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TECHNOLOGY AND THE EVOLUTION OF NAVAL WARFARE—1851–2001

by

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CONTENTS

THE CHARLES H. DAVIS LECTURE SERIES

At the close of that greatest of all contests of men and machines, World War II, Theodore von Karman could say, with deep personal conviction, that ". . . scientific results cannot be used efficiently by soldiers and sailors who have no understanding of them, and scientists cannot produce results useful for warfare without an understanding of the operations." With such simple truths fresh on their minds, von Karman and his civilian and military colleagues proceeded to forge institutional links—such as the Office of Naval Research—through which they hoped to encourage an enduring partnership between the scientific and military communities. Though the intensity of the bond has fluctuated with the ebb and flow of international relations and internal affairs, the partnership has endured to produce a military capability but dimly perceived by those who established it. But the partnership is not self-sustaining; it requires the constant vigilance of those who have not forgotten the bitter lessons of the past, the outspoken dedication of those whose vision extends beyond the next procurement cycle, and, above all, it requires open communication between the partners. It is to this latter task that the Charles H. Davis Lecture Series is dedicated.

The lecture series is named in honor of Rear Admiral Charles Henry Davis (1807–1877) whose distinguished career as a naval officer and as a scientist so epitomizes the objectives of the series, and whose clear vision of the proper role of science in human affairs redounded to the betterment of all men. The topics and the speakers in the series are chosen by a Search Committee operating under the National Research Council of the National Academy of Sciences, and two lectures are presented each year before the students and faculty of both the Naval Postgraduate School in Monterey, California, and The Naval War College at Newport, Rhode Island. The series is sponsored by the Office of Naval Research.

Rear Admiral
Charles H. Davis
(1807–1877)

CHARLES HENRY DAVIS was born January 16, 1807, in Boston, Massachusetts. His education consisted of preparation at the Boston Latin School followed by two years at Harvard University (1821–1823). In 1823, Davis was appointed midshipman and sailed (1824) on the UNITED STATES to the West Coast of South America where he transferred to the DOLPHIN for a cruise of the Pacific. Returning to Harvard he continued to work on a degree in mathematics and is listed with the graduating class of 1825.

In 1829 Davis became passed midshipman and was ordered to the

ONTARIO (1829–1832) of the Mediterranean squadron. Later, while serving aboard the VINCENNES (1833–1835), he was promoted to lieutenant. Aboard the INDEPENDENCE (1837–1841) Davis made a cruise to Russia and then to Brazil. Throughout these early years at sea Davis continued to study mathematics, astronomy and hydrology. During this period one of his superiors would write of him, "C. H. Davis is devoted to the improvement of his mind; and his country may expect much from him."

From 1842 to 1856 Davis undertook a number of special tasks and served on several commissions and boards. Notable among these was his participation in a survey of the New England coastal waters (1846–1849) during which he discovered several shoals that may have been responsible for a number of unexplained wrecks in the area. It was during this period in his career that Davis published "A Memoir upon the Geological Action of the Tidal and Other Currents of the Ocean" (1849) and "The Law of Deposit of the Flood Tide" (1852). He was also a prime mover in establishing the "America Ephemeris and Nautical Almanac" (1849) and supervising its publication at Cambridge, Massachusetts until 1855 and again from 1859 to 1862.

Promoted to commander in 1854, Davis resumed sea duty in command of the ST. MARYS in the Pacific (1856–1859). While he was captain of the ST. MARYS he was instrumental in securing the release of the adventurer William Walker and his followers who were beseiged at Rivas, Nicaragua.

With the outbreak of the Civil War Davis was immediately appointed to a number of important positions. He became the executive head of the new Bureau of Detail for selecting and assigning officers. He was one of three officers appointed by Secretary Gideon Welles to the Ironclad Board which passed judgment on the plans and specifications for the MONITOR and other ironclads. Promoted to captain in November 1861, Davis participated in the development of plans for blockading the Atlantic Coast, planning the operation against Hatteras Inlet and Port Royal Channel, and the early naval strategy of the war.

During the operations against Port Royal, Davis served as captain of the fleet and Chief of Staff to Admiral Samuel F. Du Pont. He shares with Du Pont a great deal of the credit for the excellent plan of attack carried out on November 7, 1861. Later, as flag officer of the Mississippi Flotilla, Davis led successful engagements against the Confederate fleet which contributed to the abandonment of Fort Pillow and the surrender of Memphis. He was promoted to commodore in July 1862, and to rear admiral on February 7, 1863.

In late 1862 Davis returned to Washington to head the newly established Bureau of Navigation. From this position he worked closely with such distinguished scientists as Joseph Henry and Alexander Bache to establish a "Permanent Commission" to advise the government on inventions and other scientific proposals which were being stimulated by the war. The Permanent Commission was established by the Secretary of the Navy on February 11, 1863 with Davis, Bache and Henry as members. However, Davis and his colleagues saw a wider need for cooperation between science and government and worked diligently for the establishment of the National Academy of Sciences. Their efforts were successful; President Abraham Lincoln signed a bill authorizing the establishment of the Academy on March 3, 1863.

In 1865, Admiral Davis was appointed superintendent of the Naval Observatory in Washington. In 1867 he returned to sea in command of the South Atlantic Squadron. Back in Washington in 1869 he was made a member of the Lighthouse Board and commander of the Norfolk Navy Yard. He later resumed his post as superintendent of the Naval Observatory where he served until his death on February 18, 1877.

DR. KARL LAUTENSCHLÄGER

TECHNOLOGY
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by
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The perennial concern of military planners is that technological surprise will give an opponent a decisive advantage in event of war. Technological developments combined with tactical innovation can bring fundamental change in fighting capabilities. The concern is over how to anticipate such change, particularly if it comes suddenly.

I suggest revision of some current assessments of naval developments on the basis of recent historical trends and reconsideration of the evolution of warfare at sea since 1851, when technology began producing fundamental changes in capabilities and tactics every 10 to 15 years. In an age of systems analysis, it may seem a florid diversion to review a century of history before assessing the present and speculating about the future. Yet, debate over naval policy is encumbered by fanciful history that is more popular than useful. Therefore, reconsideration of the long term could bring needed perspective to the problem. The results are two. The historical review provides case studies in how technology can affect warfare, and the analysis highlights basic trends that could be useful in predicting future developments. Together, these form a conceptual approach that breaks with the prevailing method of projecting current naval trends into the future.

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Graphic artwork by Dennis Olive.

The current method stresses overt physical features and the prospect of a revolutionary breakthrough in naval technology. Changes in the external appearance of ships, aircraft, and hardware dominate our perception of past and present technical developments in the naval sphere. If new systems look exotic, it is assumed that they must have important new capabilities. If the Soviets are building larger warships, then their naval capability is said to be expanding dramatically. Western reaction to the cruiser *Kirov* and the Typhoon-type submarine are cases in point. They are very large compared to their predecessors, but they have been a long time coming and they represent evolutionary rather than revolutionary change in capability.[1] We have also misinterpreted the nature and significance of technological change in contriving a single spectacular breakthrough at each stage. This bias is also persistent. Today, respected professionals worry openly about a single breakthrough in antisubmarine warfare technology that will seemingly make the oceans transparent.[2]

By contrast, I believe that the idea of a single technological breakthrough in the military sphere is popular mythology. Important advances in naval weaponry have not come with the introduction of spectacular new technology, but with the integration of several known, often rather mundane inventions. Developments in warship and aircraft design have tended to be evolutionary rather than revolutionary. But there have been several instances when combinations of technology were brought together to produce rapid change so significant that all existing combat fleets had to meet the new standard in fighting capabilities or remain hopelessly ineffective. The extent of these new capabilities was seldom reflected in obvious physical changes. In sum, the key to identifying important developments for the future is to concentrate on the synthesis of different technologies and how that

[1]The *Kirov* is a very large guided missile cruiser with a hybrid nuclear/oil burning propulsion plant. She carries twenty antiship missiles with an estimated range of 300 nm and an impressive array of defensive systems. The *Kirov* first went to sea in 1980. Only one sistership is known to be under construction. Nearly two decades earlier, in 1962, the first of four "Kynda"-class missile cruisers went into service, armed with sixteen 220-nm antiship missiles and a large array of defensive systems. See Jean Labayle Couhat and A. D. Baker III, *Combat Fleets of the World 1982–83* (Annapolis: Naval Institute Press, 1982), pp. 584, 616–19, 625–26; James W. Kehoe and Kenneth S. Brower, "Their New Cruiser," *U.S. Naval Institute Proceedings*, 106 (December 1980): 121–26. The first Soviet "Typhoon"-class ballistic missile submarine went to sea in 1981. She will carry twenty 4,000-nm missiles when operational in 1983 or 1984. U.S. Trident-class submarines carry twenty-four 4,350-nm missiles; converted Poseidon boats carry sixteen. Couhat and Baker, pp. 584, 602, 696, 720–21.

[2]William J. Perry, "Can't Miss Weapons—Revolution in Warfare," *U.S. News and World Report*, 89 (September 8, 1980): 61; Norman Polmar, "Soviet ASW: Highly Capable or Irrelevant?" *International Defense Review*, 12 (1979): 729.

synthesis can produce fundamental change in mission capabilities.

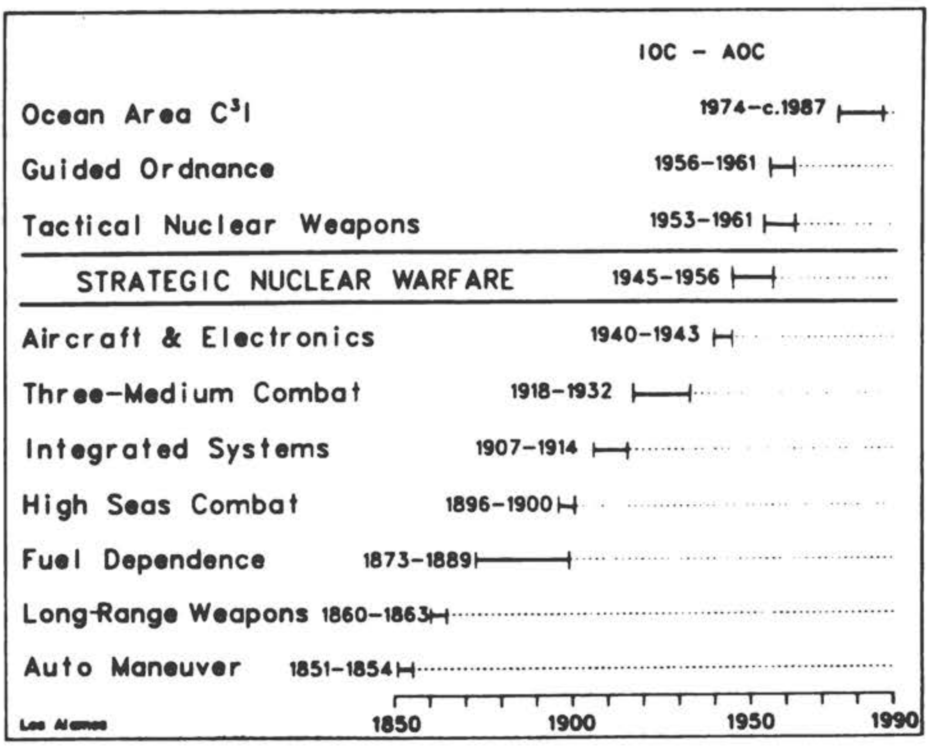
Another area of confusion in today's assessment of technological developments is in the use of benchmarks of change. The many familiar measures range from conception of a scientific principle and validating experiments to practical civilian applications or operational military capability. These measures are poorly defined and often mixed indiscriminately in making comparisons. The case studies of this historical survey use only three benchmarks. These are (1) the first practical demonstration of the principle, (2) the first complete set of basic components put into service, and (3) the first complete combat unit such as a squadron of ships or aircraft. The comparative time span used here for service adoption is measured from the first set of basic weapon components to the first combat unit. One might be called initial operational capability, familiar as IOC. The other represents a deployed fighting unit or actual operational capability. Each benchmark is a world first, without regard to nation.

In order to briefly develop these concepts, I will focus on the evolution of battle fleets, the principal combat arm of big navies. This does not presume that naval strategy must be based on the ideas of Alfred T. Mahan, Philip Colomb, and Julian Corbett. Nor does it indicate that a "balanced" fleet necessarily includes capital ships. The proper balance of components in a force depends on its intended function.

The term "combat" is used here in its more restricted sense to mean direct engagement of at least moderate duration. Both opposing forces concentrate their offensive power as well as exercise the capacity for sustained defense. This is in contrast to what the Soviets call "strike warfare," which assumes a short one-way assault on land or sea objectives and depends upon surprise, because the strike force has little or no means of defense. Ballistic or cruise missile submarines are ideal components of strike as opposed to battle forces. Commerce destruction is really another form of strike warfare, since the attacker has little means of defense and his objective is unarmed merchantmen. Commerce protection emphasizes defense of numerous dispersed convoys, as opposed to concentrated offense, and the objective is just as readily gained by avoiding contact with the enemy altogether.

The focus here on combat at sea necessarily ignores these other essential forms of naval warfare, as well as amphibious operations, mine warfare, and coastal defense. However, the evolution of the battle fleet provides a long-range view of how technology produces change in combat capability. Naval warfare in general is sensitive to changes in technology, because platforms as well as weapons are necessary for combat at sea. Whereas armies have historically armed and supported the man, navies have essentially manned and supported the arm. The battle fleet is of particular interest, because it is the one important element of navies that existed before the industrial revolution but continues to have important functions in international power politics today. Even in the age of thermonuclear weapons and intercontinental delivery systems, carrier battle groups have played prominent roles in superpower interaction, in regional conflict, and in global relations.

I will not present a treatise on the workings of naval technology. I could not even presume to catalog all of the relevant technologies, but will attempt to discover how technology has changed combat capabilities in elemental yet significant ways. Rather than looking first at technology, one must determine which changes in operating capability had the most far-reaching effects. These discontinuities in the otherwise gradual evolution of naval warfare provide points of reference for identifying sets of technology that were essential for the change. Thus, I will use 10 examples (see figure below) of evolutionary change and discontinuity to explore the dynamics of the change.



The steam engine and screw propeller ushered in what Bernard Brodie called the machine age in naval warfare.[3] For centuries, technology had made naval warfare possible by taking arms and men to sea. But the technology and tactics adopted during the early 1600s did not change for 200 years. The introduction of steam-powered ships-of-the-line brought the first of several fundamental changes in fighting capabilities that were to occur every 10 to 15 years.

The transition from sailing warships to steam ships-of-the-line exemplifies two conditions present at the start of the few rapid transitions in the otherwise gradual evolution of modern fighting fleets. First, it came rather suddenly, after technical inventions that had existed for some time were refined and combined. And second, it introduced new dimensions to the conduct of naval warfare.

The essential technologies for a self-propelled battle fleet were a reliable steam engine of several hundred horsepower and the screw propeller. The principles of the steam engine had been known since ancient times. Engines had wide use in the mining industry by 1725, but the first ship did not steam across the Atlantic until 1838. Paddle wheels used on the first steam ships were large and easily smashed by gunfire, and the necessary drive mechanism was delicate and exposed. Thus, the first naval steamships were ancillary craft such as gunboats and dispatch vessels. Perfection of the screw propeller allowed both power plant and drive train to be placed below the waterline where they were relatively safe from gunfire. The principle of the screw propeller was first advanced by Daniel Bernoulli in 1752. Yet, it was not refined sufficiently for naval use until the 1840s.[4]

Once the technology was refined and adopted, however, the transformation of fighting fleets was rapid. The first steam battleship, HMS *Sans Pareil*, entered service in 1851. In 1854, the British battle fleet sent to fight Tsarist Russia in the Baltic had 10 steamers out of 14 ships-of-the-line. The next year it became the world's first all-steam fighting force.[5] The change would not have been more dramatic if, after the

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[3]Bernard Brodie, *Sea Power in the Machine Age* (Princeton: Princeton University Press, 1941), pp. 17–91. This work is impressive for its penetrating insights and useful concepts, but more recent research revises many of its historical details.

[4]Georges G.-Toudouze, et al., *Histoire de la Marine* (Paris: Baschet, 1966), pp. 323–69; John Bourne, *Treatise on the Screw Propeller, Screw Vessels and Screw Engines, as Adopted for Purposes of Peace and War* (3rd ed., London: Longmans, Green, 1867); David Brown, "The Introduction of the Screw Propeller into the Royal Navy," *Warship*, 1 (January 1977): 59–63.

[5]Great Britain, Royal Navy, *The Navy List*, for the years 1846 through 1855. Steam ships-of-the-line here do not include eight sailing battleships converted to "steam block-ships" of low power and reduced rig. See Hans Busk, *The Navies of the World* (London: Routledge, Warnes, and Routledge, 1859), p. 58.

Nautilus (SSN-571) first went to sea in 1955, the active U.S. submarine fleet had been converted to nuclear propulsion before the end of President Eisenhower's second term. As it was, the United States, although the leader in the field, did not have nuclear propulsion in even half of her submarines until 1969 when 82 out of 161 in commission were nuclear powered.[6]

The new dimension to naval warfare was maneuver independent of the wind for extended periods. Steam completely changed fundamentals of battle tactics that had prevailed for two centuries. It made existing fleets of sailing battleships obsolete, and it introduced a basic characteristic to naval weapon platforms that persists to this day. Whether surface, subsurface, or airborne, their fuel-burning engines make tactical and strategic mobility two different problems. Since tactical mobility influences combat effectiveness, its critical elements are speed and maneuverability. Strategic mobility, on the other hand, determines the distance and duration that a force can be deployed from its base. Endurance then becomes more important. Self-propulsion gave independence from the wind only for tactical mobility at first. Fuel consumption was too high and coal fuel too bulky to permit long-range steaming. In steam ships-of-the-line and seagoing ironclads that followed, the solution to the problem was having two propulsion systems. Steam was used for tactical maneuver, but sailing rig was retained for movement over long distances.

The separation of tactical and strategic mobility factors has persisted. It is significant that today over two-thirds of the surface combatants in the Soviet navy lack the endurance, not to mention the seakeeping characteristics, necessary for ocean operations. The entire navies of many smaller countries are constrained by the endurance of their ships. In terms of strategic mobility, they are limited to a coast defense role.

LONG-RANGE WEAPONS

The next transformation was essentially a revolution in weaponry. Ironclads replaced wooden ships-of-the-line as the mainstay of fleets, but ordnance, not armor, brought the important change in naval warfare at this stage. Americans think of the *Monitor* and the *Merrimac* as the ships that ushered in the age of ironclads.[7] Europeans consider

[6]Raymond V. B. Blackman, ed., *Jane's Fighting Ships, 1969–70* (New York: McGraw-Hill, 1969), pp. 388–91, 439–57.

[7]Brodie, *Sea Power*, p. 171; Harold and Margaret Sprout, *The Rise of American Naval Power, 1776–1918* (Princeton: Princeton University Press, 1939), pp. 158–61.

that explosive shells made wooden battleships vulnerable and obsolete. They see the adoption of iron armor in *la Gloire* and HMS *Warrior* as an antidote to the shell gun and thus the critical advance of the period.[8]

With today's perspective, we can see that neither viewpoint captures the essence of the technical revolution of the 1860s. Important as ironclads were in the American Civil War, not one used on either side was suitable for navigating, let alone fighting, on the high seas.[9] They were river gunboats and floating batteries, not the components of a first-class battle fleet, nor the engines of transition in the world's big navies. The traditional European interpretation is equally skewed. Iron armor was not adopted in Europe to defeat the shell gun, nor was it the first means of protecting a warship from the effects of gunfire. Shell guns had been adopted and used in action decades before anyone thought seriously of retiring the wooden three-decker. Spherical explosive shells gave wooden warships a better capability to start lethal fires in one another, but they were unreliable and represented a fire danger themselves when stowed in a magazine. The bulk of ammunition carried by capital ships continued, therefore, to be solid roundshot.[10] Armor was not really new either. Thick oaken sides afforded considerable protection against solid projectiles when fired at normal battle ranges of 200 to 600 yards. Wooden ships-of-the-line were in effect "armored" and had been for more than a century.[11]

It was rifled ordnance that changed fighting capabilities dramatically and, at the same time, forced the adoption of ferrous armor. The new type of naval artillery had significantly greater range, accuracy, and penetrating power than the old smoothbores. The concept of rifling had been applied to small arms since the time of Columbus, but the technology necessary to produce rifled artillery was not available until the mid-nineteenth century. Improvements in metallurgy made it possible to build guns that were both much larger and able for the first time to withstand higher internal pressures inherent in efficient rifles. Advances in machining techniques made it possible to reduce

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[8]William Hovgaard, *Modern History of Warships* (London: E. and F. N. Spon, 1920), pp. 4–8; James Phinney Baxter III, *The Introduction of the Ironclad Warship* (Cambridge: Harvard University Press, 1933), pp. 17–32. Baxter provides an excellent review of European writing on this matter, and he also focuses on the shell gun at the expense of developments in rifled ordnance.

[9]The *New Ironsides* was a self-propelled floating battery about half the size and half the speed of contemporary seagoing ironclads in European navies. She was comparable to the Russian coast defense ironclads *Perventz*, *Nie Tron Menya*, and *Kreml*.

[10]Howard Douglas, *A Treatise on Naval Gunnery* (5th ed., London: John Murray, 1860), pp. 184–96, 240–340, 633–36.

[11]Brodie, *Sea Power*, pp. 172–74.

irregularities and thus "windage" in the bore.[12] The rifle fired a pointed, cylindrical projectile with three times the mass of a cannonball of similar diameter. The spin imparted to the projectile gave it stability in flight. Greater mass and streamlining gave the rifle projectile more momentum by an order of magnitude and thus far greater hitting power. Stability in flight and momentum meant much greater accuracy.[13] The effect was to extend the maximum fighting range at sea from 600 yards to between 1,500 and 2,000 yards.

Iron armor became essential because wood could not stand up to the smashing power of rifled ordnance. Iron plates were first used as hull protection on floating batteries bombarding stone forts in 1855 during the Crimean War.[14] With the success of these batteries, it was natural that the most important units of battle fleets would be given the advantage of ferrous plating eventually. Tests of the new rifled ordnance speeded the process and convinced the French in 1857 that iron armor was the only way to keep their ships afloat in combat. The next year they began building seagoing ironclads, and the British soon followed.[15] Since the largest guns could perforate the armor of most battleships, iron armor was about as effective against rifles as oak had been against smoothbores. The most significant aspect of this transition, then, was a dramatic improvement in the range of weapons.

Fuel Dependence

For the next three decades, technical change in navies was evolutionary. Tactical mobility was provided by steam propulsion, but strategic mobility continued to be under sail. The first of a few seagoing monitors went into service in 1873.[16] But another 16 years passed

[12]R. A. Stoney, "A Brief Historical Sketch of Our Rifled Ordnance from 1858–1868," *Minutes of Proceedings of the Royal Artillery Institution*, 6 (1870): 89–119; Charles Leopold Gadaud, *L'Artillerie de la Marine Francaise en 1872* (2nd ed., Paris: Arthus Bertrand, 1872), pp. 25–80.

[13]Howard Douglas, pp. 234, 236; Andrew Noble, *Artillery and Explosives* (New York: E. P. Dutton, 1960), pp. 499–501.

[14]G. Butler Earp, Ed., *The History of the Baltic Campaign of 1854* (London: Richard Bently, 1857), pp. 166, 184–85, 188–97; Edgar Anderson, "The Role of the Crimean War in Northern Europe," *Jahrbücher für Geschichte Osteuropas*, 20 (March 1972): 43–45, 61; Baxter, 69–91.

[15]Paul M. Dislere, *La Marine Cuirassee* (Paris: Gauthier-Villars, 1873), pp. 6–20; Oliver Guiheneuc, "Les Orignines du Premier Cuirasse de Haute mer a Vapeur," *La Revue Maritime*, 100 (April 1928): 459–82; 104 (August 1928): 183–202; Oscar Parkes, *British Battleships* (2nd ed., London: Seeley Service, 1966), pp. 2–6, 11–24.

[16]Thomas Brassey, *The British Navy: Its Strength, Resources, and Administration* (London: Longmans, Green, 1882), 1:343–59; J. W. King, *Report of Chief Engineer J. W. King, United States Navy, on European Ships of War and Their Armament, Naval Administration and Economy, Marine Constructions, Torpedo-Warfare, Dock-Yards, Etc., Etc.* (2nd ed., Washington: Government Printing Office, 1878), pp. 53–69; Parkes, pp. 191–202.

before they were joined by entire squadrons of their all-steam cousins.[17] Guns gradually grew in size and were mounted in fewer numbers. Turntables allowed these monster pieces to be trained inside armored turrets or fixed barbettes for protection. Armor became thicker and was made of simple steel or a sandwich of steel and iron, called compound armor.[18] With these features the "armorclad" gradually supplanted the broadside ironclad with its sailing rig.

Self-propulsion now gave independence from the wind for both tactical and strategic mobility, but this meant complete dependence on fuel. In essence, fuel dependence made logistics an important aspect of naval warfare. A fleet's endurance now depended on its fuel supply. Its area of operations depended on the proximity of bases. Complex munitions, diverse provisions, and spare parts have since added to the logistics problem, but fuel first made it significant. Consumption of fuel for both tactical and strategic mobility also brought the trade-off between speed and endurance. Most warships built since the 1880s and all naval aircraft compromise one for the other. Nuclear power and underway replenishment have reduced design sacrifices for long endurance in some warships. However, the trade-off is even more critical in aircraft, and they have become essential elements of naval forces.

High Seas Combat

Between 1895 and 1900, a series of technical innovations improved the fighting capabilities of fleets dramatically. Technology transformed the battleship into a blue-water gun platform. Chemical propellants and scientific gunnery made it lethal at four times the fighting range of its armorclad predecessor. Efficient steam engines and lighter armor made of steel gave cruisers the speed advantage they needed to serve as scouts for the battle fleet. The wireless telegraph obviated the need for visual communication. A commander could concentrate widely dispersed units of his fleet, and cruisers could report the findings of their reconnaissance from over the horizon. Finally, the rise of a novel threat to the battle fleet, in the form of surface torpedo craft, was neutralized with adoption of quick-firing torpedo defense batteries, the first specialized defensive weapons in warships.

Four sets of technology transformed the battleship by producing (1) high-velocity heavy ordnance, (2) telescopic gunsights, (3) face hard-

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[17] Commissioning dates and squadron assignments compiled from *The Navy List* and Oscar Parkes, *British Battleships*.

[18] Hovgaard, *Modern History of Warships*, pp. 43–51, 54–69, 73–90, 456–64; F. Singer, "A Graphic History of Armor Protection and Distribution on War Vessels," U.S. Office of Naval Intelligence, *General Information Series*, 8 (June 1889): 82–86.

ened, alloy steel armor, and (4) quick-firing medium- and light-caliber guns. High-velocity guns were a significant advance over earlier naval artillery, because they gave heavy projectiles the momentum required for high-striking velocity and small dispersion at much greater range. This meant substantial gains in both destructive power and accuracy. The essential technology was propellant made from a chemical compound of nitrogen and cellulose. The new chemical propellants were much more efficient than black powder, which is a mechanical mixture. Nitrocellulose propellants produced muzzle velocities 50 to 100 percent higher than had been possible with black powder.[19] Although the development of chemical propellants is usually lost in the myriad of inventions made in the 1880s, it probably ranks with steam and iron in revolutionizing naval warfare. Naturally, the potential of chemical propellants could only be realized when they were introduced in combination with other innovations such as long gun tubes and more efficient mountings.

The second set of technologies to transform the battleship brought telescopic fire control to naval gunnery. The limitations of the human eye in aiming a gun using an open sight precluded accurate shooting beyond about 2,000 yards. Normal ironclad and armorclad fighting range was considered to be 1,500 yards in spite of vast improvements in ordnance. The telescopic sight enabled gunners to shoot with consistent accuracy out to 6,000 or 7,000 yards.[20] It was the first dramatic improvement in naval fire control and a portent of how future advances in weaponry would have to be accompanied by commensurate improvements in target acquisition and weapon control.

Technological advances in the area of metallurgy finally allowed a well-protected warship to fight effectively on the high seas. Before 1900, all major naval battles but one took place within sight of land, usually in sheltered waters.[21] Armorclads, like sailing ships, steamships,

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[19] J. Corner, *Theory of the Interior Ballistics of Guns* (New York: John Wiley, 1950), pp. 24–35; Andrew Noble, pp. 405–38, 462–81; Thomas J. Hayes, *Elements of Ordnance* (New York: John Wiley, 1938), pp. 1–28; Charles Singer, et al., *A History of Technology* (Oxford: Clarendon Press, 1958), 5:284–98.

[20] William F. Fullam and Thomas C. Hart, *Textbook of Ordnance and Gunnery* (2nd ed., Annapolis: United States Naval Institute, 1905), pp. 248–56; Bradley A. Fiske, "Progress in the Naval Use of Electricity," U.S. Office of Naval Intelligence, *General Information Series*, 14 (July 1895): 119–22; Bradley A. Fiske, *From Midshipman to Rear Admiral* (New York: Century, 1919), pp. 123–28, 177–80, 213; Percy Scott, *Fifty Years in the Royal Navy* (London: John Murray, 1919), pp. 30–32, 81–82, 92–93.

[21] The "Glorious First of June" (Battle of Ushant), 28 May to 1 June 1794, was fought between British and French fleets in the Atlantic about 500 miles west of Brest, France. For a survey of naval battles, see Helmut Pemsel, *Atlas of Naval Warfare* (London: Arms and Armour Press, 1977).

and ironclads before them, could fight only on moderate seas. Earlier types had to close their broadside gunports in rough water. Armorclads were hampered by similar limitations. Many were built with low freeboard because of the great weight of their armor. This meant that waves and spray interfered with the loading and aiming of their guns. The French built high freeboard armorclads, but their upper sides were unprotected, making them liable to flooding and capsizing when waves poured into shell holes.[22]

The advent of true ocean-fighting capability, hardly noted in traditional histories, came with the revolution in armor technology. The introduction of alloy steel armor provided a tougher armor material, and cementing (carburizing) made the face harder. It was, in effect, lighter, because it was twice as effective as an equal thickness of compound armor. Now the hull and ordnance of a high-freeboard battleship could be protected adequately without a dangerous excess in topweight. High sides and high-mounted guns allowed aiming without interference from ocean spray. Harvey process armor was introduced in 1890, and Krupp cemented alloy steel followed in 1895.[23] Two years later, Great Britain had in service a squadron of battleships employing cemented steel armor in the new scheme of protection. No nation could challenge British naval supremacy without adopting the new technology.

Quick-firing guns combined a fourth set of technologies that transformed the battleship. They were made possible with the introduction of fast-operating breech mechanisms (1866), cartridge cases of cannon caliber (1877), hydraulic recoil mechanisms on pivot mountings (1881), and smokeless (chemical) propellants (1886).[24] From the 1890s until the advent of dreadnought battleships, the main battery of a capital ship consisted of both heavy guns and quick firers. Medium-caliber pieces (5- to 8-inch) augmented the offensive capability of the new type of battleship. They could wreck another battleship's upperworks with a torrent of high explosive shells, while the heavy guns punched holes in its heavy armor. Light quick-firing guns represented something

[22]Hovgaard, *Modern History of Warships*, pp. 54–56; Oscar Parkes, pp. 189–94, 199, 354, 357, 373–74; Frederic Manning, *The Life of Sir William White* (London: Murray, 1923), pp. 290–91.

[23]Roland I. Curtin and Thomas L. Johnson, *Naval Ordnance* (Annapolis: United States Naval Institute, 1915), pp. 323–38; "Armor," U.S. Office of Naval Intelligence, *General Information Series*, 5 (June 1886): 239–45; 6 (June 1887): 322–31; 10 (July 1891): 279–337; 11 (July 1892): 271–312; 13 (July 1894): 134–54; 14 (July 1895): 83–92; 19 (July 1900): 175–94; 20 (July 1901): 247–67; 21 (July 1902): 121–34.

[24]H. Garbett, *Naval Gunnery* (London: George Bell 1897), pp. 136–47, 159–87; Great Britain, War Office, *Treatise on Ammunition* (London: His Majesty's Stationery Office, 1905), pp.111–38.

fundamentally new in warships. They formed a specialized defensive battery intended specifically to counter assaults by craft that depended on surprise and stealth. In this case, the threat was from torpedo boats. The impetus for developing quick-firing guns for naval use had in fact come from the torpedo boat. The lighter weapons (4-inch and below) provided big ships with an effective defense against this threat.

The rest of the fleet underwent a transformation at about the same time. The essence of the change was in reconnaissance capabilities, and it came about in two ways. First, improvements in propulsion and armor technology finally gave cruisers the speed they needed to maintain contact with the enemy at a distance and to escape if pursued. Second, the invention of wireless telegraphy enabled scouts to report to their fleet command without steaming all the way back to within visual signaling distance of the flagship.

Cruisers were the workhorses of late-nineteenth-century navies. They served on the foreign stations of Europe's worldwide empires, and showed the flag on extended cruises. Had there been a war between the major naval powers, the French and Russian navies intended their cruisers for destroying commerce, while the British navy would have used its cruisers to protect shipping and to hunt commerce raiders.[25] The mission absent in cruisers since the age of sail was reconnaissance. In early steam navies, technology prevented cruisers from serving usefully with the battle fleet, because they lacked the speed advantage necessary to serve as the eyes of the fleet.[26]

By 1882, ship propulsion plants were reliable and powerful enough for sustained high-speed steaming. The advent of steel armor and the curved protective deck made it possible to protect cruisers against the gunfire of other cruisers without excessive weight. In 1889, the Armstrong firm of Britain delivered the first of its many fast "protected" cruisers.[27] From that time until the rise of fast carrier task forces during World War II, cruisers could be built with a 20 percent speed advantage over existing battle fleets. Although cruiser designs continued to stress commerce destruction or protection roles for a time, navies could employ their faster cruisers as scouts for the battle fleet. In 1901, the Royal Navy introduced armored cruisers with heavy ordnance and

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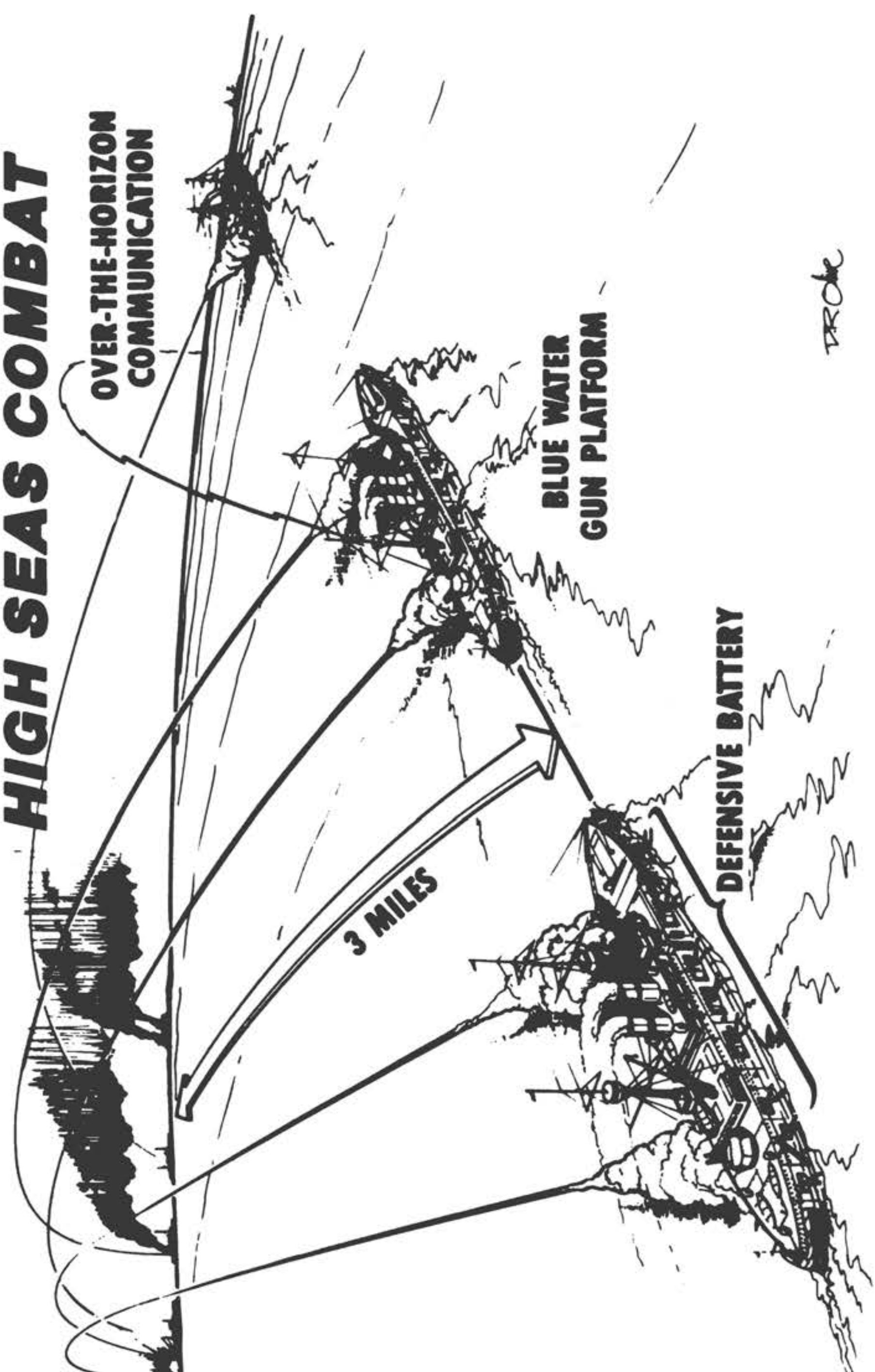
[25]Theodore Ropp, "Development of a Modern Navy: French Naval Policy, 1871–1904" (Ph.D. dissertation, Harvard University, 1937), pp. 33–35, 68–72; Thomas Brassey, *The British Navy*, 1:477–509, 513–22.

[26]Robert Gardiner, et al., eds., *Conway's All the World's Fighting Ships 1860–1905* (Greenwich: Conway Maritime Press, 1979), pp. 41, 61.

[27]Peter Brook, "The Elswick Cruisers," *Warship International*, 7 (1970): 154–76; 8 (1971): 246–73; Hovgaard, *Modern History of Warships*, pp. 174–78.


HIGH SEAS COMBAT
OVER-THE-HORIZON COMMUNICATION
BLUE WATER GUN PLATFORM
DEFENSIVE BATTERY
3 MILES

extensive armor belts. These cruisers were specifically intended for both fleet reconnaissance and as a fast reinforcing wing of the battle line.[28]

The wireless telegraph was ultimately far more significant than improved cruiser design for fleet operations. In 1899, 11 years after the results of Heinrich Hertz's experiments with electromagnetic waves were published, the Royal Navy tried out its first wireless sets on fleet maneuvers. The next year, the British fleet was the first to be equipped with wireless telegraph, beginning with an order for 32 Marconi sets. The other major navies soon followed. At the turn of the century, all ships fitted with wireless equipment were capable of communication with other ships or shore stations at ranges of 50 to 70 miles.[29]

With the wireless link, cruisers became forward-based sensor platforms that could provide the fleet commander with information about the movements of enemy forces. The system was crude by today's standards. Its sensor was merely human eyesight aided by binoculars. At its best, the communication link took many minutes to relay information. Yet this was a fundamentally new capability. For the first time, a tactical commander was served by immediate, continuous reconnaissance, extending far beyond the limit of his vision. Such a capability is considered to be essential in today's naval operations.

Surface torpedo craft also came into use during the late nineteenth century. The torpedo boat was one of those novel weapons that comes along every decade or so. At such times, it becomes popular to declare that the novel weapon has made all existing fleets obsolete. The idea that new technology can make battle fleets suddenly obsolete has been fashionable many times. In most of these cases, when technology has been employed to produce a small, inexpensive device that can sink a capital ship, the mere possibility of sinking big ships is often assumed to make them immediately obsolete. However, probability, as opposed to theoretical possibility, brings the operational utility of the novel weapon into question, because probability depends on numerous factors related to operating conditions, fleet defenses, and tactics.

In the case of the torpedo boat, there is no doubt that a new dimension was added to naval warfare, but the demise of the battle fleet was never a real possibility. Although a torpedo certainly could be potent, it had to be launched at close range, well within the lethal reach of a

[28]Manning, *William White*, pp. 365–68; Oscar Parkes, pp. 441–50.

[29]Arthur Hezlet, *Electronics and Sea Power* (New York: Stein and Day, 1975), pp. 26–52; W. L. Howard, "Wireless Telegraphy," U.S. Office of Naval Intelligence, *General Information Series*, 18 (November 1899): 277–87; Linwood S. Howeth, *History of Communications-Electronics in the United States Navy* (Washington: Government Printing Office, 1963), pp. 11–112.

warship's gun batteries. This meant that the torpedo carrier had to be small to avoid early detection and fast to avoid being hit by gunfire. These requirements precluded the design of robust, seaworthy craft. The result was that torpedo boats could threaten fleet operations in confined waters along a coast. But the fleet adopted quick-firing guns as a defense, and with new high-freeboard battleships, it moved farther out to sea where it could operate effectively but torpedo boats could not.[30] This is the period when the strategy of distant blockade began to replace the traditional close blockade.

Thus, in the late 1890s, the fleet became a blue-water combat force. Its primary gun platforms could function effectively on the oceans in rough seas, and they were effective at four times the range thought possible before. Extended reconnaissance was possible using fast cruisers and wireless communication. This over-the-horizon communication link also enabled fleet commanders to disperse elements of their forces over many miles of ocean and concentrate them again at opportune moments for action.

INTEGRATED SYSTEMS

In the relatively short period from about 1907 to 1914, the battle fleets of the major naval powers went through another fundamental transformation. The essence of the change was system integration. This was integration both of platforms with one another and of several systems aboard a single platform. In the former case, the torpedo boat destroyer matured and joined the fleet as an offensive/defensive arm of the battle line. In the latter case, integrated components of a centralized fire-control system gave the new dreadnought-type battleships twice the effective fighting range and twice the hitting power of the latest predreadnoughts.

The torpedo boat destroyer became the first specialized weapon platform, physically separated from the main body of the battle fleet, but integral to it. The destroyer, in fact, took its name from its initial mission as a counter to the torpedo boat. However, the generic type actually developed along two lines. In the Royal Navy and later the U.S. Navy, destroyers were developed as a defensive screen against torpedo boat attacks. In the continental navies, the German navy in particular, destroyers were primarily intended as the torpedo assault

[30]S. A. Staunton, "The Naval Maneuvers of 1888," U.S. Office of Naval Intelligence, *General Information Series*, 8 (June 1889): 57–58; Edgar J. March, *British Destroyers* (London: Seeley Service, 1966), pp. 21–26, 38–39; Harold Fock, *Schwarze Gesellen* (Herford: Koehlers, 1979, 1981), Vol. 1: *Torpedobotte bis 1914*, Vol. 2: *Zerstörer bis 1914*.

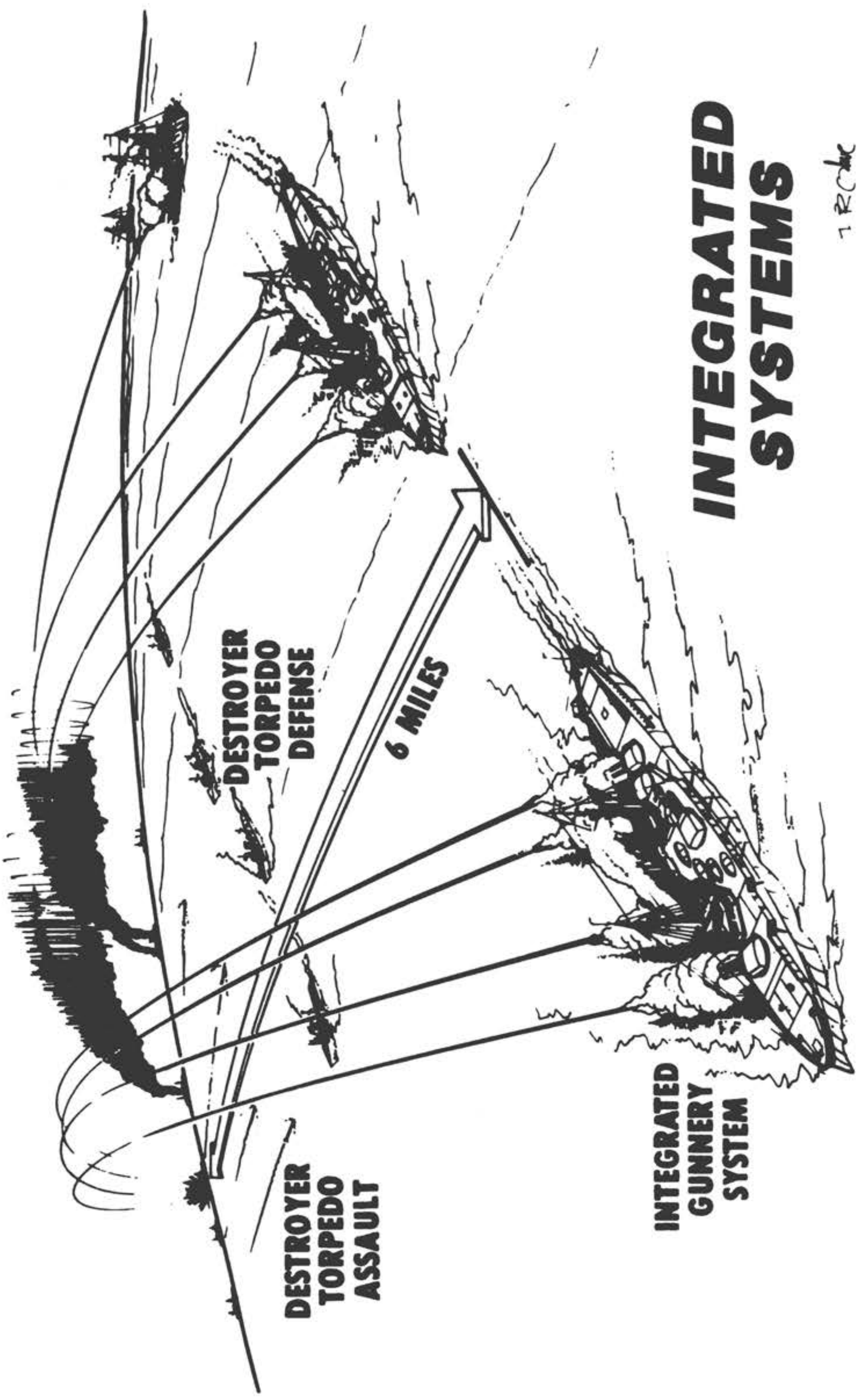
arm of the battle fleet. Each approach assumed the other as a secondary role, but the differing emphasis was clear. During the 1890s the British and German navies led in the development of the destroyer. Each intended to integrate the type into its battle fleet, and each faced serious problems of seakeeping and endurance that plagued torpedo craft at that time. These problems were eventually solved by strengthening the hull and increasing the displacement to over 700 tons, by raising and flairing the forecastle, and by replacing reciprocating engines with steam turbines. Together, these measures permitted destroyers to operate efficiently at sea with the battle fleet.[31]

By 1907, the larger units of improved design were entering service. Armed with quick-firing guns, as well as torpedo tubes, the destroyer in effect took the battleship's torpedo defense battery out thousands of yards from the battle line, extending its perimeter of defense. At the same time, the torpedo was placed in a forward position where it could be used as a preliminary assault weapon, supplementing the battleship's big guns. The high-powered electric arc light with movable shutter allowed day and night communication between ships and thus tactical integration of the now disparate units of the battle fleet. No longer were all the essential weapons of the force mounted on one type of unit operating in close proximity with its companions.

Integration of shipboard devices brought something new to the fleet and capped the development of a new type of battleship that has come to be called the dreadnought. Although generally considered to be any battleship with all heavy guns of uniform caliber (that is, no medium-caliber, quick-firing guns in the main battery), the dreadnought as a technological advancement represented much more. It was the first linking of several dissimilar components on a warship to give its weapons significantly improved capabilities. At the same time, each component became essential to the whole. Whereas the many guns of the predreadnought operated independently, the big guns of the dreadnought functioned as a single system.

In the dreadnought, the system was called central fire control. With it, effective shooting with several heavy guns was possible far beyond the lethal range of medium-caliber ordnance on predreadnoughts. This type of gunnery control consisted of a telescopic central director, optical range finders, an observer aloft to spot the fall of shot, and electrical communication to link these components with the guns and with each

[31]Edgar March, pp. 72–75; David Lyon, "Torpedo Craft," in *Conway's All the World's Fighting Ships*, pp. 87, 99; Norman Friedman, *U.S. Destroyers* (Annapolis: Naval Institute Press, 1982), pp. 11–29; Harald Fock, 2: 119–58.


INTEGRATED SYSTEMS
DESTROYER TORPEDO DEFENSE
6 MILES
DESTROYER TORPEDO ASSAULT
INTEGRATED GUNNERY SYSTEM

other. Furthermore, guns and instruments had to be calibrated according to common references in train and elevation.[32]

Three things are notable about this development. First, the individual technologies were simple and had existed for decades before they were first combined into an effective weapon system in 1911. Second, the dreadnought could shoot with consistent accuracy at twice the effective range of predreadnoughts, extending normal fighting distance from between 5,000 and 7,000 yards to between 10,000 and 14,000 yards. Third, an all-big-gun battleship with central fire control was capable of several times the hits possible for a sistership without the system. Yet, the differences between the two were invisible to all but a well-informed observer.

While the fleet was undergoing this transformation, the submarine entered the scene as the next of the novel weapons. During World War I, it supplanted the cruiser as the primary commerce raider. Once employed in an unrestricted campaign, German U-boats threatened to sever the lines of military supplies and sustenance to the British Isles. The situation remained grave until the reintroduction of the old convoy system of sailing ship days.[33]

In spite of its performance as a commerce destroyer, the submarine neither supplanted the battle fleet nor drove it from the seas. Its success against warships was in more confined waters where it could lie in ambush. During the war, most big ships were torpedoed at the approaches to naval bases, such as Heligoland Bight, or in the area of shore bombardment, such as the Dardanelles. No first-line capital ship was sunk by a submarine. Of the six dreadnoughts torpedoed, five were repaired in 1 to 3 months. Nine old predreadnoughts were sunk by submarines, demonstrating the necessity for underwater protection included in dreadnought designs.[34] However, the main difficulties for submarines operating against first-line naval forces were not the protection of battleships and defensive armament of their accompanying destroyers. The problems were finding the fleet and then overcoming

[32]Peter Padfield, *Guns at Sea* (New York: St. Martin's 1974), pp. 244–50; Percy Scott, pp. 179–86, 204, 242–47, 251–55, 258–67.

[33]John Rushworth Jellicoe, *The Crisis of the Naval War* (London: Cassell, 1920); Arthur J. Marder, *From Dreadnought to Scapa Flow* (London: Oxford University Press, 1969), Vol. 4: *1917: The Year of Crisis;* Bodo Herzog, *60 Jahre Deutsche Uboote 1960–1966* (Müchen: J. F. Lehmanns, 1968), pp. 101–26.

[34]*Jean Bart*, torpedoed 21 December 1914 (103 days to repair; *Moltke*, 19 August 1915 (32 days); *Grosser Kurfürst*, 5 November 1916 (97 days); *Kronprinz*, 5 November 1916 (31 days); *Westfalen*, 18 August 1916 (46 days); *Moltke*, torpedoed 25 April 1918 while under tow after major machinery casualty and flooding (137 days). Note that five were German dreadnoughts torpedoed by British submarines, while German submarines did not torpedo any dreadnoughts.

a gross disparity in speed. Once in contact, the submarine usually could not get into position to launch its relatively short-range weapons.[35] Submarines caused great concern among fleet commanders, but they did not particularly hamper operations of battle fleets on the high seas. Used against warships, the submarine was, like the surface torpedo boat, a defensive weapon or a means of harassment. As a commerce raider, however, the submarine opened an important new dimension in naval warfare.

The apparent inactivity of dreadnought fleets in World War I had led many to the conclusion that the leviathans served little useful purpose. The single major fleet action of Jutland was indecisive, and the struggle between U-boats and convoys was awesome in its intensity. Yet the convoys could not have been successful if the German battle fleet had not been kept in check. Less widely recognized, but equally important, is the fact that while Germany failed to impose a submarine blockade on Britain, the Royal Navy put Germany in the grip of a surface blockade from the first weeks of the war, with crushing effect. Vital raw materials were cut off, and during the last 2 years of the war, the greater part of Germany's civilian population was in a state of chronic starvation.[36] Liddell Hart concluded that the ultimate German collapse "was due more to emptiness of the stomach, produced by the economic pressure of sea power, than to loss of blood."[37] Notwithstanding the introduction of novel weapons in the 1890s and during World War I, the final arbiter in the naval war was still the battle fleet.

THREE-MEDIUM COMBAT

In an evolutionary transformation, the battle fleet acquired combat capabilities in three mediums for offense, reconnaissance, defense, and protection. Offense was still mainly the heavy gun, but during the 14 years immediately following World War I, the gun was supplemented by the aerial torpedo and bomb. Aerial scouts added considerable

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[35] Arthur Hezlet, *The Submarine and Sea Power* (London: Peter Davies, 1967), pp. 25–26, 29–42, and 67–84.

[36] A. C. Bell, *A History of the Blockade of Germany and of the Countries Associated With Her in the Great War* (London: His Majesty's Stationery Office, 1937); Ralph Haswell Lutz, *The Causes of the German Collapse in 1918* (Stanford: Stanford University Press, 1934), pp. 180–87; Ernest L. Bogart, *Economic History of Europe 1760–1939* (New York: Longmans, Green, 1942), pp. 501–505.

[37] Basil H. Liddell Hart, *Strategy: The Indirect Approach* (2nd ed., New York: Praeger, 1967), p. 358. See also F. Lee Benns and Mary Elisabeth Seldon, *Europe 1914–1939* (New York: Appleton-Century-Crofts, 1965), p. 100; Theodore Ropp, *War in the Modern World* (Durham: Duke University Press, 1959), p. 251.

reconnaissance capability, and defensive systems were refined to counter air, surface, and subsurface threats.

The obvious change was the advent of fleet air power. From 1924, aircraft contributed directly and importantly to the offensive, defensive, and reconnaissance capabilities of the main battle force. During World War I, flimsy aircraft had been used to drop small bombs and torpedoes against a few ships. Aircraft had also been used for fleet reconnaissance and employed defensively against submarines and zeppelins. However, the initial obstacle to conducting air operations in conjunction with the fleet was launching and recovering aircraft at sea. Other than zeppelins, the first naval aircraft were floatplanes. They could be launched from inclined shipboard platforms, but they could not be recovered until the carrier stopped to hoist them back aboard. HMS *Argus*, first aircraft carrier with a flight deck that permitted both launch and recovery of wheeled aircraft, entered service at the very end of the war. However, like all early carriers, she did not have enough speed to rejoin the main force after she had turned into the wind to launch or recover aircraft.[38] The first carriers with ample speed for fleet operations went into service in 1924, and by 1929, the British, American, and Japanese navies had at least two each.

As an offensive system, the carrier operated torpedo planes from the first. A single torpedo hit could disable all but the largest ships, but like surface and subsurface torpedo craft, the airplane had to launch its weapon from close range to have a reasonable chance of success. During the long, straight run in, the relatively slow biplane would be exposed to concentrated fire from antiaircraft guns that were being installed in ever increasing numbers. Development of the dive bomber gave the carrier an alternative means of attack. Bombing from level flight was unlikely to hit a moving ship, but a high-speed dive could be consistently effective. Aircraft of the 1920s could not stand the stress of pulling out of a dive. Gradually, airframe structures were refined, however, and in 1932 the U.S. Navy introduced the first attack aircraft that could deliver a 1,000-pound bomb in a dive.[39]

An aerial platform was clearly a boon to reconnaissance. It could provide a superb overall view of the situation, and inherently greater speed permitted more area to be scouted in a given time. Floatplanes,

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[38]Stephen W. Roskill, ed., *Documents Relating to the Naval Air Service* (London: Navy Records Society, 1969), Vol. 1; 1908–1918; Norman Polmar, *Aircraft Carriers* (Garden City: Doubleday, 1969), pp. 27, 31–37, 41–43, 60–61; H. H. Smith, *A Yellow Admiral Remembers* (London: 1932).

[39]Ray Wagner, *American Combat Planes* (2nd ed., Garden City: Doubleday, 1968), pp. 329–30; Gordon Swanborough and Peter M. Bowers, *United States Navy Aircraft Since 1911* (London: Putnam, 1976), pp. 314–15.

carried aboard cruisers and launched from catapults after 1922, extended the coverage of the fleet reconnaissance force. Carrier-based scouts offered even more flexibility, because they could be launched and recovered under a broader range of conditions. As an element of air defense, the carrier brought another improvement in existing capabilities. Carriers allowed the fleet to take its own fighter-interceptors to sea for continuous operation.[40] The fighter force operated as an extended line of air defense, analogous to the destroyer screen against torpedo craft. Of course, its time on station was severely limited by fuel endurance.

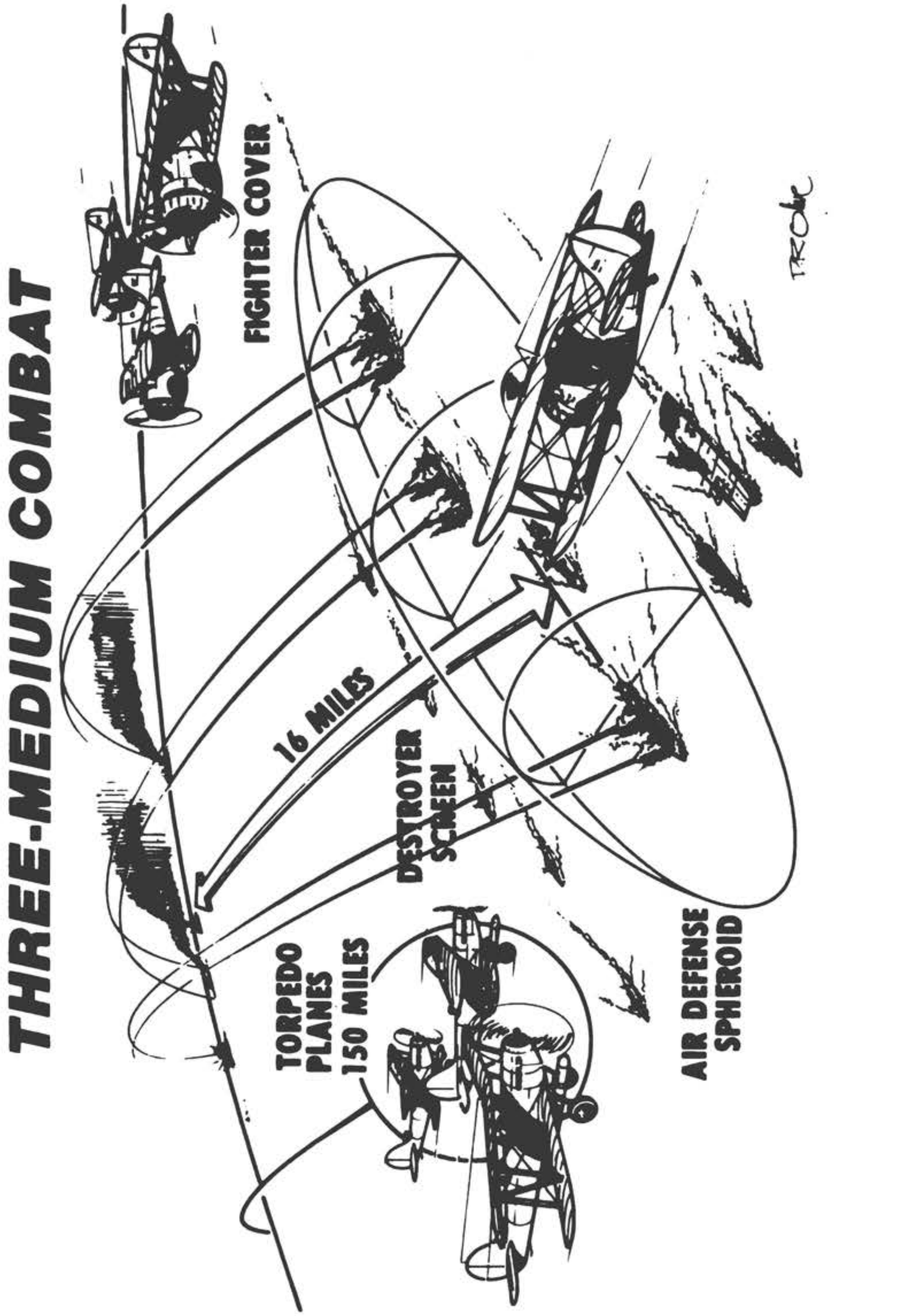
As a second line of air defense, capital ships were fitted with their own antiaircraft batteries. During World War I, a few high-angle, quick-firing guns were fitted as a defense against zeppelins. By the end of the twenties, entire batteries of director-controlled AA guns were standard. These were strengthened with automatic, multibarreled weapons for close-in defense.

The big gun remained the principal offensive weapon of the fleet, because it could deliver the most destructive power. By the 1920s, battleship guns in the major fleets fired armor piercing and high-explosive projectiles weighing from 1,400 to 2,100 pounds. Only this kind of firepower had a good chance of sinking the latest capital ships. In destructive power and accuracy (although not in striking range), the battleship was superior to the torpedo plane and dive bomber for some time to come. As late as 1941, a single dreadnought could deliver more ordnance in an hour than all the aircraft in the largest fleet could carry.[41]

Improvements in fire control permitted consistently accurate shooting almost to the horizon, more than double the fighting range of the first generation of dreadnoughts. Advanced surface gunnery was made possible by long-based range finders, gyro-stabilized optics, mechanical analog computers, and synchronous data links. The analog computer is of particular interest because it allowed reasonably accurate prediction of where the target would be when the projectiles arrived, even when

[40]Arthur Richard Hezlet, *Aircraft and Sea Power* (New York: Stein and Day, 1970), pp. 41–84.

[41]In December 1941, 162 SBD, 63 SB2U, and 75 TBD dive and torpedo bombers on six U.S. carriers could carry 251 tons of ordnance, William T. Larkins, *U.S. Navy Aircraft 1921–1941* (Concord: Aviation History, 1961), pp. 300–314; Hal Andrews and John C. Reilly, "U.S. Navy Airplanes, 1911–1969," *Dictionary of American Naval Fighting Ships* (Washington: Government Printing Office, 1970), 5:541–43. In December 1941, 135 D3A, 174 B5N, and 8 B4Y dive and torpedo bombers aboard 9 Japanese carriers could carry 215.5 tons; Rene Francillion, *Japanese Aircraft of the Pacific War* (London: Putnam, 1970), pp. 41–42, 276, 415, 451. One U.S. *Colorado* class battleship, firing eight-gun broadsides every 2 minutes, would deliver 268.8 tons of Mk V, 16-inch projectiles in an hour.


THREE-MEDIUM COMBAT
FIGHTER COVER
16 MILES
DESTROYER SCREEN
TORPEDO PLANES 150 MILES
AIR DEFENSE SPHEROID

both target and firing platform maneuvered. One contemporary gunnery manual noted that fire control now followed tactics rather than determining them.[42] Floatplanes were carried aboard battleships as aerial spotters to extend gunnery range over the horizon. Although much was claimed for this capability, it did not work well against a maneuvering force.

Protection of the heavily armored capital ship took a significant turn. In the twenties, horizontal armor became more important than vertical. Naturally, armored decks were needed as protection against aerial bombs. Somewhat earlier, advanced surface gunnery made them essential. Since shooting was now accurate at over 25,000 yards, engagements would be fought and decided at long range. Even a large, high-velocity projectile tends to plunge at the end of a long trajectory. At these new ranges, there was thus a greater chance of hitting the decks of a ship than its sides.[43] The newest and most heavily armed battleships were therefore "modernized" by having thick armor placed over their decks, and all subsequent designs paid particular attention to this feature. Underwater protection was also improved considerably. One approach was to install layers of shock-absorbing cells between the outer hull and the ship's vital compartments. The other was to extend the underwater hull outward in a blister or bulge that ran most of the ship's length. In several designs the two techniques were used in combination, and variations are still used today.[44]

Not only were later dreadnoughts designed with extensive protection against underwater explosions, the battle fleet as a whole was equipped to deal with submarines. During World War I, the destroyers of the torpedo boat screen became an extended defense against submarines as well. They could easily outrun a submarine on the surface and smother it with gunfire. Underwater, a submarine had little chance of getting into position to launch torpedoes against a fast-moving battle fleet. Even so, lookouts combed the seas for periscope wakes, and destroyers carried depth charges to attack their prey underwater. After the war, fleet destroyers were equipped with active acoustic detection devices

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[42]U.S. Naval Academy, *Notes on Fire Control 1941* (Washington: Government Printing Office, 1941), pp. 106–108.

[43]One detailed series of tests is summarized in U.S Navy, Bureau of Ordnance, "Battleship and Scout Armor," Report 34631 (A2)-0 of 3 June 1918, Box 861, Series Entry 88, Record Group 19, Old Military Branch, U.S. National Archives.

[44]Great Britain, Admiralty, *Experiments on Underwater Protection and Its Application to Warships, 1913–1920* (London: His Majesty's Stationery Office, 1920); Norman Friedman, *Battleship Design and Development 1905–1945* (New York: Mayflower Books, 1978), pp. 75–83.

developed first by the Royal Navy as ASDIC and later by the U.S. Navy as Sonar.[45]

Thus, the major fleets entered the second decade of peace able to attack and defend themselves in the air, surface, and subsurface mediums. The introduction of naval air power brought new capabilities, but the importance of this development at this stage should not be exaggerated. We now know that the aircraft carrier would eventually supplant the armored gun platform as the capital ship of battle fleets. However, the necessary technology came slowly.

The battleship-aviation controversy is a good example of the gulf that often occurs between the extremes of wild prediction and conservative skepticism when dealing with the future. Aviation pioneers like Billy Mitchell claimed in 1920 that airplanes had made traditional fleets obsolete, but this was a case of general prediction. Although ultimately correct, it was hardly a useful insight at the time. At the other extreme, the admirals saw carriers and their aircraft as nothing more than another component in a combat fleet organized around the battleship. Their conservatism can be blamed for a late appreciation of carrier air power during World War II, but in 1920 they were right. The seaborne strike aircraft would not be ready to assume primacy in naval warfare for two or more decades.

Aircraft and Electronics

Only the first of the transitions described so far occurred during a war. The next transformation of combat fleets also happened in wartime, although by the standards of measurement used here, it was no faster than the most dramatic to date. Two separate and profound changes took place. Airborne platforms became the main combat systems for both offense and defense in big navies, and electronics came to dominate weapons and sensors.

Manned flight was given a practical demonstration in 1903. It was two decades before aircraft served in regular functions with the fleet, and it would be another two decades before they became the essential offensive and defensive elements of naval warfare. The basic reasons were technological. In an offensive role airplanes needed the range, payload, and speed to be able to search for and find the enemy fleet, sink its ships, and return to their carriers. Before this was possible, the airplane had to progress considerably in its evolution. Engines needed

[45]Stephen Roskill, *Naval Policy Between the Wars* (New York: Walker, 1968), 1: 345–47; Peter Hodges and Norman Friedman, *Destroyer Weapons of World War 2* (Greenwich: Conway Maritime Press, 1979), p. 136.

much higher power-to-weight ratios than were possible in the 1920s, and variable pitch propellers would make an important contribution to their efficiency. The high-drag biplane had to be supplanted by aerodynamically efficient monoplanes. And lighter, stressed-metal airframe construction was needed to reduce structural weight and increase fuel and payload capacities.

To be a main offensive system for combat and not merely a harassing agent during the preliminaries, carrier strike aircraft would have to carry a reliable torpedo or 1,000-pound bomb. Less of a weapon load was little threat to a large armored warship, including a carrier. The strike aircraft would have to cruise at over 120 knots, combat-loaded. The normal cruising speed of most combat-loaded biplanes was less than 100 knots, giving little margin over headwinds and faststreaming battle fleets. A combat radius of at least 250 miles was essential. Peacetime maneuvers showed that range was needed to search for the enemy and to maintain separation necessary to prevent enemy battleships from pouncing on one's carriers. Finally, the strike aircraft needed a top speed near that of contemporary fighters. Slow speed over the enemy fleet made biplane bombers easy targets for defending fighters and director-controlled antiaircraft batteries. All carrier aircraft in service before 1938 and several later models were deficient in at least two of these four capabilities.

The first carrier aircraft that would seriously threaten capital ships at sea was Japan's B5N torpedo bomber. Code-named "Kate" by Allied intelligence, the Nakajima attack plane entered service in 1938. It had the combination of payload, range, and speed to make it a first-line offensive weapon. It could carry an 1,800-pound torpedo at 140 knots to a target 250 miles away and return to its carrier. Its top speed was 200 knots at sea level, only 38 knots slower than the best enemy land-based fighter until 1943. It was superior in speed to most carrier fighters for the next 4 years. An element critical to this formidable system was the robust Type 91 aerial torpedo, which could be dropped from hundreds of feet over the water by a B5N flying at full speed.[46]

American and British torpedoes were fragile and mechanically temperamental by comparison. They could only be dropped at low speeds from less than 200-feet altitude. This influenced the design of aircraft intended to carry them and helped perpetuate poor overall performance in these aircraft. The U.S. Navy inadvertently sidestepped

[46]Francillon, *Japanese Aircraft*, pp. 411–16; M. F. Hawkins, *The Nakajima B5N "Kate"*, Aircraft Profile No. 141 (Windsor: Profile, 1972); James H. and William M. Belote, *Titans of the Seas* (New York: Harper and Row, 1975), pp. 31–32.

its torpedo problem by perfecting its dive bomber. By the outbreak of the Pacific War, U.S. carriers were equipped with the SBD Dauntless. Capable of carrying a 1,000-pound bomb, this dive bomber was roughly comparable in performance to the Japanese B5N.[47]

In 1940, the Imperial Japanese Navy put the new Mitsubishi A6M, Type 0 carrier fighter into service. The "Zeke" (later "Zero") put naval aviation on a new footing in two respects. It had the range to escort the torpedo bombers all the way to their targets and back. The "Zero" fighters could thus engage defending interceptors and give the torpedo planes a much better chance to get through. Second, the "Zero" was the first carrier-based fighter whose performance was on a par with any contemporary land-based fighter.[48] The threat from land-based aviation was thereby greatly reduced.

The "Kate" and "Zero" marked the beginning of a significant and rapid change in naval aviation. In September 1939, when World War II began in Europe, three-quarters of the combat aircraft in the U.S. fleet and all in the Royal Navy were biplanes or underpowered monoplanes with biplane performance.[49] Japan led in carrier aviation, but one-third of its strength was still made up of obsolete biplane dive bombers until late 1940. By the time of the Pearl Harbor attack, the SBD Dauntless dive bomber and the F4F Wildcat fighter put American carrier air power in a league with Japan's First Air Fleet. The Royal Navy, however, did not improve its carrier air arm substantially until the adoption of American aircraft in late 1942.

Although the Japanese and American navies had modernized their carrier air forces by 1941, the supremacy of the battleship still dominated their tactical doctrine. American war plans and construction programs reflected the notion that the best approach was for carriers to provide striking range and flexibility, while the battleships would deliver the heaviest punch. American carriers had practiced in peacetime as separate task forces, but doctrine called for their operation in conjunction with the battle line.[50] Japanese doctrine was for carriers to deploy forward

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[47]Barrett Tillman, *The Dauntless Dive Bomber of World War Two* (Annapolis: Naval Institute Press, 1976), pp. 4–15.

[48]Jiro Horikoshi, *Eagles of Mitsubishi* (Seattle: University of Washington Press, 1981); Francillon, *Japanese Aircraft*, pp 362–77.

[49]Stephen W. Roskill, *The War at Sea* (London: Her Majesty's Stationery Office, 1954), 1:31; William T. Larkins, *U.S. Navy Aircraft*, pp. 243–44, 256–58.

[50]Patrick Abbazia, *Mr. Roosevelt's Navy* (Annapolis: Naval Institute Press, 1975), pp. 33–50; Clark G. Reynolds, *The Fast Carriers* (New York: McGraw Hill, 1968), pp. 5–6, 10, 17–18, 39–40; Norman Polmar, *Aircraft Carriers*, pp. 54–60.

for a preliminary engagement before the decisive gunnery dual.[51] Admirals on both sides recognized the essential role of carriers, but they were not ready to do away with the battleship because it was still both the most powerful and best-protected weapon platform in the fleet. It should also be kept in mind that during the first year of the war in Europe, carriers had produced disappointing results. Of 80 sorties flown against capital ships, only four hits were made on two ships in port. No battleship was sunk, and none was hit at sea. By contrast, a carrier was sunk by the guns of two battleships.[52]

The first carrier battles in the Coral Sea and west of Midway Island accelerated what had been a gradual reorientation in thinking. The Battle of Midway was not only a strategic turning point in the Pacific War, but also it precipitated a sudden change in the makeup and tactics of combat fleets. It is often assumed that the Japanese went into that action with fully developed tactics emphasizing the carrier. In fact, Admiral Nagumo's carrier force was merely an advanced striking arm of Admiral Yamamoto's main battleship force. According to the Japanese plan, the carriers would operate against Midway, a fixed land objective, and then soften up U.S. naval forces operating nearby. Finally, the battleships would move in for the coup de grace. In the event, the battle was decided and Japanese carrier forces were smashed without a heavy gun being fired.[53] The shift in force structures took place immediately after Midway. Within 3 weeks, the Japanese cancelled all battleship construction and implemented a new construction and conversion program that emphasized carriers.[54] The Americans already had 23 carriers under construction, but within a month of Midway, Congress authorized 13 more, and 10 of those were ordered from

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[51]Minoru Genda, "Evolution of Aircraft Carrier Tactics of the Imperial Japanese Navy," in Paul Stillwell, ed., *Air Raid: Pearl Harbor!* (Annapolis: Naval Institute Press, 1981), pp. 23–27; Mitsuo Fuchida and Masatake Okumiya, *Midway: The Battle That Doomed Japan* (Annapolis: Naval Institute Press, 1955), pp. 77–90, 97–98, 240–43.

[52]Roskill, *War at Sea*, 1:194–97, 245, 298–99, 317; Ian Stanley Ord Playfair, *The Mediterranean and Middle East, History of the Second World War* (London: Her Majesty's Stationery Office, 1954), 1:136–37; Paul Auphan and Jacques Mordal, *The French Navy in World War II* (Annapolis: United States Naval Institute, 1959), p. 133.

[53]Fuchida and Okumiya, *Midway*, pp. 145–204; Samuel Eliot Morison, *History of United States Naval Operations in World War II* (Boston: Little, Brown, 1947–1958), 4:102–56; U.S. Office of Naval Intelligence, *The Japanese Story of the Battle of Midway* (Washington: Government Printing Office, 1947).

[54]Anthony J. Watts and Brian G. Gordon, *The Imperial Japanese Navy* (Garden City: Doubleday, 1971), pp. 70, 73, 194–96, 200–203, 517–18; Norman Polmar, *Aircraft Carriers*, pp. 70, 132–34, 235–39.

shipyards within 30 days. The 18 U.S. capital ships under construction were eventually cut to 10.[55]

Less than two years after the Battle of Midway, U.S. carriers returned to the Western Pacific in force. When they did, the battle fleet had a completely different character. The new unit central to American combat forces was the carrier task group. Primary offensive capability lay with the torpedo and dive bombers aboard two to four carriers in each group. Primary defensive capability continued to be carrier-based fighters. Integral to the unit were cruisers and destroyers. If battleships accompanied the fleet at all, they were the new, fast type. Cruisers (and the few fast battleships) provided a major portion of the carrier group's close-in air defense. Specially designed antiaircraft cruisers were also part of the carrier forces. They were predecessors of today's guided missile cruiser. Outside the concentric "boxes" of carriers and cruisers was a ring of destroyers for antisubmarine and modest antiaircraft defense. Carrier task groups were joined to form carrier task forces, but the formation and command integrity of each group was maintained for flexibility. The carrier group, not individual ships, formed the basic unit of the new American battle fleet.[56]

In parallel with the refinement of aircraft technology, electronics assumed an essential role in combat at sea. By the end of 1943, the battle fleet had become an integrated set of air and surface platforms that depended on a complete range of electronic equipment. The principle of radar had been demonstrated in 1904. However, the German navy did not put the world's first crude search radar on a warship until 1936, and the introduction of dependable electronic systems did not come until 1940, when they were refined by the British and American navies. After that, it took less than 3 years for radar and associated devices to become important parts of every aspect of naval combat.

Shipboard search radar (1940) extended early warning of enemy air attacks out to 100 miles, day or night. Airborne search radar extended warning time further and could be used to detect surfaced submarines at night (1941) or low-flying aircraft (1945). Coded transponders called IFF (Identification Friend or Foe) (1940) helped to sort out the electronic blips and coordinate air defenses. Surface-to-air voice radio and height finding radar allowed fighters to be directed to the best position in

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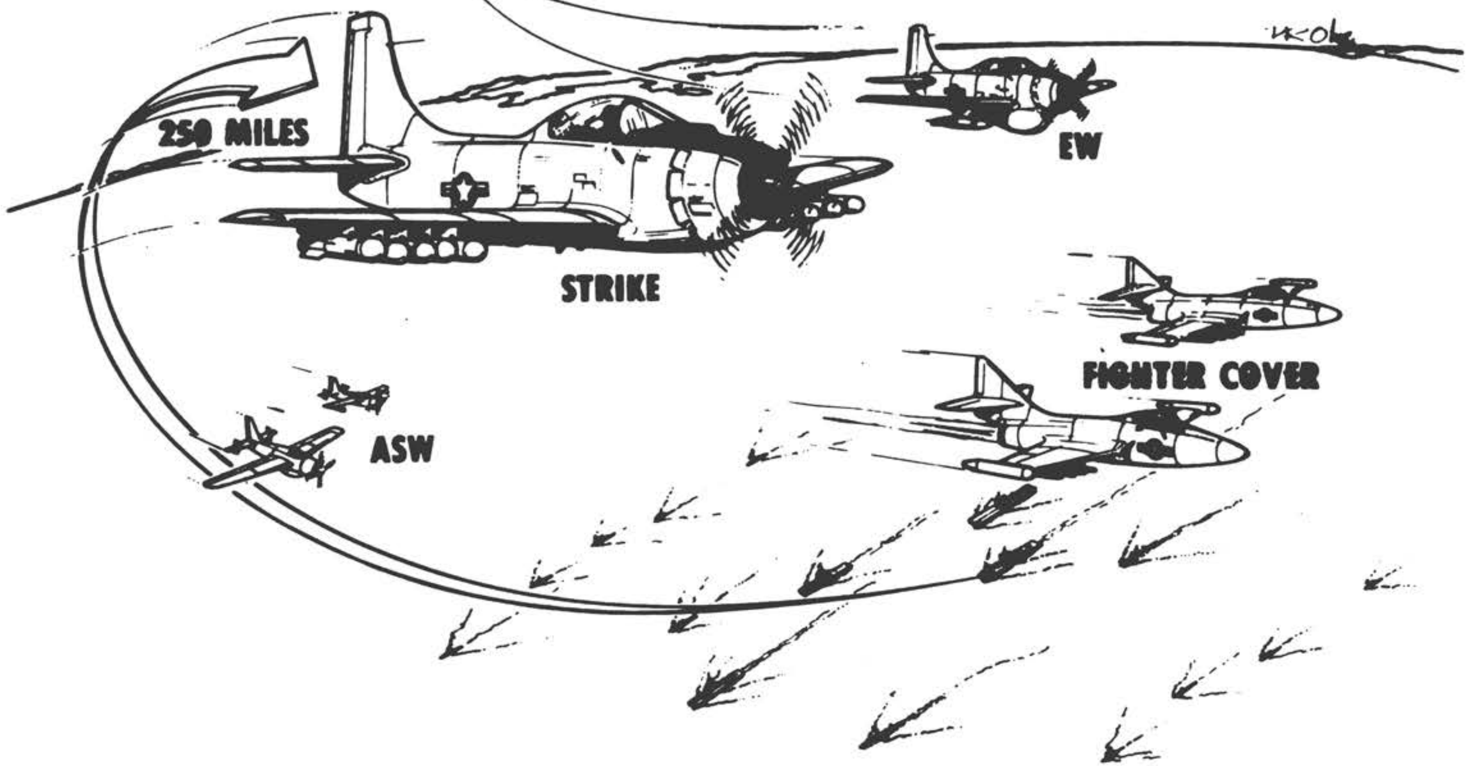
[55] "Aircraft Carriers 1908–1962," *Dictionary of American Naval Fighting Ships*, 2:464, 472–73; James C. Fahey, *Ships and Aircraft of the U.S. Fleet* (5th ed., New York: Ships and Aircraft, 1945), pp. 4, 9–10, 14.

[56] Clark G. Reynolds, *The Fast Carriers;* Belote and Belote, *Titans of the Seas*.

AIRCRAFT AND ELECTRONICS



time to defend the fleet against mass air attacks. This system of air intercept control (1943) was soon supplemented by night fighters equipped with their own small radar. Radar and communications jamming known as ECM (Electronic Countermeasures) introduced a means of disabling an enemy's sensors or weapons without having to destroy them. Although first employed in 1904, it was during World War II that ECM blossomed into one of the important fields of weapon technology.[57]

Radically different technology does not always mean significant change in military capability. An interesting example is the advent of turbojet engines in combat aircraft. The change from reciprocating engines to turbojets was revolutionary in a technical sense. The principles, design problems, and operation of each are completely different. Yet the effects on payload, range, speed, and maneuverability, the critical elements of military aircraft performance, were small. True, the piston engine had just about reached the limit of its potential for improvement, and the jet opened significant possibilities to improve aircraft performance, particularly, at first, in the realm of speed. However, the early jets were only incrementally faster than the fastest propeller planes. Moreover, fuel consumption and low power made jets poor competitors in range and payload.[58] In another decade, all of this would change, but until then, there was only gradual improvement in the combat capabilities of carrier aircraft.

Thus, between 1940 and 1943, the battle fleet exchanged the armored gun platform for the carrier strike aircraft. The essential weapons and sensors for both offense and defense were now carried by aircraft. Offensive ordnance included freefall bombs, unguided rockets, and torpedoes. Primary defensive elements were patrols of fighter and antisubmarine aircraft, each supported by search radar carried in specialized aircraft. Fighting ranges were now at least 250 miles, but aircraft not only extended combat range far over the horizon: their speed allowed them to be concentrated or dispersed over a wide area. The critical dimension of battle became area instead of distance. Offensive and defensive capabilities could be defined in terms of

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[57]Louis A. Gebhard, *Evolution of Naval Radio-Electronics and Contributions of the Naval Research Laboratory* (Washington: Government Printing Office, 1979), pp. 169–204, 206–208, 251–56, 299–307; Arthur Hezlet, *Electronics and Sea Power*, pp. 156–266; Norman Friedman, *Naval Radar* (Annapolis: Naval Institute Press, 1981): Fritz Trenkel, *Die Deutschen Funkmessverfahren bis 1945* (Stuttgart: Motorbuch, 1979), pp. 16–22, 159–93, 202.

[58]Wagner, *American Combat Planes*, pp. 352–58, 408–20; Swanborough and Bowers, *United States Navy Aircraft*, pp. 176–81, 186–88, 305–309; Owen Thetford, *British Naval Aircraft Since 1912* (London: Putnam, 1962), pp. 29, 62–63, 96–99, 228–29, 318–19.

concentric circles outlining the combat radii of given aircraft with given weapon loads. Electronics expanded combat conditions to include night and inclement weather. Ships provided bases for the aircraft and carried the second-line defenses of the fleet. It is notable that the technologies that transformed fleet combat from gunnery duels to air battles had little effect on the carriers themselves. The carrier of 1950 was essentially the same as the carrier of 1930. Conversely, the turbojet engine brought completely new technology to naval aircraft in 1948, but the effect on combat capabilities was small until a decade later.

NUCLEAR WEAPONS

Nuclear weapons obviously changed the means of waging war. At sea, the tremendous destructive capability of a single weapon now means that even with moderate accuracy, one shot has a high probability of disabling a ship. More importantly, nuclear weapons changed the entire context of war. The risk of mutual annihilation now leaves the superpowers without reasonable prospects for political gain in a general war. Thus, nuclear weapons present new strategic problems and new tactical problems in the classical sense of strategy and tactics.

Nuclear weapons changed the context of warfare by raising deterrence to new levels of importance for strategy. The basic tenet of naval strategy in the Anglo-American tradition was that the key to utilizing the sea in wartime, while denying that use to the enemy, is neutralizing the enemy's main naval forces. Neutralization could come through blockade or by winning a series of small naval engagements, but the preferred approach was a single decisive battle.

The strategic problem raised by nuclear weapons is usually called linkage. If the adversary has nuclear weapons and the means to deliver them on your homeland, he is unlikely to suffer a decisive defeat, in this case at sea, without resorting to some kind of nuclear strike, either in retribution or to regain a military advantage. A strike to redress combat losses and regain the initiative would probably be against forces at their bases and the support facilities themselves. However, highly valued population, industrial, and cultural centers would inevitably suffer, either through collateral effects of the weapons or escalation in the face of attacks on home territory.

It has been argued that the navies of the two superpowers could, under certain conditions, engage one another without precipitating a general nuclear war. Certainly, naval operations can take place far from home territory and with negligible risk of collateral damage. If the stakes were high (but not too high), a naval confrontation in a remote area could develop into a clash of arms that remained localized.

However, in the fast-moving events of war, a major defeat on land or at sea is just as likely to cause precipitous reaction as it is deliberative thinking. Furthermore, certain characteristics of modern naval forces strengthen rather than loosen the linkage between war at sea and general war. Naval strike aircraft are based in home territories, antisubmarine warfare can threaten the sea-based portion of nuclear deterrent forces, and satellites perform essential roles for both strategic and general purpose forces.

Technology did not immediately bring about a situation of mutual nuclear deterrence. Initial operational capability of the American nuclear force followed only 2 weeks after the practical demonstration of fission on July 16, 1945. But an American nuclear force was not actually deployed against the Soviet Union until May 1949, and more than a decade passed before the Soviet Union clearly had the instruments of nuclear retaliation. In the summer of 1949, the Soviets both tested their first nuclear fission device and deployed their first long-range bomber, a copy of the American B-29. At least by 1950, then, they had the capability to retaliate against Western Europe for an American nuclear strike. However, it can be argued that the Russians thought that a nuclear threat to Europe would not deter the United States in a superpower confrontation. In November 1955, the Soviets first tested a thermonuclear weapon, and in July 1956 an intercontinental bomber was deployed to carry it.[59] Thus, by 1956, the Soviet Union could threaten the United States directly, and the Soviet leadership could feel more confident of deterring the use of nuclear weapons by the United States.

At first, the American nuclear deterrent did not have an important link to combat at sea, because the Soviet navy was not capable of challenging, let alone defeating, Western carrier forces. In the first decade after World War II, the Anglo-American navies completely dominated the seas, and the United States had a virtual monopoly on the means of nuclear retaliation. By the time the Soviet navy offered any real threat to the battle fleets of the Western Alliance, a situation of mutual nuclear deterrence was well established. By an accident of history, Soviet naval forces were the first to realize any benefit from this situation, because they were inferior in capabilities and numbers for sustained conventional combat at sea.

In the tactical arena, nuclear weapons brought an unprecedented jump in destructive capability. This meant fewer weapons and less

[59]William Green, "The Billion Dollar Bomber," *Air Ehthusiast*, 1 (October 1971): 265; Samuel Glasstone, *The Effects of Nuclear Weapons* (Washington: Government Printing Office, 1962), p. 680.

accurate delivery systems were required. The U.S. Navy was the first to develop nuclear weapons that could be delivered by carrier aircraft or shipboard launchers. The first tactical nuclear weapons developed specifically for naval use were intended for antisubmarine warfare. A special penetration bomb was designed to break through huge concrete bomb shelters like those built to protect German U-boat docks from Allied bombing during World War II. Nicknamed "Elsie," and officially designated the Mk 8, this bomb could also be used against ships. Tactical aircraft equipped to deliver it from carriers were first deployed in small numbers from 1952. It was followed by the Mk 7 bomb and a depth charge called "Betty" and armed with a Mk 7 warhead.[60]

In 1956, the United States first deployed substantial numbers of carrier jet aircraft equipped to deliver nuclear weapons with the introduction of the F9F-8B Cougar. Other important additions to the fleet's nuclear arsenal followed in the next 5 years. Nuclear warheads were first deployed in a torpedo (ASTOR, 1958), a surface-to-air missile (Talos, 1960), and a surface-to-underwater rocket (ASROC, 1961).[61] By 1961, then, the battle fleet had a complete suit of offensive and defensive nuclear weapons. The advance in capabilities was revolutionary, but the rate of change was evolutionary. At 16 years from demonstration of fission to an actual operational capability, it had taken a remarkably long time to integrate nuclear weapons into the fleet for even the basic spectrum of missions.

Nuclear technology brought a jump in weapon lethality, but it has not affected naval warfare as a straightforward improvement in combat capability. The advantages of tactical nuclear weapons are offset in the strategic context by the problem of linkage. The enhanced kill probability of combat nuclear weapons offers little advantage when using them means serious risk of a devastating general nuclear war. The leaders of both superpowers seem to realize this. There are indications that neither the American nor Soviet government would release tactical nuclear weapons for use under field command unless a general war was unavoidable.

The most significant effect of nuclear weapons on the battle fleet was to change the relative importance of its roles. After World War II, the rise of nuclear deterrence strategy and the lack of a rival battle

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[60]National Atomic Museum, Albuquerque, files and displays, with special assistance from Richard L. Ray. Four AD-4B and four F2H-2B nuclear delivery aircraft deployed to the Mediterranean Sea aboard the *Coral Sea* in April 1952. U.S. Office of the Chief of Naval Operations, *Allowances and Location of Navy Aircraft*, OpNav Notice 03110, 31 July 1952, pp. 8–9.

[61]National Atomic Museum files and displays.

fleet led the U.S. Navy to develop its fleet air forces for nuclear strikes against large land targets such as Soviet submarine bases, airfields, and industrial plants. The carrier task force became first, a nuclear strike force, joining the Air Force Strategic Air Command in the role of deterrence in 1951.[62] It was second, a mobile air force for regional conventional wars, and third, a means of dissuasion and a visible demonstration of national interests. In 1957, American submarines with cruise missiles went on their first deterrent patrols, and in 1960 ballistic missile submarines began to take over the role of sea-based nuclear deterrent from the carriers, which would be very vulnerable to nuclear attack.[63] The capability for sustained offense and defense, inherent in battle fleets but lacking in strike units such as missile submarines, became less important in the context of global nuclear war.

On the other hand, as the only type of naval force with the capability for both sustained offense and defense, the battle fleet remained a primary means of dissuasion and presence. It has been employed to dissuade the Soviets from intervening by sea in regional crises such as those in the Middle East and the Persian Gulf. U.S. carrier forces dissuaded China and Taiwan from attacking each other in 1950 and 1958 and Idi Amin's Uganda from attacking Kenya in 1976. In the role of demonstrating national interests, called "presence," a carrier battle group can put first-class air power into a region without base rights that require time to arrange and can compromise delicate political sensitivities in a region. This kind of air power has been employed many times in regional conflict since World War II, including Korea in 1950–1953, the Suez in 1956, Lebanon in 1958, Vietnam in 1965–1972, and the Falkland Islands in 1982.

In sum, nuclear weapons represent a critical threshold for naval warfare, as they do for warfare in general. The significant result of this technological development was partly in fighting capabilities, but more in the context of naval strategy and the relative importance of battle fleets in war. It was a different world after 1956. As always, naval battles could mean general war, but now, general war between

[62]John T. Hayward, "The Atom Bomb Goes to Sea," *The Hook*, 9 (Summer 1981): 22–27; Norman Polmar, *Strategic Weapons: An Introduction* (New York: Crane, Russak, 1975), 19–20; U.S. Navy Department, *United States Naval Aviation 1910–1970*, (Washington: Government Printing Office, 1970), pp. 185, 187.

[63]Norman Polmar, "Die ersten Marschflugkörper für den Einsatz in See," *Marine Rundschau*, 79 (Februar 1982): 76–84; Specific dates for deterrent patrols given in *Dictionary of American Naval Fighting Ships* under names of individual submarines: *Tunny* (SSG-282), *Grayback* (SSG-574), *Growler* (SSG-577), *Halibut* (SSGN-587).

the superpowers could bring mutual annihilation. In this situation, the relative importance of battle fleets in war declined, especially when compared to naval strike forces such as ballistic missile submarines. In regional, nonnuclear conflict and in roles of dissuasion and presence, the highly visible and capable battle fleet has retained important functions. To fully appreciate the evolution of the battle fleet after 1956, this subtle shift from decisive combat to dissuasion through the *capability* for decisive combat must be kept in mind.

Guided Ordnance

The next transition raised the limits of fighting capabilities in a world without rival battle fleets. Guided standoff weapons, high-performance carrier aircraft, and computerized tactical data links were adopted first by the American and somewhat later by the British and French navies. Their chief rival at sea, the Soviet Union, developed only portions of these technological packages at first, applying them to extended coast defense rather than a sustained combat capability on the high seas.

The advent of guided ordnance led developments in three general areas that brought fundamentally new conditions to combat at sea. First, guided weapons replaced free-fall bombs, straight-running torpedoes, and guns as the primary types of ordnance used by the fleet. Dependence on electronics, acoustics, and electro-optics for guidance added a new element in weapon employment and made countermeasures a new form of defense. Second, jet aircraft matured and transformed naval aviation. Improvements in jet engine and airframe design introduced supersonic dash speeds to aerial combat and allowed strike and fighter aircraft to cruise at more than twice the speed possible with reciprocating engines. Steam catapults, the angled flight deck, and mirror landing system became necessary for carriers to launch and recover both high-performance and long-endurance aircraft. Third, ever more complex battle management was made possible with the introduction of digital computers and direct data links between many airborne and surface platforms.

Between 1956 and 1961, the U.S. Navy led the way in introducing guided ordnance as the essential weapons for all important functions of the battle fleet. Aircraft were armed with missiles and continued to be the main platforms for weapons and sensors used in long-range, first-line offense and defense. Armed principally with guided weapons, ships retained close-range, second-line defensive functions. Guided ordnance enhanced fighting capability by enabling an air or surface platform to deliver explosive warheads from considerable distances, often under conditions of poor visibility. These features allowed air attacks to be made from outside the effective range of defensive gunfire. Guided weapons also gave ships a defensive capability against high-speed jet aircraft just when guns were becoming inadequate in range and accuracy. A fundamental change that accompanied the ascendance of guided ordnance was the addition of guidance links to the basic functioning of the weapon system. Guidance, added to fire control, increased the accuracy, range, and flexibility of weapons, but it opened the sytem to electronic and other forms of countermeasures.

During World War II two types of guided ordnance were introduced to naval combat, although experimentation began as early as 1916. The homing torpedo was the first example of a guided weapon actually employed by a navy. In 1943 both German submarines and American aircraft with merchant convoys began using passive acoustic homing torpedoes.[64] The other guided weapon introduced during the war was the antiship missile. Most were radio-controlled missiles or glide bombs, and all were launched from land-based aircraft. These crude weapons were developed hastily and immediately sent to operational units. Some had initial success before countermeasures were developed. Notable examples are the German HS 293 and Fritz X weapons. Most, however, achieved little or never got beyond developmental testing.[65]

The year 1956 saw the first guided ordnance equip a battle fleet. For long-range air defense, carrier fighter squadrons were deployed that year with Sparrow and Sidewinder air-to-air missiles. For close-range air defense, the Terrier surface-to-air missile joined the fleet aboard cruisers. The Tartar and Talos surface-to-air missiles became operational in 1960. The Tartar was small enough to be carried by destroyers, and armed 23 such ships by 1964. Although considered short range by standards of the day, the Tartar was effective at 10 miles, farther than most heavy AA guns. The Talos could hit a high-speed jet aircraft at over 75 miles.[66]

Between 1956 and 1959, Soviet Tu 16 bombers were equipped with antiship missiles, but like their German predecessors, these naval aircraft were tied to land bases. Carrier strike aircraft were first deployed with

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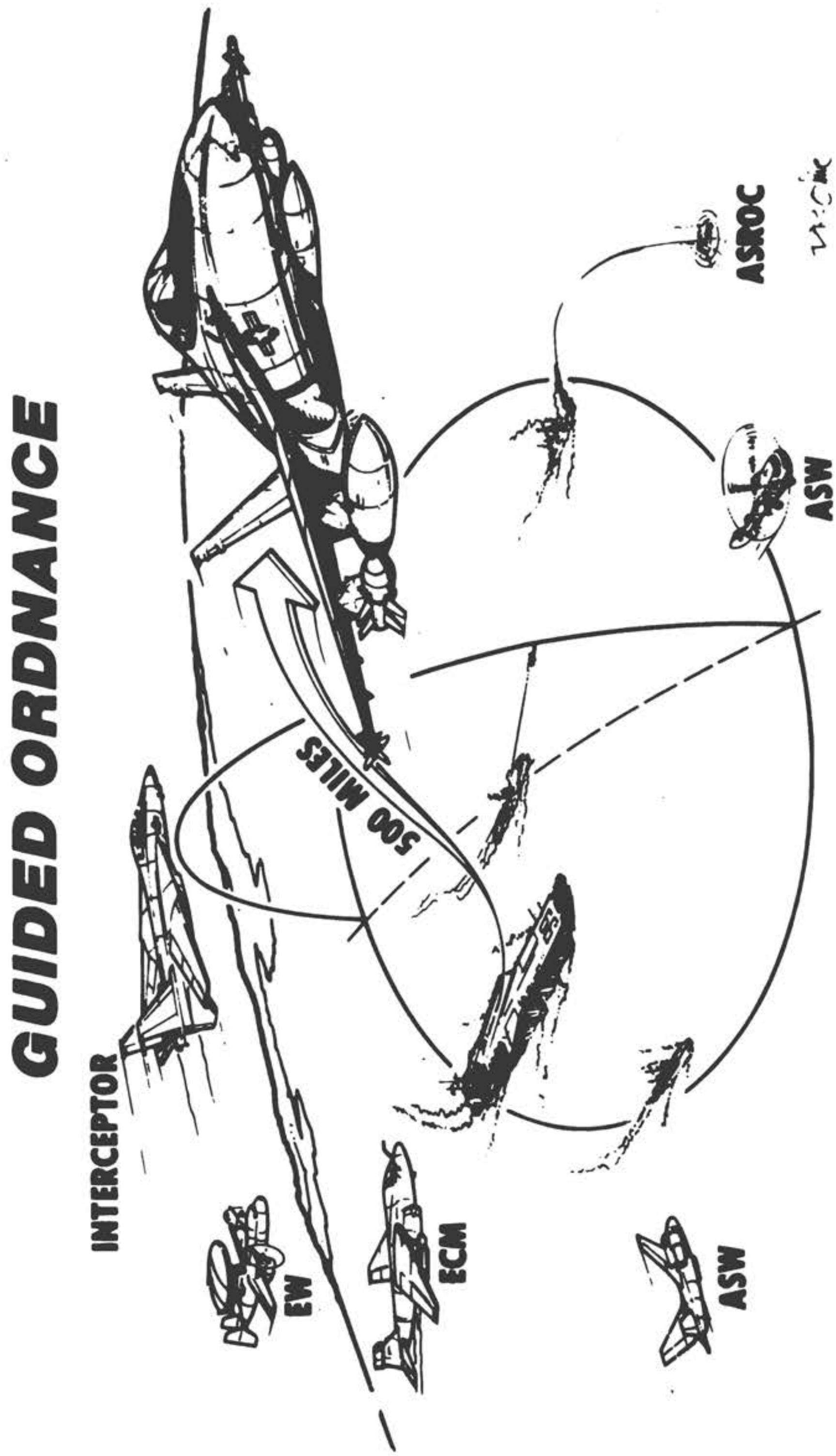
[64]E. W. Jolie, *A Brief History of U.S. Navy Torpedo Development* (Washington: Government Printing Office, 1978), pp. 36–39; Terry Hughes and John Costello, *The Battle of the Atlantic* (New York: Dial, 1977), pp. 282, 291–93.

[65]Bill Gunston, *The Illustrated Encyclopedia of the World's Rockets and Missiles* (New York: Crescent, 1979), pp. 105–108, 113, 118–21.

[66]T. Blades, "USS Galveston: The First Talos Guided Missile Cruiser," *Warship*, 4 (1980): 226–33; Norman Friedman, "The 3-T Program," *Warship*, 6 (1982): 158–66, 181–85; "Guided Missile Cruisers 1959–67," *Dictionary of American Naval Fighting Ships*, 3:820–23.


GUIDED ORDNANCE
INTERCEPTOR
EW
ECM
ASW
500 MILES
ASW
ASROC

air-to-surface missiles in 1959. The first was the AGM-12 Bullpup, with a 250-pound warhead and a range of 6 nautical miles. It was soon followed by the Bullpup B, carrying 1,000 pounds of explosive to 9 miles.[67] Thus, an aircraft could remain outside the range of a ship's antiaircraft gun batteries and guide its ordnance with precision onto a moving target. This meant that without air cover, a ship now needed surface-to-air missiles for defense. Today, French carrier aircraft are equipped with the 39-mile Exocet AM39. U.S. carrier aircraft currently have four types of air-to-surface weapons available, including the 60-mile Harpoon.[68] In 1957, both the American and Soviet navies put the first operational cruise missiles on surface combatants, but neither the Regulus I nor the SS-N-1 had the range of carrier aircraft if employed against moving targets such as ships.[69]

The battle fleet carried a full spectrum of guided ordnance by 1961. In that year, the last component of the set was introduced when ships received a standoff ASW system in the form of ASROC. This is a short-range ballistic rocket, but it acts as the means of delivery for a torpedo with acoustical homing guidance. Subsequent surface-to-underwater systems, such as the Australian Ikara (operational 1964), the French Malafon (1965), and the Soviet SS-N-14 (1970) are guided missiles that carry homing torpedoes.[70]

Aircraft, still the primary ordnance carrier of the battle fleet, also changed in substantive ways. Advances in jet engines and airframe technology contributed to the new fighting regime of fleets. The change from piston to turbine engines came much more gradually than the substitution of guided weapons for guns. The first jet aircraft flew in Germany in 1939. The first jet did not land and take off from a carrier until 1948, and the first jet squadrons finally went to sea on operational deployments in 1950. Payload limitations of jets kept them in the fighter role, with propeller planes dominating both tactical strike and long-range nuclear strike missions for another 8 years.

The A3D Skywarrior became the first operational jet capable of long-range nuclear strikes from carriers in 1957. The same year, the FJ-4B Fury joined the fleet as the first single-engine jet capable of

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[67]Bill Gunston, *Rockets and Missiles*, pp. 123, 134.

[68]Ronald T. Pretty, ed., *Jane's Weapon Systems 1979–80* (London: Mcdonald and Jane's, 1979), pp. 142–44, 151–52; Bill Gunston, *Rockets and Missiles*, pp. 123–25, 131; R. Meller, "The Harpoon Missile System," *International Defense Review*, 8 (February 1975): 61–66.

[69]Bill Gunston, *Rockets and Missiles*, pp. 79, 91.

[70]Norman Friedman, "SS-N-14: A Third Round," *U.S. Naval Institute Proceedings*, 105 (June 1979): 110–14; Ronald T. Pretty, *Jane's Weapon Systems 1979–80*, pp. 107–108; Bill Gunston, *Rockets and Missiles*, pp. 256–57.

carrying more ordance than a propeller plane of similar size and weight. Strike elements of U.S. carrier air groups made a rapid transition to jets during the remaining 2 years of the decade. However, most air groups retained one squadron of propeller-driven AD Skyraiders until well into the 1960s.[71]

The potential of high-performance jet aircraft could not be realized by navies until the aircraft carrier also benefited from new applications of technology. Techniques of shipboard launch and recovery represented a major obstacle to the introduction of supersonic aircraft. Aircraft performance was simply outstripping the carrier's ability to handle its planes safely. In 1955, HMS *Ark Royal* went into service with all three features essential for jet-age naval aviation. She had steam catapults that could accelerate heavier aircraft to the higher airspeeds required for swept-wing jets to become airborne. The old hydraulic catapults had about reached the physical limits of their capabilities. Until Colin C. Mitchell developed a practical steam catapult in 1950, it seemed that high-performance jets might be confined to shore bases. Second, the *Ark Royal* had an angled flight deck. This permitted safe recovery of jet aircraft, which must land at relatively high speed or stall. A straight flight deck meant a slow approach and cutting the engine upon landing. If the tailhook missed the arresting cables, only a heavy net barrier prevented collision with aircraft parked forward. An angled deck allowed landings safely above stalling speeds for swept-wing jets, because the aircraft could go around for another pass if it missed the arresting gear. Third, the *Ark* had a landing system that used lights and a mirror to show the pilot the proper glide slope for a safe landing as he made his approach at over 120 miles per hour.[72] In 1956, the United States deployed her first four carriers having these three vital features developed by the Royal Navy.[73]

Command and control, often considered within the broader context called battle management, was becoming a significant problem because of its growing complexity. The concept of a single type of all-purpose capital ship was now quite obsolete. From the time destroyers joined

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[71]Detailed data on the composition of air groups for specific carriers on each deployment are given in *The Hook*, 6 (Spring 1978): 26–27; 6 (Summer 1978): 26–27; 6 (Fall 1978): 28–29; 6 (Winter 1978): 30; 7 (Fall 1979): 26–27; 8 (Spring 1980): 24–25; 8 (Summer 1980): 30–31.

[72]Norman Friedman, *Carrier Air Power* (Annapolis: Naval Institute Press, 1981), pp. 93–94, 99–100, 106–107; Paul Beaver, *The British Aircraft Carrier* (Cambridge: Patrick Stephens, 1982), pp. 125–41.

[73]Norman Friedman, "SCB-27: The Essex Class Reconstructions," *Warship*, 5 (1981): 98–111; John S. Rowe and Samuel L. Morison, *The Ships and Aircraft of the U.S. Fleet* (9th ed., Annapolis: Naval Institute Press, 1971), pp. 4–5.

the blue-water battle fleet, offensive and defensive functions had been dispersed in a number of different surface and later airborne platforms. Three-medium combat became four-medium combat with the widespread dependence on electronics during World War II. Weapon guidance added new capabilities and vulnerabilities to the employment of ordnance. Both guided missiles and high-performance jet aircraft significantly increased the pace of combat. All of these developments have made naval combat an extremely complex process.

Combat information and control centers evolved into a complex nexus of radar scopes, plotting boards, and communications equipment during World War II. But reading, recording, correlating, and relaying the data were done manually. In the age of jets and missiles, however, the situation would change too rapidly to plot on a board by hand with a grease pencil. A partial solution, and certainly an essential tool, came with automated data processing, display, and relay, made possible by the refinement of electronic digital computers. The first to be deployed by a fleet was the U.S. Navy's Naval Tactical Data System (NTDS), which went to sea in 1961 on the carrier *Oriskany* and the guided missile ships *King* and *Mahan*. The prototype for Britain's Action Data Automation Weapon Systems (ADAWS) was installed on HMS *Eagle* shortly before the carrier was recommissioned in 1964.[74]

These systems collect, process, store, and present information from various sensors on many platforms. The sensors can be electronic, acoustic, or optical, and the platforms are usually both ships and aircraft. All are tied together by electronic data links. The tactical data systems provide automated organization and video display of information for command and control. With this type of system and a competent team to operate it, a force commander has the services of rapid threat detection and assessment as well as systematic allocation of weapons onto targets. In modern situations of multiple, high-speed missile and aircraft systems, both for employment by a force and as threats to it, automated data processing has become a basic element of naval combat.

Ocean Area C^3I

We are probably now in the midst of the next major transition. It has already brought ocean area coverage in command, control, and communication, as well as intelligence, navigation, and meteorology

[74]Raymond V. B. Blackman, ed., *Jane's Fighting Ships 1968–69* (New York: McGraw-Hill, 1969), p. 360; Harris R. Robinson, "C^3: Progress and Developments," *U.S. Naval Institute Proceedings*, 108 (December 1982): 114–17; R. D. S. Stubbs, "Development Trends in Data-Handling Systems," *International Defense Review*, 8 (February 1975): 54–58; J. Claisse, "Tactical Data Handling in the Royal Navy," *International Defense Review*, 4, No. 5 (1971): 436–39.

information. The same transition will make it possible to conduct tactical reconnaissance over areas as large as the North Atlantic or Indian Oceans by the end of the decade. The culmination of this series of developments may well bring tactical integration of ocean areas.

The major technological development that permitted these advances in capability is the earth-orbiting platform. After the Soviet Union placed the first man-made satellite in orbit around the earth in 1957, it was another 7 years before an orbiting system intended specifically for a navy was in place. This system for navigation became operational in 1964 when the first of three Transit series was complete to become the Navy Navigation Satellite System (NNSS). A decade later, the Soviet navy may be said to have reached an initial operational capability with the first basic set of space-based support systems. By then, the Soviets had communications relay, routine monitoring of weather, navigation information, and intermittent radar surveillance of the oceans, all using satellites.[75] Ocean area tactical support of naval operations thus reached an IOC in 1974. Ocean area systems now perform many more than these four basic functions, and further expansion of their capabilities is in progress. A brief review of these systems shows the broad spectrum of their functions and their growing importance.

The fleet benefited from weather satellites as early as 1960 when the first Tiros (Television and Infra-Red Observation Satellite) went into orbit. The first 10 of the Tiros series were both meteorological survey and rudimentary military reconnaissance satellites. The Soviet Union launched meteorological satellites in component tests as early as 1963 with Cosmos 14. The first operational Soviet weather satellite was Cosmos 122, launched in 1966, and the Meteor series gave the Soviets regular weather data from 1969. In 1972, the U.S. Navy tested the delivery of real-time weather data directly from satellites to ships at sea. Other related programs have added to the services provided to naval forces. Satellites monitor ice movements and solar activity as they relate to variations in the earth's magnetic field. In the future, the National Oceanic Satellite System will use radiometers to detect small changes in water temperature of the oceans, an important type of data in ASW operations.[76]

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[75]David C. Holmes, "NAVSTAR Global Positioning System: Navigation for the Future," *U.S. Naval Institute Proceedings*, 103 (April 1977): 101–104; Reginald Turnill, *The Observer's Spaceflight Directory* (London: Frederick Warner, 1978), p. 184; SIPRI, Outer *Space—Battlefield of the Future?* (London: Taylor and Francis, 1978), pp. 135–36, 139–40.

[76]Reginald Turnill, *Spaceflight Directory*, pp. 188–90; Barry Miller, "USAF, Navy Join in Weather Program," *Aviation Week and Space Technology*, 99 (December 3, 1973): 52–55; SIPRI, *Outer Space*, pp. 145–57.

Navigation aids in the form of earth satellites are developing into global positioning systems with accuracies down to meters. The Transit series or NNSS has been mentioned. Probably the first navigation satellites operational for the Soviets were Cosmos 385 and 422, placed in orbit in 1970 and 1971.[77] The U.S. Navy's Global Positioning System, also called NAVSTAR is operational, but it will be expanded in this decade. The first six satellites were placed in orbit by booster. Another twelve will be orbited using the Space Shuttle. According to current plans, the system will provide latitude and longitude anywhere on the globe by 1985 and altitude anywhere above the globe by 1987. Position accuracy is advertised as 16 meters in three dimensions and 0.1 feet per second in velocity.[78]

In the field of satellite communications, experimental and commercial units were followed by the first of the Soviet Molniya series in 1965, with seven operating by 1967. The first seven satellites of America's Initial Defense Satellite Communication System were orbited with a single launch in 1966. Improved systems have been placed in orbit since. One of the most significant for naval forces is the FLTSATCOM system, which has provided not only communications but also computer-to-computer data links since 1977.[79]

The last group of satellite systems to be developed is intended for ocean surveillance. Aside from photographic satellites, which are really intelligence gatherers, the surveillance platforms use radar, infrared, and passive electronic detectors. The Soviets orbited Cosmos 198, probably their first radar ocean reconnaissance satellite (RORSAT), in 1967. Their first paired RORSATs were operational in 1974. Cosmos 954, which came down in Canada in 1978, was a later version of a high-powered RORSAT. The White Cloud program put an array of passive electronic ocean reconnaissance satellites (EORSATs) into orbit in 1976. Other U.S. programs in the 1980s are the Navy's Integrated Tactical Surveillance System (ITSS) using high-resolution radar and the Teal Ruby experimental infrared sensor patterns systems being developed by the Defense Advanced Research Projects Agency.[80]

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[77] Walter B. Hendrickson, Jr., "Satellites and the Sea," *National Defense*, 67 (October 1982): 26–28, 84; SIPRI, *Outer Space*, pp. 135–43; Louis Gebhard, *Evolution of Naval Electronics*, pp. 407–408.

[78] "NAVSTAR GPS: Global Positioning System," *Aviation Week and Space Technology*, 116 (June 28, 1982): 16.

[79] Reginald Turnill, *Spaceflight Directory*, pp. 182–84; SIPRI, *Outer Space*, pp. 105–109, 114–29.

[80] Alan Hyman, "Ocean Surveillance from Land, Air and Space," *Naval Forces*, 3, No. 2 (1982): 56–58; "The Soviet Military Space Program," *International Defense Review*, 15, No. 2 (1982): 149–52; SIPRI, *Outer Space*, pp. 43–44, 91–92; "Expanded Ocean Surveillance Effort Set,"

Ocean area sensors are not confined to orbiting platforms. Growing numbers of acoustic systems are coming into operation. Probably the first such system was SOSUS (Seabed Sound Surveillance System). The system is made up of passive hydrophone arrays fixed on the ocean floor. The first arrays were under test by 1948, but the system was probably not ready to support operational forces until the end of the 1950s or early 1960s. Open sources claim detection ranges of hundreds of miles and accuracy to fix a submarine's position within a radius of 30 to 50 nautical miles.[81]

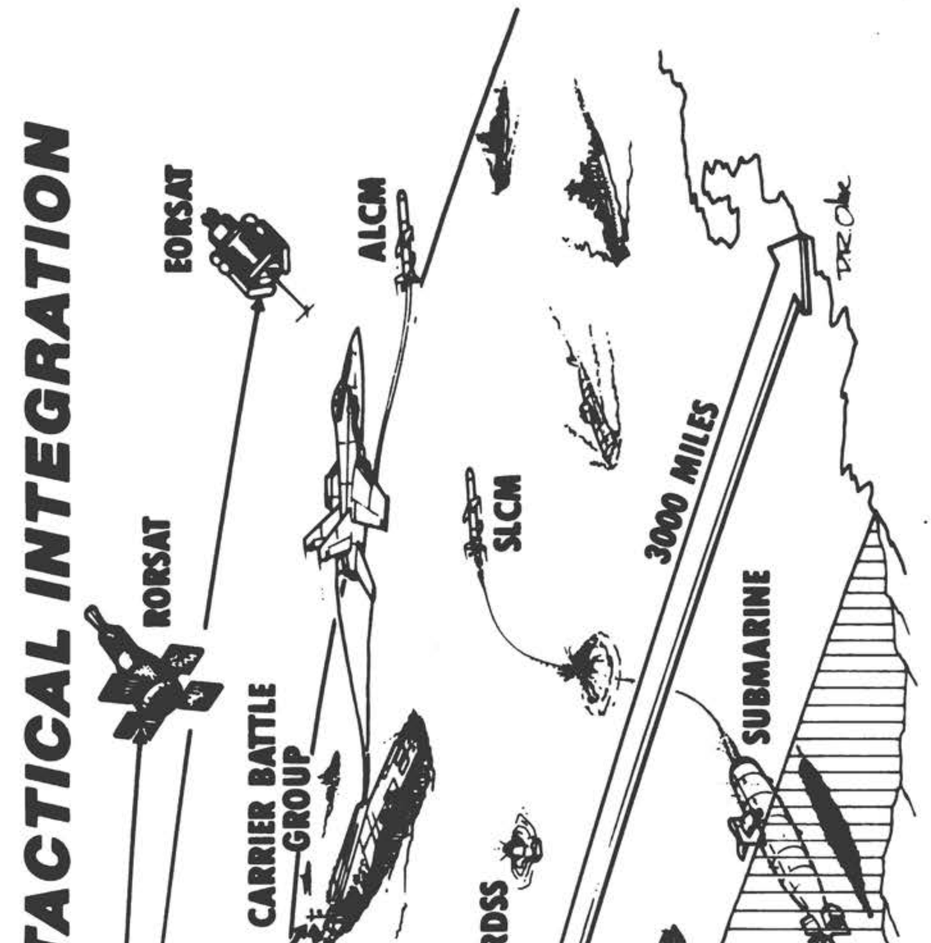
More recently, the U.S. Navy began development of a large, towed array sonar to complement the SOSUS system called the Surveillance Towed Array Sensor System (SURTASS). The sensor for this system is a passive hydrophone array, several hundred feet long, which will be towed at the end of a 6,000-foot cable by a small ship. Data will undergo preliminary processing onboard the ship before being transmitted via satellite to a data processing center ashore. Twelve units were under construction or on order by 1982. The first is scheduled to become operational in 1983. A project to provide the fleet with rapidly deployable moored arrays, designated MSS or RDSS is also under way.[82]

To date, these ocean area sensor and communications systems have had only support functions. As the big navies have become more and more dependent on this support, its importance has naturally increased. However, there are critical limitations that have prevented the transition from ocean area C^{3}I support to ocean area tactical integration. One problem is resolution versus area of coverage in radar and optical surveillance satellites. Broad-area coverage tends to be low in resolution and therefore target discrimination. High resolution tends to be confined in area of coverage. Before a high-resolution sensor can be utilized effectively, it must be directed to within the vicinity of the target or considerable time will be consumed scanning merchant shipping and empty areas of the ocean. As one analyst put it, "in this situation, a word is worth a thousand pictures."

Aviation Week and Space Technology, 109 (July 10, 1978): 22–23; Philip J. Klass, "Soviets Push Ocean Surveillance," *Aviation Week and Space Technology*, 99 (September 10, 1973): 12–13; "Teal Ruby slips, Teal Emerald is DARPA's New Jewel," *Defense Week*, 5 (April 30, 1984): 2–4.

[81]Norman Polmar, "The U.S. Navy: Sonars, Part 2," *U.S. Naval Institute Proceedings*, 107 (September 1981): 135–36; Joel S. Wit, "Advances in Antisubmarine Warfare," *Scientific American*, 244 (February 1981): 32; Alan Hyman, "Ocean Surveillance," pp. 58–59.

[82]John D. Alden, "Tomorrow's Fleet," *U.S. Naval Institute Proceedings*, 107 (January 1981): 117; 108 (January 1982): 119; Norman Polmar, *The Ships and Aircraft of the U.S. Fleet* (12th ed., Annapolis: Naval Institute Press, 1981), p. 198; Couhat and Baker, *Combat Fleets*, 1982/83, pp. 801–802.


OCEAN AREA TACTICAL INTEGRATION
FLTSATCOM
RORSAT
EORSAT
ALCM
CARRIER BATTLE GROUP
DATA PROCESSING
AWACS
RDSS
SLCM
3000 MILES
SURTASS
SUBMARINE
SOSUS

A second major problem is the time lag between data collection and its availability to a deployed weapon system. Unlike fixed land targets, naval platforms are constantly moving. At 25 knots, a ship can be anywhere in an area of 54 square miles after 10 minutes, and 490 square miles after 30. Images, acoustic returns, and electronic intercepts must be correlated with geographic references, processed for use by guidance systems, and transmitted to the unit that will use the information. In current systems, the time lag between detection by a broad area sensor and completion of the fire control solution allows a potential target to move well beyond missile guidance range. A missile's homing sensors simply cannot acquire a target much beyond its horizon without the assistance of a local sensor.

The solution will probably be advanced data processing. In consonance with a theme of this paper, system integration will precede new components. By correlating the general positions from more than one ocean-area sensor with intercepted radar and radio signals, a ship can be identified and the estimate of her position refined. High-powered over-the-horizon radar, large airborne radar, and more advanced sensors in underwater and orbiting systems will certainly improve the accuracy surveillance for targeting purposes. However, the capability to process vast amounts of data will accelerate this transition. The recent development of super computers such as the CRAY-2 and the Control Data Cyber 205 make this capability possible in the immediate future.[83] With ocean-area sensors, high-speed data processing, and instantaneous global data links, ocean-area C^3I support will become ocean-area tactical integration. A cruise missile utilizing this type of ocean-area targeting grid can have an effective range of two or three thousand miles without any basic changes in engine or airframe technology.

CONCLUSIONS

With today's perspective we can reconsider how technological innovation has produced fundamental changes in the methods and conditions of warfare at sea. Salient improvements in operational capabilities provide the best measure of important change. Usually developments in technology are considered first and then their effects. In analyzing trends, changes in capabilities provide a better context. Within this context, the essential technologies can be identified. The means and rate of introducing these essential technologies then provide

[83] Joel Wit, "Advances," p. 33; Alan Hyman, "Ocean Surveillance," p. 59; Norman Friedman, *Modern Warship Design and Development* (Greenwich: Conway Maritime Press, 1979), p. 101.

insights into the dynamics of each major change or discontinuity. This survey focused on conspicuous improvements in the fighting capabilities of battle fleets, but its conclusions can be applied to other aspects of naval warfare, such as commerce protection, amphibious operations, and mine warfare. The key is to identify the essential capabilities for the general mission, whatever that mission or function might be, and then to identify the technologies essential for those capabilities. This reverses the usual order of analysis, putting the dependent variable, capability, first. Capability thereby becomes the context for assessing the application, the rate, and the effects of a particular type or ensemble of technology. The independent variable, technology, is thus considered second, in relation to operational or combat capability, rather than in isolation as is our habit.

Based on the cases considered in this study, three general conclusions can be made about the dynamics of technological change in the naval sphere. One is that change is usually evolutionary but it can be dramatic. When a change in combat capability is truly dramatic, its effects are far reaching, and the time required for the transition is relatively short. Important change is not always planned, and the full potential of such a change is seldom realized in advance. It does not necessarily occur in wartime. The rate of such change has no apparent correlation with how basic and important the change will be, and the rate of change has not increased as technology has progressed. However, when dramatic technological change has occurred, it has had profound effects on the balance of naval power.

Another conclusion is that *new* technology has not revolutionized naval warfare. Here an important distinction is made between new technology and new capabilities made possible by applications of existing technology. Significant changes in the military and political capabilities of naval forces have come when long-existing technologies were eventually refined and integrated. It was the final integration of several technologies that came quickly in some cases. In other cases an essential component was lacking from the ensemble, but by itself it would have been useless. Certainly no single technological "breakthrough" has brought immediate change in naval capability.

As we look to the future, the dynamics of change are most likely to reflect the process found in these case studies from the past. Instead of merely looking for some new technology that might revolutionize naval warfare, as we are prone to do today, it should prove more useful to examine combinations of existing technologies. Their effects will be felt first, probably in one of three ways. These are: (1) synthesis—new combinations of existing technologies, (2) a keystone—a missing link for a new ensemble of technologies, or (3) tactical innovation—

new uses for existing forces. This is not to ignore new technology, but it argues at least for first consideration of existing technology and it avoids a fixation with new technology that obscures important potential of existing technology. New capabilities using existing technology are the ones that will affect the maritime situation next. These will have to be addressed first. Once these imminent new capabilities are identified, more distant projections of possible applications of new technologies will be more useful, because they can be better put in context.

A third conclusion is that important changes in capability are seldom reflected in obvious physical features or the size of warships and other naval weapon platforms. A significant feature in the ironclad was its rifled ordnance, in the dreadnought battleship its fire control system, in the modern aircraft carrier its airborne sensors and computers. None of these features is obvious in a photograph. The most important characteristic of the Soviet "Oscar"-class submarine is not its great size, but the likelihood that its missiles will use space-based sensors for guidance.

Projections about the future tend to be general predictions of radical change or detailed rejection of anything but gradual change. There is a gap between prediction that is ultimately correct but happens too far in the future to be of use to planners and skepticism that precludes the possibility of rapid and fundamental change. Unfortunately, most analysis falls at these extremes. Taken together, these conclusions offer an alternative. It is the kind of perspective that can facilitate assessment of the current balance of naval power and can help to identify ways in which technology is most likely to change that balance.

By concentrating on dramatic improvements in mission capability, one can see more clearly the nature of fundamental changes in the way war has been conducted at sea and predict more safely the essence of future revolutions. In this era of renewed great-power naval rivalry, such an approach could be more useful to planners of policy, budgets, and advanced research.

CURRICULUM VITAE

Karl Lautenschläger is on the research staff of the Los Alamos National Laboratory. There, he evaluates trends in international politics and evolving naval problems as part of long-range planning for the Lab's nuclear and nonnuclear weapon programs.

Born March 11, 1944, in Boca Raton, Florida, Dr. Lautenschläger grew up in central California. Upon graduation from the University of Washington in 1966, he received a B.A. degree in history and a regular commission in the U.S. Navy. As an air intelligence officer with Attack Squadron 155, he made two combat deployments aboard aircraft carriers to the Tonkin Gulf. Upon resigning his Navy commission in order to pursue an academic career, he had received the Navy Commendation Medal and seven unit and campaign decorations.

In 1973, Dr. Lautenschläger completed an M.A. in history at San Jose State University. He was an Advanced Research Scholar at the Naval War College in 1976–77, where he developed an original theory of strategic warfare. In 1978, he received his Ph.D. in international relations at the Fletcher School of Law and Diplomacy. From 1977 through 1979, he taught courses in international politics and Asian history at Pine Manor College. He has also been invited back to the Fletcher School as a visiting faculty member, teaching graduate courses in the International Security Studies Program in 1978 and 1983.

Dr. Lautenschläger joined the Los Alamos Laboratory in 1979. He received one of the Laboratory's few Distinguished Performance Awards for 1984.

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