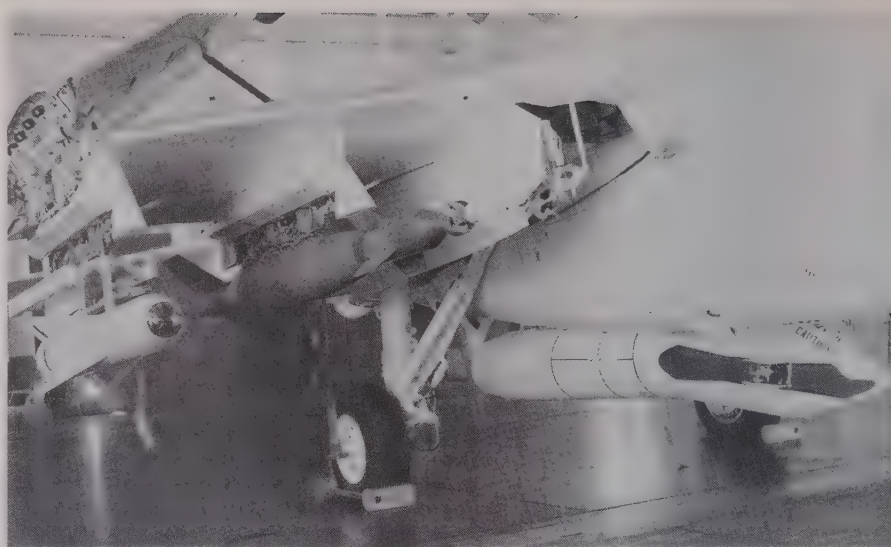
(Air Force) designator pods were used by A-6 Intruders from November 1972 onwards, guiding a total of 33 Mk 83 and 21 Mk 84 bombs. These figures contrast with a total of about 25,000 laser-guided bombs used during the war, as well as 980 Walleye used in 'Linebacker II' strikes on North Vietnam alone, between April and December 1972.

Precision weapon technology continues to receive far more favor from all three services than does the technology associated with unguided weapons, with particular current (1983) attention given to seekers which can themselves lock-on after launch, as in antitank attacks. Such systems do remove the pilot from the vicinity of the target, and overcome the problems of that long straight approach; they are typified by ERDL Walleye. Some also overcome the problem of saturation, ie of the inability of a pilot to designate against more than one target at a time. This is the analog of the air defense saturation problem, and a favored approach (at least in the antiarmor systems) is self-homing once a weapon has approached the target area.

Maverick

Although the Navy has maintained a nominal interest in short-range guided bombs, in fact its attention, since Vietnam, has been concentrated on much longer-range weapons. In 1972 the Director of Defense Research and Engineering ordered all three services to develop modular guided-weapons programs to reduce costs; the Air Force response was a Modular Guided Glide Bomb program, including, incidentally, laser guidance for Rockeye. The Navy preferred to emphasize subsystem research and development, and expansion of existing programs (Walleye I and II, Condor, and Harpoon). It divided weapons into direct and indirect (standoff) attack types, the first embracing Maverick (with a small blast-fragmentation warhead) and Walleye, and the second Condor, Harpoon and data-link Walleye.

Indeed Maverick, originally an Air Force program, is the Navy missile closest in spirit to Bullpup and Walleye, with the great advantage over the latter of being powered and hence releasable at relatively low altitude. Adaptation



to Navy requirements included the development of an alternate (250lb) warhead which, according to the Air Force program director, 'will broaden the Maverick target spectrum to include destroyer escort and surfaced submarines and will improve Maverick effectiveness against armor and bunkers'. The original missile had a television seeker much like that developed for Walleye; it was built to a 1964 operational requirement, and fitted within small bomb racks (maximum weight was 462lb, which limited motor weight and, therefore, range).

Maverick (AGM-65A) entered Air Force service in January 1972, and at least thirty were fired in Vietnam, with another 69 used by Israel that fall. Production was completed in 1976, with 20,000 built by Hughes. Maverick was severely limited in part by the low magnification of its television camera; in poor weather a pilot might have to approach to well within its motor range merely in order to see a target well enough to lock onto it. In the AGM-65B (scene magnification) version, the television image is magnified to twice its previous size. Deliveries began in May 1975. The next type, AGM-65C, was a laser-guided variant designed for the Marine Corps, homing on a signal which might

Laser-guided weapons can hit point targets which are otherwise ill-defined - if an airplane or a ground-based laser can illuminate them. This Grumman A-6 at China Lake displays both ends of the system in a February 1978 photograph: an AGM-65 laser-guided Maverick, a laser-guided bomb (a standard low-drag type fitted with parts from a standard kit) and, on the centerline, an AN/AVQ-10A Pave Knife laser pod. Note that the Maverick is slung from a triple bomb rack.

most conveniently be provided by troops on the ground, and therefore particularly well adapted to close air support. It received little Air Force backing but a further development, AGM-65E, with a specialized penetrating warhead (Mk 19, originally developed for Bulldog, a penetrating blast-fragmentation type with a three-position selectable fuze delay, in the 300lb rather than the 125lb class) is to be produced for the Marines. Similarly, the Air Force is developing an IIR Maverick, AGM-65D (which it plans to procure in very large numbers) and the Navy is to adopt an AGM-65F with the penetrating warhead and a slightly modified seeker.

7. Long-range air-to-surface missiles

Raven

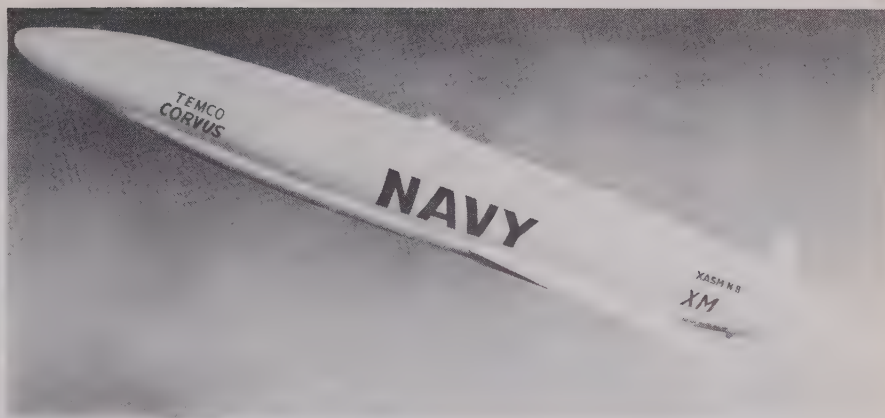
Just as the intense groundfire of Korea drove the Navy towards a short-range tactical standoff missile, Bullpup, the prospect of Soviet surface-to-air missiles motivated the development of a generation of long-range, generally nuclear-armed, heavy air-to-surface standoff weapons. In April 1956 the Operational Evaluation Group (OEG) reported the results of its study of operational requirements for carrier-based attack aircraft in the 1960-65 era.

Given probable advances in Soviet radar coverage, it seemed unlikely that an attack bomber (such as the North American Vigilante) could achieve immunity from interceptors by speed or ceiling, and surface-to-air missile efficiency seemed little affected by altitude; the best counter was a very low-altitude penetration or at least run-in. Indeed, surface-to-air missiles would inevitably drive the attack bomber to very low altitudes. Alternatively, there might remain some small

advantage in very high (and very expensive) speed, but a long-range standoff weapon would clearly confer major advantages.

Such a weapon was already under development. On 1 April 1955 the CNO initiated 'Raven', ASM-N-8, a weapon system to hit hard (and well-defended) targets from a safe standoff range. An existing project for an anti-radar missile guidance system. Corvus, was re-oriented to the Raven requirements at the same time, taking the ASM-N-8 designation. A year

This is an artist's sketch of the Corvus long-range standoff weapon, which first flew (from a Skyhawk) on 18 July 1959 off Point Mugu. Corvus was canceled partly because of the Navy's withdrawal from the carrier strategic attack role, and partly because SAC did not (at the time) have any requirement for a defense-suppression nuclear weapon. Corvus was designed to home either semiactively or on enemy radar emissions, and for a time a conventionally armed version was contemplated.



later the Air Development Center looked at alternative Raven sketch designs, with speeds of Mach 0.9 or 2.0, and ranges of 50, 200 or 400nm. Basic requirements were the ability to penetrate enemy airspace and destroy defended targets with small nuclear warheads; minimum technical risk; carrier compatibility; simplicity consistent with all-weather operation; and an initial operational capability (IOC) of 1962. The latter date was consistent with LRO estimates of the transition from major strategic operations to tactical nuclear warfare, as systems such as Regulus and Triton (see Part VI) came into fleet service. That is, Raven would become more and more important as the fleet had to hit more and more small precise targets. In 1956 there was little expectation that very long-range *conventional* attacks would become vitally important within a few years, only that nuclear war would become more tightly controlled.

Guidance was a considerable problem. Possibilities studied included a radar relay system (as in the Soviet SS-N-3 anticarrier missile, whose guidance system may have been derived from a US prototype), as well as inertial; another was an airborne equivalent of the 'Trounce' system (see Part VI) used by Regulus. The Corvus antiradar missile (ARM) system had the advantage of simplicity; on the other hand, it could hardly be said that all important defended targets had radars very close by. ARM did allow for an alternative in which an airborne radar reflected from some important structure or terrain feature near the target, allowing the missile to home semiactively.

Corvus

The need for some advanced standoff missile was recognized quite widely within the Navy. In October 1956 the Bureau of Ordnance made a series of forecasts of future weapon requirements for the 1961-66 period, probably for the LRO Group. Two classes of air-to-surface weapons were recognized: a very long-range strategic weapon, which might weigh up to 40,000lb and attain a range of 1500nm; and a tactical weapon in the Bullpup class, specified as either 600lb (visually guided, 8-10nm, Mach 3) or 1000lb (all-weather, 20-30nm, Mach 4 or 5).

In January 1959, the LRO Group surveyed future Navy antisurface missile requirements, concluding that there was an urgent need for an air-launched conventional or low-yield nuclear weapon adequate against future field air

defense systems (comparable to Redeye and Mauler); 'while it is granted that the feasibility of a TNT version is difficult to estimate, the early provision of at least a nuclear version, and probably of both versions, is considered mandatory if naval concepts of carrier aviation as the backbone of a limited war striking force are in fact to continue valid'. Corvus was considered an essential long-range program, but only a collateral requirement of low urgency was seen for low-precision, high-yield weapons such as the proposed Corvus B: the series of long-range studies suggested strongly that massive nuclear strikes would not be a feature of the late 1960s and 1970s, in view of growing Soviet strategic power. Low-yield nuclear war, on the other hand, was quite possible; Corvus would destroy radiating or high-contrast radar targets. An entirely new weapon, possibly an Air Force type then under development as White Lance (GAM-79) would neutralize airfields, moderately hard missile and gun positions, and tanks. In a limited non-nuclear war, Bullpup would be inadequate due to its short range; field defenses were credited with a range of 5nm, fixed defenses of 20-100nm.

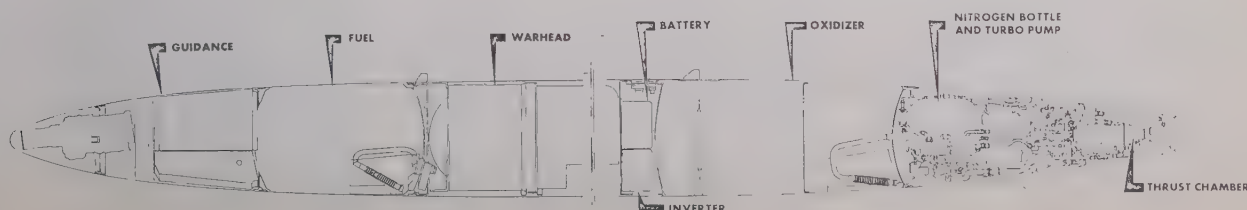
That February, the CNO, Admiral Burke, released a new LRO study (LRO-59). He saw two alternative future lines of development for the Navy attack bomber force. One would emphasize penetration of enemy defenses: high performance and electronic countermeasures would permit a quarter to a third of the bombers to penetrate; offensive ECM, saturation, deception and decoy tactics would help; aircraft would fly at minimum altitude; and antiradar missiles (ARM, not Corvus) would disrupt defenses. This was actually the approach taken. The alternative was a very long-range standoff weapon, Corvus, which was limited in the targets it could attack, but which, even so, seemed essential.

At this time the Bureau of Naval Weapons, successor to BuOrd and BuAer, proposed two new standoff missiles: AWS-302B, a Bullpup effective to 20nm; and AWS-303B, an inertial-

ly guided Corvus, effective at 200nm (twice maximum Corvus range), presumably with terminal antiradar guidance. Neither appears to have been pursued.

The contract for ASM-N-8, Corvus, was awarded to Temco Aircraft in January 1957. It was to be effective against microwave pulse radars (X- and S-bands); against nonradiating targets such as ships when they were illuminated by a compatible launch aircraft radar; or against targets marked by a co-operating beacon, which would convert an otherwise passive target into a radiating one. Design objectives included a launch speed of 150kts up to Mach 1; a range of 100nm against a nonradiating target, or 170nm against a radiating target (launched at 40,000ft and Mach 0.8); target altitude from sea level to 10,000ft; launch altitude from 400 to 50,000ft within line of sight of the target; accuracy and reliability such that at least 80 percent would hit within a cylinder 400ft high, with a base radius of 600ft; and 85 percent checkout reliability 'with no more than minor adjustments'. The warhead was a new lightweight type designated XW-40. Special features included an ability to discriminate between radar targets on the basis of PRF and frequency; in the nonradiating target mode, a command link was established between the launch aircraft and the missile. Data were transmitted via the launch aircraft radar, and the special signals could be decoded by the missile for control until it came close enough for effective semiactive guidance. Corvus was powered by a bipropellant liquid rocket engine (1000lb of thrust for 177 seconds at 40,000ft). At 1750lb, it could be carried underwing (two missiles each) by a Skyhawk or Skywarrior; three could be carried in the internal bay of the new Seamaster jet flying boat bomber. Corvus first flew on 18 July 1959, launched by a Skyhawk, and fully guided

THE XASM-N-8 (CORVUS) MISSILE (INBOARD PROFILE)



V. AIR-TO-SURFACE WEAPONS

flights followed in March 1960. However, it was canceled that July, the victim of an inter-service agreement awarding long-range standoff nuclear missiles to the Air Force, which considered this particular one unnecessary.

Condor

The requirement for a long-range standoff weapon did not die with Corvus, although emphasis shifted towards a non-nuclear warhead. Moreover, the new television systems (as in Walleye) promised a form of standoff missile accurate enough to attack point targets with conventional warheads. In 1962 a requirement was issued for a new Condor (ASM-N-11) missile, which would employ remote television guidance, locking onto its target well after launch, with command midcourse guidance to bring it into the target area. Proposals were received in 1964, and Rockwell received a contract in July 1966. Propelled by a solid-fuel rocket engine (rather than the originally specified storable liquid type), Condor reportedly had a range of about 60nm; a much longer-range (about 100nm) turbojet version was tested. Out of a total weight of 2130lb, 630 went into a linear shaped-charge warhead.

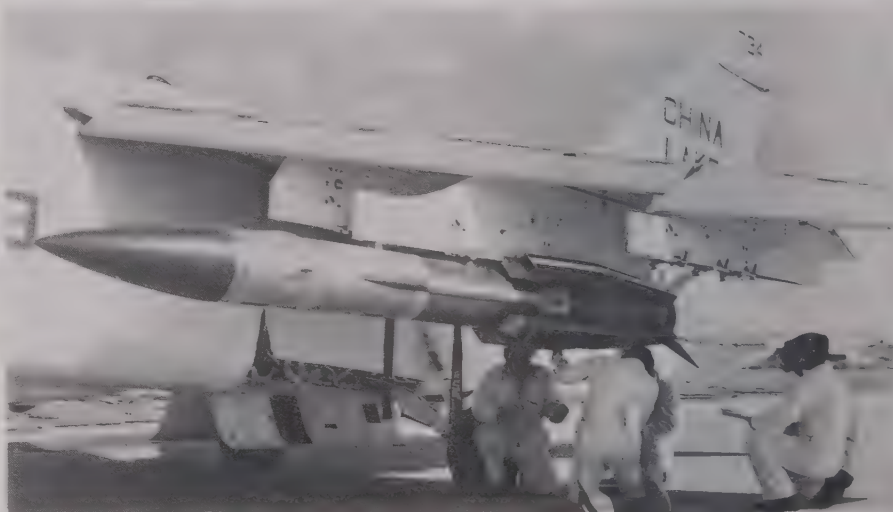
Condor first flew, from a Phantom, on 31 March 1970, and development was reportedly extremely successful. A contract for pilot production of 50 was signed on 28 June 1974 (20 under FY73 and 30 under FY74). Operational evaluation followed in the fall of 1974, with the missile planned for all Navy attack (A-6, A-7 and F-4) and ASW patrol (S-3 and P-3) aircraft. Full-scale production of 250 Condors was planned for FY76/FY76T. However, it was very expensive, and Congress canceled it in March 1976. Much of its cost could be attributed to the sophistication of its two-way secure data link, essential for long-range television guidance. For example, in FY74 fifty Condors cost \$822,000 each, compared to \$241,600 for the production Phoenix air-to-air missile or \$30,444 for a Shrike, both in somewhat more inflated FY75 terms.

The data link itself was both costly (about \$1 million at the time) and unreliable. Condor was criticized as having too small a warhead (in both weight and volume) for effectiveness against hard or wide-area ground targets and as too costly (it was sometimes referred to as a 'silver bullet') for use against certain point targets, such as vehicles. Ships were considered relatively low priority targets for Condor, as they would be covered by submarines, ARMs and other weapons.

To some extent it appears that the mere existence of a much less expensive Harpoon, also apparently effective against surface ships, and also suitable for air launch, was a major factor in the original decision to cancel Condor. Certainly in 1983 there is no air-launched Navy missile capable of very long-range (50nm) point attack on land targets, as Condor would have been.

Current Projects

Again, the underlying operational requirement could hardly vanish, and about 1977 work began on a new program, an Air to Ground Standoff Weapon. It was to be a 2000lb supersonic missile for use against ship and land targets; there were indications that the former would be attacked underwater. Funds were denied in FY78, but \$5.5 million was asked in



FY79, with further funding requested in the FY81 budget. To some extent this AGSW was competitive with an air-launched version of the Standard Missile successor tentatively designated Long Range Dual Mode Missile, or LRDM. Recently the Navy has defined this requirement as a Supersonic Tactical Missile (STM), and an X-band synthetic aperture radar (SAR) is being developed as a potential

antiship seeker for it; such a radar has the advantage of permitting great reductions in missile cross-section (and therefore in aerodynamic resistance). However, because it is side-looking and thus cannot see directly ahead, its use requires the weapon to fly a sinuous path to the target. An airframe and power plant for a supersonic air-to-ground weapon were developed by Vought during the

Condor was developed for long-range precision attack; this prototype is shown under an A-6 Intruder at China Lake in April 1969. It was criticised as being a 'silver bullet' due to its very high unit cost, and questions were raised about the jam resistance of its data link. The large tail radome above the two rocket nozzles accommodated the missile antenna for the long-range link, which in theory should have allowed a launch airplane to control it at a distance of over 50nm. There was also a proposed turbojet version, for even greater aerodynamic range; however, the key issue in Condor range was always the distance at which its data link could function, as the missile could not lock onto its target until it had approached to within a few miles.

Under Navy contract, Vought developed a new high-performance missile power plant, the Low Volume Ram Jet (LVRJ); here a test missile is shown as carried by an A-7. The first LVRJ was flown from an A-7 on 2 December 1974, covering over 40nm at a speed well above 1450mph. Four flights in 1976 demonstrated sustained speeds in excess of 1700mph and a range of over 100 miles. The test vehicle shown was 15ft long and 15in in diameter, incorporating a solid-fuel boost rocket which accelerated it to ram speed in about 5 seconds. LVRJ technology has been proposed for long-range, high-speed, air-to-surface weapons as well as for surface-to-air and surface-to-surface use; for a time, for example, it appeared that a ramjet would succeed the SM-2 as the standard Navy SAM.

Vought

The Supersonic Tactical Missile (STM) was developed from earlier Vought studies of low-volume ramjet technology, and bears a strong resemblance to the company's Advanced Low Volume Ram Jet (ALVRJ) of 1974-76. In its first flight at Point Mugu, on 21 April 1979, it flew about 90 miles at 2000mph and at an altitude of 35,000ft. Solid propellant in the ramjet combustion chamber boosts it to supersonic speed, after which the liquid-fuel ramjet fires, port covers over the ramjet inlets blowing away and an inner nozzle at the rear of the missile being ejected to leave a larger-diameter nozzle compatible with ramjet operation. Total weight of the STM was about 1500lb, and it matched the earlier ALVRJ in overall dimensions. Although it appears that the ALVRJ/STM inspired initial Navy interest in what became the Medium Range Air to Surface Missile (MRASM), OSD instructed the Navy to cooperate with the Air Force in developing a medium-range version of the subsonic Tomahawk instead, and in 1983 the advanced integral rocket-ramjet technology is without a projected production vehicle.

Vought

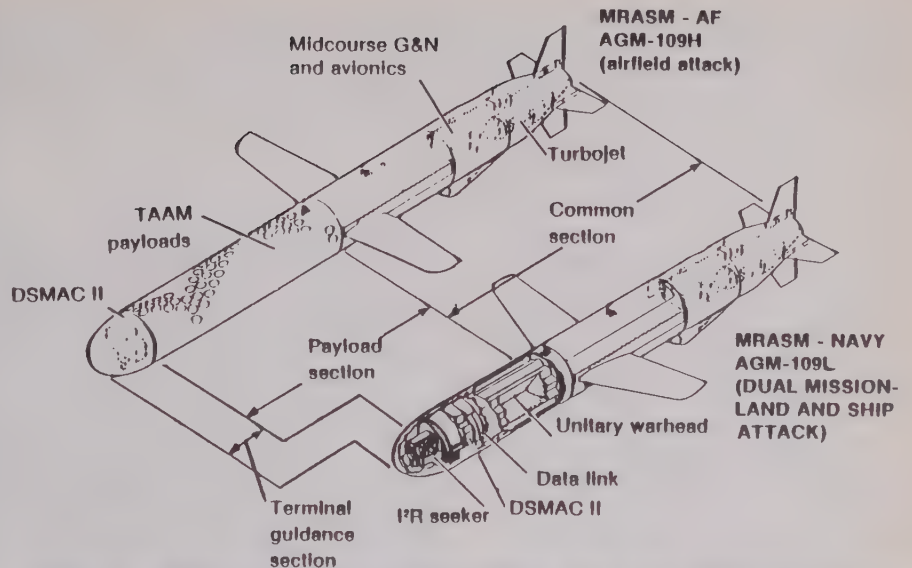
MRASM VARIANTS (USAF/USN)

The MRASM prototype, its tail folded and its wings still retracted, is shown on the hangar deck level weapons elevator of the carrier *Kitty Hawk* during carrier suitability tests in 1981. This photograph dramatizes the limitations inherent in naval air operation of weapons: for example, given the limited length permitted for the weapon, it is necessary to sweep its wings back slightly, to maintain an appropriate center of pressure relative to the center of gravity. MRASM remains folded aboard its airplane, the wings deploying only after launch.

Pacific Missile Test Center

late 1970s as an exploratory R&D project (the Advanced Low-Volume Ram-Jet, or ALVRJ), and from time to time this system is described as a suitable STM starting-point. The Condor television seeker and data link were also proposed for incorporation in a Harpoon air-frame (1978).

In 1978 the Navy established an operational requirement for a new air-to-surface missile, a follow-on to Harpoon. Quite possibly it was to have been a development of the low-volume ramjet (LVRJ) technology which Vought had been testing for some time. However, on 27 March 1980 William J Perry, the Undersecretary of Defense for Research and Engineering, directed the Navy to use a derivative of the General Dynamics Tomahawk cruise missile in a joint Navy-Air Force program; it was to be designated MRASM, the



4

5



Medium Range Air to Surface Missile. The Navy's version was tentatively designated AGM-109I; it was to have had an imaging infrared seeker for attacks against ships. However, this version was canceled by the Secretary of Defense on 31 July 1980. The Navy, which had been funding the entire MRASM effort for FY80 and FY81, attempted to abandon the program in favor of an IIR version of Harpoon, claiming at one point that such a Harpoon would cost \$820,000, compared to \$1.25 million for MRASM (OSD figures were \$810,000 vs \$1.5 million).

However, the Navy was directed to return to the MRASM program. It had argued that the basic long-range Tomahawk could do much the same job without adding the cost and complexity of an airplane - which in its case reduces the maximum size of the MRASM missile (to a length of 192in, requiring swept wings to hold the proper center of pressure). In 1983, then, there is a considerable family of Tomahawk variants: AGM-109A, the strategic nuclear version; BGM-109B/E, antiship variants with conventional warheads (E is the MRASM version); BGM-109C, the land

attack version with a unitary warhead; BGM-109E/F, a land attack version with submunition warheads, for airfield strikes (and with an optical correlation seeker; F is the MRASM variant); BGM-109G, and land attack variant with a dial-a-yield nuclear warhead, for the European theatre; BGM-109H, a proposed Navy replacement for AGM-109C with a simplified guidance system; and AGM-109J, a proposed Air Force variant for airfield attack. In each case, BGM represents a ground- or ship-launched weapon, AGM (as in AGM-109E) a form of MRASM. The IIR Harpoon has been revived, and in 1983 there is some doubt as to whether the Navy forms of MRASM will ever enter service.

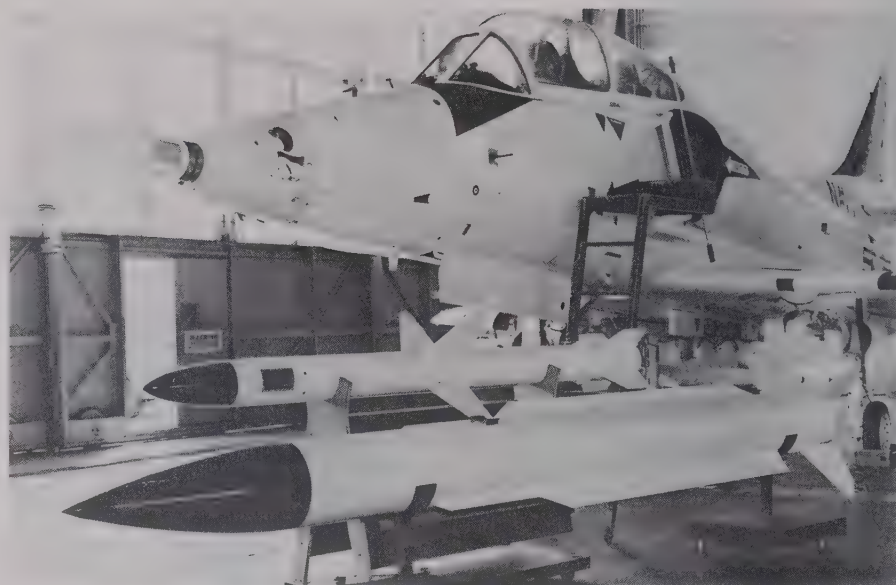
8. Antiradar missiles

Shrike

The specialized antiradar missiles (ARMs) are another branch of the Navy air-to-surface missile family, requiring separate listing because they are above all a means of improving the survivability of conventional attack aircraft (often using gravity bombs) by deterring an enemy from operating his defensive radars, or by destroying those radars directly. Corvus used an ARM-like guidance system, but it was the primary means of destroying a hard target of inherent value. Experience in Vietnam showed that even the small ARM warhead was often sufficient to disable a modern warship by damaging her topside electronic antennas; ARM weapons such as Shrike then became potential means for directly attacking warships, with the great advantage that they could home from great distances.

The first specialized Navy tactical ARM, Shrike (ASM-N-10, later AGM-45A) was essentially a Sparrow airframe with an enlarged (145lb) blast-fragmentation warhead and a somewhat smaller rocket motor, for a speed reported as Mach 2, a range of up to 25nm, and a total weight of up to 390lb. Shrike was initially carried by Skyhawks and Intruders, and later by Air Force 'Wild Weasels' and by Israeli aircraft in the 1973 war. It was not entirely satisfactory in combat, due to limitations inherent in its design. First, it required a pretuned seeker set for the particular radar it was to attack; a total of thirteen such seekers have reportedly been developed. Thus an aircraft armed with only one or two Shrikes might well be defeated by a sufficiently varied enemy radar system. The seeker is, moreover, rigidly mounted in the missile, so that the entire missile must be pointed at the target at the moment of launch. The sudden diving attack which results is in itself a warning to the threat radar, which can be shut down to protect itself. In that case the missile goes ballistic, as it has no memory circuits to act as a backup. Even so, Shrike was widely and successfully used both in Vietnam and in the Middle East, procurement ending only in FY80 with an Air Force order for 600. Total production was about 18,500; Shrike will remain in service through the 1980s pending replacement by the new HARM.

Shrike was always considered an interim weapon, for short ranges only. Its development began in 1958, and in February 1960 a requirement for a short-range ARM was issued. Production began in 1963, by a consortium headed by Texas Instruments and Sperry. Shrike entered fleet service in 1965, and combat in 1966. Meanwhile, Operational Requirements for longer-ranged weapons were framed. For example, a Requirement issued in March 1962 called for two new ARMs: ARM I would be effective at up to 50nm, and ARM II would outrange and defeat Soviet-bloc early warning and GCI (Ground Controlled Intercept) radars, which implies a range of about 100nm. Neither was built, but the requirements suggest what was needed. In fact the



next ARM, Standard ARM, was extemporized to overcome the failings Shrike demonstrated in Southeast Asia.

Standard ARM

In September 1966, with Shrike performing poorly in combat, the Naval Air Systems Command contracted with General Dynamics (Pomona) for a higher-performance, longer-range ARM with a more powerful warhead, an ARM version of the existing Standard surface-to-air missile, AGM-78. Initially the seeker was the existing Shrike type (Mod 0) but it was soon replaced by a Maxson wide-band type (Mod 1, or AGM-78B) requiring no pretuning. The seeker was, moreover, gimballed to permit a wider range of maneuver by the launch aircraft and, perhaps more importantly, to eliminate the need for the characteristic diving approach of Shrike carriers. Standard ARM

1 The Standard ARM (AGM-78, foreground) and Shrike (AGM-45, rear) antiradar missiles were employed in Vietnam by both Navy and Air Force aircraft; this February 1978 view gives some idea of the size difference between the two weapons. The TA-4 Skyhawk at the rear is probably carrying a HARM test seeker in its nose. Shrike itself was based on the Sparrow III airframe; it will probably remain in production through the early 1980s.

2 The Texas Instruments High-speed Anti-Radiation Missile (HARM, AGM-88A) is to replace both Shrike and Standard ARM, the latter now out of production. This prototype HARM was photographed at China Lake on 21 February 1978, slung from an A-7.

also incorporated a memory circuit which was expected to permit it to attack even after the threat radar had shut down; some sources report that its launch aircraft computed a flight trajectory, using an IBM Four-Pi computer and and TIAS (Target Identification and Acquisition System). Finally, it had an impact

marker, to facilitate subsequent attacks on a concealed target. Development was very rapid, with tests in FY67-68 and production beginning in FY68. AGM-78A production was completed in FY70, AGM-78B in FY71, AGM-78C (for the Air Force) in FY71-72, and AGM-78D (developed FY70-71) in FY74. Deliveries of the last model, AGM-78D-2, were completed in August 1976. Altogether, over 3000 were produced. General Dynamics proposed a new version with a lighter rocket motor as an interim HARM, but it was not approved. Speed is reportedly Mach 2.5, which may include the booster effect of the launching aircraft. Range is reported as up to 35nm, which is probably a gross understatement, given the range of the ship-launched Standard SAM (which, after all, has no booster and must be flying at maximum speed and altitude at the limit of its rated range – and must therefore have a surface-to-surface range of about twice its rated surface-to-air range) and also the ranges of the threat radars: Standard ARM is reportedly effective against early warning and GCI radar. A more realistic figure, then, might be 60nm or more.

HARM

Standard ARM was clearly an interim weapon. Indeed, it was used in Southeast Asia on only a limited basis, and its memory circuits proved less than successful. In addition, it was very expensive – five times the cost of Shrike (and three times as heavy). Standard ARM production therefore terminated long before that of the earlier missile, while efforts proceeded to develop some more satisfactory ARM. The approach taken was to emphasize high speed. The faster the missile, the more difficult for a radar operator to shut down in time, partic-

ularly if the missile required no characteristic launch maneuver. Higher speed also, incidentally, conferred longer aerodynamic range, although it might be argued that radar shutdown tactics might reduce effective homing range considerably. However, if the missile could acquire its radar targets well after launch, that problem, too, might be overcome. HARM, the High Speed ARM, is an attempt to follow this approach. AGM-88A is a bi-service (Navy and Air Force) program, but the Navy is the lead service, with work beginning at China Lake as early as FY70, *ie* late 1969. The Proposed Technical Approach paper was published in FY71 and breadboard models of the guidance system built during FY72, when the first captive flights were undertaken. This rapid progress was halted by severe technical problems, which were overcome only late in 1973. Hughes was originally the guidance contractor, but in 1973 proposals, including those for guidance, were requested from a wide range of contractors; Texas Instruments won a preliminary design award on 24 May 1974, when it was hoped that each missile would cost about \$85,000 (compared to \$30,444 for a Shrike in FY75, or \$123,400 for AGM-78).

HARM has a warhead comparable to that of Shrike or Standard ARM but it is smaller, with greater range and improved sensitivity, and with broadband seeker coverage. HARM is also unusual in its capability against continuous-wave (CW) radars such as those in the Soviet SA-6 system, and in its dependence upon software (programming), so that it is easier to update to meet an evolving threat. In addition, it must be one of the first missiles to use a laser proximity fuze: its 145lb warhead is detonated at a preset height by a laser ranger. As of 1979, HARM requirements were

reportedly 6636 for the Navy and 7718 for the Air Force, with a reported price (FY79) of \$199,000 per missile. Operational evaluation was scheduled for January 1981.

In fact, however, HARM suffered a number of delays, as problems in its guidance system were encountered. For example, against some Soviet naval radars, at low frequency, it could not distinguish easily between threats forward or aft of the airplane carrying it. At high frequencies, it suffered from multipath, *ie* from an inability to distinguish between a direct signal and one reflected from some point on the ground; the solution was a change in seeker logic, changing the way the seeker responds to the leading edge of the pulse it receives. These improvements were made in December 1979, and flight-tested the next January: three out of four missiles were successful. However, the program was delayed over a year in the process, and the production decision delayed to September 1981.

HARM was first test-flown in 1975, and can operate in three alternative modes: self-protect, in which a threat receiver (ALR-45) on the carrier aircraft detects the threat radar, and instructs the missile, which is then fired. In the target of opportunity mode, the missile itself locks onto threat radars, using its great sensitivity. Finally, in the prebriefed mode it is fired blind in the direction of a known radar, seeking emissions. The existence of the latter mode, for a missile capable, probably, of well over Mach 2, suggests a very long range indeed; HARM has been officially described as out-ranging Shrike. Like Shrike and Standard ARM, HARM can now be fired in a 'loft' mode in which it acquires its target on the way down, and gains considerably in range due to its trajectory.

9. Harpoon

Origins

The other major US air-to-surface weapon of the 1980s and 1990s, Harpoon, is sufficiently important, and sufficiently unusual, to deserve specialized coverage. It originated as a weapon against surfaced submarines, as its name implies: a 'harpoon' to attack 'whales'. They were an important target because the principal Soviet anticarrier missile, SS-N-3 ('Shaddock'), required its launch submarine to spend a considerable period on the surface, launching and then guiding it. Such a submarine might well be detected by a long-range patrol airplane, but it would be able to submerge before the airplane could attack with rockets, torpedoes, depth charges, or even Bullpup. It should be noted, too, that the earliest Soviet ballistic missile submarines had to surface in order to fire.

The early origins of Harpoon are somewhat obscure; NAVAIR began a study of a long-range antiship missile in 1965, and McDonnell Douglas privately financed studies of a long-range antiship missile at the same time. The US Navy considered mounting such a weapon

aboard surface ships even before the sinking of the Israeli destroyer *Eilat* in October 1967 dramatized its value. At this time the CNO accelerated anti-surface-warfare (ASUW) programs. The Navy project did not begin as such until 1968, at which time Harpoon was an air-to-surface missile. NAVAIR formally released an RFP in 1970, and McDonnell Douglas was selected officially as prime contractor in June 1971; Harpoon first flew as a surface-to-air missile on 17 October 1972, the submarine-to-surface simulated test following on 15 November. The first development drop of the air-to-surface version was made from a P-3 in May 1972, powered flights beginning in July, with a particularly successful shot (including the 'pop-up' terminal maneuver) against the target ship *Ingersoll* on 20 December 1972.

Technical Characteristics

From the first, Harpoon development emphasized simplicity and low technical risk. Guidance is 'fire and forget': once the missile is on its way, the launch platform has no further

contact with it. The frequency-agile active radar seeker can be set for large, medium or small target acquisition windows, which settings determine the range at which the radar is switched on. The smaller the window, the more precise the initial target data must be, but also the smaller the chance that the missile can be defeated by decoying. Generally Harpoon is launched with preset range and bearing (RBL, or range-and-bearing launch mode), turning on its radar only at the last possible moment to avoid alerting an enemy. However, there is an alternative bearing-only (BOL) mode in which the radar seeker operates for most of the missile flight path. The seeker itself can scan to 45° to either side of the missile flight path, and the missile follows a preset search pattern if it fails to find a target on its first path. Once the target is detected, it can climb rapidly ('pop-up') and then dive into the target so as further to disrupt target defenses.

The design requirement for long (over 50nm) range was set late in the program, after McDonnell Douglas was selected, and a turbojet was substituted for the rocket

V. AIR-TO-SURFACE WEAPONS

originally planned. Ranges as great as 75nm have been reported. Since the turbojet does not produce much thrust, the surface ship and submarine versions (see Part VI) require additional solid-fuel boosters. Long range also requires some form of midcourse guidance. In the case of Harpoon, it is a three-axis Attitude Reference Assembly (ARA) consisting of three body-mounted rate gyros which together provide angular rate data almost equivalent to that which a full free inertial system might provide, and adequate for the ranges involved. ARA was the first US production strapdown system, and it is considerably less expensive than a more conventional inertial type.

Harpoon has a 510lb penetrating blast warhead developed by China Lake, originally to destroy pressure hulls but then to destroy the compartment or compartments which it might penetrate in striking a surface warship. It has been criticized as too small to kill a massive warship such as a *Kiev* or *Kirov*; the warhead (not the missile as a whole) is little larger than a 10in shell. On the other hand, the missile imparts considerable kinetic energy and itself is likely to damage the target ship; its liquid fuel will add to the fire which the explosion will probably start. Moreover, even a relatively small missile such as Harpoon has the potential to incapacitate a large modern warship by damaging or destroying 'soft' topside systems such as antennas and wiring. Harpoon is not in the size class of the standard Soviet antiship missiles, but the Soviet weapons presumably were designed with larger, and much tougher, targets in mind, such as aircraft carriers.

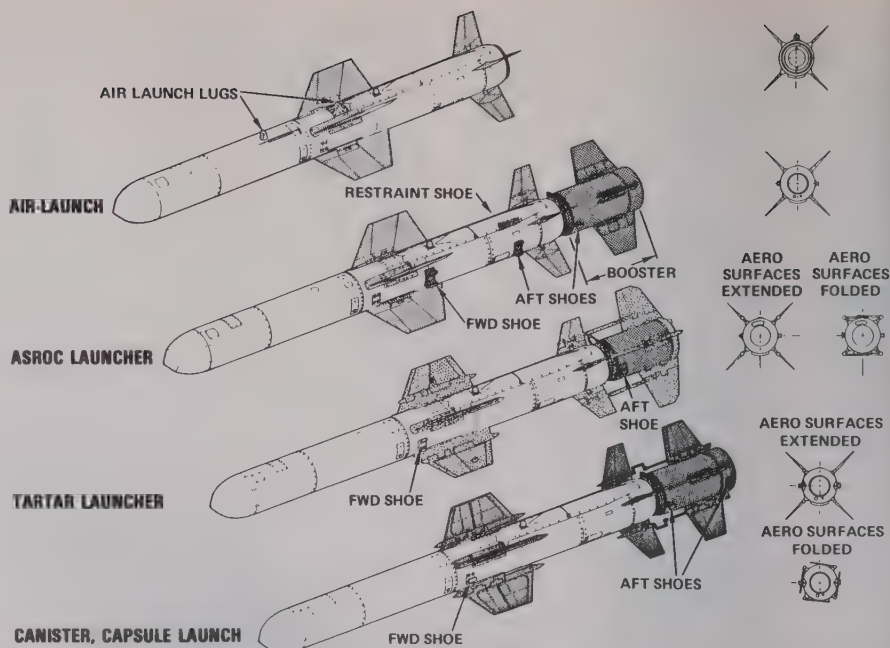
Reportedly one Harpoon will destroy an 'Osa', 'Komar' or 'Nanuchka' class missile boat; two will suffice to disable a destroyer (presumably a 'Krivak') and four a missile cruiser; five hits should disable a *Kiev*. These figures do not allow for missiles lost against Soviet countermeasures, such as the SA-N-4 point defense missile and the Soviet equivalent of the US Gatling gun. Estimates of the survivability of Harpoon against such threats vary widely, reflecting the absence of knowledge of their detailed workings.

The air-launched version of Harpoon, AGM-84A, entered service in 1979 aboard P-3 Orion patrol aircraft, followed (1981) by A-6 Intruders, and installations have also been proposed for the S-3 carrier ASW aircraft. The F-18 fighter-bomber is also a candidate platform, and the Royal Norwegian Air Force is to carry Harpoon aboard its F-16 fighters. Harpoon is more important as a surface-launched than as an air-launched weapon, but it was initially designed for the latter role, and so deserves description here.

Future Development

Blocks IB and IC, now being introduced, show increased range and a new sea-skimming flight profile; they introduce way points and 'terminal pop-up' into the design. Survivability in the face of improving Soviet defenses is a major issue: when Harpoon was designed, Soviet SAMs had poor low-altitude performance. The terminal pop-up counters systems such as Phalanx by imposing a high angular rate on them. McDonnell Douglas expects to produce a Block II for the 1990s, with a range of over 100nm, variable mission profiles, and improved discrimination between targets and nontargets.

For example, missile range will be improved



about 15 percent merely by exchanging JP-10 for JP-5 fuel; the Navy is also considering larger increases by means of an 11in plug (extension) to the airframe proper, for added fuel capacity. There is also continuing interest in countermeasures resistance, as well as interest in a radar seeker improvement which will permit the radar to set priorities and thus to select high-value targets though they may have smaller radar cross-sections than nearby lower-value ones. Such a system is essential if Harpoon (or, for that matter, any radar-guided antiship weapon) is to be used effectively against groups of ships, or warships among nontargets. McDonnell Douglas has reportedly proposed to modify the missile and its fire control system to feed target signature to the weapon before launch, so that it can choose one of several potential targets on the basis of radar signature comparisons.

THE HARPOON MISSILE FAMILY
One missile body used for all applications

2 A Harpoon, presumably one of the earliest test series, under the wing of an A-4 Skyhawk at Point Mugu, 29 May 1972. Note the hinges for wing and tailfin folds, to fit the weapon into a constricted launcher, such as the ASROC 'box' aboard surface ships. This photograph, then, emphasizes the commonality between different Harpoon versions, the shipboard one having, in addition, a booster at the tail.

Part VI

Surface-to-

surface missiles

Production Evaluation Model 5 of the Poseidon (UGM-73A) missile is fired from the *Daniel Boone*, 6 October 1970. Poseidon suffered severe guidance problems during the late 1960s, and for a time the entire fleet was considered ineffective. The mast rising from the sea alongside the missile is a submarine telemetry antenna, and would not be required in a wartime mission



1. Introduction

Missiles have had a long history in the US Navy, from the earliest American surface-launched pilotless aircraft, the Sperry 'Aerial Torpedo' of 1916, onwards. Generally they have competed with the other major long-range naval weapon system, the carrier airplane. For example, the Assault Drone program was canceled in 1944 after the Chief of Naval Operations decided that the only missile programs to continue would be those applicable to carrier aircraft. Postwar, the program to fire Regulus from carriers died largely due to opposition from the carrier aviators. However, with the advent of Polaris, naval strategic attack firepower shifted to the missiles, a shift symbolized by the reassignment of the North American Vigilante (A3J/A-5) to the long-range reconnaissance role. On the tactical level, the dominance of carrier airplanes was such that there was no serious program for a ship-to-ship missile until the shock of the *Eilat* sinking (by a Soviet-built 'Styx') in October 1967. To be fair, there was a US ship-to-ship capability before that, but it resided in secondary capabilities of existing surface-to-air missiles, which were tested from time to time in the anti-ship role.

Compared to a manned airplane, a missile is generally considerably smaller, and hence less subject to antiaircraft fire; it also has the advantage of not exposing its pilot to danger. It is also considerably less expensive on a single-shot basis. More generally, compared to any multiple-shot naval weapon system (such as a gun or an attack bomber), a self-propelled missile concentrates more of the total system cost and size in its expendable single shot. The remainder of the system, the part which affects ship size and cost, is necessarily smaller. It follows that the missile can be fired by a relatively small ship, such as a fast patrol boat, and yet may have the same impact per round as a major-caliber naval gun or a heavy attack bomber. Since such economics depend upon the impact of a single round, they may be reversed if many missiles (*ie* many relatively massive projectiles) must be carried. For example, the Talos surface-to-air missile was about the size of the Soviet 'Styx', which could be carried by a modified torpedo boat. Yet it took a large cruiser to accommodate the launching and handling system for about 40 to 50 Talos. Missiles are therefore most attractive in roles calling for single hits, *ie* in attacks on point targets. The major exception was nuclear attack, in which a single weapon sufficed against an area target.

The major case of area *vs* point targets was shore bombardment in support of landing operations. As the heavy-gun ships were retired, the need for some new landing fire support weapon seemed more and more urgent, and in the early 1960s a variety of missile solutions were proposed. The survival of a gun system, the lightweight 8in/55, at this time testifies to the poor economics of sophisticated missiles assigned to attack area targets requiring heavy concentrations of fire. On the



Missile tubes of the *Sam Rayburn*, at Newport News.

other hand, missiles do appear to be quite capable of supplanting guns in the antiship role, in which one or two hits can be decisive. In Vietnam, they were also quite effective against North Vietnamese radar stations, again point targets.

2. Pre-1945 projects

The Sperry Aerial Torpedo

The first US Navy missile, the Sperry Aerial Torpedo, was conceived even before the aircraft carrier. Elmer Sperry, the inventor of the gyroscope, proposed an unmanned airplane which could be set to fly a steady course and to dive into a target at a preset range. He was originally financed privately by Dr P C Hewitt, later a member of the Aeronautics Committee of the Naval Consulting Board; a BuOrd representative, Lt T S Wilkinson, witnessed a test of such an unpiloted airplane on 12 September 1916. The pilot took off, handed over control to the Sperry equipment, and the plane climbed to a preset altitude, maintaining altitude and compass heading until its preset dive. Wilkinson was impressed with the concept, but did not consider the weapon accurate enough to attack ship targets; he saw it as useful primarily to the Army, for use against city-sized targets. In concept, the Aerial Torpedo was equivalent to later inertially guided missiles, with all of their faults of excessive CEP. Despite Wilkinson's views, Navy interest continued; on 11 April 1917 the Naval Consulting Board (of which Sperry was a member) appropriated funds for additional work.

It appears that no one at the time appreciated the extent to which the success of the project depended on a combination of a successful guidance system and a suitable missile airframe. Sperry initially approached the Curtiss company, which promised him a small unmanned airplane (without guidance) within 30 days (!), actually meeting this deadline – though with an unsuccessful design. There was also some difficulty in launching, and a special flywheel catapult had to be designed. It was the work of Carl Norden, who thereby entered the gyroscope and fire control field; the flywheel catapult was later installed, in enlarged form, aboard the earliest US carriers. It was the only element of the Sperry system to see operational service, the first successful catapult launch being made on 23 September 1918. In October, the well-tried N-9 training biplane was made the test airframe, and on 17 October an N-9 made a successful flight. Set for 14,500yds, it kept flying until its fuel was exhausted, at about 70 miles range. Its gyroscope kept it within 2° of the original course. Work continued post-war, with a series of alternative airframes, but interest fell off early in 1921 as it became clear that the missile could not be set to fly at the low altitudes needed to attack ships; nor was it accurate enough, as Wilkinson had predicted five years earlier.

Sperry himself suggested radio control (from an accompanying airplane) as the cure for poor guidance, using it successfully in Army experiments in June 1922. BuOrd saw radio control as the basis for an air target, flying an N-9 under the control of an HS flying boat on 15 September 1924. Unfortunately the N-9 sank on landing and a VE-7H to which the system was transferred failed on takeoff. Better control equipment was evolved in 1926–28, but

there were no further flights, and the concept fell into disfavor. In 1935, however, Commander Aircraft, Battle Force asked the Chief of Naval Operations to provide fast radio-controlled aircraft targets for bombing practice. The Bureau of Aeronautics supported him, fearing that current antiaircraft training was unrealistic, and in a 2 February 1936 memorandum the Commander of the Battle Force, Admiral Harris Laning, asked for radio-controlled targets on the ground that existing towed targets could not simulate dive-bombers. The Chief of Naval Operations, Admiral William H Standley, was favorable, partly in view of his own experience witnessing Queen Bee target operations in England. He authorized the project in March 1936, and that July Lt Cdr D S Fahrney was ordered to supervise the project within BuAer. He was responsible for the term 'drone', which was later generally applied to such radio-controlled aircraft.

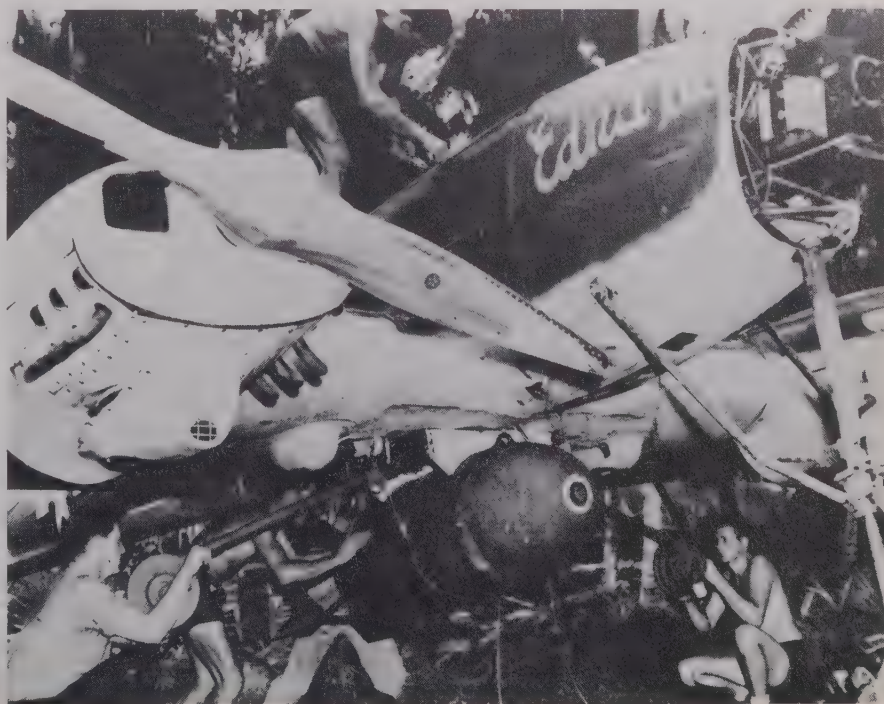
Attack Drones

Fahrney looked beyond the target project towards offensive use of drones. For example, in his progress report of 2 July 1937 he called for remote-controlled low-altitude bombers; for remote-controlled interceptors (launched from a carrier catapult, but controlled from a fast fighter); for composite aerial bombers (drones launched from twin-engine fighters; and for drone torpedo-carriers. He was not encouraged at first, but found some senior officers, such as the CinC US Fleet, Admiral Claude Bloch, favorable. In November 1939 the CNO authorized a drone to simulate a torpedo run (as a target), and the following

February he approved a drone torpedo-bomber. In July 1940 the drone squadron VJ-3) showed that a drone could be directed visually from a distance to attack a target; the new technology of television might be used to permit control from a considerable distance. The drone was conceived of as a torpedo or depth-charge bomber, controllable by an observer as much as a mile and a half astern; by August 1941 control range had been increased to as much as six miles, using a television camera aboard the drone, and control pilots no longer had to keep in visual contact with the attacking drone. The Bureau of Aeronautics proposed drone conversions of existing obsolete aircraft, such as the TBD torpedo-bomber. There was some hope that a drone could pick up a target at sea at eight miles, while under remote control (from the air) at 50 or 60.

Two drone attack projects were begun, using visual (Project 'Dog') and TV (Project 'Fox') guidance; on 9 April 1942 a 'Fox' drone made a successful torpedo run against the destroyer *Aaron Ward*. Ten days later a TV-guided BG-1 drone dove into a target. The simpler visual system ('Dog') was less successful. With the success of the 'Fox' tests, BuAer was ready for a service test of its weapon, ordering 200 plastic drones (100 TDN-1s from the Naval Aircraft Factory, and 100 TDR-1s from Interstate). They were very low-performance aircraft, chosen more for their lack of impact on the

The TDR-1 assault drone was the first US Navy guided missile to enter combat. Here one is prepared for an attack on Rabaul, probably in September 1944.



wartime aircraft program than for any inherent value. The original specification called for a speed of 150kts, a range of 600nm, a 2000lb payload, and television guidance; the improved TD2R was expected to make 200kts and a range of 1700nm. In retrospect it appears that this low performance made for reduced enthusiasm; the drone did not appear to many aviators to be a serious combat weapon, capable of overcoming enemy defenses. For a time, however, it prospered. Admiral King saw movies of the 'Fox'/'Dog' tests in May 1942, and approved a program for 1000 drones on an urgent basis; eighteen squadrons would be used for the first attack, with 162 control planes and 500 attack drones (plus another 500 in reserve). BuAer feared that it would be unable to mount so large a program, and asked that it be cut back to 500, which the CNO accepted.

At first it was hoped that the weapon might enter combat by mid-1943, but there were numerous delays; tests did not begin until February and March 1943. They were successful enough for the Vice CNO (Admiral F J Horne) to direct an increase to 3000 drones; BuAer cut the program back to 1500 beyond the 500 already on order. A Special Air Task Force, US Fleets (SATFOR) consisting of three Special Air Task Groups (STAGs) was formed, with all three STAGs (each consisting of three drone squadrons) in training by 1 January 1944. By that time, however, conventional carrier aircraft were clearly winning the Pacific War, and enthusiasm for the unconventional attack aircraft was waning. STAG 1 (TDR drones using Avengers for control) was scheduled to make the first combat test, at Eniwetok, but that battle ended before it could be used. On 10 March 1944 STAGs 2 and 3 were decommissioned, and STAG 1 was reconstituted with four drone squadrons. Admiral King began to remark that effort should be concentrated on guided weapons suitable for use by carrier aircraft, and not on 'one-shot' weapons which would consume valuable carrier deck space – such as the drones.

STAG 1 did get a brief chance at combat. It arrived in the Russell Islands in June 1944, and successfully attacked the beached Japanese freighter *Yamazuki Maru*, at Cape Esperance,

30 July 1944, control planes operating at a range of 7 miles. The first Pacific combat operation was an attack on a beached anti-aircraft ship at Khili, South Bougainville, on 27 September 1944. It was quite successful, the small size of the TDR drone apparently making it a difficult anti-aircraft target. However, STAG 1 was soon withdrawn and the entire program killed.

Assault drone technology was also applied to the control of war-weary heavy bombers in Europe, PV-1 control aircraft operating with PB4Y Liberators. The first such aircraft exploded in midair, killing its pilots (who were supposed to bail out after takeoff), but one drone did successfully attack Heligoland on 3 September 1944, in what appears to have been the first combat use of television guidance. Not long after, the Navy drone program was disbanded, leaving a parallel Army program. Full scale combat drone operation would not be revived until the Korean War, using F6F Hellcats.

Loon

Almost at the same time that the drone program was ending, a second Navy long-range missile program, 'Loon', was begun. Loon was a radio-controlled adaptation of the Army's copy of the German V-1 missile; presumably its popularity was due in some part to the success of the latter in evading British interception, at least early in the V-1 campaign. The Army program began in July 1944, orders for a thousand 'jet bombs' following on 2 August. Early in November, Admiral King showed interest in experimental operation of these weapons from an escort carrier, as a form of long-range artillery. The Army was asked for 51 JB-2s and a conference in BuAer decided that the Navy version would use radio control (with three signals: right, left, and dive) and would incorporate a radar beacon for guidance by shipboard or airborne radars. Minimum operational range would be 100nm, the missile cruising at 1000–6000ft, and its control aircraft at 10,000–20,000ft; in December, planning called for use against land (area) targets using airborne early warning aircraft ('Cadillac') for control at 100nm, and against ship targets at less than 100nm using ship fire control radars.

Drones were to be launched every two minutes. Since the pulsejet required an initial speed of 300mph to operate, BuAer began work on a powder-powered slotted-tube catapult (XM-1).

The V-1 copy proved considerably more popular than the assault drone; Admiral King approved a large-scale program on 12 April 1945, and the codename 'Loon' was assigned on the 16th. Point Mugu was chosen as the test site, a complete escort carrier unit beginning training there in July 1945. The special catapult was installed and tested in September – by which time the end of the war had reoriented the program to research and development, with more effective surface-to-surface weapons in sight. The first Loon was fired on 7 January 1946, but its engine died and it crashed.

Although Loon was the primary Navy surface-to-surface missile of this period, there was also interest in a ship-launched variant of Gorgon IIC (see Parts IV and V), capable of carrying a 1000lb warhead at 410mph for 65 miles (with an increase to 130 planned) and with a somewhat better accuracy (1-mile CEP) than Loon. In May 1945, it was estimated that Gorgon could be operational aboard escort carriers or even LSTs by 1 January 1946. However, with the end of the war, Gorgon vanished as an alternative; Loons, ordered in very large numbers (up to 50,000) by the Army, were more available as test vehicles. Loon, designated KUW-1 in a new 'utility drone' series, was not considered a potentially operational weapon as much as a means of exploring the potential of guided missiles.

A Loon missile, the US version of the German V-1, being prepared for launching from the submarine *Carbonero*, 19 May 1949. The large radar is SV-4.



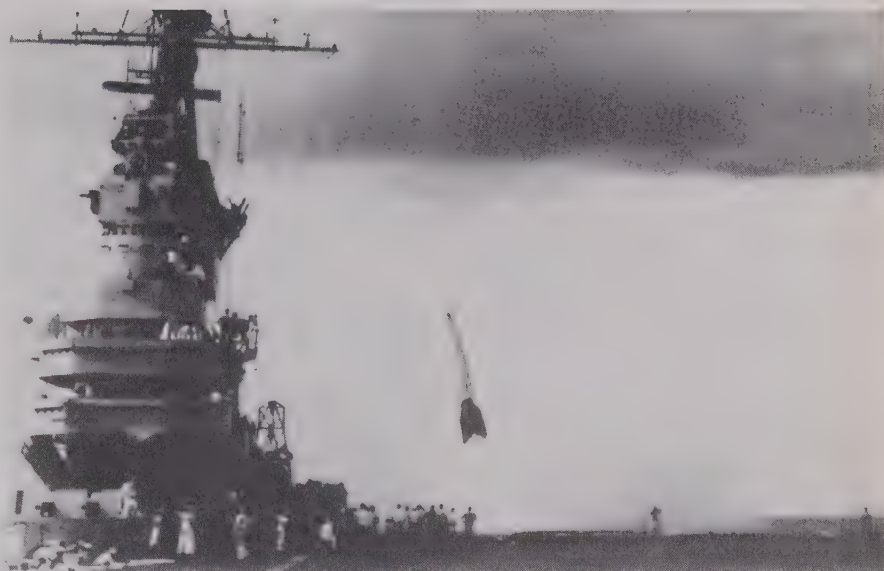
3. Strategic missiles

Early Studies

Missiles and nuclear weapons seemed very much the wave of the future at the end of World War Two, to the extent that a special Guided Missile Division (Op-51) was established within the organization of the DCNO (Air) in the Office of the Chief of Naval Operations. It was clear that future wars would be fought by missiles, and that a very great variety of such weapons was already under development, both by BuOrd and by BuAer. The primary issue was which weapons to choose, which kinds of weapons to press forward. The submarine community very early began to press for a missile-attack mission, which desire was natural in view of the lack of submarine targets in the Soviet naval and merchant fleets, *ie* in the fleets the United States would most likely confront in any future war. The aviation community was less interested in surface-to-surface missiles, as it was beginning work on long-range carrier-launched bombers such as the North American AJ (Savage). Nor was it entirely clear whether future naval missiles would be air-breathers descended from the German V-1/Loon or pure rockets such as the German V-2 (which the Navy successfully launched from the carrier *Midway* in 1947).

Several studies were made. For example, on 30 April 1946, Rear Admiral H G Bowen, then chief of the Navy Office of Research and Inventions, submitted a study of shipboard guided missiles to the General Board. He considered four types: antiaircraft (which he considered most urgent); antiship; anti-land-target; and antisubmarine. Bowen thought of the V-1 as his prototype antiship weapon. Stowage would probably be in broken-down condition, with assembly and launch aboard ship. Only aircraft carriers would be able to stow sufficient numbers of these large surface-to-surface missiles (5200lb for antiship, perhaps 20,000lb for antiland) with 2000lb warheads; battleships might possibly be suitable, but existing submarines seemed too small. On 4 June 1946 BuOrd suggested carriers for a 'vertical' launcher, or escort carriers, LSTs or submarines for a 'near horizontal' one. Plans were actually made for several experimental surface-ship conversions, most notably one of the incomplete large cruiser *Hawaii* (SCB-26); in addition, the original expectation for the *Essex* conversion (SCB-27); was that it would be a missile ship, and the *Kentucky* was to have been completed as a missile-carrying battleship under Project SCB-19 (BB-AA). Finally, SCB-28 was a missile submarine conversion (Loon); there were also SCB-33 for a submarine (Guided Weapons) and SCB-34, for a submarine (Aircraft Launcher). Some of these designations were somewhat ambiguous, as BuAer called its missileless aircraft (P/A).

On 12 March 1946 the Chief of Naval Operations began to reorient and consolidate existing Navy missile programs. Loon became a Launching Test Vehicle (LTV) and a possible interim weapon; Bat (see part V) became



an interim war reserve weapon; and high priority was given to ASW and AAW missile projects. It should be kept in mind that, at the time, nuclear weapons weighed about 8000lb; to fire a conventional weapon at an area target was grossly uneconomical. Thus the German V-2 was ruled out as an efficient area bombardment weapon, at least for the time being. However, an air breather could carry a much larger percentage of its weight in payload, and was therefore much more promising as a long-range attack weapon. Moreover, given existing technology, it could be guided effectively, whereas the ballistic missile would have to be largely or completely inertial.

BuAer conceived a large P/A program (see Part IV), which included three 'surface-to-ground' (S/G) projects: P/A V (long-range, Douglas and Goodyear); P/A VI (short-range, landing support operations, Vought); and P/A VII (medium-range, Grumman). As an interim weapon, BuAer proposed the Carrier Bomber, which was to deliver an 8000lb (read nuclear) weapon to within a 1nm CEP at a range of 1200-1400nm. Existing carriers could not operate aircraft over more than about 700nm, but, according to the Bureau, 'it is now [1947] fairly well agreed that carrier striking power cannot be limited to a range of 600 to 700 miles, otherwise the carrier program would stand in a precarious situation when compared to the long range bombardment plans of the Army Air Forces... The carrier must extend its bombing range to 1200 to 1400nm... to be of any great value. It is possible that a future enemy, by seizure of certain islands, could make fleet operation impossible closer than 1000nm to some of his important coastal bases.' The contemplated solution was a drone version of the new AJ nuclear attack bomber, accompanied by a control airplane. In fact the drone AJ was never deployed, nor did Douglas and Goodyear succeed in developing the long-range surface-to-surface missile. Instead, the

As early as 1946 there were serious proposals within the Navy for firing large ballistic rockets, such as the German V-2, from surface ships. It is not clear in retrospect whether nuclear warheads were contemplated, or indeed whether those making the proposals were aware of the extremely poor accuracy of such weapons. Even so, sketch designs for the conversion of the 'large cruiser' *Hawaii* to a missile test/operational ship show large stabilized pits for V-2s. Operation 'Sandy', the firing of a V-2 from the deck of the carrier *Midway* (October 1947) was part of this program. It was officially advertised as the first firing of a large bombardment rocket from a ship (or, indeed, from any moving platform); immediately afterwards the *Midway* resumed normal flight operations.

short- and medium-range projects were considerably upgraded to become, respectively, the turbojet *Regulus* and the ramjet *Rigel*, SSN-N-8 and -6, respectively. Both were designed for a range of about 300nm and for launch from submarines.

The precise origins of the submarine missile program cannot be traced, but on 5 March 1946 the CNO ordered the conversion of two submarine hulls to fire Loon. The submarine *Cusk* was scheduled for conversion in November, but actually entered Mare Island on 8 January 1947, emerging on 6 February and firing her first Loon (unsuccessfully) on the 18th, success following on 7 March with a 60-mile flight. By this time the CNO (then Admiral Nimitz) was enthusiastic, as he was looking towards a 500-mile missile with a 3000lb payload in the FY49 Guided Missile Development Program, as an immediate operational requirement for a submarine bombardment missile.

Rigel

Of the two major missile programs of the time, *Rigel* was the more advanced, and was considered more survivable against antiaircraft fire. On its first flight, 4 May 1950, it attained a speed of Mach 1.9 and a range of 20.7 miles;

VI. SURFACE-TO-SURFACE MISSILES

- 1 Regulus I firing from a mobile pad, 1960, with an FJ chase plane above. This is undoubtedly a training round with retractable landing gear for recovery. The simplicity of the launching device is noticeable; it was relatively easy to adapt cruisers, and even *Essex* class carriers, to accommodate the 'RAM' or Regulus Attack Missile, system. Note the absence of a horizontal tail on the missile.
- 2 The submarine *Grayback*, built specifically to fire the Regulus I missile, is shown entering San Diego harbor, with her missile raised into firing position. Missiles were stowed in the two large cylindrical hangars forward; all that is lacking in this picture is the Regulus guidance radar raised from the submarine's sail.

later it attained Mach 2 and a range of 73.7 miles. These figures applied to the Flight Test Vehicle (FTV), a scaled-down version with an ultimate planned performance of Mach 2, 100nm, and a cruise altitude of 50,000ft at a launch weight of 5517lb, carrying a 1000lb warhead and achieving a CEP of 600yds; the full Tactical Missile (TM) was to fly at a similar speed and altitude, but to a range of 500nm, again with a 600yd CEP, and with a 3000lb warhead at a launch weight, including booster, of about 23,800lb. As of 1950, only the FTVs had flown, powered by a 28in supersonic ramjet developed by Marquardt from 1947 onwards.

It was expected that a converted fleet submarine would be able to carry one Rigel in a watertight hangar, launched by booster (and accelerated to Mach 1.7) up a short rail launcher inclined at 25–50°. Guidance would be by a modified form of LORAN, using a pair of guidance submarines with beacons. The latter could be submerged to periscope depth; the missile, at 50,000ft, would be able to interrogate them from a great distance, flying along a hyperbolic path established by their signals. In 1950 it appeared that a range of 500nm would permit a submarine to hit targets 200nm inland. Arrival at the release point was determined in the missile by comparison of a separate range measurement to one of the submarine beacons to the guidance signal from that beacon; at that point the missile would push over into a programmed, a ballistic, or a homing path to the target. In 1950 the hyperbolic guidance system had already been tested aboard aircraft, with very satisfactory results. However, Rigel was canceled on 5 August 1953, partly due to the size of the catapult it required to boost it to supersonic speed: even with rocket boosters, it needed 400ft. By way of contrast, the turbojet-powered Regulus could lift from a very short ('zero-length') launcher.

Regulus

Regulus began with a 3 October 1945 BuAer contract for missile design studies; in January 1946 Chance Vought was invited to bid on a 25nm P/A VI, a 300nm P/A VII, and also for a short-range air-to-surface missile, P/A V/AX. BuAer wanted it to work on the short-range surface-to-surface weapon, but Vought proposed instead a 200-mile missile, which BuAer accepted; some time later the requirement was doubled. Early concepts called for conventional warheads and very high accuracy, presumably because Regulus could carry only a 4000lb warhead. US nuclear weapons development before 1950 was oriented much more towards enlargement of the very small existing



stockpile than towards the design of more compact weapons; the first lightweight bomb, Mk 5 (3300lb, 43.5in in diameter, and, incidentally, the warhead for Regulus I, with a yield estimated at 120kt) was not tested until 1951. It is not, however, by any means clear to what extent BuAer or the Navy at large foresaw this development. Certainly by December 1950 Regulus was being described as a nuclear attack missile. However, in 1948, the General Board was told that DCNO (Operations) 'feels that the primary usefulness of a guided missile submarine is as an atomic headed weapon and I don't believe there is any weapon capable of carrying such a payload'. Probably the best explanation for BuAer's enthusiasm was a generic belief that guided missiles were the weapons of the future, that the problems would, somehow, be solved.

Admiral Gallery (Op-57) formally asked the Opnav atomic energy division to develop a Regulus warhead on 6 June 1949; the AEC Military Liaison Committee formally proposed four missiles as the first candidates for nuclear warheads that September, shortly after the detection of the first Soviet nuclear test.

Contract work on Regulus I began in June 1946, with studies covering a variety of supersonic ramjets. However, from August 1947

onwards Vought concentrated on an interim submarine-launched weapon, a conventional airplane powered by a turbojet. The first Flight Test Vehicle (FTV) flew under the control of a nearby airplane on 29 March 1951, the first shipboard launch (from *Norton Sound*) following on 3 November 1952, with the carrier *Princeton* launching a Regulus and two control aircraft on 16 December. The fleet submarine *Tunny* was converted to carry and launch two Regulus I between February 1952 and March 1953, firing her first on 15 July 1953; a second submarine, *Barbero*, was converted under the FY55 program. In addition, two diesel attack submarines, *Grayback* and *Growler* (FY53 and FY55 programs) were completed as Regulus launchers (four Regulus I or two of the larger Regulus II), and an additional diesel-powered missile submarine was reordered in 1956 with nuclear power (*Halibut*, FY56, for five Regulus I or two Regulus II). She was to have been followed by a class of even larger nuclear missile submarines (SSGN-594–596 of FY58 and SSGN-607 of FY59, each to carry four Regulus II) but all were reordered as attack submarines after the cancellation of the Regulus II program. By about 1955, the Regulus II program was envisaged as consisting of two diesel and fourteen nuclear submarines.



1 The Regulus II supersonic cruise missile is fired from the missile submarine *Grayback*; on this first test flight, 17 September 1958, the missile carried a payload of 'missile mail'.

2 Had the Regulus II program continued, submarine hull 594 would have been completed to this missile-firing configuration, with two hangars abeam the sail and two more in the bows. Instead, hull 594 became the attack submarine *Permit*. The large dome raised above the sail is probably a star-tracker or an electronic sextant, for precise navigation; there is also an antenna for missile tracking and guidance. Also visible in the model are a pair of bow torpedo tubes. The only nuclear cruise missile submarine to be completed for the US Navy, the *Halibut*, had her single hangar (for two Regulus II or five Regulus I) faired into her hull forward. In all of the Regulus submarines, the missile was moved out of the hangar onto a railed launcher. By way of contrast, Soviet cruise missile submarines employ their hangars as launch tubes, elevating them to fire.

3 *Halibut* fires a Regulus I, 31 March 1960. The Missile color scheme marks it as a training round.

There were also surface ship launchers; by 1957 four heavy cruisers (*Helena*, *Los Angeles*, *Macon* and *Toledo*) had been modified to fire Regulus, with zero-length launchers aft and special guidance radars; three Regulus I or two Regulus II (or, with warheads removed, three Regulus II) could be stowed in their floatplane hangars. The nuclear cruiser *Long Beach* originally was designed with provision for Regulus II amidships, and similar proposals were made for the *Albany* class missile cruiser conversions. Indeed, Regulus stowage and launch facilities were even designed for the large ASW ship *Norfolk*: Regulus had only a very limited physical ship impact. The other major Regulus surface-ship program was carrier operation: by 1957 ten carriers were certified for its operation. However, it was never popular, in view of its competition with manned aircraft, and the carrier program died very quickly. The cruiser program, while less unpopular, still presented difficulties, as the cruiser had simultaneously to operate as a strategic platform and in its primary role, *eg* as a fleet flagship.

Even so, in the mid-1950s some in the Navy saw surface-launched guided missiles such as Regulus as the major sea-based strategic weapons of the future; their advent would change the function of the fleet as a whole. For example, the Long Range Objectives Group, reporting in December 1955, believed that within a decade missiles would begin to limit the requirements for high-performance attack aircraft; missile battleships

...will in 1970 provide the primary long range (1000 or more mile) nuclear delivery capability of the air-surface striking force. As long range surface-to-surface missile and attack seaplane capabilities phase in, carrier aircraft specialized for long-range nuclear delivery will phase out. CVA air groups will emphasize a maximum capability for precision delivery of conventional or small nuclear weapons at up to about 1000 miles, including a substantial close air support capability, with a supplementary capability for nuclear delivery at greater ranges through in-flight refueling. CVA air groups will also contain high endurance all-weather fighters. The function of CVS and CAG air units will be to provide submarine detection and kill, ASW and airborne CIC, and air interceptions...

In fact the appearance of Polaris did remove the long-range nuclear bomber from the carriers, and with increases in Soviet strategic nuclear firepower conventional warfare became more and more important, as the LROG suspected. The only major surprise was that surface ships were never the strategic missile strike platforms; the fleet became divorced, in effect, from any primary strategic attack role. Instead, there were the submarines, and their role was continuous deterrent presence rather than wartime deep strike. To some extent this shift should be ascribed more to a shift in national perceptions of nuclear warfare than to shifting technology.

As for Regulus, the Regulus Attack Missile (RAM) system was declared operational in May 1954. The existing submarines were transferred from the Atlantic to the Pacific Fleet in July 1959; they were joined by the *Halibut*, when she was completed in 1960. There they were counted as four units (*Tunny* and *Barbero* forming one), four missiles (one unit) operating continuously on station until the first Pacific Polaris unit, USS *Daniel Boone*, appeared at the end of 1964. The system

included not only these submarines, but also a much larger number outfitted with specialized Regulus guidance equipment, for midcourse guidance correction.

Several guidance systems were proposed for Regulus. The first, Bi-Polar Navigation System (BIPONS), employed a pair of submarine pickets forming a baseline 100–200 miles from the target; the missile flew the first part of its course on a compass heading, then interrogated the pickets for range and bearing, correcting its course and choosing the point at which it had to dive. Alternatives included the Rigel LORAN type and an inertial guidance system. However, the system actually chosen was 'Trounce', a close relative of the system originally developed for the Loon missile; it permitted control by a single ship or picket submarine. For example, on 19 November 1957 the cruiser *Helena* launched a Regulus I in the Pacific, controlling it for 112 miles and then handing it over to the submarine *Cusk* for 70 miles and to the submarine *Carbonero* for the final 90, achieving, ultimately, a target error of 150yds.

A total of 514 missiles was built before production of Regulus I ended in December 1958. At that time a follow-on program, Regulus II, was canceled, and the four large Regulus II SSGNs (four Regulus II or eight Regulus I) were reordered as attack submarines. The new program had been begun after a Navy-wide review of the Navy missile program in February 1953. Regulus II was to be a supersonic successor to Regulus I and an alternative to the more advanced supersonic Triton (see below); Chance Vought received a development contract in June, and a Navy operational requirement drafted in August called for it to be operational by 1960. It was to supplant Regulus I as target defenses rendered the latter too vulnerable. Regulus II flew at Mach 2 (Mach 0.9 for Regulus I) at 60,000ft (35,000ft) with a range of 1200nm (575nm); and it weighed about twice as much as the subsonic missile. As late as 1958 the Navy's policy was to install it aboard AAW missile cruisers, subject only to a cost limitation of \$3.3 million per ship; however, it would not be carried by aircraft carriers, which in any case usually did not carry Regulus I but were only fitted to operate it in specific contingencies. The new missile first flew in May 1956 and it was launched by the missile submarine *Grayback* on 18 September 1958 off Point Mugu. Not long afterwards it was canceled in favor of Polaris; although the Navy had been promised budget supplements to permit development of both weapons, that proved impossible. Polaris requirements also caused the cancellation of two other major naval strategic attack programs, Triton (December 1957) and the Sea-master jet flying boat (21 August 1959).

Triton

Triton was a parallel effort, a potential replacement for Regulus; indeed, the BBG conceived by the Long Range Objectives Group in 1955 was to have been armed with it (and with the Talos long-range antiaircraft missile). Unlike Regulus, it was a BuOrd system, part of the 'Bumblebee' family of antiaircraft missiles (Talos, Terrier and Tartar). Indeed, it was an earlier project, designated SSM-N-2, approved in September 1946. As of 1950, it was to be a 36,000lb missile (including a 15,500lb booster and a 4000lb warhead) capable of a speed of Mach 1.6–2.5, and with a range of 2000nm.

Service test was expected by December 1959. Guidance techniques then being explored included a daytime star tracker and magnetic guidance for midcourse; terminal systems included infrared, magnetic homing, ATRAN (map-matching), and 'similar beacon effects of industrial targets'. A CEP of 600yds was sought. By 1956, the requirements had become somewhat more modest, and the operational date had receded to about 1965; Triton was to deliver 1500lb of warhead to a target at 1200nm or more (a range set by geography, as in Polaris), at Mach 2.4 or more, still with a 600yd CEP, at a gross weight of about 27,300lb. At the time of its cancellation figures of Mach 3.5 and 1500nm were being quoted. Officially, the marginal improvement over Regulus II which it represented did not warrant continuation.

Polaris

To some extent, it would appear that Regulus II and Triton fell victim to a new wave of the future, the ballistic missile; in 1958 it seemed self-evident that any air-breather was inherently subject to interception and hence obsolescent. Navy interest in ballistic rockets began with test-firings of captured V-2s including one from the carrier *Midway* on 6 September 1947; afterwards the Navy developed the Viking research rocket, which was fired from the research ship *Norton Sound* on 11 May 1950. However, proposals for a weaponized Viking with a 500nm range were rejected by Op-51 in 1952. Two years later they were revived by, among others, R F Freitag, BuAer director of the Regulus project, and M W Rosen, a civilian scientist working on Viking. In 1955 President Eisenhower formed the Killian Committee to study missile developments current and projected, and their strategic implications; it considered, among others, the fleet ballistic missile concept. It urged the development of a 1500-mile ballistic missile for both land and sea basing (September 1955); in November, Secretary of Defense Charles E Wilson ordered the Army and Navy to begin, as a program of the highest national priority, what would become the Jupiter intermediate-range ballistic missile project. The 1500-mile figure was dictated by geography, by the requirement to strike Soviet targets from NATO bases. Within two weeks the Navy had created a Special Projects Office to develop a ship-launched version of Jupiter, looking towards a surface-ship weapon by 1965, with a submarine-launched form to follow. Problems included the handling difficulties inherent in a large liquid-fueled rocket.

Two other major studies contributed to the origin of the Polaris system. One was 'Nobska', a study by the Committee on Undersea Warfare of the National Academy of Sciences, convened at the request of the Chief of Naval Operations at Nobska Point at Woods Hole, Massachusetts, to consider the implications for ASW of nuclear weapons and propulsion. Among its major recommendations was the extension of nuclear warheads to such ASW weapons as torpedoes, a step which was practicable because of the rapid shrinkage of the warheads, as described during its deliberations by Edward Teller. A panel on Strategic Uses of the Underseas learned of the possibility of a new lightweight (solid-fuel) missile, which, aboard nuclear submarines, might prove a great strain on Soviet resources. Given Teller's

faith in the new warheads, the small missile might be quite effective; in 1956 'Nobska' recommended that the Navy build a solid-fuel ballistic missile with a weight of 8–15 tons and a range of 1200–1500nm. At the same time, the Office of Naval Research (ONR) conducted a study of future submarine missile systems, using General Dynamics (*ie* Convair and Electric Boat) as its consultants. To a considerable extent it made a systems analysis case for what would become the Fleet Ballistic Missile System. On the negative side, there was some fear that development of a massive strategic system would revive the Air Force's enmity and bring back the problems of the B-36 *vs* carrier fight of 1948–49. Admiral Arleigh Burke, who became CNO in August 1955, felt otherwise, and pressed forward, appointing Rear Admiral William F Raborn Jr as his SPO; Raborn is generally credited with the efficiency with which Polaris was developed.

From the first, the Navy asked for a solid-fueled rocket, a choice supported in February 1956 by the Secretary of Defense's Science Advisory Committee; discussions with Lockheed began even earlier, in January 1956. Lockheed initially proposed 'Jupiter-S', in which six solid-fuel rockets were clustered as a first stage; it would have weighed 160,000lb compared to 30,000lb for Polaris A-1, and would have required an 8500-ton submarine to carry only four of them in its conning tower; sixteen Polaris were accommodated on about the same tonnage. The key was the lightweight warhead promised by Teller (and, in the summer of 1956, by the Atomic Energy Commission, for completion by 1965 or perhaps as early as 1963). By July 1956 the Secretary of Defense Science Advisory Committee was recommending a full Navy solid-fuel missile program, and in August the Navy formally withdrew from the Jupiter program. Gradually the Fleet Ballistic Missile edged out existing Navy long-range missile systems. For example, in 1957 the Long Range Objectives group estimated the size of the fleet which could be built up by 1966 and 1971 under various funding assumptions. Its fleet included 11 to 18 Triton SSGNs and 3 Triton SSGs (for 1966), plus 6 to 9 fleet ballistic missile submarines, the latter force rising to 15 (under very optimistic funding assumptions) by 1971. A more probable 1966 force mix was 14 Triton submarines (3 diesel) and 6 SSBNs (each with four missiles). In 1959, however, Admiral Burke spoke publicly of a requirement for 30 submarines on station, equivalent to a total force of 45 to 50; the ultimate figure was 41.*

In January 1957, Polaris was scheduled for operational evaluation in 1963, at a system range of 1500nm. However, that August the Soviets fired their first successful ICBM, an SS-6, dramatizing the potential vulnerability of the major US strategic system, the Strategic Air Command. The Navy SPO reexamined its schedule; the AEC promised its lightweight warhead by 1960, and the SPO staff promised a 1200nm weapon that fall. A 1500nm weapon would be available by 1963. The first test vehicle (AX-1) was fired, unsuccessfully, on 24 September 1958; success was not achieved until AX-6, 20 April 1959, flown 400nm down

*Under current conditions, as many as 60 to 90 submarines would be required to maintain 30 reliably on station.

the Atlantic Missile Range. A shipboard test (AX-22) from the special surface test ship *Observation Island* followed on 27 August, and the first 'tactical' prototype (A1X-1) was fired successfully from Cape Canaveral on 21 September 1959; the first Polaris submarine was commissioned on 30 December, firing her first missiles on 20 July 1960.

Polaris A-1 was the original interim 1200nm weapon, carrying a single warhead with a reported yield of 700 to 800kt. Originally it had been conceived as a low-yield weapon, and the warhead actually employed presumably showed the new AEC technology first proposed in 1956. Both first and second stages were steel-encased, and each had four nozzles, with control by 'jetevator' (thrust-vectoring). A-2 was the full 1500nm weapon, filling the launch tube completely, with a first stage 30in longer and a second stage cased in fiberglass, with a single rotary nozzle for thrust-vectoring. Proposed in 1959, A-2 first flew in November 1960. By that time solid propellant technology had improved very considerably: in June 1960 the Polaris Operational Requirement was amended to increase range to 2500nm. A higher-energy propellant was used in the second stage, both stages were cased in fiberglass, and the first had four rotary nozzles, the second having fluid-injection thrust vector control. The guidance package was about 60 percent lighter than in A-1. In addition, the missile gained volume by using a fatter nose shape (ogive). Although the original Mk 2 reentry vehicle (RV) had only a single warhead, it

The first submerged firing of a Polaris A-1 missile, from the *George Washington*. Note the single small reentry vehicle atop the weapon; in later versions the entire volume of the Polaris launch tube would be employed, and there would be three RVs.

2 SSBN-608 CLASS FLEET BALLISTIC MISSILE WEAPON SYSTEM

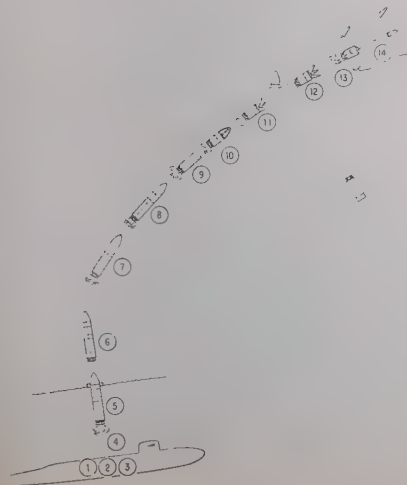
3 POLARIS A-3 MISSILE FLIGHT SEQUENCE

Key

- 1 Prelaunch preparations
- 2 Launch
- 3 Launch first motion
- 4 Ignition arm

- 5 First stage ignition
- 6 Launch steering
- 7 Pitchover
- 8 Minimum impulse steering
- 9 First stage motor burnout
- 10 First separation/SS ignition
- 11 Nose fairing eject

- 12 $VgCO$, REB (Reentry Body) separation
- 13 REB jettison
- 14 REB ballistic phase
- 15 Second stage pitchup
- 16 Second stage burnout
- 17 Second stage reentry
- 18 REB reentry phase



VI. SURFACE-TO-SURFACE MISSILES

1 A Polaris A-3 firing, in the summer of 1964. The large nosecone of the missile covers three separate but singly targeted reentry vehicles; this MRV configuration was adopted to overcome early Soviet ballistic missile defenses and also to use the available throw weight more efficiently against '50ft' area targets, such as cities. In such cases the effect of a single relatively large weapon falls off rapidly with distance from the point of impact, whereas several smaller ones can sufficiently damage a much larger area. At this time there was no question of Polaris accuracy rising so far that the missile could be used effectively against point or hard targets. Later, improved accuracy was actually foresworn on the theory that it would upset the balance of deterrence; this view has since been reversed in the design of the Trident system.

2 BOOST PHASE FLIGHT TRAJECTORY OF POSEIDON MISSILE MIRV section

IGN: Ignition

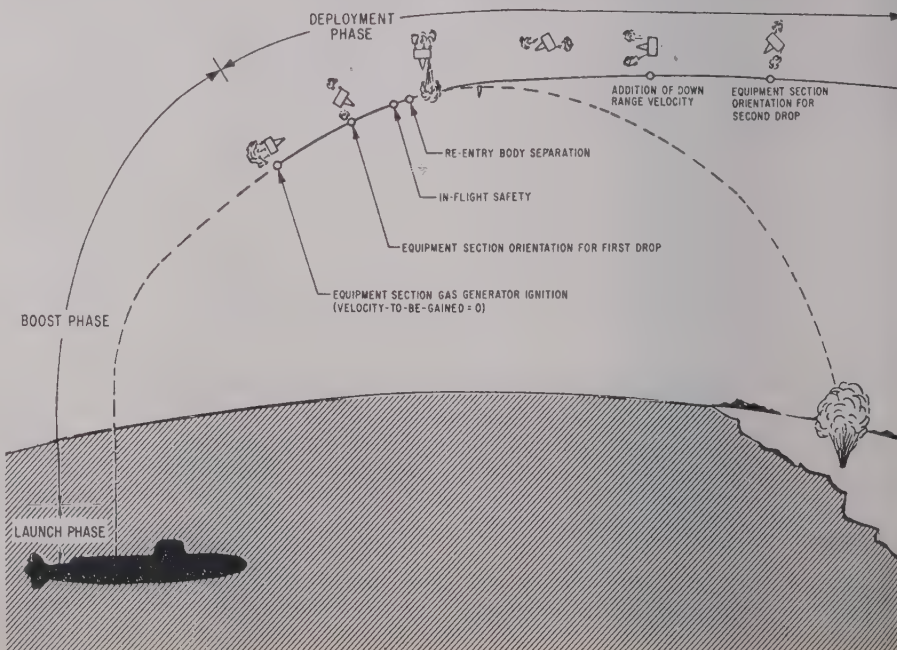
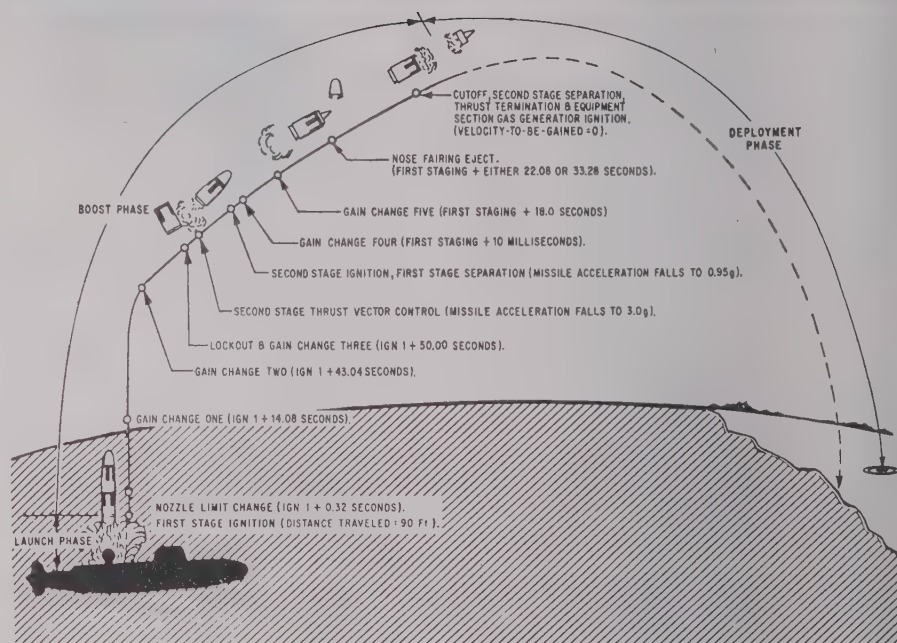
Gain changes are changes to guidance system to compensate for changing missile weight and center of gravity

3 DEPLOYMENT PHASE SEQUENCE OF POSEIDON MISSILE

was modified to carry three 200kt RVs, all directed at a single target. They achieved both greater area effect per unit weight (at, however, a lower total yield) and improved penetration of Soviet ballistic missile defenses, which began to appear about 1964.

The first five Polaris submarines (*George Washington* class) were commissioned with the A-1 missile; the next thirteen (five *Ethan Allen* and eight *Lafayette* class) with A-2; and the last twenty-three (*Lafayette* class) with A-3. Beginning with the *George Washington* (June 1964 through June 1967), the earlier submarines were refitted to fire A-3; A-1 was retired in the fall of 1965, and A-2 in 1974. A-3 was first test-flown from Cape Canaveral on 7 August 1962, and first fired from a submarine on 26 October 1963. It represented the largest missile which could be fired from an unmodified Polaris missile tube; the large Poseidon required an enlarged tube, available only in the 31 later missile submarines. Improvements in the system continued through its career, particularly in accuracy. For example, the CEP of Polaris A-1 was probably about 1nm, ie about 2000yds. Figures of from 0.5 to 0.7nm (about 1000-1400yds) have been quoted unofficially for A-3, at a longer range, with the lower figure more likely in the late 1970s.

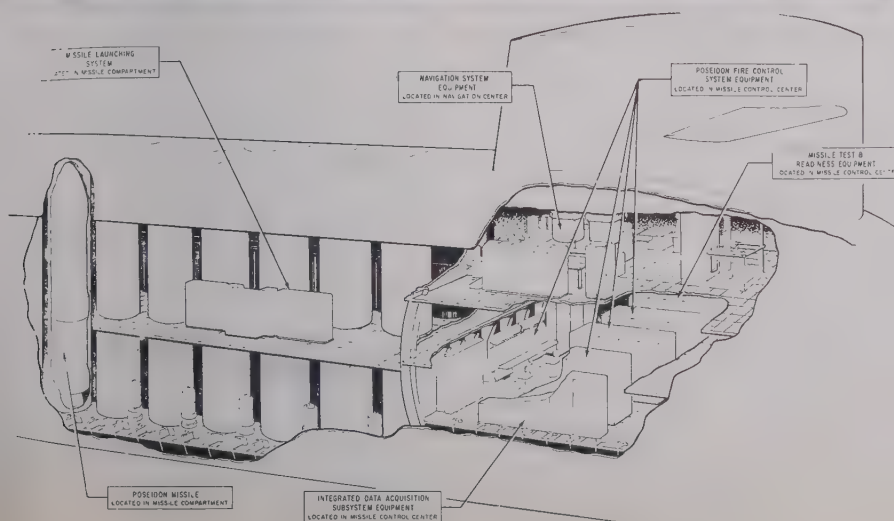
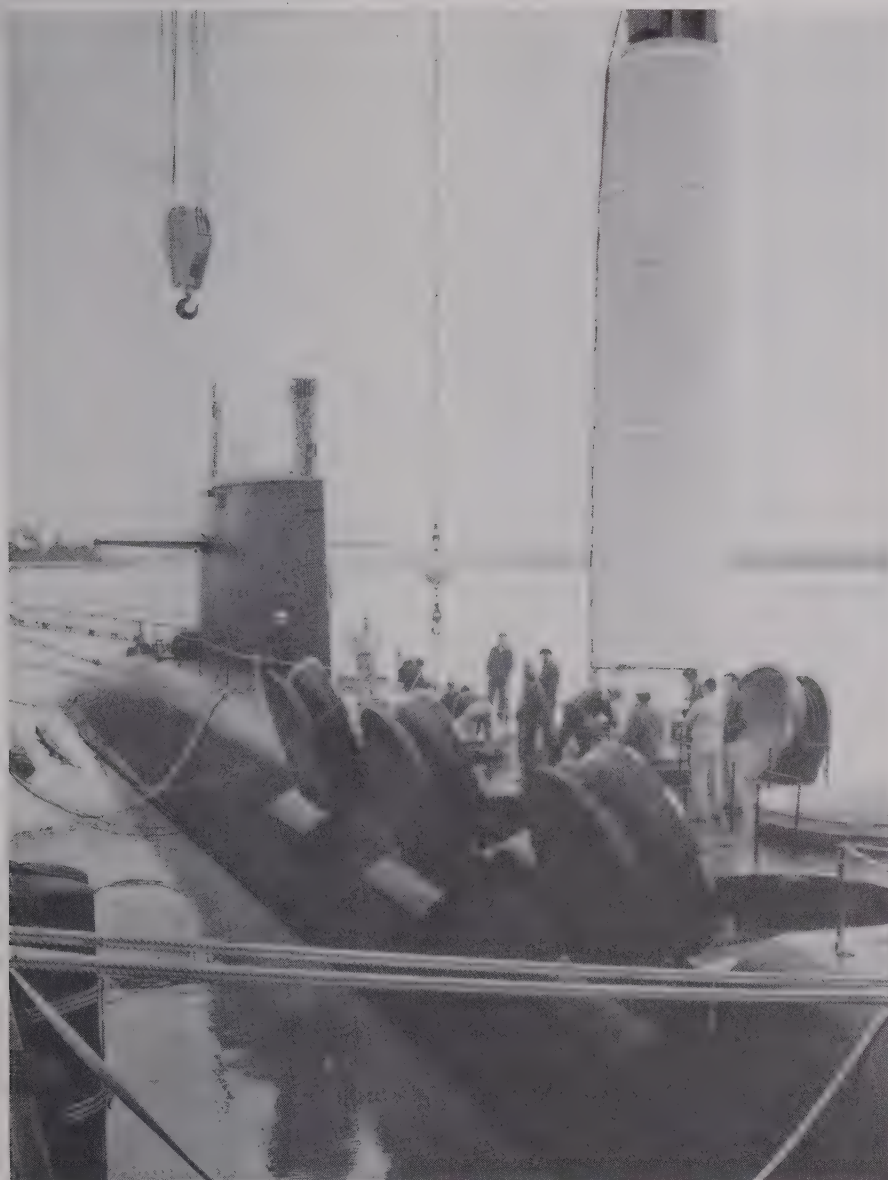
There were two pressures for the increased range represented by A-3. Firstly, at 1200 or even at 1500nm ranges there were some areas of the Soviet Union not subject to missile fire. Initially this limit was of little consequence, as the criterion for an effective missile system was the ability to strike Moscow from the sea. However, improvements in Soviet coastal ASW did make additional range (and thus additional sea room from patrol) desirable. It would appear that 2500nm was satisfactory, since the next stage of missile development did not make for additional range, and there was no pressure for another step up until the late 1960s (STRAT-X, ULMS, and then Trident). In this respect US requirements for missile range differ considerably from those apparently levied on Soviet designers. The Soviets accept the probability that their submarines will be hunted by Western ASW forces, and design them to operate from home waters, under the protec-



A Poseidon missile is lowered into a missile tube of the *James Madison* at Charleston, South Carolina, 22 March 1971. Note the raised periscope and snorkel, both bearing spotted camouflage schemes. For some years the strategic submarines have been considered a secure reserve, available to present a deterrent after a US-Soviet strategic exchange. An issue of recent interest has been the possibility of

salvoes, so that they would represent more than a single-shot capability. One problem is the delicacy of the missile itself, and the need to align it precisely with its launch tube, as here.

POSEIDON FLEET BALLISTIC MISSILE WEAPON SYSTEM



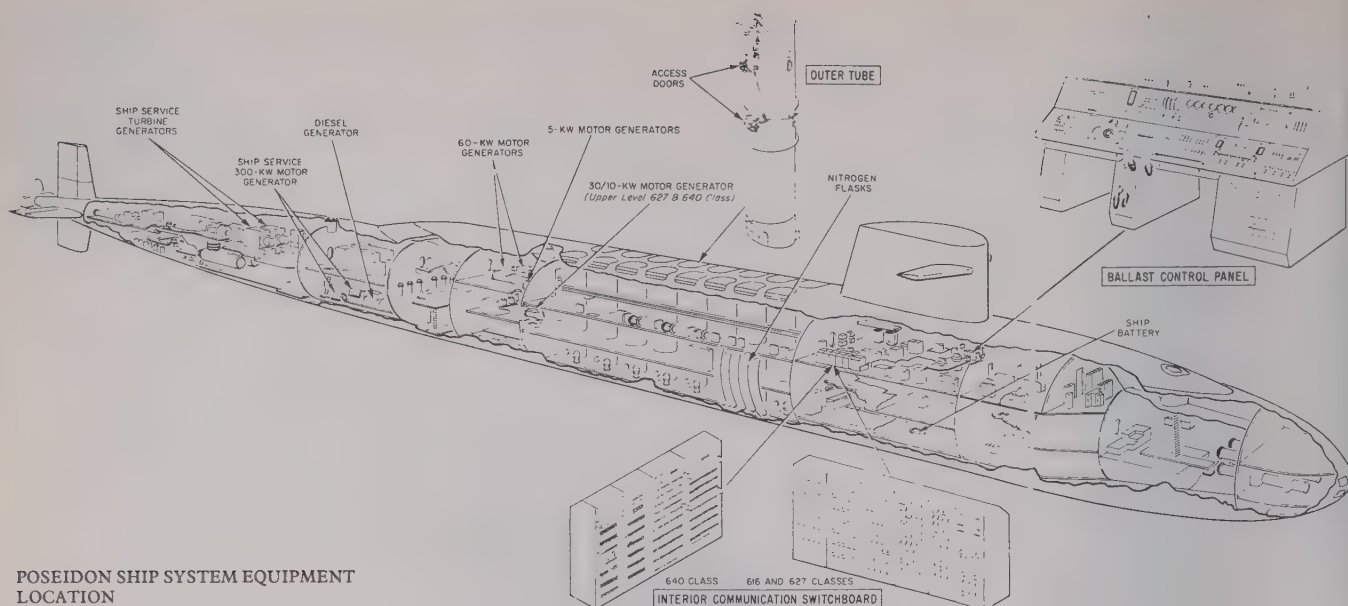
tion of Soviet naval and air forces. The US Navy, on the other hand, tends to assume that such hunting is beyond Soviet capabilities, and that the sheer size of potential patrol areas will protect its submarines, given their silencing and their ability to detect potential attackers.

As in the case of Regulus, there was some interest in surface platforms for the Fleet Ballistic Missile; for example, a spectrum of warship conversions including large cruisers and battleships was examined in 1958-59. However, such ships did not really accord with the transition from war-fighting to deterrence represented by Polaris, which required a missile platform essentially invulnerable to any preemptive strike. The major advantage of the surface ship, its superior communication with land commanders, appears to have attracted little attention at the time, although two decades later command and control problems continue to haunt the SSBNs. That is, the same opaque sea surface which shields a submarine from detection also shields it (almost) completely from the signals which should command its missile fire. Communication often, therefore, requires severe operational limitations on the submarine, either to trail a wire antenna, or to decipher signals of very limited information content, as in ELF systems.

Poseidon

By 1964 there were two Navy proposals for a Polaris follow-on. One was a torpedo-tube ballistic missile (TTBM) which would fit within the 21ft x 21in envelope of a standard torpedo tube; the other was Polaris B-3, the largest missile compatible with existing launch tubes. It was chosen for further development and, at the urging of the Director of Defense and Engineering, Dr Harold Brown (later Secretary of Defense), it was combined with a MIRV (Multiple Independently-targetable Reentry Vehicle) payload, to achieve the ability to attack several targets per missile. Alternatively, a Small Ballistic Missile (SBM), with a diameter of about 30in, could be developed, to be loaded four to a standard Polaris tube. The MIRV missile could deliver ten or even fourteen warheads per tube, SBM only four, though of larger individual size. Compared to a TTBM, SBM gained about 7in in diameter, and 10ft in length, for great improvements in range and yield. Proposals were made in 1964-65 for new submarines (perhaps capable of carrying SBMs) and also for surface forces. However, perhaps the greatest force favoring the B-3 missile was its potential to use the existing investment represented by the Polaris submarines. Ultimately, 31 out of the original 41 were refitted as Poseidon (C-3, formerly B-3) boats.

To some extent the CNO, Admiral Anderson, opposed 'mirving' because he preferred to improve the hard-target kill represented by the much larger warheads of the A-3; it was not clear, in 1963, whether hard-target kill or resistance to ABM systems (a major MIRV advantage) should be stressed. Indeed, the October 1963 Program Change Proposal which led to the new missile called for development of the new propulsion system involved, as well as continued Navy work on the large Mk 12 reentry vehicle (as in Minuteman III missiles) for possible use in B-3. In January 1965, President Johnson announced the development of a new submarine ballistic missile system; the name of Polaris B-3 was



POSEIDON SHIP SYSTEM EQUIPMENT LOCATION

hurriedly changed to Poseidon C-3 to support him. He announced that the new weapon would have twice the accuracy and twice the payload of Polaris A-3; increased range was not sought. Lockheed later claimed that C-3 would have eight times the overall effectiveness of A-3, not mentioning 'mirving' as a consideration. However, by 1966 Poseidon was being accelerated as a hedge against Soviet improvements in ballistic missile defensive and offensive force. A Presidential Draft Memorandum of 22 September 1966 called for deployment by 1970, aboard a total of 31 submarines. Flight tests began in August 1968, and the first Poseidon submarine to deploy was the *James Madison*, which fired her first missile (six RVs to 2422nm) on 3 August 1970. Up to fourteen Mk 3 RVs (40kt) could be carried, although the usual load was ten, and C-3 reportedly attained a CEP of about 600yds (0.3nm).*

System development ran afoul of a new concept of the role of the submarine-launched strategic force: it was to be limited to attacks on 'soft' targets, *ie* on Soviet cities, in retaliation for Soviet attacks on the United States. High precision and high warhead yield were rejected because they would directly threaten the Soviet ability to attack the United States and thus (in theory) make the Soviets more likely to exercise those forces in a crisis, to use them rather than lose them. In the 1970s Mutual Assured Destruction was considered a strong stabilizing force in superpower politics, and Polaris/Poseidon, survivable and capable of striking large soft targets rather than small hard ones (such as missile silos) was often seen as its most effective expression. Thus the Department of Defense refused to develop the stellar-inertial guidance system required to give C-3 high accuracy, and also refused to sanction the development of a new high-yield warhead. Both of these decisions were reversed in the subsequent development of Trident.

Trident

Secretary of Defense McNamara ordered a new study of future US strategic offensive forces in November 1966, STRAT-X. Among its conclusions was a requirement for a new

sea-based system, either surface- or submarine-launched; the surface ship concept soon moved to a very low priority, attention being concentrated on what was then called ULMS, the Undersea Long-range Missile System. Now range was again stressed, some suggesting that ULMS should be able to operate from US territorial waters (*ie* that it should have a range of about 6000nm). That in turn would have required a massive new missile and with it a massive new submarine. The Polaris/Poseidon SPO much preferred a smaller weapon, with a range of about 4500nm, compatible with existing Poseidon launch tubes; the large ULMS was generally visualized as an external missile. The solution, in the end, was to adopt the SPO missile (EXPO) as Trident I (C-4). A larger submarine with internal missile tubes would be built, initially to fire C-4, but later to fire a larger weapon, Trident II (D-5) with the longer range. D-5 would finally exceed the tube length of the existing submarines, which in any case would be nearing the end of their useful lifetime as it became available.

As compared to C-3, C-4 was designed to emphasize long range with substantial accuracy but without any great increase in throw weight. There were several innovations in its design. The most noticeable was an 'aero-spike', a spike which extended from its blunt nose after launch, creating a region of flow separation equivalent to that of a slender, conical nose. It was credited with a reduction in frontal drag of 50 percent, *ie* an increase in range of about 300nm. In addition, it made possible the use of a very blunt nose shape which accommodated a third rocket stage as well as the reentry vehicles. C-4 again benefits from advances in propellant chemistry, and from lighter-weight casings. In addition, it makes fuller use of all of its fuel, burning out each stage instead of cutting off thrust; according to Lockheed, 'instead of blowing open ports at the head of the motor to neutralize thrust during the second stage flight, a calculated trajectory excursion off the main trajectory path is flown, and the missile may even rotate 180° in flight before being vectored back

to the main trajectory'. As a result, more propellant could be packaged in each stage, and the missile could be simplified, for less weight. The new high-energy, high-density, cross-linked, double-base propellant is credited with about 40 percent of the propulsion range improvements; another 35 percent is due to improved chamber material (Kevlar), which permits increased propellant loading and higher operating pressure. C-4 also incorporates stellar inertial update guidance, which can overcome the inaccuracies inherent in submarine navigation; the missile is credited with a CEP of 500yds, carrying eight Mk 4 RVs (W76 warheads, 100kt yield). Reportedly, improved guidance optics may reduce CEP to 250yds in future.

Lockheed received the Trident I contract in 1974, the first missile launch following on 18 January 1977. Twelve *Lafayette* class submarines are to carry the missile, the *Francis Scott Key* serving as test ship. She began her first Trident patrol in October 1979, and the entire 12-ship conversion program was scheduled for completion by March 1982.

Given the advanced technology required to reach the C-4 goal of 4500nm, D-5 has always been considered a much riskier enterprise. Several possibilities for an advanced Trident have been raised. One is a lengthened missile, between 42.5ft and 43.5ft long (compared to 34.1ft for Trident I), which might carry the eight Mk 4 RVs to 6000nm, maintaining the reported 250yd CEP of the present C-4. Such a weapon would have the same diameter as Trident I and would retain much of the Trident I design. Alternatively, D-5 might use the full missile tube volume available in the

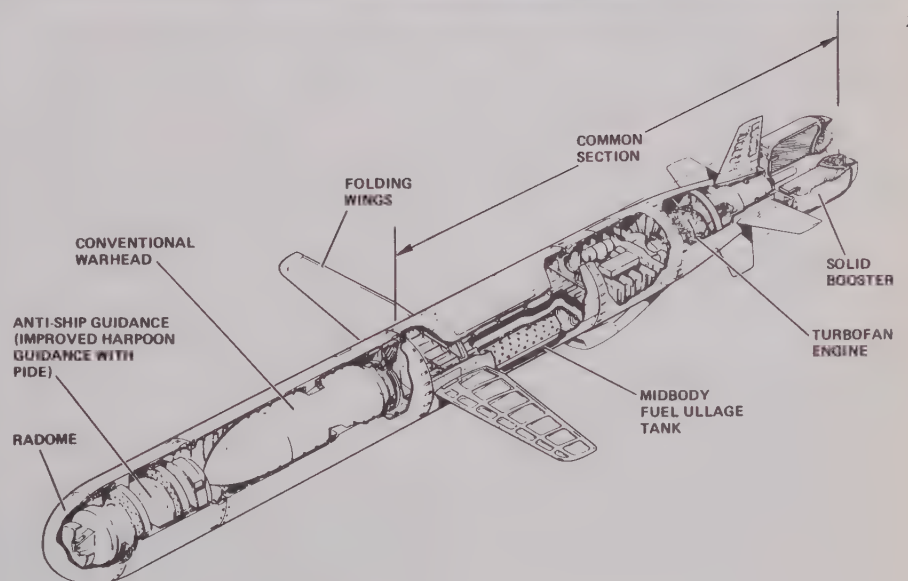
*In the early 1970s, C-3 encountered severe reliability problems, many missiles reportedly failing to fire in routine tests. In addition, reportedly, a substantial percentage of Poseidon warheads were defective to the point where they would not have functioned. More recently, Navy spokesmen have contrasted the excellent record of C-4 to the relatively terrible one of C-3.

new *Ohio* class submarines, increasing diameter from 74in to 84in. Such a missile might carry Mk 12A RVs similar to those carried by the Minuteman III and the MX, with W78 warheads unofficially credited with a yield of 335kt, and with a CEP of 250yds at 6000nm. Yet another alternative is the 'flat deck' D-5, in which the upper stage would be eliminated to increase payload, perhaps to ten Mk 12A RVs. Such improvements, combined with superior communications, might bring Trident very close to the capabilities inherent in land-based ICBMs, at the same time that the latter are critically vulnerable to Soviet strategic forces. Thus one major current in the MX debate has been the proposal to abandon land-based weapons entirely in favor of improved Trident. Increased accuracy due to an improved stellar-inertial guidance system would be a major consideration in any such move.

Tomahawk

The other major US naval strategic surface-to-surface missile system of the 1980s is the Tomahawk cruise missile, employing terrain-comparison (TERCOM) guidance. Navy studies for a long-range cruise missile began about 1972 as an outgrowth of tactical projects such as Harpoon (see below). The technology required for a compact very long-range missile was available at the time: lightweight turbofans for good fuel economy at low altitude, and for a small missile; compact electronics which made TERCOM (a concept in development from about 1960 onwards) practical; and the continued development of compact warheads. Interest in strategic cruise missiles did survive the demise of Regulus and Triton, but was depressed to a very low level in order to avoid competition with Polaris/Poseidon. However, during the late 1960s the cruise missile was sometimes advertised as a means of rearming the older Polaris submarines not suited to Poseidon conversion, and in 1971 Op-97 (Systems Analysis) postulated a 2600nm missile, eight of which could be fired from each Polaris tube; a variant (with range reduced to 1600nm) could be fired from a Terrier launcher. Early in 1973 Secretary of Defense Elliot L Richardson requested \$15 million for preliminary studies, noting that such weapons were not covered by the existing Strategic Arms treaties. It has often been reported that the cruise missile was initially favored by Secretary of State Henry Kissinger primarily as a 'bargaining chip', looking toward SALT II, since the United States would find it relatively easier to develop (in compact form) than would the Soviet Union.

As of 1971, five basing options for a US sea-launched strategic cruise missile were under consideration: vertical launch from existing Polaris/Poseidon tubes; horizontal (torpedo tube) launch from attack or strategic submarines; vertical launch from a new cruise missile submarine (see STAM, below); or development of a new tactical/strategic weapon without reference to its platform. The last option, with launch from torpedo tubes, was chosen; the SLCM program was approved 2 June 1972, and on 6 November the SLCM program was combined with an ongoing tactical (300nm) program which had begun as an extended-range Harpoon. Two competitive programs were funded: the General Dynamics ZBGM-109 and the LTV ZBGM-110, both suitable for torpedo-tube launching, and both capable



of a range of about 2000nm. In 1977, after a flyoff, the Defense Systems Acquisition Review Council (DSARC) chose the General Dynamics BGM-109 for full-scale engineering development as the Sea-Launched Cruise Missile (SLCM), and also recommended it for development as a Ground-Launched Cruise Missile (GLCM).

The Carter Administration resisted deployment of strategic SLCMs because it feared that they would breach the observability requirements inherent in a SALT treaty. On the other hand, SLCM deployment is a very simple means of extending the US strategic force, and late in 1980 decisions to deploy the tactical SLCM automatically opened the possibility that strategic SLCMs (physically almost

1 The first Trident I launch, at Cape Kennedy, 18 January 1977. The 'aerospike' extended from the missile increases its effective aerodynamic length and thus reduces its air resistance as it accelerates through the atmosphere. Reportedly it halves frontal drag, increasing range by about 300nm, and makes possible the use of a blunter nose shape which in turn accommodates a third rocket stage as well as the usual reentry vehicles.

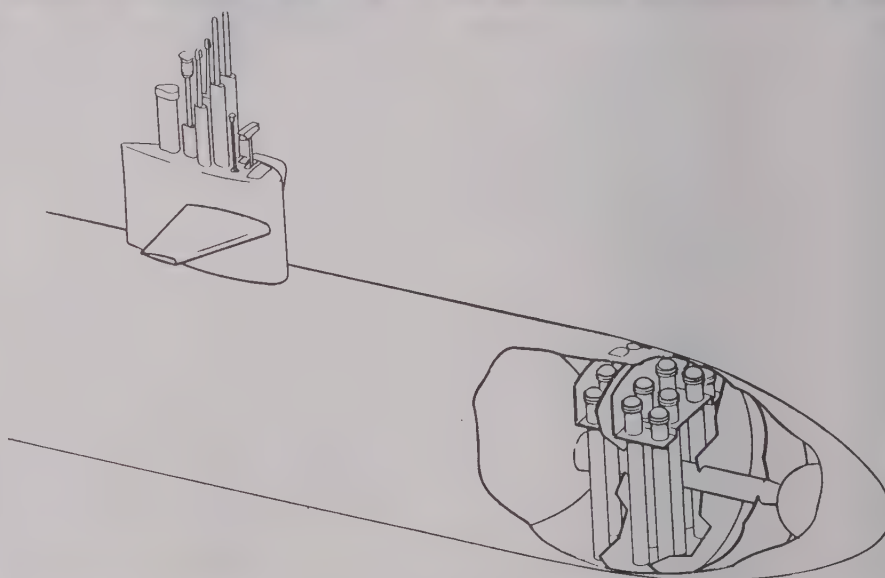
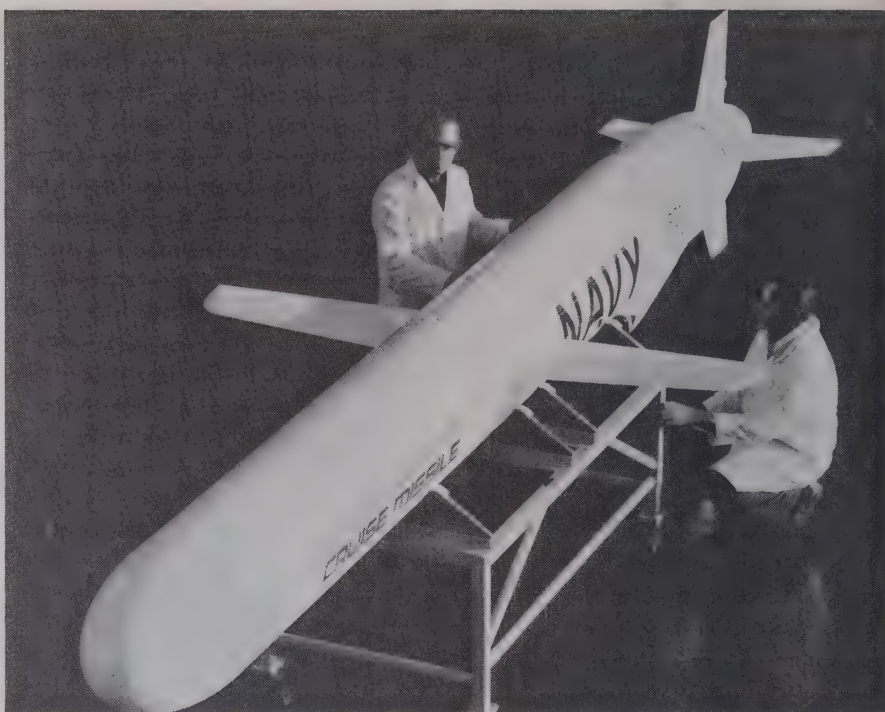
2 THE TOMAHAWK ANTISHIP MISSILE

identical) might soon be deployed to follow. Submarines are a particularly interesting case. Originally Tomahawk was designed to be fired from a conventional torpedo tube, sharing the flexibility of the TTBM originally proposed in the mid-1960s. However, weapon space is very scarce aboard a submarine; figures as low as

VI. SURFACE-TO-SURFACE MISSILES

twenty weapons are often reported for the number of torpedo reloads aboard a nuclear attack submarine. However, the same submarines have an unutilized space between their pressure hulls and their spherical sonars forward: as many as twelve vertical tubes can be fitted there. The Reagan Administration has decided to deploy the strategic SLCM aboard *Los Angeles* class submarines beginning with SSN-719. Reportedly earlier units as well as *Permit* class submarines will be retrofitted, one unofficial source listing eight Tomahawks each for these units (as well as fifteen, presumably including three in torpedo tubes, for a *Los Angeles*).

Strategic SLCM deployment aboard surface ships is attractive as a means of multiplying the number of seaborne strategic platforms with which the Soviets must contend, in hopes of saturating their elaborate sea surveillance system. Without strategic SLCM, it is argued, the Soviets need track only US carriers and perhaps US major amphibious formations. However, if all SLCM launchers at sea, aboard most US combatants, cannot be divorced from the strategic missile, then the Soviet problem should be very considerably complicated. This argument may be particularly significant for the fate of the *Iowa* class battleships, which were being advertised, in 1983, as the cores of Surface Action Groups (SAGs) capable, in some circumstances, of replacing forward-deployed carriers. As of mid-1981, announced Navy plans called for twelve Tomahawks in Vertical Launching Systems aboard each Aegis cruiser (CG-47 class), and for 45 aboard each modernized *Spruance* class destroyer, also in Vertical Launching Systems. The destroyers and some cruisers would initially receive armored box launchers (ABL), as would the refitted *Iowas*, with four weapons per box. These figures include both strategic and tactical versions of the weapon.



1 A test version of the General Dynamics Tomahawk (BGM-109) cruise missile, which the Navy is buying in both strategic and antiship versions. The missile body completely fills a standard submarine 21in torpedo tube, the wings, air scoop and tail folding for stowage. A subsonic missile, Tomahawk depends for its ability to penetrate Soviet defenses on a combination of low cross-section (stealth), low altitude, a flight plan plotted to avoid many ground defenses and, perhaps most of all, very large numbers to overwhelm the defenders. Cruise missiles were attractive, first because they were relatively inexpensive (although in 1981 the cost of a Tomahawk, exclusive of warhead, was sometimes quoted at \$3 million), and second because their efficient turbofan engines and their terrain-correlation guidance system both exploit American technological strengths compared to the Soviets. Thus Soviet matching systems were considered unlikely.

2 VERTICAL LAUNCH PAYLOAD CAPABILITY (SSN-668 CLASS)

Vertical stowage/launch concept shown
12 missiles per submarine

3 A submarine-launched Tomahawk breaks the surface; the bursts on either side are probably the wings beginning to deploy, driven explosively. Originally the missile was designed to take advantage of the torpedo tubes built into every submarine. However, current nuclear attack submarines are very limited in the number of torpedo-size weapons they can carry, figures as low as twenty (plus those in the tubes) commonly being cited. Indeed, the provision of twenty vertical tubes in the abortive 'mid-seventies attack submarine' project was in large part an attempt to avoid further drawdown of the already limited number of torpedoes. From SSN-719 onwards, new *Los Angeles* class submarines will each be fitted with twelve vertical tubes for Tomahawk, and earlier units will probably be back-fitted.



4. Tactical missiles

The Hellcat Drone

Interest in surface-to-surface tactical missiles was quite tenuous postwar; for example, the December 1950 edition of the *Navy Guided Missile Program Summary* lists no such weapons. Carrier aircraft were the major tactical weapon, supplemented by the heavy guns remaining aboard cruisers and battleships. However, the wartime drone program did survive in the form of a large target aircraft program, using wartime operational types, particularly the F6F Hellcat. Heavy ground fire encountered in Korea inspired the tactical use of such drones by Guided Missile Unit 90, flying from the carrier *Boxer* from 28 August 1952 onwards. The directors for these F6F-5K drones were AD-2D Skyraiders, and television was used for terminal guidance; each drone could carry a 2000lb bomb, and could also be used for reconnaissance beyond 100nm from the carrier.

Of the first six weapons launched between 28 August and 2 September, one was a hit, four were misses, and one was aborted. Three categories of high- and low-contrast targets were attacked: two undefended (one bridge, which was hit, and one tunnel mouth); two defended (railroad bridges); and two discretionary (an earth dam, against which the drone, with a faulty autopilot, aborted, and a hydroelectric plant). The drone was not well liked. It required 30 minutes of servicing before takeoff, during which time the starboard wing could not be folded, as the television pod was installed. The ship also had to maintain a steady course to permit the drone gyro-stabilizer to be checked out prior to flight. In addition, the drone was considered vulnerable to groundfire because its control system was relatively easy to disable; it was considered five times as vulnerable as a manned F6F-5. Since 5–15 percent pilot losses were expected under Korean conditions (for the Hellcat), it appeared that over half of all drones would be shot down before reaching their targets. This experience, incidentally, may belie the claim that the Assault Drone program would have succeeded had it been provided with higher-performance aircraft.

APL Proposals

The Hellcat drone program appears to have been extemporized; certainly it had no postwar successor, as Navy attention turned very largely to deep nuclear strikes by fast carrier task forces. In 1956, for example, the Chief of the Bureau of Ordnance, looking ahead ten years, saw surface-to-surface firing as a secondary capability of such anti-air weapons as Tartar and Terrier. The latter, using beam-riding, would have to be directed in an up-and-over trajectory, necessarily imprecise; however, that aiming error could be compensated for by using a nuclear warhead. Ranges as great as 40nm might be expected. In January 1957 the Applied Physics Laboratory (APL), the developer of Navy surface-to-air missiles, produced a proposal for surface-to-surface

weapons compatible with existing surface-to-air missile launchers:

Anti-aircraft missiles had to replace anti-aircraft guns when guns could no longer destroy modern aircraft with high probability. Missiles seem able to preserve and even increase the ability of ships to destroy hostile aircraft, but they have exacted a price not charged by anti-aircraft guns: they replace the heavy main battery of the ship. The missile cruiser has lost part or all of its ability to fight a surface engagement. A fully converted cruiser could defend itself and its neighbors capably against air attack, but would be sunk easily by the first conventional cruiser that elected to attack it.

Of course the situation is well understood at the Laboratory. Recent studies have shown that present anti-aircraft missiles will be difficult or impossible to modify for ship-to-ship use, at least with non-nuclear warheads. And we dare not depend entirely on a nuclear capability against other ships. The use of nuclear warheads is likely to be permitted only in a desperate general war; moreover, dependence on nuclear weapons increases the risk of nuclear war.

It will be taken as axiomatic that the smallest possible number of launcher types will handle all classes of weapons. Thus we should try to design surface bombardment missiles that can be launched from the air defense missile launchers. If at all possible, the below-decks handling equipment should also handle all types of missiles with equal facility.

These considerations remain applicable a quarter-century later. At the time APL proposed two classes of antiship missile, Trident (trajectory entirely in air), and Terne, a torpedo carrier analogous to Petrel – and, for that matter, quite close to the discarded Grebe of the postwar ASW program. Each would need an active homer, and the requisite radar and sonar technology had just been demonstrated by the successful Petrel program. Moreover, homing would sharply reduce the requirements on shipboard midcourse guidance; tests had just shown that ‘Terrier guidance is no better than marginal for a ship-to-ship capability’. Useful range would be limited by the radar horizon of the firing ship, about 25nm, although some small additional range might be justified to fire on a ship fleeing an engagement and thus vanishing from radar observation. Somewhat better range might be justified by an airborne radar such as Eyes-In-Sky (an airborne early warning radar carried by a helicopter), but only if radar accuracy better than one degree could be provided;

...it will not be easy to furnish data of this accuracy.

Neither missile would need the high speed or maneuverability of an anti-aircraft missile. The target ship's ability to evade is almost negligible. The chief advantage of a fast missile would be low vulnerability to the target ship's anti-aircraft; but even a slow missile could be fired so as to saturate the target's defenses ... One can make a good case for building Trident and/or Terne able to cruise at the lowest possible altitude, say, fifty feet (Petrel now flies at a minimum altitude of 100ft, at Mach 0.5). Defense radar will detect and lock onto such a missile late if at all. On the other hand, low altitude

may again force slow speed. Possibly the greatest disadvantage to a slow missile will be its large wing and control surfaces, which would aggravate the below-decks handling problem.

Either a Trident or a Terne would outrange cruiser guns, and air defense weapons would not appear to be sufficiently effective against them. One is forced to the conclusion that the best defense would be to engage the attacking ship in a duel with weapons of comparable effectiveness. Arming US combatant ships with effective ship-to-ship missiles would either make enemy cruiser strength obsolete or force him to develop weapons of similar effectiveness and equip his numerous surface combatant ships with them.

This was remarkably prescient, except that it was the Soviet Fleet which developed ship-to-ship missiles and forced the United States into a crash program to answer that development. At the time, it seems to have had very little effect; for example, when the next major anti-air missile, Typhon, was developed, its surface-to-surface capability was vested in its nuclear warhead, as late as 1963. Indeed, the lack of an effective antiship variant of existing missiles led President Kennedy to order the installation of 5in/38 guns aboard all-missile cruisers in 1961. He was primarily interested in countering small attack craft such as PT boats; in 1961 Soviet surface combatants were not yet considered a major naval problem.

‘Taurus’

The demise of the big-gun cruiser/battleship fleet was not taken lightly, since it greatly reduced naval capacity to offer fire support to the Marines. Indeed, if the Long Range Objectives Group was correct, and the future held a multitude of small wars around the Eurasian periphery, fire support would, if anything, increase in importance. In March 1960 the then Bureau of Naval Weapons issued an Operational Requirement for a Tactical Surface-to-Surface Missile (TRSSM) with a range of 3–50nm and a simple guidance system, to achieve a CEP of 143 meters at maximum range (1.90mils) and 13 meters (2.58mils) at minimum.

The Operational Requirement originally included ship and submarine as well as land targets, but an early study at APL showed that the latter would be impractical, and they were eliminated in a revised OR issued in August 1961. Two principal targets were now specified: (i) troops in the open; (ii) trucks or artillery in the open, or hastily dug-in troops. The warhead was to be non-nuclear, although ultimately it might be interchangeable with a nuclear or chemical type. Two range bands were specified: for a beach assault weapon, up to 30nm; and, for medium and long ranges, an interim capability to 50nm, and an ultimate one to 199nm in all weather. Against beach targets, the new Landing Force Support Weapon (LFSW) was to equal or exceed the efficacy of existing rockets and naval gunfire. At longer ranges, it was to achieve a 90 percent assurance of 30 percent incapacitation of class (i), or an 80 percent assurance of 40 percent incapacitation

of class (ii). Hard point targets (in support of helicopter assault operations) were abandoned as an LFSW requirement, and, for the moment, restriction to Terrier and Tartar launchers was given up. An important issue in weapon development was the much improved lethality of new classes of antipersonnel warheads, far above that of conventional fragmentation weapons on a weight-for-weight basis, and therefore promising much more effectiveness within a given warhead weight. These included flechettes, controlled fragmentation (as in the Army Improved Conventional Munitions), and microjets (tiny plastic darts loaded with propellant). For a given weight of warhead, controlled fragmentation was only slightly less efficient than the experimental microjets. A study showed that warhead weight rose sharply with CEP; a 1000lb warhead, for example, required a CEP of 150yds to achieve the target (i) criterion, assuming a target area about 130yds in diameter. To achieve similar results at 300–500lb (ie using the weight of a large SAM warhead) would require a 75–100yd CEP, ie 1mil at 50nm.

Guidance was clearly the crucial issue, generally involving a combination of mid-course and terminal elements. Television guidance was rejected because the primary target, troops, did not present an object of sufficient size or contrast. Inertial guidance would be expensive; moreover, its accuracy would depend upon the detailed accuracy of the map to be used by the forward observer. Spotting would help, but, according to APL, 'with missiles, spotting is a luxury that one may not be able to afford. Spotters would not be too useful in this particular system because the type of warheads that are envisioned do not provide a well defined impact point.' Radio navigation, reminiscent of the system once conceived for Rigel, was also considered, but was subject to map errors. Finally there were two classes of terminal aids to determine target position. One employed an offset beacon which a seeker in the missile could track. The other was a forward controller, who could track the missile and then guide it in, as in the Army's La Crosse system. The ideal line-of-sight terminal beacon, the laser designator, did not yet exist. The best APL could do was to try to simplify the forward observer system by seeking the best possible midcourse accuracy (via an inexpensive inertial guidance system), then using a simple missile tracker pointed at the target.

The APL missile was tentatively designated 'Taurus' (ZRGM-59A), and its characteristics were established by 1964. It was to fit the existing Terrier launcher, and to carry a 1000lb warhead; range would be varied between 17 and 50nm by varying launcher elevation angle. A CEP of 210yds with only the inertial guidance system was expected, and the forward beacon system might reduce this figure to as little as 30yds; net accuracy depended in part on how good a 'fix' the launching ship could get on its own position, perhaps employing beacons ashore. One unusual feature of the APL missile was that it employed a Terrier-sized solid-fuel booster and an unpowered (but tail-controlled) missile. In August 1964, APL looked towards flight test of its Norden Simplified Inertial Guidance System (SIGS) aboard an Army Sergeant missile early in 1965. However, Taurus was never built.

The LFSW Requirement

By June 1965 the Bureau of Naval Weapons was actively interested in an adaptation of the Army Lance, which, the manufacturer (LTV) claimed, could be deployed aboard the two earliest missile cruisers, with tests aboard the *Norton Sound* in the last quarter of 1965, aboard *Boston* in the first quarter of 1966, and aboard the *Canberra* at the beginning of 1967. It would employ the storable liquid fuel of the Army weapon, would carry the 1000lb warhead, and would require only minimal adaptation to the Terrier launcher: in fact, the launcher would need most of the modification, including an inertial measuring unit and a rate gyro. Range and accuracy would fall somewhat short of the APL Taurus, but cost would be far lower. However, by this time funds for new shore bombardment weapons appear to have been scarce, and the Lance Landing Force Support Weapon did not see the light. Indeed, the new Landing Force Support ship (LFS), work on which began about this time, incorporated no missile launcher for a long-range weapon; it was limited to guns (including the new 8in long-range type) and unguided rockets.

That is not to say that all interest in antishore surface-to-surface weapons died out. For example, in the spring of 1967 the Naval Weapons Center developed a range of surface-to-surface weapons requirements, including an LFS missile which was to outrange and destroy coast defenses; to neutralize, clear and provide flanking cover for landing beaches and helicopter zones, the latter up to 50 miles inland; and to provide direct fire support of the landing force until its organic artillery could come ashore. Interdiction in support of the landing might require fire as much as 100nm inland. In addition, a Tentative Specific Operational Requirement was issued in May 1967 for a Long Range Interdiction Missile, which was to be able to attack soft or moderately hard targets up to 500nm away, in support of aircraft. The North Vietnamese SAMs and even conventional anti-aircraft artillery were already imposing high loss rates on naval attack aircraft, and the Interdiction Missile was to counter them. It would also perform a secondary mission: quick-reaction against massed troops, supplies and light armor, as in the LFSW. There was also still some interest in Lance, particularly if its warhead could be loaded with the new bomblets to overcome its relatively poor CEP performance at maximum range. The next year Ryan proposed its Firebee drone as an LFSW, carrying two 500lb bombs to a range as great as 300nm, with LORAN midcourse guidance and television terminal guidance, using an S-2 Tracker as the missile director aircraft. It is not clear whether this proposal, or a later one involving the supersonic Firebee II (BQM-3E), had any official support.

No LFSW was produced, and the antishore missile mission appears to have been very largely abandoned, except for attacks on vital point targets by a land-attack version of Tomahawk, using its strategic-missile guidance system. SMARTROC was an interesting approach to an inexpensive surface-to-surface weapon, a Mk 82 laser-guided bomb projected by an ASROC booster and controlled by a shipboard or shore designator. A range of about 12,000yds was claimed, consistent with standard ASROC capability. As of 1975, there

was no stated Operational Requirement for such a weapon, and work was continuing as an investment in useful technology. Presumably the key disadvantage was very short range; as APL found in 1960–64, useful range for shore bombardment implied a substantial missile, far beyond the capacity of a ship of destroyer size; however, a decade later, most of the very large missile launchers in the Fleet were close to retirement. For the surviving ships, laser-guided artillery shells represented a far more realistic investment.

Antiradiation Missiles

One surface-to-surface category deserves special mention. During the Vietnam War, both Talos and Shrike were fired by US surface ships against shore targets as antiradiation (ARM) weapons. By 1965 North Vietnamese surface-to-air missiles were beginning to cause severe problems; Talos, the longest-range US shipboard missile, was a possible solution. Members of the Institute for Defense Analysis suggested in August that a Shrike antiradar seeker might be incorporated in Talos; a test was authorized on 8 September, and the first missile flown on 26 October passed within 8ft of a radar van over 50nm uprange. Improvements proposed at the time included a higher-density fuel for longer range (and thus for greater standoff from the Vietnamese coast) and increased receiver sensitivity. At first the targets were P-band radars, but ultimately kits for frequencies as high as C-band were developed, including ECCM features. Flight tests were carried out at White Sands and aboard the cruiser *Galveston*. Four missile cruisers were fitted for Talos-ARM, and ten weapons were fired in combat (as RGM-8H) by the *Chicago*, *Long Beach* and *Oklahoma City*.

Shrike was the other shipboard ARM, intended to help destroyers defend themselves from North Vietnamese coastal guns. In April 1972 NAVORD directed the Naval Weapons Center (China Lake) to design, test, and install a shipboard version of the air-launched weapon aboard at least one ship in the Western Pacific within six weeks. The first weapon was fired at sea on 17 May, the first combat firing following early in August 1972. Shrikes were carried on Aero-5B launchers atop each upper ASROC cell and fired when enemy radar signals were detected; all were removed upon US withdrawal from Southeast Asia, and no indication of their effectiveness has survived. In service, the system was known as Shrike On-Board (SOB).

5. Antiship missiles

Tartar/Terrier Derivatives

Since the early 1960s the bulk of Navy tactical surface-to-surface missile development has been concentrated on antiship weapons. The Soviet 'Komar' class fast patrol boat in the Cuban Navy (1962) appears to have been the initial inspiration. In February 1963 the Operational Test and Evaluation Force reported an anti-Komar study, conducted at high priority at the request of the Atlantic Fleet. It found that the missile boats could be detected by existing ASW (P-2 or S-2) or airborne early warning aircraft, and destroyed either by Sparrow III air-to-air missiles or by shipboard surface-to-air missiles, although the range of the latter would be reduced by land background. For example, in relatively calm seas a target launch could be hit at 7-13nm, but this range would be cut to only 6nm when the launch was 30nm offshore; in such circumstances the 'Styx' missile would outrange the existing '3-T' Navy SAMs. Moreover, Tartar and Terrier (homing) tended to lock onto the sea return at high sea states. Beam-riders were much worse, generally less than one-tenth as effective as the homing missiles. On the other hand, Sparrow proved quite effective, and the test seemed to show that a 'Komar' was a much better air than sea target. Sparrow's only important defect was its fuze, which increased greatly the number of hits required to sink even so flimsy a target as a 'Komar'.

Tartar and Terrier were also tested against a larger target, the former escort carrier *Makassar Strait*; they proved fairly successful, scoring (in one series) four hits out of eight. Their primary defect, however, was that they were semiactive homers, limited to targets within the radar horizon of their illuminators. A truly long-range weapon, such as the Soviet 'Styx' or 'Shaddock' (SS-N-3), required its own active radar seeker. In the early 1960s such seekers appear to have been beyond existing US radar technology; the Soviets could obtain

them because they used much more massive missiles, which in turn could employ lower-frequency seekers. Terrier (BT-3A) was described as achieving surface-to-surface capability without loss of surface-to-air performance; it had a longer-burning sustainer motor and auxiliary power system. Tartar was generally credited with some antiship cap-

ability, and indeed was incorporated in the German missile frigate studies of the 1960s partly for that reason. It was a horizon-range (*ie* about 15nm) missile, due to its guidance limitations. Thus a Naval Weapons Center study, completed early in 1967, listed only evolved versions of the existing Tartar and Terrier as potential ship-to-ship weapons.



1



2

1 In 1983, Harpoon is the US Navy's immediate answer to the massive Soviet force of antiship missile ships. Here one approaches the target ship *Haraden*, a *Fletcher* class destroyer, on 19 December 1975. The diving approach was selected both to confuse terminal defenses and to place the missile detonation deep in the hull, so that a missile homing, for example, on a ship's masts would not just pass through them to explode relatively harmlessly. Even so, there must be some skepticism as to the lethality of a single 510lb warhead, when the Soviets seem to consider 2200lb barely adequate and, indeed, when they go so far as to assure a generous supply of liquid fuel in the missile when it strikes, to set off a fire which will add to the damage of the explosion. Harpoon does have the enormous advantages of compactness and long range when it is compared to other Western weapons such as Exocet.

2 Many frigates have been modified to fire Harpoon from two of the eight missile cells of their ASROC boxes: this is *Knox*, in the summer of 1975. The destroyer force welcomed such weapons as 'equalizers', but it might be argued that the submarine remains the principal threat and that in some cases there are no ASROC reloads, so that two of eight weapons have been exchanged; moreover, doctrine is almost certainly to fire two ASROCs per submarine. Then even the eight of the 'pepperbox' represent no more than four attacks. Note the dual director (Mk 91) for NATO Sea Sparrow above the frigate's bridge.

VI. SURFACE-TO-SURFACE MISSILES

As for Talos, its original antiship capability resided in its nuclear warhead; in April 1959, for example, that (relatively small) warhead was described as sufficient to achieve severe damage against a battleship at maximum direct missile range. That was hardly the sort of missile performance useful with a conventional warhead. However, an extensive program of antiship Talos development was carried out in 1961-64, leading to homing modifications which were found useful in the anti-air role (and which were incorporated in the RIM-8G version of the missile). The program was, however, terminated before completion, and the antiship role eliminated from the Talos Specific Operational Requirement. It was revived in 1967, emphasizing the 'Komar' missile boat as a target; the ability of the RIM-8G to home on 'Komar' and escort-size targets almost irrespective of the sea state, was in marked contrast to the smaller missiles. It was also found that an air burst was most effective against a 'Komar', and a modification of the Talos fuzing made it possible for the missile to

engage either the missile boat or its 'Styx' missile. Pure kinetic energy was found most effective against larger ships; typically the fuze was deactivated at launch time when Talos was to be fired against them. It was so massive a missile that its sheer weight sufficed to do great damage.

Harpoon*

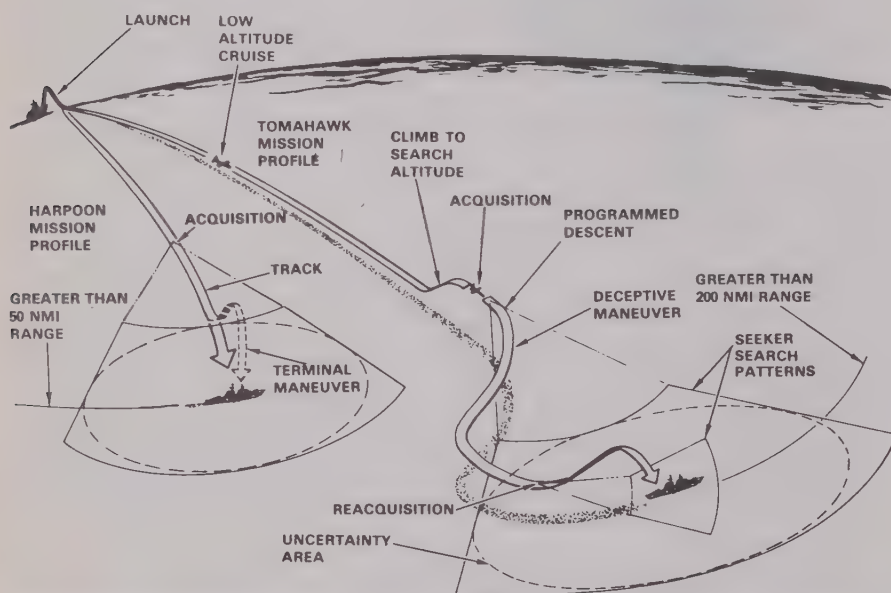
The great shift towards interest in antiship missiles within the US Navy began with the sinking of the Israeli destroyer *Eilat* in 1967. To some extent the United States had already taken steps to counter weapons such as 'Styx', in the form of improved ECM and progressive improvements to the fleet anti-air (and, therefore, anti-cruise-missile) systems. However, in 1967 there was a widespread feeling in the Fleet that the United States badly needed its own antiship missile, that without one American surface warships would lose much of their credibility. Harpoon was formally proposed at this time, but there was also a search for an interim alternative.

Possibly the most interesting such weapon was Fireflash, the Ryan Firebee low-altitude ship-to-ship homing missile. It already existed as a private venture, and Firebees were being used widely in Vietnam as reconnaissance drones. Moreover, soon after the *Eilat* sinking, NAVORD ordered development of a ship-launched Firebee to simulate the Soviet 'Styx'. Six were fired from a modified ground launcher on the aft gun mount base ring of the decommissioned destroyer *Killen* during the summer of 1968; others were launched from small craft simulating 'Styx' missile boats.

Meanwhile NAVORD sought an existing airframe for conversion to an interim antiship missile; the BQM-34A was chosen in November 1968. Ryan proposed to supply 80 missiles for 10 destroyers, which would use helicopters for airborne control, with television guidance. In April 1971 two Firebees were placed aboard the destroyer *Anderson* to test their ability to survive exposure, one in the open and one in a plastic radome. Then, in September, flights of the full system against the target destroyer *Builer* began. NWC China Lake even devised a new warhead.

By this time the Firebee SSM was perceived as a competitor to Harpoon, which was considered much more desirable; by late 1971 Fireflash was dead, despite considerable interest within the Fleet. Harpoon itself was begun under the FY68 program as a 50nm antiship missile, suitable for air platforms.

The air-to-surface origins of Harpoon survive in the designation of the Naval Air Systems Command as its program manager. By 1970, however, if not well before, it had been extended to ship launch; Admiral Zumwalt, the new Chief of Naval Operations, was particularly concerned to increase US antiship missile firepower to make up for the declining strength of the carrier force. Perhaps the greatest advantage of Harpoon, as procured, was that it did not require a dedicated launcher (although, in many cases, one has been provided); it did not materially reduce shipboard resources already provided for the two major naval missions, anti-air and antisubmarine warfare, which continue to predominate. In particular, the canister launcher avoids intrusion into AAW and ASW weapon capacity at a relatively low cost in ship space and weight. Requests for Quotation were issued in January 1971, a prime contractor (McDonnell Douglas) being selected that June, without a flyoff, given



*See Part V for a detailed description.

1 MISSION PROFILES OF TOMAHAWK AND HARPOON

2 For a time in the mid-1970s four fast motor gunboats armed with antiship missiles operated as US 'tattletales' against the Soviet fleet in the Mediterranean. The Standard ARM antiship missile was developed on a crash basis as the Interim Surface to Surface Missile System, and was installed in several frigates, as well as two Iranian destroyers and the gunboats; it was, however, canceled as the Harpoon reached maturity. This is *Antelope*, underway after refit in 1971 with her missiles raised to firing position. The box in front of each launcher held a reload, for a total of four weapons. Note, too, the characteristic 'egg' shape of the Dutch-designed Mk 87 fire control system. Most of the PGMs had, instead, the old US Mk 63, which could be recognized by the radar antenna carried on the 3in/50 gun forward. *Antelope* was making 35kts when this photograph was taken. Although the class was advertised as capable of 40, cavitation effectively limited them to about 37; they were also notoriously uncomfortable in rough weather.

the cost and urgency of the program. The first missile flew in February 1972. Technical Evaluation was completed in June 1975, delayed to some extent by small system problems; however, Harpoon was operationally evaluated in 1977, production beginning that year. It was envisaged at first as an air and surface-ship weapon, but also replaced the proposed submarine missile, STAM (see below); studies of an encapsulated version for torpedo tube launch began in 1972.

STAM

Just as Harpoon was being proposed, a new Submarine Tactical Missile (STAM) was also being evolved. It began as a dual-role (antisubmarine/antiship) successor to the non-nuclear (torpedo-bearing) SUBROC originally proposed in 1962; the STAM Specific Operational Requirement was issued in March 1969. It called for a 5–30nm missile bearing a short-range, high-performance torpedo somewhat smaller than the existing Mk 37 (19in diameter, less than 150in long and weighing less than 2000lb); STAM itself would be 30in in diameter, 300in long, and would weigh 6000–8000lb. It would, therefore, be too large for a torpedo tube; a new vertical launcher was proposed, and in the early 1970s a new submarine, for construction under the FY75 budget, was proposed to carry twenty of these tubes abaft her torpedo compartment. The STAM torpedo itself was to be compatible with existing submarines (SSN-594/637 class). The new 'mid-seventies attack submarine' incorporated improved quieting and propulsion, and by December 1972 it was being described as much larger (13,700 tons submerged, 472ft long) than the existing *Los Angeles* (6630 tons, 335ft) – and as four-fifths as expensive as a Trident ballistic missile submarine (about \$400 million in FY73 dollars). Admiral Zumwalt ordered it, and its outsize missile, killed; Sub-Harpoon was the result.

The new ASW Stand-Off Weapon will presumably fill the ASW role originally envisaged for STAM.

Standard Missile Derivatives

When he entered office in 1970, Admiral Zumwalt considered the development of a US shipboard antiship capability one of his greatest priorities. In Project 'Sixty', his initial outline for Navy priorities, he ordered Harpoon accelerated, and also sought to provide an interim surface-to-surface missile, using either a drone (presumably Fireflash) or some variant of the existing Standard Missile. Some consideration was also given to adopting NATO antiship cruise missiles (Exocet, Kormoran or Otomat) but they were rejected because they would not fit US missile launchers, as Harpoon would. Instead, two versions of the Standard Missile were adopted. Each needed some type of terminal homing, to achieve better than horizon range.

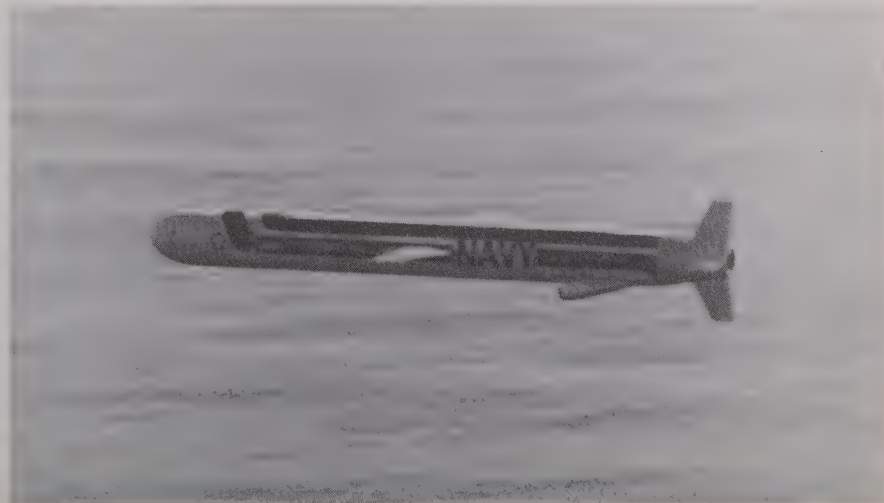
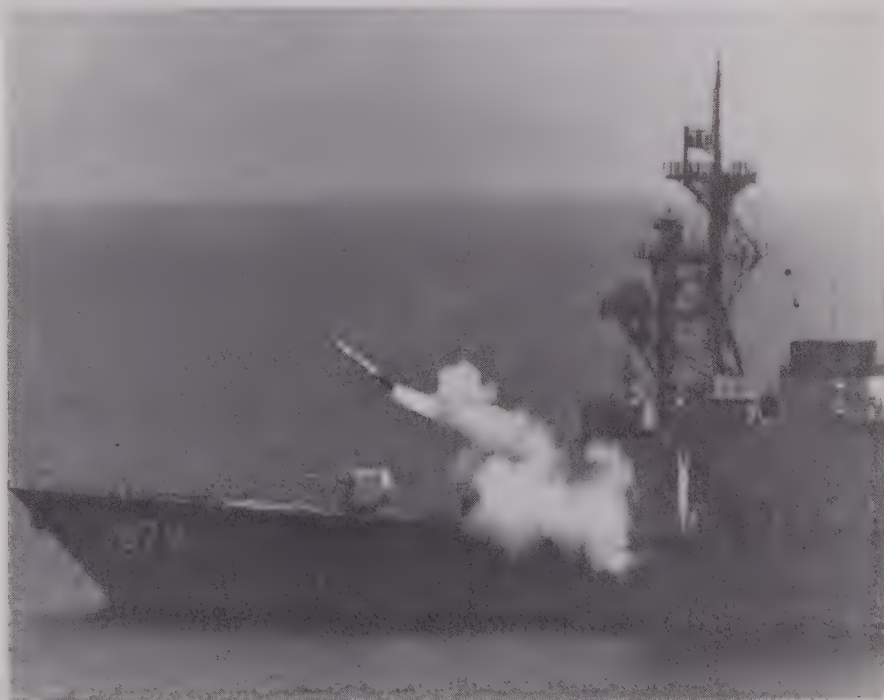
Standard ARM (RGM-66D) was carried by missile gunboats (*Asheville* class), as well as by missile frigates (then DEG) and destroyers. It was the simplest possible adaptation of existing

technology, a surface-to-air missile with an antiradar homing seeker. Approved for service use on 9 July 1970, it had a maximum range of about 35nm, compared to about 60 for the later Harpoon. The first test-firing, from a gunboat, was carried out in 1971.

The alternative was an active radar seeker, requiring rather sophisticated technology. Standard Active (RGM-66F) followed an up-and-over trajectory, its radar looking down at a high grazing angle to sense the high-clutter return from a target. APL and the Naval Ordnance Systems Command evolved a coherent monopulse doppler radar, a side-looking (synthetic aperture) system whose range gates rejected sea clutter in front of and behind the target, while doppler filters rejected it to left and right. The missile destroyer *Hoel* (DDG-13) made three direct hits out of three rounds fired on the Pacific Missile Range, April to June 1973, and the FY75 budget request included \$2.05 million for research and development, as well as \$32.1 million for a one-time buy of 74 RGM-66F missiles. The entire request was denied in view of imminent procurement of the Harpoon missile, which

1 The *Spruance* class destroyer *Merrill* fires her first Tomahawk from an experimental armored quadruple box launcher, 19 March 1980. Ultimately all such ships will be fitted with vertical launching systems capable of accommodating all US naval missiles up to and including Tomahawk, and they will then have very large potential Tomahawk capacities, although it seems unlikely that sufficient weapons will be purchased to fill all of those launch cells. For example, a *Spruance* can probably accommodate more than 100 missiles without any loss in her current ASW capability: the ASROC box forward was designed to be replaced by a Mk 26 Mod 0 launcher (24 missiles), and the Mk 41 VLS replaces Mk 26 on much better than a one-for-one basis. Armored box launchers already on order for missile cruisers will probably be diverted to accelerate the recommissioning of the battleships *New Jersey* and *Iowa*; there has been speculation that ultimately these ships would receive VLS systems in place of their after 16in turrets, although that would be relatively difficult physically.

2 A Tomahawk in flight after launch from an A-6 Intruder. Although Tomahawk was not initially considered for launch by carrier attack aircraft, the MRASM version is being designed for them; it is somewhat smaller than the original missile due to the restrictions of carrier ordnance elevators and also of carrier aircraft. Tomahawk was a contender for the Air Force ALCM contract, calling for a strategic weapon to be launched both by heavy bombers and by special cruise missile carrying aircraft (CMCA); it lost out to the Boeing competitor. This particular test missile, photographed on 6 December 1976, was the first to be equipped with an antiship missile guidance set with an active (Harpoon-type) radar seeker. There has been some speculation that operational antiship Tomahawks will be hampered by the long delay between launch and arrival at the projected target location, and that without some means of midcourse correction they will be relatively ineffective at their advertised ranges. For example, in 45 minutes of flight time a 30kt target moves as much as 22.5 nautical miles, far beyond the sweep width of the seeker.



would achieve better range performance and which, in view of its much flatter trajectory, would probably provide significantly less warning time.

Tactical Tomahawk

In 1983, then, the US Navy has turned towards the antiship missile mission so often rejected in the past, and is procuring Harpoon on a large scale: over a thousand missiles had been delivered by the end of 1981. Interest in an extended-range Harpoon, sometimes described as a 100nm missile, led in 1972 to the decision to develop a tactical version of the sea-launched (strategic) cruise missile, Tomahawk, a decision reflected in the much later choice to size the new vertical launch system (VLS) to accept not only Standard-size but also Tomahawk-size missiles. Initial deployment of Tomahawk (tactical version) will entail the installation of quadruple armored-box launchers, competing with other weapons for scarce

topside space aboard surface ships; however, future warships will have the vertical launcher, and Tomahawk, like Harpoon, will become interchangeable with the anti-air missiles. For submarines, Tomahawk fits the existing torpedo tube, requiring no capsule (as in the case of Harpoon).

Penguin

Beside Harpoon and Tomahawk, the US Navy is testing a Norwegian antiship missile, Penguin II, for its 65ft Mark 3 Patrol Boat, normally operated in support of Naval Special Warfare Forces in coastal operations. During operational evaluation of the boat itself, the Commander, Operational Evaluation and Test Force, found its ability to perform the coastal missions deficient in view of its lack of an effective antisurface weapon. The Norwegian Penguin II was selected as the best available such system, capable of close-in surface-to-surface combat, passive operation, and opera-

tion near land masses. The missile was originally developed with US and West German assistance, and incorporates a Bullpup warhead; midcourse guidance is inertial, with infrared for terminal homing. Mk II, the type under US evaluation, has a reported range of about 16nm; officially 'its minimum and maximum ranges are consistent with both the mission and the sensor capabilities of the Mark 3 boat'. In the version under consideration, Penguin incorporates both 'dog-leg' and salvo capabilities. A contract with the Royal Norwegian Navy for a Penguin weapon system was signed in June 1979; early in 1981 a Mk 3 was fitted with it, and Operational Test and Evaluation was scheduled for November–December 1981, with a production decision scheduled for January–February 1982. Opeval was very successful, but production did not follow because the missile was considered too large for the 65ft boat. As of late 1982 other applications were being considered.

6. Bombardment rockets

The 4.5in Rocket

Rockets solved a major amphibious assault problem of World War Two: how to lay down intense fire during the crucial landing phase of the assault, after bombardment by aircraft and by distant warships had to cease for fear of hitting troops as they disembarked. Rocket launchers were inherently light and could provide enormous volumes of fire, albeit not for very long. On 16 June 1942, Vice Admiral Wilson Brown, newly appointed Commander of Amphibious Forces Pacific, witnessed a demonstration of Mousetrap and other CalTech rockets; he almost immediately suggested a beach bombardment rocket with a range of about 1000yds as the solution to the landing support problem, between the naval barrage and the emplacement of landed artillery on the beach.

Progress was extremely swift; CalTech

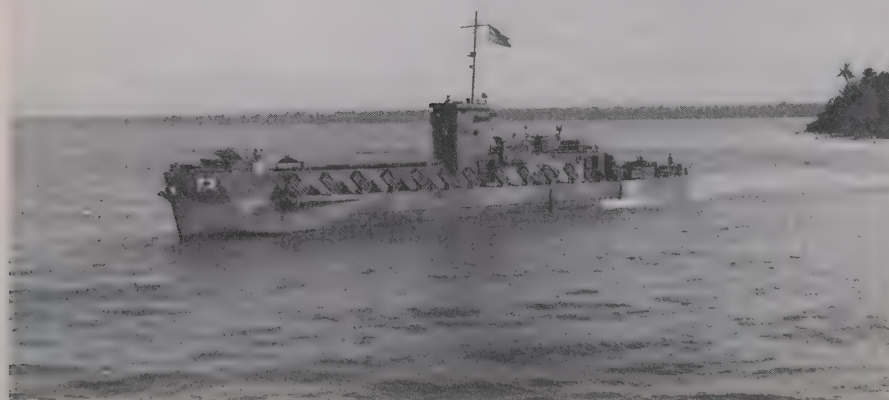
mated the existing Mousetrap (2.25in Mk 3) motor to a standard 4.5in, 20lb GP bomb, which carried about 6.5lb of TNT. A range of about 1100yds was achieved, and the first rocket successfully tested on 24 June. A Mk 1 launcher was also designed by CalTech: a 'crate' holding 12 rockets in four layers of three, in a frame which could be elevated but not trained. A Light Support Craft (LCS) could carry one on each side. Tests in August 1942 were so successful that within four days BuOrd had asked CalTech to supply fifty launchers and 3000 rockets, and the Beach Barrage rocket was successfully fired at Casablanca that November. By 1943 the original Mk 1 'egg crate' had been replaced by a simplified Mk 8, of fixed elevation, since the best results with the original rockets had been obtained at maximum elevation. As for the rockets themselves, both fragmentation and

smoke heads were developed and used.

CalTech and BuOrd developed a number of improved rocket launchers during the war. Mk 7 (late 1943) was a single rail with a gravity magazine above it feeding rockets continuously; it could fire twelve in four seconds, but consumed about a third of the deck space of Mk 1 or 8. By the end of the war more Mk 7s had been procured than any other Navy rocket launcher. Mk 11 was an improved version capable of jettisoning duds.

The 4.5in rocket was originally employed primarily as an antipersonnel weapon; from early 1943 onwards, for example, converted LCI(L) rocket ships, with forty launchers each, appeared. However, similar rockets were also considered a useful means of clearing underwater obstructions, using 7.2in demolition heads on either 2.25in or 3.25in motors. The first launcher was a 120-rail installation filling the entire well of an LCM, with a range of either 840 or 1260ft, depending upon the rocket motor used. It was called 'Woofus', or Mk 24; Mk 25 was a 21-guide launcher for paired installation in a DUKW amphibious truck. Woofus first entered action in the invasion of Southern France, having been delivered in April 1944. As an alternative, a rocket grapnel was designed to attack beach obstructions; this 'Cutteroo' (with launcher Mk 26) never saw action, but was used to collect earth samples after the Bikini tests.

Finally, the 4.5in rocket saw PT boat service. Early attempts in the South Pacific to increase



The first US rocket-firing ships were converted infantry landing craft, such as LCI(R)-73, shown on 28 May 1944, her sides lined with Mk 8 'crate' launchers, and with a single Army-type 40mm gun in her bows. This hull was later modified into the (large gun-armed) landing craft support, or LCS.

US National Archives

PT boat firepower had employed clustered Army Bazookas, but the much more powerful barrage rocket was soon adopted, with modified Mk 8 'egg crate' launchers with blast shields.

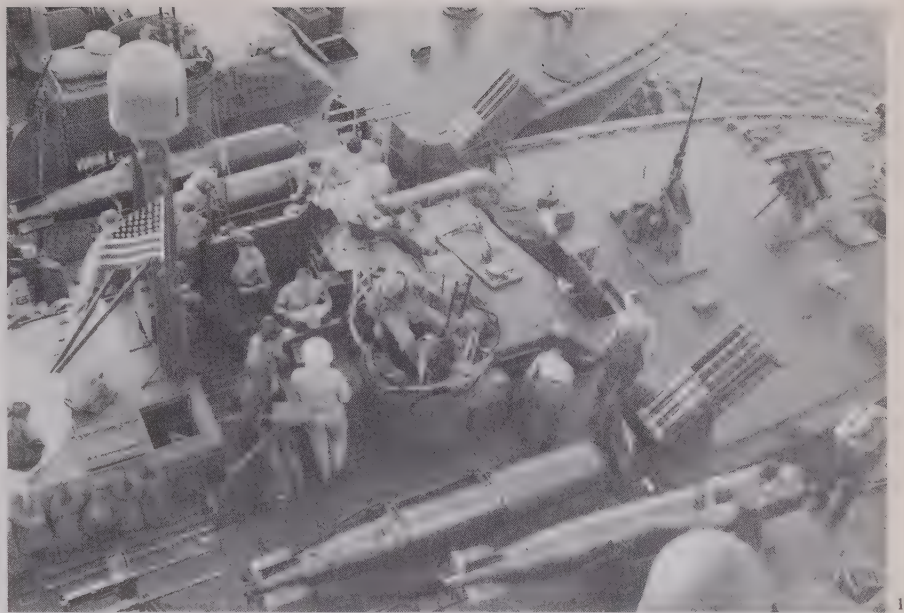
The 3.5in and 5in SSR

Buord proposed a new 10,000yd ship-to-shore rocket in May 1943. Accuracy was a major problem, since the dispersion of 25–85mils, acceptable in a barrage weapon at a 1000yds, was far less acceptable at 10,000. Moreover, fin stabilization in itself demanded too much space on a dense rocket launcher: NDRC proposed instead to spin-stabilize its new rockets, with no fins at all. These weapons could also be shorter, and launchers could fire much more rapidly. Both 3.5in and 5in Spin-Stabilized Rockets (SSR) were designed, the drawings reaching BuOrd in August 1944. The former was proposed to replace the existing 75mm pack howitzer, a single-barrel Mk 40 launcher being mounted on a conventional machine gun tripod, but its dispersion was too great. Late in the war the 3.5 was also considered as a partisan weapon by the OSS. The 5in SSR, on the other hand, was employed extensively, by PT-boats and also as a shore bombardment weapon, by landing craft and even by submarines.

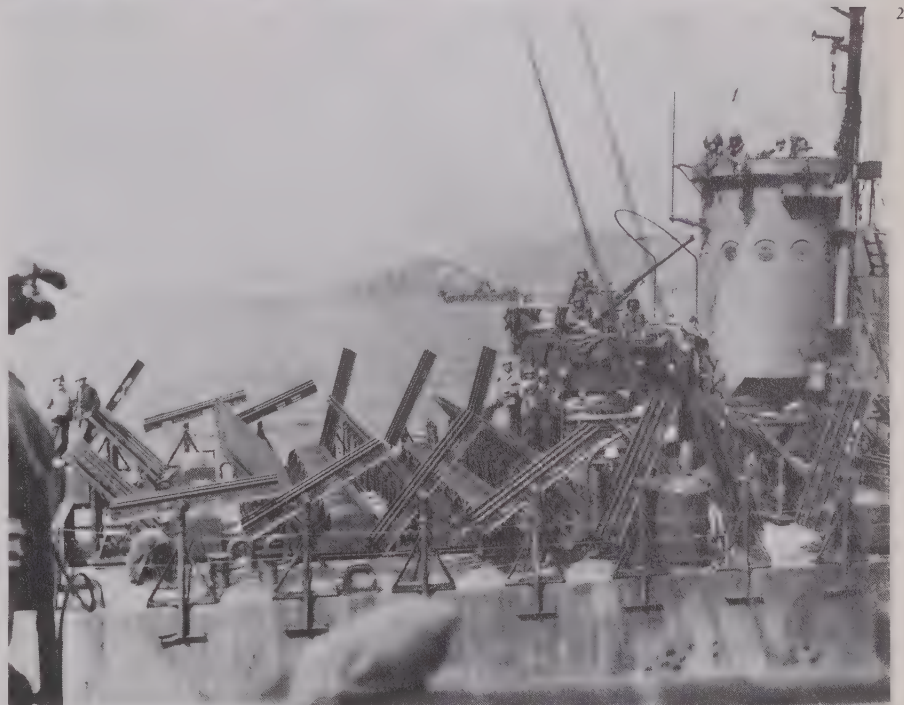
All of these weapons moved from concept to hardware extremely fast. For example, a spin-stabilized rocket was first tested by CalTech only in October 1943, yet rocket and launcher were available for sea trials in a PT boat in August 1944. Boats at advanced bases in the Philippines were equipped during the following March and April 1945. The new Mk 50 launcher, which replaced a torpedo rack on each side of the boat, carried eight rockets in two tiers of tubes. It was generally interconnected to a 20mm gun in the bows, which had a similar trajectory.

At about the same time that it developed the 10,000yd PT-boat rocket, CalTech also devised a 5000yd beach bombardment equivalent with a high-capacity head and a Mk 51 launcher similar to the earlier Mk 7: it could deliver 80 percent hits within a 500yd × 500yd box. Longer range was desirable in a beach rocket because offshore obstacles such as reefs sometimes kept the rocket boats too far from the beach, as at Saipan. CalTech ultimately carried out a program of 10,000, 5000, 2500 and 1250yd rockets, all of the same weight, about 50lb, and therefore all suited to the same family of launchers.

Admiral King directed the conversion of twelve medium landing ships (LSMR) to rocket support ships for the Pacific theatre in October 1944 and the first eight, equipped with 5in finned aircraft rockets, sailed that December. The last four of these 'interim' LSMRs had Mk 51 launchers with spin-stabilized rockets. The first eight could fire 480 rounds in 30 seconds, after which 2½ hours were needed for the first reload and 4½ for each additional. The spinner ships, on the other hand, could fire 1020 rounds in the first minute, and required 45 minutes for one reload and 1½–2 hours for another. They entered action at Okinawa, although it had been hoped that they would be available for the Iwo Jima landing. When that became impossible, sixteen LCIs were outfitted with 5in barrage spin-stabilized rockets (six gravity-fed launchers each), firing the first SSRs in action on 19 February 1945.



1



2

Meanwhile an 'ultimate' LSMR was designed, its Characteristics set in November 1944, for operation in June 1945. It was to have an entirely new launcher, with a rate of fire of 30 rounds per minute for the first minute, continuously loaded from below decks, and trained and operated by remote control. This Mk 102 was a twin-barrel type based on the existing power-operated twin 40mm gun mount, fed by a pusher-type hoist from below. The 'ultimate' LSMR had ten. An interim Mk 101 rocket launcher consisted of eight Mk 51s welded together on a 40mm twin mount. However, because the Naval Gun Factory was able to develop the Mk 102 from freehand sketch to general arrangement drawings in only two weeks, it was not needed, and only two were ever built.

Beside the shore bombardment operations of the LSMRs, 5in shore bombardment rockets

1 PT-boats preparing for the Battle of Surigao Strait display their characteristic weapons, including, aboard *PT-131*, fin-stabilized rockets in 'crate' launchers (Mk 8). Note, too, the Army mortar atop the bridge, the 20mm Oerlikon forward of the bridge, and the twin 0.30-caliber machine guns, which can be distinguished from the larger 0.50s by their perforated barrel jackets. An Army-type 37mm automatic gun can just be seen at the right. The torpedoes in racks are Mk 13 air-launch types; blast shields protect the torpedoes from the rocket launchers.

US National Archives

2 A converted landing ship (medium) shows her combination of single-shot railed rocket launchers. Such ships were credited with a total of seventy-five 4-rail (Mk 36) and thirty 6-rail (Mk 30) launchers, all for 5in fin-stabilized rockets. They could discharge 480 rounds in 30 seconds – after which 2½ hours were required for reloading. Note the pipe frame around the Army-type 40mm gun forward of the bridge, to prevent it from firing into the bridge as it tracked an airplane. A similar LSM(R) can be seen in the background, with its single 5in/38 gun visible aft.



- 1 With the adoption of spin-stabilized rockets came rapid-reloading, since the rocket had no projecting fins to obstruct an ammunition hoist. The Mk 102 rocket launcher, based on a twin 40mm gun mount, loaded vertically from a pusher-type hoist and then depressed to fire. These examples, of which the mount closest to the camera is in the loading position, were photographed aboard LSMR-536, the *White River*, near Da Nang, July 1966.
- 2 A 5in spin-stabilized rocket leaves a Mk 102 launcher aboard the support ship *White River* off the Vietnamese coast, June 1966. The sparks are from the previous rocket fired; note the effect of the blast deflector at the rear of the launcher.

were also fired on three occasions in 1945, by the submarine *Barb*, equipped with a Mk 51 forward; three others (*Chivo*, *Chopper* and *Requin*) had been fitted in 1945, but did not see action. These installations generally involved the welding of a baseplate to the submarine deck, the launcher and rockets being emplaced after the submarine surfaced. In 1945, too, plans were drawn for the installation of a Mk 102 director-controlled weapon for shore bombardment.

Other Wartime Developments

Two other wartime uses of shipboard rockets deserve mention. One was radar counter-measures: rockets could project 'window' (chaff) for ship self-defense, and Rocket Launchers Mark 31 and 32 were devised for this purpose. Postwar they were sometimes used to fire NAD noisemakers for escort defense against homing torpedoes. All of these devices were, in turn, the predecessors of the Zuni chaff rockets of the Vietnam War period, in which 5in aircraft SSRs loaded with chaff were fired from their standard aircraft quadruple launchers, mounted on shipboard and linked with shipboard ECM systems. More recently, specialized chaff rockets and chaff rocket-launchers have appeared. Of the two major wartime chaff systems, Mk 32 (two rails) was the first, and Mk 31 (four rails) followed; both employed finned aircraft-type rockets.

The other case of interest is the use of unguided rockets against aircraft; on 6 December 1944 BuOrd began Project 'Coso', to determine the comparative effectiveness of quadruple 40mm mounts and VT-fuzed rockets for antiaircraft protection. Although the VT fuzes were not effective, the program continued into 1945 with the Army 2.75in SSR. Although LSMRs were actually used as pickets, it seems unlikely that their rocket batteries were considered a major contribution to antiaircraft barrage at Okinawa. At that time Coso and its successors were still in train.

Many rocket launchers were developed but did not see action, as the partial list of mark numbers above would suggest. Mk 2 and 4 were portable devices, sometimes used from LCVs but more often used ashore for fire support. Mk 17 fired target rockets, an important if nonweapon application. Mk 20 and 22 were Mousetrap launchers (Mk 21 was a training device for this weapon), and Mk 30 and 36 were six- and four-rail interim aircraft rocket launchers for the early LSMRs. Mk 10 and 11 were the Hedgehogs which, to be accurate, were not rockets at all; Mk 13 was the 2.36in (bazooka) Launcher Mark 1, and Mk 14 was the 2.5in Rocket Launcher Mark 4. Many mark numbers referred to equipment not issued, such as the original Mk 3, 5, 6 and 9, the 3in Mk 4 (which became Rocket Launcher Mark 15 in 1944), the 7.2in Mk 21 and 23, and the 3.5in Mk 2 (which became Mk 33 in 1944).

Post-1945 Systems

There was an active program underway in 1945, the Mk 100 series having evidently been started at that time. Thus Mk 103 was based on the quadruple 40mm mount (December 1945); Mk 104 was a 12-tube launcher for 5in SSRs based on the Martin 250CH aircraft machine gun turret, with the operator in the mount, for PT-boats (May 1945); Mk 105 was a two-tube launcher with continuous reload, similar to Mk 102 but lighter (May 1945); Mk 106 was similar

to Mk 101 and 102, but had 64 closed-breech launchers for 5in SSRs (January 1946); and Mk 107 was based on the Maxson quadruple 50-caliber machine gun mount, for PT-boats, with nine closed-breech guides for 5in SSRs (January 1946). In each case, the date is the date of nomenclature assignment, somewhat later than the date of conception but close to it. Mk 108 was the launcher for Weapon Alfa, originally based on the twin 40mm mount (see Part III).

Since 1948 the rocket-launcher series has included the actual launchers of the principal guided missiles: Mk 110 (RAT, for ASW), Mk 112 (ASROC), Mk 113 (Launching System Mark 15), Mk 115 (Polaris, Mark 17 Missile

Launching System), Mk 116 (Tartar single rail), Mk 117 (Terne), Mk 118 (Polaris, Mark 17 Launching System), Mk 122 (Poseidon, Mark 21 Launcher System), Mk 123 (Tartar, Mk 22 system), Mk 124 (Poseidon, Mk 21 system), and Mk 126 (Typhon Medium Range, Mk 14 system).

Not so much has been done to improve on the shore bombardment rocket technology of World War Two. Throughout the postwar period the issue of a replacement for the LSMRs, and therefore of a new generation of rockets and launchers, was an active one. The *Carronade* was completed in the mid-1950s with the Mk 105 launcher, and for a time in the mid-1960s the construction of a new fire-

support ship, the LFS, was planned. She was, at first, to have had both rockets and guns, the former considered important for their ability to smother area targets (*eg* to keep beach defenders occupied as the first waves went in), while the latter would destroy point targets such as beach fortifications. However, when the LFS was abandoned, the shore bombardment function was passed over to the gun alone, the Marines hoping, at best, for a single 8in lightweight gun aboard each of the new *Spruance* class destroyers. They did not receive even that, and the total absence of an American shore bombardment rocket program may conceivably prove embarrassing in some Middle Eastern future.

Appendices

These appendices are an attempt to include all US Navy designated gun, missile, fire control, sonar and airborne radar systems, even those never placed in production; they give as full as possible a picture of the range of concerns of the Navy. The reader is, however, cautioned that they are unlikely to be totally exhaustive, as some designations were never assigned, while some projects were never properly designated. Nearly all Bureau of Ordnance weapon projects were assigned mark numbers in numerical series, which makes it easier to track down abortive projects. However, there were important exceptions, and there were several radical shifts of nomenclature. For example, after World War Two Army and Navy missile projects were all classified in a single series with mission designators (AAM, SAM, ASM,

SSM) and Service suffixes, *eg* ASM-N-6 for a Navy air-to-surface missile. In theory the Navy was to use only even, the Army only odd numbers, but in practice both were used; the problem is that the apparent absence of, say, ASM-N-9 might mean either that there was an abortive project or that the number was not used. The system replaced an earlier standard Navy aircraft system, indicating both mission and manufacturer. In 1962 it was succeeded by a Defense Department triservice system, a single numerical series with alternative mission prefixes, such as AIM for air-to-air and RIM for surface-to-air (ship-to-air); thus AIM-7 and RIM-7 are two versions of essentially the same weapon – the Sparrow missile. To make matters worse, there was also a Bureau of Ordnance mark numbering system in use in the

late 1950s; the Tartar missile, for example, appears to have had no separate SAM number at all.

As a final note, the reader is advised that range data for guided weapons, even where official, are inherently approximate: these weapons are generally designed to expend considerable energy or fuel (or, more likely, both) searching for and attacking maneuvering targets at the end of their nominal ranges. If the target is somewhat more distant but does not require so great an energy expenditure at the end, the missile can generally bridge the gap. SAMs, for example, hardly fall to earth just beyond their rated ranges – which is why the Standard ARM surface-to-surface missile greatly outranges the Standard (MR) SAM, and why SM-2 greatly outranges SM-1.

I-1 Guns

In the notes which follow, weights are given as without/with breech block, as in 26/113lb; 'MV' is muzzle velocity, 't' is tons and 'g' is grams.

Machine Cannon

20mm gun barrels

Mark 1

Oerlikon gun, 70-caliber, with a 450 round per minute cyclic rate; made from a single forging with the first 2in of the bore flared at the muzzle as a flash-hider. The shell weighed 0.27lb and MV was 2770ft/sec; charge was 442g and chamber pressure 19.6t. Rifling was uniform (1/36), and weight 37/150lb. Mk 2 had two locking slots and cooling ribs; Mk 3 had a single locking slot, and Mk 4 was very similar except for manufacturing tolerances, converted from metric to English units. Mod 2 had no cooling ribs.

Mark 7

Aircraft machine gun for fixed mounting; flattened low-silhouette weapon for jet aircraft wing installation. Originally known as a component of the 20mm single-barrel Shirgun EX-1 Type 3 (lightweight). Cyclic rate was 1000 rounds per minute and weight 26/113lb.

Mark 8

Double-barreled aircraft gun using radially expanded barrel, formerly Shirgun EX-3; cyclic rate 2000 rounds per minute; MV 3000ft/sec, weight with breech block 190lb. Gas-operated.

Mark 9

Double-barreled aircraft gun, formerly

Shirgun EX-4; MV 3100ft/sec, cyclic rate 5100 rounds per minute, weight 41.4/162lb. Recoil-operated, double-feed type with revolving chambers.

Mark 10

Alternate to Mk 9 with 20mm Gun Mechanism Mark 11; fixed or flexible mounting. Weight 57.4/170lb.

Mark 11

Single-barrel gas-operated aircraft gun, part of Aircraft Gun Mark 12 (Mechanism Mark 12). Weight was 31.5/88lb.

Mark 12

Single-barrel gas-operated aircraft gun, firing at 1000 rounds per minute; used with 20mm Gun Mechanism Mark 13.

Mark 13

Single-barrel aircraft gun (fixed type), used with 20mm Gun Mechanism Mark 14.

Mark 14

Single-barrel aircraft gun (fixed type), used with 20mm Gun Mechanism Mark 15.

Mark 15

Single-barrel aircraft gun (fixed type), used with 20mm Gun Mechanism Mark 15.

Mark 16

Single-barrel aircraft gun (fixed type) used with 20mm Gun Mechanism Mark 12. Mod 1 was the first production of a 20mm Machine Gun Assembly with a short barrel – 29.5 rather than 52.5in (Mk 11) or 57.4in (Mk 10) or 60in (Mk 13).

AN M2

Hispano-Suiza gun, 39.7in long, 600–700

rounds per minute, using combined blow-back and gas operation. Weight with breech block was 102lb, MV 2900ft/sec and chamber pressure 18.8t.

20mm gun mechanisms

Mark 9

Used with 20mm Mk 7 barrel; Army designation T55, developed from the Oerlikon by Shirgun. 1000 rounds per minute.

Mark 10

Used with 20mm Mk 8 barrel; Army T54; gas-operated double-barrel type, 2000 rounds per minute. Both barrels were fed from one belt.

Mark 11

Used with barrel Mk 9 or 10; Army T117; recoil-operated, short two-barrel, double-feed gun, MV 3175 or 3320ft/sec, firing 5100 rounds per minute, effective to 1500yds. There were eight chambers in the revolver through which carbon dioxide was passed for cooling. The gun used a standard projector with electric primer to extract the round from the belt, load it into the gun, extract the case, and rebelt the case.

Mark 12

Army T118: combination blow-back and gas; 1050 rounds per minute. Pneumatic or electric feed.

Mark 13

Used with 20mm Mk 12 barrel; Army T129; gas-operated, 1000 rounds per minute. Similar to Mk 9 but had a higher MV (3300 *vs* 2700ft/sec) and chamber pressure (25.9 *vs* 21.4t).

Mark 16

Aircraft gun: M3 with receiver body modified

to use the Mk 8 pneumatic feed mechanism. Gas-interlocking blowback gun. Mod 1 operated at 650–800 rounds per minute at 2750ft/sec and had a 'soft' recoil mechanism. Mod 5 is a shipboard gun for light craft, in Gun Mount Mark 67; it fires 600–800 rounds per minute, with an automatic magazine load of 385 rounds and a total weight (unloaded) of 99lb; it is 77.7in long.

EX-29

Small-craft gun, rated at 250/550 rounds per minute with a 1000-round magazine, and designed to achieve fewer than two failures per 1000 rounds. The barrel is 48in long. General Electric. Mk 28 is the 30mm gun of the Emerlec Mk 74 gun mount, rated at 550 rounds/minute with 1950 rounds in the magazine, and a 3543ft/sec MV.

1.1in gun

Mark 1

Recoil-operated 75-caliber gun with a cyclic rate of 150 rounds per minute. The 0.917lb shell had a 115g charge. MV was 2700ft/sec and chamber pressure 16t. The barrel (rifling 1/30) was chrome plated inside and out except for the chamber, and the weapon was water-cooled. Mod 1 was threaded for a flash-hider. Weight without breech block was 105lb.

57mm gun

M4

Browning aircraft gun (56-caliber, MV 2000ft/sec, weight 55/213lb), also mounted on PT-boats for surface action. It was a long-recoil, percussion-firing gun with a vertical sliding-wedge breech block, capable of firing 150 rounds per minute, and effective to 4000yds. Chamber pressure was 10.4t.

40mm gun

Mark 1

The Bofors gun: 56.3-caliber, recoil-operated (160 rounds per minute) and water-cooled, for twin or quadruple mounts. It had increasing rifling (1/45 to 1/30). The gun weighed 202lb without breech block and fired a 1.985lb shell (300g charge) at 2890ft/sec. Chamber pressure was 19.5t. There appears to have been no Navy designation for the single air-cooled Army-type mount.

Light Guns

The 1, 3 and 6pdr guns of the 'New Navy' corresponded to particular calibers: the 1pdr, the smallest explosive shell allowed under the Rules of War, was 37mm (1.457in) in caliber; the 3pdr, 47mm (1.85in); and the 6pdr, 57mm (2.244in). The original designations corresponded to the manufacturers, which produced distinctive designs with their own breech blocks. All of these weapons fired fixed ammunition.

The earliest light cannon of the New Navy were 37mm and 47mm Hotchkiss revolvers similar in appearance (but not in mechanism) to Gatling guns. Of these, all 47mm and early 37mm guns were manufactured in France. By the early 1890s they had been replaced in production by a variety of single-barrel rapid-fire guns of Hotchkiss and Driggs-Schroeder design with, respectively, vertical sliding-wedge and sliding and rotating breech blocks, in 1, 3 and 6pdr sizes. In 37mm caliber a distinction was drawn between light and heavy ammunition, meaning between short and long

cartridges (4.3 vs 7.32in³ chamber).

1pdrs

The earliest, without a mark number, was the Sponsell Gun, manufactured by Pratt and Whitney, 40 calibers in length, with a vertically sliding breech block. Hotchkiss produced Mk 1 (20 and 27 calibers), originally the Hotchkiss light, short Mk 1 gun on a nonrecoil mount. Mk 1 Mod 1 was 35 or 45 calibers long, and was originally the Hotchkiss light, long Mk 2 gun on a recoil mount. Mk 3 (40 calibers) was originally the Hotchkiss heavy, long Mk 1 gun; Mk 5 (Hotchkiss heavy Mk 2) was similar, as was Mk 8 (Hotchkiss heavy, semiautomatic Mk 3). Mk 10 was a rapid-fire aircraft gun with a Hotchkiss-type breech, and Mk 11 was a 20-caliber Hotchkiss-type line-throwing gun. Mk 13 was a Mk 5 of monoblock rather than built-up construction.

Driggs-Schroeder produced the Mk 2 (50 calibers) as the Driggs-Schroeder heavy Mk 1; Mod 1 was 40 calibers in length; Mk 4 was the Driggs-Schroeder heavy, long Mk 2 (50 calibers); and Mk 12 was a 40-caliber monoblock gun with a Driggs sliding and rotating drop breech block.

Mk 6 was the heavy machine cannon which reappeared as an anti-aircraft weapon during World War One. It was originally designated Maxim-Nordenfeldt heavy, automatic Mk 1 gun, and entered service before the Spanish-American War. It was 42.5 calibers in length, with a waterjacket extending up to 3.15in from the muzzle. Mk 7 was a 30-caliber version for anti-aircraft fire.

Mark 9 was originally known as the Maxim-Nordenfeldt light, automatic Mk 1.

Mark 14 was a Baldwin design, manufactured by Poole during World War One. It was an automatic gun with a flexible mount. Mk 15, of similar parentage, was described as an automatic motor gun. It had a much larger cartridge with a chamber volume of 22in³, and a muzzle velocity of 3000ft/sec (maximum pressure 20.5tons). By way of contrast, the muzzle velocity of earlier heavy 1pdrs was generally 2000ft/sec, and of light 1pdrs, 1500ft/sec.

3pdrs

Hotchkiss was responsible for three marks. Mk 1, 40 calibers, was the Hotchkiss 3pdr rapid-firing gun (Mod 1, 50 calibers, was of French manufacture). Mk 4 (50 calibers) was also by Hotchkiss and was originally the semiautomatic Gun Mark 4 (Mks 10 and 11 were very similar). Mk 8, 40 calibers, was a Hotchkiss-Armstrong gun similar to Mk 1. Powder chamber volume was 45.8in³, and muzzle velocity for Mk 1 was 2026ft/sec.

Driggs-Schroeder produced Mk 2 (Driggs-Schroeder Mk 1, 45 calibers) and Mk 3, which differed from Mk 2 in not having trunnions; and Driggs-Seabury and Ordnance Corporation manufactured Mk 14, similar in design to the Hotchkiss Mk 10.

Mk 5 (50 calibers) was the Maxim-Nordenfeldt semiautomatic Gun Mark 1, using a rotating and sliding breech block. Mk 6 was the Maxim-Nordenfeldt semiautomatic Mk 2; Mk 7, 45 calibers long, was the Vickers Sons & Maxim semiautomatic Gun Mark 3, with a vertical sliding breech. It introduced monoblock construction for 3pdrs. With a powder chamber volume of 47in³, Mk 7 attained 2119ft/sec. Mk 12 (50 calibers) was

the Maxim rapid-fire gun Mk M, with a rotating and sliding breech block. Only two were purchased, and they were later withdrawn from service.

Mk 9, 50 calibers in length, was the Nordenfeldt Gun Mark 1, with a rotating and sliding breech block; Mk 12 was the Nordenfeldt semiautomatic Gun Mark 1.

6pdrs

Hotchkiss manufactured Mk 1 (40 calibers), which was the Hotchkiss Gun Mark 1; Mk 2 was very similar but without trunnions, and Mk 3 (45 calibers) was Hotchkiss Mk 1, long; Mk 7 was Hotchkiss Mk 2, long (Mod 3 was Hotchkiss Mk 3, originally a Coast Guard gun). Chamber volume was 50.23in³, and initial velocity 2240ft/sec, in the 40-caliber guns.

Mk 4 was a Driggs-Schroeder monoblock field gun with a revolving drop breech block (30 calibers); Mk 5 was a 30-caliber Lynch field gun. Mk 6, 45 calibers, was the Driggs-Schroeder rapid-fire Mk 1 gun; and Mk 8, 50 calibers, was the Driggs-Schroeder Mk 2. Mk 11, 50 calibers, was the Driggs-Seabury semiautomatic Mk 1.

Mk 9, 42 calibers, was the Maxim semiautomatic Mk 2 gun, of monoblock construction with a vertical sliding breech block; Mk 10, also 42 calibers, was the Nordenfeldt rapid-fire Mk 2, of similar construction.

Mk 12 was a 32-caliber Davis nonrecoil gun, and Mk 13 was a 33-caliber Davis nonrecoil gun bored out for a 9lb projectile.

3in Guns

Mark 1

Landing gun, 21 calibers, rapid fire; monoblock construction, with Fletcher breech (down-swing carrier type). Weight including breech block was 384lb, and the gun fired a 13lb shell with an MV of 1150ft/sec to 5000yds at an elevation of 19° 33.3'. Pressure was 9.5t.

Mark 2

Built-up rapid-fire gun, 50 calibers. The standard antedestroyer weapon of late US predreadnoughts, armored cruisers and some destroyers, it weighed 2086lb with breech and fired a 13lb shell at 2700ft/sec to 14,590yds at an elevation of 43° 02'. Charge weight was 2.7lb and chamber pressure 17t. Side-swing carrier breech. Mk 3 was of simpler construction, at 1986lb with breech. Mk 5 was a new semiautomatic design (2280lb) with uniform rifling (1/25 instead of increasing from 0 to 1/25) and with a Driggs-Seabury semiautomatic vertical sliding breech. Mk 6 was similar to Mk 5 but with slide length increased from 29.4 to 37.4in (2339lb including breech in Mod 0 version); Mods 4, 5, 6 and 7 were designed for submarine (wet) mounts, and in Mod 6 the slide surface and rear cylinder were chromium-plated and other exposed parts painted. Mk 8 was a Mk 6 with a horizontally instead of vertically sliding breech block; only one was built.

Mark 4

Bethlehem Steel 23.5-caliber rapid-fire landing gun; single forging; side-swing carrier breech. Rifling was uniform at 1/29.89. The shell weighed 13lb and MV was 1650ft/sec, giving a range of 8800yds at 45° 20.2'.

Mark 7

Erhardt-type rapid-fire, 23-caliber landing gun built by the American-British Manufacturing Company, with horizontally sliding breech block. The 13lb shell required a 560g charge and ranged to 8800yds at 45° 20.2'. MV was 1650ft/sec and chamber pressure 13.5t. Mk 9, with a comparable performance, was a submarine (wet) gun, similar in general design to Mk 6 Mods 4, 5, 6 and 7, and provided with a vertical sliding-wedge breech block. Mk 9 Mod 1 was the monoblock Bridgman gun; weight of Mod 0 was 749lb (including breech), and rifling was a uniform 1/29.89. Mk 11 was a very similar landing gun built by Bethlehem (578/632lb, vertical sliding-wedge breech). Mk 13 was a boat gun built by Driggs, with a semiautomatic horizontal sliding-wedge breech (457/531lb, chamber pressure 11t) and of monoblock construction. Mk 14 (521/593lb, chamber pressure 13t) was the boat gun adapted by the Poole Engineering and Machine Company for destroyer antiaircraft use during World War One. It had a horizontal sliding-wedge breech. Mod 1 was used aboard patrol craft (590.5/658lb); it had a muzzle blast reducer and a counterweight at its breech. Mk 14 was officially described as a 23.5-caliber gun, but its ballistics matched those of the other 3in/23s.

Mark 10

Semiautomatic, rapid-fire, 50-caliber fleet antiaircraft gun derived from Mk 6, with modified breech (vertical sliding wedge) to adapt it to its Mk 11 mount. Rifling was increasing, 0 to 1/25. It weighed 2547lb without breech and fired a 13lb shell at 2700ft/sec to 14,590yds at 43° 02'. The charge weighed 3.85lb and pressure was 17t. Mod 4 became Mk 17, for submarine wet mounts, with its bore and outside working surfaces chrome plated (2365/2547lb). Mk 18 was similar but had a slide surface without a guide key (2830lb with breech). Mk 19 was lighter (monoblock construction, 1423/2162lb), and Mk 20 was Mk 6 converted for fleet AA service. Rifling in Mk 18 was a uniform 1/32; in Mk 19, 1/32; in Mk 20, increasing, 0 to 1/25 (but Mod 1 had uniform 1/25). Mk 21 was a new-construction fleet AA gun, of monoblock construction, derived from Mk 19 but differing in the length of its slide cylinders (1240/1760lb). Mod 1 was adapted for submarine (wet) mounts. Mk 22 (1242/1562lb), of wartime construction, was virtually identical except for the addition of a collar, 78.9in from the muzzle. Mod 1 was produced from an unexpanded (as opposed to a radially expanded) forging of higher physical strength. Mod 2 was radially expanded, Mod 3 nonexpanded. Mod 6 had the entire length of the bore and chamber chrome-plated with a heavier plating. Service life for a 3in/50 barrel is about 4300 rounds.

Mark 12

Mountain gun, 15-caliber. Weight 181.5/205lb, shell 13lb, MV 1000ft/sec, range 4000yds at 15° 57.2'.

Mark 15

Davis 24-caliber, rapid-fire, nonrecoil gun, consisting of two monoblock barrels aligned with their breech blocks adjacent, one firing a shell (rifled 1/75 increasing to 1/30), the other a charge of bird shot (smoothbore). It was simi-

lar in design to the 6pdr Mk 12 and was designed for aircraft use. Chamber pressure was 15t and weight excluding breech block 182lb; other details as 3in Mk 12.

Mark 16

Lined-down 7in Gun Mark 2, 105 calibers. No performance data available.

Mark 23

Rapid-fire, 70-caliber monoblock fleet AA gun for automatic operation, on post-World War Two ships. Weight was 1875lb (excluding breech block) and pressure 22.5t. The 15lb shell ranged to 19,500yds at 45°. MV was 3400ft/sec and charge weight 8lb. Mk 24 was similar but slightly lighter (1853lb without breech block). In each the bore was tapered over the last 9.976in to form a flash-hider. Rifling was uniform, at 1/25. Mk 25 (2073lb without breech block) was secured to its housing by interrupted threads, and had a rapid-fire horizontal-wedge breech. Mk 26 (2650/4900lb) was a built-up, water-cooled gun, 12 grooves between liner and tube being provided for circulation. The water pipe extended along the top of the muzzle, from slide bearing to muzzle collector ring.

OTO-Melara 3in/62

Italian 62-caliber rapid-fire gun in the Mk 75 mount of the *Perry* class frigate and the PHM. The barrel is two-piece with a replaceable liner. Weight (including breech block) is 1686lb and shell weight 13.9lb.

4in Guns**Mark 1**

Breech-loading, 40-caliber gun (3388lb without breech block) firing a 33lb shell (MV 2000ft/sec) to 11,500yds at 31° 11.5'. Shell charge was 4.85lb and pressure 15.25t. Mod 1 was adapted to take fixed ammunition, with a screw-box liner and a chamber liner. Mod 2, 39 calibers in length (3398lb), was very similar (pressure 15.5t), and also fired fixed ammunition. Mk 3 reverted to 40 calibers, as did Mk 4 (3160lb with breech), Mk 5 (3100lb), and Mk 6 (3529lb). All had rifling increasing from 0 to 1/25, and side-swing carrier-type breeches.

Mark 7

Rapid-fire gun weighing 5747lb excluding breech block. It fired a 33lb shell at 2500ft/sec and ranged to 20,940yds at 45°. Chamber pressure was 15.5t and the charge weighed 9lb. Maximum range was measured at 2800ft/sec, corresponding to a 12.3lb charge. Mk 8 was a simplified two-piece design (gun tube and jacket rather than tube, jacket, hoop, locking ring and liner) weighing 6640lb including the breech. Rifling increased from 0 to 1/31.17. Mk 9 was a lightweight gun (5900lb including breech) designed for destroyer and submarine use, and rated at 2900ft/sec (chamber pressure 17t); in some versions rifling was 0 to 1/25. Mod 11 introduced a uniform 1/32 twist, whilst Mods 18–23 were wet guns, of which Mods 22 and 23 were of monoblock construction. Mk 10 differed from earlier types in employing a vertically sliding breech block (6860lb including breech block). It was intended for antiaircraft use. In 1944 4in/50 (Mk 9) life was rated at 400 rounds.

5in Guns**Mark 1**

BL guns, 31-caliber, MV 2300ft/sec, weight excluding breech block 6190lb. The original weapon was later modified for semifixed ammunition.

Mark 2

The first US rapid-fire gun for battleship secondaries, using semifixed ammunition. It weighed 7000/7080lb and was 40 calibers long. Shell weight was 50lb, MV 2300ft/sec, range 16,000yds at 29° 53.2'; charge weight was 10lb and chamber pressure 14t. Mod 5 was cut down to 35 calibers. Mk 3 and 4 were similar (although Mk 3 Mod 3 was cut down to 25 calibers for antiaircraft use at the proving ground). Rifling was increasing, 0 to 1/25.

Mark 5

High-powered 50 caliber BL bag gun originally designed for battleship secondary batteries, with a side-swing breech. Chamber pressure was 16.5t and the charge for the 60lb shell weighed 19.2lb. MV was 2700ft/sec. However, range (19,000yds at 25° 19.9') was measured with a 21lb charge and 50lb projectile, at which figures muzzle velocity was 3000ft/sec. Mk 6 differed in construction: a single jacket replaced the jacket, chase hoop and locking ring of the earlier gun, and uniform rifling (1/25) replaced the earlier increasing type (0 to 1/25).

Mark 7

Introduced in the *Florida* class, this high-powered BL gun replaced the 5in/50 introduced in the *Delawares*, to become the standard secondary weapon of US dreadnoughts. It measured 51 calibers and weighed 11,274lb with breech. The 50lb shell fired to 20,142yds at 45° (MV 3150ft/sec); charge weight was 23.8lb and pressure 17t. Rifling was increasing, 0 to 1/25, and design resembled that of Mk 6. In the Mk 8 gun steel was used for some parts, and the chamber was modified. From Mod 2 onwards, rifling was increasing, 0 to 1/35. Mod 9 was generally similar but was unique among 5in/51s in using semifixed ammunition (uniform rifling, 1/30); it was a wet gun (10,824/11,375lb). Mk 14 was Mk 8 relined, and Mk 15 was Mk 14 with an enlarged chamber and a chrome-plated bore. In 1944 the rated lifetime of a Mk 15 was 800 rounds.

Mark 10

Semiautomatic, rapid-fire fleet AA gun of monoblock construction, 25 calibers, using a vertical sliding block breech, and with uniform rifling (1/25). Weight was 2125/5175lb, charge weight 9.5lb and pressure 16.7t. The 53.85lb shell fired at 220ft/sec to 14,126yds at 42° 11'. Mk 11 was similar except that the rifled bore was chrome plated. In Mark 13 the barrel and housing were joined by interrupted threads, for easy barrel replacement. Mark 17 (2163lb without breech block) was a new submarine (wet) type, unusual in that it required no muzzle or breech plugs. In 1944 the rated life of a 5in/25 AA gun was 3000 rounds.

Mark 12

Semiautomatic, rapid-fire, 38-caliber fleet dual-purpose gun of monoblock construction with uniform rifling (1/30). Its gun barrel was secured to the housing by interrupted threads for easy barrel replacement. Weight was 3985lb

excluding breech block and the shell weighed 54lb with a 14.75lb charge. MV was 2600ft/sec and range 17,306yds at 45°. Pressure was 18t. Mod 2 used a nonexpanded barrel of higher-strength steel. In 1944 the 5in/38 Mk 12 was rated at a lifetime of 2500–4000 rounds.

Mark 16

Semiautomatic RF fleet dual-purpose gun developed from the 5in/38, with similar features, including the vertically sliding breech block and the interrupted-screw barrel mount. The 54-caliber barrel had uniform rifling (1/25). The shell weighed 70lb and ranged to 25,909yds at 47° 24' and 2650ft/sec. Charge weight was 18.25lb and pressure 18.5t; total weight (excluding breech block) was 556lb. Mk 18 was a modified version, with its slide cylinder lengthened by 21in and the band seat of its chamber modified. It was used in the postwar Mk 42 rapid-fire mount. Mk 19 (3500lb) is the barrel of the current lightweight Mk 45 mount, rated at a lifetime of 7000 rounds, compared to 3070 for the earlier Mk 16/18. Mod 0 is two-piece with a replaceable liner; Mod 2 (data given) is a one-piece type.

Type F

Experimental loose-liner RF antiaircraft gun of 70 calibers which could be fired from a 6in/47 mounting. Weight was 9340lb without breech block, MV 3400ft/sec, shell weight 70lb, charge weight 35lb and pressure 21.5t. Mods 0 and 2 had uniform rifling (1/25), but in Mod 1 it increased from 1/50 to 1/25. For a time this weapon was considered as a standard postwar antiaircraft gun.

6in Guns

Mark 1

This was the 6in BL gun of the original ABCD squadron, consisting of a jacket, tube, 16 hoops and one elevating band, with the old-fashioned integral trunnions. Barrel length was 30 calibers, shell weight 105lb, charge weight 18.8lb, MV 1950ft/sec and range 9000yds at 15° 20'. Chamber pressure was 13.3t and the gun, minus breech block, weighed 11,010lb. Mk 2, with similar performance, had only ten hoops, and fired semifixed case ammunition. Mk 3 was also comparable but fired bag ammunition. Mod 1 was 35 calibers long and Mod 2 was 40 (2150ft/sec, range 18,000yds at 30° 13' elevation). Mods 3 and 4 reverted to 30 calibers. Mod 5 was a 35-caliber type adapted to semifixed ammunition. Mod 6 was the 40-caliber type converted for semifixed ammunition. There was no Mod 7, but Mod 8 was a 40-caliber semifixed case gun. Mod 9 was Mod 0 or Mod 3 converted for semifixed ammunition. Mk 4 was similar to Mk 3 Mod 2, firing semifixed ammunition; Mod 7 (a single gun) was modified to fire bag ammunition. Mk 4 weighed 13,370lb without its breech block. The last of the 40-caliber types was Mk 7, a Bethlehem type very similar to Mk 4 Mod 5. Rifling varied greatly: 1/180 to 1/30 in Mk 1, 1/40 to 1/30 in Mk 2, 0 to 1/25 in Mk 3 and 0 to 1/35 in Mk 4 Mod 0; others reverted to 0 to 1/25).

Mark 5

British Armstrong RF type, aboard the two light cruisers purchased from Elswick in 1898. Length 50 calibers, shell 105lb, MV 2300ft/sec, range 17,500yds at 30° 46.2', charge weight 18.5lb, pressure 15.8t.

Mark 6

New US 50-caliber BL type designed about 1898; bag ammunition. Weight was 18,112/18,628lb, shell 105lb, MV 2600ft/sec, range 15,000yds at 14° 53.9', charge 31lb, pressure 17t. Rifling was 0 to 1/25. Mk 8 was similar, but was built entirely of nickel steel. The Mk 11 designation was given to a Vickers-built wire-wound 6in/50; no data survive.

Mark 9

Bethlehem 44-caliber RF design for capital ships; 15,032/15,340lb, shell 105lb, charge 20lb, MV 2250ft/sec, range 19,000yds at 30° 17.2', pressure 15t. Mk 10, 45 calibers, was a Vickers gun; no data survive.

Mark 12

Main battery for *Omaha* class light cruisers, and planned secondary battery for the US battleships and battlecruisers of the 1916 program. A 53-caliber BL weapon weighing 22,143/22,648lb, it ranged to 26,600yds at 44° 27.1' and fired a 105lb shell (44lb charge) at 3000ft/sec. Pressure was 17.5t. It was a high-powered bag type; rifling was increasing, 0 to 1/25, but Mod 1 and later mods had uniform (1/35) rifling. Mod 2 was intended for submarines, as were Mods 4 and 6. Mk 14 was a monoblock gun duplicating the dimensions and performance of Mk 12; Mk 15 was to have exploited the weight advantages of monoblock construction (13,113lb including breech) but was not built. Mk 18 was a relined Mk 12 (chrome-plated); Mod 1 was a wet gun version. In 1944 Mk 12 was rated at 400 rounds lifetime and Mk 18 at 700, which for an allowance of 235 rounds meant re-gunning at, respectively, 165 and 465 rounds. The high-capacity round, fired at 2400ft/sec, was equivalent to only 0.16 of the standard round and the training round, 2300ft/sec, to 0.13.

Mark 13

Depth charge gun, redesignated Depth Charge Projector Mark 2 Mod 0.

Mark 16

Monoblock 47-caliber RF cruiser gun for *Brooklyn* and later classes, weighing 9632/14,542lb; semiautomatic, with vertical sliding breech blocks and uniform rifling (1/25). Shell weight was 105lb (34.5lb charge) and, with an MV of 2800ft/sec, the gun ranged to 24,010yds at 46° 35'. Chamber pressure was 18.5t. As in 5in guns, the barrel was secured to the housing by interrupted threads. It was developed from the experimental guns Mk A, B, C and D, which were all converted from 6in/50 guns Mk 8. The ammunition was semifixed. Mk 17 (10,020/11,733lb) was similar to the Mk 16, but modified for bag ammunition, for the *Erie* class gunboats. In 1944 gun lifetime was rated at 750–1050 rounds, the 130lb AP round (2500ft/sec) or the 105lb round (2800ft/sec) being the standard. A 105lb HC round fired at 2665ft/sec was equivalent to 0.71 standard rounds, a 130lb target round at 2050ft/sec to 0.21, and a 105lb target round at 2300ft/sec to 0.21. The Mk 16 gun was used in both the standard triple turret and in the *Worcester* class two-gun turret.

7in Guns

Mark 1

Originally a battleship secondary gun (*Connecticut* class), this weapon was later

removed during World War One and converted to mobile land artillery (tractor mount); still later, surviving 7in guns were fixed in land emplacements. It was a 44-caliber BL weapon weighing 28,860lb (with breech) and with a chamber pressure of 17t. The shell weighed 165lb and fired to 16,500yds at 15° with an MV of 2700ft/sec. Charge weight was 58lb, and rifling was uniform (1/25). Mk 2, 45 calibers in length, was very similar, but had a liner and increasing rifling (0 to 1/25).

8in Guns

Mark 1

The first heavy gun of the New Navy, Mk 1 was built up of a tube, jacket, 19 hoops and an elevating band with integral trunnions. A BL gun of 30 calibers, it fired a 260lb shell at 2000ft/sec. Charge weight was 49.6lb and total weight (excluding breech block) was 29,100lb. In the Mod 1 version the trunnions were removed. Mk 2 was similar but was designed without trunnions. The primary difference between the two was that the hoops were differently arranged; moreover, Mk 2 (like the 6in Mk 3) had its rear sights controlled by worm and miter gears. Rifling increased from 1/180 to 1/30.

Mark 3

Advances in construction included a reduction to eleven hoops in this 35-caliber BL gun. Rifling increased from 0 to 1/25; weight (without breech block) was 29,400lb and MV 2100ft/sec. The 260lb shell had a 43.8lb charge and ranged to 16,000yds at 20° 5.6'. One gun was altered to Mod 3, 40 calibers in length. Mk 4 was Mk 3 with trunnion hoop and elevating band removed, the threads formerly under the trunnion hoop being continued to the rear to allow the gun to be screwed into the sleeve of a two-gun turret mount. One gun, Mod 10, was cut down to 23 calibers for experimental work with high-explosive shells; muzzle velocity was reduced to 650ft/sec. Mk 5 was a new 40-caliber (2500ft/sec) design intended for battleship secondary turrets (40,151/40,621lb); it was superseded by Mk 6.

Mark 6

A 45-caliber BL of 41,518/41,988lb, and part of the generation of new smokeless-powder guns developed at the end of the Spanish-American War, the 8in/45 armed large cruisers and formed the intermediate battery of US predreadnoughts. Range was 22,500yds at 20° 4', shell weight 260lb, charge weight 98.5lb and MV 2750ft/sec. Mod 0 had uniform rifling (1/25), but all later versions had the increasing type, 1/44.4 to 1/25. The gun consisted of a tube, jacket, four hoops, a locking ring and a liner, all of nickel steel. It was the last 8in gun developed for the US Navy until after World War One.

Mark 7

ASW howitzer, interchangeable with the standard destroyer gun (the 4in/50 Mk 9 on a Mk 12 mount). Rapid-fire, 23 calibers, 5516lb/5560lb, shell 285lb, MV 650ft/sec, range 2600yds at 20° 49'.

Mark 8

Land howitzer (BL, 15-caliber) for Marine Corps (Vickers Mk 6 Model 1917). Weight 6132/6552lb.

Mark 9

Standard Treaty-cruiser 8in gun, 55-caliber BL, built up from a tube, jacket, liner, five hoops, three locking rings, a yoke ring in halves, and a screw-box liner; it was built of nickel steel. Rifling was uniform (1/35). It weighed 66,145/66,693lb and its 260lb shell (110lb charge) ranged to 31,982yds at 45° and at 3000ft/sec. Chamber pressure was 17t. Mod 4 was relined (1/30 rifling) and Mod 5 became Mk 14 Mod B. Mk 10, which was not built, was a lighter gun (58,500lb including breech) constructed of only three hoops. Mk 11 (65,700/66,718lb) was even simpler, consisting of a tube, jacket, one hoop, a yoke ring, and a screw-box liner; it was assembled with zero shrinkage and then radially expanded as a single forging. In Mk 12 (37,147/38,317lb) this process was taken further, the gun consisting only of a radially expanded tube and a shrunken jacket; the bore was chrome-plated. In Mod 1 the rifling was changed from 1/35 to 1/25 and the entire bore (38lin) plated, instead of 84in at muzzle and chamber. Mod 2 was assembled with an adapter to increase its weight to that of Mk 9, as a wartime re-gunning measure. Mk 13 was Mk 9 relined with a partially chrome-plated bore, and Mk 14 was Mk 9 relined with a small chamber, 1/25 rifling and full-bore plating. Mk 15 was very similar to Mk 12, but had the reduced chamber volume (4860 *vs* 5300in³) of Mk 14; it was used in the *Baltimores*. Mod 1 had an adapter sleeve to fit the *San Francisco* class. Rated lifetime was 550 rounds, based on the wartime 335lb, 2500ft/sec AP round. Other rounds were 335lb HC, 2000ft/sec, 0.15 full-round equivalent; 260lb AP, 2700ft/sec, 0.68 (but 1.0 at 2800ft/sec); and 260lb HC, 2300ft/sec, 0.19.

Mark 16

Semiautomatic 55-caliber RF gun fitted to *Des Moines* class cruisers, consisting of a monoblock radially-expanded tube and a loose-liner held by a locking ring. Derived from the 8in gun Mk E and converted from an existing Mk 15 tube, it weighed 37,380lb (without breech block) and the 335lb shell (78lb charge) had an MV of 2500lb and a range of 30,500yds at 45° 17'. Chamber pressure measured 18.2t. The bore was completely chrome-plated, with 1/25 rifling.

9in Guns**Mark 1**

What is remarkable about this 98-caliber BL weapon is that BuOrd listed it as an obsolete service type, not an experimental project. It was never completed, and presumably had been inspired by the German 'Paris Gun'. Weight complete with breech block was 209,429lb, and the 9in Mk 1 Mod 0 was to have been built up from a 14in/50 by lengthening it with a hoop of alloy steel to 900in, the whole gun being lined with a heavy alloy-steel liner. The breech had a volume comparable to that of a 14in gun's, and rifling gradually increased from 1/48 to 1/45.

10in Guns**Mark 1**

The first heavy BL gun of the New Navy, mounted aboard its monitor *Miantonomah* in pairs, two of 30 (basic model) and two of 34 calibers (Mod 2). It weighed 57,500lb without its breech block and fired a 510lb shell at 2000ft/sec. Chamber pressure was 14t and

charge weight 93lb. It was built up of a tube, jacket, 15 hoops and one locking ring, and rifling increased from 1/180 to 1/35. Mod 2 increased from 0 to 1/25. Mk 2, for other monitors and for the *Maine*, was lighter (50,200lb without breech) and simpler, with eleven hoops.

Mark 3

This was one of the post-Spanish-American War high-powered smokeless-powder BL guns, arming the last of the American armored cruisers. The barrel, 40 calibers long, consisted of a jacket, tube, three hoops and a locking ring, all of nickel steel; rifling was uniform (1/25). Weight was 74,836/79,500lb, shell 510lb, charge 200lb, MV 2700ft/sec and range 20,000yds at 14° 25.4'. Pressure was 16t.

12in Guns**Mark 1**

Designed for the monitors of the New Navy, this 35-caliber BL gun was built up of a tube, jacket, ten hoops and a locking ring, all of gun steel; rifling increased from 0 to 1/25. Weight was 100,800/102,550lb, shell weight 870lb (charge 160lb), range 21,000yds at 30°, MV 2100ft/sec and pressure 15.5t. Mod 3 was mounted in the battleship *Texas*. The very similar Mk 2 (99,650/101,400lb) was mounted in the *Iowa*.

Mark 3

The 12in member of the new smokeless-powder series, the 40-caliber BL Mk 3 was originally rated at 2800ft/sec, but had to be derated to 2400 in view of excessive bore erosion. Weighing 114,960/116,480lb, it consisted of a tube, jacket and eight hoops. The 870lb shell had a 237.5lb charge and originally ranged to 19,000yds at 15° 30.1'. Chamber pressure was 16t. Mod 1 had a smaller chamber, and at least from Mod 3 rifling was increasing, 0 to 1/25. Mk 4 was very similar, with a smaller chamber.

Mark 5

Introduced in the *Connecticut* class, this 45-caliber BL gun was a lengthened Mk 4, built up of a tube, jacket and six hoops (as in Mk 4 Mod 1; Mod 0 had seven hoops). The shell weighed 870lb and the charge 305lb; MV was 2700ft/sec and range 37,000yds at 20° 32.8'. Chamber pressure was 17t and total weights 117,032/118,552lb. In Mod 10 the liner had uniform rifling (1/32 rather than 0 to 1/25). Mk 6 was very similar, but had seven hoops (0 to 1/25 rifling).

Mark 7

Arkansas class 50-caliber BL gun, built up of eight hoops, and uniformly rifled (1/25). Shell weight was as in Mk 5 but charge increased to 336lb and MV to 2900ft/sec. Weights were 121,489/123,160lb and pressure 17.5t. In Mod 1 rifling increased from 1/50 to 1/32, although late relinings reverted to the uniform type. Lifetime was 200 rounds for an unplated 1/32 gun. There was a 740lb HC round (2125ft/sec) equivalent to only 0.05 of the service AP round; at 3000ft/sec the same shell was equivalent to 0.68 of a full AP round. A training round (2100ft/sec) was equivalent to only 0.08 of a full round.

Mark 8

Alaska class BL gun (50-calibers), of World War Two vintage, built up of a liner, jacket,

three hoops and two locking rings, with a fully plated (1/25 rifling) bore. Weighing 108,800lb without breech block, its shell was 1140lb, charge 268lb and MV 2500ft/sec, but it could also fire a 940lb shell at 2650ft/sec to a range of 38,021yds at 45° elevation. Chamber pressure was 19t and lifetime 350 rounds (1140lb AP at 2500ft/sec). Alternative rounds comprised a 940lb service at 2650ft/sec (0.67 full-round equivalent); HC at 1850ft/sec (0.06); or 1140lb target at 1500ft/sec (0.07).

13in Guns**Mark 1**

This 35-caliber BL gun was built up of a tube, jacket and nine hoops (rifling increased from 0 to 1/25). At 136,000/137,900lb the gun fired a 1130lb shell at 2000ft/sec (180lb charge), and chamber pressure was 14t. Mod 2, with a nickel steel liner, had eight hoops, as did Mk 2.

14in Guns**Mark 1**

This weapon was introduced in the *New York* class. It was a 45-caliber BL weapon built up of eight hoops; rifling increased from 1/50 to 1/32. It weighed 140,670/142,492lb and fired a 1400lb shell at 2600ft/sec. Chamber pressure was 18t and charge weight 365lb. Mod 12 had an enlarged chamber, 18,200in³ rather than 15,332, for an increased muzzle velocity, 2700ft/sec. Mod 6 introduced a down-swing breech plug for confined turret spaces, and from Mod 7 onwards there were uniform-rifling (1/32) liners. Mk 2 was very similar, but Mk 3 had a longer slide. Mk 5 was built of five rather than eight hoops. Mk 8 was Mk 1 lined or relined with a one-step conical liner. Mk 9 was Mk 3 relined, Mk 10 was Mk 5 relined, and Mk 12 was Mk 4 relined with a chrome-plated bore and uniform twist rifling. Lifetime was 175 rounds for Mk 8 and 10, 225 for Mk 12 (plated, 1/25 rather than 1/32). Alternative rounds were 1500lb service (2600ft/sec, standard round); 1275lb HC (service round, 2735ft/sec, 0.78 full-round equivalent but 0.07 at 2000ft/sec); and target round, 1500lb (1935ft/sec, 0.10).

Mark 4

During the 1920s the US Navy had severe difficulties with its 14in/50s at long-range target practice; there are several (probably apocryphal) stories of the solution, including the correction of erroneous range tables, delay coils (to avoid mutual interference between guns), and the reduction of chamber volume to overcome 'fall-back' of the shell against an incompletely filled chamber at high elevation. The gun itself was built up from three hoops, with the usual increasing rifling (1/50 to 1/32). Muzzle velocity was 2800ft/sec and chamber pressure 18t; the shell weighed 1400lb and the charge 470lb. Total weights were 178,211/180,385lb. Mk 6 was similar, but had a one-step conical liner and uniform-twist (1/32) rifling; Mk 7 was Mk 4 relined; and Mk 11 was Mk 4 relined with a chrome-plated bore and uniform-twist rifling. Gun-lifetime was 175 rounds (225 for Mk 11). Alternative shells were the 1500lb, at 2700ft/sec (standard), the 1275lb at 2825ft/sec (0.75), the 1275lb HC at 2000ft/sec (0.05), and the 1500lb target at 1935ft/sec (0.07).

Mark B

Prototype 50-caliber BL gun for BB-55-56,

abandoned when the 14-inch limit was relaxed, and never completed. In contrast to the earlier 50-caliber guns, its diameter at the chamber was 41in (*vs* 48 in Mark 11); it consisted of a tube, jacket, liner, three hoops, two locking rings and a yoke ring as in earlier types. Weight excluding breech block was 147,000lb and the 1500lb shell (440lb charge) fired at 2700ft/sec. Chamber pressure measured 18t. Mk A was the ballistic prototype of the 14in gun, a 13in Mk 2 bored out and lined down, capable of 2200ft/sec and 33 calibers long.

16in guns

Mark 1

This was a built-up gun consisting of a tube, jacket, liner, seven hoops, four locking rings and a screw-box liner, with increasing rifling (1/50 to 1/32). The ballistic prototype was a bored-out 13in/35 (Mk A, 1800ft/sec). The Mk 1 was a 45-caliber BL weighing 235,796lb (including breech block) and with a chamber pressure of 18t; the 2100lb shell fired at 2600ft/sec with a 590lb charge. Mod 1 reverted to uniform rifling (1/32). Mk 5 was Mk 1 relined, and Mk 8 was Mk 1 relined with an alloy-steel liner having heavy liner shrinkages, and plated over its full length (uniform 1/25 rifling). It was rated at 2520ft/sec with a 2240lb shell and a 556lb charge, for a range, at 45° elevation, of 40,600yds. Gun-lifetime was 400 rounds, and alternative rounds comprised a 1900lb shell at 2635ft/sec (0.74), a 1900lb HC at 2000ft/sec (0.09), and a 2240lb target shell at 1935ft/sec (0.12).

Mark 2

Designed as the main battery of *South Dakota* (BB-49) and *Constellation* (CC-1) class capital ships (canceled after the Washington Conference), these BL weapons were turned over to the Army and installed in coast defenses. The guns were 50 calibers long and weighed 287,050lb including breech. The 2100lb shell fired at 2800ft/sec with a 700lb charge; chamber pressure was 18t. Mk 3 was very similar, except for its one-step conical liner. Construction corresponded to that of Mk 1.

Mark 4

This was the 18in Gun Mark 1 (56-caliber BL) lined down to 16in caliber and chambered for 16in ammunition. It weighed 416,465lb with breech. There were nine hoops, and rifling was uniform (1/35). The shell weighed 2100lb and fired at 3000ft/sec to 25,100yds at 40° 4.6'. Charge weight was 800lb and pressure 17.5t. Compared to Mk 2, its diameter at chamber was 62in rather than 56.50in.

Mark 6

Lightweight 45-caliber BL gun for *North Carolina* and *South Dakota* class battleships, reflecting in its characteristics the advances in gun design since the end of World War One. Diameter at the breech was 46in (53.50in Mk 1) and there were three rather than seven hoops. The weight excluding breech block was 192,310lb and the 2700lb (505lb charge) had a muzzle velocity of 2300ft/sec. Pressure was 18t. Individual guns differed in rifling, options being a uniform 1/25 and increasing rifling (1/50 to 1/32). The bore was chrome-plated, and the gun was removable from the gun port without dismantling the turret. Mod 2 had an adapter sleeve to fit the turrets of *Maryland* class battleships; it was a wartime measure to

simplify re-gunning. Lifetime was 400 rounds. Alternative shells were the 1900lb service round at 2525ft/sec (0.74) or as HC at 2000ft/sec (0.09); and the 2700lb target shell at 1800ft/sec (0.14).

Mark 7

As in the case of Mk 6, this was a lightweight BL design; diameter at the chamber was 49.0in (56.5 in Mk 2), with three rather than seven hoops; the gun was removable without dismantling the turret. Length was 50 calibers and weight 239,156lb without breech block. The 2700lb shell fired at 2500ft/sec and ranged to 42,345yds at 45° (chamber pressure 17.5t). A 2240lb shell (640lb charge, MV 2700ft/sec) was also used. Rifling was uniform (1/25) and lifetime 300 rounds (2700lb at 2500ft/sec). Alternative rounds comprised the 1900lb service shell at 2690ft/sec (0.43), the 1900lb HC at 1900ft/sec (0.03), and the 2700lb target shell at 1800ft/sec (0.08).

18in gun

Mark 1

The only example of this 48-caliber BL gun ordered was converted into the 16in/56 Mk 4, and then reconverted into the 18in/47 Mk A. Weight was 398,350lb (without breech block), pressure 18t, and the shell weighed 2900lb and fired at 2700ft/sec; however, with a 3850lb 'super-heavy' shell of World War Two-type, it would have achieved a muzzle velocity of 2400ft/sec on an 810lb charge (17.25t pressure).

I-2 Fire control systems

This series began with directorscopes and continued with directors; Mk 37 was a fire control system because it incorporated below-decks components, and the series continued from it. Thus this list does not include current directors, which are components of fire control systems. In 1947 a new series of underwater battery fire control systems began with Mk 100, the two series merging in the 1970s as the Mk 1 through 99 group was filled. Missile and gun/missile fire control systems are all numbered in the same basic series.

Mark 1

Attachment for trunnions of 12in sights, for Nos 2 and 3 turrets of the *Delaware*, and the main top of the *Wyoming*.

Mark 2

Fire control tower or masthead installation, installed on predreadnought *Louisiana* and on all dreadnoughts through *Tennessee* except, apparently, *Delaware*, *North Dakota*, *Pennsylvania* and *Arizona*.

Marks 3/4

Periscope secured to and projecting through turret roof. Mk 3 Mod 0 was originally for the turrets of *Florida*, *Michigan* and *South Carolina*. Mark 4 Mod 1 had a ring gear for a target bearing transmitter (TBT) for use in a fire control tower and in the superfiring turrets of *California* and *Tennessee*.

Mark 6

Secondary battery and light cruiser main

battery director, a pedestal type carrying operators on seats in a revolving tower. It had a convergence mechanism, and sights could elevate 20° or depress 15°. Mod 1 allowed for 32° sight depression; Mod 2 was a broadside director without a tower, canopy or seats, for the *Californias*. Mod 4 was similar to Mod 1 but not mounted in a director tower, controlling broadside fire for the two *Wyomings* and the *New York*. Mod 5 was a broadside director, pedestal mounted, for the two *Nevadas*. Mod 7 was for the *Texas*. Mod 8 controlled the main batteries of *Omaha* class light cruisers; it was pedestal-mounted as in Mod 6 but had separate target bearing and gun train order transmitters, plus a Ford rangekeeper and a deflection converter for the after director.

Mark 7

No convergence mechanism (Vickers system). Used for secondary battery control of the *Delaware* through *Mississippi* classes, and later extended to the *Californias*, carried on forward and broadside stations. Superseded by the GE Mk 16. These systems operated with the Mk II ('Baby Ford') rangekeeper; battleships had Mk I for main battery control. Mk II did not generate target bearing, only a deflection based on the speeds of the firing ship and the target.

Mark 8

Main battery control for flush-deck and earlier destroyers and for some *Omaha* class light cruisers, a pedestal with a revolving carriage, Ford rangekeeper (with a deflection converter) and elevation and train repeat indicators. Vickers system. Superseded by the GE Mk 17 in some destroyers (DD-212-217, 275-280).

Mark 9

Stable horizon (in plotting room), originally for *Utah*, then for main battery plot of *California*, also other ships. Mod 4 became the Mk 32 stable vertical element.

Mark 10

Main battery director, originally for *California* class.

Mark 11

Main battery director for maintops of *Colorado* and *Maryland*; Mod 2 was a foretop installation in *West Virginia*, and Mod 4 a modernised version for that ship (Puget Sound Navy Yard). Mk 20 was an analogous unit for aloft main battery control of the modernized battleships, *New York* through *Arizona*.

Mark 12

Conning-tower director for *Colorado* class, a periscope projecting through the tower roof with other equipment spring-suspended from the underside of the roof; there was no range-finder. Mk 21, weighing 715lb, was similar; it was installed in the conning towers of the modernized battleships during the 1920s and 1930s (*New York* and later classes). The latter served through World War Two, being fitted to the thinly armored towers which replaced the original heavily armored conning towers in several ships. Mk 40 and 55 were modern successors.

Mark 13

Main battery director, a pedestal-mounted stable zenith gyro sight for plotting-room installation (*Maryland* and *West Virginia*).

Mark 14

Periscope sight, similar to Mk 12, for high turrets of *Maryland* and *Colorado*; Mk 21 consisted of a target bearing unit (of Mk 12) plus the base, supporting frame, and associated gearing of Mk 14. It provided relative target bearing and director correction, and received target designation. Mk 23, installed in battleship turrets upon modernization (*Nevada* and *Pennsylvania* classes), was similar.

Mark 15

'Auxiliary gun director' or transmitter for *Colorado* class main battery plots. It converted the 'advance range' computed by the rangekeeper into a sight angle and then applied the director correction for transmission to the guns; it also applied the appropriate deflection (bearing) angle derived from the rangekeeper and other plotting room instruments. Originally it had been designed to incorporate a stable zenith as well, as in later plotting room directors, but no satisfactory instrument of that type was developed until 1930, and the Mk 15 was not a true director. GE system; in the Sperry system separate instruments performed the range conversion and transmission tasks.

Mark 16

Broadside director for *Colorado* class secondary battery; main battery director for *Omaha* class light cruisers. General Electric system, the first wholly US director for secondary batteries. The GE system differed from Vickers (Mks 7 and 8) in using selsyn rather than step-by-step data transmission. Early versions employed the Mk II ('Baby Ford') rangekeeper, but the modernized battleships had Mk VII (as in the Mk 31 installations aboard the *New Mexicos*); it appears that Mk VII was also fitted to many Mk 16 directors.

Mark 18

First modern 8in director, in *Lexington* class carriers and *Salt Lake City* class cruisers. These ships had no plotting rooms. Their Mk III rangekeepers were mounted with the directors. Sights were set for range and deflection automatically by the rangekeeper, and this was achieved by tilting mirrors rather than by the more conventional technique of moving the telescopes proper. Ship's own course and relative bearing were also automatically introduced into the rangekeeper. The system was developed by Arma, the director and rangekeeper by Ford.

Mark 19

First dual-purpose (5in/25) director, development of which began about 1922. Built by Ford Instrument Company, it was perhaps the world's first shipboard antiaircraft fire control system to provide a continuous three-coordinate solution of the dual-purpose fire control problem. It first appeared in 1928, and in 1939 was still installed in the *Lexingtons*, in *Pensacola* and *Northampton* class cruisers, and in nine battleships, the exceptions being the three earliest (with no AA fire control) and the three *New Mexicos*, with Mk 28. About 1940 it was fitted with a stabilized stereo rangefinder, as well as with a blast shield from which the rangefinder protruded; previous versions had had a coincidence rangefinder-altimeter. It operated by measuring the target range and bearing rates, adjusting its gyros until it tracked the target (rate control); the technical

problem was how to separate errors in range rate from errors in bearing rate, since errors in one would affect observations in both. It originally consisted of a rangekeeper (Mk IV), ballistic computer and transmitter, and used a level gyro and an angle gyro to stabilize its optics in space (level and cross-level) and on the target (if the 'set-up' was correct). It was superseded by Mk 28/33. Obsolete in 1941, but not replaced until 1943-44.

Mark 20

See Mark 11.

Mark 21

See Mark 12.

Mark 22

Stable vertical for *Pensacola* class cruisers.

Mark 23

See Mark 14.

Mark 24

Main battery director for *Northampton* class cruisers, incorporating a below-decks plotting room; predecessor to modern systems. In 1941 this system generally used Range Keeper Mark 8; wartime replacement was a Mk 34 director with Mk 8 rangekeeper. The fundamental limitation of the earlier unit was that it did not generate in bearing, making it impossible for a ship fitted with it to fire divided indirect short bombardment missions.

Mark 26

Experimental stable vertical.

Mark 27

Main battery director for *Portland* class; pedestal with 0.5in bulletproof shield.

Mark 28

Dual-purpose director (5in/25) for *Mississippi* class and first five *New Orleans* class cruisers, superseded by Mk 33; it had a stabilized stereo rangefinder and could accept a 220kt target speed. The principal weakness was lack of a power drive; it was too slow to get on and then to track a fast target. Modernization was impractical, particularly in view of the lack of effective weather shielding and the need for radar. In view of the lack of below-decks space in ships with Mk 28s (since the director proper incorporated none), they were replaced by Mk 33 in wartime; all three *Mississippis* had them by late 1944, and two of the four surviving heavy cruiser installations had been replaced by the end of the war. In view of the kamikaze threat, Mk 37 installations were scheduled for the battleships, despite space limitations, in 1945.

Mark 29

Stable vertical for *Portland* class.

Mark 30

Standard prewar stable vertical, using selsyn transmission, for *New Orleans* through *Helena*; superseded in wartime by Mk 41. Mod 3 was installed in the *Northampton*s.

Mark 31

Single-purpose director for main and secondary batteries of *Mississippi* class battleships as modernized and for *New Orleans* class cruisers (successor to Mk 24). It was a pedestal

mounted in a bullet-proof shield with local trunnion correction but no horizontal parallax or cross-level, carrying a rangefinder-like spotting glass with 30° freedom of elevation. In the battleships, it operated in conjunction with Range Keeper Mark VII for 5in/51 control, and with Range Keeper Mark VIII for 14in/50 control.

Mark 32

Battleship stable vertical for *New York*, *Nevada* and *Pennsylvania* classes, and *Colorado* and *West Virginia*.

Mark 33

ntiaircraft (5in/38) director, originally designed for destroyers from *Farragut* onwards, but also installed in many cruisers and carriers, and in some battleships (Mod 20 for *Mississippi* class). Mods 13 and 15 were installed in the Brazilian *Marcillio Dias* class. Similar to Mk 28, with the same model rangefinder, but incorporating power drives to permit operators to track targets even aboard a levy destroyer, it also replaced Mk 19 in the *Portlands*. Later improvements included increases of target speed, first to 275 and then to 320kts, plus a 'dive attack' feature to control fire against a target diving at up to 400kts. Production continued in wartime, with 124 built by VJ-Day and about 85 in service in December 1941. The only units replaced by Mk 37 in wartime were two in the carrier *Enterprise*, one each in the rebuilt destroyers *Cassin* and *Downes*, and two in the cruiser *Nashville* after guided bomb damage. Principal wartime modifications were complete weather shielding and radar, the latter difficult because the director could not accommodate much weight without unbalancing. The Range Keeper Mark 10 was also too slow, both in reaching an initial solution and in reacting to changes in target course and speed. However, there was no alternative director which did not require below-decks space; for example, Mk 33 was specified for a proposed heavy-gun conversion of destroyer escorts, since they could not accommodate a below-decks computer. Typical weight, for an open type with $\frac{1}{16}$ in shield, was 13,850lb, and with closed $\frac{1}{4}$ in shield, 15,500lb.

Mark 34

Principal cruiser main battery director from the *Brooklyn*s onwards, with Range Keeper Mark 8, operating either in primary control (observed target bearing transmitted directly to the rangekeeper in plot) or in secondary and auxiliary control (transmits director train to and receives sight angle and deflection from an auxiliary computer in an adjacent main battery fire control station; the director adds corrections and transmits gun orders directly). Originally it carried a spotting glass instead of the later 18ft rangefinder, and there were none of the secondary and auxiliary control features provided later by trunnion tilt and director correction correctors, no radar equipment, manual drive, and a light shield. The inclusion of such features crowded Mk 34, and drive, accomplished by a single receiver regulator and drive motor to train the separately mounted light director and its heavy shield, was considered too rough. At the end of the war it was to have been replaced by a newly designed Mk 54 director. Typical weights were 41,300lb topside and 10,742lb below decks, with a topside

crew of 16 and 10 more below decks (2 plotting rooms), including the Mark 8 Range Keeper and a Mk 13 radar.

Mark 35

Single-purpose 5in/38 director for 1850-ton destroyers; units from these ships were later used to replace existing Mk 18 directors on the cruiser *Pensacola*, and were scheduled for her sistership and for the *New Orleans* class at the end of the war, since the Mk 34 director could not be accommodated due to topweight.

Mark 36

Fire control for 6in/47 guns in *Erie* class gunboats.

Mark 37

Dual-purpose 5in/38 fire control system incorporating a below-decks Computer Mark 1 and a Stable Element Mark 6; its flat top was said to have been designed for radar from the first, and it was first specified for the *North Carolina* class battleships and *Sims* class destroyers, about 1937. Design began in 1936, with first tests in 1939; the computer replaced the former Ford rangekeeper series. It incorporated a horizontal rate of 400kts and a vertical rate of 250, which proved sufficient until the kamikaze attacks by Baka bombs late in the war. Other valuable features were high speed controls, an effective fully automatic rate control in the computer (which could reach a target solution without operator aid), faster solution times, and improved housing for personnel. However, the closed loop represented by the computer and director had never previously been tried, and in early tests it caused considerable trouble. War-time improvements included a slewing sight permitting the director officer to reach his selected target very rapidly and to track it until the pointer and trainer could take over; modifications to the director shield to increase its freedom; and radar (Mk 4, then Mk 12 and 22, and Mk 28 for some weight-critical installations). It was succeeded postwar by Mk 67 and 68. Typical weights were 29,700lb above decks and 10,200lb below (0.5in shield), with a crew of 6 above and 6 below decks. This includes a 15ft stereo rangefinder.

Mark 38

Main battery (battleship) director, analogous to Mk 34 for cruisers. The first director to use amplidyne control, it was installed from the *North Carolinas* on, with sufficient plotting room space to accommodate two Range Keepers Mark 8 plus Stable Verticals Marks 41 or 43; generally it operated in conjunction with a Mk 40 auxiliary director. It did not accommodate the secondary and auxiliary control mechanisms of Mk 34 but could be trained by hand or by power (local or automatic). Its main functions were to obtain target bearing, level angle and cross-level, as well as target range. Weights were 50,450lb above decks and 10,305lb below, with 12 men above and 20 below decks (2 plotting rooms). Range Keeper Mark 8.

Mark 39

Experimental lightweight auxiliary 5in/25 director tested in *Vincennes* in 1938 for use in *Omahas*, then aboard *Utah* in 1939–40. Selected for further development, but as a full-size (4000lb) unit rather than the portable (500lb) type originally envisaged. See Mk 47.

Mark 40

Standby director, *North Carolina* and *Iowa* classes, in the conning tower roof, analogous to Mk 12/21 but carrying a 15ft spotting glass as well as two periscopes. Later the spotting glass was replaced first by Mk 3 and then by Mk 27 radar. Since it was not stabilized, Mk 40 was not a blind-fire director; nor was it power-driven. Mk 55, in the two *Fargo* class light cruisers, was analogous.

Mark 41

Stable vertical for all major combatants completed after 1941, similar to Stable Element Mark 6 of Mk 37 system; BB-57–60 had instead Mk 43, which used a new gyro erecting system. Arma (Mk 41) and GE (Mk 43). Both proved satisfactory in wartime.

Mark 43

See Mk 41.

Mark 44

Interim 1.1in director, developed by BuOrd; it was a simple dummy gun carrying optics and a spotting glass, but no lead computing elements; in effect it moved fire control off the 1.1in mount. It incorporated a traverse axis in analogy to the 1.1in mount. Later, Mk 44 was also used to control 40mm guns; a total of 85 were manufactured. It proved ineffective in combat.

Mark 45

Ford Instrument Company two-man, power-driven, fully-stabilized director, begun in 1940 and later unsuccessfully adapted to radar control. It was abandoned as overcrowded, difficult to maintain, and inaccurate; although 1252 were originally ordered, production stopped in September 1942 at a total of 51. Most became test devices.

Mark 46

General Electric light AA director, begun 1941 and soon canceled.

Mark 47

Arma relative-rate AA director, based on the experimental Mk 39; originally planned for 1.1in guns but too cumbersome and complex. Changed to 3in/50 and redesignated Mk 50 with ballistic but no other changes. It employed the fully electrical Computer Mark 10, which could easily change ballistics, to control the full range of AA guns from 1.1in up through 5in/38. The lightweight 3in/50 director was considered particularly important for the older battleships and for the *Omaha* class cruisers, as these ships had never received antiaircraft directors, principally in view of the lack of funds. Nor could they afford the weight of standard 5in directors. Mk 50 was also envisaged as a destroyer escort director; before it had been completed there was a requirement for about 2000 units. However, the ease of improvement to the electrical circuits of the Mk 10 computer made for excessive alteration during development, to the point that late in 1942 Arma reported it unsuited to mass-production; production ended at 43 units in 1944. However, the all-electrical computer later formed the basis of Mk 57 and 61.

Mark 48

Ford Instrument AA director, based on Mk 28, 33 and 37; it was intended for ships which

could not accommodate Mk 37 weight or below-decks volume. It was visualized as similar to Mk 33 but with computing elements in the director itself. It was canceled in view of the Ford Instrument work load. Proposed 1941.

Mark 49

A smaller-size Mk 45, for one-man operation, without cross-level or a spotting glass. However, it was limited to a 10° lead angle, and retained Ford clutch-type power drives. Thus it could not be used effectively to support another ship under attack, which would have required a lead angle of up to 20°. The power clutches gave poorer tracking than the much simpler Mk 51, and attempts to fit the better amplidyne drive were given up with the availability of large numbers of the superior Mk 51; production ended in mid-1943 with 343 Mk 49s delivered. Many were installed in fleet units; the decision to cancel was influenced in part by the failure to develop an adequate blind fire radar. Typical weight was 3400lb with Radar Mark 19.

Mark 50

See Mk 47. Typical weight 19,000lb including Radar Marks 10 or 14; in addition there was a Ballistic Converter Mark 10, 2000lb, below decks.

Mark 51

The most successful wartime light director, essential a 'dummy gun' with a Mk 14 lead-computing gun sight on it. Mk 52 was an improved Mk 51 with a Mark 15 gun sight and a Mk 26 range-only radar, which was still not suited to blind fire; it became the standard destroyer escort director. Typical weights were 710lb for Mk 51, 1710lb above decks and 1320lb below for Mk 52. The latter incorporated Computer Mark 6 for surface fire. Limits (Mk 52) were 350kts, 20° lead angle, 12,000yds for surface fire, 7000yds for AA fire.

Mark 52

See Mk 51.

Mark 53

Director Mark 49 modified for 3in and 5in fire control, with cross-level, for small ASW ships. It was proposed during the winter of 1942–43, but was subject to the deficiencies of Mk 49 as well as to those of the ultra-simple Computer Mark 6; meanwhile the need for an interim system receded as the ASW situation improved.

Mark 54

Replacement for Mk 34 single-purpose director, ultimately installed only in *Des Moines* class cruisers. It was first proposed in January 1943 as a redesigned Mk 34, a base-ring type rather than the pedestal (with separate shield) of the earlier model; in this sense it resembled Mk 38, but would retain distinctive cruiser features suitable for a ship with only a single rangekeeper or computer; estimated weight was 40,000lb. Pointer's and trainer's optics were stabilized by a direct link to the rangefinder as in Mk 37, and a 26.5ft rangefinder was planned. The first model was delivered in January 1946. Weight as delivered was 40,452lb above-decks, 13,792lb below, with 10 men topside and 20 below decks. Limits were 45kts for surface fire, 800kts for AA.

Mark 55

See Mk 40.

Mark 56

Principal postwar 3in/50 director, begun May 1943 at MIT Radiation Laboratory as a radar-equipped director for long-term development suited for blind firing at surface as well as air targets. It was to be suited, too, as the primary director for small ships such as destroyer escorts. Its Mk 35 radar incorporated automatic tracking in range, bearing and elevation, for lead angles up to 30° and range rates up to 630kts; it could be synchronized in bearing with an incoming designation signal by a control knob. Initially it was to have had a converter allowing simultaneous control of guns of alternative ballistics to those incorporated in its computer; later this was abandoned in favor of two separate complete computing systems for dual ballistics.

In the spring of 1945 Admiral King intervened in the design; MIT had considered the director no more than a radar mount, with automatic tracking accomplished below decks; tests showed that its automatic radar tracking was equal to optical tracking, but service experience at the time showed that optical tracking was valuable against close-in (eg kamikaze) targets. Nor did any existing search radar promise complete coverage, or full flexibility to deal with rapidly changing close-in situations. A second crew member with a slewing sight was therefore added, and the cockpit and controls rearranged. Moreover, Mk 56 did not have the expected surface capabilities because its stable vertical was inadequate. Tests of a prototype began late in 1945, the first unit going to sea aboard the destroyer *Winslow*. Typical weights were 7655lb above and 11,492lb below decks, including Computers Marks 42 (primary ballistics and secondary ballistics) and 30 (primary gun orders). Limits were 630kts, 30° lead angle and 15,000yds.

Mark 57

Machine gun director developed by the Applied Physics Laboratory of Johns Hopkins University, beginning in August 1943; similar in configuration to Mk 51, 52 and 63, but different in principle, intended from the first for combination with a radar. It employed a fixed (rather than 'disturbed') line of sight, the precessions of the gyros being detected by electrical pickoffs and transmitted to a below-decks computer for lead computation (Computer Mark 16); the latter was related to the Computer Mark 10 of the abortive Mk 50 fire control system, and could be switched from 40mm to 5in/38 ballistics (a later Mk 33 computer could compute both simultaneously; it was intended for the more advanced Mk 61 system). The electrical computer could easily be modified for any gun's ballistics; for example, it took only six weeks to convert a Mk 57 to 6in/47. The undisturbed line of sight was particularly well adapted to provision of a radar antenna, as a sufficiently strong support could be provided. A total of 450 was ordered in March 1944, deliveries beginning in October, with first installations on the *Missouri*, *Alaska* and *Guam*, all of which received them in time for Okinawa. Probably the chief drawback of the Mk 57 system was the absence of a target acquisition mode for its radar, so that it could not operate effectively in blind fire.

Mk 59 and Mk 61 were developments;

neither entered service. In Mk 59 the director was mounted on a rotating circular ring atop a cylindrical splinter shield, as in the scarf-ring mounting of aircraft machine guns, for better blast protection; it was canceled in favor of Mk 57. Mk 61 was a power-driven version of Mk 57, reverting to the prewar concept of Mk 45 through 50; power drive permitted automatic radar tracking in train and elevation (although not in range) and a Target Acquisition Control Unit (TACU) was added. In 1945 only Mk 56 and 61 were available as Class 2 directors (medium-range, power-driven) and Mk 61 was 6000lb lighter; but it was not procured. Mk 62 was a competitor to Mk 61, more nearly resembling Mk 57 but power-driven; it retained a pedestal support, with operators, directors elements and power drives assembled around the central pedestal. By way of contrast, Mk 61 had two men seated in a 'basket' suspended within a nonrotating cylindrical foundation structure; the basket moved in bearing, with elevation introduced in the line of sight through a tilting prism in the pointer's telescope mounted on the basket, and the radar antenna on a framework above the operators.

Mark 58

The blind-fire director first developed by Dr Draper's MIT group, descended from his 'disturbed line of sight' handlebar directors (Mks 51 and 52) and leading to the major machine gun blind-fire director, Mk 63. Compared to Mk 52, blind-fire required a much narrower radar beam for radar pointing (in effect, a 45in antenna) and provision for displacing this antenna from alignment with the director axis so that it could remain parallel to the line of sight to the target. Mk 58 added such a radar to Mk 52, using electrical pickoffs to transmit line-of-sight displacements to the antenna mount. However, it was not powered, and the antenna itself imposed almost uncontrollable wind loadings on the director operator. In Mk 63, therefore, the antenna was removed from the director proper and mounted instead on the gun slide; tracking data was projected into the field of vision of the Mk 15 sight on the director. Prototype firing trials were held in June 1944, and the first systems were installed in the new carrier *Bon Homme Richard* in November; other early installations were aboard the cruisers *Mobile* and *Oakland* and the destroyer *Purdy*, and postwar use was very extensive, for example in the new twin and single 3in/50 rapid-fire guns and also on twin and quadruple 40mm guns. It was modified after the spring of 1945 to incorporate a Target Acquisition Control Unit, or TACU, searching through about 10° to each side of neutral. The original limit of 500kts was extended to 800 to counter Baka suicide weapons. Typical weights (Mk 63) were 1975lb above and 2025lb below decks, using Computing Sight Mark 29, with 4 personnel above and 2 below decks. Limits were 800kts, 20° lead angle and 7000yds.

Mark 59

See Mk 57.

Mark 60

Proposed General Electric 'disturbed line of sight' machine gun fire control system built around a single free gyro whose spin axis remained in the line of sight; it was precessed to maintain that alignment by torques the magnitudes of which measured target angular rates;

the systems actually bought used a gyro which precessed to follow a target. In 1943 GE produced an experimental Army T4 Sight, applied to naval guns as Mk 20 with 20mm ballistics, but production difficulties cut production from an initial order for 5000 to 1000, only 50 of which had been delivered by VJ-Day; it was, however, considered much superior to Mk 14. Sights Marks 26 and 27 were improved versions with, respectively, electrical pickoffs for data transmission of gyro position and with telescopic optics, as in the Mk 15 sight of the Mk 52 director. Mk 60 was to have used a K-band radar, for limited antenna size; the electrical pickoffs of its Mk 26 sight permitted it to position its antenna (mounted below the director line of sight) parallel to the displaced optical line of sight; it also had a 'search' setting corresponding to the action of a TACU ($\pm 20^\circ$ antenna nod). At 2600lb it was the simplest and lightest of all the blind-fire systems, and 1000 were ordered; trials in June 1944 showed 40mm fire control capability equivalent to Mk 57 and 63. However, production problems (such as the need for an increased lead angle in the sight, which itself precluded successful Mk 20 gunsight production) ended the program, the first five units being delivered only after the end of the war. The slightly less satisfactory Mk 57 and 63 replaced it.

Mark 61

See Mk 57.

Mark 62

See Mk 57.

Mark 63

See Mk 58.

Mark 64

In this system the entire fire control system was shifted to the gun mount proper; indeed, it was soon renamed GUNAR and the mark designation abandoned.

Mark 65

Designation for Bell Laboratories study of general naval anti-aircraft fire control problem, resulting in the development of Threat Evaluator and Weapon Assigner (TEWA) and then of weapon designation equipment for missile and gun/missile ships.

Mark 67

Replacement for Mk 37, using a Mk 47 electronic/electro-mechanical analog computer in place of the Mk 1A of the Mk 37 fire control system, providing smoother computation and more efficient tracking of faster targets. It incorporated Radar Mark 25 from the first, with ballistics for 5in/38 and 5in/54, 3in/50 and 3in/70; crew was 4 topside, 3 below decks. There was a 15ft stereo rangefinder. Lead angle was up to 50°, speed up to 2000kts (although a standard postwar handbook states that Mk 67 was not effective against supersonic targets). Total weight was 50,000lb, including 16,000 for the director proper. It was installed only aboard the command cruiser *Northampton* and the *Mitscher* class destroyer leaders.

Mark 68

An improved Mk 67, the standard postwar medium-caliber director, capable of dealing with 2000kt targets, with a detection range of 90,000yds, a tracking range of about 100,000,

and a computing range of 18,000, and suited for a lead angle of up to 50°. It incorporated the new SPG-53 radar and in 1974 was credited with a Mean Time Between Failures of 20 hours. The rangefinder was an 11ft stereo unit, and weights were somewhat reduced compared with those of Mk 67; 3 rather than 4 men were required in the topside position. It employed a new computer (Mk 116, which did not require a separate starshell computer) and stable element (Mk 16 rather than Mk 10).

Mark 69

Offmount GUNAR, with radar SPG-48; not used. Complement was 2 topside, 2 below. It could handle supersonic targets.

Mark 70

Developed Mk 63, originally for *Forrest Sherman* and *Claud Jones* classes, incorporating a modified Mk 51 plus a Gun Sight Mark 31 and an SPG-52 radar, with two men topside. It was limited to 650kts and a 24° lead angle, and does not appear to have entered service.

Mark 71

Boston and *Canberra* missile fire control system, initially with Mk 25 Mod 7 and later with SPQ-5 control radars, operating at up to 60,000yds and 900kts. Topside weight was 71,300lb, with another 37,740 below decks in the initial version. It incorporated Weapon Direction System Mark 1 (a Bell TEWA).

Mark 72

Gyatt gun/missile fire control system for Terrier missiles, with Mk 25 Mod 8 radar for both gun and missile control.

Mark 73

Terrier control system in DLG-6-8 and CLG-6-8, with SPG-5 radar and Weapon Direction System Mark 3 (one in the frigates, two in the cruisers).

Mark 74

Tartar fire control system, initially for missile destroyers, with SPG-51 radar and Weapon Direction System Mark 4; also in *Albany* class missile cruisers with Tartar/Talos WDS Mk 6. As upgraded with NTDS it became Mk 74 Mod 6 (WDS Mk 13); converted *Forrest Sherman* class destroyers have Mk 74 Mod 2 with WDS Mk 4 Mod 5. *California* class cruisers have Mod 4 (WDS Mk 11, SPG-51D, or Tartar D digital system); *Virginias*, with ASW capability in their Mk 26 launching systems, have Mod 5 (WDS Mk 13); both of the last two include interfaces with NTDS. The DEGs have Mod 2 or 6 with WDS Mk 4.

Mark 75

Simplified version of Mk 56, intended to replace Mk 63 and 70, for auxiliaries and armed merchant ships.

Mark 76

Terrier guidance system with SPG-55 radar. The original type, in the missile frigates (DLG-9-14), incorporated Weapon Direction System Mark 3; in the *Leahy* class it was replaced by WDS Mk 7 and then, on refit and addition of NTDS, with WDS Mk 11; this latter was also applied to the *Dewey*s as they were refitted with SPG-55 and the Mk 76 (Mk 3, 7 and 8) system with NTDS.

Mark 77

Talos fire control system, associated with WDS Mk 6 and SPG-49 radar in *Long Beach* and *Albany* class cruisers, and with WDS Mk 2 in *Cleveland* class conversions. WDS Mk 2 employs Designation Equipment Mark 8, capable of handling up to six missile and one gunnery targets simultaneously, with a range of 360,000yds; WDS Mk 6 could handle tracking of up to 24 targets, designating up to eight (four Talos and four Tartar) in the *Albany* class system (Mod 1) or up to six (two Talos and four Terrier) in the Mod 0 installed aboard the *Long Beach*. All of these systems employed Computer Mark 111, an electromechanical analog device performing four major functions: designation, evaluation, launcher and guidance radar positioning, and guidance programming, operating at up to 400,000yds. In the late 1960s a modernization program called for replacement of the existing SPG-49B missile control radar by a new and much more reliable SPG-61, with a new modified Mk 11 WDS and an associated Mk 152 digital computer; at the same time the new SPS-48 radar would replace the earlier SPS-39 and one SPS-30 in *Albany* class ships. This program was never fully carried out, however. Total weight of the Mk 77 installation (Mod 1) was 83,700lb above decks and 82,400lb below.

Mark 78

Tartar fire control system incorporating SPG-57 radar (not built), with a Mark 118 computer; nomenclature was assigned in April 1957.

Mark 79

Talos fire control system, with the SPG-56 radar and a Mk 136 digital computer, for CG-13-15. Not built.

Mark 81

Typhon fire control system. This nomenclature was assigned in April 1959 and canceled in October 1961.

Mark 82

Typhon fire control system for missile frigate, employing WDS Mk 9, a Mk 133 digital computer, and the huge SPG-59 radar. Part of Weapon Control System Mark 1.

Mark 83

Abortive Talos control system, probably employing the SPG-51E 'universal' tracking and illuminating radar.

Mark 84

Polaris A-3 fire control system for *Lafayette* class ballistic missile submarines.

Mark 85

Polaris fire control system for cruisers.

Mark 86

New surface and missile fire control system, using the SPQ-9 track-while-scan radar for surface and limited air search, and the SPG-60 tracker and illuminator; installed aboard *Spruance* class destroyers and *Virginia*, *California* and *Ticonderoga* class missile cruisers. It replaces Mk 68 in the DDG Upgrade configuration. Mod 1 is fitted in DLGN-36, and Mod 2 in the *Norton Sound*; Mod 3 (16,600lb), with two lightweight 5in/54, is presumably for the *Spruance*, and Mod 4 for the LHA (18,877lb). Mod 7 weighs 7200lb.

Mod 8 (14,750lb) is for the DDG-2 Upgrade (for which it was considered, ultimately, too heavy), and Mod 9 is for the Aegis cruiser.

Mark 87

Dutch M22 system, bought for US *Asheville* class gunboats.

Mark 88

Poseidon C-3 fire control system for *Lafayette* class ballistic missile submarines.

Mark 89

Land-based test system for Poseidon firings.

Mark 90

Phalanx fire control system. Designation canceled in favor of a single designation for the entire Phalanx system.

Mark 91

Interim Sea Sparrow fire control system (NATO Sea Sparrow), an automatic tracker with separate CW receiving and transmitting antennas, by Raytheon; there is also a television. Computer is Mk 157. Typical weight is 10,668lb. Supersedes Mk 115.

Mark 92

Modified Dutch M20-series fire control system, similar to M25 and M27, built under license by Sperry for US *Perry* class frigates (Mod 2), for the PHM and the Coast Guard medium-endurance cutter (Mod 1), and for the Saudi Navy PCC/PCG craft (Mod 5); Mod 2 includes a separate tracking and illuminating radar (STIR), reportedly a modified SPG-60, to provide a second Standard Missile control channel.

Mark 93

Honeywell fire control system developed as EX-93 for the Coastal Patrol Interdiction Craft (CPIC), a lightweight (1100lb) digital integrated system based on an LN-66HP radar with a computer permitting TWS operation (two targets); it controls two separate gun mounts. Two additional target tracks can be supplied by a pair of optical manned directors. Ballistics are for 20mm through 76mm.

Mark 94

Fire control system for the lead PHM, a Dutch WM28.

Mark 98

Trident missile control system.

Mark 99

Aegis fire control system.

Mark 100

First postwar underwater fire control system, for torpedoes, Hedgehogs and depth charges, on board escort destroyers, for prototype installation in 1948; it was superseded by Mk 102 (1951) and incorporated a Torpedo Data Computer Mark 5 (a modified submarine Mk 4 computer), solving continuously for gyro angle order for fixed torpedo tubes, as well as a Computer Mark 58, a multiple stabilizer to handle sonar, torpedo tubes, trainable Hedgehogs, and Weapon Alfa; an automatic Plotter Mark 5 (to use inputs of range and bearing to plot ships of the hunter-killer group, submarine contacts, own-ship position, and generated target positions from the fire control

equipment); and the associated Computer Mark 55, to allow automatic analysis of submarine contact course and speed for weapon prediction. Attack Director Mark 4 would control the Hedgehog and the stern-dropped depth charges.

Mark 101

First postwar submarine fire control system, for the new generation of fast submarines (*Tang* class), but also suitable for existing fleet submarines of earlier design; like Mk 100, it used the Mk 55 computer-analyzer and an automatic plotter (in this case Mk 3) which replaced the former dead-reckoning tracer (DRT) in the attack station. It could handle speeds of up to 45kts and ranges up to 20,000yds, with 1000ft depths. Mark 101 became available in 1952. Arma.

Mark 102

Advanced surface-ship fire control system, begun in 1946 and first tested in 1951, replacing Mk 100. The Attack Director Mark 4 of the earlier system could not accept data fast enough to counter a medium-speed submarine at short range, and was unsatisfactory for stern-chase depth charge attacks; it was replaced by an Attack Director Mark 5, used in Mk 105. Mk 102 employed both search and attack (SQG-1, designed for it) sonars. Sonar data were fed through a horizontal range computer (Mk 65), a depth plotter which smoothed depth data, and, if the search sonar were in use, through a parallax computer which corrected search sonar data to the attack sonar reference point. These data were then fed to an analyzer which computed target course and speed on a least-squares basis (using at least fifty sample points); the operator selected the interval. Under favorable conditions, a solution could be reached in 20–30 seconds, about half the time required by Mk 105, for a nonmaneuvering submarine. If a turn was detected by sonar or by the failure of the analyzer solution to settle down, the operator could choose a curved-course option. The results were fed into ballistic computers (Mk 67 for depth charges and Hedgehogs, Mk 68 for Weapon Alfa, and Angle Solver Mark 12 for torpedoes); stabilization was achieved through Computer Mark 59. Limits were 45kts and 1000ft (submarine) and up to 40kts (own-ship). Complement was one officer and six enlisted men, and, with 2300 vacuum tubes, Mk 102 weighed about twice as much as Mk 105. Even the 30-second solution time might be excessive in some cases. For example, at bow aspect a 15kt destroyer and a 10kt submarine at 400ft would close at 833yds/min, so that the submarine would pass through the Weapon Alfa range band (750 down to 300yds) in 30 seconds, time for only 7 rounds. Even a 30-second computation would require, in addition, provision for 23 seconds of blind time (12 flight and 11 of sinking), so that the submarine would have to be detected at 1500yds (well outside SQG-1 and QHBa range). It followed that, with short-range sonars and FCS Mk 102, it was best to turn away as the submarine approached closely, to maximize the number of firing opportunities.

Mark 103

PT-boat fire control system for electrically set torpedoes; development began in 1947, for the *PT-809* class, and it was completed in 1954. It

could handle speeds of up to 45kts, and torpedo runs of up to 15,000yds, on the basis of optical or radar inputs at up to 10,000yds. Librascope.

Mark 104

Underwater battery fire control system, an interim installation in the DDE-445 class pending availability of Mk 102. It was based on Attack Director Mark 4 (1950) and used Computer Marks 55 and 59. It could control Mk 11 and Mk 15 Hedgehogs as well as depth charge racks.

Mark 105

Destroyer escort and nonspecialized ASW destroyer fire control system, in service through the 1950s and 1960s. It was based on Attack Director Mark 5, which was first tested at Key West in a destroyer escort in 1952. The weapon system employed a QHBa scanning sonar, a QDA depth-finding sonar, and an OKA-1 range recorder (later SQR-4) which used both sonar inputs to obtain actual target depth and range (from bearing and elevation); it controlled trainable Hedgehogs and depth charges, and initial evaluation showed little improvement over the earlier Attack Director Mark 4; the limiting factor at the time was the sonar. However, as sonars improved, so did the efficiency of the fire control system.

Mark 106

Fire control system for older submarines which could not accommodate the full Mk 101 system.

Mark 107

Abortive destroyer escort fire control system (1953) by Librascope, comparable in capability to Mk 102, to control Squid, depth charges, and homing torpedoes; it was installed only in *Dealey*, whose sisters all had Mk 105s. Complement was one officer and four enlisted men.

Mark 110

Fire control system for RAT (Rocket-Assisted Torpedo) or Hedgehog, for fleet destroyers. It appears to have been a modified Mk 105; service tested (with RAT) in 1958, aboard *Sarsfield*. At that time the RAT system was ahead of sonar capability. Mod 3 was assigned to the DDE-719 class, Mod 4 to DDE-764 class, and Mod 5 to standard fleet destroyers (DD-692/710 classes), but all were canceled with the RAT program.

Mark 111

Digital ASROC and subsidiary weapons fire control system (with digital Mk 38 attack console) for surface ships, widely installed in the late 1950s and the 1960s, *eg* aboard FRAM destroyers.

Mark 112

Submarine fire control system, superseding Mk 101, in *Tullibee* and *George Washington* and *Ethan Allen* class submarines; it was itself replaced by Mk 113. Mod 1 controls Mk 37 and 45 torpedoes; Mod 2 adds Mk 48 capability.

Mark 113

Standard submarine fire control system from *Thresher* onwards, controlling SUBROC and Mk 48 wire-guided torpedoes; it incorporated the first submarine digital fire control computer, Mk 130, with Computer Mark 129 for leveling and for SUBROC calculations. Mk

48 torpedo capability was added in the late 1960s. Current inputs include PUFFS, the BQR-7 passive sonar and the BQS-13 and -14 active sonars (BQQ-2 system). Librascope. Mod 1 could track four targets and fire on two simultaneously. Mod 2 was limited to two targets at a time, and Mod 3 (which was not used) to one. Mod 4, also not procured, was limited to two tracks and one engagement (one rather than two Attack Directors Mark 75). Mod 5, in SSBN-616 and -640 classes, was limited to a single attack director. Mod 6 adds Mk 48 capability to Mod 2. Mod 8, in later SSN-637 class submarines, has four attack consoles. Mod 9, a modified Mod 7 or 5, has a better analyzer (Mk 78 rather than Mk 51) of target motion (SSBN-616 and 640 classes). Mod 10 adds Harpoon and SUBROC, and has increased computer capacity for surveillance and analysis of target/objective acoustic horizon (two attack directors). Mod 12 is fitted for Mk 48 TELCOM guidance, and has a new computer-driven CRT display. It is to be used with BQS-13 under a Shipboard Requirements Improvement Program (SHRIMP) for 31 SSN-594/637 class submarines; the others will be fitted with Mk 11.

Mark 114

Analog ASROC control system, also capable of controlling homing torpedoes and Hedgehog, incorporating Attack Console Mark 53 and Stabilization Computer Mark 134. Position Keeping Computer Mark 143, to control the Mk 37 wire-guided torpedo, was planned for *Knox* class frigates but not used operationally due to surface launch problems. Mk 114 was less expensive (and more versatile) than the digital Mk 111.

Mark 115

Basic Point Defense Missile System (Sea Sparrow) fire control system, a handlebar-mounted CW illuminating radar which an operator keeps aligned with the target; error signals are displayed in his eyepiece. It is a modified wartime-type Mk 63. The CW radar is adapted from that of the F-4 Phantom, the transmitter standing on the left and the receiver on the right, looking towards the target. The director proper is designated Mk 76, in a series distinct from that of the fire control systems.

Mark 116

ASW surface fire control system, successor to Mk 114, using the SQS-53A sonar; it is installed in the *Virginia* class cruisers to control ASROC and Mk 32 torpedo tubes. Unlike earlier systems, it employs a standard Navy digital computer, the UYK-7, thus reducing the logistics burden. Librascope.

Mark 117

All-digital fire control system for attack submarines; successor to Mk 113, first tested in *Narwhal*. It incorporates an All-Digital Attack Center (ADAC), three computer-driven CRT displays. Mod 0 is for SSN-700 through -715; Mod 1 is a backfit for SSN-594-596, 603-607, 612-615 and 621. Mod 2 equips SSN-637-639, 646-653, 660-670 and 672-677. There are no attack directors, only three Weapons Control Consoles Mark 81. Mod 5 (Tomahawk) is to be fitted in place of Mod 1; it adds a digital navigational system, DMINS. Mod 6 is Mod 2 plus digital navigation (ESGN) for Tomahawk;

Mod 7 is Mod 3 plus ESGN and Tomahawk, for SSN-671 and 678-687. Mod 8 (SSN-716-720) provides for SUBROC/Tomahawk, having a Submarine Integrated Attack Center (SIAC), and four computer-driven CRT displays (Mk 81).

Mark 118

All-digital torpedo fire control system for Trident submarines.

Mark 119

Advanced digital underwater fire control system for surface ships, incorporating some submarine technology (such as Weapon Control Console Mark 81). The first is to be installed at NUSC San Diego.

Mark 121

'Seafire' electro-optical fire control system, a modular addition to Mk 86/68/92 or a stand-alone system. It performs three-dimensional tracking to generate ballistic orders, and can track and illuminate a target for guided projectile engagement. Capabilities include day or night passive imaging or detection, manual or automatic tracking, and laser-ranging of surface targets. In FY82 the Navy withdrew its request for funding, but Congress provided funds, as 'Seafire' and its associated laser-guided projectile were part of the DDGX project.

I-3 Gun mounts

Until after World War Two, gun mounts were listed in separate mark series for each caliber; after Mk 42, all weapons were included in a single continuation of the 5in series. All weights are weights of the rotating mass. Where possible, maximum elevation/depression and elevation/train per handwheel turn or per second (powered mounts) are given; the reader will note that anti-aircraft mounts generally show faster train rather than faster elevation, to follow a rapidly crossing target. Rotating weights are in pounds (lb) or in long tons (t) of 2240lb each. For hand-loaded guns, trunnion height above deck has been given, about 45in for single-purpose and about 66in for dual-purpose guns; the latter generally had a platform for the loader, carried by the gun mount. In early mounts, 'recoil' denotes a gun returned to battery by recoil springs or hydraulics; the alternative was a gun recoiling up an inclined slide, and returned to battery by gravity, as in muzzle-loading days.

Early carriages (before center-pivot) employed separate trucks (again, as in the earlier muzzle-loaders) with wheels running in deck circles laid on the decks, often with rack-and-pinion train; pivot mounts employed a tongue carried forward of the truck and attached to it, connected to the deck by a pin. Shifting carriages could move from one set of training circles to another on deck. Center-pivot mounts, on the other hand, turned about a pin directly beneath the gun carriage, with their training racks on the central bearing. In a base-ring mount, the gun rode a ring of bearings and the space directly beneath it was clear to receive, for example, an ammunition hoist. Finally, two- or three-gun mounts had separate weapons elevating separately, although they could be linked together if so desired; twin or

triple turrets or mounts, which were often more compact, had their separate weapons either rigidly linked or attached to the same slide.

This section is divided into an enumeration by calibers and a list of the post-1945 unified gun mount series.

16in Turrets

There were four types. The two-gun turret of the *Colorado* class was closely related to the three-gun turret of the *Mississippi* (880-920t, elevation +30°/-5°, loading angle 1°, ie about 2000yds with a 2240lb AP round at full charge, with a roller path inside diameter of 27ft 7½in and a 48in recoil); the three-gun turret of the canceled *South Dakota* class would have been similar but larger, carrying the 16in/50 gun in place of the earlier 16in/45: 1390t except for No 2 turret, a secondary command position, 1403t, elevation +40°, barrette (not roller path) inside diameter 35ft (compared to 31ft in the earlier ships). The estimated weight of the *Colorado* installation was about 835t, and the higher figure given may reflect World War Two modifications. The *North Carolina* and *South Dakota* classes had three-gun 16in/45 turrets with very different ammunition-handling arrangements and lower silhouettes: 1403-1437t, elevation +45°/-2°, except No 2 turret, with a peacetime lower limit of 0° degrees and a 5° loading angle, corresponding to about 10,000yds for a 2700lb AP shell at full charge, 2500ft/sec. Rates of movement were 12°/4° per second, the fast elevation making up for the fixed loading angle. Roller path diameter was 34ft 5in, and recoil 48in. The *Iowa* class turret, which would have been repeated in the *Montana* class, was similar if heavier (1701-1708t, with similar elevation limits and speeds, and a similar roller path diameter).

14in Turrets

There were three distinct types. A two-gun turret was used in the *New York* and *Nevada* classes: 506t for *New York*, 532t for *Nevada*, increasing to, respectively, 532 and 618t. Elevation was +15°/-5°, increased in *Nevada* to +30°/-5° during reconstruction, with rates of 4°/1.7° per second; recoil was 40in. Inside barrette diameter was 28ft, and the roller path was 25ft 1½in. The triple 14in/45 turret of the *Nevada* and *Pennsylvania* classes weighed 693t and 721t respectively, increasing to 748t and 714-724t in 1945, with elevation limits of +15°/-5° increased to +30°/-5° during reconstruction and roller path diameter increased to 27ft 1½in. The three-gun 14in/50 turret of the *Mississippi* and *California* classes had revolving weights of, respectively, 897t and 958t in 1945; elevation limits were +15°/-5°, increased in the first class on reconstruction and in the second as built to +30°/-5°. Loading angles were 0° in the *Mississippi* class and 1° in *California*. Roller path diameter was 28ft 1½in. Only *New York* and *Texas* were not modernized with increased elevation and hoists for 1500lb shells.

13in Turrets

There were four marks. Mk 1 was apparently not used, but Mk 2, in the *Indiana* class, was similar to earlier 10in and 12in monitor Mk 1 turrets. It was unbalanced, and had elevating limits of +15°/-5°, with a 10° loading angle. Revolving weight was 440t, and return was hydraulic. Mk 3, *Kearsarge* class, superposed

two 8in guns above two 13in; elevation was +15°/-5°, with a 2° loading angle and spring return. It was electrically powered, with a rotating weight of 712t, and shell capacity was 125 8in and 60 13in per gun. Mk 4 (*Illinois* class) was a balanced, barrette-style mount, with a conventionally shaped gunhouse on top, elevating to +15°/-5°, with a loading angle of 2° and spring return. Revolving weight was 503t, and there was stowage for 60 rounds per gun standard issue.

12in Turrets

There were eight marks as well as the two-gun turrets of the *Arkansas* class and the very different World War Two turrets of the *Alaska* class large cruisers. Mk 1, similar to the 13in Mk 1 and 2 and to the 10in Mk 2, was mounted in the monitors *Puritan* and *Monterey*. Elevation limits were +15°/-3°, and loading angle 9.5° (hydraulic). Mk 2 was in the *Texas* and featured fixed loading in train as well as in elevation, this limit being removed shortly before the outbreak of the Spanish-American War. Elevation was +15°/-5°, loading angle 0°, and return hydraulic. Mk 3, in the *Iowa*, was the first US balanced turret and had a rotating weight of 448t, an elevation of +14°/-3°, and a loading angle of 3°, with spring return, hydraulic training, and electric- or hand-ramming). Mk 4, in the *Maine* class battleships and in the *Arkansas* (later *Ozark*) class monitors, introduced the barrette/gunhouse style of construction (similar to 13in Mk 4) and had +15°/-3° elevation, 0° loading angle and spring return, whilst Mk 5 was the combined 12in/8in mounting in the *Virginia* class (+20°/-7° elevation, 0° loading angle for 12in guns, 90-second loading interval), and had a rotating weight of 604t, with 125 rounds per 8in and 60 per 12in. Mk 6 was the *Connecticut* class turret (427t in *New Hampshire*, 60 rounds per gun), and Mk 7 was the turret of the *Mississippi*, *South Carolina* and *Delaware* classes (414t in *Mississippi*, 437t in *South Carolina*, +15°/-5° with all-elevation loading and all-electric power). Mk 8 was the *Utah* turret, weighing 443-450t and very similar to Mk 7. Then the mark system stopped; the *Arkansas* class used a two-gun 12in/50 turret (471t, increased to 491t by 1945, +15°/-5°, with a roller path diameter of 24ft 11in). The *Alaskas* had a new three-gun turret, similar to those of the new battleships, which weighed 922-934t, elevated at +45°/-4°, and loaded at 7°. Range was about 15,500yds with an 1140lb AP shell and a full charge, and muzzle velocity was 2500ft/sec. Elevation/train rates were 12°/5° per second, and roller path diameter 27ft.

10in Turrets

Mk 1 was a hydraulic turret for the monitor *Miantonomah* (+13.5°/-3°, loading angle 13.5°), and Mk 2 corresponded to the 12in Mk 1, for the *Amphitrite* class monitors and the *Monterey* (after turret; hydraulic operation, +15°/-3°, loading angle 10°). Mk 3, the *Maine* turret, corresponded to 12in Turret Mark 2, differing from Mk 2 primarily in the details of the means of checking the recoil. Mk 5, for the monitor *Terror*, had all-angle loading and pneumatic return (+13°/-3°), and a later turret armed the armored cruisers of the *Tennessee* class (275t, 60 rounds per gun).

8in Turrets and Gun Mounts

The early cruisers of the 'New Navy' were armed with 8in guns enjoying varying levels of protection in nonrecoil mounts, very similar to contemporary 6in carriages. Mk 1 was a steam-powered barbette mount for the *Boston* and *Atlanta*, Mk 2 a 'half-turret' (cylindrical shield with top) for *Chicago*, similar to 6in Mk 3 and 4, and Mk 3 was a center-pivot gun mounting, with Mk 4 similar but using a single-casting slide (these weapons were for the *Charleston* and *Baltimore*). Mk 5 was the turret installed on the cruisers *New York* and *Olympia* and had gravity return, elevation $+13^{\circ}$ – -4° , loading angle 0° (one source identified a very similar Mk 6 with *Olympia*); Mk 7 was the *Indiana* class secondary turret (spring return, $+13^{\circ}$ – -7° elevation, 0° loading angle); and Mk 8 was the *Brooklyn* and *Iowa* class turret (data as Mk 7). Mk 9 was the superposed 8in turret of the *Kearsarge* class (elevation $+14^{\circ}$ – -7° , loading angle 0°). By 1896 there was an experimental spring-return recoil mount, presumably to replace earlier gravity types, and by 1900 there were new types, a Mk 10 single mount and a Mk 12 two-gun turret. The latter was for both the *Pennsylvania* class armored cruisers and for the *Virginia* class battleships and had spring return, $+20^{\circ}$ – -7° elevation, and 0° loading angle. Typical weights were 147t in the *Pennsylvania* class, 151t in *Virginia* and 149t in *Connecticut*, with allowances, respectively, of 125, 125, and 100 rounds per gun. This was the last US 8in mount developed prior to the Washington Treaty.

New twin and triple 8in/55 mounts were developed for the carriers *Lexington* and *Saratoga* and for the *Salt Lake City* class cruisers: 418,000lb for a twin, 553,000 for a triple mount (as of 1945), with a 21ft 6½in roller path, and elevation angles of $+41^{\circ}$ – -5° , and a loading angle of 5° , corresponding to about 10,000yds with a 260lb AP shell at 2700ft/sec, or rather more with the higher velocities originally adopted. It was very lightly built, and its mechanism did not extend very deep into the ship. The *Chester* and *Portland* class cruisers employed a similar turret (559,000lb, with similar elevation and loading angles), but in the *New Orleans* class armor protection was emphasized. This triple mount weighed 294t, had an 18ft 11in roller path with a 21ft inside barbette diameter, and had the same elevations but a 9° loading angle, corresponding to a range of about 15,000yds, although later ships, beginning with the *Tuscaloosa*, had a somewhat lighter, more compact turret (250t) with a 17ft 8in roller path. *Wichita* and probably *Astoria* and *Quincy* had a new three-gun turret (ie with independent elevation) which was the prototype for that of the *Baltimore* class: it had a coned barbette, weighed 314t (297–304t *Baltimore* class), and had a 19ft 9in roller path deeper in the mount. Elevating and training were at $10.13^{\circ}/5.29^{\circ}$ per second, with the same elevations and loading angle as before. Finally, the *Des Moines* class introduced an automatic 8in/55 gun in a massive three-gun turret weighing 451t, elevating at $+41^{\circ}$ – -5° , and having all-angle loading, elevation and train at $8.2^{\circ}/5^{\circ}$ per second, a 24ft 2in roller path, and a 27ft 0½in barbette diameter).

7in Gun Mounts

There was only one type, although it was ultimately moved from battleships to coast

defense installations. Weight was 25t for gun and mount, allowance was typically 100 rounds per gun, and the trunnions were 52in above the deck (in the shore mounting). Recoil was 21in and elevation limits were $+15^{\circ}$ – -7° .

6in Gun Mounts and Turrets

Development of the 6in mount began with classical gravity mounts. Mk 1 (shifting pivot) was fitted in USS *Dolphin*, and Mk 2 (muzzle-pivot mount) in *Chicago*, *Atlanta* and *Boston*; there was also a related Mk 2 gravity return broadside carriage. Mk 3 was a central-pivot carriage, a radical departure from previous policy, and began with carriage No 22. It depressed 7° or, in later units, 10° ; shields were cut for $+12^{\circ}$ – -10° . Mk 4 (central-pivot, beginning with No 44) used a single-piece slide combining truck bearings, transoms, shield shelves and securing eyes in one casting, compared to twenty pieces in No 1 of 1884, but was similar to Mk 3 in other respects. Mk 5 was the first rapid-fire recoil mount, using a central pivot, a slide on trunnions, and a training circle on its stand; a hydraulic recoil cylinder and counter-recoil springs were also used. Mk 6, a pedestal mount for the *Illinois* class, was modernized to Mk 7 standards by about 1905; typical weights were 21,856lb with a 6in/30 and 25,430lb with a 6in/40. The next major open 6in mount was 6in/50 Mk 10, which was still in service in 1945 aboard some auxiliaries. It weighed 32,260–37,000lb, with elevation and train rates of $39^{\circ} 12''/1^{\circ} 2' 58''$ per hand-wheel turn and a 15in recoil, and elevation limits of $+15^{\circ}$ – -10° . Mk 11 carried the 6in/44 Mk 9 gun (28,737lb).

Development then largely ceased until World War One, when the *Omaha* class cruisers received Mk 13 single mounts (with a 0.25in half-circular shield, weighing 35,700–41,800lb and with $+20^{\circ}$ – -10° elevation, $58' 10.6''/2^{\circ} 25.8' 18''$ per handwheel turn and 18in recoil) and Mk 16 twin enclosed base-ring mounts (trunnions 76in above deck, elevation $+30^{\circ}$ – -10° , weight 116,000lb, with a maximum elevation speed, as powered, of $7^{\circ} 37' 23''$ per second). Mk 15 was a submarine wet mount for the large cruiser submarines (37,700lb, $58' 4.8''/1^{\circ} 23' 2.4''$ per handwheel turn, with a trunnion height of 60.8in and no loading platform, elevation limits of $+25^{\circ}$ – -10° , and 18in recoil), and Mk 17, the last of the single 6in mounts, was designed for the large gunboats *Erie* and *Charleston* (0.86in shield, pedestal mount for 6in/47, 52in trunnion height, $+20^{\circ}$ – -10° elevation, 34,500lb and 24in recoil). All of the *Brooklyn* through *Fargo* class light cruisers had essentially the same triple 6in mount. This weighed 154–167t in early versions, or 165–173t in later ships. Elevation was $+60^{\circ}$ – -5° (originally $+40^{\circ}$ – -5°) and loading was at all angles from 0° to 20° , ie at up to almost 18,000yds with a 105lb AP shell and a muzzle velocity of 2565ft/sec. Maximum rates were $10^{\circ}/10^{\circ}$ per second in the *Brooklyns*, and $11^{\circ}/10^{\circ}$ in the *Clevelands*, and roller path diameter was 15ft 4in. The *Worcester* class two-gun mount was even more massive at 208.5t and a 17ft 2in roller path. Elevation was $+78^{\circ}$ – -5° and elevation/train rates $14.8^{\circ}/25^{\circ}$ per second, characteristic of an anti-aircraft rather than a single-purpose gun, and comparable with the performance of the twin 5in/38.

5in Gun Mounts

As in the other calibers, 5in mount development began with a Mk 1 of gravity-return type, followed by Mk 2 (similar to 4in Mk 2 but with two counter-recoil spring cylinders cast on the sleeve) and Mk 3 of conventional, rapid-firing design. These mounts had typical weights of 14,198lb for Mk 2 Mod 2 with a 5in/40 gun and 7850lb for Mk 3 Mod 3 with a 5in/40 gun Mk 2 and were still in service on the eve of World War One. The Mk 5 pedestal mount, introduced about 1896, was installed on the new armored cruiser *Brooklyn* and on the battleships *Kearsarge* and *Kentucky*; it was succeeded by Mk 6, and by a Mk 7 later converted into a Mk 8; all of these mounts, for the standard 5in/40 gun, weighed about 14,500lb including the gun proper. They were followed by a series of battleship broadside mounts for the new high-powered 5in/50 gun: Mk 9, with a trunnion height of $45\frac{1}{2}$ in, elevation $+15^{\circ}/10^{\circ}$, weight 20,400lb; and Mk 12, also with a trunnion height of $45\frac{1}{2}$ in, but with a loader's platform $26\frac{1}{2}$ in below the trunnion line, at 18,700lb. These in turn were succeeded by the more powerful 5in/51s: Mk 13, with trunnions 48in above deck, elevation $+20^{\circ}/10^{\circ}$, weight 24,100–24,600lb; and Mk 15, at 15,700–22,400lb, with a 30in recoil rather than the 15in of the earlier weapon, and $+20^{\circ}$ – -15° elevation. Mk 14 was a proposed twin 5in/51 for capital ships, sketched in the fall of 1917; one may actually have been built. The only other major 5in single-purpose mount was the Mk 18, a wet mount for submarines weighing 24,000lb and with 21in recoil and an elevation of $+25^{\circ}$ – -8.5° or 10° . Mk 17 was the first US heavy AA mount, for the 5in/25, showing its function both in its elevation ($+85^{\circ}$ – -15°) and in its trunnion height (60in, although it had no loader's platform); recoil length varied from 24in to 12in with elevation, and total weight was 12,625lb. In Mk 19 a loader's platform was added, and trunnion height raised again, to 66in. For each turn of the handwheel the gun elevated $1^{\circ} 52.5'$ or trained $4^{\circ} 10'$ (low speed) or $6^{\circ} 17'$ (high speed). By way of contrast, single-purpose guns elevated at a similar speed but trained far more slowly: $1^{\circ} 17' 14''/1^{\circ} 10' 44''$ for Mk 15, or $1^{\circ} 31' 27''/5^{\circ} 55' 3''$ in the dual-purpose Mk 17. The 3in/50, a lighter gun, trained even faster at high speed (see below). The other major 5in/25 mounts were Mk 23 (21,670lb, otherwise as Mk 19), Mk 27 (23,270lb, power-driven at $20^{\circ}/30^{\circ}$ per second in automatic or $21.95^{\circ}/32.61^{\circ}$ per second in local control), and Mk 40, the 5in/25 single-purpose wet mount (14,000lb, $+40^{\circ}$ – -10° , $1.5^{\circ}/2.5^{\circ}$ per handwheel turn, with 48in high trunnions and a 20in recoil).

Mk 21 began the series of 5in/38 mounts with an open dual-purpose type weighing 29,260lb, with trunnions at 54.125in but with a loader's platform. Recoil was 15in, elevation $+85^{\circ}$ – -15° , and elevation/train at $4^{\circ} 54' 7''/9^{\circ} 52' 36''$ per handwheel turn, considerably faster than the 5in/25. Mk 22 was the single-purpose twin mount for 1850-ton destroyers and weighed 75,260lb with a 0.125in shield, it had $+35^{\circ}$ – -10° elevation with ammunition hoisted up through its center, with power drive at $11.6^{\circ}/14.7^{\circ}$ per second and a 19in recoil. Mk 24 was an improved open-pedestal dual-purpose mount for destroyers: when power-operated, elevation/train took place at $15^{\circ}/28.75^{\circ}$ per second. It weighed 31,200lb, and had trunnions 73.5in above deck. It was

superseded by the Mk 25 base-ring mount, 42,000–44,900lb including a flat-sided shield, and power-operated at 15°/28.7° per second. Mk 25 was, then, the prototype of the major US destroyer weapon of most of the war period, Mk 30, which measured 33,500lb in an open form, or 40,900–41,400lb fully enclosed in its earliest version, and was power-operated at 18°/34° per second (with Ford controls) or at 15°/28.75° per second (with GE controls). Versions of the Mk 30 ran through Mod 86. In variants specifically for destroyer escorts, the shield was cut off at an angle at the rear end, to clear Hedgehog projectiles fired dead ahead; however, such shields were also widely used in other positions. Mk 37 was a simplified base-ring mount for auxiliaries and merchant ships (34,700lb, 15°/30° per second).

Twin 5in/38 mounts constituted the other major wartime series. Mk 28, for battleships, had a 2in or 2.5in shield (64,700 or 79,800lb of shield, for a total mount weight of 153,000 or 169,000lb – over twice that of the single-purpose twin mount. It elevated at +85°/–10°, with 15°/25° per second power-operated elevation/train and a 15in recoil. Mod 1, for cruisers, with a 0.125in shield, weighed 134,000lb. Mk 29, (0.75in shield, 108,000lb) was for light cruisers. Mk 32, a new medium-weight type intended to succeed Mk 29, was installed in older battleships, cruisers and carriers. Weight was 118,000–119,000lb with an 0.75in shield, or 132,000lb with a 1.25in shield (for LSVs and light cruisers); elevation/train was 15°/25° per second. Mk 38 was for destroyers (0.5 or 0.125in shield, 95,700–105,600lb, 15°/25° per second).

Late-war and postwar efforts concentrated on the 5in/54 in semiautomatic and automatic forms. Mk 39 was mounted in the *Midway* class carriers; a single mount, it had a 0.75in shield, weighed 73,900lb, elevated to +85°/–10° and elevated/trained at 15°/30° per second. Recoil was 19in and trunnion height 84.25in. It was to have been followed by a twin Mk 41, which began as the secondary weapon of the *Montanas* and then progressed, in more compact form, to become the main armament of proposed anti-aircraft light cruisers and large destroyers. Instead, the automatic Mk 42 was developed (145,930lb in Mod 0 form, 18.75in recoil, +85°/–7.5°, 25°/40° per second). From Mk 43 onwards, gun mount designations have followed a single series, which is listed separately.

4in Gun Mounts

Mk 1 was a prototype only, and not issued. Mk 2 (9248lb with Mk 3 40-caliber gun) and Mk 3 (eg 9075lb with Mk 3 40-caliber gun) were central-pivot rapid-fire types, Mk 3 differing from Mk 2 in having no directing bar, training by handwheel with sights on the slide, and being nonrecoiling. The directing bar was a single coaxial shaft which, in some mounts, carried both training and elevating wheels at its end, for a single trainer-pointer; in later mountings training and pointing were separate functions, requiring separate men. Many Mk 2 mounts were converted to Mk 3 standard, and by 1896 there was a new 4in pedestal mount for *Iowa* and the new gunboats *Helena*, *Nashville* and *Wilmington*; presumably it was Mk 4, but in 1913 a list of 4in mounts included also Mk 7 and 9, for the 4in/40 (typically 7700–8600lb). Mk 8 was the new 4in/50 mount (about 12,500lb in various mods), with Mk 10 a lighter

equivalent (10,456lb with a Mk 9 gun). In 1945 the surviving 4in/50 mount was Mk 12, for example in the old destroyers. It weighed 10,140–10,660lb, had a 27.5in recoil and a 45in trunnion height, and elevated to +20°/–15°; some mods were wet, for submarine use. There was also a twin 4in mount, experimentally installed on some flush-deck destroyers.

3in Gun Mounts

The earliest mounts for which records can be found are pedestal types for the 3in/50 gun, either as an antidestroyer weapon on battleships or as a destroyer main battery weapon: Mk 2 (6053lb) and Mk 4 (5030lb, with an 8in recoil, elevation +15°/–10°). Mk 5 (5240lb) and 7 (5560–5640lb) were similar, with longer recoils (9.25in and 16in, respectively). Mk 11 was the first 3in AA mounting. Weighing 6820–6980lb, it had a trunnion height of 66.25 rather than the 45in of the single-purpose mounts, elevated at +85°/–10°, and had a 12in inch recoil; some mods had a platform for the loaders raised well above the mount base. Mk 14, for the 3in/23 'boat gun', was a limited AA weapon at +65°/–15°, 1510lb, and with a 19in recoil; Mod 1 elevated to 75°, and Mod 3 had a shield, for Yangtze River gunboats, at 2090lb. There were also wet mounts, since the 3in/50 was for many years the standard submarine gun: Mk 18 (Mk 19 gun, +40°/–15°, 6500lb), Mk 19 (+88°/–15°, a Mk 18 gun, 8200lb, for dual-purpose operation), and Mk 21 (7320lb, +85°/–13°). Mk 20 was a new-construction, dual-purpose mount elevating at +84°/–10°, and weighing 7070 or 7430lb, and was followed by Mk 22 at +85°/–13°, 6700–7510lb, 3°/2° 52' 48" per handwheel turn. Where Mk 20 was an interim mount to use existing 3in barrels, Mk 22 was a new development. In power-driven form (1945) it became Mk 26, with a speed of 24°/30° per second. Mk 24 was an entirely new DP single mount, designed by Northern Pump and characterized by a counter-recoil spring wrapped around the base of the barrel; elevation was +85°/–15° and weight 8235lb. Mk 27 was the new twin rapid-fire mount, developed in 1945 as part of the antikamikaze program (which also brought about the development of Mk 26); it was built in both open and enclosed versions (30,960–31,700lb, +85°/–15°, 24°/30° per second). Mk 33 differed in that its slide had been modified to permit removal of a gun barrel from the front of the mount, for easier regunning; it had similar characteristics and weighed 31,435–32,400lb; Mk 34 was the corresponding single mount (17,004–18,943lb). Mk 37 was the last of the wartime 3in series, a twin 3in/70 with power operation for very high anti-aircraft performance and with high-powered drives, for 35°/50° per second. At 125,500lb, it was comparable to a large 5in mount; elevation was +90°/–15° and maximum recoil 15.62in. From time to time a corresponding single mount was proposed, but it was never built.

40mm Gun Mounts

There were three types in wartime naval service: Mk 1 (twin base-ring mount, 13,000–14,000lb without fire control, or 14,700–14,900lb with Mk 63; +90°/–15°, and 30°/24° per second); Mk 2 (quadruple base-ring mount, typically 24,900lb with a 0.375in shield, or 26,600lb with Mk 63 fire control system, with similar performance); and the

Army Mk 3 single mount (+90°/–6°, 2440lb, or 4200lb with power drive and performance comparable to that of Mk 1). Mk 3 was intended primarily for submarines and PT-boats, although in wartime it was often used to supplement destroyer and destroyer escort batteries. Mk 4 was a lightweight quadruple mount developed by Northern Ordnance, in which about 1000lb was saved by the use of GE drive, and an additional 2500lb of electrical equipment, including the amplidyne motors, was stowed below decks. About 100 had been made by VJ-Day. It weighed 25,140lb, elevated/trained at 55°/50° per second (which shows the needs of the Fleet of 1945) and had elevation limits of +90°/–15°.

1.1in Gun Mounts

Mk 2 was typical: 10,500lb, or 12,000–14,000lb in some mods. Mods 2 and 3 incorporated a traverse, allowing the four barrels to slew 30° to either side of neutral at a fixed mount bearing. Power-driver versions, using the twin 40mm power drive, operated at 24°/30° per second. Elevation was +110°/–15°.

20mm Gun Mounts

The original Mk 2 with a 0.5in shield on a pedestal weighed 1695lb, a figure characteristic, too, of Mk 4 (+87°/–5°); the latter incorporated a feature permitting the operator to raise and lower the trunnions (which often corroded at sea) to accommodate his height. Mk 5 was a British-designed, fixed-trunnion mount (1540lb); all but 916 of 6101 produced went to Britain. During 1941–42 attempts were made to develop a lighter or more reliable mount. Pontiac produced Mk 6, with a hydraulically adjustable trunnion height (1691lb, +90°/–15°), and at the same time Mk 10 was produced as a lightweight mount (950–1100lb) for special applications, although in the event this supplanted all previous marks in production.

There were attempts to increase 20mm hitting power in the form of multiple mounts, twin, triples and quadruples. Mk 15 (Elco quad, about 560lb) had been designed initially for PT-boats, and it proved unserviceable. However, a Maxson quadruple mount Mk 22 (power-operated, with the operator seated within the mount, carrying four T31 aircraft guns on a weight of 2250lb) was tested in several ships in 1944; in 1946 it was replaced by a Mk 26 with a self-contained power source (Maxson, about 3000lb). Mk 23 was a triple mount developed at Pearl Harbor; although 50 were ordered, it was canceled in May 1944. Then there were the twin mounts, one of which, Mk 24, became standard at the end of World War Two. Mk 20 was the prototype (1340lb) and was followed by Mk 24 (typically 1400lb with an 0.5in shield); Mk 25, the Emerson twin, was an improved version (about 1300lb) with T31 aircraft-type weapons rather than Oerlikon guns. Finally, Mk 27 was a Mk 4 with fixed trunnion height, and Mk 28 was an experimental 20mm mount on an aircraft-type scarf ring, tried in 1945. Mk 16 was the standard postwar single 20mm mount. In 1982 it was described as unreliable and difficult to maintain; it is to be replaced by the Army 25mm M242.

Postwar Gun Mount Series

Mark 43

Twin 5in/54 similar to Mk 41 but with reduced trunnion height (1947).

Mark 45

Lightweight single-purpose 5in/54, in *Spruance* class and other ships: 54,000lb, +65°/-15°, 20°/30° per second, 100-hour MTBF.

Mark 46

Double mount, 1966, with 0.50-caliber machine gun and 40mm grenade launcher.

Mark 47

40mm grenade launcher on 0.30-caliber machine gun tripod, developed by NOP Louisville for SEAL-RAG teams.

Mark 48

20mm/40mm grenade launcher, one-man self-contained armor-shielded mount for riverine operations, 1968. Mod 1 had two 7.62mm machine guns, Mod 2 had two 0.50-caliber HB (M2) machine guns; Mod 3 was similar, but power operated. Mod 4 had a 3.5in Rocket Launcher Mark 47 (2 pods, 4 tubes) in the 20/40 mount.

Mark 49

Training version of Mk 48 Mod 0 in mild steel; mods of Mk 49 corresponded to mods of Mk 48.

Mark 50

0.50-caliber machine gun/40mm grenade launcher combination for LCM-6 landing craft converted to riverine warfare craft.

Mark 51

Armored 20mm pedestal mount for LCM-6 conversions.

Mark 52

Originally a combined manual-drive M3 40mm Bofors gun and a 0.50-caliber machine gun in an armored shield; later the machine gun was removed (1970).

Mark 53

Twin 0.50-caliber machine gun on a modified shock-absorbing M9 cradle, for rail-mounting on motor gunboats, with a capacity of 250 rounds.

Mark 55

40mm grenade launcher for ASPB (riverine craft) gunwale.

Mark 56

Twin protected mount for 7.62mm, 0.50-caliber or 20mm machine gun or for 40mm grenade launcher.

Mark 57

Mount for M60 Army 7.62mm machine gun.

Mark 63

Mount for 40mm grenade launcher designed in 1963 for LCM conversions, as a converted 0.50-caliber machine gun mount; it was modified in turn in 1971 for a machine gun.

Mark 64

Combination 40mm grenade launcher and machine gun.

Mark 65

Lightweight faster-firing 5in/54 gun, projected successor to Mk 45; 48 rounds per minute, with 112 rounds of ready-service ammunition.

Mark 66

Twin lightweight 5in/54, essentially a pair of Mk 65s, with 100 rounds per gun.

Mark 67

Lightweight 20mm mount, aluminum except for the shield; Mod 2 could accommodate machine gun EX-29-0, the GEC 120B 20mm gun (475lb, +75°/-30°).

Mark 68

Mount for Mk 16 Mod 5 machine gun.

Mark 69

Major Caliber Light Weight Gun (8in/60), about 185,000lb. 1970.

Mark 70

Similar to Mk 69, but firing a longer round. About 200,000lb.

Mark 71

Major Caliber Light Weight Gun mount (8in/55), canceled in 1978. Weight 224,471lb including 32,611lb below decks; 12 rounds per minute, with 75 rounds of ready-service ammunition on the mount; elevation +65°/-5°, elevation/train 20°/30° per second. Six enlisted men required for operation.

Mark 72

Phalanx mount, part of Close-In Weapon System Mark 15. Elevation +80°/-25°, elevation/train 86°/100° per second, firing at 3000 rounds per minute with 1000 rounds on the mount, at a total weight of 12,000lb above decks and 466lb below. Standard manning is three enlisted men.

Mark 73

Emerlec 84MX mount, for two 20mm (500 rounds) or one 40mm and one 20mm (300 and

500 rounds, respectively), or for two 0.50-caliber machine guns (1000 rounds each), armored against 0.50-caliber fire and weather, with diameter limited to 48in and height to 38in.

Mark 74

Emerlec twin 30mm mount for CPIC coastal interdiction craft. Weight 8263lb above decks, 650lb below, elevation +80°/-15°, elevation/train 80°/80° per second power-driven, with the operator in the middle of the mount. Rate of fire is 550 rounds per minute with a total on-mount load of 1950 at high velocity; 3543ft/sec.

Mark 75

OTO-Melara 76mm/62 single lightweight mount, firing at 80 rounds per minute, with 80 rounds of ready-service ammunition. Elevates at +85°/-15°, elevates/trains at 35°/60° per second, and weighs 16,500lb above decks and 763lb below. Manning is 3 enlisted men. In hydrofoils and *Perry* class frigates.

Mark 77

Lightweight Gatling gun mount (7.62mm, with 3000 rounds in four 750-round containers).

Mark 78

Twin shielded M60 7.62mm machine gun, firing 1500 rounds per minute (two 600-round containers in the shield). For light craft.

Mark 79

Twin 20mm machine gun (Mk 16 Mod 5 in Mod 0 mount, EX-29 in Mod 1).

Mark 80

'Hip-Pocket II' anti-cruise-missile weapon, an M61A1 Vulcan, manually operated with a stabilized computing sight and 1000 rounds on

I-4A Armor penetration data

Gun	MV (ft/sec)	Shell (lb)	6000yds	9000yds	12,000yds	16,000yds	20,000yds
6in/50	2800	105	3.99	2.98	2.70		
7in/45	2700	165	5.21	3.84	3.43		
			6.3*	4.3*	3.2*		
8in/45	2750	260	7.58	5.48	4.63		
			8.6*	6.6*	5.0*		
8in/35	2100	260	5.6*	4.1*	2.9*		
10in/40	2600	510	10.74	8.21	6.78		
			12.1*	9.8*	7.8*		
10in/30	2000		6.9*	5.8*	4.2*		
12in/35	2100	870	10.5*	8.5*	6.7*		
12in/40	2600	870	14.6	11.6	9.4		
	2400	870	12.9*	10.7*	8.7*		
12in/45	2700	870	16.6	12.2	9.9		
			15.6*	13.1*	10.8*		
12in/50	2900	870	17.4*	14.7*	12.3*	9.5*	7.0*
13in/35	2000	1130	12.13	10.09	9.11		
			10.3*	8.1*	6.1*		
14in/45	2600	1400	17.2*	14.4*	11.9*	8.9*	6.7*
14in/50	2800	1400	19.2*	15.3*	13.6*	10.5*	8.8*
16in/45	2600	2100	25.8*	22.2*	18.9*	14.8*	11.5*
16in/50	2800	2100	29.0*	25.1*	21.5*	17.3*	13.5*

Data is for face-hardened (Harvey) plates, considered as side armor. When two figures are given for the same caliber and initial velocity, the second refers to the long-nose shell introduced in FY08 (7 caliber head radius). 'MV' is muzzle velocity; penetration thicknesses are in inches.

Starred figures are taken from the BuOrd table 'Elements of US Naval Guns' of 17 May 1918; unstarred data are from detailed 'Ordnance Data Sheets' compiled in 1905, at the time of the *South Carolina* design. The 1918 data is corrected for angle of fall and may refer to harder armor than the 1905 data; note that in some cases the higher-velocity shell does not penetrate as much armor. For example, at 6000yds the longer 12in shell would retain a velocity of 2173ft/sec, the shorter, 1877ft/sec (12in/45 fired at 2700ft/sec). Data for 16,000 and 20,000yds are from General Board file (430 of 1916).

the mount. Mod 1 had external control via a Mk 68 fire control system, and Mod 2 was a proposed production system. About 5000lb.

Mark 81
Three-barrel XM197 Gatling gun for surface defense, manually operated, under the 'Hip-Pocket II' program; 1200lb, 1972-73, firing 600 or 1200 rounds 20mm per minute.

Mark 82
M60 machine gun for 40ft plane personnel and rescue boats.

Mark 83
Unmanned mount for GAU-8/A seven-barrel, 30mm Gatling gun, 8200lb with a weather shield, carrying 1350 rounds. Originally a GE private venture, but given Navy funds in 1976.

Mark 84
Modified version of existing mount for 20mm lightweight Gatling gun (M197), capable of accepting several gun types from 7.62mm to 40mm grenade; with the 20mm weapon it could fire 750 rounds per minute to 3000yds. It was developed for the 65ft Patrol Boat Mark 3, and weighs about 1000lb. Mount, Universal Gun System (1977).

I-4B Armor penetration

Gun	MV (ft/sec)	Shell (lb)	Side armor (in)								Deck armor (in)						Remarks
Major caliber			8	10	12	14	16	18	20	22	1.5	2	4	6	8	10	
12in/50	2900	870	24	20							13.5	17	28.5	34			Arkansas
12in/50	2500	1140	33	26.5	21.5	17	13.5					14	24	31.5	36		Alaska
14in/45	2700	1400	30.5	24.5	20.3	16.8					10	13.7	25.4	32.5			
14in/50	2800	1400	31	24.5	21.5	18.8					10.3	14.3	26	33			
14in/50	2700	1500	36.9	30.3	25	20.5	16.5	12.1				14.8	25	32.6	38		
14in/45	2600	1500	34.3	28.3	23.4	18.8	14.8	11.5				13.5	24.5	31.5	36.3		
16in/45	2600	2100	37	30.5	25	21.5	18				7.5	11.5	22.5	29.8	34.5		
16in/45	2520	2240		35.5	29.5	24.5	20.3	16.8					22	28.2	34.5	38.5	
16in/45	2300	2700		36.4	31.6	27.2	23	19.5	15.6				18.8	25.6	31	34.4	New battleships
16in/50	2800	2100		33	26	22.2	19				8	12	23.5	30.5			
16in/50	2500	2700		42.2	38	32.8	28.2	24	20.2	16.6			20.5	28	33.6	38	Iowa
Minor caliber																	
			2	3	4	5	6	8	10		1.0	1.5	2	3	4		
4in/50	2900		6.3	3.7							18.3						
5in/38	2600	54	11	7.4	5.4	4					13.8						
5in/51	3150		8	5.2	3.2						19.6						
6in/47	2800	105	24	16.2	12.6	10.2	8.2				14.8	18.6	22	26.6			
6in/53	3000	105	13.8	9.0	6.3						17.2	20.8	23.6				3.8-caliber shell
(common shells)			17.0	12.2	8.2						19.4	22.6					4.5-caliber shell, for submarines
8in/55	2800	260		29.6	23.6	19.5	16.6	12.4	9		13.5	17.6	21.2	26.4	30.2		
8in/55	2465	335			28.6	24.4	20.8	15.4	10.8				18.4	23.8	27.6		

Guns penetrate *side* armor of a given thickness at all ranges below that given, and *deck* armor at all ranges *greater* than that given. For example, a ship with a 12in belt and a 4in deck would not be penetrated by a 12in/50 gun (as in the *Alaska* class) between 21,500 and 24,000yds; however, she would be immune to the earlier 12in/50 between 16,000 and 28,500yds. Such a ship would have no immunity at all against the 16in/45 (2100lb shell), which could penetrate her side armor at all ranges up through 25,000yds, and her deck at all ranges *below* 22,500yds. Sloping belt armor increased its effective thickness.

These figures are taken from armor penetration curves published in January 1942. Under side and deck armor thicknesses are given ranges at which a given thickness could be penetrated, in thousands of yards.



II-1 Airborne radars

In these notes, kW are kilowatts of peak power, PRF is pulse repetition frequency per second (which determines maximum unambiguous range of the radar, although *not* effective range on a given target). Beam-widths are horizontal except as indicated. For the shipboard radars and their associated electronic systems, which had at least an equal impact on fleet air defense, see the companion volume, *Naval Radar* (Conway Maritime Press and US Naval Institute Press, 1981).

AS series (wartime air search radar)

ASA
75cm surface search radar and altimeter for patrol planes, not widely used; developed by RCA, using a pair of yagi antennas with lobe-

switching for accuracy. A total of 303 were delivered for US and British use. Peak power was 15kW (2-microsecond pulses at 1020 pulses per second) permitting detection of a large ship at 55nm, or a submarine at 7; the beam was 60° wide, with a bearing accuracy of 2°.

ASB
Surface search radar light enough for carrier aircraft, the midwar workhorse of the carrier Navy, over 20,000 being built by RCA, Bendix and Westinghouse from May 1942 onwards; developed by NRL. It operated at 60cm, using a pair of yagi antennas fixed in azimuth to generate a 60° beam (peak power 5kW, PRF 400, 2-microsecond pulses) and could detect a battleship at 40nm or a submarine at 5; lobe-switching gave a directional accuracy of 1°. It was replaced by microwave radars such as APS-4.

ASC
S-band (10cm) surface search radar for

bombers, also designated (Army) SCR-517B. A modified version was used as an interim search radar for PCs and PT-boats. The antenna was a dipole in a 29in paraboloid, producing a 9° × 9° beam. About 1800 were delivered in all. Peak power was 100kW (1-microsecond pulses, PRF 800) which sufficed to detect a large ship at 70nm and a submarine at 18, with a bearing accuracy of 3°. Together with ASG it was one of the first US microwave radars. Western Electric.

ASD (APS-3)
X-band (3cm) surface search radar for smaller patrol and carrier aircraft, credited with the success of the Aleutians operation in 1943. It was developed by Philco and produced by Sperry and Philco, using a dipole in an 18in paraboloidal antenna, for a 5-7° beam (6-20kW, 0.5 and 1.0 microseconds, PRF 1300); a large ship could be detected at 50nm and a submarine at 10, although a range of about 30nm (large destroyer or small cruiser) was considered more typical.

ASE

US equivalent of the original British ASV radar, too heavy for carrier aircraft (which used ASB instead); the Army called it SCR-521 and it was based on the British ASV Mk II, operating at 170cm (176mc) with 8kW pulses (1.7 microseconds, PRF 400), for a range of about 40nm on a large ship, or 5 on a submarine. There were two yagi antennas, with lobe-switching 30 times per second, for a bearing accuracy of 3°. A total of 2212 was delivered by Philco, with another 2624, designated ASVC, by REL.

ASG (APS-2)

Large (patrol) aircraft or blimp surface search radar, operating at 10cm (S-band), with a dipole in a 30in paraboloid (9.5° beam) at 50kW (1-microsecond pulses, PRF 650) to detect a large ship at 60nm (destroyer at 50, compared to 25 for ASD) or a submarine at 3; it was installed, for example, aboard PBM-3s and PB4Ys. Philco.

ASH (APS-4)

Carrier bomber radar, slung underneath in a bomb-like nacelle, produced by Western Electric. It operated at X-band (3cm) with a 14in parabolic antenna, for a 6° beam; peak power of 35kW (0.6-microsecond pulses, PRF 1000 or 600) permitted detection of a large ship at 50nm, a submarine at 15, a fighter at 3nm and a bomber at 5. Deliveries totaled 3100 (Westinghouse).

APS Series (Search Radar)**APS-6**

Principal wartime carrier night fighter radar, ultimately replaced by APS-19 postwar; developed by Westinghouse on the basis of the experimental Sperry AIA, operating at X-band (40kW, 1.0 or 0.5 microseconds, PRF 1000 or 2000) with a conically scanned 17in paraboloid antenna (5° beam); it could detect a fighter at 7000yds or a bomber at 8000, and could track to 1000yds; angular accuracy, with the scan rate of 1200rpm, was 1/2°. Deliveries totaled 2160 (Westinghouse).

APS-15 (H2X)

The principal US late-war large-airplane surface search radar, used extensively for snorkel detection in 1944-45 from such aircraft as Privateers and Liberators. It was produced by Sperry and Philco, and had two alternative antennas: a pencil beam for low altitude and a cosecant-squared beam for high altitude, the former most useful in high sea states (3°-wide beam at X-band); 20kW pulses (1.0 and 0.5 microseconds, PRF 500 and 1000) allowed detection of a large ship at 70nm, a cargo ship at 60, and a surfaced submarine at 10, with a bearing accuracy of 3°. However, at an optimum search altitude of 500ft, the postwar APS-15A (24kW, 40in antenna, in PBM-5S and P4Y-4S) had a sweep width of only 5-7nm against a snorkel in Sea State 0-1; in Sea State 2-3 it was only 2nm; these figures compared to 2.1 and 0.6nm for the APS-3A (PBY and PV-2 aircraft) and 4-5nm and 1nm for APS-4 (TBM-3S). Scan rate was 12 or 24rpm.

APS-18

First AEW data link (ASB radar); 30 produced, 1943 (NRL development).

APS-19

The postwar successor to APS-6 as the standard US Navy single-seat night fighter radar, carried in a wing nacelle by the F4U-5N Corsair and internally in the F7F-4N Tigercat and, as an alternative to the later APQ-36A, in the F2H-2N Banshee. It was about half the weight of the earlier set, and was later described as the first reliable fighter set, with a detection range of 6-10nm (compared to 4 for APS-6). It operated at X-band (40kW, 1.5- or 0.5-microsecond pulses for search, 0.25 for intercept and gun aiming, with corresponding PRFs of 660, 2000 and 4000, the latter corresponding to a range of about 1500yds).

APS-20

'Cadillac' airborne early warning radar, just reaching operational units at the end of World War Two, with a data link transmitting its PPI picture down to a surface ship. It was widely used postwar as a snorkel detector (search radar) for ASW aircraft, with a sweep width against a snorkel of 60nm in Sea States 0-1, 35nm in Sea State 2, 17nm in Sea State 3, and 10 in Sea State 4, at altitudes of, respectively, 5000, 2000-4000, 1000 and 1000ft. Corresponding widths against surfaced submarines were 125, 125, 85 and 75nm (in each case these are twice effective detection range). Against larger surface ships, radar range was about the radar horizon, 38.5nm at 1000ft, or 87nm at 5000ft. Aircraft could be detected at much greater ranges, and 'Cadillac' was originally prized as a detector of low fliers invisible to shipborne radars. There were two different antennas, an 8ft (3.5° beam) type for carrier aircraft and Neptunes, and a 20ft (1.6° beam) type for land-based early warning aircraft such as Warning Stars, and power gradually rose from 750kW in the first versions carried by converted Avengers (2 microseconds, 300 pulses per second, scanning at 2, 6 or 15rpm to 1MW and then to 2MW in late models of the large-plane system (which could scan only at 2 or 6rpm). Typical ranges on a standard air target were calculated as 115nm for the large, high-powered APS-20E, 80nm for a 2MW transmitter but smaller antenna, and 40nm for the original system, which suggests the extent of growth over time. It was superseded in naval service by the APS-82 of the Grumman E-1B Tracer. General Electric.

APS-21

Postwar large-fighter radar, developed in parallel with APS-19, and forming part of APQ-35.

APS-31, -33

ASW attack and search/attack radars, both using the same electronics but with different antennas; APS-31 was installed aboard aircraft such as the PBM-5A, P2V-4, AF-2S Guardian (wing antenna), and the AD-4N Skyraider (nacelle). APS-33 was intended for larger aircraft (P2V-2 and P2V-3 Neptunes and P4M-1 Mercator, in belly radomes). Antennas were stabilized in tilt so that signals would not be lost as an airplane climbed, dove or maneuvered; they produced, respectively, a 6° pencil beam (small wing nacelle antenna) and a 3.6° fan beam (large search antenna), with 60° (and, in APS-31, 150°) sector scan; APS-33 could scan over 360° from its belly position. Maximum range was 200nm, minimum 200yds (52kW, X-band, 0.5- and 5-microsecond pulses), and

sweep widths against a surfaced submarine and a snorkel were (APS-31) 60 and 11nm in Sea State 0-1, 60 and 8 in Sea State 2, 40 and 3.5 in Sea State 3, and 40 and 1.5 in Sea State 4, at altitudes of, respectively, 1000, 700, 500 and 500ft. For the APS-33 search radar, corresponding sweep widths were 65/20, 65/14, 50/10 and 50/2nm at altitudes of 1500, 1000, 700 and 700ft. APS-31 was a stabilized version of an earlier radar, APS-30, which could accept bombing calculations for fire control; it was a late-war replacement for APS-3 and -15, operating on two very different bands by means of interchanging a single component. It was lighter and more reliable, with greater range and accuracy. APS-35 used a larger antenna (than -33), shorter pulses (0.25 microseconds) at higher power (70kW), with an unstabilized pencil beam scanning at 8rpm; it was not stabilized. APS-32 and -34 were, respectively, K-band equivalents of -31 and -33; they were not placed in production. K-band operation dictated lower power (22kW) and a shorter maximum range (60nm). Philco.

APS-38

Periscope and snorkel detection radar for the Grumman S2F-1 Tracker, operating at X-band (50kW, 0.5-, 2.5- and 4.5-microsecond pulses at PRFs of 800, 400 and 200) using a 28in antenna scanning at 8 or 24rpm (or sector-scanning). It was succeeded, in the S-2D and -2E, by APS-88. It superseded the proposed APS-37, which was an APS-33A modified for carrier operation. Philco.

APS-44

Snorkel search radar for the Martin P5M seaplane, operating in both X- and S-bands (1° × 2.6° and 1.8° × 4.8° beams respectively, at 500kW and 1MW respectively, with 3.2-microsecond pulses at both wavelengths, and 0.5-microsecond pulses at X-band as well). It used an 8ft × 3ft antenna, scanned over a 160° sector looking forward, and in 1952 estimated sweep widths against a snorkel were 120nm in Sea State 0-1 and 89nm in Sea State 2; scan rate was 3, 6 or 12rpm. In an alternative version it could be mounted in a 360° belly radome. Display was a high-brilliance scope with a book-type scan. Philco.

APS-45

Airborne early warning height-finder, an X-band 'orange peel' typically mounted in a fin radome atop a Lockheed Warning Star (converted Constellation), operating in conjunction with the belly APS-20. Maximum instrumented range was 120nm (minimum 1.5nm). Typical scan rate in azimuth was 1rpm and in elevation 15°/sec between +11° and -5° or within any 5° sector. Pulse width was 1.8 microseconds, accuracy 2 miles in range and 2° in azimuth on azimuth dial (4 on PPI), and elevation to within ± 250ft ± 20ft per range mile. Peak power was about 450kW. Philco (APS-45A by Texas Instruments).

APS-62

Height-finder for airborne early warning airship, with an effective range of 200nm and altitude limits of +56,000ft and -4000ft with respect to the airship; it operated at X-band (425kW, 1.8-microsecond pulses, PRF 300) with a 3.1° × 1° beam. Lavoie Laboratories (1956).

APS-67

Radar for the F8U-2 Crusader fighter, providing very limited all-weather capability (16nm); it was replaced in the F8U-2N by APQ-83 with about a 25 percent range improvement. It operated at X-band (43kW, 0.7-microsecond pulses, PRF 1200), and the 14.5in dish antenna gave a 7° beam scanning a maximum sector of 90° in azimuth and 14° in elevation, at 30 scans per second.

APS-70

Improved airborne early warning, considered for a time as a destroyer radar. Peak power was 2MW (6-microsecond pulses at PRF 300), for greater range and less sea return than earlier types. Beam-width was 9.5° × 20° (30ft × 6ft antenna, or 24ft × 2ft for carrier use), scanning at 6rpm, and range was 200nm at 25,000ft. It was the first UHF airborne early warning radar, operating at 425mc and requiring, in consequence, a massive antenna; even so, it had a relatively broad beam, and in this sense it was a predecessor of APS-96 and -120 (E-2 Hawkeye systems). For ZPG-3W airship and WV-2 Warning Star; 40 percent range improvement. General Electric, 1957. Experience with this radar led directly to the development of APS-96/120.

APS-80

ASW radar system of the Lockheed P-3A Orion, replaced in more recent versions by APS-115. It operates at X-band (143kW, 2.35-microsecond pulses, PRF 400) and the 42in × 24in antenna produces a variety of beams, all 2.4° wide: a 3.6° beam and an 18° cosecant-squared fan beam. Coverage is 45° in azimuth (to either side) and -20° and +10° in elevation, and scan rate is 6rpm or 48 scans per minute in sector scan. Calculated range on a 1m² target is 48nm. Texas Instruments.

APS-82

S-band airborne early warning radar of the Grumman E-1B Tracer, operating at 1MW (2-microsecond pulses, PRF 300); the 17.5ft wide antenna produced a 1.5° × 6° beam (4ft deep) scanned horizontally at 6rpm and vertically at 1rpm to achieve both search and limited height-finding in a single system. It could also sector-scan at 10 scans per minute. Range on a standard air target was 119nm (1m²) vs 115nm on the large APS-20E or 80nm on APS-20F (8ft antenna); in effect, then, APS-82 achieved the performance of the land-based airborne early warning aircraft in a carrier-compatible configuration. It was superseded by the APS-96/120/125 series of the later Grumman E-2 Hawkeye.

APS-87

Similar to APS-82 but with a klystron for improved frequency stability, to permit aircraft to operate in close proximity. It was not produced (1957).

APS-88

Improved antisnorkel radar, superseding APS-38 on Grumman S-2D/E Trackers, and superseded in turn by the APS-116 of the S-3A. It operated in X-band (45kW with 0.35-, 0.8- and 4.5-microsecond pulses at PRFs of 2000, 1025 and 200); the 42in × 20in antenna produced a 2.6° × 5° (or 18° cosecant-squared) beam which scanned at 6 or 28rpm, or at 36 sector scans per second. Calculated range on a 1m²

target was 36nm. Texas Instruments.

APS-96

UHF airborne early warning radar of the Grumman E-2 series, operating at 425mc (1MW) with a large rotodome (24ft × 2.5ft enclosure) antenna; the use of a rotating dome reduces beam distortion, encountered in earlier radars as the moving beam passed through a fixed radome. The rotodome also carries the radar clear of the aircraft structure. There were several major innovations: pulse compression, as in contemporary destroyer and carrier radars, to achieve fine resolution and high effective power level, improved clutter rejection, a new moving target indicator, and a form of monopulse height-finding. APS-96 was the first high-altitude Navy airborne early warning radar, and it could take advantage of the fact that there were always two paths between it and a target: direct and sea-reflected. Since the signal could travel direct one way and be reflected the other, there would always be three echoes per target; pulse compression allowed them to be distinguished, and the difference in their apparent ranges was used to measure target altitude. The antenna within the rotodome was an array of yagis. APS-96 was originally developed as a result of the success of the APS-70 installed in the ZPG-2W airship, about 1955; it appeared in 1960. Ranges as great as 250nm are claimed. General Electric.

APS-115

Improved X-band sea search radar for the P-3C Orion, with nose and tail antennas to achieve 360° coverage. Peak power is 143kW with long-pulse (2.5 microseconds, PRF 400, scan rate 6rpm) and short-pulse (0.5 microseconds, PRF 1600, scan at 12rpm) modes; the antenna is 42in, for a 2.4° × 3.6° beam. It can also scan a 45° sector, and has manual tilt positioning over -20° to +10°. Total weight is 523lb. Operational from 1969 onwards. Texas Instruments.

APS-116

X-band sea search radar for the S-3A: it achieves high resolution through pulse compression, scans rapidly (at 6 or 300rpm) and employs scan-to-scan integration to overcome sea clutter in high sea states. There are three modes: search (high PRF of 2000, pulse compression, fast scan); navigation (low PRF of 500, pulse compression, frequency agility, slow scan); and long range (low PRF, pulse compression, slow scan). Peak power is 500kW, pulse width 0.5 microseconds (compressed to 3 nanoseconds); the 24in × 42in antenna produces a 2.4° × 4° beam. Range resolution is approximately 1.5ft with pulse compression, and total weight amounts to 360lb. Nose radome. Texas Instruments.

APS-117, -118

ARM target identification and acquisition systems for, respectively, Shrike and Standard ARM.

APS-120, -125

Modified successors to APS-96, for the E-2C, and descended from the experimental APS-111 of the E-2B; this had improved clutter rejection for overland operation, including special circuits to cancel out clutter frequency-shifted by aircraft operation, which would have interfered with both moving target indication

and pulse compression. There were also new techniques for side-lobe suppression. Two were tested in 1964-68, and APS-120 incorporates these improvements, as well as an automatic detector, linking the radar to the tracking and intercept computer. In effect, then, this is the airborne equivalent of Navy Automatic Detection and Tracking (ADT) radars. There is also a new transmitter with greater stability and reliability. The computer operates to achieve a constant false-alarm rate (CFAR) and sorts target returns before presenting them to the intercept operators. ARPS (Advanced Radar Processing Sub-System) again improves sensitivity and incorporates anticlutter and ECCM improvements for fully automatic overland capability. APS-125, which succeeded APS-120 in production in 1976, adds a digital rather than analog MTI (Moving Target Indicator) to ARPS. ARPS was first tested in December 1972, and existing APS-120s are being retrofitted to APS-125 standard (from 1977 on). General Electric.

APS-124

LAMPS III X-band (350kW) helicopter sea search radar, employing scan-to-scan integration and fast scanning to overcome sea clutter in periscope search. Selection of scan speed (6, 12 or 120rpm) automatically adjusts PRF, pulse width and receiver band width for optimum scan-to-scan integration. The short-pulse (0.5 microseconds, 120rpm) mode is for weather, the long-pulse (2 microseconds, 6rpm, or 1 microsecond, 12rpm) for long-range detection and mapping. PRFs are, respectively, 1885, 940 and 470. The antenna is a 72in × 12in planar array (1.2° × 20° beam), and total weight 163.5lb. Estimated range on a 1m² target is 16nm (20 for APS-115, -116). Texas Instruments.

APS-127

Texas Instruments X-band surface search set (2.0- or 0.5- microsecond pulses, PRF 400 or 1600, 200kW, 2ft × 2.6ft planar array antenna, 5° × 6° beam, scanning at 12 or 120rpm). Gross weight is 295lb and calculated range on a 1m² target 18nm.

APG Series (Fire Control Radar)**APG-4**

Carrier bombing radar ('sniffer') designed to compensate for relative speed in line of flight and for altitude at six preselected altitudes. It employed dipole arrays similar to those of ASB, mounted half a wavelength from the wing proper, and could detect a destroyer at 1nm, operating at FM rather than in a pulse mode (73cm, or 410mc). The APG-6 'super sniffer' employed three half-wave dipoles (58cm) to drop a bomb automatically at low altitude; it could detect a battleship at 5nm. Both were developed by RCA for the Navy.

APG-6

See APG-4.

APG-30

Range-only radar for postwar fighter gunnery, in such aircraft as the Panther and the Fury. It was an X-band horn, not scanning in any way, producing a 19° beam (4in × 6in) at 5kW (0.3-0.55 microseconds, PRF 800). APG-45 was a miniaturized version for patrol aircraft turrets. General Electric.

APG-37

Hughes X-band fire control radar for F2H-4 Banshee night fighters; F2H-3 had APQ-41. It could operate in search, track or beacon modes, always at a peak power of 200kW, with a $4^\circ \times 4^\circ$ beam. Search mode employed a 2.4-microsecond pulse (PRF 415); beacon mode used the same pulse at a PRF of 330, whilst track used a 0.5-microsecond pulse (for greater accuracy) at a PRF of 910 (for a higher probability of accurate detection). Scan patterns were two-line Palmer scans over $140^\circ \times 13^\circ$ (17 scans per minute) and over $80^\circ \times 13^\circ$ (30 scans per minute); and a 3° conical scan for tracking at 75 cycles per second. It was part of the E-10 (Air Force-developed) fire control system, the first with good stabilization and with lock-on at 12-15nm (detection at 18-25nm). Descendants included the systems of the F4D, F-4B and F-4J.

APG-45

See APG-30.

APG-51

Hughes all-weather fighter radar (X-band, 250kW) in the F3H-2N Demon (F-3C), connected to a Navy version of the Air Force E-10 fire control system. When modified for Sparrow missile operation it was superseded by APQ-51 (F3H-2M, or MF-3B Demon). It used a 22in antenna, had an effective range of 13nm, and was used for Sparrow I guidance.

APG-53

Attack radar of the A4D-2N Skyhawk, providing it with limited all-weather capability (search and terrain avoidance); it was a two-lobe monopulse radar with a 5° conical beam, operating in three modes: air-to-ground, terrain clearance, and search. Maximum air-to-ground range was 15,000yds (X-band, 7kW, 0.35-microsecond pulses, PRFs 3000 and 1500). Sector coverage was 60° in azimuth, and elevation manually adjustable (followed boresight) between $+20^\circ$ and -15° . APG-53 adds three new modes: television, Shrike, and typical display. Naval Avionics Facility.

APG-59

First operational pulse-doppler fighter radar and first look-down capability, as part of the AWG-10 weapon control system of the F-4J fighter; AWG-11 and -12 were British counterparts, for the F-4K and F-4M Phantom. It provided both pulse doppler and pure pulse (noncoherent) radar modes as well as CW illumination for the Sparrow III air-to-air missile. Total volume was about 15ft^3 , weight about 1200lb, compared to a similar volume and less than half the weight for the APQ-50 of the F4D Skyray. Average power was 1kW, duty cycle was 44 percent, and the 32in dish produced a $8^\circ \times 120^\circ$ beam, detecting a 5m^2 target at 60nm. Approximate weight was 1040lb. Westinghouse.

APG-65

Air intercept radar of the F-18 Hornet, a digital pulse-doppler type with a programmable signal processor. Modes are high-PRF velocity search; range-while-search (high/medium PRF); track-while-scan (can maintain 10 tracks and display 8); single target track; gun direction; HUD, boresight, and vertical acquisition with automatic lock-on; raid assessment, terrain avoidance; ground target track; sea surface

search; air-to-ground ranging; long-range real-beam ground mapping; dropper beam-sharpened patch; doppler beam-sharpened sector; and precision velocity update. The radar is effective in the look-down shoot-down mode. The programmable processor is unique; for example, in the APG-63 of the Air Force F-15, which introduced the digital signal processor to tactical fighter radars, the logic was hard-wired. In the APG-65, doppler filter and range-gate configurations are defined by a program which can be modified with relative ease. In the attack mode, a pilot can designate a ground target or a landmark on his radar, then turn it off and use his inertial system to steer him to the target. There are three air-to-air combat modes: an acquisition mode in which the radar scans the entire volume defined by the head-up display and locks onto the first target it encounters; a narrow-width vertical scanning mode; and a boresight acquisition mode in which the pilot points his aircraft at the target. In the raid assessment mode, the pilot can expand the display of the area of a single target to achieve higher resolution. The special gun director mode uses pulse-to-pulse frequency agility to reduce target scintillation, tracking the target with extreme accuracy for gun engagement. As in the AWG-9 system, the longest-range search mode is velocity search, with a high PRF which provides only velocity and bearing data. In the range-while-search mode, high and medium PRF waveforms are interleaved; the high-PRF waveform provides some range data (FM ranging) while the medium-PRF waveform permits the use of range-gate processing for range data. Track-while-scan is the shortest-range search mode. Single target tracking uses monopulse angle tracking logic and can extrapolate target position during 180° turns and split-S maneuvers by the target; it employs a special high-PRF waveform for Sparrow (AIM-7F) guidance. In the air-to-surface mode, doppler beam sharpening achieves a 19:1 effect in sector scan, and a 67:1 improvement in sharpness in a patch mode. The entire system weighs 340lb (exclusive of rack) and occupies less than 4.5ft^3 , including its antenna; by way of comparison, the APG-63 of the F-15 weighs 483lb and occupies less than 9ft^3 , exclusive of the antenna. High reliability was required in the design, with a guaranteed mean time between failure (MTBF) of 106 hours. Digital operation greatly reduces adjustment in the field, and Hughes claims that built-in test equipment can detect 98 percent of all faults and can isolate them to a single weapon replaceable assembly (WRA) 99 percent of the time; a WRA can be replaced and the radar restored to operational condition in 12 minutes. Texas Instruments.

APQ Series (Multipurpose Radar)**APQ-5**

Bombing radar for patrol aircraft, replaced by APA-5 (Farnsworth) for all Navy patrol planes, and in the last year of the war by the lightweight APA-16 (Western Electric), both operating with the basic aircraft radar. APQ-5 was similar in that respect, acting as a specialized indicator. APQ-5B used a preset release bombing technique, but -5C was fully integrated with the Norden bomb sight (NOSMO) allowing a fully synchronous solution of the bombing problem by the sight, which could be converted to electrical information; it also

incorporated doppler drift attachments, permitting the determination of the true ground track and drift of an aircraft.

APQ-35

Airborne installation of the F3D Skynight, consisting of a search radar (APS-21), a fire control radar (APG-26B), and a tail warning radar (APS-28), all operating at X-band; it was the first lock-on night fighter system (4nm) and could detect targets effectively at 18-25nm; instrumented search range limit was 52nm. Output was, respectively, 200kW, 50kW and 35kW, with 0.4-microsecond pulses for search, beacon and gun-aiming (2400-2500 per second) or 1.75-microsecond pulses for search and beacon operation (PRF 550), or 2.25-microsecond pulses for beacon only (PRF 300); for tail warning, the figures were 0.5 microseconds at a PRF of 2000. Typical performance included detection of a medium cargo ship (broadside) at 60nm, and of a medium bomber at 25nm, with a fighter at 15nm. Maximum gun-aiming range was 4000yds, with future range computed at 2000 and a minimum of 150, based on a medium bomber as target; for tail warning (head-on fighter), maximum range was 4nm. Westinghouse.

APQ-36

Airborne intercept radar for F2H-2N and F3D-2 Skynight night fighters, essentially an APQ-35 without the tail warning radar. This radar was originally proposed for Sparrow guidance, but was rejected in favor of APQ-51; both were semiautomatic all-weather radars. Sperry.

APQ-41

Airborne intercept radar for the F2H-3 night fighter, originally specified for the F3H-1 Demon as well; it was derived from the APS-21/APG-26 combination of the earlier APQ-35, and could search or track, with an effective search range of 24nm and lock-on out to that range. Maximum reliable gun-aim prediction was at 2000yds, consistent with normal gun ranges; it could track to within an accuracy of 25yds between 200 and 2000, and could scan a 69° cone about the airplane, searching (at longer range) within $\pm 53^\circ$ in azimuth and 13° in elevation (centered about a position within 30° above or below the airplane). It operated at X-band at 250kW (0.5-microsecond pulses at PRF 2000 or, as a beacon, with an effective range of 200nm, 2.35-microsecond pulses at a PRF of 300). Westinghouse. APQ-65 was a modified version for the French Navy's Aquilon fighter (1954).

APQ-50

In 1959 this was the most powerful operational Navy airborne radar, carried by the Douglas F4D and by the F3H-1 Demon, and it was initially specified for the new F4H (later F-4A) Phantom; the APQ-72 actually adopted for the F-4B was a version modified to operate Sparrow III missiles. It used the first complex airborne computer system; to achieve detection at 25-40nm, and permitted blind attacks in conjunction with the Aero-5B fire control system. In the F4D it was associated with the Aero-13 system, and Westinghouse described it as the first radar fitting into a cylindrical package for convenient installation; it could lock-on at up to 14.2nm. It operated at X-band (1.75 microsecond pulses at 150kW, 0.5-

second pulses at 180kW) and could track at up to 15°/sec with an accuracy of 8yds between 200 and 2000, with scan limits (search) of 106° or (narrow mode) 30° positionable within 35° of the aircraft centerline. It used a 24in dish. Westinghouse.

APQ-51

Control radar for Sparrow I missiles in Cutlass and early Demon fighters, providing both tracking and beam-riding guidance pulses, with one guidance pulse sent in each quadrant of the radar's conical scan, stabilized by the aircraft gyroscope. Effective missile range was 200–12,000yds, gun range 200–5000yds (for radar, not weapons) with a range tracking rate of up to 400yds/sec and a power output of 250kW (0.42-microsecond tracking pulses at PRF 1200; 0.66-microsecond guidance pulses at PRF 200) using a 4° X-band beam. Target acquisition was achieved at up to 12nm. Sperry.

APQ-64

APQ-50 modified to control Sparrow II missiles, for the abortive Douglas F5D Skylance, in the Aero X-24A system; it could search at up to 25nm, lock-on at 24, and weighed 675lb (*vs* 478lb for the Aero-13 installation in the F4D). Westinghouse.

APQ-67

Non-pulsed doppler backup for the development of pulse-doppler radars such as APG-59.

APQ-72

Primary F-4B Phantom fighter radar, controlling Sparrow III missiles, and directly descended from APQ-50; it could detect targets at over 50nm. APQ-72B added Sidewinder Extended Acquisition Mode (SEAM); a display was added to the radar set to provide the pilot with a fixed SEAM-allowable steering-error circle and a SEAM aim dot indicating missile head position when the missile was locked onto a target; this informed the pilot as to which target the missile was tracking, so that he could discriminate between friendly and hostile targets in the event both were in the same area, and also aided him in determining when the target was within missile launch envelope. It was X-band (153kW, 0.4–2.0-microsecond pulses, PRF 1060, 330 or 500), and the beam, 3° × 3°, scanned over 60° × 60° at 120°/sec. APQ-74 was similar, and the following data refer to it: X-band operation, 135kW with 0.5-microsecond pulses (PRF 1200, for 12 and 14nm range and tracking) or 1.75-microsecond pulses (PRF 330 at 200nm, PRF 550 at 12, 24 and 100nm scales); lock-on memory time was at least 4 seconds, and the range gate could scan a 2000yd interval in 0.6–1.4 seconds. For wide scan there were two lines, each 92° wide in the horizontal plane with a vertical separation of 3° and adjustable through 51° up and 31° down, in 1.6–2.4 seconds; narrow scan (30° wide) was complete in a similar time interval. The entire pattern was stabilized against climb, dive and roll. There was also CW injection for the Sparrow III missile, and the radar dish had a 28in diameter. Westinghouse.

APQ-81

The first major US airborne pulse-doppler radar, developed by Westinghouse for the abortive Eagle/Missileer project, and related

to Westinghouse work on the C-band version of the SPG-55 shipboard Terrier guidance radar. It was to have operated at C-band, for long range, with a peak power of 20kW and an average power of 2kW (PRF set at 56,800–69,500, with a pulse-width of about 1.4 microseconds). The 60in dish sufficed to achieve a beam-width of 2.7°, for high accuracy at extreme range, and the search sector was set at 33° in azimuth and 5° in elevation. In theory it was to be able to achieve a 0.9 cumulative probability of detection at 120nm (velocity detection) and full range tracking against 16 targets simultaneously (track-while-scan) at 80nm. These figures referred to a 'service environment', presumably including ECM. Development at Westinghouse began in December 1958, and it is not clear whether any model actually flew; A3Ds were to have been used as the test platforms.

APQ-83

Air intercept radar for the F8U-2N Crusader limited night fighter, modified to incorporate SEAM. Compared to APS-67, it had more power (160kW) but appears to have used the same size antenna and similar pulses and PRF. It could scan a vertical sector at 30 or 144 scans per second, over a range from –30° to +45°. Estimated range on a 1m² target was 20nm. Magnavox.

APQ-92

A-6A search and attack radar, sharing the antenna of the APQ-112 target tracker: it has air-to-air and air-to-surface search/target acquisition, mapping, terrain clearance, and air-to-ground ranging modes. Scanning is mechanical, but a high data rate is achieved by use of a phased interferometer which eliminates the need for scanning in elevation; it produces a fan of between 35° and 50°, which replaces the usual raster scan of a pencil beam. Since its introduction, improvements have included incorporation of some APQ-112 subsystems, to permit APQ-92 to track in three axes. It is being replaced by APQ-148/156. Norden.

APQ-94

F8U-2N (F-8E) Crusader air intercept radar with Sidewinder semiactive missile capability; it incorporated some APQ-82 components. Search range on a bomber was 60nm, with lock-on at 40nm. It appears to have been essentially an APQ-83 with a new 20in dish (4.5° rather than 6.5° beam), with auxiliary track on jam and IR slave modes. Magnavox.

APQ-112

A-6A target-tracking radar; it shares the APQ-92 aperture, and development efforts have been directed at its elimination as a distinct system. Norden.

APQ-116

A-7B nose radar, operating at Ku-band and at 60kW, with a 12in × 20in antenna (2.5° × 5° beam). Texas Instruments.

APQ-124

F-8J fighter radar by Magnavox; it corresponded to APQ-94 but was lighter and had a greater output, 200 rather than 160kW.

APQ-126

Nose radar for A-7E (and for the Air Force

A-7D). Compared to the earlier APQ-116, it added a third pulse mode (2 microseconds, as well as the earlier 0.2- and 1-microsecond modes; PRFs were, respectively, 360, 720 and 3600) and used a slightly larger antenna, 19.5in × 13in (2.5° × 18.4° beam), in each case with rapid scanning for high ground definition. There is a terrain avoidance mode, in addition to ground ranging, ground mapping for navigation or blind bombing. Angle coverage is 45° horizontal and –30° to +70° vertical, and scan rates are 90°, 120° and 180°/sec (horizontal) and 150°/sec (vertical). The antenna, plus receiver, weighs 45lb, for a total system weight of 230lb. Seven frequencies can be selected in flight over a 600mc/s band, and frequency agility (30mc/s range at 100cps) is used to improve ranging accuracy and to achieve long-range target detection. APQ-139 is a later version with AMTI. Texas Instruments.

APQ-148/156

Norden replacement for former A-6 radars, APQ-92/112; APQ-156 is APQ-148 plus TRAM, the Target Recognition and Attack Multisensor system, incorporating a forward-looking infrared television (FLIR) and a laser. It has track-while-scan capability in both versions; target elevation is obtained from a separate phase interferometer carried beneath the conventional fan-beam radar antenna. The former consists of two rows of 32 horns each, moving with the main dish in azimuth; time differences of arrival are used to calculate elevation angle. The interferometer produces a continuous elevation-range profile of approaching terrain for terrain avoidance, as well as target elevation. Norden received a contract to convert existing APQ-92 radars to track-while-scan operation in August 1969; a contract for the full APQ-148 followed the next year, with a contract for a new Airborne Moving Target Indicator (AMTI) in 1978.

AN/ASB* Series (Bomb Director Radar)

ASB-1

Bombing radar system used on early US strategic attack carrier bombers, from the North American AJ through the Douglas A3D. It operated as a ground mapper, furnishing current ground position in latitude and longitude on the ground position indicator, and permitting radar and optical search. In addition, it operated as a switch, automatically opening bomb-bay doors and releasing bombs at the appropriate time. It used a 52kW X-band radar, searching with 0.75-microsecond pulses at PRF 800 at 0–60nm, or 3-microsecond pulses at PRF 300 at 60–200nm; tracking with 0.25-microsecond pulses at PRF 2400 at 0–25nm; and having beacon operation with 2.25-microsecond pulses at PRF 400. Antenna pattern was a fan beam 2.5° wide. There was an expanded search mode using a 25° sector scan between 1.6 and 20nm. Norden.

ASB-7

ASB-1 with new doppler radar and computer, for A3D-2. Norden.

ASB-11

Radar-equipped doppler navigation system for the North American Vigilante (A3J, later A-

*Not to be confused with ASB radar.

5A), for all-altitude all-weather bomb delivery. It was designed to navigate the airplane from its base to the target area, automatically directing the aircraft ground track to the release point and triggering release. It provided doppler navigator position and velocity data, and radar or television sight mapping for target or check-point acquisition and position correction.

ASB-12

Radar-equipped bomb director set, including terrain avoidance and doppler mapping, for the North American A-5 Vigilante. It employed a Ku-band, 60kW radar with a 2ft parabolic antenna ($2^\circ \times 3^\circ$ beam) which could sector-scan at 60 or 120 scans per minute for ground mapping. General Electric.

ASB-19

Angle-rate bombing set for A-4M Skyhawk, including TV imaging and laser designator receiving techniques and airborne computer angle-rate bombing techniques for target acquisition, weapon selection and delivery. It includes Built-In Test Equipment (BITE). One version was designed for the AV-8B Harrier. Hughes.

AWG Series (Weapon Control Radar)

AWG-6

Aircraft Fire Control System Mark 6; continuing a series begun in 1945; for day interceptors, with APG-30 ranging radar.

AWG-9

Fire control system for very long range air-to-air (Phoenix) missiles, currently installed on the Grumman F-14 Tomcat, but developed originally for the F-111B; weight was reduced by 700lb to about 1300lb, and volume by 3ft^3 to 28ft^3 . The antenna is a 36in slotted-plate planar array, apparently with 12 (6×2) IFF dipoles on its face; it is capable of a variety of raster scan patterns, denoted by horizontal sweep width and by vertical extent in 'bars' (lines). They range from 8 bars and 65° to either side of the aircraft every 13 seconds, down to 1 bar and 10° in a quarter-second. Other azimuth limits are 20° and 40° , and search in elevation can be

1, 2, 4 or 8 bars. In another mode, vertical scan lock-on (VLS), the radar sweeps up and down in front of the aircraft in a 4.8° beam over a 40° vertical sector, which can vary from -15° to $+25^\circ$, up to $+15^\circ$ to $+55^\circ$. The radar is capable both of conventional pulse and of pulse-doppler operation, in six modes. Pulse-doppler modes are pulse-doppler search (PDS), permitting detection of a nominal 5m^2 target at 115nm; range-while-search (RWS), effective up to 90nm, giving range, range rate and angle (where PDS gives only range rate); track-while-scan (TWS), out to 90nm (forming a complete track file, and limited in search program to 2 bars/ 40° or to 4 bars/ 20° to achieve a high enough data rate); and PD single-target track (PDSTT), including both velocity tracking and jam angle tracking (JAT) modes, locking on to a single target. There is also an associated slaved mode for use with the IR tracker, permitting radar illumination of an IR target. PDSTT is comparable to the operation of the AWG-10 of an F-4J except that it can be accomplished at much greater ranges, corresponding to Phoenix missile range; 63nm is a typical figure. Pulse modes are pulse search (PS), effective out to 62nm; and pulse single-target track (PSTT) including both range and jam track modes, the former out to 49nm, a figure presumably set by the lowest available PRF. There is also a slaved pulse mode. Finally, there are three transitional modes: pilot rapid location (PRL), a pilot-initiated radar lock-on using a 2.3° beam centered along the line of sight; vertical scan lock-on; and manual rapid lock-on. Each mode is effective out to 5nm, and the radar provides range and angle tracking. The TWS mode is for Phoenix launch only, giving the radar a 2-second data rate, *ie* a limited search program. Reportedly the AWG-9 can obtain 2.5 times the range capability of the AWG-10 of the F-4J.

The following data apply to AWG-9 as originally designed for the F-111B, and as scheduled to enter service in 1967. Operation was in X-band, with an average output of 3kW (compared to 1kW for APG-59) and a 25 or 44 percent duty cycle. At a closing rate of Mach 4 against a 5m^2 target, range was 80nm (probability of detection 0.85, compared to 60nm for APG-59). Effective illuminating power was

750 or 1300W, depending upon the radar mode, compared to 440 for APG-59, and operation was, for the first time, to be digital rather than analog. System weight was given as 2000lb, compared to 1040lb for the APG-59. Hughes.

AWG-10

Pulse-doppler control system for the F-4J Phantom, using an APG-59Q radar, to provide look-down engagement of low-altitude targets, permit operation independent of vectoring, advance countermeasures immunity, include air-to-ground attack modes, add doppler navigation, improve system reliability and maintainability, and add realistic air-to-air missile computations for long-range interception and air combat maneuvering. It includes ordnance delivery computations and a head-up display. AWG-11 and -12 were British counterparts.

AWG-15

F-14A weapon control system, presumably for air-to-ground weapons.

AWG-16

Walleye (Guided Weapon Mark 6 Mod 0) video uplink and command downlink for extended range operation. It is $15\text{in} \times 136\text{in}$, with a fin span of 45in (jettisonable wings).

AWG-19

P-3 and S-3 Harpoon launch control system.

AWG-21

Launch control for Standard ARM (AGM-78) missile, receiving and processing information from four selectable frequency bands. It is displayed for operator analysis and forwarded to the missile launcher adapter station.

AWG-24

Gun fire control system, similar to AWG-6, for the T-2 trainer.

AWG-25

AGM-88 (HARM) launch control set, providing the necessary mode, launch and target parameters as guidance information.



III-1 Sonars

In the notes which follow, kc is kilocycles, thousands of cycles per second; kW is kilowatts of power, thousands of watts; ms is milliseconds, thousandths of a second. Very approximately, one millisecond can be equated to 1.25yds. The range scale gives the keying, or pulse repetition, rate, since there must be enough time for one pulse to come and go before the next is sent out. Thus one second between pulses allows sound to travel about 1250yds, *ie* equates to a range scale somewhat less than 600yds. In designations of postwar sonars (*eg* AN/SQS series) the initial 'AN' has

been deleted. Ranges are given against targets above/below a thermal layer, as in 1500/600yds.

J Series (Passive Listening Sonars)

JA

12 spot microphones, with an electronic compensator and carbon microphones, in metal blisters; sonic range.

JB

18 spot microphones; sonic range.

JC

12 spot microphones, wooden blister; sonic range. In DD-199, 1933.

JD

18 spot microphones, wooden blister; sonic range.

JE

12 spot microphones, acoustic compensator, rubber nipples, in a metal blister; sonic range.

JF

6 spot microphones, electric compensator, carbon microphone, metal blister; sonic range.

JG

6 spot microphones, electric compensator, carbon microphone, hull mounts, sonic range. In 1933, installed in DD-132, 133, 148, 150, 338 and 339.

JH

12 spot microphones, electric compensator, carbon microphone, hull mount; sonic range.

JK

First US supersonic passive equipment, using multiple broadside rochelle crystals and electric compensators for rotation of beam. It was also described as a hand-trained, T-shaped listening device for 'R' and 'S' class submarines, 1936, operating at 14–32kc. JK-9, for small boats (17–25 kc), was converted to the QBE sonar. JK-5 was redesignated JKA-1 in 1938; it was for submarines, had a hydraulic hoist with electric train, and had a 20° beam at 25kc. Prototype was tested in trials ship *PE-58*, 1933.

JL

Sonic gear, 6 spot microphones, electric compensators, magnetophones, hull mounted. In 1933 it was planned for installation (with XQC active sonar) in the new *Farragut* class destroyers, and was fitted to the test ship *PE-58*.

JM

Harbor defense (entrance) sonobuoy, operating at 1–12kc, with rochelle salt transducer. Delivered 1941–42. Effective range was 1500–2000yds and there was a radio link to shore. A total of 510 were delivered.

JN

Small-boat sonic-range receiver dropped overboard as alarm, 1941.

JO

Picket-boat semipermanent installation, 1942; 100 were delivered. It operated at 500 cycles to 10kc, using four fixed hydrophones in parabolic reflectors; each assembly consisted of two hydrophones each in parabolic reflectors arranged to give 135° coverage from 3° across the bow to 45° abaft the beam. Each pair of hydrophones was mounted in a soft rubber blister, one on each side of the ship.

JP

Small-craft sonic outrigger hydrophone; 510 were delivered 1943–44, and it was accurate to within 1.5°, at 70 cycles to 12kc. The hydrophone was a 24in toroid or a 3ft tube. JP-1, for submarines (1943; 311 JP-1/2 delivered) was a modified version, a 40in magnetostrictive tubular hydrophone with baffles. JP-2/3 (50 JP-3 delivered 1944) were further modified versions for submarines, differing in mounting: JP-2 was on a separate shaft, JP-3 on the JK shaft under the JK head (crystal side).

JQ

Outrigged parabolic microphone for stationary listening by Coast Guard craft and picket boats; 550 were delivered in 1943. It used a rochelle salt transducer in a parabolic reflector, for 500 cycles to 20kc.

JR

Harbor defense system.

JS

Outpost listening system.

JT

Submarine listening device (225 delivered 1945), a 5ft magnetostriction line hydrophone

with a 22° beam scanning at 4rpm; 100 cycles to 12kc (to 65kc with a converter). The hydrophone was in 10 'delobed' sections for better resolution; it had a bearing deviation indicator (BDI) applied to the audible range (6–9kc). JX was an improved version with a new 100 cycle to 20kc receiver.

JAA

Sonar horizontal triangulation device, with a bearing accuracy of 0.5°; JAB was similar, but operated at 14–30kc. JBA was a vertical triangulator, and JCA was also a triangulator.

Q Series (Wartime Supersonic Echo-Ranging Equipment)**QA series (quartz crystal transducers)****QA**

First US shipboard sonar, operating at 15–20kc, 20W. The QA prototype was a combination of two equipments, the XN quartz-steel supersonic projector with a horizontal beam, tube-mounted and hand operated, and the ND supersonic echo-sounder, also using a quartz-steel projector (vertical). In 1933, QA was aboard DD-113, 114, 115, 127 and 206–209.

QAA

Portable sonar, 1945, operating at 500kc.

QB series (rochelle salt transducers)**QBA**

Submarine sonar using spherical transducer with hydraulic hoist and hand-training: 14–32kc at 20W. Range scales were 800yds and 4000yds. This and the very similar QBA-1 were both 'twin' systems having duplicate projectors, receiver-amplifiers and power supplies. Two and three, respectively, were produced. QBA was a rebuilt QB-1. QBB of 1938 (2 built) was similar, but also incorporated an echo-sounder; it was installed in the submarines *Cachalot* and *Cuttlefish*.

QBC

Offshore ranging and listening system for harbor defense, also known as HERALD (Harbor Echo-Ranging and Listening Device). Development began in 1941, but only 13 were built, as it was superseded by the more compact QBD (40 built). It used an 18in spherical transducer at 10–50kc (300W) with 1000–5000yd keying. QBC-1 operated at 350W and QBD was more compact, with a 14.5in transducer (15–35kc).

QBE

Converted passive JK-9 for small ASW units, giving range and bearing, plus passive listening on other frequencies, with a 1000–5000yd indicator; 18–25kc 35W, hand-held, in a 'fish-type' retractable dome (15in diameter 'banjo' projector). QBE was topside gear for submarines (Lend-Lease); QBE-3 was for small boats (Lend-Lease), and QBE-5 was a canceled submarine sonar for Lend-Lease (12–25kc, 75W). QBE-3b was QBE-3a with a bearing repeater added. Production totaled 230 QBE (1941), 300 QBE-1 (1941), 4 QBE-2 (1942), and 677 QBE-3 (1943); there are no figures for -3a/-3b, which were probably modified -3s.

QBF

Surface ship sonar for units up to frigate (PF) size, using a rectangular (10.5in × 10.5in) projector with resonating blocks on the back of its diaphragm to sharpen tuning. It operated at 22–28kc (150W, 1000, 2000, 3000, 4000, 5000 and 10,000yd scales). Hoist and train were electrical. A total of 300 were built, beginning in 1943.

QBG

Landing craft (usually LCC) sonar, mounted through-the-hull or outboard, manually lowered and trained; in some cases the projector could be tilted through 0–90°. It was a combination sonic and supersonic listening and ranging unit (22kc nominal), using a 6in transducer. Keying was manual, at 250–2000yds, and range was determined by adjusting the 'pinging' rate for coincidence between 'ping' and return. Power output was 5W. A total of 60 QBG were built. QBG-1 had a tunable receiver-amplifier; production figures are not available.

QBH

HERALD harbor defense sonar with electrical train from short (17–27kc, 200W). Postwar developments included QBH-1 with short pulses, and QBH-2 with an A-scan indicator to replace the former flash of a neon tube along a scale.

QC series (magnetostrictive transducers)

The original QC-1 through -5 were largely rebuilt under other designations: QC became QCF: QC-1 became QCA and QCA-1; QC-2 became QCB through QCB-3; QC-3 became obsolete; QC-4 became QCD and QCC; QC-5 became QCE. QC-7 became QCH-3. Early QC installations consisted of paired QC-J (24kc) to starboard and QC-L (20kc) to port, each a 19in sphere, filled with a mixture of ethylene glycol and distilled water, with a 15in diameter diaphragm, operating at 400W. The beam was about 30° wide. Presumably the frequency difference was to avoid mutual interference.

QC-6

Large-ship sonar, with a 19in spherical transducer and electrical train and hoist (400W at 24kc; keying for ranges of 1000, 2000, 5000 and 10,000yds). QC-6A operated at 18kc. Production totaled 12 QC-6 (1937–38), and 12 QC-6A (1937–38).

QC-7

Submarine sonar, similar to QCG; 7 were built (1938). It used a 19in spherical transducer (24kc, 400W, with 1000, 2000, 5000 and 10,000yd scales).

QCA

Modified QC-1; 6 were built in 1937–38, and 3 QCA-1. Large-ship sonars, with 19in spherical projectors and electrical operation; 1000, 2000, 5000 and 10,000yd scales (24kc, 400W). QCA-A was modified for MTB (Maintenance of True Bearing).

QCB

Destroyer sonar, a modified QC-2. Deliveries comprised 33 in 1938, 39 QCB-1 in 1938 and 2 each of QCB-2 and -3. All used a 17.5in spherical transducer (24kc, 400W, with an alternative low-power switch reducing power to about 280W) and range scales of 1000, 2000, 5000 and 10,000yds.

QCC

Submarine sonar, a modified QC-4 installed in combination with JK-2b listening gear, with 17.5in spherical transducer (24kc, 400W). Hydraulically hoisted and hand-trained, with 1000, 2000, 5000 and 10,000yd keying in QCC (2 built, 1938) but 800 and 4000yd scales in the sole QCC-1. QCD (3 built, 1938) and QCD-1 (4 built) were also modified QC-4s, but with combination magnetostriction and rochelle salt transducers (19in diameter spheres, 24kc at 400W, range scales as, respectively, QCC and QCC-1.

QCE

Large ASW ship sonar, a modified QC-5, with a 17.5in spherical transducer (400W, 1000, 2000, 5000, 10,000yd keying) and hydraulic hoist and train. QCE-1 was a modified QC-5b (19in projector, 18kc); QCE-2 and -3, with similar characteristics to QCE, were modified QC-1a and QC-5a. Production totaled 18 QCE, (1938-39); 15 QCE-1 (1938-39); 1 QCE-2 (1940); and 4 QCE-3 (1940). QCF, a modified QC, had similar characteristics but was all-electric; 2 were built.

QCG

Submarine sonar, converted to QCM.

QCH

Submarine sonar series, with combination projectors (magnetostriction and rochelle salt) at 24kc (400W, 19in diameter spherical projector). QCH-3 was a modified QC-7. All were installed in combination with listening gear: QCH-2 with JKA-2, QCH-3 with JKA or JKA-3, and QCH-4 with JK-4. Electric train and hoist.

QCJ

Large ASW ship sonar series; QCJ and QCJ-1 were similar to QCK, -2 to QCL, -3 to QCL-2, -4 to QCL-3, -5 to QCL-4, -6 to QCL-5, -8 to QCL-7 and -9 to QCL-8. Production comprised 10 QCJ (1937-38), 8 QCJ-1 (1938), 45 QCJ-2 (1940), 19 QCJ-3 (1940), 5 QCJ-4 (1939), 2 QCJ-5 (1940), 114 QCJ-6 (1941), 57 QCJ-8 (1942-43) and 44 QCJ-9 (1943). Most were built by the Submarine Signal Company. All had 19in spherical transducers (24kc, 400W, 1000, 2000, 5000 and 10,000yd scales). QCJ-6 had a modification for side-lobe reduction; QCJ-9 was adapted for BDI (Bearing Deviation Indication).

QCK

Similar to QCJ: 10 built, 1937-38. Operated at 18kc (400W). Also QCK-1 (8 built, 1938).

QCL

Operated at 20kc; QCL-1 through -5 and -8 had the lobe-reduction feature. Production totaled 45 QCL (1940), 68 QCL-1 (1940), 15 QCL-2 (1940), 7 QCL-3 (1940), 1 QCL-4 (1941), 114 QCL-5 (1941), 57 QCL-7 (1942-43) and 47 QCL-8 (1941-43). Only QCL-8 operated at 600W rather than 400W, but all had electric hoists and train.

QCM

Submarine sonar, installed in combination with JKA-2 (QCM-1 with JKA-5, -2 with JKA-5a, -3 with JKA-1, -4 with JKA-4). It had a combination projector (19in sphere) with lobe reduction in QCM-1 and -2 (24kc, 400W; listened at 14-32kc) and 1000, 2000, 5000 and

10,000yd keying scales. Production (Submarine Signal) comprised QCM (modified in 1940 from QCG/QCH), 3 QCM-1 (1941), 3 QCM-2 (1941), 4 QCM-3 (modified QCH) and 6 QCM-4 (1939). Hydraulic hoist, train.

QCN

Combination projector for submarines and for ASW ships (QCN-1 through -4), operating at 24kc (400W) with a 19in transducer (lobe-reduction feature in QCN-1 through -4, BDI in QCN-4), with 800 and 4000yd scales in QCN but 1000, 2000, 5000 and 10,000yd scales in other versions. QCN-4 had a special 'low power' output feature. Production (Submarine Signal) totaled 16 QCM (1940), 25 QCN-1, 16 QCN-2 (1939); 45 QCN- (1941) and 28 QCN-4 (1943). Operation was all-hydraulic. QCN was similar to QCO, QCN-1 to QCJ-3, QCN-2 to QCO-1, QCN-3 to QCJ-5, and QCN-4 to QCJ-9 (600W).

QCO

A combination projector similar to QCL-2, operating at 20kc (19in spherical with lobe reduction in all versions (400W except 600W in QCO-3). Production (Submarine Signal) totaled 25 QCO (1939), 25 QCO-1 (1939), 46 QCO-2 (1941) and 28 QCO-3 (1942). QCNs and QCOs were all-electric hoist and train; QCO-3 had BDI, low power setting.

QCP

Harbor defense sonars with 9in oblate projectors (400W, choice of frequency between 21 and 27kc) and 1000, 2000, 5000 and 10,000yd scales; 10 QCP and 10 QCP-1 were built. QCW, QCX, QCY and QCZ were similar, with 9in magnetostrictive or rochelle salt transducers and frequencies of, respectively, 21, 23, 25 and 27kc. They also omitted the chemical recorder incorporated into the QCP shore gear. All scanned continuously.

QCQ

Sonar for large ASW ships, a modified QCJ-7 (-1 was a modified QCJ-10, -2 a modified WFA-1; similar to QCR and QCJ-6). The principal production model, QCQ-2, was by RCA; others were by Submarine Signal. Production comprised 14 QCQ (1941), 33 QCR-1 (1943), 300 QCR-2 (1943), and 25 QCQ-3. The transducer was a 17in $\times$ 5½in banjo (19in in QCQ-2) operating at 24kc (26kc) and 400W (600W in QCQ-1) with 1000, 2000, 5000 and 10,000yd scales (400, 1000, 2000, 4000 and 8000 in QCQ-2). QCQ and QCQ-1 and -3 had the lobe-reduction feature, with BDI in QCQ-1. QCQ-3 had a 24° beam at 24kc. QCQ-2 differed from most sonars in having a belt indicator rather than a two-speed disc.

QCR

Similar to QCQ (modified QCL-6) but operated at 20kc with a 17in banjo (no lobe reduction); QCR-1 had BDI, and 600W instead of 400W power, with the 'low power' feature. Production totaled 15 QCR (1941), 33 QCR-1 (1942), and 25 QCR-2. Both QCQ and QCR used electric hoist and train.

QCS

Combination projector (magnetostrictive and rochelle salt) with BDI banjo transducer (17in $\times$ 7½in); QCS was a modified QCM-5. They operated at 24kc, 600W (with a low-power

feature) and had range scales at 1000, 2000, 5000 and 10,000yds. Pulse-lengths were 1, 2, 5, 10ms plus two adjustable ones, 0-90yds and 2-200yds. Beam-width at 24kc was about 22° for the magnetostrictive active element and about 21° for the rochelle salt passive one (14-32kc). Production comprised 500 QCS (1942), 293 QCS-1 (similar to QCQ-1) and 250 QCS-2 (1942). All had electric hoist and train, and were built by Submarine Signal Co.

QCT

Combination projector, similar to QCQ and QCS, but operating at 20kc (600W, BDI, 17in $\times$ 7½in banjo). Production comprised 500 QCT (1943), and 293 QCT-1. They had electric hoist and train, and were built by Submarine Signal Co.

QCU

RCA sonar for medium and small ASW ships, replacing WEA-1 and using its 'fish' dome (25/27kc, 14in permanent magnet projector with BDI, 200W) with 2000, 3000 and 6000yd keying and associated pulse-lengths of 25, 75 and 200yds. A total of 575 were built beginning in August 1944. QCV was very similar, resonant at 27kc. Manual hoist, electric train.

QD series (depth-determining sonars)**QDA**

Ammonium dy-hydrogen phosphate (ADP) transducer with a 119° $\times$ 4° 'sword' beam, tilting over a range of 115° (90° aft, 25° forward), at 50-60kc (3-10ms pulses with OKA equipment off, 20-50ms with OKA on, with the keying interval set by the OKA unit). Two-axis stabilized, training at 12rpm (150W). This unit was to replace the British Asdic Type 147, 50 of which were obtained in wartime by 'reverse Lend-Lease'.

QF series (training equipment)

Not listed.

QG series (console versions of QC series magnetostrictive sonars, with BDI).**QGA**

Dual-frequency sonar for *Sumner* and *Gearing* classes; 187 were built by the Submarine Signal Company. It had two separate transducers (14 and 30kc, 18½ and 14½in in diameter, respectively, both at 400W) and a 38° search beam. Alternative range scales were 1500 and 3750yds using the recorder, 3000 and 5000yds in manual search. Pulse-length was proportional to the keying interval. The 14kc transducer was for target acquisition, the 30kc unit for target definition; it could also tilt for MCC (Maintenance of Close Contact). Features included IRR (Indicating Range Recorder), BDI, TVG (Time Varied Gain) and MTB (Maintenance of True Bearing) and QGA was installed in a fixed 100in free-flooding dome. Electric train.

QGB

Standard wartime large-ship sonar by RCA: 400 were delivered in 1944. It had a single 19in $\times$ 7in projector, split for BDI and using a permanent magnet for compactness, operating at 20/22/24/26kc (400W) with a 21° $\times$ 22° beam at 24kc. QGB-a had MCC, ie had vertical beam-width increased to 60°. QGB-b had ODN (Own Doppler Nullifier). Other features included TVG, IRR and MTB, and electric

train. OGC was comparable (24kc, 400W), and QCD operated at 20kc (400W). QGE, QGF and QGG were all designated QGB variants in 1951.

QH series (scanning sonars)

QHB

The ultimate US World War Two sonar development, and a connecting link to all post-war systems, scanning at 30 cycles per second, using omnidirectional 7kW pulses (25.5kc) and a $15^\circ \times 15^\circ$ beam (35ms pulses) with 1500 and 3750yd keying. Some sources claim a power level of 2kW at first. In QHBa this was increased to 3kW; QHBc introduced a high-speed scan (150 cycles per second), and in QHBd a field change reduced resonant frequency to 20kc. Some QHB were also modified for MCC with vertical beam-width increased to 60° . QHB-1 had a sturdier transducer, for submarine use, and -1b had an MTB feature, operating at 26kc. QHB-3 became SQS-10 in 1950. Fleet installations of QHB in destroyers began in 1948.

QHC

Summer class type, with PPI and sector scan presentations, scanning at 30 cycles per second, with 600, 2000, 4000 and 6000yd keying (pulses at 12, 35 and 85ms) and 20kW power (three alternative transducers: 22, 24, 26kc) and a $17^\circ \times 10^\circ$ beam. It did not enter service.

QHD

Destroyer scanning sonar with advanced features (preformed beams and electronic scanning) which appeared in 1951 but was not produced. It could operate at 30, 90 or 300 scans per second, with 600, 1200, 4000 and 6000yd range scales (12, 35 and 70ms pulses; 19–27kc; 40kW power) and a $16^\circ \times 10^\circ$ beam.

QJ series (console versions of QB series, with BDI)

QJA

QBF with modifications, including BDI and MTB, in a new rack; 235 were produced, beginning in 1944. It had 1000, 2000, 3000, 4000, 5000 and 10,000yd range scales (150W, 10–30kc). Western Electric.

QJB

New sonar for medium ASW ships; 227 were built by Western Electric in 1944. It employed an enlarged $24\frac{7}{8}\text{in} \times 12\text{in} \times 8\text{in}$ ADP projector split for BDI, at 22–28kc, with a 25° wide beam at 24kc. Range scales were 2000, 3000 and 5000yds (3750 with a recorder) and pulse-widths 1, 1.5, 2, 3, 3.75 and 5ms.

QL series (FM sonars)

QLA-1

Precision mine-evasion sonar for submarines, permitting US submarines to penetrate Japanese home waters late in World War Two. Maximum scan rate was 5000/range per minute; minimum (short range) 10rpm. Scales were 300ft, 300, 600, 1200 and 3000yds, and cycle rates $\frac{2}{3}$, 2, 4, 8 and 20 seconds respectively. Power level was 250kW; during the cycle frequency was varied from 46.7 down to 35kc. The transmitting beam measured $80^\circ \times 10^\circ$ and the receiving beam $12^\circ \times 12^\circ$. There was a memory trace display, and an ADP transducer.

QX series (auxiliary equipment)

QXB

'Sonaromic Receiver' passive sonar under consideration postwar as a torpedo detector for evasion; it was redesignated ULR-4 in December 1953. The first 65 were delivered in 1949, and for a time it was specified for all major ships. It could scan at 100 or 1000 cycles per second, detecting all pulses of 1ms or more, and receiving 3–120kc signals (sweeping with a width of 100 or 1000 cycles per second, or else searching a 10kc band).

W Series (Combined Range and Sounding)

WA was magnetostrictive, WB rochelle salt, WC combined (magnetostrictive sounding, with both for listening), WD combined (rochelle salt for sounding), WE combined light-weight echo-ranging set without a sounder, and WF ranging-sounding-listening using ADP crystals.

WAA

Combined ranging and sounding for *PC-449–452*, small ASW patrol craft: 400W at 24kc with electrical hoist and train.

WAB

Separate magnetostrictive sounding projector, for ASW vessels: 400W at 24kc. Only one was built, with four WAB-1.

WAC

Single system with magnetostrictive ranging and sounding (20kc, 400W).

WBA

Submarine system, with hand hoist and train, 18kc ranging (20W), 14–32kc listening, both rochelle salt. Five were built in 1939, using QB components for ranging and listening. WBA-1 was canceled and reassigned as WDA.

WCA

Ranging with both magnetostriction and rochelle salt (24kc, 400W), plus a rochelle salt echosounder (20W) with hydraulic hoist and electric train. WCA-3 had a 5000yd scale, and used a 175yd pulse; in effect it combined QC-JK with QB and the NM (magnetostrictive) sounder. WCA-3 incorporated an object locator, a TDM (torpedo detection modification), and a sweep modulator. The display was a range dial, and true or relative bearing could be indicated. Production totaled 116 WCA, 100 WCA-1 (1941), 120 WCA-2 (1943), for submarines. Submarine Signal.

WDA

Submarine system, 1941; 6 built. Ranging and listening were by a combination of QC-JK and QB systems; sounding was magnetostrictive. The former used a 19in spherical projector at 24 and 14–32kc (rochelle salt) at, respectively, 400 and 20W, with 1000, 2000, 5000 and 10,000yd keying. Submarine Signal.

WEA

Echo-ranging at 25kc (magnetostrictive) and 200W, listening at 22–27kc, hand hoisted and trained, for antisubmarine ships; the magnetostrictive projector was used for sounding when it was directed at a mirror at the rear of the 'fish' dome. The sounder was removed in WEA-1, which was electrically trained; WEA-2 was hand hoisted and trained with a flexible

cable. WEA-1 had 1000 and 3000yd range scales with, respectively, 50–75yd and 150–200yd pulses and a 38° beam. WEA-2 echo-ranged at 400W and sounded at 150, with an 18° beam. WEA-2a was modified for electrical training. Production comprised 100 WEA (1941–42), 610 WEA-1 (1943) and 400 WEA-2 (1943). WEA-2a was a modified version with electric train control added, and -2b added a bearing repeater. WEA-1 had both dial and belt-type indicators, for true or relative bearing; it also had TVG (Time Varied Gain) and manual keying, and was originally modified for BDI.

WEB

Submarine equipment with a single transducer for ranging and sounding: 400W at 24kc, listening at 17–26kc, with hydraulic hoist and electric train.

WFA

Standard submarine sonar, 1945; 30 WFA and 110 WFA-1 were delivered, the latter differing in that it employed the standard hydraulic hoist gear and the standard sea chest; there was no dome, as the system used a spherical projector. Fire control features were added in WFAa. It combined echo-ranging, listening and sounding features, with two projectors: an upper one consisting of three ADP transducers, 'hydrant' shaped, and a lower one, a single ADP 'banjo' operating at 100cps to 15kc and 15–100kc for the upper section and 17–26kc for the lower. Range scale (pulse-lengths in ms) were 600yds (7), 1500yds (7), and 2750yds (192), with sounding to 100–200ft, 100 fathoms and 2000 fathoms. Peak power was 100–125kW. Features included BDI, GTT (Generated Target Tracking, for fire control), MTB, sweep modulation, and RGC (Reverberation Control of Gain), and the display was a chemical (paper tape) recorder.

BQG Series (Passive Underwater Fire Control Sonars)

Systems for submarines, originally described as PUFFS, the Passive Underwater Fire Control Feasibility Study. BQG-1, -2 and the current -4 each have three hydrophones; BQG-3 had four. The original concept was for three equally spaced 6ft (vertical) lines on a 250ft base, operating at 0.2–8kc, and capable of obtaining ranges to within 2 percent against snorkeling submarines at 10,000–15,000yds, by measuring the curvature of the wave front of the target signal, comparing time of arrival at the three detectors and correlating. Feasibility studies began in March 1953, and an operational requirement was issued in July 1954, a contract following in April 1957. A product-engineered model showed good results aboard the submarine *Blenny* in November 1960. PUFFS I was BQC-2, installed in the nuclear ASW submarine *Tullibee* in conjunction with BQQ-2; the *Threshers* had the improved BQG-3. BQG-4 is the current version, with three above-hull sonar domes. Current nuclear submarines have a PUFFS integrated with their other sonars, consisting of three conformational hydrophones spaced along their hulls, the aftermost being in vertical fins at the stern. Raytheon has proposed a mini-PUFFS for installation in the current generation of foreign diesel-electric submarines.

BQQ Series**BQQ-1**

Integrated low-frequency sonar system for passive and active detection as well as Secure Communication (SESCO); it consisted of a conformal array of omnidirectional transducers plus a bow spherical transducer, as well as target classification and data reduction equipment. It consisted, then, of the BQS-6 active sonar, the BQR-7 passive sonar, and the BQA-3 computer-indicator group. Echo-ranging was at 3.5kc with a peak power of 170kW; SESCO operation was at 1.65–2.35kc; and receiving was at 50 cycles to 2kc (conformal) and at 500 cycles to 5kc (spherical). Replaced in service by BQQ-2 with similar components. The first contract for two was let to Raytheon in May 1958, with installations in *Tullibee* (3 June 1960) and *Thresher* (22 July 1960).

BQQ-2

Integrated sonar for *Thresher/Permit* class, consisting of BQQ-1 and BQG-1 (PUFFS); it is being replaced by BQQ-5. Feasibility studies were begun in January 1956, an operational requirement having been issued in October 1952; a contract with Raytheon followed in May 1958, and operational evaluation began in December 1962.

BQQ-3

Submarine sound classification (LOFAR) set. Feasibility studies began January 1954, an Operational Requirement being issued in May 1954, and a contract in September 1960; operational evaluation followed in December 1962. Generally it employed three arrays: bow, amidships and aft.

BQQ-5

Replacement for BQQ-2, *Los Angeles* class. It incorporates DIMUS for lower internal noise. It also includes a towed array.

BQQ-6

Trident missile submarine integrated sonar, with spherical bow transducer, in effect a passive equivalent of BQQ-5. It incorporates a towed array and two line arrays on the hull surface as well as an acoustic communication system.

BQQ-7

Sonar to enhance capabilities of *Permit* class submarines, working with BQS-11, -12 and -13.

BQR Series**BQR-1**

Depth charge range and bearing indicator, 1947. It was similar to a combination of the DCDI and DCR-1, with a PPI indicator. There were six channels (ahead/astern, port/starboard, above/below) fed by paired hydrophones, operating at 100–1000 cycles.

BQR-2

Listening array for postwar submarines, including SSKs, operating either in searchlight or in scanning mode, with forty-eight 3ft vertical elements in a 6ft circular array, with an 18° beam, operating between 500 cycles and 15kc. BQR-2B had a sound bearing recorder for 1–4kc but could detect (aurally) at 0.3–15kc. Typical performance for a quiet submarine against a snorkeling or cavitating target

was 110,000/8000yds; for a 13kt submarine against a snorkeling target 13,000/4000yds; and for a quiet submarine against a quiet (shallow) target, 10,000/2500yds, all with 1956 technology. Auto target following could give an accuracy of 0.25° on a noisy submarine at 12,000yds. As installed in the experimental submarine *Albacore*, it included DIMUS for simultaneous listening in all directions, and for the detection of weak signals which would otherwise be lost in the background. It was installed in the SSBN-598 class. BQR-2C was modified for use with BQS-4 in such a way that the source 'ping' of the latter was muted; it could also use a circular array of modified BQR-7 hydrophones aft of the missile tubes in an SSBN, to solve the hindsight problem, with one hydrophone high. BQR-2B was also part of PADLOC (see SQQ-23).

BQR-3

Improved JT, a 5ft line array with a 22° beam. It incorporated sum/difference BDI. Typical performance, against a snorkeling submarine from a quiet one, was 18,000yds, but at 13kts the listening submarine could detect only at about 4000yds (1956). Typically it was mounted in a dome over the BQR-4 of an SSK.

BQR-4

Conformal bow array based on German GHG for SSK, both new construction and conversion, as well as some postwar submarines; it was a 10ft wide, 20ft long horseshoe-shaped array of 58 vertical hydrophones using a commutator for scanning, and operating between 150 and 5000 cycles (recording 0.6–4.8kc). Typical performance (-4A) for a quiet submarine against a snorkeling or cavitating submarine was 160,000/30,000yds; for a 13kt quiet submarine against a snorkel or cavitating submarine, 20,000/9000yds; for a patrol quiet submarine against a quiet submarine 17,000/9000yds (all 1956 figures). BQR-4A differed from -4 in having 96in rather than 120in hydrophones.

BQR-5

Submarine passive sonar using electrical scanning and incorporating MTB, similar to BQR-4: 150 cycles to 10kc, 1949.

BQR-6

Passive ranger on surface ships, 1949.

BQR-7

Passive bow conformal array sonar, part of BQQ-2, consisting of 52 groups each of three vertically-mounted units. In 1956 an experimental model was described as effective at 30–100nm against a snorkeling submarine (10–50nm against a cavitating submarine) using broad and narrow-bands; localization could be as good as 2° against a snorkeling submarine.

BQR-10

Sonar data analyzer.

BQR-13

Sonar trainer.

BQR-15

Towed array for ballistic missile submarines.

BQR-17

Depth sounder.

BQR-19

'Top Hat' sonar receiver, a mast-mounted sonar to detect surface ships near a surfacing strategic submarine; part of the BQR-15/19/21 program for SSBNs.

BQR-20

Sonar receiver for *Los Angeles* class, to improve narrow-band detection and classification (interim capability).

BQR-21

DIMUS passive sonar for attack and missile submarines, replacing the earlier BQR-2 for broad-band detection; can track as many as five targets simultaneously with sufficient accuracy for weapon delivery. It employs a hull-mounted conformal array with preformed beams. Honeywell received the development contract in June 1972, sea trials following in 1974.

BQR-23

Signal processor for BQR-15 towed array.

BQR-24

Computer-controlled signal-processing and display system.

BQS Series**BQS-1**

System canceled; not produced.

BQS-2

Modified surface ship scanning sonar, with 60 staves spaced 6° apart; seven adjacent staves were used to generate a 'single-ping' searchlight signal, 42° wide. It could also scan passively at 8rpm. Operation was at 10kw (31kc, with a 12–13° beam, and 3ms or 6–30ms pulses) with range scales at 600, 2000, and 4000yds. The display was a PPI. First installed 1954.

BQS-3

'Single ping' sonar (2000 and 8000yd scales, plus a 3200yd scale for station-keeping) operating at 12kc (5kW, with 5, 10 and 20ms pulses), 1950. Typical performance (1956) was 10,000yds for a submarine in the layer.

BQS-4

Successor to SQS-4 in submarines, consisting of seven vertically stacked cylindrical transducers inside a BQR-2C through which it transmitted; it could operate in listening, 'single-ping' or automatic echo-ranging modes. It operated at 7kc (BQS-4B) and listened at 150 cycles to 16kc, with three alternative power levels, up to 25kW. Typical range was 6000–8000yds. First BQS-4 installation was in 1959.

BQS-5

Noise pulse transmitting sonar (1–2kc, 50kW for 1- to 5-second pulses) with directional transmission and preformed beam reception, using convergence-zone, bottom-bounce, or surface-duct propagation. A development set for submarine installation, limited to a 120° search sector in azimuth and using an emission line hydrophone, with 60 channels (2° beams). Naval Electronics Lab (1959).

BQS-6

Spherical bow array sonar of BQQ-1 and -2

systems. It operated at 3.5kc, and was 15ft in diameter, with ODT, RDT and tribeam features, *ie* it was roughly equivalent to SQS-26. By way of contrast, a 5kc sonar proposed about 1956 for SSN-585 (*Skipjack*) had the following estimated performance: 21,000/4500yds from a quiet shallow submarine; 16,000/3500yds from a noisy shallow submarine; and convergence-zone and bottom-bounce performance. Presumably it would have been the submarine equivalent of SQS-23, which was originally credited with bottom-bounce and even convergence-zone propagation. The first was installed in 1961.

BQS-7

Frequency modulated sonar for underwater object detection, presumably a lineal descendant of QLA, continuously sweeping the 64–80kc range. Deck mounted, with 320° sector scan. Also described as a means of finding holes in overhead ice packs. First installation 1960.

BQS-8

Under-ice sonar, for polynya delineation, iceberg detection, bottom sounding and recording, and overhead ice surface sounding and recording. It uses a 24–32kc FM slide at 200W. BQS-9 and -10 perform the same function, the latter using three sonar bands (32–24kc at 250W, 45kc at 160W and 205kc at 130W).

BQS-11

Passive-active sonar, 'pinging' at 3.5kc (196kW) or transmitting CW at 1.45–3.2kc, while listening at 500 cycles to 5kc; primarily active sonar for detection and tracking for fire control. Similar to BQS-12 and -13, which have similar frequencies and outputs; for example, it operates at about 3.5kc in either CW or FM mode, in the latter case incorporating nine steps in frequency. Its CW pulse power is 196kW.

BQS-12

Long-range low-frequency (3.5kc) sonar, presumably a failed alternative to BQS-11.

BQS-14

Under-ice sonar, similar to BQS-8, with three bands.

BQS-15

Under-ice sonar.

BQS-16

Vertical obstacle-detecting sonar, using a fan beam in a vertical plane.

BQS-17

High-resolution pulse sonar to distinguish features in a stricken submarine escape hatch so that a mate may be effected with a rescue vehicle. Frequencies are 116 and 1000kc.

BQS-18

DSRV search sonar, using continuous-transmission frequency-modulated (CTFM) technique to detect objects in the region lying ahead of the DSRV; sweeps the 87–72kc range.

BQS-19

Side-looking sonar for bottom mapping; 182–184kc.

BQS-20

Under-ice sonar.

BQS-21

Similar to BQS-18, but with higher frequency (206–186kc). BQS-22 is similar.

SQA Series

SQA-2

Sonar hoist/train mechanism; retractable type, for scanning sonar, with a total lift of 44in (1950). It was designed to hoist both the transducer and the 60in rubber dome then current into a sea chest, and was scheduled for installation in most large destroyers about 1951.

SQA-3

Sonar hoist/train mechanism for UQS-1 mine-detection sonar, allowing depression between +5° and -50°, with a total hoist travel of 42in. SQA-3A was for the SQG-5 fire control sonar, which tilted between +20° and -85°.

SQA-4

Sonar computer-recorder group, formerly OKA, for SQS-4; it computed horizontal range and depth, measured slant range, synchronized sonar keying, and provided rate-aided tracking in depth; it was used with pairs of horizontal-scanning and depth-determining sonars (1951). SQR-8 obviated it.

SQA-5

Variable-depth sonar, in one Atlantic Fleet DE and three DDEs, 1955; it operated at 25kc, and was not successful in practice, apparently largely due to material difficulties. It was designed to operate with QGB and QHB sonars, and could be towed at up to 120ft; the power level was 200W.

SQA-6

Hoist-transducer group for 10kc variable-depth sonar (transducer diameter 3.6ft) using an articulated strut to lower the transducer to as much as 120ft; to be used with existing equipment, such as SQS-14 (1952).

SQA-7

Torpedo range indicator, processing received sonar signals to obtain range and range rate (1957). Edo.

SQA-8

Hoist-transducer group for variable-depth sonar in conjunction with SQS-4. Used with SQA-9. Installed 1958 aboard *Brownson* (DD-868) and compared to SQA-10, which latter was adopted.

SQA-9

Amplifier and other electronics for VDS with SQS-4 (Mod 3).

SQA-10

VDS hoist mechanism in conjunction with SQS-31 and -32; widely used in FRAM II destroyers. It was also sometimes used with SQS-23. Both hull and VDS transducers operated off the same electronic 'stack', and each could operate in ODT or RDT mode. First tested 1958–59 aboard *John Willis* (DE-1027). It used a full 48-stave transducer with SQS-31 and -32, half-size with SQS-29 and -30 (standard 'fish' body).

SQA-11

VDS hoist and transducer for SQS-4 (Mod 1),

and SQS-29; similar to SQA-10.

SQA-12

VDS hoist and transducer for SQS-4 (Mod 3 and 4) or SQS-26. Through-the-hull (centerwell) hoisting and lowering, as compared to earlier over-the-side or over-the-stern methods, for better stability and noise reduction.

SQA-13

VDS hoist and transducer for small ASW vessels, in conjunction with SQS-17 sonar, 1959. It was later adapted to SQS-35.

SQA-14

Sonar listening group, taking, processing and displaying SQS-20 signals in the manner of the BQR-2B sonar listening set; similar functionally, but does not include the BQR-2 hydrophones and amplifier (1959).

SQA-15

Passive detection system working in the 1–10kc band, using the SQS-29 transducer, and scanning at 10rpm (1959).

SQA-16

Target depth-determining group.

SQA-17

Experimental VDS hoist for SQS-23 and larger transducers to test VDS in convergence zone and bottom-bounce modes. It had a 40,000lb 'fish' and a 90,000lb hoist, and could tow at 50–300ft at 25kts, with 600ft of cable. Feasibility study June 1956; contract May 1961.

SQA-18

Range and range-rate indicator for SQS-29 to -32 series sonars, for Mk 5 attack director (1961).

SQA-19

VDS hoist and transducer for SQS-23. It was to have replaced SQA-11, at 33 rather than 50 tons. A variant of SQA-10, it was canceled in view of problems with SQA-11.

SQA-20

Detecting-tracking display group, improving the detection and tracking capabilities of an SQS-23 modified for preformed beam reception, 1963.

SQA-21

Improved display for SQS-23, using a direct-storage cathode ray tube, 1963.

SQA-22

VDS hoist and transducer, similar to SQA-10B, with the SQA-13 towed body.

SQG Series

SQG-1

Triaxially stabilized depth-determining sonar with 9° × 9° beam, operating at 45–55kc (1, 5, 12, 36 or 60ms pulses at 400W–10kW); the beam tilted to -85° and could swing right aft. Range scales were 1000, 2000 and 4000yds.

SQG-2

Operated as a searchlight in azimuth, but scanned in depth; it had two-axis stabilization and was scheduled for service test in 1953. It

scanned at 12rpm in azimuth, and 150 cycles per second in depth, with a $10^\circ \times 6^\circ$ beam (5, 15 or 30ms pulses, 30kW), and operated at range scales of 300, 600, 1200 and 1800yds.

SQG-3

A searchlight sonar, transmitting continuously in azimuth and depth, and employing two-axis stabilization, scanning at 12rpm each way. The beam was $20^\circ \times 30^\circ$, at 40–50kc (10kW for pulses, 250W average for continuous transmission; range scales 300, 600, 1200 and 1800yds). It was designed for automatic tracking in azimuth and depth, giving continuous range and range-rate.

SQG-4

SQS-11A plus SQR-4, forming a search and attack sonar, first delivered 1951, and stabilized in line of sight. It had a 3000rpm train rate, and scanned at 150 cycles per second: SQR-4 in vertical scanning was used as the depth determining and listening feature of the 25.5kc active sonar. Effective beam was $15^\circ \times 16^\circ$.

SQG-5

Improved Underwater Object Locator, originally SQQ-10; one was delivered in May 1952. It scanned at 1000 cycles per second in azimuth and 2000 in depth, using 9kW (2 and 5ms) pulses and a $30^\circ \times 15^\circ$ beam (300, 750 and 1500yd scales).

SQG-6

Combined tracking and attack sonar, operating at 35–45kc, using a continuous-transmission system combined with a 'ping' system whose pulse was transmitted during 'dead time' to obtain true range; outputs were range, range-rate, bearing, depression angle and target aspect. There were two separate units, a target-holding unit (continuously rotating hydrophone) and a target-attack unit (nutating hydrophone and reflector, to lock on a designated target and track it automatically in range, bearing and depression. It used a 10ms (1kW) 'ping', scanned at 12rpm in both directions with three-axis stabilization, and had 400, 800, 1600 and 2400yd range scales, with an $8^\circ \times 15^\circ$ beam.

SQQ series

SQQ-1, -2

Submarine sonar beacons for training, to be ejected underwater; transmission, reception and recording; 1948. Frequency ranges were 20–50kc and 50–100kc respectively.

SQQ-3, -4

Sonar beacons (decoys) for surface-ship launch by rocket, similar to SQQ-1 but without the recording feature; frequency ranges were 20–50kc and 50–100kc.

SQQ-5

Doppler sonar decoy.

SQQ-6

Doppler sonar decoy, similar to SQQ-4.

SQQ-7

Doppler sonar decoy, rocket launched from surface ships, adding 60 ± 30 cycles to input for retransmission (10–50kc range). After water entry it hovered at 40ft for a 15-minute life-

time. In service about 1960.

SQQ-8

Doppler sonar decoy similar to SQQ-7 but adding 100 ± 50 cycles to its input, and operating at 50–100kc.

SQQ-9

Submarine simulator for torpedo-tube launch (sonar beacon).

SQQ-10

Sonar for submarine attack, operating at 75kc (1kW), an improved General Electric Underwater Object Locator, 1949.

SQQ-11

Sonar countermeasures (torpedo detection) set. Received 15, 16.5, 18 and 19.5kc, transmitted on 18kc; could detect and display two sound sources simultaneously. In active operation it used a $12^\circ \times 12^\circ$ beam, scanning at 150 cycles per second (35ms, 7kW). Evaluated in cruiser *Salem*.

SQQ-12

Torpedo detection sonar, scanning in azimuth; similar in appearance to SQS-10 but retains functional characteristics of SQQ-11, with higher power: 50kW on short, 10 on medium and 2 on long pulses (1–60ms). Frequency is 18kc and range scales 1000, 3000 and 6000yds.

SQQ-13

Cavitation measuring set (1960).

SQQ-14

Mine classification sonar (1960), a towed body operating at 80 and 350kc; the standard US mine countermeasures sonar.

SQQ-16

Mine detector, similar to SQQ-14, employing 100kc for search and 300kc for classification; it could detect at 300yds and classify at 200yds. It used a towed vehicle.

SQQ-17

Sonar classification set, production version of CXRP.

SQQ-18

Buoy transponder.

SQQ-19

Sonar detection and ranging set, to locate the impact area of shipboard missiles (1960); canceled.

SQQ-20

Abortive integrated sonar system for 'Sea-hawk' ASW destroyer of the early 1960s, comprising a large bow array and a large VDS, the latter to fill the shadow area under the ship. It is not clear whether any particular system was ever defined.

SQQ-21

Moored sonobuoy comparable to SSQ-38, weighing about 200lb and with a life of over 30 days; deployed by a ship rather than by air-drop, and more seaworthy than the air-dropped buoy. Its radio could transmit to aircraft, ships or a receiver ashore.

SQQ-22

Integrated (conformal array) sonar, trans-

mitting at 2.75–3.45kc, and receiving at 0.1–72kc. Capabilities included underwater communications and IFF, as well as alarm and tracking.

SQQ-23

Active-passive sonar based on SQS-23 but incorporating a second transducer for pure passive operation, generally in a second dome. Output is 160kW for 160ms in ODT mode and 60kW for 5.6 seconds in RDT mode at 4.3–5.7kc, using 48 channels (1 per stave rather than 2 per stave as in the original SQS-23). In SQQ-23A equipment was revised and simplified, so that transmission could be accomplished by three solid-state cabinets as against 21 vacuum-tube cabinets and 10 motor generators. SQQ-23B integrates both transducers in a single sonar dome, and has been specified for the *Long Beach* refit and for the DDG Upgrade program; it also uses a solid-state transmitter. SQQ-23 is often referred to as PAIR or PADLOC (Passive-Active Detection and Localization). The original PADLOC was a combination of SQS-29 and BQR-2B in the destroyer *Glenmon*, tested in 1959. At 27kts the destroyer could detect a 9kt snorkeling submarine at 15,000yds, and a 17kt submarine at 25,000; at 6kts she could detect a 10kt submarine at 46,000yds. PADLOC variants were proposed for SQS-26 in the 1960s.

SQQ-24

Sonar transponder for training, suspended by cable.

SQQ-25

Sonar interrogator-receiver, part of the three-dimensional sonar tracking system used with the DSRV deep-diving research vehicle.

SQQ-26

Integrated multisensor sonar, consisting of SQS-26 plus SQS-35 plus SQR-17 for signal processing plus the Escort Towed Array System.

SQQ-27

Broadband high-resolution sonar system for small boats, operating from 1–250kc, with 10-microsecond to 10ms pulses.

SQQ-28

Signal processor for sonobuoys, eg for LAMPS III. Similar to SQS-54 and SQR-17 but not interchangeable with them.

SQQ-29

Mine classification sonar with two ahead- and one side-looking mode; navigation equipment and position location for a towed body.

SQQ-46

Buoy transponder; physical and acoustic reference (radar/sonar, presumably) for improved submarine localization.

SQR series

SQR-1

Long-range listening and search set, 100 cycles to 30kc, using two 20ft arrays of hydrophones, 36 in each, hull-mounted along a 20° baseline. It had three listening channels, one rotating at 10rpm, and the others being manually directed; the listening beam could be electrically steered over 135° on each side of the bow. It

was patterned after the GHG installed on the *Prinz Eugen* and had a range of about 25,000yds. It was not used operationally; the nomenclature was assigned 1947.

SQR-2

Replaced by SQQ-11.

SQR-3

Depth-scanning passive sonar operating at 20kc, 1951; similar to SQR-4.

SQR-4

Depth-scanning passive sonar operating at 25.5kc, 1951. Beam was $75^\circ \times 10^\circ$.

SQR-5

Torpedo-warning passive sonar, operating below 20kc; port and starboard hydrophones, 1953. Beam was $180^\circ \times 30^\circ$, and there were lights for port and starboard.

SQR-6

Torpedo-warning passive sonar, operating below 20kc; port and starboard array of 18 hydrophones. For merchant ships (1953).

SQR-7

Towed passive torpedo-warning sonar for merchant ships (under 20kc).

SQR-8

Depth-determining sonar portion of SQS-4.

SQR-9

Doppler attachment for sonar (presumably SQS-4) to measure and transmit range and range-rate to Mk 5 attack director; operated at 8–14kc, with a 2.5kc bandwidth. Bendix Aviation Co (1954).

SQR-10

Passive sonar, 11.6–12.4kc. Edo (1955).

SQR-11

Sonar target depth-determination at 13.6–14.4kc, presumably similar to SQR-8.

SQR-14

Very long-range towed array sonar (Interim Towed Array Surveillance System, ITASS). Gould.

SQR-15

Improved SQR-15, Towed Array Surveillance System (TASS) for specialized surveillance ships, as a backup to SOSUS. It was not procured in FY79 because SURTASS is expected to succeed it; however, seven were produced under earlier programs. It is similar to, but not interchangeable with, BQR-15. Gould.

SQR-16

Redesigned SQR-15 with some change in frequency range. Gould.

SQR-17

Sonar signal processor taking LAMPS data over a radio link; it takes this broadband input and provides a graphic display on a chart recorder and CRT of discrete frequency components, with a high order of resolution, permitting an operator to perform detection of underwater objects, limited classification, and target localization. It is similar in function to BQR-20, WQR-2, SQS-54, AQA-5 and AQA-7.

SQR-18

Interim Tactical Towed Array Surveillance System (TACTASS), developed under the Escort Towed Array Sensor (ETAS) program, and widely deployed aboard frigates. It consists of 32 vibration-isolated hydrophones towed from an SQS-35 VDS 'fish', with preamplifiers in the 'fish' proper. Edo.

SQR-19

Tactical towed array sonar, intended as the successor to SQR-18, but troubled during development and so badly delayed. It is scheduled for installation aboard most important ASW and fleet escorts, including the *Perry* class frigates and the *Spruances*.

SQS series

SQS-1

QHB replacement which entered production in November 1952; little used although 236 were made. It operated at 20–28kc (30kW, 12 or 36ms signals) with a $19^\circ \times 16^\circ$ beam, scanning at 90 cycles per second with 1500, 4000 and 6000yd range scales.

SQS-2

Redesignated as an SQS-1 variant, April 1951.

SQS-3

Redesignated SQQ-2, February 1950.

SQS-4

The first major postwar long-range sonar, first tested in the destroyer *Witek* in 1951; in effect it was a lower-frequency QHB with similar beam shape, and with three alternative pulse-lengths: 6ms (50kW), 30ms (30kW), and 80ms (10kW) at the original frequency of 14kc. Other variants reduced this to 8kc (Mod 1), 10kc (Mod 2), or 12kc (Mod 3), the original version becoming Mod 4. SQS-4 was generally considered reliable at about 5000yds, and it introduced a passive mode. Functioning as both a search and an attack sonar, it incorporated both ship-centered (PPI) and target-centered displays. Scanning at 150 cycles per second, it originally had 1000, 2000 and 5000yd range scales, but demonstrated long-range performance called for recalibration (2000, 4000, 6000 and 8000yds, and later 1000, 2500, 5000, 10,000 and 15,000yd scales). Later variants also reduced power at 80ms to 4 or 5kW. The sonar beam could be depressed by special DMCC (Dual Maintenance of Close Contact) windings on the sonar transducer staves, and in 1955 the destroyer *Sarsfield* tested SQR-8, which employed the DMCC windings for depth determination. The other major improvements were RDT (Rotational Directional Transmission), in which a single more intense beam was itself scanned. This system, devised by Sangamo, replaced the former transmitting system with 48 individual power amplifiers each of which could drive a single stave of the transducer at 2.8kw. There was also MCAR (Multiple Channel Aural Reception), also by Sangamo, in which three separate beams spread 7.5° apart, for a total beam-width of 22.5° , were used instead of a single 10° scanning beam, for faster search against high-speed targets. SQS-4 first entered the Fleet in 1954. SQS-10A was very similar, and SQS 29–32, 43–46 and 49–52 were developed versions, described below; the different frequencies called for different-size transducers and hence

for different-size sonar domes. Typical performance (1956) was detection at 4500/1500yds (with contact held out to 7500/2500); with RDT, detection at 7500/2100yds; with tribeam, at 8000/3000yds; and with VDS (then theoretical, not yet tested) at 8000/7000yds. In each case the destroyer was assumed to be moving at 15kts. First installed 1954; 250 produced for submarines and surface ships.

SQS-5

This was the first really low-frequency scanning sonar, achieving a spectacular 27,000yd detection during sea trials in 1955, aboard one Atlantic Fleet destroyer; it also introduced tribeam reception for faster search at very long range, and incorporated MCC. It operated at 7–15kc and 60kW (35ms pulse; alternative pulse-lengths were 5, 14 and 100ms) and scanned at 100 cycles per second, with range scales of 2000, 4000, 6000 and 8000yds. Directional transmission was possible. SQS-5 was never produced, presumably in view of the greater capability of SQS-23.

SQS-6

A small-ship variable-depth sonar, tested in 1951–52 aboard the destroyer escorts *Francis M Robinson* (DE-220) and *J Douglas Blackwood* (DE-219); it was developed from a somewhat simpler model tested in 1950 aboard the *Maloy* (DE-791). In each case the sonar was towed over the side because the ideal place from which to tow was thought to be the center of turn of the ship. Of a total equipment weight of 15 tons, the 'fish' weighed about 3 tons. The *Maloy* equipment worked with her QJB searchlight set; in the other two the hull set was QGB. 'Fish' depth was as great as 120ft. The over-the-side installation was rejected partly because the location of the tow point caused the 'fish' to pitch as the ship rolled.

SQS-7

A VDS version of the submarine sonar BQS-3 with higher power (12kc; 50kW at 3ms, with alternative pulse-lengths of 10, 30 and 60ms) and a $20^\circ \times 20^\circ$ beam; range scales were 2500, 5000 and 10,000yds. Service-tested 1953, and not adopted.

SQS-8

Abortive 10kc, 50kW (3ms) sonar, 1 pulse per second (corresponding to a range of only about 800yds, which seems unlikely). Canceled about 1952.

SQS-9

Towed sonar at a fixed depth of 40ft (weight less than 5000lb) for small ASW craft (PC, SC, coastal minesweepers). Service-tested March 1953 but not adopted. It had a $30^\circ \times 30^\circ$ beam and operated in searchlight mode at 14kc (1kW; pulse-lengths 3, 10 and 90ms, with 1500 and 3000yd range scales). Expected performance was 2000/2000yds for a 'fish' at 100ft with a 100ft layer.

SQS-10

Originally QHB-3, somewhat similar to SQS-4 but operating at higher frequency (20kc) and lower power (50kW at 6ms, 10 at 30ms, and 3 at 80ms), scanning at 150 cycles per second with a 19° beam (1000, 3000 and 6000yd range scales); SQS-1A was fitted with a capacitor to give a peak power of 30kW at 35ms pulse-length. It was specified for destroyers, escorts

and ASW conversions (DDE), as well as for the submarines of the first postwar (*Tang*) class; the first entered service in September 1951.

SQS-11

Similar to SQS-10 but operating at 25.5kc. SQS-11A had a capacitor to boost power at 35ms to 30kW, compared to 10kW without it. Typical performance was 1600/800yds (probability of detection 0.25 compared to the 0.5 figure more commonly used with more recent sonars) at 15kts, and 1300/800yds at 18kts.

SQS-12

Similar to wartime QCU-1; canceled about 1952.

SQS-13

Mine-detection sonar, sector-scanning at 110kc (location) and 385kc (classification), with $7.5^\circ \times 7.5^\circ$ and $1.5^\circ \times 1.5^\circ$ beams, respectively, tilting from 0° to 50° , and scanning at 1000 cycles per second (1kW, 0.4ms pulses; range scales 100, 500 and 1000yds). It appeared in January 1953 but was not produced; requirements were similar to those of the UQS-1 mine locator, not described here.

SQS-14

Long-range 10kc searchlight sonar, 1956; later credited with other frequencies between 5.8 and 10kc. It employed two-axis stabilization, and could scan at up to 8rpm, with 1500, 4500, 15,000 and 24,000yd scales, and alternative 1, 3 and 200ms (35kW) pulses and an $11^\circ \times 11^\circ$ beam which could tilt at 25° . Later versions operated at 60kW for the long pulse, or 200 for the shorter ones. It was said to combine the short-pulse features of SQS-8 with the long pulses of an NRL developmental sonar, for small-object location on the 1000yd scale and long range at 15,000yds. Searchlight operation was adopted to permit detection at very long ranges.

SQS-15

Variable-depth sonar mine-detector (searchlight type, with sector scanning); the first test model appeared in 1953, operating at 100kc with a $60^\circ \times 10^\circ$ beam which could be tilted from $+5^\circ$ to -50° . Scanning rate varied with range scale: 24rpm at 200yds, 5 at 500 and 2.5 at 1000, in each case with 1ms, 10kW pulses. It was not produced.

SQS-16

Experimental storage scanning sonar, similar to QHC, and tested in 1953. It trained at 8rpm but scanned at 150 cycles per second at 20–28kc with a $14^\circ \times 10^\circ$ beam. Pulse-lengths were 6 and 36ms (20kW maximum) and range scales 1500, 4000 and 6000yds.

SQS-17

Small-ship searchlight sonar for PCs and smaller ASW craft; service-tested in 1954. It was designed to achieve higher coverage rates than conventional searchlights by utilizing the USNUSL 'MASS' reception system, stepping 30° rather than the usual 5° . Use of low frequency (13kc) and a 35-cycle sector scan indicator in the 50-cycle band pass of the ear contributed to increased effective range. Peak power for a 35ms pulse was 30kW; several were exported to Allied navies.

SQS-18

Mine-locating sonar, operating at 55–65kc. Sangamo, 1955.

SQS-19

Mine-detection sonar, continuously sweeping the 75–85kc range. Edo, 1956.

SQS-20

Low-frequency sonar, presumably developmental (3.5kc, up to 60kW); RDT active, BQR-2B passive. In 1959 it was planned for the DERs. Edo.

SQS-21

Low-frequency sonar with special lightweight transmitter (5kc, up to 60kW). One source suggests instead a range of 13.5–14.5kc.

SQS-22

Torpedo-detection and -tracking sonar, designed to be suspended from a strut about 2ft forward and 8ft below the forefoot of a large combatant or auxiliary. It could operate passively against cavitating torpedoes, or actively against submarines and noncavitating torpedoes; displays included a torpedo range indicator (TRI). It operated at 13kc (20kW) in single-sector or tribeam modes, and could track automatically. Feasibility studies began in January 1956, a contract with Edo following that July; in 1959 it was tested aboard *LSD-29*, but was lost in rough weather almost at the end of the trials. Although a new transducer was delivered in 1961, the project appears to have died soon after.

SQS-23

The lower-frequency replacement for the SQS-4 series, in FRAM I ships and new construction; first installed 1958, 197 sets were produced. Base frequencies are 4.5, 5 and 5.5kc, and frequency can be varied within 380 cycles per second of the base frequency to reduce intership interference. Pulse-lengths are 2 (later versions 5), 30 and 120ms, with range scales of 1000, 2500, 5000, 10,000, 20,000 and 40,000yds, and a scan rate of 150 cycles per second. There are 48 staves, each with two transducers, for a total of 96 channels. The sonar beam can be depressed electronically to maintain contact with nearby targets. In the long-pulse, wide-sector, RDT mode, SQS-23H transmits 60kW for 4.3 seconds. Both fixed-frequency and FM-slide (400-cycle) pulses are employed in current versions. Recent development has focused on reliability and, presumably, a noise reduction for longer range (LORA). SQQ-23 is a modification with improved passive detection; SQS-23 was the '10,000-yard sonar' associated with ASROC. A performance estimate (1956, at 15kts) gave 12,000/3500yds. However, from time to time in the late 1950s, it was credited with a bottom-bounce capability. SQQ-23 was the active-passive equivalent.

SQS-24

An abortive 4.5kc replacement for SQS-4 (1956), with higher power.

SQS-25

An abortive 4kc replacement for SQS-4 (1956), with higher power.

SQS-26

The culmination of US low-frequency sonar

development of the 1950s, designed to achieve maximum direct-path range (probably about 20,000yds reliably) plus longer range through bottom-bounce or convergence-zone (about 70,000yd) operation. Very long range was achieved through low frequency (3–4kc) and very high power (reportedly up to 192kc). Feasibility studies began in July 1955; the Edo XN-1 model was installed aboard the large destroyer *Willis A Lee* in September 1961, the General Electric XN-2 aboard the *Wilkinson* in June 1961 (scheduled dates were, respectively, November 1959 and June 1960). General Electric then produced 12 SQS-26AX sonars, Edo following with 18 SQS-26BX, and General Electric producing all sonars to SQS-26CX standard from a contract date of October 1964 onwards. Production sets were first installed in 1963, and 81 were produced (77 for ships, 4 for trainers). In March and April 1965, GE received contracts to modify existing -26AX to -26AXR standard. The SQS-26 sonar itself was approved for service use only on 4 November 1968 after considerable difficulties. For example, evaluation of the XN-2 model in 1963–64 showed that it was incapable of bottom-bounce operation. Major improvements over the course of SQS-26 development included much higher power and a rubber rather than a steel sonar dome, as well as measures for increased reliability. The first installations required a separate 450kW or even 600kW turbogenerator for the sonar and its signal processor, but operational units use standard-ship service power. The transducer is about $5\frac{1}{2}$ ft high and 16ft in diameter, and weighs about 60,000lb. SQS-26BX operated at 3.05–3.85kc (114kW); it could also operate passively at 2.5–3.5kc. The alternative SQS-26CX version originally operated at 100kW (down to 1.5kc passive, 3–4kc active). A considerable degree of electronic beam steering in elevation was required to permit beam depression for bottom-bounce and convergence-zone operation. The current SQS-53 is a solid-state version, reportedly with similar performance but greater reliability and better signal processing.

SQS-27

Designation not used.

SQS-28

Commercial sonar; Minneapolis-Honeywell 1B1 Sea Scanner (175kc, 30° sector), 1958.

SQS-29

SQS-4 (Mod 1) with RDT; pulse-lengths are 2, 7, 30 or 120ms with a 4–50kW power level. Range scales are 1000, 2500, 5000, 10,000, 15,000 and 30,000yds and there is also passive search. The series (through -32) introduced ASPECT (Acoustic Short-Pulse Echo Classification Technique), in which a short burst of transmissions in a steered beam provides some indication of target shape; it also incorporates a test set and control unit as part of the system. Analogous RDT versions of SQS-4 Mods 2, 3 and 4 were SQS-30, -31 and -32.

SQS-33

Modified SQS-20, a towed projector being added. Canceled.

SQS-34

Redesignated SQS-26A.

SQS-35

Independent variable-depth sonar using SQA-13 hoist, operating at 13kc and a peak power of 30kW, with 12 preformed RDT beams and a total of 24 channels (staves). Development began in 1959, and prototypes appeared in 1962. A total of 45 were produced, the first installations taking place in 1967. SQS-36 is a hull-mounted equivalent with the same electronics; SQS-35V substitutes solid-state electronics for the miniaturized vacuum tubes of SQS-35 and -36. Feasibility studies began in June 1956, the first contract following in June 1960. It was a development of SQS-17. Edo.

SQS-37

Mine-detector for riverine craft, modified from the swimmer-carried PQS-1B.

SQS-38

Hull-mounted small-ship sonar, operating at 11.9, 13 and 14.1kc; a solid-state version of SQS-36. *Hamilton* class Coast Guard cutters. First installed 1967; 14 produced.

SQS-39

SQS-4 (Mod 1)/SQS-29 with SDT (Steered Directional Transmission) via MARK (Maintainability and Reliability Kit) added. Total of 48 channels, 2.8kW per channel in RDT/SDT mode. Sangamo.

SQS-40, -41, -42

Analogous modifications of SQS-30, -31 and -32.

SQS-43

SQS-29B or -C modified for RDT, SDT, and operation of a VDS off the same electronic 'stack'. MARK modified.

SQS-44, -45, -46

Analogous modifications of, respectively, SQS-30B or -C, -31B or -C, and -32B or -C.

SQS-47

Mine-detecting sonar.

SQS-48

Doppler sonar.

SQS-49

SQS-4 Mod 1 with MARK.

SQS-50, -51 and -52

Analogous conversions of SQS-49 Mods 2, 3 and 4.

SQS-53

General Electric SQS-26CX redesigned with digital interface for Mk 116 underwater fire control system; performance generally similar to SQS-26 but benefiting from improved electronics.

SQS-54

Sonar spectrum analyzer, not a sonar proper.

SQS-55

High-precision underwater object tracker, using 100kc, 1 and 2ms pulses, with sixty $2^\circ \times 10^\circ$ beams and 300 and 600m scales. It uses an acoustic lens and a core memory display.

SQS-56

The small hull-mounted direct-path sonar of the *Perry* class frigates, operating at 5.6, 7.5 and

8.4kc (36kW); built by Raytheon. DE-1160B is an export version. It operates entirely digitally in both passive and active modes. It was first tested in 1975, and completed Operational Test and Evaluation in 1978, production beginning in 1979.

AQS Series (Airborne Sonars—Blimp-Towed and Helicopter-Dipped)**AQS-1**

Prototype helicopter-dipped sonar, tested 1947 from an HUP, and discarded because of the large number of helicopters required for effective operation. Its two transducers were mounted back to back. Operation was at 28, 30, 32 or 34kc, with an additional 3–10kc receiving band.

AQS-2

Prototype blimp-towed sonar, also known as ATERE (Airship-Towed Echo-Ranging Equipment). AQS-3 (21, 23 or 25kc rather than a single channel at 25kc) was an unsuccessful competitor. At a speed of advance of 24kts, it could detect a submarine in the layer at 2900yds, and one below at 1800. It was evaluated in 1956. Weight was about 450lb. Raytheon (DE-110B).

AQS-4

The first operational helicopter-dipped sonar, operated by HO4S machines in 1953. It operated at 20–22kc, producing a 30° search-light beam with an initial design power of 1kW for a range against a shallow target of 4700yds. In fact power was only 200W (15–100ms pulse) and range only 1900/1300yds. AQS-4D increased power to 300W, and operation was at 21kc. The initial contract called for 152 units, increased by 600 under the Third Supplemental FY51 program. By 1956 it was clear that much lower frequencies would increase detection range; in 1957 NRL hoped to test a new LOMASS-2 which could be either towed or dipped. At 2kc it could detect a submarine at 12,000/3200yds if dipped, or at 15,000/3500yds if towed, in both cases at an average speed of advance of 35kts, compared to 11 for AQS-4. The latter typically operated at 20–60ft, with a 70ft cable; it was replaced by AQS-10. Raytheon.

AQS-5

In effect an AQS-4 with a much longer (200ft) cable and similar performance (300W in -5A) and with an auxiliary underwater communications feature (0.287–11.087kc at 20W). It originally operated from HSS-1N (SH-34J) helicopters. General Electric.

AQS-6

Airship dipping sonar operating at 15kc (Raytheon DE-113). It was intended to operate from a hovering airship.

AQS-7

Airship or helicopter mine-location sonar (towed); it was similar to the shipboard UQS-1 of the early 1950s, operating at 175kc, with a 1200ft cable.

AQS-8

Helicopter mine-hunting sonar, detecting bottom mines by FM operation at 97.5–112.5kc. This nomenclature was assigned in 1954; it does not appear to have entered service.

AQS-9

Helicopter-dipped sonar, operating at 19–24kc (1954).

AQS-10

Bendix low-frequency scanning dipping sonar, development of which began in 1955; it became operational in 1959 aboard HSS-1N and HSS-2 helicopters. Operating at 10kc, it weighed 750lb and had a 210ft cable; it was rated at two to six times the search rate of AQS-4, thanks to its greater average range, 7500/4000yds *vs* 1900/1300yds. It was replaced in turn by AQS-13. AQS-11 was an unsuccessful alternative.

AQS-12

Abortive helicopter-dipped ASW sonar, described in 1961 as much lighter than AQS-10 or -13 and so possibly suited to drone operation.

AQS-13

Developed AQS-10 with longer (500ft) cable and higher reel-in rate (13 *vs* 5ft/sec), operating at 9.25–10.75kc (5kW, 3.5 or 35ms, with range scales of 1000, 3000, 5000, 8000, 12,000 or 20,000yds). Typically it is dipped by the SH-3A (HSS-1N) helicopter. It employs a 180° wide pulse with scanning reception, and is sometimes credited with 3.5kW for 40ms. The dip cycle, the time from transducer launch to recovery, including transmission, is 2–3 minutes, and operating depth (with the helicopter at 50ft) is 450ft. Typical range is 4000yds, and weight, installed, is 775lb, matching that of the earlier AQS-10. It appeared in 1960, and in 1964 was succeeded by AQS-13A (825lb); by -13B in 1969; and by -13Ein 1981, with -13F scheduled for 1982. AQS-13B, 625lb, has sixteen preformed beams; -13C added a sonobuoy interface feature; -13E adds APS (Adaptive Processing Sonar) for better shallow-water performance through Fast Fourier Transform narrow-band analysis of the coded sonar pulse. That is, the typical 35ms rectangular pulse of the earlier versions is equivalent to a complex pattern of frequencies. By selecting instead a 200ms cosine-squared pulse in APS, the sonar gains a much narrower frequency spectrum at the cost of poorer range definition. That in turn allows much better measurement of doppler shifts in the presence of considerable reverberation. AQS-13B adopted hybrid microcircuits which saved 200lb and allowed the adoption of a single 360° ODT 'ping' for faster scan. It also incorporated BITE equipment. APS was made possible by the adoption of a microprocessor, and a 7dB gain in target detection was claimed. AQS-13F is all-digital, 615lb, with a new 1500ft cable and higher power (5dB). Digital data in turn permitted the use of a much lighter cable. Two prototypes were tested, but receiver beam patterns were badly distorted at depth due to increased pressure, and US Navy involvement ceased. AQS-18 is the developed version.

AQS-14

Westinghouse towed mine-hunting sonar, a side-looking array.

AQS-17

Bendix helicopter-dipped and -towed mine-hunting sonar.

AQS-18

Development of the Bendix AQS-13F, currently limited to the West German Navy but under study for the US Navy as well; 580lb with a 1000ft cable. Hoist rises at about 27ft/sec, and lowers at 17ft/sec, operating at 9.2-10.8kc (3.5 and 35ms; range scales 1000, 3000, 5000, 8000, 12,000 and 20,000yds); modes include MTI, passive, and voice communication. APS is optional. Like AQS-13F, it uses a separate transmitter and receiver, with a lead-acid battery pack in the sonar 'fish' proper and no capacitor to store energy for each pulse; rather, the helicopter passes power to recharge the battery between transmission cycles, and power is said to be twice that of the original AQS-13B. The high-speed winch keeps the dip cycle as short as 950, or, at 1450ft, at 450 as in earlier systems.

III-2 Sonobuoys

Only the World War Two buoys had CRT designations; all postwar types were designated in an SSQ series, the 'C' (portable) prefix becoming obsolete in 1945. Postwar buoys generally fall into two sizes: 'A' (4 $\frac{1}{4}$ in $\times$ 36in) and the larger 'B' (6 $\frac{1}{8}$ in $\times$ 60in), and typically operate on 31 radio channels at 162-174mc.

CRT-1

The first US air-dropped sonobuoy, about 'A' size (4in $\times$ 36in, 12-14lb), with a 4-hour life, listening broadband at 100 cycles to 10kc, and descending by parachute, with a 30ft deep hydrophone. There were six radio frequencies around 70mc, with buoys color-coded by frequency. A total of 59,700 CRT-1A were bought by the Navy through 1944, and this buoy remained standard for the early postwar period.

CRT-4

First US directional (passive) sonobuoy, operationally evaluated in 1945 but not produced; slightly smaller than 'B' size (6 $\frac{1}{4}$ in $\times$ 52 $\frac{1}{2}$ in, 30lb), and with a 5-hour life. It was rotated by the drop of a weighted fishline, a gravitational motor, at 1 hour per 100ft of packaged line; it scanned through 360° at 3-5rpm, depending on sea state, and had an accuracy of about 11°. Parachute descent.

SSQ-1

Postwar directional listening buoy. Work began 1949 but both first and second contractors failed, Magnavox being the third (developed 1954-60); it was replaced by DIFAR. It was 'B' size, 60lb, operated at 5-17kc at 50ft and had a 1-hour life.

SSQ-2

Postwar omnidirectional passive buoy, intended to complement SSQ-1. Work began in 1946 but the first contractor failed, and Hazeltine built a successful model (XN-2) in 1950-51. It was lowered by rotocute, and was 'A' size, 16lb, with S- and X-band radar beacons; it listened at 100 cycles to 10kc (-2B, 200 cycles to 20kc; -2D, 100 cycles to 2kc). Succeeded by SSQ-23.

SSQ-3

Developmental active sonobuoy, 750lb.

SSQ-7

Abortive sonobuoy. No data.

SSQ-10

Buoy communications relay between aircraft and submarines.

SSQ-15

Omnidirectional active 'pinger', operating at 28.4-38kc, 40W; 'B' size, 100lb, with a transducer 40ft below the surface and a rotocute. Nomenclature was originally assigned in 1950 and SSQ-15 appeared in 1952, but it was initially eclipsed by 'Julie', then revived in view of the failure of the CODAR data processor.

SSQ-17

Passive omnidirectional buoy for harbor defense, 5ft $\times$ 10ft, 1952.

SSQ-20

British-designed buoy, interim for SSQ-1, bought 1954-56: 8in $\times$ 60in, 81lb, parachute descent. A total of 3500 were bought.

SSQ-23

Passive sonobuoy for 'Jezebel'; 'A' size, 16lb, rotocute descent, nondirectional; 400 cycles to 6kc.

SSQ-26

Developmental sonobuoy for 'Julie' explosive echo-ranging; first US line hydrophone; 'A' size, 16lb.

SSQ-28

Omnidirectional 'Jezebel' buoy used with LOFAR-CODAR, 1960-65 (AQA-3 airborne equipment).

SSQ-31

Underwater sound source for 'Julie', using SSQ-2 housing, dropping an explosive charge to a preset depth.

SSQ-36

Expendable bathythermograph; cable probe to 1000ft; 'A' size, 20lb.

SSQ-37

Buoy, Underwater Sound Source (BUSS) with multiple charges; developmental only.

SSQ-38

Passive LOFAR search buoy, 1964, about 10lb ('Jezebel').

SSQ-39

Passive 'Julie' sonobuoy, 1961, at 1-3kc; differed from earlier 'Julie' buoys in using a line hydrophone providing vertical directionality from an array operating at a depth of 12,000ft.

SSQ-40

Classified sonobuoy.

SSQ-41

Nondirectional sonobuoy, a line hydrophone for 'Julie-Jezebel', operating at 10 cycles to 20kc at a depth of 60 or 300ft, for 1-, 3- or 8-hour lifetimes; the 1 hour version has a night light (1965). SSQ-41B operates to 10kc at 60 or 1000ft; SSQ-41A by Magnavox (others by Sparton) is similar.

SSQ-42

Nondirectional buoy, miniaturized 'Julie-

CODAR' with speed brake, 1958 (3in $\times$ 24in). A competitor to SSQ-46, it lost out largely because of the extensive aircraft modifications which would have been required.

SSQ-44

Combination of SSQ-23 and -28 functions, 1960 ('Julie-Jezebel'), listening at 20-1500 cycles: Command-activated, it was developmental only.

SSQ-45

Passive sonobuoy operating at 40 cycles to 4kc, with a line hydrophone; developmental only (1960-63).

SSQ-46

Comparable to SSQ-42, for explosive echo-ranging, with a miniaturized line hydrophone; it was directional. Developmental only (1960-65).

SSQ-47

Omnidirectional active buoy developed by Sparton from SSQ-15 (XN-4) from 1959 onwards: 13-19kc, 1ms pulses, one every 10.2 seconds, at a depth of 60 or 800ft.

SSQ-48

Classified sonobuoy.

SSQ-49

Directional passive sonobuoy ('Julie'), developmental only, 1965-69; 200 cycles to 4kc.

SSQ-50

CASS (Command-Activated Sonobuoy System), operating at 6.5-9.5kc at 269W, with 10, 100, 500 or 1000ms pulses, one every 12 or 48 seconds; nondirectional; depth 60 or 1500ft. Sparton, developed from 1964 onwards.

SSQ-51

Similar to SSQ-38; passive sonobuoy, 17ft long including antenna, with 8in $\times$ 122in case, 200lb (1964).

SSQ-52

Similar to SSQ-41 but active; developmental only (1964-65).

SSQ-53

Passive directional sonobuoy, operating at 90 or 1000ft, with a lifetime of 1 or 8 hours, 'A' size, 26lb, for Directional LOFAR (DIFAR) at 10 cycles to 2.4kc (1969).

SSQ-55

Directional passive sonobuoy, similar to SSQ-53 (10-300 cycles); it used a continuously rotating beam. Developmental only, 1966.

SSQ-56

Bathythermograph buoy.

SSQ-57

Sound reference buoy, nondirectional at 10 cycles to 20kc with very flat response, at 60 or 300ft depth, with 1-, 3- or 8-hour life. Sparton.

SSQ-58

Sonobuoy similar to SSQ-38 for 'Jezebel'. It could be anchored in up to 500 fathoms with a 30-day lifetime, in currents up to 5kts and Sea State 5, and could withstand Sea State 6 and 40kts.

SSQ-60

Bathythermograph similar to SSQ-56, for through-the-hull launch.

SSQ-61

Bathythermograph, reaching 1500ft in 90 seconds.

SSQ-62

DICASS directional active sonobuoy, at 60 or 1500ft, 39lb; feasibility contract let to Sparton, 1968.

SSQ-63

Sonobuoy; canceled 1969.

SSQ-66

Classified sonobuoy.

SSQ-68

Sonobuoy similar to SSQ-57. Depth 1000ft, 10 cycles to 20kc, omnidirectional, lifetime 1, 3 or 8 hours. Sparton.

SSQ-71

Air-launched two-way air-submarine acoustic communications buoy (ATAC); 'A' size, 25lb.

SSQ-73

Air-launched 'A'-size deep directional 'Jezebel' buoy.

SSQ-75

Long-range active sonobuoy, command-activated. 'B' size, 175lb, using 2- or 5-second pulses, with a 3-hour life; depth 60-16,500ft.

SSQ-77

VLAD (Vertical Line Array Directional) sonobuoy, 'A' size, 29lb, using nine omnidirectional

hydrophones and two geophones in place of the usual single DIFAS hydrophone; a conventional DIFAR hydrophone mounted at the array phase center provides bearing data. The vertical elements of the array permit detection of bottom-bounce sounds and allow shipping noise to be filtered out; SSQ-77 should be particularly valuable in very noisy areas such as the Mediterranean. Coverage is 10 cycles to 2.4kc, transducer depth 1000ft, and operating lifetime 1 or 8 hours. All beam-forming functions are performed within the sonobuoy, and signal processing is by AQA-7.

SSQ-79

Passive sonobuoy, comparable to SSQ-41, -48, -57 and -72; SVLA (Steerable Vertical Line Array), 'A' size, operating at 1000ft, with 4- or 8-hour lifetime.

SSQ-83

Search and rescue buoy, transmitting continuously for 60 hours and acting as a communications link between personnel in the water and rescuers.

Other SSQ designations

SSQ-4, -8, -9, -14 and -16 were stable elements (stabilization sets), the last specially for SPN-6. SSQ-6 and -18 were time signal sets; SSQ-11 and -12 were countermeasures receivers; SSQ-13 monitored the temperature around electronic equipment (1951); SSQ-19 was an abortive target data distribution set; SSQ-21 and -22 were experimental automated CICs for, respectively, cruisers and destroyers; SSQ-24 was a data-receiving and -transmitting set for a drone surface craft equipped with an underwater obstacle detector and depth sounder (1955); SSQ-25 was a Naval Elec-

tronics Laboratory automated CIC (only one of which was built); SSQ-27 was a frequency-time standard; SSQ-29 and -30 were NTDS data terminals; SSQ-32 through -35 were operations centrals, later redesignated SYQ-1 through -4 (1959); SSQ-43 was a chemical attack detector (1963); SSQ-54 was a shipboard emitter status monitor to permit more effective (electronic) emission control, EMCON; SSQ-59 was a remotely operated shipboard switching system; SSQ-64 was an amphibious command ship intelligence center (1969); SSQ-65 was a quality monitoring set; SSQ-67 was a facility control system for shipboard communication (1977); SSQ-69 was an infrared searchlight; SSQ-70 was an operational information collection system; SSQ-76 was a moored intruder detector to protect against small surface craft; SSQ-78 is a tactical display unit; SSQ-80 is a van containing an operational information collection system, for surface ships; SSQ-81 was a radar emitter for a target boat, to test the Standard Missile (1976); and SSQ-82 was a shipboard emission control system (1976), MUTE (Multiple Unit for Transmission Elimination). Two units deserve special mention. SSQ-72 was 'Classic Outboard', for signal acquisition and direction-finding, in combination with SRD-19 ('Diamond') and SLR-16 (an ESM receiver). SSQ-74 was a van-mounted simulator station, for temporary installation on destroyer weather decks, with a gross weight of 18,000lb. A 1974 development, it was described as a radar and communications simulator, presumably for deception tactics.

III-3 Torpedoes

Torpedo	Diameter (in)	Length (in)	Weight (lb)	Warhead (lb)	Range (yds)/at (kts)	Remarks
Howell	14.2	132	580	100	400/25	
Whitehead Mark 1	17.7	140	845	118	800/26.5	3.55m version; cold-running.
	17.7	197	1160	220	800/27.5	5m version; gyro control. Designated Type B in 1913.
Whitehead Mark 2	17.7	140	845	118	800/27	3.55m version; very similar to Mk 1.
	17.7	197	1232	132	1500/28.5	Developed from 5m Mk 1, using 20 percent more air pressure to achieve much greater range. Designated Type C, 1913.
Whitehead Mark 3	17.7	140	845	118	800/26.5	Gyro control reduced error right or left from 24 to 8yds; redesignated Type A, 1913.
Bliss-Leavitt Mark 1	21	197	1500	200	4000/27	Turbine torpedo with greater air pressure and a heater, introduced 1904. Mk 1, 1913.
Bliss-Leavitt Mark 2	21	197	1500	200	3500/26	Contrarotating propellers introduced to overcome unbalanced torque of Mk 1. Introduced 1905, designated Torpedo Mark 2 in 1913.
Bliss-Leavitt Mark 3	21	197	1500	200	4000/26	Mk 2 with increased range; Torpedo Mark 3, 1913.
Bliss-Leavitt Mark 4	17.7	197	1500			Submarine torpedo; Torpedo Mark 4, 1913.
Whitehead Mark 5	17.7	204	1452	200	4000/27 2000/36 1000/40	Heater torpedo; first to permit variable range adjustment. First torpedo manufactured at Newport (1908). Replaced by Bliss-Leavitt Mk 7.
Bliss-Leavitt Mark 6	17.7	204	1800		2000/35	Destroyer and cruiser torpedo (1911); horizontal rather than vertical turbine.

APPENDICES

Torpedo	Diameter (in)	Length (in)	Weight (lb)	Warhead (lb)	Range (yds)/at (kts)	Remarks
Bliss-Leavitt Mark 7	17.7	204	1628	326	6000/35	Submarine and destroyer torpedo, introducing water spray into combustion pot: steam torpedo. Issued 1912, in service through 1945. Also air-dropped. TNT or TPX warhead instead of wet guncotton.
Mark 7 (Type D)	17.7	144	1036	281	2000/35	Short version of Mk 7 for some submarines, developed by Washington Navy Yard, 1917. Not produced in quantity.
Bliss-Leavitt Mark 8	21	256.3	2600	466	16000/36	First US 21in × 21ft torpedo; destroyer weapon. Introduced 1911; some issued to Great Britain for use in flush-deck destroyers, 1940.
Bliss-Leavitt Mark 9	21	197	2015	210	7000/27	Battleship torpedo (1915), used in World War Two to supplement stocks of Mark 14 ('R' and 'S' class submarines). Last Bliss torpedo.
Mark 10	21	195	2215	497	3500/36	Submarine ('R' and 'S' class) torpedo with unusually large warhead (1915); developed by Bliss and NTS.
Mark 11	21	271	3511	500	15000/27 10000/34 6000/46	'Universal' torpedo with first three-speed setting selectable in tube (1926); first all-Navy developed torpedo. Destroyer-launched.
Mark 12	21	271	3505	500	7000/44	Refined Mk 12 with lower high-speed setting for greater reliability (1928).
Mark 13	22.5	161	2216	600	6300/33.5	Aircraft torpedo (1936). TPX warhead.
Mark 14	21	246	3209	643	9000/31.1 4500/46	Submarine torpedo developed from Mark 10 (1931), still in use late 1970s.
Mark 15	21	288	3841	825	15000/26.5 10000/33.5 6000/45.0	Destroyer torpedo (1935) to replace Mk 11 and 12. Last major surface-ship torpedo.
Mark 16	21	246	4000	746	11000/46.2	'Navol' (hydrogen peroxide) torpedo, developed 1944 and withdrawn from service 1975.
Mark 17	21	288	4600	879.5	18000/46	Destroyer equivalent of Mk 16. Development dropped in 1941, resumed 1944 in view of knowledge of Japanese 'Long Lance.' Withdrawn 1950.
Mark 18	21	245	3154	575	4000/29	Submarine-launched electric torpedo, based on German G7e, developed by Westinghouse. In service 1943–50.
Mark 19	21	246	3240	800	4000/29	Developed Mk 18, superseded by Mk 26 (1942).
Mark 20	21	246	3100	500	3500/33	NTS electric torpedo (1943); not pursued.
Mark 21	22.5	161	2300	400	/25	Aircraft-launched electric homing torpedo (antiship). Successful launch tests 1943, but soon abandoned in favor of Mod 2 (homing version of Mk 13 torpedo for Petrel missile).
Mark 21 Mod 2			2130	350	6000/33.5	Bell Labs; 312 produced 1946–55.
Mark 22	21	246	3060	500	4000/29	Bell/Westinghouse electric anti-surface-ship homing torpedo; begun 1944, discontinued 1945 in favor of Mk 35.
Mark 23	21	246	3259	643	4500/46.3	Essentially Mark 14 limited to its high-speed feature (1943–46).
Mark 24	19	84	680	92	4000/12	Originally Mine Mark 24; air-launched passive acoustic homing torpedo with 10-minute run. Replaced by Mk 34 (service 1942–48).
Mark 25	22.5	161	2306	725	2500/40	NDRC replacement for Mk 13 (1943) with thermal propulsion; never mass-produced, due to large Mk 13 inventory postwar.
Mark 26	21	246	3200	900	6000/40	Electric submarine antiship torpedo (1944); rejected in favor of Mk 16.
Mark 27	19	90	720	95	5000/12	Mk 24 modified for submarine launch with 21in guide rails; 12-minute run. In service 1943–46. Mod 4 was antiescort, replaced 1960 by Mk 37.
Mark 27 Mod 4		125.75	1175	128	6200/15.9	Introduced 1946.
Mark 28	21	246	2800	585	4000/19.6	Submarine acoustic torpedo (electric power) with 6-minute run; 1750 produced 1944–52, replaced 1960 by Mk 37.
Mark 29	21	246	3200	550	12000/21 4000/28	Westinghouse antiship electric torpedo with same acoustic guidance as Mk 28, but faster, operated as either straight-run or homing weapon, and had external depth-setter. Mod 1 had two speeds and anti-circular-run device. Canceled April, 1945.
Mark 30	21	246		600	4000/29	Wake-following antiship torpedo project, 1944–46; Mk 14 and 18 test bodies.

Torpedo	Diameter (in)	Length (in)	Weight (lb)	Warhead (lb)	Range (yds)/at (kts)	Remarks
Mark 30	10	96	265	50	3000/12	Torpedo-mine, backup for Mk 24 (1942).
Mark 31	21	246	2800	500	4000/29 12000/20	Acoustic version of Mk 18; interim project (1944-45).
Mark 32	19	83	700	107	9600/12	Surface-ship-launched homing torpedo; first active acoustic type; 25.4in fins; launched over the side. Run time 24 minutes. Developed in 1950; about 330 were made by Philco. Withdrawn 1955 in favor of Mk 43.
Mark 33	21	156	1795	550	19000/12.5 5000/18.5	Passive acoustic antiship/antisubmarine torpedo for submarine or air launch; first cast aluminum shell. Tested 1943-46; features incorporated in Mk 35.
Mark 34	19	125	1150	116	12000/11 3600/17	Initially designated Mine Mark 44; improved Mk 24 with magnetostrictive not crystal hydrophones. Also had two batteries in parallel/series arrangement to permit lengthy search (30 minutes at 11kts) and then faster attack (6-8 minutes at 17). Developed in 1944; about 4050 made (service 1948-58); replaced by Mk 43. Measured 26.4in across fins.
Mark 35	21	162	1770	270	15000/27	'Universal' torpedo derived from work on Mk 24, 32 and 33; about 400 produced 1949-52. Replaced by Mk 37 about 1960.
Mark 36	21	246	4000	800	7000/47	Electric submarine pattern-runner optimized for high speed and long range, designed early 1944 under amended Mk 20 contract; abandoned postwar in favor of Mk 42.
Mark 37	19	135	1430	330	8000/24 18000/16	Mk 0 and 3 standard US submarine weapons from 1956 on, Mod 3 being refurbished Mod 0. Engineering development began 1946: passive/active homer. Guide rail 21in. Mk 1 and 2 wire-guided (1690lb, 21in x 16in, 1962). Acquisition range 700yds. (Performance data for Mod 1; enable 300-9500yds).
Mark 38	21	246	3000	600	10000/35	Planned postwar replacement for Mk 28, terminated in favor of Mk 37.
Mark 39	19	133	1275	130	13000/15.5	First US torpedo with wire for midcourse guidance, derived from Mk 27. Run time 26 minutes. In service 1946-56.
Mark 40	21	105	1250	300	2000/80	Abortive air- or missile-launched antiship torpedo with hydro-turbojet or pumpjet propulsion, based on wartime German work; abandoned due to changes in requirements away from antiship.
Mark 41	21	120	1327	150	8000/25	Air-launched version of Mk 35, 1949. About 200 made, but abandoned in favor of Mk 43.
Mark 42	21	246	4000	800	20000/40	Submarine-launched pattern-runner, 1949, abandoned 1952 in favor of proposed pattern-running version of Mk 16.
Mark 43	12.75	88.25	370.4	60	4300/20	Electric air-launched ASW torpedo. This Mk 0 (1950) abandoned in favor of Mod 1 (500 built).
Mark 43	10	91.5	260	54	4500/15	Mod 1 data given; Mod 3, 265lb, made same 4500yds at 21kts (6 vs 9 mins). Surface and air launch. Mod 1 13.4in across fins, Mod 3 10in overall. Replaced by Mk 44 1957, after about 5000 produced.
Mark 44	12.75	100	425	75	6000/30	Mod 0 data; Mod 1 101.3in long, 433lb, 73lb warhead. Seawater-activated battery; helix search; active acoustic homing. Production began 1957; replaced from about 1967 by Mk 46.
Mark 45	19	225	2330			Nuclear torpedo (ASTOR), wire-guided and electrically propelled; developed 1957, withdrawn 1976, bodies being converted into conventional 'Freedom Torpedoes' for sale abroad. Mod 1, 227in long, 2213lb, had 2050yd enable range.
Mark 46	12.75	102	568(dry)		12000/45 6000/40	Speeds for 50 and 1500ft, respectively, for Mod 0: current lightweight torpedo, developed 1960, in service 1963. Solid propellant; Mod 1, 508lb, uses liquid (Otto) fuel. This and Mk 44 have runout to escape own-ship interference, after which they spiral-search. EX-8 was Mk 46 Mod 0. Acquisition range 1600yds (1964), 60 percent improvement over Mk 44 at that time.
Mark 47						Proposed submarine antiship torpedo, terminated in favor of Mk 48, 1970.
Mark 48	21	230	3480		35000/55	Current heavy torpedo: wire midcourse guidance. Mod 1 uses piston engine; Mod 2 (abandoned) used turbine. Performance based on stated range of 20 miles at 'nearly twice the speed' of Mk 37. Can dive to 2500ft, acquire target at 4000yds (vs 1000 for Mk 37, 650 for Mk 43 Mod 1).
Mark 49						Carried on books since 1977; may denote successor to Mk 48.
Mark 50	12.75	117	800			Honeywell Advanced Light Weight Torpedo, chosen 1981.
Mark 51						Unsuccessful McDonnell Douglas Advanced Light Weight Torpedo.

III-4 Mines

Mks 1 through 4 were originally designated Naval Defense Mines; in each case where weights are given, the first figure is total mine weight, the second explosive weight. Mks 1 through 4 were declared obsolete in 1930.

Mark 1

Spherical (34in) moored mine with inertia pistol.

Mark 2

Sauter-Harle (French) mine: spherical, with a charge of about 175lb of guncotton, contact-inertia exploder; approximate date 1909.

Mark 3

Vickers-type mine; manufacture began about 1915. It had a protruding float, 3ft long, for inertia explosion; diameter was 30in, with a 120lb charge.

Mark 4

Similar to Mk 3 but larger (33in diameter, 250lb charge); 1916.

Mark 5

Moored Hertz horn mine, still in use during World War Two: 1700/500lb.

Mark 6

Mine for North Sea antisubmarine barrage of World War One; spherical antenna type, 34in diameter, 1400/300lb (TNT charge). Could be moored in up to 3000ft of water; K-type pistol. Mod 2 was a rising type; Mod 3 had a Mk 9 case, 100ft lower antenna; Mod 4 had a Mk 6 case, 50ft lower antenna.

Mark 7

Originally assigned to a moored magnetic mine which was not developed, then applied to Drifting Mine Mark 7, which was based on the K-mechanism of Mk 6: 943/525lb. Mod 1 was an oscillating mine.

Mark 8

Surface-planted acoustic mine, development of which was not completed.

Mark 9

Similar to Mk 6, but with supersensitive detonator: float and antenna and sea-cell grid, plus horns; development was not completed.

Mark 10

Moored contact mine for firing from 21in torpedo tubes, with horn antennas, about 1760/300lb. This project began about 1921, was dropped for a time, then revived. Mod 3 was magnetic (1800/420lb); Mod 4 (1000lb TNT) was a submarine-moored magnetic mine (discontinued); Mod 5 was an aircraft-moored contact mine (Mod 2 plus parachute; canceled); Mod 6 and Mod 8 were parachute versions of Mod 3, replaced by Mod 9 (1850/420lb); Mod 7 was a Mod 3 modified for PT-boat launch; Mod 9 was a moored aircraft magnetic mine (1918/420lb); and Mod 11 was a moored contact mine for the *Argonaut* (1900/500lb).

Mark 11

K-type mine for submarine laying by *Argonaut* (1875/500lb).

Mark 12

Cylindrical, aluminum-case, submarine-laid bottom mine, derived from German S-type in 1920s; the first batches delivered to Manila just before the outbreak of war had to be dumped in deep water to avoid compromise. Weights were 1445/1100lb TNT or 1595/1250lb TPX, and dimensions 20 $\frac{1}{16}$ in $\times$ 94 $\frac{1}{4}$ in. Magnetic. Mod 1 was for aircraft launch (not over 130.94in long total); Mod 2 was adapted for PT laying (abandoned); Mod 3 was a redesign for submarines (1390/1060lb TNT or 1500/1200lb TPX); and Mod 4 (aircraft ground mine, 1560/1060lb TNT or 1700/1200lb TPX) superseded Mod 1.

Mark 13

Aircraft-laid magnetic mine (1048/640lb TNT, 1118/710lb TPX), planted without parachute; it could also be used as a bomb. Mods 1 and 2 became Mk 26 Mods 0 and 1; Mod 3, with a parachute (1080/640lb TNT or 1150/710lb TPX), was not issued; Mod 4 was for shallow water; Mod 5 (990/640lb TNT or 1060/710lb TPX) had no parachute, but was fitted with an acoustic exploder; and Mod 6 was acoustic with a parachute (1020/640lb TNT, 1090/710lb TPX).

Mark 14

Aircraft-laid drifting mine with K-mechanism; not produced.

Mark 15

Aircraft-laid acoustic ground mine (900/500lb). Nondirectional acoustic (A-2) mechanism; 19in $\times$ 80in. Stopped September 1944.

Mark 16

New antenna mine superseding Mk 6. Mod 1 weighed 2040/600lb; Mod 2 was acoustic. The original Mk 16 was a magnetic project (M-6 or M-6 Mod 1) held in abeyance by the Vice Chief of Naval Operations (September 1944).

Mark 17

Submarine-laid ground magnetic mine (1825/1375lb), in design 1945. Mod 1 became Mine Mark 25.

Mark 18

Highly sensitive magnetic bottom mine laid by surface craft (2040/1350lb).

Mark 19

Drifting, oscillating mine laid by Army aircraft; C-4 mechanism, 550/190lb. Mod 2 was for Navy use.

Mark 20

Controlled (defensive) mine; 435/300lb.

Mark 21

Assembly of sealed mechanisms for use with various explosive charges. Magnetic; 27lb.

Mark 22

Defensive ground magnetic mine (425/160lb), requested by Marines for island defense, and abandoned due to changing circumstances. It had an M-8 mechanism, and was stopped by the CNO in September 1944.

Mark 23

Antisweep mine: mine anchor, moored float, small explosive charge (1125/2lb). In service 1944.

Mark 24

Homing torpedo (see Torpedo list).

Mark 25

Large aircraft-laid bottom mine (2000/1274lb TPX or 1200lb HBX); magnetic. Mod 1 was acoustic (A-5; 1950/1274lb TPX); Mod 2 was pressure (A-6 mechanism, 2000/1274lb); Mod 3 was also acoustic, 1950/1274lb. Depending upon the flight gear used, Mk 25 was 22.4in $\times$ 87.2-93in. In 1980 new flight gear was being issued to permit Mk 25 to be carried at high speed.

Mark 26

Small aircraft-laid bottom mine (magnetic); not produced. Weight was 1000/465lb. Mod 1 was 1016/465lb, or 1072/520lb with TPX filling.

Mark 27

Mobile ground mine launched by submarines (21in $\times$ 246in, 4500yds at 10.5kts, 877lb charge).

Mark 28

Sabotage mine (10/5lb). Design stopped.

Mark 29

Towed 400ft explosive-filled hose to protect against torpedoes, for merchant ships.

Mark 30

Canceled project; similar to Mark 24 but launched by surface ship.

Mark 31

Moored mine-torpedo, related to Torpedo Mark 28.

Mark 32

Became Torpedo Mark 32.

Mark 33

Became Torpedo Mark 33.

Mark 34

Adaptation of Army Bangalore Torpedo, a moored mine launched by small boats with a contact exploder (22/9lb amatol). Service tests failed.

Mark 35

Land mine for railroad sabotage.

Mark 36

As Mk 26 Mod 1 but with a greater charge and a slanted nose for better underwater trajectory (1024/570lb TNT, 1082/638lb TPX); magnetic, MM2 exploder, 940/570lb and 1008/638lb TPX; basic version was acoustic. Mods 2 and 3 were 'special', with low-frequency acoustic (A-5) or pressure (A-6 or A-8) exploders.

Mark 37

Similar to Mk 20 but with Mk 7 Mod 0 depth charge case; shore-controlled (738/600lb TNT). In service September 1944.

Mark 38

Universal ASW torpedo, 19-21in $\times$ 123in, 13,000-14,000yds at 20-21kts, 350lb warhead (new characteristics of November 1944).

Mark 39

Aircraft-delivered (high-altitude) magnetic

bottom mine (NOL designation XH-1A); 2000/800lb. No parachute.

Mark 40

Practice mine for Mk 25, for air launch, made from empty 100lb practice bomb.

Mark 41

Practice mine for air launch, simulating Mk 26 or 36 (or any other 1000lb mine with a 6ft parachute).

Marks 42, 43

Canceled mines; no data.

Mark 44

Torpedo Mark 34.

Mark 46

Oscillating contact mine, principle as Mk 19; was XOM. Designation assigned June 1944.

Mark 47

Moored or drifting contact mine launched from small boats, in test 1945 (45/25lb HBX, with Mk 1-2 vibration mechanism); was originally XSCM-C. Canceled in design, April 1945.

Mark 48

Mk 27 type submarine-launched bottom mine; could be used as a torpedo (self-scuttling).

Mark 49

Submarine-launched 2000lb mine, 21in × 120in; otherwise described as free-fall air launched.

Mark 50

Aircraft-launched acoustic ground mine (against small craft) of 500lb bomb size, 1949.

Mark 51

Controlled mine for harbor defense.

Mark 52

1000lb-class ground mine of new modular series: Mod 1 is acoustically fuzed, Mod 2 magnetic, Mod 3 combined pressure and magnetic, Mod 5 combined acoustic and magnetic, and Mod 6 combines all three mechanisms. In all variants dimensions are 18.8in × 70.2in. Weights are, respectively, 1130, 1170, 1190, 1200 and 1235lb, in each case with a charge of 625lb of HBX-1. All mods use identical mine cases and removable instrument racks, so that the firing assemblies can be stored apart from the explosive-laden mine case. Mod 4 was not used.

Mark 53

500lb-class sweep-obstructor.

Mark 55

2000lb-class bottom mine (23.4in × 89.9in, or 142.6in faired) for air drop, with a 1290lb charge of explosives. Mods 1 through 6 correspond to Mk 52 Mods 1 through 6 except for weight; Mod 7, unique to Mk 55, uses an improved dual-channel magnetic firing mechanism. Weights are, respectively, 2039, 2110, 2120, 2119, 2128 and 2118lb.

Mark 56

2000lb-class aircraft-laid moored mine (22.4in × 114.3in, with a 360lb charge of HBX-3), operationally similar to the submarine-moored

Mk 57. Its magnetic firing mechanism uses a total-field magnetometer. Weight is 2135lb.

Mark 57

Submarine-laid magnetic moored mine (2059lb, 340lb of HBX-3, 21in × 121.1in), for water up to 200 fathoms deep. Fiberglass case, cast steel anchor.

Mark 58

Air-launched bottom mine, for evaluation 1962.

Mark 59

Moored mine (800/70lb; 1500/100lb in Mod 2).

Mark 60

CAPTOR encapsulated torpedo-mine (Mk 46 Mod 4 torpedo) with aluminum case, for launch by aircraft, surface ships and submarines; total weight 2610lb (air/surface launch) or 2356lb (submarine launch). Dimensions are 21in × 138in for submarine launch, 145in for air/surface launch).

EX-61

Advanced modular warhead (500lb) with mine modifications, superseding Destructor EX-41.

Mark 62

Conversion of Mk 82 bomb, superseding Destructor EX-52.

Mark 63

Conversion of Mk 83 1000lb bomb; supersedes Destructor EX-53.

Mark 64

Conversion of Mk 84 2000lb bomb; supersedes Destructor EX-54. Dimensions are 25in (across fins) × 150in, and it has a variable-influence target detection system as in the destructors. Such weapons can be dropped either on land (where they explode against military equipment, vehicles or personnel) or in shallow water (against small craft and larger ships).

Mark 65

2390lb, 29in (across fins) × 128in modular mine, intended to replace destructors, with a similar land/sea capability. However, unlike Mk 64 it has a new thin-walled mine-type case (Mk 64 has the usual thick-walled bomb casing) as well as a special arming device, a nose fairing, and a tail section adaptable to a parachute.

Mark 66

Practice version of CAPTOR.

Mark 67

Submarine-launched mobile mine (influence type), converted from Mk 37 torpedo; 19in × 161in.

Mark 68

Rocket-propelled moored rising mine (PRAM); 1765lb, 21in × 135in. Canceled 13 September 1978.

Naval Blockade Mine

Designation assigned June 1905. Spherical (43in) moored mine (weight without anchor 1265/250lb wet guncotton) with inertia

exploder (pendulum type).

Drifting Mines

Mark 1

Total weight 232lb (16in × 30.5in), using buoy for suspension for one hour; two could be bridled together.

Mark 2

K-device and M-1 magnetic device; 15ft suspension below buoyant float; Mk 6-type case.

Mark 3

Mk 6 type suspended 35ft below surface, with K-device (1923).

Mark 4

Fired from 21in torpedo tube; 111in long (K-2 and A-1 firing devices). About 100 were made.

Mark 5

For 40in mine tubes of *Argonaut*, using altered Mk 5 case (1924).

Mark 6

Shaped like a depth charge; 24in × 34in, 700/362lb, K-2 and H-4.

Mark 7

Similar to drifting (drill) Mine Mark 3 but explosive, with K-2 mechanism and 523lb charge. Mod 1 oscillated, and was superseded by Mine Mark 19. This designation was assigned in 1942.

Destructors

Destructors (DST) were developed during the Vietnam War; they are Mk 80-series GP bombs converted to mines by the addition of mine-type arming, detection and filling systems. They differ from conventional sea mines in being usable against both land and sea targets. Mk 36, 40 and 41 were, respectively, conversions of Mk 82, 83 and 84 bombs. Other destructor mark numbers appear to have been assigned to self-destruction charges associated with entirely different types of munitions, and the destructor designations were probably intended as covers of what was, at the time, a relatively closely held program. Arming, detection and firing devices were common to all three types. See also Mines Marks 61 through 64.

III-5 Depth charges

Depth charge	Total weight (lb)	Explosive weight (lb)	Sink rate (or terminal velocity) (ft/sec)	Settings (ft)	Remarks
Mark 1	200	50		25-100	Designed 1916; float detonator.
Mark 2	420	300	6	50-200	First US hydrostatic type.
Mark 3	420	300	6	50-300	Mk 2 with greater depth.
Mark 4	745	600	6	50-300	First sent overseas Sept 1918.
Mark 5					For mortar projection; 1921.
Mark 6	420	300	8	30-300	Redesigned Mk 3.
Mark 7	768	600	9	30-300	To 600ft in Mod 1, 1942. Redesign of Mk 4.
Mark 8	525	270	11.5	50-500	Magnetic pistol, armed at either 35 or 200ft; early 1944. Aluminum case, 150lb lead.
Mark 9		200	22.7	30-300 or 600	Teardrop; hydrostatic. Lower limit 1000ft in some Mod 2, 3, 4. Data for Mod 2. Mod 0 14.5ft/sec.
Mark 10	29	25	4.5	25, 50, 75 or 100 fixed	For use against midget submarines, frogmen; limited numbers, 1944.
Mark 11	480	230	35	No depth	Magnetic teardrop depth charge.
Mark 12		45		Contact	Fast-sinking torpedo shape; supplement to Mk 11.
Mark 13					Subcaliber practice charge, one depth only; superseded by Mk 15.
Mark 14	340	200	23	No depth	Acoustic depth charge, 1945.
Mark 15					Subcaliber practice depth charge. Mod 8 was 'Julie' sound source.
Mark 16	435	295	31	2500	Projector use only, postwar: Mod 0 hydrostatic, Mod 1 acoustic.

III-6 ASW projectors

Mark 1
Y-gun (two 300lb depth charges); Mk 5, 7 and 8 were similar, and the last was not produced.

Mark 2
Single depth charge mortar, World War One.

Mark 3
Experimental mortar, presumably for the Mk 5 depth charge; Mk 4 was similar.

Mark 6
K-gun, single depth charge projector, firing Mk 6, 9 and 14 (300lb class) depth charges to ranges of 60-150yds (flight time 3.4-5.1 seconds). It weighed 310lb and required a crew of 2 for firing and reloading. Mk 9 was a revised version, abandoned during World War Two.

Mark 10
Hedgehog, firing an elliptical pattern at a range of 283yds in postwar ships, with up to 25° of train effected through tilting spigots. Pattern size was 195ft in deflection and 168ft in range for the dual Hedgehog installation. Total weight, with rounds for six patterns, was 28,720lb. Reload time was 3 minutes, and typical blind time 10 seconds flight time plus 18.2 seconds to sink to 200ft. Mk 11 was similar but fired a circular pattern, 267yds in diameter, at a range of 267yds. Maximum velocity was 175ft/sec. Mk 11 Mod 1 was reclassified Mk 15.

Mark 12
Submarine identification signal projector, 1945.

Mark 13
Mortar-type flare projector (2.4in × 36in), 1946.

Mark 14
Interim trainable Hedgehog, a Mk 11 on a twin 40mm mount, as proposed by the Operational

Development Force, 1946, with follow-the-pointer control by an attack director. It led to Mk 15.

Mark 15
The standard postwar trainable Hedgehog, stabilized and power-trained by a remote fire control system, very widely installed. Total weight was 17,425lb, all topside (26,785lb with the standard allowance of six patterns) and it required a crew of eight; loading took five minutes. The typical pattern was a 279ft circle at a range of 265yds, with a blind time of 29 seconds to reach 200ft (10.4 in flight, 18.6 to sink).

Mark 16
Multiple Hedgehog proposed in 1948 but not used (36 charges).

Mark 17
Proposed 61-round Hedgehog on 5in/38 mounting, with a hexagonal pattern 470ft wide over the flats, 1951; it was almost adopted for the *Dealea* class.

Mark 18
Signal projector from submerged mines for drill, 1954.

Mark 20
Mousetrap rocket projector (originally in Rocket Launcher series) with four rails. It fits late into this ASW series because it retained its original mark number. The warhead matched that of Hedgehog, but it was a rocket rather than a spigot mortar, *ie* the propellant burned much more slowly. The sixteen projectiles of a Mk 22 installation formed a pattern about 80yds wide at a range of about 300yds; 100 were in service by November 1942.

Mark 21
Subcaliber training launcher for Mousetrap ('Minnie Mouse').

Mark 22
Mousetrap with eight rails (four above four).

Mark 23
Signal marker for practice torpedoes, 1959.

ASW Rocket Launchers (such as Mk 108) were included in the general Rocket Launcher series. Those of consequence for ASW were:

Mark 108
Weapon Alfa launcher, originally based on the twin 40mm mount; total weight was 22,760lb on mount and 25,240lb off; total with 72 rounds was 85,000lb. It could fire 12 rounds per minute, and held 22 in a ready-service ring. Train rate was 30° per second, elevation 85°, and the rockets flew at up to 280ft/sec, for flight times of about 10 seconds to 760yds, or 14 to 975yds - the maximum ranges, respectively, of Rocket Marks 1 and 2 (minimum ranges 300 and 250yds). Terminal velocity (sinking) was 38ft/sec, for total blind times to a 200ft submarine of, respectively, 26.5 and 33.1 seconds. Each round weighed 525lb.

Mark 110
RAT projector fixed atop a twin 5in/38 gunhouse. There was to have been an alternative version for ships, such as missile frigates, without 5in gunhouses. It was a twin-arm launcher. Neither Mk 110 nor the proposed launcher had an elaborate mechanical reload capability comparable to the Guided Missile Launching Systems.

III-7 ASW missiles

Missile	Diameter (in)	Wingspan (in)	Finspan (in)	Length (in)	Range	Speed	Total weight (lb)	Warhead weight (lb)	Remarks
Grebe		168	60	196.5	500-40,000yds	MO.26	3000	250	SUM-N-2, Kingfisher E missile.
Petrel	54	160		282	500-5000yds* 20nm	MO.5* MO.47	2500* 3900	250* 826	Pulsejet in powered version.
RAT		33		162	1500-5000yds		479		AUM-N-2 (Kingfisher C);
ASROC	13.25	33		180	c10,000yds		949-957		development of SWOD Mk 15
SUBROC	21	-		252	c25-30nm		4000		airframe, a wooden glider.
									Torpedo Mark 44 payload;
									177.43in long, 1071-1073lb with
									Mk 46 (Mod 4 vs 3); RUR-5A.
									Two-stage solid fuel; inertial;
									nuclear warhead only.

*Unpowered

IV

IV-1 Guided missile launching systems

Mark 1

Test system for USS *Mississippi*, 1951, with horizontal handling and loading, and a total weight of 131,000lb.

Mark 2

Land-based Terrier system for the Marine Corps, 1951, with four launchers; trailer system.

Mark 3

Land-based Terrier system for the Marine Corps, 1951, with sixteen launchers.

Mark 4

First operational Terrier shipborne system, for the cruisers *Boston* and *Canberra*, with a total weight of 279,291lb. There were two twin launchers (Mk 5) and missiles were stowed upright, without their fins (144 total). After finning (11 seconds per missile) blast doors opened, the missiles were hoisted, positioned, and the loading rail retracted before training and firing; a total of about four missiles per minute could be fired from the two rails. Total crew was 30 men. The Italian missile cruiser *Giuseppe Garibaldi* had a single-launcher version of this system, which was reportedly similar to stowage in a soda dispenser.

Mark 5

Talos launching system, a shipboard prototype without a stowage magazine.

Mark 7

Talos launching system for *Cleveland* class conversions, 1956. The missiles were stowed horizontally and had to be finned and checked out before launch; 16 ready-service rounds were stowed in trays, with 30 more in a replenishment area, which might not be mated to their boosters. Total weight including missiles was 403,910lb. Ready-service rounds were held separately for each launcher arm, whereas

replenishment rounds could be supplied to either launcher arm of the single twin-arm launcher. The missile handling rate was ready-service to firing in 57 seconds for the first salvo (one or two missiles) and 46 seconds between salvos in continuous firing. Train rate was 28.6° per second, elevation 19.3° per second. Total crew was 30, twelve of whom were required to fin a missile. This was actually an austere (lightweight) system, replacing an earlier below-decks concept which would have been more difficult to install in a light cruiser hull: all of Mk 7 lay above the weather deck.

Mark 8

Gyatt (DDG) Terrier launching system, 1955, with a single twin-arm launcher and all fourteen missiles stowed in two revolving 7-missile 'rings' in a magazine abaft the launcher (horizontal). A monorail above each ring picked up the missile for finning and then for ramming onto the launch rail. The launcher proper (Mk 5) duplicated that of the Mk 4 system, but the use of horizontal 'rings' presaged the later Mk 10 system. Total weight was 88,095lb, with a crew of 16, and rate of fire was 2 rounds per minute.

Mark 9

Terrier installation for *Cleveland* class conversions, entirely above the weather deck, carrying 120 missiles for a twin-arm Launcher Mark 5, at a weight of 510,040lb. As compared to Mk 4 it required much more length but relatively little hull depth; 4 rounds per minute was claimed, taking finning into account.

Mark 10

The standard frigate and aircraft carrier Terrier launching system, using two, three or four 20-missile stowage rings, the missiles being carried without their fins. A rate of fire of four rounds per minute (one every 30 seconds per rail) was claimed, and a typical weight was 400,347lb including missiles and fluids, or 275,875lb without; the weights listed above are all without missiles. Mod 2, with 80 missiles (450,857lb empty or 695,329lb loaded), was the superfiring launcher in the cruiser *Long Beach* (with a 40-missile Mod 1 forward); Mod 3 was installed in the carrier *Kitty Hawk* (Mod 4 aft port installation, Mod 3 aft starboard), and

Mods 5 and 6 were in *Leahy* class missile frigates/cruisers. Mods 7 and 8 (*Belknap* class and *Truxtun*) had three rings, and could carry twenty ASROC rounds interspersed with their Terriers in the upper rings (546,734lb loaded, 361,994lb empty in Mod 7). The great virtue of the system, from a ship stowage point of view, was its compactness in length. A crew of 16 was required. Northern Ordnance.

Mark 11

Twin-arm Tartar launcher, virtually automatic because the missiles did not need finning; it was, however, considered unreliable and so was replaced by the single-arm Mk 13. It could accommodate 42 rounds, weighing 201,370lb loaded or 148,450lb empty, with a crew of 3; rate of fire was one 2-missile salvo every 18 seconds. Magazine diameter was 196in and height 209in, compared to a width of 360in and a length of 395in for Terrier Mk 10. Northern Ordnance.

Mark 12

Albany class and *Long Beach* Talos system, utilizing considerable hull depth to stow 52 ready-service rounds including two test rounds. It used the same twin-arm launcher as Mark 7, with similar firing rates and train and elevation rates. Total weight was about 800,000lb with a crew of one officer and 32 enlisted men. Northern Ordnance.

Mark 13

Single-arm Tartar launcher, first installed in late *Adams* class destroyers. It matches the firing rate of Mk 11, with one missile every ten seconds (reportedly 8 missiles per minute in the Mod 4 version of the *Perry* class), and requires one officer and two enlisted men. The missiles are stowed in two concentric rings; Mk 22 is, in effect, a one-ring equivalent. Both the rings and the launcher rotate; the blast door is fixed. Dimensions slightly exceed those of Mk 11, with a diameter of 203in. The system trains at 90°, and elevates at 45° per second between -15° and +95° (Mk 10: 30° and 20° per second, limits of -10° and +90°). Weight is 132,777lb empty (Mod 0). Northern Ordnance claims a reaction time of 7.1-9.1 seconds (SM-1 missile) and a cycle time of 7.5-9.2 seconds. The Harpoon surface-to-surface missile can be

accommodated. Mod 4 fires Standard and Harpoon, which require no warmup: hence it has no warmup connectors.

Mark 14
Mk 13 modified for Typhon (MR) operation, with provision for nuclear warhead safety.

Mark 15
Polaris missile launching system; two tubes had provision for test and evaluation missiles.

Mark 16
ASROC 'pepperbox' carrying eight missiles in pairs, vertically, with an above-decks weight of 49,164lb and a crew of two. Maximum rate of fire is 3 rounds per minute, with elevation limits of -3°/+85° and a train limit of ± 177°. This lightweight launcher has often been criticized for its vulnerability to weather damage.

Mark 17
Polaris launcher group for ballistic missile submarines.

Mark 21
Polaris A-3 launcher group.

Mark 22
Single-arm Tartar launcher for missile escorts, with a total of 16 rounds in one fixed stowage ring (blast door revolves), firing 7 per minute; trains at 85° per second and elevates at 45° (limits -10°/+85°), with a crew of 2 and a weight of 94,003lb empty. Magazine diameter was reduced to 146in. Northern Ordnance.

Mark 24
Poseidon C-3 launching system.

Mark 25
Basic Point Defense Missile System launcher, consisting of ASROC 'boxes' distributed on a former 3in/50 twin mount, two between the trunnions and two outboard, all elevating and training as a unit, carrying eight Sea Sparrows and firing them at a minimum interval of 2 seconds (all eight in 16 seconds); there is no automatic reload. It elevates at 24° per second (limits -15°/+65°) and trains at 30°; system weight is 31,500lb, and no crew is required. Mod 1 has frangible doors.

Mark 26
Modular vertical-stowage missile system with greater flexibility than Mk 13; it can accom-

modate ASROC, Harpoon and future missiles up to 200in long, with a diameter of 14.75in and a weight of 2200lb, compared to 186.45 and 13.5in and a weight of 1500lb for Mk 13. The twin-arm launcher, first installed in the *Virginia* class, trains at 90° per second and elevates at 50°. There are three versions at present: Mod 0, 24 missiles (162,302lb empty/193,022lb loaded), largely for ASROCs, replacing the former combination of 8 missiles in the box and 16 stowed; Mod 1, 44 missiles (208,577/264,897lb); and Mod 2, 64 missiles (255,111/337,031lb). Rate of fire per launch arm approximates that of each arm of a Mk 13, so that a Mk 26 can fire, in theory, two missiles every 10 seconds. Northern Ordnance; to be succeeded by Mk 41.

Marks 27, -28
Shipboard chaff rocket launchers for 'Zuni' air-to-surface missiles. Mk 28 was an improved version of the original EX-27, using three or four aircraft-type 4-rocket pod launchers (Mk 49); Mod 5 uses three or six Mk 44 launchers. These interim systems remain in service, but they are being superseded by Mk 33 and 36. Mk 28 installation was suspended in favor of Mk 33, December 1972.

Mark 29
NATO Sea Sparrow eight-round launcher, more compact than Mk 25 and considerably lighter at 12,768lb, with a claimed MTBF (Mean Time Between Failure) of 75 hours and a rate of fire of one round every 2 seconds. Elevation and train are at 65° and 40° per second respectively, with elevation limits of -5°/+85°.

Mark 32
Box launcher for Standard Missile in the surface-to-surface role: Mod 2 was installed on *Gearing* class destroyers for Iran, Mods 0 and 1 on *Asheville* class gunboats (PG-86, 87, 98 and 100). It is fixed in train and can elevate to a fixed angle of 25° for firing, with a maximum rate of fire of two rounds per minute and a total of two rounds per launcher, carried in a magazine forward of the launcher proper. Total weight is 22,420lb and one man is required for operation. The launcher itself is Mk 134, 205in long, with a 203in magazine.

Mark 33
Chaff rocket launcher, replacing Mk 28; mortar type, firing three 10lb, 112mm cartridges,

for FF-1052, FFG-1 and the first ten *Spruance* class destroyers. The standard installation consists of four or two (for ships under 450ft in length) triple launchers.

Mark 34
Two-barrel chaff launching system for *Pegasus* class hydrofoils, firing the same round as Mk 33.

Mark 35
Trident C-4 launcher for strategic submarines.

Mark 36
Chaff rocket launcher, using a larger round than Mk 33 (130mm, 40lb). The earlier system is being converted by interchange of launchers and stowage lockers.

Mark 37
Launcher for CAPTOR (Mk 60) mines from surface ships; Mk 38 launches them from P-3 aircraft, and Mk 39 from submarines.

Mark 41
Martin-Marietta modular Vertical Launching System (VLS) for Standard Missile and Tomahawk, consisting of eight modules (seven of 8 missiles each, one with 5 missiles and a strikedown crane). System weight is about 188,000lb. As an alternative, the number of missile modules can be reduced to three and total capacity to 29 missiles (about 94,000lb). Rate of fire is reportedly to be one missile per second. Each missile is struck below still in its corrugated shipping container. It is to replace Mk 26.

Mark 43
Box launcher for 24 RAM (X-RIM-116) point defense missiles on a Phalanx chassis, part of ASMD Weapon System Mark EX-31; the system is generally described as EX-31.

Mark 44
Armored box launcher for Tomahawk Weapon System Mark 32; Mod 1 was for ground launch (GLCM), Mod 2 for shipboard installation.

IV-2 Surface-to-air missiles

Missile	Diameter (in)	Wingspan (in)	Finspan (in)	Length (in)	Range (nm)	Speed	Total weight (lb)	Warhead weight (lb)	Remarks
Little Joe	22.7			132	2	350kts	1210	100	KAN-1, -2: 1945-46 program. SAM-N-2, then test vehicle CTV-N-9; booster 8091lb, 55in long. Semiactive; liquid fuel. NOTS.
Lark	18	74	48	167	2-30	MO.85	1214	100	
Terrier BW-O	13.5	47.3	40.5	177	10	M1.8	1060	218	SAM-N-7, later RIM-2A; booster 1290lb. Against targets at 600kts, up to 40,000ft.
Terrier BT-3	13.5	24	42.3	162	20	M3.0	1180		Booster 1820lb, 18in x 310in, 63in fins; flew to 80,000ft.
Terrier HT-3B	13.5	24	42.3	162	40	M3.0	1180		New end-burning sustainer motor, Performance Extension Program (PEP) 1964.

Missile	Diameter (in)	Wingspan (in)	Finspan (in)	Length (in)	Range (nm)	Speed	Total weight (lb)	Warhead weight (lb)	Remarks
Talos	28	110	84	230	50	1184kts	2700	300	SAM-N-6, later RIM-8A. Booster 2950lb, 30in × 100in with 144in fins; to attack incoming targets at 35nm, up to 60,000ft.
Talos 6b	28	110	68	236	50		3185		Booster 4150lb, 30in × 139in with 77in fins; 6bw nuclear version was 3215lb, 249in long, no antennas at nose.
Talos 6b1	28	110	77	254	100	M2.5	3340		Booster 4360lb, 30in × 139in, 77in fins; effective to 70,000ft. Pulse-homing, 1960. Later RIM-8C.
Talos 6cl	28	110	81	252	100	M2.5	3400		Booster 4400lb, 30in × 132in, 77in fins; effective to 80,000ft; 'unified Talos', 1962, with CW homing (RIM-8E). RIM-8F was corresponding conventional-warhead version; -8G and -8J (130nm) were guidance improvements. Conventional versions had 300lb CR warhead.
Typhon (ER)	16	23		185	200	M4.0	1700	150	Booster 1920lb, 18.5in × 146in, with 62in fins; SAM-N-8, later RIM-50. Line-of-sight range 110nm, effective to 95,000ft.
Typhon (MR)	13.5	24	42.4	186	40	M4.0	1375	150	SAM-N-9 or RIM-55; to 90,000ft; no separate booster. Line-of-sight range 25nm. TRIP missile with command guidance, effective to 80,000ft.
Tartar	13.5	24	42.3	181	7.5		1280	117	RIM-24A, to 55,000ft.
Tartar (Improved)	13.5	24	42.3	186	17.5	M1.8	1310	130	RIM-24B, against targets from 50ft to 70,000ft.
Standard (MR)									All-electric missile similar to TRIP, with Typhon (MR) performance in line-of-sight. SM-2 is presumably equivalent to full Typhon command performance. Motor improvement programs (see text). RIM-66.
Mauler	5	13		72	5	120			RIM-46 missile.
Sea Sparrow	8	40	32	144	8-12	435	65		RIM-7E similar to AIM-7E, but with folding wings and clipped tail. Effective against targets up to 50,000ft.
RAM	5	17.25		110	5	159			X-RIM-116 missile.

IV-3 Air-to-air-missiles

Missile	Diameter (in)	Wingspan (in)	Finspan (in)	Length (in)	Range (nm)	Speed	Total weight(lb)	Warhead weight (lb)	Remarks
Sidewinder I	5	22	15	103.69			147		AAM-N-7 prototype; AIM-9A. Guided 5in HPAG rocket.
Sidewinder IA	5	21		111.5	2.6	M1.7	155	10.5	AIM-9B.
Sidewinder IB	5	24.8		113	11.5		185		AIM-9C; semiactive homing version.
Sidewinder IC	5	24.8		113	11.5		195		AIM-9D; -9G, -9H similar with better seekers.
Sidewinder ID	5	24.8		112.2			188		AIM-9L; all-aspect medium-range weapon.
Sparrow I	8	37	34.8	147.3	1.8-5.4	M2.4-1.15	315	45	Beam-rider, AAM-N-2; APQ-36 radar guidance.
Sparrow II	8	39		144.3	1.0-8.3		420		Abortive active homing version, AAM-N-2A, later -3.
Sparrow III	8	40		144	6		380	65	AIM-7C, introduced in 1958; semiactive. Originally AAM-N-6.
Sparrow IIIA	8	40	32	144	9.1		398	65	AIM-7D; supersonic launch. Formerly AAM-N-6A.
Sparrow IIIB	8	40	32	144	16		435	65	AIM-7E; formerly AAM-N-6B.
Sparrow III	8	40	31.6	143.85	24-38		510	85.6	AIM-7F; dual-thrust engine. AIM-7M has monopulse seeker.
AMRAAM	7	20.7	24.7	140.7			327		AIM-120; chosen 1982.
Meteor	8.25	29.4	40.25	114	10 or 25	M2.0	390	60	AAM-N-5 (MIT), using 8.9in × 53.25in, 190lb booster; launch at 400kts; semiactive.

Missile	Diameter (in)	Wingspan (in)	Finspan (in)	Length (in)	Range (nm)	Speed	Total weight (lb)	Warhead weight (lb)	Remarks
Eagle	14	34		139.06	100	M4.5	650		AAM-N-10; booster 16in × 54.5in (50.14in fin), 634lb.
Phoenix	15	36.4		157.8	72.5	M4.3	985	132	AAM-N-11 and then AIM-54; data for -54A version.



V-1 Bombs

Bomb	Total weight (lb)	Charge weight (lb)	Diameter (in)	Length (in)	Remarks
<i>30lb bombs (fragmentation)</i>					
Mark 5	30.3	4.66	4.74	24.51	Mod 1, 1929; Mod 2 was 4.14in × 22.18in; Mod 3, 1940, was 4.17in × 25.4in. Modified Army weapon.
<i>50lb bombs</i>					
Mark 3	53	25			Reconditioned Army Mk 1; demolition bomb, obsolescent by 1938.
<i>100lb bombs</i>					
Mark 1	116	65	7.9	47.2	GP bomb; Mod 2 for Army, Mod 3 for Navy.
Mark 3					Army demolition bomb, obsolescent by 1938.
Mark 4	119.5	54.5	7.9	49.1	Demolition bomb, ex-Army.
<i>112lb bombs</i>					
Mark 1	124	36	9.25	31.5	With 250lb Mk 1 and 550lb Mk 1, part of new program of heavy-case bombs begun at end of WW1; fifty of each type cast at Naval Gun Factory.
<i>230lb bombs</i>					
Mark 1	237.5	137.5	10	50.5	Antisubmarine bomb with flat head, WW1; could also be used against towns and railroads with nose bucket removed. Copy of RN type.
<i>250lb bombs</i>					
Mark 1	287	96	12.75	37.5	Late WW1 series heavy-case bomb; see 112lb type.
<i>Clarke Bombs</i>					
Mark 4	146.8	120.8	10	54.7	ASW bomb; Bureau type, WW1. Mod 1: 202.8/172.8lb, 10in × 66.6in. Pointed nose.
Mark 5	225	220	10	78.7	ASW bomb of WW1; Bureau type. Pointed nose.
<i>520lb bombs</i>					
-	501	340	19	61	Copy of British type, WW1; no mark number. Light-case type analogous to 230lb type.
<i>550lb bombs</i>					
Mark 1	683	190	15	62.4	Heavy member of late-WW1 heavy-case family of bombs; see 112pdr.
<i>500lb Bombs</i>					
Mark 3	475.5	340			Light-case bomb.
Mark 7	500.75	392	16	67.3	Aluminum-case bomb, abandoned by 1938.
Mark 9	491	323			Light-case bomb.
Mark 12	515.6	252	14	63.6	Heavy-case bomb, only one of this weight in use by 1944.
<i>1000lb bombs</i>					
Mark 3	973	509	17.7	87.8	Heavy case; replaced by Mk 13.
Mark 5	998	771	19.0	84.1	Light case; obsolescent by 1938.
Mark 9	1023.5	731			Light case; out of service by 1944.
Mark 13	1020.6	537	17.7	72.6	Heavy-case bomb; obsolescent by 1945.
<i>2000lb bombs</i>					
Mark 9	2040		21	130	Aero Bomb Mark 9, 1921; out of service by 1931.
Mark 11	1990		21	120	Demolition bomb, 1924; out of service by 1931.
<i>AP bomb series</i>					
Mark 1	1590	215	14	83.5	1600lb AP bomb; see also Mk 33 below.
<i>Bomb series</i>					
Mark 15	97		8	41	Practice bomb, 1941.
Mark 16	2		4.2	9.1	Radio acoustic ranging bomb, 1943; some mods weighed 4lb.
Mark 17	325	234	15	52.5	Aircraft depth bomb, with TNT filling.
Mark 18			2.5	10.9	Sound bomb, 1940; no filling.
Mark 20	1131.6		17.7	55.3	Demolition bomb (TNT), 1941.
Mark 21	489		15	61.8	Practice bomb, 1941.
Mark 22	1013.7		19	79	Practice bomb, 1941.
Mark 23	3				Miniature practice bomb.
Mark 24	500				Demolition bomb, 1941.
Mark 25	1000				GP bomb, not used, 1941.
Mark 26	500		11.75		GP bomb, not used, 1941.
Mark 27	2000		18.63		GP bomb, not used, 1941.

Bomb	Total weight (lb)	Charge weight (lb)	Diameter (in)	Length (in)	Remarks
Mark 28	67.1		8	47.8	Incendiary bomb, 1941; black powder.
Mark 29	650				Aircraft depth bomb.
Mark 30	3		2.5	8.3	Miniature practice bomb, 1941.
Mark 31	500				SAP bomb (Army M58).
Mark 32	3		2	15	AA bomb, not approved for production.
Mark 33	1008		12	73	AP bomb, filled with Explosive D, 1943.
Mark 34	5.6		3	15	AA bomb, TNT-filled, 1942.
Mark 35	650		17.7	67.2	Aircraft depth bomb.
Mark 36	1028		18.6	71.6	Demolition bomb, 1943 (modified Army M44).
Mark 37	658.5		17.7	67.2	Aircraft depth bomb, TNT-filled.
Mark 38	629	425	17.7	61.1	Aircraft depth bomb, TNT-filled, 1941.
Mark 39	10		3.7	13.1	Miniature practice bomb.
Mark 40			2.2	10.9	Sound bomb, 1942.
Mark 41	347	227	15	49.9	Aircraft depth bomb, TNT-filled.
Mark 42	94.5		8	39.4	Chemical bomb, 1942.
Mark 43	4.5		2.2	8.3	Miniature practice bomb.
Mark 44	330	249	15	52.5	Aircraft depth bomb, Torpex-filled.
Mark 45	127		8	38	Reinforced-concrete practice bomb, 1945.
Mark 46	100				Demolition bomb.
Mark 47	355	252	15	49.9	Aircraft depth bomb, Torpex-filled.
Mark 48	850		18.6	68	Aircraft depth bomb, no hydrostatic cross fuze.
Mark 49	668	472	17.7	61.1	Aircraft depth bomb, Torpex-filled, 1943.
Mark 50	1269		12	85.24	AP rocket bomb, 1943 (1250lb weapon).
Mark 51	100				Aircraft depth bomb for blimps.
Mark 52	99.2		7	45.9	Aircraft depth bomb for blimps, 1943 (TNT); total weight 104.1lb with TPX filler.
Mark 53	330	225	13.8	52.5	Aircraft depth bomb; TNT-filled.
Mark 54	354	250	13.8	52.5	Aircraft depth bomb, Torpex or HBX.
Mark 55					SWOD (guided missile): Pelican.
Mark 56					SWOD (guided missile).
Mark 57					SWOD (guided missile): Bat.
Mark 58	100				Water sand-filled practice bomb with spotting charge; Mk 15 modified instead.
Mark 59					Miniature practice bomb, 1945; too light.
Mark 60	110				Cylindrical cavity filled with $\frac{3}{8}$ in steel balls with black powder one end, 1945.
Mark 61	552		14	59	Reinforced concrete practice bomb, 1945.
Mark 62	1036		18.6	69.2	Practice bomb, 1945.
Mark 63	3876	325	18	82.5	AP bomb to penetrate 12in from 20,000ft, filled with Explosive D (dive-and level bombing), 1945.
Mark 64	1100				Dove homing bomb (built of 1000lb GP bomb, M65).
Mark 65	500				Incendiary (napalm) bomb, 25 gallons, 1944, same dimensions as standard GP bomb.
Mark 66	884		18.6	67	Practice white smoke (WSF) bomb; with 45 gallons of gas-gel, could be used as incendiary, 1945.
Mark 67	1473		23	90	Incendiary (napalm), 97 gallons, 1944.
Mark 68					Torpedo-size napalm bomb, using 2000lb tail, carrying 200 gallons, 1944.
Mark 69					SWOD (guided missile) Mk 10.
Mark 70					Redesign of electric horn type bomb used in scatter bomb cluster for blimps, 1945.
Mark 71	525				M64A1 GP bomb modified to take athwartships hydrostatic fuze, permitting low-level attacks on water targets, 1944.
Mark 72	8				Target identification bomb, 1945, using maritime distress signal with parachute. Mod 2, 45lb, was thermal smoke generator, visible 8–10nm at 15,000ft.
Mark 73	45		8.75	36	Target identification flare (colored).
Mark 74	500				Caltrop bomb, carrying 1300 caltrops in hexagonal fairing, used in conjunction with fragmentation clusters to keep aircraft from taking off.
Mark 75	375				Aircraft depth bomb, redesigned Mk 53 with thicker case, smooth interior to avoid cracks which caused premature bursts.
Mark 76	25				Practice bomb for dive-bombing, 1947.
Mark 77	750	668	18.6	138	Napalm tank, 114 gallons (aluminum), 1951; Mod 1 cuts 2in from nose and tail, 11.5in from each end of center section, and these are welded together to form a 75-gallon, 500lb tank, for 500lb bomb racks (1953).
Mark 78	760	670	26	89	Air Force F-51 drop tank filled with 110 gallons napalm.
Mark 79	912	700	19.6	168	Low-drag-shape 112 gallon napalm bomb, 1954.
Mark 81	260	100	9	76.1	Low-drag GP bomb, 1952.
Mark 82	512	192	10.8	90.9	Low-drag GP bomb, 1952.
Mark 83	985	445	14	110.9	Low-drag GP bomb, 1954.
Mark 84	1970	945	18	154	Low-drag GP bomb, 1951.
Mark 85	260		9	77	Low-drag fragmentation bomb, Mk 81 shape, 1959.
Mark 86	217		9	76	Practice bomb.
Mark 87	333		10.8	91	Practice bomb.
Mark 88	783		14	120	Practice bomb.
Mark 89	56		4	31.3	Practice bomb.
Mark 90					Nuclear depth bomb ('Betty').
Mark 91	3500				Mk 11 nuclear bomb, 1954.
Mark 92	3250				Training weapon for Mk 91.
Mark 94	470	168	10.8	88.8	Chemical low-drag bomb.
Mark 95			14	120	Reserved for Mk 94 replacement, EX-38.
Mark 98	1885				Practice bomb for Mk 28 nuclear weapon for A-5.

APPENDICES

Bomb	Total weight (lb)	Charge weight (lb)	Diameter (in)	Length (in)	Remarks
Mark 99					Practice bomb for Mk 90 depth bomb.
Mark 100	2500		31.34	125.2	Practice bomb for Mk 90 depth bomb.
Mark 101	1200				Nuclear depth bomb ('Lulu').
Mark 102	1200		18	92.4	Practice bomb for Mk 101.
Mark 103					Practice bomb for Mk 101 (assembly, handling).
Mark 104	2025		20	107.6	Simulates nuclear bomb Mk 28 for A-3.
Mark 105	1500				'Hotpoint' high-speed low-altitude nuclear bomb.
Mark 106					Subcaliber training round for Mk 105.
Mark 107					'Hotpoint' training round (service personnel).
Mark 108					Simulated Mk 101 depth bomb.
Mark 109	350	200	16	90	Cluster chaff bomb, 1958.
Mark 110					Antitank cluster bomb, assembly of 2.75in HEAT rocket heads.
Mark 111	3659				Nuclear weapon Mk 27 for A-5; internal carriage.
Mark 112	2695				Nuclear weapon Mk 43 for A-5; internal carriage.
Mark 113	2507				Nuclear weapon Mk 28 for A-5; internal carriage.
Mark 114	2507				Training weapon for A-5.
Mark 115	55	14.5	5	31.5	Helo trap weapon, to cut obstructions below in landing zones, 1967.
Mark 116			14	90	Weteye chemical bomb, 1963.
Mark 117			2 $\frac{7}{8}$	3 $\frac{1}{4}$	Small bomblet to attack light trucks, parked aircraft, rolling stock, light ships; 1964, for Rockeye.
Mark 118			2.1	13.5	Antitank bomblet for Rockeye; can penetrate 8.5in steel.
Mark 119			3.3	2.5	Target identification bomblet, 1968.
Mark 120					Practice bomb, canceled 1967.
Mark 121					Target identification bomb, 1968.
Mark 122	225		14.3	88.8	Fireye incendiary bomb for delivery at up to 600kts, 1966.
Mark 124					Practice bomb for Snakeye I.
<i>Cluster bombs</i>					
Mark 1					Six Hedgehog charges banded together, fired from K-gun. Mks 2-4 also combinations of these 7.2in charges.
Mark 5	500				Twelve 70lb bombs, explosive arbor, for blimps.
Mark 6					Six 100lb bombs, 1945; unsatisfactory.
Mark 7					Eight 20lb fragmentation bombs, to replace M1A2, 1945.
Mark 8					Army M29 type.
Mark 9	500				56 AN-M69 incendiaries, 1946.
Mark 10	750				Eight 90lb fragmentation bombs, 1946.
Mark 11	1720				56 20lb fragmentation bombs M41A1, 1956.
Mark 12	750		16	90	Rockeye I, 96 bomblets.
Mark 15	700		16	92	Sadeye antipersonnel weapon.
Mark 17					Gladeye, 330 M40 antipersonnel bomblets.
Mark 18					Practice bomb for Mk 15.
Mark 19					Mk 15 with 2100 M219 fuze test vehicles, in place of M40.
Mark 20	500		17.2	94.5	Rockeye II, 247 Mk 118 bomblets.
Mark 21			18	92	Sadeye, 2100 M38 and M40 (ratio 3:1).
Mark 22			18	92	Sadeye, 2100 M38 bomblets.
Mark 23					Padeye, 15BZ (gas)-filled bomblets, 1965.

All mark numbers are expressed in arabic numerals, but before World War Two roman numerals were generally used. There were originally separate series for different types of bombs, and these series were only gradually merged into a single Bomb series.

V-2 Nuclear weapons

All US nuclear weapons are numbered in a single mark sequence, 'B' for Bomb, 'TX' for Bomb Prototype, and 'W' for Warhead; in some cases the same weapon design serves as both bomb and missile warhead. The initial date given is the date of authorization of weapon engineering development, followed by service introduction and then by retirement from the stockpile. All data on yields is unofficial and has not been checked against official figures.

B-4

First US 'production' nuclear weapon, its design reportedly tested at Eniwetok in April and May 1948. Its success allowed the AEC to pursue the development of lighter weapons. Operational March 1949; Mod 2 was retired in March 1953. Used by both Air Force and Navy. Improved implosion weapon, probably about 10,000lb.

B-5

Began development May 1948, entered service March 1952. Reportedly an implosion weapon. First US lightweight bomb, about 3600lb, 43.5in in diameter, reportedly about 120kt. Length was 10ft 8 $\frac{1}{2}$ in. The success of this bomb encouraged Navy interest in nuclear missiles, as it could be carried by missiles then in the design stage. Mod 3 was begun in March 1951, entered service in January 1955, and was retired in July 1963. W5-0 was the Regulus I warhead; it was also planned for the canceled Rigel and Triton, and for canceled depth charges 'Candy' and 'Chris', surface-to-underwater unguided rocket 'Clara', and torpedoes 'Claudia' and 'Clifford'.

B-7

Began November 1950 and in service January 1952; Mod 3 was begun July 1952 and entered service June 1953 (retired December 1954); Mod 4 began November 1953, in service December 1954, retired January 1957. The first fighter-bomber weapon, with kiloton-range yield, length 15ft 5in, diameter 30.55in, weight 1680lb. W-7 Mod 1 armed the 'Betty' nuclear depth charge and the BOAR missile (in

service 1955 and 1956, respectively, and retired 1963). BOAR maximum range (excluding drop altitude) was 40,000ft; it could also be used as a free-fall bomb. When rocket-launched, it was lofted, the motor igniting after half a second of free fall.

B-8

Navy-only bomb, known as LC ('Elsie', presumably for 'light case') and designed specifically to penetrate armored land or water targets, such as submarine pens. It was a gun-type weapon, 9.7ft long, 22in in diameter, 3230lb, with a 20kt yield. Developed largely by BuOrd, in parallel with the Los Alamos Mk 5. Elsie was the first nuclear weapon which could function after striking the ground. It was begun in March 1950, fielded in December 1951, and retired in February 1956 (the last mod, 3, was retired in August 1957). A W-8 was proposed for Regulus I but not built.

TX-10

Air Force/Navy bomb project, begun February 1951 and canceled 1952. 'Airburst Elsie'/LF/'Little Freddie', conceived as a 1750lb air-delivered weapon. First proposed

May 1950, to have a yield equivalent to the original 'Little Boy'. Proposed as a warhead for a weaponized Loon, May 1950, to give the Navy an instant nuclear capability. Not produced; developed as a backup for Mk 7 (Thor) and Mk 12 (Brok).

B-11

Navy Mk 91 bomb, a penetration type, begun September 1953, fielded September 1956, and retired June 1960. Improved 'Elsie'; considered at one time for thermonuclear trigger. It could penetrate up to 22ft of reinforced concrete, 90ft of packed sand, or 120ft of clay (or 5in of armor plate) and was 14in in diameter, with a length of 12ft 5in.

B-12

The first really small tactical bomb, only 1200lb (21in diameter, 12ft 10.5in length) for carriage at up to supersonic speeds, with a reported yield of 100kt. Development began in September 1952, with service entry in December 1954 and retirement in October 1958 (Mod 2: April 1956; December 1956; June 1962). Canceled applications: BOAR, Talos, Bomarc (Air Force), depth charges 'Alice' and 'Alvin', torpedoes 'Adeline' and 'Andy' and surface-to-underwater rocket 'Anna'.

TX-13

Air Force/Navy bomb project, begun August 1954 and canceled the same year. The warhead version would have armed such Air Force missiles as Snark and Navaho.

B-15

Air Force/Navy 7600lb bomb, reportedly thermonuclear in megaton range, with a length of 11ft 6in and a diameter of 34.7in. Begun October 1953, fielded July 1955, and retired June 1964.

B-18

'Super Orallloy Bomb', the largest all-fission bomb developed by the United States, reportedly about 500kt and the competitor to fusion weapons. It was a modified version of B-6, which was sometimes described as an improved 'Fat Man' and was used only by the Air Force (weight 8500lb). Development began in August 1952, and it was fielded in July 1953 and retired in December 1955; a Mod 1 was retired in December 1956.

TX-20

Canceled Air Force/Navy bomb, begun October 1953.

W-23

Nuclear 16in shell, begun September 1953, fielded December 1956 and retired October 1962. It was slightly smaller than a conventional 16in shell.

W-27

Navy-only thermonuclear bomb and missile warhead, reportedly about 2Mt. Replaced W-5 in Regulus about 1958. The warhead was begun in September 1954 for Regulus I, fielded in September 1957 and retired in June 1963; Mod 1 was begun in July 1961, fielded in April 1963 and retired in October 1965. Canceled applications were Triton, Matador, Snark, Rascal and Redstone. The bomb version was begun in September 1955, fielded in

November 1958 and retired in October 1962; a Mod 2, begun in February 1961, was retired in October 1964. Length was 11ft 10in and diameter 30.27in; weight was 3020lb as dropped by an A-5 Vigilante.

B-28

Air Force/Navy thermonuclear bomb, begun March 1955, fielded September 1958 and retired May 1960; Mod 3 was begun in December 1962 and remains in service. Proposed as a lower-yield replacement for Regulus W-27 in view of improved CEP (1000yds) expected. Versions reportedly range in yield from 1.1 to 20Mt, and also in shape, some having plastic aerodynamic covers and parachute retarders. The externally carried type weighs about 2040lb, the internal type (*eg* for the A-5) 1885lb. A W-28 was planned for Regulus but canceled.

W-30

Talos nuclear warhead, begun March 1955, fielded February 1959 and retired August 1962; a Mod 2 was begun September 1960, fielded June 1961 and retired in 1978. Reported yield was 5kt.

W-33

Canceled Navy 8in shell project. All other Navy 8in shells were apparently for Marine Corps howitzers. No dates are available.

W-34

Navy nuclear ASW weapon, employed in various forms. Begun June 1955 for Mk 105 ('Hotpoint'), an 18in × 7ft 10in weapon with airburst and underwater-burst capabilities; Mk 101 ('Lulu'), a nuclear depth charge (18in × 7ft 8in, 2016lb), and ASTOR, the Mk 45 torpedo. Mod 0 was fielded in all three versions in June 1958, and the last mod, 4, was begun in December 1961 and fielded in August 1962. It applied only to 'Lulu' (retired 1971) and to ASTOR (1977). Lulu could be triggered either hydrostatically or by a timer (backup). The last 'Hotpoint' version was Mod 2, fielded in September 1960 and retired in November 1965.

Descent was slowed by a 12ft 6in diameter ringslot parachute, Hotpoint being the first parachute-retarded laydown weapon. The nose fairing was blown away before the bomb touched down on its 'cookie-cutter' nose. Nose fairing, tail and parachute package could be changed for external *vs* internal carriage; length was 12ft or 8ft respectively. Reported yield was 10kt.

B-39

Air Force/Navy bomb, reportedly essentially a B-15 with a parachute added, so that it could be retarded for low-altitude release. Dimensions were 34.5in × 11ft 7in (42in over tailfins) and weights were reportedly 6000lb empty, 9000–10,000lb complete. It was begun in September 1954, fielded in February 1957 and retired in January 1960.

W-42

Canceled air-to-air nuclear warhead for Sparrow and Eagle, begun July 1958.

B-43

Standard Air Force/Navy bomb, built in various versions; begun October 1956, fielded April 1961 and retired 1968; Mod 3 was begun

in May 1972 and fielded in 1973. It can be carried externally (18in × 13ft 8½in, 2060lb) and remains in service in 1983.

W-44

ASROC warhead, begun November 1956 and fielded May 1961.

W-45

Warhead for Terrier (fielded February 1962) and nuclear Bullpup (fielded 1962); begun November 1956.

TX-46

Air Force/Navy bomb project, begun July 1957 but canceled 1958.

W-47

Polaris Mark 1 Re-Entry Body warhead, begun August 1957, fielded May 1960, and retired 1968; Mod 3 was begun in January 1967 and retired in 1975. Reported yield was 600kt, in an 875lb warhead.

W-55

SUBROC warhead, begun March 1959 and fielded January 1964.

B-57

Multipurpose weapon, usable as bomb (laydown or airburst) or as a nuclear depth charge; it was 14.8in × 9ft 10½in in its external high-speed bomb version. Begun January 1960, fielded January 1963, and retired 1967 (Mod 0); Mod 4 was begun November 1965 and retired in 1973.

W-58

Warhead for Polaris A-3 (Mk 2 REB), begun August 1960 and fielded March 1964. Reported yield is 200kt in each of three RVs.

W-60

Warhead for Typhon, begun October 1961 but canceled 1964.

B-61

Current Air Force/Navy bomb, begun January 1963 and fielded in 1967; the latest version, Mod 5, was begun in July 1975 and fielded in 1977. Typical dimensions are 13.4in × 10ft 11in. Reported yields vary with version, one unofficial claim being 10–100kt for Mod 0/2, 300kt for Mods 3–5, and 900kt for Mod 1.

W-62

Livermore design for Poseidon and Minuteman III warhead, begun June 1964 and canceled for the former.

W-67

Los Alamos design for Poseidon and Minuteman III warheads, begun June 1966 and canceled 1967.

W-68

Livermore design for Poseidon Mk 3 REB, begun July 1966 and fielded 1970. Reportedly a 164lb, 40kt warhead, it is also listed as a 48kt weapon.

W-72

Nuclear warhead for Walleye, begun May 1969, fielded in 1970 and retired in 1979. Reported yield was 100kt.

W-73

Warhead for Condor, begun May 1969 but canceled.

W-76

Warhead for Mk 4 REB of Trident I (C-4); reported yield 92kt. Begun April 1973 and fielded 1978.

W-80

Tomahawk warhead, begun April 1976. Also proposed for GBU-15 glide bomb, but dropped in FY80. Reportedly a 1050lb, 170kt warhead.

W-81

Warhead for nuclear version of SM-2 anti-air-

craft weapon, reportedly with a yield of 2 or 4kt.

V-3 Air-to-surface missiles

Missile	Diameter (in)	Wingspan (in)	Finspan (in)	Length (in)	Range (nm)	Speed	Total weight (lb)	Warhead weight (lb)	Remarks
Bat		120	143		15-20		1880		ASM-N-2 postwar. Range data for glide weapon.
Dove	18.75	22.63		99	0.25	M0.98	1350	1000	Guided unpowered bomb, ASM-N-4, dropped from 8000-30,000ft.
Gorgon V		120		346	25-31	M0.95	1420 empty		Glide chemical weapon, spraying a 5-11nm × 5nm area; range 26nm in 16° dive from 35,000ft. Speed data at 20nm glide.
Gargoyle		102	121		c5		1517	1000	KSD-1, 1944. Range data from 27,000ft.
Bullpup	12	37		126	7	M1.8	571	250	ASM-N-7, later AGM-12A.
Bullpup B	18	48		163	10	M1.8	1785	1000	ASM-N-7B, later AGM-12C.
Walleye I	12.5	45.5		136	16		1100	1000	AGM-65; Walleye II, with 2000lb warhead, weighs 2400lb (18in × 51in × 159in).
Condor	17	53		166	60	M2.9	2100	630	AGM-53; solid-fuel rocket.
Maverick	12	30		97	c14		630	300	AGM-65F version.
Shrike	8	36		120			400		AGM-45, ex-ASM-N-9.
Standard ARM	13.5	42		180			1356		AGM-78, RGM-66D in surface-launched version for antiship use.
HARM	10	44.5		164			780		AGM-88.
Corvus	19	60		192	170	M0.8	1750		ASM-N-8; W-40 warhead. Range/speed data for 40,000ft launch.

VI

V-1 1 Surface-to-surface missiles

Missile	Diameter (in)	Wingspan (in)	Finspan (in)	Length (in)	Range (nm)	Speed	Total weight (lb)	Warhead weight (lb)	Remarks
Loon	33.75	212.1	80.8	325.1				2000	Willys-Overland-built copy of German V-1, with claimed CEP of 0.5nm. First US missile launched from a submarine.
Gorgon IIC	23	59.25	138	235.4	80	M0.54	1948	1000	Originally area-bombardment weapon, but used postwar as control test vehicle, CTV-N-2, with various guidance systems. Project began May 1945, with 220 or 330lb thrust pulsejet above fuselage. Had 900lb booster and was sled-, catapult- or air-launched.
Triton	54			576	2000	M2.4	18600	4000	SSM-N-2; ramjet with 17,400lb booster, 1800ft CEP (1953).
Rigel	45	173 over engines		545	100-500	M2.0	13000	3000	SSM-N-6, with 10,800lb booster, powered by two 28in Marquardt Mach 2 ramjets.
Regulus I	56	252		400	500	M0.85-0.95	10311	3000	SSM-N-8 turbojet missile, with 1752lb JATO booster (in two units), each 33,000lb thrust. Redesignated RGM-6 under unified system.
Regulus II	50	241		690	1000	M2.0	23000		SSM-N-9, later redesignated RGM-15 or MQM-15A target (KD2U); 7000lb booster.
Polaris A-1	54	-	-	336	1200		28000		Single RV, 0.5 MT, UGM-27A; A-2 was 30,000lb, range 1500nm, length 369in.
Polaris A-3	54	-	-	387.5	2500		35000		Three RVs, 200kt each; UGM-27C.
Poseidon C-3	74	-	-	408	2500		65000		Ten 50kt MIRVs (Mk 3 RV): UGM-73A.

Missile	Diameter (in)	Wingspan (in)	Finspan (in)	Length (in)	Range (nm)	Speed	Total weight (lb)	Warhead weight (lb)	Remarks
Trident C-4	74	—	—	408	3800		70000		UGM-93A; length does not include extendible aerospike. Eight Mk 4 RVs (100kt).
Harpoon	13	36		180	75	M0.85	1304	510	RGM-84; there is also a 163lb booster, not included in air-launched version.
Tomahawk	20.9	100		252	2000	M0.7	3181		Data for strategic version (W-80 warhead about 200kt); tactical version similar, with 1000lb Bullpup warhead and range about 400nm. BGM-109.

Source material

Much of the material for this book was taken from official sources, particularly those at the Naval Historical Center (Washington Navy Yard), those at the US National Archives, and those at the Historical Archives of the Naval War College, the latter containing lectures at the War College describing US naval developments of the early years of this century. I also benefited greatly from the collection of material on US naval nomenclature held by NAVSEA Code 06G4D, including unclassified descriptive cards on electronic equipment produced at Fort Monmouth. I am grateful to Jim Glander of that office for his assistance. The list of documents below includes only those which were fully declassified; I have also used declassified or unclassified portions of documents not fully declassified. In general, the word 'reportedly' in the text identifies data or information derived from unofficial sources. A major source which cannot be cited specifically is the voluminous testimony given to Congressional committees in connection with annual appropriations, particularly since the early 1970s.

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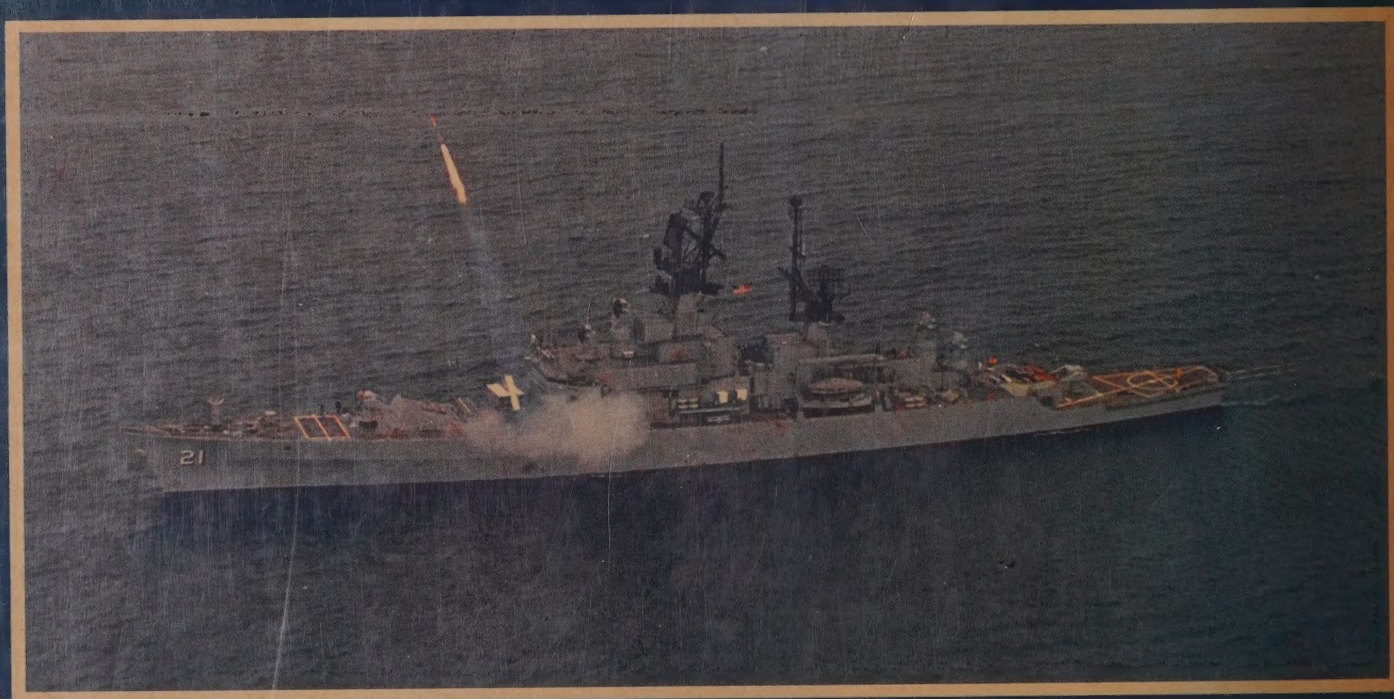
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