The Submarine in Naval Warfare, 1901–2001

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This article surveys the evolution of submarine technology, submarine capability, and strategy for the use of submarines. It traces change in the operational capabilities of submarines since their introduction, evaluates the past effectiveness of submarine forces in war, and suggests how their roles and capabilities are likely to develop in the future. It also addresses the current debate over the proper roles of submarines in naval strategy and discusses prevalent misconceptions about their past and present capabilities.

Submarines are fundamentally different from other warships. Because they function in the underwater medium, submarines tend, unlike surface ships and aircraft, to operate best in isolation; they require unique combinations of weapons and sensors; and they require tactics based on stealth and surprise. They are most capable in the role of hunter in hit-and-run attacks, in attrition warfare, and as platforms for single-salvo strikes ashore. They are least capable in missions that require prolonged exposure and the capability for sustained defense, such as sea control, naval presence, and projection of force ashore in a manner that requires more than a single salvo. Submarines further differ from surface and naval air forces in being most effective when dispersed rather than concentrated. Finally, submarines are different in that the strategies that give them their greatest warfighting potential do not conform to the classical Mahanian naval strategy of defeating the enemy by annihilating his main naval forces. Instead, whether they are employed in commerce warfare, as in the past, or for the delivery of nuclear weapons, submarines are the most effective means for a navy to circumvent classical battle and engage in direct anti-state warfare.

This article is drawn from research in long-range trends being conducted at the Los Alamos National Laboratory, which is operated by the University of California for the U.S. Department of Energy. The conclusions and opinions expressed herein are solely those of the author. I would like to thank Linda L. Riley and Thomas W. Dowler for their very helpful comments and suggestions, as well as Norman Friedman for providing material on British submarines.

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International Security, Winter 1986-87 (Vol. 11, No. 3)

Submarines have been in regular naval service only since 1901 and have been effective as warships only since about 1910. Yet during their relatively short history, developments in technology have given them the capabilities to perform six basic roles in naval warfare. By the outbreak of World War I, submarines were fully capable in three roles: coast defense, naval attrition, and commerce warfare. Their capacity to perform three additional missions—projection of power ashore, fleet engagement, and assured destruction—matured in the 1960s, after a long period of relative equilibrium in submarine technology that lasted well into World War II. All six remain the basic mission capabilities of submarines today. Current trends suggest three further developments in the near future: a new capability to perform strategic counterforce missions, a decline in the capacity to wage commerce warfare, and the possibility of a new capability in the form of decisive naval battle.

The history of how these capabilities were developed and used in war suggests five principal conclusions about submarine warfare. First, submarines possess no general immunity against countermeasures. Although they are difficult to find and largely immune to attack while cruising submerged, they become vulnerable once they disclose their presence by attacking. In fact, when actively employed in most combat missions, submarines are usually more vulnerable than other types of warships. This reflects the conflicting requirements of lethality and survivability in submarines and is a basic problem of submarine operations.

Second, navies have had difficulty solving the twin problems of properly integrating new submarine technologies into existing force structures and strategies and organizing timely measures to counter new submarine technology. Submarines have sometimes been used unwisely: their existing capabilities have not been fully utilized, while they have sometimes been prematurely assigned new roles before they were ready to carry them out. At the same time, states facing emerging submarine threats have sometimes been slow to respond effectively, leaving themselves vulnerable. Thus submarines have been overutilized, underutilized, and under-prepared-against. This reflects the general problem that military organizations face in adopting appropriate strategies for exploiting and countering fundamentally new technologies and capabilities.

Third, competing demands on available submarine forces during wartime have often prevented them from realizing their full potential through a concerted effort in one strategy. The capability to perform several types of missions brought a tendency to divide and allocate the force to perform all

of them. With the singular exception of the U.S. submarine campaign in the Pacific during World War II, this problem has plagued the submarine forces of the world from their inception. Since 1960, this problem has been aggravated by the addition of essential roles, such as strategic nuclear deterrence and the related missions of hunting and protecting ballistic missile submarines, just as submarines are becoming more complex, expensive, difficult to build, and therefore fewer in number.

Fourth, submarine campaigns, against either naval forces or merchant shipping, are not a quick and simple route to victory. They are major undertakings of profound complexity. They extend over entire oceans and involve hundreds of submarines and anti-submarine vessels, and since they require prolonged effort to produce effect, there are ample opportunities for significant change in technology and tactics.

It is therefore delusive to draw simple analogies between past submarine campaigns and current naval problems. For example, it is often argued that the current Soviet submarine fleet has many times the commerce destruction potential of the World War II German submarine fleet, since "a few" German U-boats sank substantial numbers of merchant ships off the U.S. Atlantic coast in 1942, and the current Soviet submarine fleet is much larger than the pre-World War II German submarine fleet.[1] In fact, German U-boat strength in 1942 was about the same as Soviet submarine strength today, and Germany built more submarines in four years than the Soviet Union has built in the last forty.[2] Due to a variety of changed circumstances, Soviet potential to

1. For an example of how such mythology gains credence through repetition, see Lockheed Aircraft Corporation's two-page spread advertisements: "In 1942, we took a beating from a handful of enemy subs. Today we have to be ready for 377 unfriendly subs." U.S. Naval Institute *Proceedings*, Vol. 108, No. 10 (October 1982), pp. 20–21; or "If the enemy had 377 subs in 1942, the Battle of the Atlantic could have gone the other way." U.S. Naval Institute *Proceedings*, Vol. 108, No. 9 (September 1982), pp. 18–19.

2. Unclassified sources list 378 submarines for the Soviet navy in 1982, when the Lockheed advertisements cited above were published. Subtracting the 90 ballistic missile submarines, but counting all other types including training boats, the Soviets had 288. The numerical trend has been gradually downward since then. In 1942, the German navy had between 259 and 397 U-boats in commission for an average monthly strength of 330 submarines. Of these, deployed U-boats (*Frontboote*) rose from 101 in January to 168 in August 1942. Jean Labayle Couhat and A. David Baker III, *Combat Fleets of the World, 1982/83* (Annapolis: Naval Institute Press, 1982), pp. 581–582, 602–615; Bodo Herzog, *U-Boote im Einsatz 1939–1945* (Dorheim: Podzun, [1971]), p. 126; and Germany, Seekriegsleitung, "Ubootsverluste (Stand 24.8.42)," Anlage zu 1.Skl.Ib 1663/42, 29 August 1942, PG 31762F, National Archives Microfilm Series T1022, roll 3407. Based on many unclassified sources, a reasonably accurate estimate of Soviet submarine construction from 1946 through 1985, including those for export, is 724 new units. Between the beginning of May 1941 and the end of April 1945, the German navy commissioned 1,007 newly constructed U-boats.

wage commerce warfare is probably substantially smaller than that of Germany in World War II. The opposite conclusion derives from assessing a few rather than the several factors that determine the capability to wage commerce warfare.

Another basic flaw in many current analogies between the present situation and World War II lies in the common assumption that quick and decisive results are possible: that the U-boats were on the verge of victory and that next time we will not be so lucky. While the Battle of the Atlantic was a bitter struggle for the Allies with profound importance for the outcome of the war, the U-boats required prolonged effort to sink as many ships as they did, and they never came close to severing Allied sea lines of communication. Submarine campaigns, whether against commerce or warships, are inevitably protracted affairs. This fact has significance in a world in which the possibilities for nuclear escalation increase with the duration and intensity of conventional conflict.

Fifth and finally, this historical review suggests that the persistent debate over whether submarines or major surface units will have primacy in naval warfare is sterile and misdirected. Submarines and surface fleets are not alternatives to one another. They have parallel, complementary, and independent functions. Naval strategists do not face an "either/or" choice between surface forces and submarines, but rather the task of balancing these forces in a way that enhances the capacity of the whole navy to achieve overall mission goals.

With these problems in mind, this article will describe the basic characteristics of submarines, review the evolution of their basic roles and capabilities, and project current trends in submarine capabilities to the end of this century.

Characteristics of Submarines

The basic characteristics of submarines can be distilled into three generalizations. First, a submarine's effectiveness in war and deterrence depends on stealth, surprise, and a high probability of destroying its target on the first shot or salvo. Second, tactical reconnaissance and target acquisition pose persistent problems for submarine forces used against naval units and merchant shipping. Third, the most effective uses of submarine forces depend on unconventional strategies that differ from classical Anglo-American concepts of naval warfare.

The first set of characteristics—the importance of stealth, surprise, and a high single-salvo kill probability—applies to the use of submarines in warfare at sea, in striking targets ashore, and in deterrent or dissuasive roles by the threat of either.[3] Submarines hardly ever engage in combat, in the sense of sustained use of weapons for assault and defense. They generally carry only enough ready weapons for one or two salvos, and they have little means of defense. In today's naval warfare, they cannot shoot down a torpedo-carrying aircraft or an incoming missile, although they can use decoys to distract torpedoes. Aircraft operating in conjunction with surface ships usually have a greater sensor/weapon range than a submarine, and, with very few exceptions, submarines are highly vulnerable to a single hit.

On the other hand, submarines are very difficult to find when they are not launching torpedoes or missiles or using active sensors such as radar or pinging sonar. This poses a three-part problem for anti-submarine warfare (ASW) units, which must not only detect, but also locate the submarine and direct ordnance against it with precision.[4] As long as a submarine remains passive and quiet, it is seldom detected at all. Thus, the first element of a submarine's ability to survive is not its capability to defend itself or its resistance to damage as in a surface ship; it is its ability to remain undetected.

If a submarine is to be employed as a weapon system, it must make a transition from stealth to active use of its weapons. The employment of an active sensor and the launch of a weapon gives away its position and makes it vulnerable. Passive sensors are capable of detecting and locating a target, but precise data for launching a weapon usually come from active sensors, such as pinging sonar. Whether fire control sensors are active or passive, the launch of weapons is routinely a noisy affair, which discloses the presence of the submarine.[5]

In the attack situation, survival therefore depends upon surprise and a high single-salvo kill probability. Surprise allows the submarine to attack first, just as it compromises its stealth. A high probability of destroying the intended target with a single salvo of torpedoes or missiles allows success without requiring the submarine to remain in contact with enemy forces.

3. An excellent summary of many operational characteristics of submarines is provided by Norman Friedman, *Submarine Design and Development* (Annapolis: Naval Institute Press, 1984), pp. 9–16.
4. David R. Frieden, *Principles of Naval Weapons Systems* (Annapolis: Naval Institute Press, 1985), pp. 189–285.
5. The main exception is torpedoes that "swim" out rather than being launched out of a torpedo tube.

Destruction with a single weapon would be ideal, but in practical terms, simultaneous firing of two or more is required for a high probability of a lethal hit. Then, the submarine can immediately commence evasive maneuvers and attempt to regain concealment in the ocean depths.

A second set of characteristics in submarines makes tactical reconnaissance and target acquisition major problems. By its very nature, a submarine is short-sighted and vulnerable when on or near the surface, and it is blind but has acute hearing when submerged. Optical and radar sensors have a very short range in submarines because they are close to the water and therefore the line-of-sight horizon is only a few miles. Passive detection of surface ships and aircraft from electronic emissions of their radar and radio equipment is possible at hundreds of miles under ideal atmospheric conditions; this can help a submarine in its search for targets. But submarines cannot obtain the precise and continually updated location necessary to fire a missile at a moving target by this method.

When submerged, a submarine is served by highly sensitive acoustic sensors, called sonar. These too are limited in range compared with electronic sensors that function in the atmosphere, and their performance varies considerably, depending on environmental conditions. Underwater ambient noise, surface disturbances, thermal layers, depth of water, the topography of the ocean floor, and the speed of the sensor platform all affect acoustic sensor range and accuracy. Many conditions, such as those related to thermal layers and higher speed, reduce sonar performance. However, the use of bottom bounce or the focusing of bending sound paths into convergence zones can extend today's detection ranges, in the latter case to 35 and 70 miles but with "blind" areas in between.[6] Sonar can be used as a passive listening device or an active transmitter and receiver of sonic signals, roughly comparable to radar. In general, passive sonar has greater range but is less satisfactory for fire control. While at shorter ranges (out to about 10 miles), active sonar provides more refined target location data, but can disclose the stalking submarine's presence.

Airborne or earth-orbiting platforms can provide submarines both with tactical reconnaissance to allow them to close for a torpedo attack or target location and with firing data necessary to fire missiles from long range. As these capabilities are developed, submarines will be able to sink moving ship

6. Edwin W. Shaar, Jr., "ASW and the Naval Officer Oceanographer," U.S. Naval Institute *Proceedings*, Vol. 104, No. 2 (February 1978), pp. 43–49.

targets from hundreds of miles just as aircraft have been able to do since the middle of World War II. The persistent problem with any external reconnaissance or targeting system is that it has the same vulnerabilities as the systems that serve the surface fleet. As the evolving capabilities of submarines are surveyed in this paper, it will become clear that as submarines become more capable against first-line naval combatants, they assume vulnerabilities not associated with other submarine roles and missions. This might be called the submarine's capability/vulnerability paradox.

The first two sets of characteristics lead to a third and less familiar aspect of submarines: the best strategies for employing submarines do not conform to the classical principles of naval warfare. Thus, the evolution of submarine technology and tactics is also the evolution of unconventional strategies at sea.

A central part of classical, or conventional, naval strategy is the destruction of the enemy's naval forces in order to gain military objectives as a means to political objectives. The Anglo–American approach, as codified and advocated by Philip Colomb, Alfred T. Mahan, and Julian Corbett, is to concentrate forces for a few decisive battles to gain the military objective of controlling the seas, so that they could be used for military and commercial transportation, while denying that use to the enemy. The alternative version of classical naval strategy, historically adopted by the continental powers of Europe, is to deny an opponent the opportunity to engage in decisive battles for command of the sea while defending important coastal points and conducting attrition warfare against the opponent's naval and merchant shipping. Maintaining a fleet-in-being was a means of threatening the enemy with an inferior battle fleet and tying down a substantial portion of his forces, while avoiding major battles and the risk of defeat at sea. Attrition was a way of wearing the enemy down by attacking weak points. In this context, commerce raiding, or *guerre de course*, was used to harass the enemy, but it was not considered by itself to be a war-winning measure.[7]

From the adoption of fleet tactics for the seagoing gun platform in the early seventeenth century until the development of submarine warfare, fleet actions were the only way to gain control and thereby secure the use of the seas. Although dispersed attrition warfare and fleet-in-being strategies were often the only alternative for a continental power facing a stronger maritime nation, they could not bring a decision in a war at sea. They could only

7. Geoffrey Till, *Maritime Strategy and the Nuclear Age* (London: Macmillan, 1982), pp. 1–43.

contribute to the general war effort and avoid defeat by stalemate. Thus, for three centuries, major fleet actions were the most direct and efficient method to win a war at sea.

When first employed as regular units of the world's navies at the beginning of this century, submarines were just another instrument of classical naval strategy or a defensive alternative to it. They were intended for attrition warfare against the enemy's naval units, either on offensive sorties to the vicinity of the enemy's naval bases or as a kind of extended coast defense force. However, this soon changed. The development of submarine capabilities produced alternatives to the classical Mahanian approach to naval warfare.

Submarines have been employed in two basic kinds of unconventional strategy. Both are unconventional (that is, not classical) because the immediate objective is the enemy state rather than its armed forces. Nonmilitary objectives are attacked, and, if possible, the adversary's military forces are avoided altogether. The first kind was intended to cripple maritime commerce, which is an economic component of a state that lies exposed outside its borders on the sea lines of communication. Conceived first for surface torpedo boats in the late nineteenth century, it changed the function of commerce warfare from a means of harassing an opponent's flanks to major offensives against shipping that could decide the outcome of a war.[8] This type of strategy was attempted with submarines three times in two world wars with varying degrees of success.

The second kind of unconventional warfare at sea came when ballistic missiles armed with nuclear warheads were deployed aboard submarines at sea. This gave submarines the capability to destroy population centers, industrial capacity, or economic infrastructure of a state, and the threat of this kind of destruction is of course the basis of assured destruction strategies for deterring war between nuclear powers today.

Unconventional naval strategies using submarines provided alternatives to the classic approach in naval warfare but they have not replaced it. The strengths and weaknesses of these strategies are best explored as they evolved with the new capabilities brought to submarine forces by new ap-

8. Theodore Ropp, "Continental Doctrines of Sea Power," in Edward Mead Earle, ed., *Makers of Modern Strategy* (Princeton: Princeton University Press, 1943), pp. 446–456. See also Theodore Ropp, "Development of a Modern Navy: French Naval Policy, 1871–1904" (Ph.D. dissertation, Harvard University, 1937), pp. 33, 258–275.

plications of technology. Thus, we now turn to the salient developments in the operational capabilities of submarines.

Evolving Capabilities

During the twentieth century, technological developments have given submarines six generic capabilities of significance. These six capabilities—coast defense, naval attrition, commerce warfare, projection ashore, fleet engagement, and assured destruction—remain the basic roles of submarines in naval warfare today. However, the evolution of these capabilities was not a smooth process. In some cases, a basic new role was assigned before submarine capabilities were adequate to carry it out, with the requisite technology coming only later. In others, technology was refined sufficiently to provide new capabilities before services adopted a role to utilize them fully.

David Bushnell's barrel-like *Turtle* of 1776 was probably the first functional submarine. But 125 years would pass before a submarine was commissioned for service in a major navy. Continuous development began in 1860, with about fifty experimental prototypes being built in various countries during the rest of the century, and although most submerged and resurfaced successfully with men in them, none was a practical weapon system. Historical literature is replete with declarations that one experimental boat or another marks the advent of the modern submarine, but many technical problems had to be overcome first. These included ballast systems, underwater propulsion, surface and underwater endurance, air supply for the crew, underwater stability and control, suitable weapons, and the means for navigating while submerged.[9] In fact, the modern submarine was not born with one invention. It evolved gradually over many decades before it could become a truly effective naval craft.

The submarine actually became an effective warship in 1910, with the introduction of what was technically a seagoing submersible torpedo boat. This first submarine with all the basic technology to make it effective as a

9. Murray F. Sueter, *The Evolution of the Submarine Boat, Mine and Torpedo* (Portsmouth: J. Griffin, 1907), pp. 5–261; Hans-Joachim Lawrenz, *Die Entstehungsgeschichte der U-Boote* (München: J.F. Lehmanns, 1968); Richard Compton-Hall, *Submarine Boats: The Beginnings of Underwater Warfare* (New York: Arco, 1984); Wallace Hutcheon, Jr., *Robert Fulton: Pioneer of Undersea Warfare* (Annapolis: Naval Institute Press, 1981), pp. 31–50; and John M. Maber, "Nordenfelt Submarines," *Warship*, Vol. 8, No. 32 (1984), pp. 218–225.

naval weapon system was the Imperial German Navy's fifth *Unterseeboot*.[10] Commissioned for service in 1910 as U-9, the 485-ton submersible had a range of 3,200 nautical miles, giving it an operational radius of 1,000 miles with five days on station in an assigned patrol area. The boat was armed with six fairly reliable Schwartzkopf torpedoes, and was the first submarine to be equipped with a gyrocompass, which enabled it to navigate while submerged.[11] Although the German navy did not introduce diesel engines in its submarines until 1913 when U-19 was commissioned, the first U-boats had relatively safe Korting kerosene engines.[12]

Coast Defense

Submarines were formally given their first role in naval warfare before they acquired the capability to accomplish it. Several basic technical problems had yet to be solved when the major navies began putting small submarines into service for coast defense, nearly a decade before U-9 was commissioned. The submarines built with navy funds before 1901 were one-of-a-kind projects used only for experiments and limited training. But beginning in 1901, France put submarines into regular service, followed by Britain in 1902, the United States in 1903, and Russia in 1904.[13] All of these early submarines had operational radii of only a few hundred miles as well as major deficiencies in their design, and none had any means of navigating under water. Although first to introduce diesel engines in submarines, the French navy clung to either steam and electric or all-electric propulsion in spite of the inherent limitations of each because of the problems encountered with early diesels. The British, American, and Russian navies adopted dangerous and unreliable gasoline engines for the submarines in their first service flotillas.

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10. Actually eight boats were built to the same basic design beginning with U-5, of which four were commissioned in 1910, although U-9 went into service three months before U-5 did. Four earlier boats were much less capable and largely experimental in nature.
11. Eberhard Rössler, *The U-boat: The Evolution and Technical History of German Submarines*, trans. Harold Erenberg (Annapolis: Naval Institute Press, 1981), pp. 23–27. There are several somewhat important translation errors in other sections of this English language edition.
12. The problem with the clouds of white exhaust from the kerosene engines was solved by stockpiling a more expensive grade of fuel for use only in wartime. Ibid., p. 33.
13. The first submarines commissioned in these four navies for regular service and not merely for experiment and training were: *Sirene* and *Triton* (France), December 1901; *Holland* No. 2 and *Holland* No. 4 (Great Britain), August 1902; *Adder*, later A2, and *Moccasin*, later A4 (United States), January 1903; and *Delfin* (Imperial Russia), June 1904.

The numbers required for an actual operational capability were not available immediately. In 1905, the French navy was the first to have the equivalent of a flotilla of sixteen submarines in service.[14] By the end of 1909, all four navies listed above had in fleet service the equivalent of one to four flotillas of sixteen submarines each. However, pure numbers and the official adoption of the submarine by the major navies could not compensate for critical limitations in operational capability. It was not until the second decade of commissioned service that the technological ensemble was completed and the component technologies were refined sufficiently to give the submarine reliability and fighting effectiveness.

Small submarines with short range have retained their usefulness in contemporary navies because they are relatively inexpensive. Although inadequate for a major naval power with an oceangoing fleet and overseas interests, the coast defense capabilities of submarines allow a few of them to make a valuable contribution to coastal security. Led by Sweden in 1904, countries with modest navies acquired small numbers of submarines for this role. The practice has continued, and for the past decade, Third World countries have been acquiring the latest types of diesel-electric submarines at an impressive rate. Today more than thirty small navies have from 3 to 15 modern submarines for coast defense. Many represent the best in diesel-electric submarines for range, speed, and armament, and are better than many nuclear submarines in quieting.[15]

Naval Attrition

As a type of submarine warfare, naval attrition is used here to indicate a strategy of wearing down enemy naval forces through gradual attrition of

14. There is nothing magical about the number 16. Surface and subsurface torpedo boats have traditionally been organized into flotillas of 6, 8, 12, or 16 units. To be useful in warfare, submarines need to be deployed in numbers, making a single large flotilla a reasonable baseline here for dating the beginnings of a combat capability. Different measures are used later in this paper for missile submarines.

15. Mark Hewish, Christopher Dawson, and Bob Dicker, "Diesel–Electric Submarines and Their Equipment," *International Defense Review*, Vol. 19, No. 5 (1986), Special Supplement; Jean Labayle Couhat and A.D. Baker III, eds., *Combat Fleets of the World*, 1986–87 (Annapolis: Naval Institute Press, 1986); Christian Eliot, "Nuclear and Conventional Submarines," *Naval Forces*, Vol. 5, No. 1 (1984), pp. 60–72; Klaus Winkler, "Developments in the Design of Conventional Submarines," *Naval Forces*, Vol. 4, No. 6 (1983), pp. 50–58; Ulrich Gabler, "Further Development of Conventional Submarines," *Military Technology*, Vol. 7, No. 3 (1983), pp. 42–48; and F. Abels, "Developments in Conventional Submarine Design," *Naval Forces*, Vol. 5, No. 6 (1982), Special Supplement, pp. 61–65.

ancillary, obsolescent, and independently steaming warships. In contrast to commerce warfare, which is attrition of merchant shipping, it is directed specifically at combatant vessels. At this early stage in their evolution, submarines were not yet capable of engaging a first-line battle fleet, except through chance encounters that occasionally led to a single "hit and hide" attack. It would be several decades before new technologies would enable submarines to intercept and engage a concentration of high-speed surface combatants.

As diesel engines were refined and fuel capacities increased, submarines acquired a seagoing capability, and their roles expanded to include naval attrition. The typical seagoing submarine had a range of 3,200 miles on the surface at 8 knots using diesel engines and a range of 65 miles submerged at 5 knots on electric motors powered by batteries. The Royal Navy was the first to deploy seagoing boats in flotilla strength, with its first sixteen "D" and "E" class boats joining operational units between 1911 and 1914, although they lacked a basic capability for underwater navigation until 1914, when they were fitted with gyrocompasses.[16]

The early seagoing submarines introduced two forms of naval attrition, and in the midst of World War I they were employed in a third. British submarines were intended to cruise in the approaches of enemy naval bases and sink warships. This was an offensive anti-warship mission and explains why the Royal Navy called their seagoing submarines "overseas boats." A defensive version of this strategy was envisioned in the French and American navies for their first seagoing boats. They planned a kind of extended coast defense in which their submarines would cruise several hundred or a thousand miles from home bases and sink as much of the enemy fleet as possible before it could approach friendly shores. Anti-submarine warfare was established as a third form of naval attrition in 1917, when the Royal Navy made hunting U-boats the primary task of its submarine force.

Submarines engaged in naval attrition for the first time during World War I, when navies on both sides adopted this strategy. British submarines patrolled off German naval bases located on the North and Baltic seas, and German submarines planted mines and lay waiting to torpedo Allied war-

16. Great Britain, Ministry of Defence, Ship Department, *The Development of HM Submarines, From Holland No. 1 (1901) to Porpoise (1930)*, by A.N. Harrison, BR 3043, January 1979, pp. 4.1–4.25, 22.3–22.4, and Appendices 1 and 3. British submarine D-1, commissioned in 1909, was a seagoing diesel-electric prototype of shorter range than its near sisters and was employed mainly for trials for its first few years in commission.

ships in waters near their bases in the British Isles and the Mediterranean. German submarines were also used to keep the British fleet away from German shores, Austro–Hungarian submarines were deployed to keep French and Italian warships out of the Adriatic, and both attacked Allied warships supporting the landings at Gallipoli.[17]

Submarines were not particularly effective against battle fleets steaming in formation. Their greatest success against these forces during the European conflict of 1914–18 was in constraining their areas and modes of operation. Fleet commanders on both sides suffered considerable anxiety over submarines, in spite of the fact that their losses to submarine attack were minimal. No first-line capital ship on either side was sunk by a submarine. Only two British cruisers and one destroyer were torpedoed and sunk while steaming with a battle fleet, and of its modern warships, the German navy lost only two destroyers to British submarines.[18]

The general problem for submarines attempting to engage a battle fleet was that they could seldom get into firing position. Even at modest cruising speeds, the fleet was two to three times faster than a submarine running submerged. If a submarine surfaced, it would be vulnerable to the fleet's destroyer screen, and it would still have a speed disadvantage. Second, in order for submarines to conduct attrition warfare against first-line naval forces with any effect, they had to sink its dreadnought battleships. Even if a submarine could get into firing position, first-line capital ships were very difficult to sink because of their relatively stout construction, extensive hull compartmentation, and internal torpedo bulkheads. The six dreadnoughts torpedoed by submarines on both sides during the war were operating alone at slow speed, and they were repaired within a matter of several weeks.[19]

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17. Arthur Hezlet, *The Submarine and Sea Power* (New York: Stein and Day, 1967), pp. 24–42, 67–84; Arno Spindler, "The Value of the Submarine in Naval Warfare," U.S. Naval Institute *Proceedings*, Vol. 52, No. 5 (May 1926), pp. 844–851; and Wladimir Aichelburg, *Die Unterseeboote Österreich-Ungarns*, 2 vols. (Graz: Akademische Druck- und Verlagsanstalt, 1981), Vol. 1, pp. 75–76, 84–91, 121–123, Vol. 2, pp. 490–495.

18. HM cruisers *Nottingham* and *Falmouth* (19 August 1916), HM destroyer *Scott* (15 August 1918); Henry Newbolt, *Naval Operations*, History of the Great War Based on Official Documents, Vols. 4 and 5 (London: Longmans, Green, 1928, 1931), Vol. 4, pp. 35, 38, 45–46. German fleet torpedo boats (destroyers) *V 188* and *S 33* were sunk by British submarines on 6 October 1914 and 3 October 1918, respectively. Erich Gröner, *Die deutschen Kriegsschiffe 1815–1945*, 7 vols. (3rd ed., München: Bernard & Graefe, 1982–), Vol. 2, pp. 49, 54.

19. One French and five German capital ships were torpedoed by submarines. *Jean Bart*, torpedoed 21 December 1914 (103 days to repair); Robert Dumas and Jean Guiglini, *Les Cuirasses Frances de 23.500 Tonnes*, 2 vols. (Grenoble: 4 Seigneurs, 1980), Vol. 1, pp. 54–55, 236–237. *Moltke*, 19 August 1915 (32 days); *Grosser Kurfürst*, 5 November 1916 (97 days); *Kronprinz*, 5 November

However, submarines sank many second-line and obsolete warships, because the older ships were poorly protected against underwater explosions and because they were employed on independent patrol missions and on slow speed operations in confined waters or close to shore. Still, overall results were not great compared to the losses from gunnery actions and mines.[20] During World War I, submarines thus contributed to offshore coast defense through dissuasion rather than sinking warships. They had little effect on battle fleets but modest success against second-line units in their attempts at attrition warfare against warships.

In the Second World War, submarines of both sides engaged in naval attrition in the Atlantic, Mediterranean, and Pacific theaters. Their performance against fleet units was much better than in the First World War.[21] In the Atlantic and Mediterranean, German U-boats sank 54 first-line surface warships, including 3 carriers and 2 battleships.[22] In the Pacific, American submarines sank 62 fleet units, including 5 carriers and a battleship.[23] Ironically, the Japanese navy, which emphasized the employment of submarines against warships, was not nearly as successful, sinking only 9 first-line warships, including one carrier.[24] However, early in the war, Japanese submarines helped curtail U.S. fleet operations by damaging 2 battleships and a carrier on two separate occasions. The most spectacular feat of a submarine operating against a fleet formation took place when the Japanese submarine

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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); Hans H. Hildebrand, Albert Röhr, and Hans-Otto Steinmetz, *Die deutschen Kriegsschiffe*, 7 vols. (Herford: Koehler, 1979–1983), Vol. 3, p. 32, Vol. 4, pp. 55, 137–138, Vol. 6, p. 47. The British dreadnought *Audacious* was sunk indirectly by a submarine when it struck a mine laid by a German U-boat and sank 27 October 1914; Julian S. Corbett, *Naval Operations*, History of the Great War Based on Official Documents, Vols. 1–3 (London: Longmans, Green, 1920–1923), Vol. 1, pp. 249–251.

20. Great Britain, Royal Navy, *Navy Losses* (London: His Majesty's Stationery Office, 1919), pp. 3–6, 8; and Jean Labayle Couhat, *French Warships of World War I* (London: Ian Allan, 1974), pp. 290–294. See also pp. 12–122 for details of circumstances surrounding individual losses. Aldo Fraccaroli, *Italian Warships of World War I* (London: Ian Allan, 1970), pp. 13–71; and Gröner, *Die deutschen Kriegsschiffe 1815–1945*, Vol. 1, pp. 46, 78–80, 85, 128–140, Vol. 2, pp. 43–62.

21. Hezlet, *The Submarine and Sea Power*, pp. 124–136, 191–209.

22. Stephen W. Roskill, *The War at Sea 1939–1945*, 3 vols. (London: Her Majesty's Stationery Office, 1954–61), Vol. 3, Part 2, pp. 439–442, 448.

23. Anthony J. Watts and Brian G. Gordon, *The Imperial Japanese Navy* (Garden City: Doubleday, 1971), pp. 43–72, 127–164, 172–201, 257–295; and Hansgeorg Jentschura, Dieter Jung, and Peter Mickel, *Warships of the Imperial Japanese Navy 1869–1945*, trans. Antony Preston and J.D. Brown (Annapolis: Naval Institute Press, 1977), pp. 26–58, 80–87, 105–112, 141–153.

24. Jürgen Rohwer, "Die Erfolge der japanischen U-Boote 1941–1945," *Marine Rundschau*, Vol. 61, No. 4 (April 1964), pp. 86–88; and Mochitsura Hashimoto, *Sunk: The Story of the Japanese Submarine Fleet*, trans. E.J.M. Cole Grave (London: Cassell, 1954).

I-19 launched a single salvo of six torpedoes at the carrier *Wasp*, sinking the carrier, damaging a battleship, and sinking a destroyer.[25]

In wearing down the enemy's main fleets by attrition, the American and German submarine services in particular made major contributions to their countries' war at sea. However, the significant turning points in the struggle for control of the sea were still fleet engagements. The destruction of naval combatants in fleet actions was what blunted or sustained naval and amphibious offensives. Unlike the losses inflicted by submarines, the destruction of warships in fleet actions was concentrated in time and often caused by combinations of weapons. In the Pacific, American submarines destroyed or disabled over half of Japan's warship tonnage, but most of these ships were torpedoed in late 1944, after command of the sea had been decided in major naval battles off Midway, the Eastern Solomons, Guadalcanal, and in the Philippine Sea. In major fleet actions, the big killer of fleet units during World War II was aircraft. Submarines sank large numbers of warships, but their effect on enemy naval strength was through gradual attrition. By the end of the war, the submarine was thus a major contributor but not yet an arbiter in deciding who controlled the seas. For submarines, naval attrition had not yet become fleet engagement and certainly not decisive battle.

The first two types of naval attrition remain important uses of submarines today. In the South Atlantic war of 1982, for example, Argentina deployed its submarines for extended coast defense of the Falkland Islands, and Britain employed its in offensive anti-fleet operations that resulted in the sinking of the cruiser *General Belgrano*.[26] These roles are important for superpower navies as well. For example, just as the commanders of the British Grand Fleet had to be concerned about losses to U-boats in the North Sea during World War I, American carrier battle groups operating in the Gulf of Sidra today must be prepared to deal with Libya's small but relatively modern submarine force.

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25. Ben W. Blee, "Whodunnit?," U.S. Naval Institute *Proceedings*, Vol. 108, No. 7 (July 1982), pp. 42–47.
26. Robert L. Scheina, "Where Were Those Argentine Subs?," U.S. Naval Institute *Proceedings*, Vol. 110, No. 3 (March 1984), pp. 114–120; Steven Gorton, "Thoughts on the Falkland Islands War," U.S. Naval Institute *Proceedings*, Vol. 108, No. 9 (September 1982), pp. 105–107; J.V.P. Goldrick, "Reflections on the Falklands," U.S. Naval Institute *Proceedings*, Vol. 109, No. 6 (June 1983), pp. 102–103; Carlos E. Zartmann, "An Old-Fashioned Modern War," U.S. Naval Institute *Proceedings*, Vol. 109, No. 2 (February 1983), p. 87; and John Byron, "The Submarine and the Falklands War," U.S. Naval Institute *Proceedings*, Vol. 108, No. 12 (December 1982), p. 43, Vol. 109, No. 4 (April 1983), pp. 11–12.

The third form of naval attrition, the use of submarines against submarines, has only recently become a significant wartime role of submarines. Although this was the primary mission of British submarines in the latter part of World War I, only 18 German U-boats, or 10 percent of the losses sustained by the German submarine force, were sunk by British submarines. German submarines sank 5 of their British counterparts, also representing only 10 percent of the losses sustained by the force. In World War II, these two submarine forces achieved even less against one another. The best performance was by American submarines, which sank 20 Japanese submarines, accounting for about 15 percent of the Imperial Navy's submarine losses. The main problem was target detection and location. In the First World War, submarines had to search for each other on the surface, because they had no means of underwater detection. In the Second World War, sonar provided submarines with an underwater sensor, but it had an effective range of only a few thousand yards under the best of conditions.

Today, submarines have become the most lethal anti-submarine systems under many conditions. Highly sensitive, long-range acoustic sensors give them the capability to detect and localize targets operating within a common underwater medium. Near an adversary's naval bases or under polar ice, submarines are essentially the only effective anti-submarine weapon and sensor platforms. Most significantly, the capability to hunt and destroy ballistic missile submarines now gives this third form of naval attrition importance as a threat to the submarine's role in nuclear deterrence through the capability of assured destruction. However, without significant advances in detection technology, neither superpower would probably destroy more than a few ballistic missile submarines, even in the most aggressive of attrition campaigns.

Commerce Warfare

The capability of submarines to destroy commerce on the high seas introduced a new form of naval warfare that did not depend on exercising control of the seas. Commerce destruction as a mode of naval warfare is difficult to describe, let alone assess accurately. Like most activities in war, the contributing factors are numerous and diverse and their overall effects cumulative.[27]

27. Several, but not nearly all, of these factors are explored in the development of a mathematical model for planning and assessing submarine warfare against merchant shipping in Robert

Some of today's outspoken commentators oversimplify the problem by searching for a few decisive factors, leading to erroneous conclusions about commerce warfare. But there is no question that the cumulative effects of the major submarine campaigns in both world wars have been significant for naval warfare and for the conduct of war as a whole.

Submarines acquired the capability to conduct commerce warfare in the last year before the First World War, as the German navy began to build up its submarine arm. The U-boats put into series production were comparable to the British "D" and "E" classes in speed and armament, but they had three times the range. Beginning with U-19, commissioned in 1913, diesel engines were used for surface propulsion in German submarines, but just as significant was the boat's range of 9,700 nautical miles. Except for specialized coastal types designed during the war to operate from bases seized in Flanders, German submarines built during the next five years had ranges of over 9,000 miles.[28] This oceangoing force could stay on patrol for four weeks at a radius of 2,500 miles from its bases. The German navy, alone among the navies of the world, had essentially, though not intentionally, skipped the coastal and seagoing stages in developing the operational capabilities of its submarines. Comparable cruising radius was introduced in American and Japanese submarines during the 1920s, in British submarines in the 1930s, and in Soviet submarines in the 1950s.

The oceangoing submersible torpedo boat would soon demonstrate formidable capabilities as a commerce destroyer, but in this case, the new capability was developed before the new role was adopted in a strategy. Before the outbreak of war in Europe, the German admiralty had no intention of employing its submarines for commerce warfare. The only prewar study of submarine requirements for a campaign against British merchant shipping was prepared by an obscure lieutenant named Ulrich-Eberhard Blum at the Submarine Inspectorate.[29] German war plans anticipated using submarines for coast defense off major ports and naval bases, for anti-warship patrols in the North Sea, and for naval attrition and reconnaissance in cooperation with

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Eugene Kuenne, *The Attack Submarine: A Study in Strategy* (New Haven: Yale University Press, 1965).

28. Rössler, *The U-boat*, pp. 28–80, 328–333; and Gröner, *Die deutschen Kriegsschiffe 1815–1945*, Vol. 3, pp. 28–62.

29. Philip K. Lundeberg, "The German Naval Critique of the U-Boat Campaign, 1915–1918," *Military Affairs*, Vol. 27, No. 3 (Fall 1963), pp. 106–107.

battle fleet operations in the North Sea. Not until the land war settled into a stalemate on the Western Front, did the German naval staff begin to seriously consider the possibility of using submarines to sever vital sea lines of communication to Great Britain.

Submarines have been used in three major campaigns against ocean commerce. German submarines sank shipping around Great Britain from 1914 to 1918, but a concerted effort to sever sea lines of communication only came in 1917–18. Germany attempted the same strategy in the Second World War, with the major surges in effort coming in 1941 and 1943. The third submarine campaign was waged by the United States against Japan, beginning in 1941 and continued for the duration of the Pacific war.

Each of these campaigns underwent a series of evolutions. There was no single key to the successes or setbacks on either side. Not only was there a series of initiatives and countermeasures in each case; the campaigns also comprised thousands of diverse and individual operations, each with its own set of tactical conditions and technical factors.

THE FIRST WORLD WAR

The German submarine campaign against Great Britain during the First World War demonstrated both that the submarine could be a lethal commerce destroyer and that it could be defeated, but there were only false starts and intermittent efforts for the first thirty months of the war.[30] During the first six months, U-boat commanders, on their own initiative, sank only 10 merchant ships totaling about 20,000 tons. Most of these were ordered to stop by surfaced U-boats according to international prize rules and sunk with scuttling charges in their holds after the crew pulled away in lifeboats.

In February 1915, Germany declared the first of two submarine blockades of the British Isles during the Great War. Because the early German submarines carried only six torpedoes, more ships could be sunk if the U-boats continued to operate under international prize rules. However, a number of

30. Albert Gayer, "Summary of German Submarine Operations in Various Theaters of War from 1914 to 1918," U.S. Naval Institute *Proceedings*, Vol. 52, No. 4 (April 1926), pp. 621–659. The official history of the U-boat campaign from the German naval archives is Arno Spindler, *Der Handelskrieg mit U-Booten*, 5 vols. (Berlin: E.S. Mittler und Sohn, 1932–34, 1941, 1966). Summaries of war patrols of nearly every U-boat are provided in U.S. National Archives and Records Service, *U-Boats and T-Boats 1914–1918*, prepared by Harry E. Rilley and Johanna M. Wagner, Guides to Microfilmed Records of the German Navy, 1850–1945, No. 1 (Washington: U.S. Government Printing Office, 1984), pp. 1–138.

ships, including passenger liners, were torpedoed without warning, bringing protests from neutral countries and causing the German admiralty to issue more and more restrictions (today called "rules of engagement"). At the same time, Britain gradually armed its merchant ships, and deployed heavily gunned decoys called Q-ships, making it increasingly dangerous for U-boats to attempt to operate according to international prize rules. This first attempt at concerted submarine warfare never gained momentum. The blockade was formally ended just six months after it had begun, under pressure from the neutral United States.

Although a few U-boats continued a restricted campaign against maritime commerce around the British Isles, most of the North Sea boats were sent to the Mediterranean. They inflicted substantial losses on shipping in the Mediterranean during much of the war, but this never threatened the survival of France or Italy and in some respects it was a diversion of effort, because the shipping vital to England was on the North Atlantic sea lanes. Restrictions on areas of operation and tactics were not the only obstacles to success. Until the numbers of submarines on patrol could be increased, their effect in any theater would be limited. As more U-boats were built and the newer boats went to sea with 8 to 12 torpedoes, the monthly rate of sinkings began to rise. In September 1916, the monthly total went above 200,000 tons for the first time.

Finally, in February 1917, Germany began a second unrestricted submarine campaign, hoping to knock Britain out of the war before the United States could mobilize to take part in the Allied war effort. The German navy had had oceangoing submarines since 1913, but it was not until this time that there were adequate numbers of these submarines to wage effective commerce warfare. The next six months were the worst for British shipping in either world war. German U-boats were able to sustain an average of 614,000 tons sunk per month for the entire period, and most of the sinkings were inflicted where they had the greatest effect: close to the British Isles.[31] The

31. Excellent statistical summaries of the World War I German submarine campaign are in Bodo Herzog, *60 Jahre Deutsche U-boote 1906–1966* (München: J.F. Lehmanns, 1968), pp. 67–129; Arthur J. Marder, *From the Dreadnought to Scapa Flow*, 5 vols. (London: Oxford University Press, 1961–1970), Vol. 5, pp. 110–120; Newbolt, *Naval Operations*, Vol. 5, pp. 387–429; C. Earnest Fayle, *Seaborne Trade*, History of the Great War Based on Official Documents, 3 vols. (London: John Murray, 1920–1924), Vol. 3, pp. 465–479; and Great Britain, Royal Navy, *Merchant Shipping (Losses)* (London: His Majesty's Stationery Office, 1919), pp. 162–164.

title of Admiral John Jellicoe's book about this period, *The Crisis of the Naval War*, aptly summarizes the British perspective on what was happening.[32]

Although loss rates were alarming, German submarines were never able to impose a blockade on Britain. Allied and neutral shipping not only delivered vital foodstuffs and raw materials, but supplied the war effort on the Western Front from overseas. No single countermeasure defeated the German submarine campaign of 1917, although reintroduction of the ancient convoy system is often cited. The combination of Allied shipping control, the availability of neutral shipping, the merchant convoy, special anti-submarine weapons, thousands of mines laid in the approaches to German submarine bases, and a vigorous construction program to replace shipping losses all contributed in significant ways.[33] Some brief examples show how these factors worked together.

A fundamental cause of Germany's failure to establish a submarine blockade was the availability of neutral shipping for the Allied war effort. The German high command calculated that Britain would be knocked out of the war if 600,000 tons of British shipping were sunk every month for six months, but this assumed that neutrals would be coerced into keeping their ships in port by the ruthlessness of the U-boat offensive. In the event, diplomacy put neutral shipping back to sea after some initial hesitation and, in effect, raised the requirement for victory to a rate of about 900,000 tons per month.[34] Even at its peak strength of 172 boats, Imperial Germany's U-boat arm could not hope to accomplish this.

Further scrutiny of how the U-boats were defeated shows that anti-submarine warfare was not like the more traditional methods of naval combat. Although there was a frantic search for technological antidotes to the submarine, the only useful weapon developed during the war was the depth charge, and it was hardly more successful in sinking U-boats than gunfire or ramming and far less successful than mines. Of the 320 U-boats that sortied during the war, 178 were lost, including 134 to anti-submarine measures. But loss rates for the U-boats were in fact higher in late 1916, long

32. John Jellicoe, *The Crisis of the Naval War* (London: Cassell, 1920). See also Marder, *Dreadnought to Scapa Flow*, Vol. 4, pp. 49–292; and John Jellicoe, *The Submarine Peril* (London: Cassell, 1934).
33. Hezlet, *The Submarine and Sea Power*, pp. 93–107; Fayle, *Seaborne Trade*, Vol. 3, pp. 454–458; James Arthur Salter, *Allied Shipping Control* (Oxford: The Clarendon Press, 1921); and Patrick Beesly, *Room 40: British Naval Intelligence 1914–1918* (London: Hamish Hamilton, 1982), pp. 253–270.
34. Hezlet, *The Submarine and Sea Power*, pp. 85–86, 90–92.

before the convoy system was introduced and when they were operating more against warships. There was something more fundamental at work here than weapons or convoy tactics.

In this new and very different kind of naval warfare, the important measure of success was not how many submarines were sunk, but how many merchant ships reached their destination. The defeat of the U-boats in 1917–18 was not due so much to actual losses, as to the submarines' growing difficulty in finding targets and an inability to get past the convoy escort to sink them when they were found. Centralized shipping control allowed the merchantmen to be routed around areas where U-boats were known to be operating, and even more significantly, convoys greatly reduce the opportunities for visual contact. Once in contact, the submarine was not so often sunk as it was forced to stay submerged below periscope depth while the convoy passed in safety.[35] Thus, the first major submarine campaign against ocean commerce was defeated not in the usual way of sinking enemy ships, but by preventing the enemy from sinking one's own ships.

THE ATLANTIC: ROUND TWO

The German navy waged its second submarine campaign against British commerce, beginning in the summer of 1940. The campaign developed into five major phases, each representing a different set of tactics, new countermeasures, and a shift in operating areas.[36] The objective was to sink as much Allied tonnage as possible for smallest losses to the U-boat force in what was called "tonnage warfare." The task for the U-boats had grown considerably since World War I. The British Empire and the United States alone had 33 million tons of shipping in 1939, and during the war they would build another 42 million tons. To have an effect on merchant fleets of this size, there would indeed have to be tonnage warfare. But seen in retrospect, tonnage warfare was carried out as a series of shifts toward and away from the ultimate objective of severing the sea lines of communication to Great Britain.

Today, countless allusions are made to this campaign as a model for what might happen in a third world war. However, most of these fail to take into account the many complex factors determining its course and final outcome.

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35. Marder, *Dreadnought to Scapa Flow*, Vol. 4, pp. 285–286, Vol. 5, pp. 88–104.
36. Statistics and outlines of the various stages in the campaign are given in Herzog, *U-Boote im Einsatz, 1939–1945*, pp. 59, 85–86, 125–127, 187–188, 225; and Willem Hackmann, *Seek and Strike: Sonar, Anti-Submarine Warfare and the Royal Navy 1914–1954* (London: Her Majesty's Stationery Office, 1984), pp. 235–237, 239.

For reasons of both its popularity as a model and the complexity of its execution, the second Atlantic submarine campaign against commerce bears at least brief description.[37]

The first nine months of the European war saw only preliminaries to the U-boat campaign. The German navy had not prepared for a submarine offensive, because the U-boat campaign of 1917–18 was seen as a failure and a mistake, and because the admirals dominating the naval staff preferred a fleet of heavy surface units. The staff had gradually adopted a strategy of commerce destruction from the late 1920s, but the means were to be a kind of combined arms approach, using surface action groups, independent cruiser raiders, aircraft, and submarines. Lack of preparation before the war meant that an average of only 6 submarines operated in the Atlantic for the first several months of the war. Such small numbers were capable of little more than harassment, and in March 1940, all available U-boats were recalled to take part in the German invasion of Norway.

The first phase of the German submarine offensive against shipping really began in late May 1940, when the U-boats were redeployed to the western approaches of British seaports. In August, they began operating from bases on the Atlantic coast of German-occupied France, which significantly reduced transit time to patrol areas. Individual U-boats operated on the surface so that they did much to alleviate the perennial problems with tactical reconnaissance faced by all submarine forces; but it would also become a major vulnerability.

Numbers were a problem for both the offense and defense at this stage. In November 1940, Dönitz ordered the U-boats to coordinate their attacks on convoys in what he called wolf pack tactics, but since the monthly average of U-boats at sea was only 10 in this phase, the rate of sinkings stayed at around 200,000 tons per month, in spite of the fact that losses to ASW were insignificant. On the defensive side, a shortage of suitable warships forced the Royal Navy to escort merchant convoys for only a few hundred miles to and from British ports. This was also within the range of land-based aircraft,

37. Basic histories of the Campaign are Karl Dönitz, *Memoirs: Ten Years and Twenty Days*, trans. R.H. Stevens (Cleveland: World, 1959); and Roskill, *The War at Sea 1939–1945*. Detailed statistics are provided in Herzog, *60 Jahre Deutsche U-Boote 1906–1966*, pp. 209–296; and Jurgen Rohwer, *Axis Submarine Successes 1939–1945*, trans. John A. Broadwin (Annapolis: Naval Institute Press, 1983). Summaries of war patrols of nearly every U-boat are provided in U.S. National Archives and Records Service, *Records Relating to U-Boat Warfare, 1939–1945*, prepared by Timothy Mulligan, Johanna M. Wagner, and Mary Ann Coyle, Guides to Microfilmed Records of the German Navy, 1850–1945, No. 2 (Washington: U.S. Government Printing Office, 1985), pp. 23–198.

which actually sank no U-boats, but worried their commanding officers and kept them from attacking in daylight.

In the second phase of the campaign, beginning in April 1941, the U-boats moved their main area of operations farther westward, to the central Atlantic. German submarine strength rose steadily from 120 to 200 boats over the next six months and losses remained low, but rate of sinkings fell off during the summer as ASW measures improved. More escorts became available, and they were able to accompany merchant convoys all the way across the Atlantic. The cover of darkness was being penetrated by the middle of 1941, when escorts were equipped with radar that could locate a surfaced submarine out to about 3 miles, beyond effective torpedo range. The Admiralty was able to reroute convoys away from known concentrations of enemy submarines using direction finding on radio transmissions from the U-boats to Dönitz's command center. British naval intelligence also began breaking German naval codes and was able to learn much of what Dönitz intended for his submarines from the content as well as the numbers and origin of radio messages. In September, the German naval command began diverting its submarines to the Mediterranean to attack British naval forces which were threatening to sever German and Italian supply lines to North Africa. In November, as more U-boats were being sent to the Mediterranean and loss rates in the North Atlantic began to climb, Dönitz temporarily suspended U-boat attacks on convoys.

U.S. entry into World War II led to the third phase in the German submarine campaign in January 1942. For Dönitz's concept of tonnage warfare, this was an opportunity to attack unprotected shipping with little initial risk of losses. Unprotected, the shipping in American waters was easy prey for the U-boats, and the rate of sinkings rose rapidly. From March until November 1942, U-boat strength rose from 284 to 379, but only 6 to 12 boats were in American waters at any one time, because of long transit times, the demand for boats in other operating areas, and the fact that several months were required to train each crew for the scores of new boats. Yet German submarines sank an average of 500,000 tons of shipping per month in the Atlantic during this period, most of which was west of 50°W in a great crescent from Newfoundland to the Amazon delta. About one-third of this tonnage was American.

When the U.S. Navy introduced convoys and relays of coastal escorts in a kind of "bucket brigade" approach, the U-boats were ordered to move their area of operations southward. By late summer, their main area of success

was the Caribbean. As Dönitz shifted the areas of operation farther south to avoid each new patrol and convoy area, the U-boats moved farther from their primary objective. Every Allied merchantman sunk added to the cumulative effort, but the United States was not dependent on the seas for survival and Britain was. For the limited number of U-boats available to put direct pressure on Britain, they had to attack ships steaming to and from the British Isles. Toward the end of 1942, as the coastal convoy system was extended, the numbers of American escorts increased, and the coverage of air patrols expanded, sinkings in American waters declined significantly.[38]

In the fourth phase, as the campaign in American waters lost momentum, the German navy renewed its offensive against the north Atlantic convoys from about October. By January 1943, it had over 400 U-boats in commission, of which over half were operational. Night wolf pack tactics were used in the mid-ocean area out of range of land-based aircraft. The worst month for the Allies was November 1942, when 743,000 tons of shipping were sunk by German submarines in all theaters. The culmination of the struggle came in March 1943 with a series of big convoy battles. In one case, 49 U-boats attacked two convoys totaling 88 merchantmen with only 14 escorts, sinking 21 ships for the loss of one submarine. After March, U-boat successes fell off rapidly and their own losses began to rise as Allied ASW measures were improved and expanded. By May, the offensive had been defeated, and at the end of August, Dönitz withdrew his submarines from the central Atlantic.[39]

In the fifth and last phase, the U-boats were dispersed to search for weak points in the Allied sea lines of communication, but from August 1943 until June 1944, when the U-boats were recalled to participate in the defense of "fortress Europe," the monthly tonnage sunk exceeded 100,000 on only one occasion.

A number of technical and tactical developments defeated the U-boats.[40] The gap in air cover was closed with the use of small escort aircraft carriers.

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38. Samuel Eliot Morison, *History of United States Naval Operations in World War II*, 15 vols. (Boston: Little, Brown, 1947–1962), Vol. 1, pp. 114–418.
39. Jürgen Rohwer, *The Critical Convoy Battles of March 1943* (Annapolis: Naval Institute Press, 1977).
40. Some of these are outlined in detail in Hackmann, *Seek and Strike*, pp. 233–323; Alfred Price, *Aircraft versus Submarine* (Annapolis: Naval Institute Press, 1973), pp. 43–228; Peter Hodges and Norman Friedman, *Destroyer Weapons of World War 2* (Annapolis: Naval Institute Press, 1979), pp. 56–60, 131–140; and Alastair Mitchell, "The Development of Radar in the Royal Navy 1935–1945," *Warship*, Vol. 4, No. 13 (January 1980), pp. 2–14; No. 14 (April 1980), pp. 117–134.

Operations research introduced statistical analysis in solving the complex problems of submarine warfare to the great benefit of the Allies.[41] One conclusion of operations research was that large convoys lost fewer ships than small ones, and this allowed the most economical use of escort ships. With more efficient use of the growing number of escorts, the Allies were also able to form ASW support groups to reinforce convoys under heavy attack. High frequency radar, carried by ships and aircraft, was effective in locating U-boats at night, and its electronic pulses were not picked up by German warning receivers. Finally, British signal intelligence now provided sufficient information for 60 percent of the May 1942 to May 1943 convoys to be routed clear of U-boat patrols, again showing that avoiding submarines could be as important as sinking them in this kind of warfare.[42]

It has been a bitter struggle fought on a grand scale. The Germany navy commissioned a total of 1,171 submarines between 1935 and 1945. Of these, 940 sortied and 784 were lost, 593 to Allied ASW measures. But the U-boat offensives of the Second World War had not been as threatening as the campaign of 1917. For their heavy losses, the U-boats sank 14 million tons or about 17 percent of the 84 million tons of shipping available to the Allies during the war. These figures are significant when making comparisons between this historical case and the current or future Soviet submarine threat to the sea communications of the Western Alliance.

The second submarine campaign against Great Britain demonstrated a number of important things about commerce warfare. There would always be competing military requirements imposed on a submarine force, making it difficult to muster the numbers required for a concerted campaign. The withdrawal of U-boats for the Norway invasion in 1940, to conduct naval attrition in the Mediterranean in 1941, and to help defend against the Allied landings on the continent in 1944 are clear examples of conflicting priorities. Where merchant shipping was sunk could be as important as aggregate tonnage sunk, as shown by the relief of pressure on British shipping when the U-boats were sent to American waters in 1942. Outside sources of tactical reconnaissance helped submarines find targets, but represented sources of vulnerability, particularly to signal intelligence. In the course of hundreds of

41. C.H. Waddington, *OR in World War II: Operational Research Against the U-Boat* (London: Elek Science, 1973); and Keith R. Tidman, *The Operations Evaluation Group: A History of Naval Operations Analysis* (Annapolis: Naval Institute Press, 1984), pp. 17–94.
42. Patrick Beesly, *Very Special Intelligence: The Story of the Admiralty's Operational Intelligence Centre 1939–1945* (Garden City: Doubleday, 1978), p. 192. See also pp. 63–75, 92–122, 160–211.

encounters between U-boats and ASW forces, some advances in ASW technology were countered merely with changes in tactics, while others denied submarines the ability to attack and survive even when technical countermeasures were developed.

THE PACIFIC WAR

The right combination of circumstances allowed the U.S. Navy to wage a devastating submarine campaign against Japan during World War II. The most basic factor was Japan's vulnerability to commerce warfare. Over three-quarters of the country's requirements for seventeen basic raw materials and significant percentages of other raw materials and foodstuffs came from overseas. Compared to the shipping available to the Allies, the Japanese merchant marine was relatively small, having 1,600 ships totaling 6 million tons on hand when the war began. The Japanese merchant marine was working to capacity before the war and was sensitive even to small losses. The island nation had a limited shipbuilding capacity to replace losses. Adding ships built and captured during the war, the U.S. submarine force was attacking total maritime assets of only 3,100 ships of 10 million tons.[43]

At the time of the Japanese attack on Pearl Harbor, the U.S. Navy had 51 submarines stationed at forward bases in the Pacific. During the next four years, 249 U.S. submarines would conduct about 1,500 sorties against Japanese shipping, with the operational force in the theater never exceeding 156 "fleet boats." They sank half of the merchant tonnage available to Japan during the war. Another quarter of this tonnage was sunk by carrier and land-based aircraft, and 8 percent was sunk by mines. The combined result was to eliminate the vital services of the Japanese merchant marine.

U.S. submarines were able to operate deep in enemy waters from the first days of hostilities, even though Allied surface and land forces were losing engagements and being forced to retreat. Although Japan controlled the western Pacific for the first two years of the war, U.S. submarines were able to maintain pressure on Japanese merchant shipping, generally increasing their rate of sinkings until the last months of the war, when ships no longer ventured out of port. During 1944, carrier task forces made sweeps into

43. United States, Strategic Bombing Survey, *The War Against Japanese Transportation 1941–1945*, Pacific War, Report 54 (Washington: U.S. Government Printing Office, 1947), pp. 1–2, 13–20, 32, 53–54, 116–118. See also U.S., Strategic Bombing Survey, *Japanese Merchant Shipbuilding*, Pacific War, Report 48 (Washington: U.S. Government Printing Office, 1947).

Japanese home waters, sinking large numbers of ships. Land-based aircraft accounted for only a few ships sunk each month, but were able to maintain this modest rate of attrition for the entire war. Mines had their effect in the last months of the conflict, when Army Air Force B-29s could deliver them from island bases within range of the Japanese homeland.[44]

Submarines were by far the most important factor in the destruction of the Japanese merchant marine, yet their losses were very low, particularly compared to the casualties suffered by the German U-boat arm during the same period. Only 31 American submarines were lost to Japanese ASW measures and probably another 8 to mines.[45] The reasons for the low efficiency of Japanese anti-submarine countermeasures were institutional, doctrinal, and technological.

Between the wars, the Japanese admirals planned strategy based on decisive battle, and tactics were developed accordingly. As a result of this emphasis, they ignored commerce protection almost completely in both building programs and fleet training. There were few escort ships in the Japanese navy in 1941, and large scale construction of this type of vessel was not undertaken until late in the war. Until April of 1942, the Japanese navy had no unit assigned to convoy escort. The training situation was much the same. Officers questioned after the war said that before 1942 they had never seen exercises involving defense against submarine attacks on merchant shipping.

During the war, most Japanese navy personnel did not wish to be assigned to convoy escort duty, but preferred instead the more glamorous offensive operations of the Combined Fleet. Those who manned the escort ships were unaggressive, poorly trained, and inadequately equipped for their mission. They were prone to accept the slightest evidence that a submarine had been sunk, thus giving up the attack too early and in many cases allowing it to escape.[46] Coupled with these factors were technical difficulties. Even as escort commands were established and expanded, the shortage of such basic items

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44. Strategic Bombing Survey, *War Against Japanese Transportation*, pp. 2–8, 34–48, 114–134; Clay Blair, Jr., *Silent Victory: The U.S. Submarine War Against Japan* (Philadelphia: J.B. Lippincott, 1975); and Theodore Roscoe, *United States Submarine Operations in World War II* (Annapolis: Naval Institute Press, 1949).

45. John D. Alden, *The Fleet Submarine in the U.S. Navy* (Annapolis: Naval Institute Press, 1979), pp. 249–266; and W.J. Holmes, *U.S. Submarine Losses in World War II* (Washington: U.S. Government Printing Office, 1946). Detailed accounts of each submarine's loss are given in Blair, *Silent Victory;* and Roscoe, *United States Submarine Operations in World War II.*

46. Toshiyuki Yokoi, "Thoughts on Japan's Naval Defeat," U.S. Naval Institute *Proceedings*, Vol. 86, No. 10 (October 1960), pp. 68–75; and Y. Horie, "The Failure of Japanese Convoy Escort," U.S. Naval Institute *Proceedings*, Vol. 82 (October 1956), pp. 1072–1081.

as depth charges remained serious. Many ASW ships were not equipped with sonar. Japanese airborne radar was inadequate for detecting surfaced submarines at night. Although great confidence was placed in magnetic anomaly detection (MAD) gear installed in aircraft, probably no more than five American submarines were sunk by Japanese aircraft at sea.[47] In terms of cost exchange, the American submarine campaign against Japan was probably the closest thing to an offensive against negligible ASW opposition.

The submarine campaigns in both world wars represented fundamental innovation in the conduct of naval warfare. The objective of each campaign was to sink merchant shipping and if possible avoid engaging the adversary's naval forces. Instead of strategic and tactical concentration of naval forces for major fleet actions in a classical approach, there was both strategic and tactical dispersal. The submarine force was dispersed strategically to cover wide areas crossed by major shipping routes, and in World War I there was no tactical concentration of submarines. In World War II, German and American submarines would form small tactical concentrations using wolf pack tactics, but strategic dispersal was still a key to success. The counter to the submarine campaign was also strategic dispersal and tactical concentration. Since no decisive battle could be fought, naval forces used in antisubmarine operations were distributed in small groups, but concentrated tactically to protect convoys and to patrol the near approaches to major ports.

Commerce warfare remains an important role of submarines today, although the situation, as it is now evolving, is different than it was in World War II, as I will note below. To briefly summarize relevant conclusions from the three historical cases reviewed here, proper assessment of current and future commerce warfare scenarios using submarines must consider at least nine essential factors. These are: 1) the numbers, individual tonnage, and aggregate tonnage of merchant ships available to the target state; 2) the capacity of the target state's shipyards to expand its merchant marine and replace losses; 3) the availability of allied and neutral shipping to the target state; 4) the number of submarines in the attacking force; 5) competing mission demands that would be placed on the attacker's submarine force; 6) the attacker's shipyard capacity to expand its submarine force and replace combat losses; 7) the vulnerability of the target state's economy to serious

47. Atsushi Oi, "Why Japan's Anti-Submarine Warfare Failed," U.S. Naval Institute *Proceedings*, Vol. 78, No. 6 (June 1952), pp. 587–601; and U.S. Strategic Bombing Survey, *Pacific War*, Report 72: *Interrogations of Japanese Officials*, OPNAV-P-03-100, pp. 161, 196, 228, 441, 485.

Table 1. Submarine Campaigns in Two World Wars

	Germany vs. Great Britain 1914–1918	Germany vs. Great Britain 1939–1945	United States vs. Japan 1941–1945
Submarines			
In Commission	374	1,171	311
Sortied	320	940	249
Lost	178	784	48
Lost to ASW	134	593	31
Total Sorties	3,274	?	1,569
Merchant Shipping			
Tonnage Available (millions)			
Before War	43.1	41.4	6.0
Built during War	10.8	42.5	3.3
Captured	2.4	0.7	0.8
TOTAL	56.3	84.6	10.1
Tonnage sunk (millions)			
by Submarines	11.2	14.7	4.9
by Mines	1.1	1.4	0.4
by Surface Warships	0.6	1.6	–
by Aircraft	–	2.9	2.5
TOTAL	12.9	20.6	7.8
Percentage Losses			
Submarine Force	47.6	67.0	15.4
Merchant Fleet to Sub	19.9	17.4	48.5

loss of its shipping capacity; 8) the relative effectiveness of submarine and anti-submarine capabilities; and 9) the geographical relationship between vital shipping lanes, submarine bases and lines of transit, and sustained deployment areas of ASW forces.

Technological Equilibrium

For the submarine, the period between 1913 and 1943 saw little significant development either in new applications of technology or in new capabilities. After slow initial development of more than a century, rapid synthesis of technologies in the last decade before the First World War had produced three basic capabilities in submarines. After that, submarine technology settled down to three decades of stable equilibrium. The one new development

was the advent of acoustics in naval warfare, but with a few exceptions, the capabilities of submarines and their weapons stayed about the same.

Table 2 compares the salient capabilities of U-27, the most advanced submarine type completed before World War I, with the German Type VIIC U-boat and the American *Gato* class "fleet boat," the standard submarines used in the Atlantic and Pacific commerce warfare campaigns of World War II. In range and speed, both surfaced and submerged, performance is virtually the same. Torpedo range and speed are also similar. The main areas of improvement for submarines were operating depth, made possible by stouter hull construction, and better armament in terms of the numbers of torpedoes carried and the lethality of their warheads.[48]

Significant new developments in submarine technology began to emerge in 1944, when the German navy transformed the submersible torpedo boat

Table 2. Submarine Capabilities in Two World Wars

	U 27—1914	Type VIIC—1940	Gato—1941
Displacement (surfaced):	664 tons	750 tons	2,025 tons
Range (surfaced):	9,800 nm @ 8 kn	8,500 nm @ 10 kn	11,000 nm @ 10 kn
(submerged):	85 nm @ 5 kn	80 nm @ 4 kn	96 nm @ 2 kn
Speed (surfaced):	17 knots	17 knots	20 knots
(submerged):	10 knots	8 knots	9 knots
Diving Time:	45–80 seconds	30 seconds	30–50 seconds
Operating Depth:	160 feet	330 feet	300 feet
Torpedo Tubes:	4 20-inch	5 21-inch	10 21-inch
Torpedoes (carried):	6	14	24
(range):	9,000 yd @ 27 kn	8,200 yd @ 30 kn	9,000 yd @ 31 kn 4,500 yd @ 46 kn
(warhead):	360 lbs TNT	617 lbs TNT	643 lbs HBX

48. Submarine development in the interwar period is summarized in Friedman, *Submarine Design and Development*, pp. 37–43; and in Ermino Bagnasco, *Submarines of World War Two* (Annapolis: Naval Institute Press, 1977), pp. 24–28. See also Great Britain, Ministry of Defence, Ship Department, *The Development of HM Submarines*, p. 12.1–29.4; Alden, *The Fleet Submarine in the U.S. Navy*, pp. 10–102; and Rossler, *The U-Boat*, pp. 88–119.

into a true submarine. Then, after the Second World War, submarines acquired in quick succession three fundamentally new capabilities of projection ashore, fleet engagement, and assured destruction. The first submarines with the entire technological ensemble necessary for each of these new capabilities completed tests and trials in 1957, 1958, and 1960, respectively. Integrated units with minimum numbers of submarines necessary to exercise each basic new capability were in service between 1960 and 1967.

Projection Ashore

In today's terminology, the projection of naval power ashore refers to the ability of naval forces to strike targets inland with manned aircraft or guided missiles and the ability to conduct amphibious operations. The concept emphasizes striking or seizing objectives a substantial distance inland, but it can be said that shore bombardment by gun-armed ships is a modest form of this capability. Submarines acquired a capability to strike targets a few hundred miles inland in 1957, when they were first deployed operationally with an armament of cruise missiles.

Small unguided rockets had been launched from the deck of a submerged U-boat in unofficial tests at Peenemünde during the summer of 1942, and two years later the German air force launched the first of several thousand guided missiles known as the V-1 at London and Antwerp.[49] In 1947, a U.S. version of the V-1, called the Loon, was the first cruise missile test-fired from a submarine. The series of tests that followed contributed to development of the Regulus cruise missile. The 500 nautical mile range of this missile enabled submarines to hit targets far inland, but it was the missile's nuclear warhead that gave it much more than the nuisance capability of the V-1s. The German missiles had been launched in great numbers, but submarines could only carry two to four missiles each. Therefore, the development of smaller (3,600-pound) nuclear warheads that could be carried by a missile was essential to give submarines the new capability. The U.S. Navy maintained a unit of four Regulus missiles (aboard either one or two submarines) on deterrent patrol in the Pacific from 1957 until 1964, when the mission was taken over by ballistic missile submarines.[50]

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49. Jak P. Mallmann Showell, *U-Boats Under the Swastika: An Introduction to German Submarines 1935–1945* (New York: Arco, 1973), p. 114.
50. Norman Polmar, *The American Submarine*, 2nd ed. (Annapolis: Nautical and Aviation, 1983),

The Soviet navy had its own cruise missile program in which the first version of the SS-N-3 "Shaddock," a land-attack cruise missile with inertial guidance and a range about equal to the Regulus, was put aboard converted submarines beginning about 1959. By 1963, the Soviet navy had 17 submarines carrying 68 land-attack missiles, while the U.S. Navy stopped its cruise missile program with 5 submarines capable of carrying 17 Regulus missiles.[51] The mission of the Soviet force was most likely to provide theater nuclear strikes in support of land operations in the Baltic and Pacific areas, but the nuclear-powered cruise missile submarines of the "Echo I" class, introduced in 1960, could certainly have struck major U.S. population centers along both coasts.

In some ways, the submarine was an ideal platform to carry and launch cruise missiles against inland objectives. Since the target is fixed, no active guidance would be required. The submarine could launch its missiles and retire quietly while pre-programmed or inertial guidance took them to their targets.[52] Although a new capability and a notable technical achievement, the ability of submarines to project power ashore with cruise missiles, was at first only a modest addition to naval power. At the time it was introduced, the submarine-launched cruise missile was overshadowed in the U.S. Navy by the carrier, whose jet aircraft could not only deliver many nuclear weapons at more than twice the range of a cruise missile but also effectively deliver conventional munitions, compensating for their lower explosive power by flying multiple missions.[53] The early cruise missiles carried by both American and Soviet submarines had to be launched from the surface, leaving the submarine most vulnerable during the critical part of its mission. All of these factors reduced the initial significance of the new capability, and illustrate the difficulties that can arise in matching technology with strategy. But most

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pp. 101–107; Norman Polmar, "Die ersten Marschflugkorper fur den Einsatz in See," *Marine Rundschau*, Vol. 79, No. 2 (February 1982), pp. 76–84; and Viktor Frampton, "Ask Infoser," *Warship International*, Vol. 22, No. 1 (1985), p. 104.

51. Norman Friedman and Przemyslaw Budzbon, "Soviet Union," in *Conway's All the World's Fighting Ships 1947–1982*, ed. Randal Gray, 2 vols. (Annapolis: Naval Institute Press, 1983), Vol. 2, pp. 493, 495; Siegfried Breyer and Norman Polmar, *Guide to the Soviet Navy*, 2nd ed. (Annapolis: Naval Institute Press, 1977), pp. 128–131, 156; and Norman Polmar, *Guide to the Soviet Navy*, 3rd ed. (Annapolis: Naval Institute Press, 1983), pp. 103–104, 109, 363.

52. For greater accuracy, the Regulus system used guidance by radio commands from a separate radar picket submarine.

53. Some argue that cruise missiles continue to be overshadowed by tactical aircraft capabilities as in Robert Nutwell, "'Silver Bullets' and Coups de Grace," U.S. Naval Institute *Proceedings*, Vol. 110, No. 6 (June 1984), pp. 73–79.

important was the introduction of ballistic missiles in submarines, which eclipsed the cruise missile submarine in both superpower navies within a few years.

Recent developments in various technologies are giving the submarine-launched cruise missile new importance in the role of projection ashore. With the introduction of compact cruise missiles the size of a torpedo, a submarine can carry larger numbers of land-attack missiles, and these can be launched from underwater. New guidance technology, such as terrain contour matching (TERCOM), provides cruise missiles with the accuracy necessary to strike tactical targets with conventional or low-yield nuclear munitions. Furthermore, as land-based nuclear delivery systems become more vulnerable to attack because of improving accuracy in short and medium range ballistic missiles, the submarine begins to look more attractive as a secure launch platform for medium-range tactical and theater nuclear systems.[54] The submarine's capability for projection ashore, in existence since 1957, will at last become a significant theater strike capability when compact cruise missiles are deployed aboard submarines in significant numbers by the end of this decade.

Fleet Engagement

In 1959, submarines first acquired the long-sought capability to operate with or against a battle fleet. The unsolved problem from the beginning had been speed. The first oceangoing submarines completed from 1913 were called fleet submarines (*Flotten-Uboote*), indicating the German navy's intention to employ them as part of the battle fleet. The limitations of available propulsion plants were soon evident, and as tactics were established, German emphasis was on coordinated but separate operations. The British Admiralty, however, established the requirement in 1912 for submarines with sufficient surface speed and sea-keeping qualities to accompany the fleet under all conditions. For the next twelve years, the Royal Navy pursued the elusive goal of high surface speed, building 28 large submarines in an attempt to meet the 1912

54. Richard K. Betts, ed., *Cruise Missiles: Technology, Strategy, Politics* (Washington, D.C.: Brookings, 1981), pp. 48, 83–91, 99–100, 388–393, 526–528; Miles A. Libbey III, "Tomahawk," U.S. Naval Institute *Proceedings*, Vol. 110, No. 5 (May 1984), pp. 150–163; and J. Philip Geddes, "The Sea Launched Cruise Missile," *International Defense Review*, Vol. 9, No. 2 (April 1976), pp. 198–202.

requirements. Most of these were steam powered, and all were unsatisfactory.[55]

A major step was taken at the end of World War II when new ensembles of technology were developed to give submarines greater speed submerged than on the surface. In 1937, the Japanese navy built a single experimental submarine capable of just over 21 knots submerged, and a modest program produced three production boats in 1945; but the major developments took place during World War II in Germany.[56] Propulsion designs proceeded along two lines: a hydrogen peroxide turbine that needed no outside air supply and a diesel-electric system with powerful electric motors and a high capacity battery outfit. The second system was adopted for mass-produced operational units of the large, long range Type XXI "electroboat" and the much smaller Type XXIII coastal boat. Both had streamlined hull designs for better underwater speed and a snorkel for running the diesels and charging the batteries without surfacing. The best American submarines in the Pacific campaign were capable of 20 knots on the surface but only 9 while submerged. While the Type XXI could do only 16 knots using diesels on the surface, it was capable of 17 knots on electric propulsion while submerged and its underwater endurance was several times greater than that of any submarine built to that time. With high-capacity batteries and the snorkel, submarines at last also had propulsion for long range operations while submerged. The surface torpedo boat that could submerge had become a submarine torpedo boat that did not need to surface. When Germany surrendered in May 1945, there were 120 Type XXI and 62 Type XXIII U-boats in commission, but only a few were ready for war patrols.[57]

The electroboat became the new standard for submarine performance with the completion of six U.S. *Tang* class submarines in 1951–52. In the meantime, the great expense of the high-capacity battery plants led to the slightly less capable Guppy (greater underwater propulsion program) conversions of 50 U.S. fleet boats between 1947 and 1951.[58] The Soviet navy did not fully exploit the advantages of electroboat technology at first. Its 236 postwar "Whiskey"

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55. Richard Compton-Hall, *Submarine Warfare: Monsters and Midgets* (Poole, Dorset: Blandford Press, 1985), pp. 18–30, 43–50.
56. Dorr Carpenter and Norman Polmar, *Submarines of the Imperial Japanese Navy* (Annapolis: Naval Institute Press, 1986), pp. 100, 116–117.
57. Rössler, *The U-Boat*, pp. 168–187, 198–204, 208–210, 214–247; Eberhard Rössler, *U-BootTyp XXI*, 3rd ed. (München: Bernard und Graefe, 1980).
58. Friedman, *Submarine Design and Development*, pp. 53–66; and Norman Friedman, "Project Guppy," *Warship*, Vol. 3, No. 9 (1979), pp. 38–44.

boats were only modest improvements over the U.S. fleet boats of World War II, but with 14 instead of 24 torpedoes and less endurance, indicating an intention to use them for extended coast defense rather than for commerce destruction. Of the more than 300 Soviet submarines completed between 1950 and 1957, only 20 "Zulu" class boats were true oceangoing submarines, comparable to the German Type XXI in performance.[59] Today, the basic design concepts developed by the German navy are found in all diesel-electric submarines, the Type XXI being the model for oceangoing units and the Type XXIII the pattern for coast defense submarines for the last four decades.[60]

Although more than an evolutionary development, the electroboat did not introduce a basic new capability for submarines. It improved an existing capability, making submarines much more effective against troop and merchant convoys, but the advent of the fast carrier task force during the Second World War left even these very fast submarines with insufficient speed to engage the battle fleet in its new form. Furthermore, ASW aircraft, equipped with radar, sono-buoys, MAD gear, and homing torpedoes represented formidable threats to submarines snorkeling or maneuvering at periscope depth to attack.[61]

The basic new capability to engage a first-line battle fleet came with the introduction of nuclear propulsion and a hull form optimized for underwater speed. The U.S. Navy's *Albacore*, completed as a "hydrodynamic test vehicle" in 1953, was the first submarine with a hull that was *optimized* for underwater speed. The USS *Nautilus*, completed in 1955, was the first to have a nuclear propulsion plant, and the *Skipjack*, first to combine the two features, was operational in 1959.[62] Submarines now had the capability for sustained high underwater speed. They could cruise for weeks at 20 to 25 knots like carrier task forces, and they could match the carrier force's 30-knot speed in combat

59. Although often called a Soviet version of the Type XXI U-boat, the "Whiskey" class submarine is 35 percent smaller and not comparable in speed submerged, in range both surfaced and submerged, and in armament. Compare data on "Whiskey" and "Zulu" in Couhat and Baker, *Combat Fleets of the World*, 1986–87, pp. 508–509; Polmar, *Guide to the Soviet Navy*, 3rd ed., pp. 116–118; and John Jordan, "Soviet Attack Submarines," *Jane's Defense Weekly*, September 22, 1984, pp. 500–502, with Rössler, *U-BootTyp XXI*, pp. 149–151. The most common designations for Soviet submarines built since World War II are assigned by Western intelligence using the U.S. Navy phonetic alphabet. These designations are given here in quotes.
60. Ulrich Gabler, *Unterseebootau*, 3rd ed. (München: Bernard und Graefe, 1986).
61. Norman Friedman, *Carrier Air Power* (Annapolis: Naval Institute Press, 1981), pp. 122–129.
62. Raymond V.B. Blackman, ed., *Jane's Fighting Ships*, 1968–69 (New York: McGraw–Hill, 1968), pp. 398, 401, 403.

operations. The buildup of nuclear submarine forces was gradual, the United States completing a nominal flotilla of 16 high performance nuclear attack submarines (SSNs) in 1966 and the Soviet Union matching this force a year later.[63]

Until this time, the only weapon available to submarines for attacking surface ships was the torpedo, although the effectiveness of this weapon was improved considerably with the introduction of acoustic homing by the German and American navies in 1943 and wire guidance by the U.S. Navy in 1946. The Soviet navy introduced a rudimentary stand-off capability with the modification of its land-attack cruise missile, the SS-N-3 "Shaddock," as an anti-ship weapon. Between 1961 and 1969, 45 "Echo II" and "Juliett" submarines were built to launch these missiles while surfaced against NATO aircraft carriers from about 25 miles using radar guidance from the submarine. With the aid of a Tu 20 "Bear D" radar aircraft, introduced in about 1967, the "Shaddock" missile could hit a moving ship at 250 miles. In 1967, the Soviet navy also commissioned its first "Charlie I" class submarine, which can fire eight SS-N-7 "Siren" missiles while submerged at ships 35 miles away, although acoustic conditions probably reduce this range considerably.[64]

Submarines were capable of engaging a force of surface combatants and causing serious losses, but parallel developments in ASW systems prevented them from acquiring the capability for decisive battle. Concern that the Soviet navy would produce Type XXI submarines in large numbers led the U.S. Navy to develop significantly better ASW capabilities for its carrier task forces. Fixed-wing ASW aircraft had operated from slower escort aircraft carriers to protect merchant convoys since the middle of World War II, and from 1953 they were complemented by helicopters with dipping sonar. Operating from much larger, faster carriers after 1954, both types of aircraft could protect the fleet as well. In 1961, the U.S. Navy introduced variable depth sonar in some destroyers and armed many others with the first true stand-off ASW weapon (called ASROC for antisubmarine rocket) with a range

63. Ibid., pp. 397–398; Budzbon and Friedman, *Conway's All the World's Fighting Ships 1947–1982*, Vol. 2, pp. 494, 497; and Polmar, *Guide to the Soviet Navy*, 3rd ed., pp. 108, 110. The Soviets built fourteen "November" class submarines, which did not benefit from the *Albacore*-type hull, but attained high speeds with a nuclear plant twice as powerful as that of the *Skipjack*. The first of these was commissioned in August 1958 but was probably not operational until the next year. Subsequent Soviet attack submarines had *Albacore* hulls.

64. Polmar, *Guide to the Soviet Navy*, 3rd ed., pp. 98–102, 333–334, 363; and Siegfried Breyer and Armin Wetterhan, *Handbuch der Warschauer–Pakt–Flotten* (Koblenz: Bernard & Graefe, 1983–85), sections 004.04, 007.02, 007.03.

ten times the previous maximum of 1000 yards. These surface and airborne systems precluded missile submarines from closing to 25 miles on the surface, and carrier-based fighter aircraft easily neutralized the capabilities of the "Bear D" radar aircraft. Thus, in spite of great potential range in submarine-launched anti-ship missiles, the nuclear-powered submarine and torpedo or short-range missile have been, until recently, the most effective combination against a first class battle fleet, and the requirement to fire from short range made stealth as important as speed.[65]

Assured Destruction

The advent of the submarine-launched ballistic missile and the deployment of these nuclear delivery systems in large numbers enabled submarines to make a significant contribution to nuclear deterrence through the strategy of assured destruction. In this case, technological developments provided new capabilities that combined with the submarine's inherent advantages at just the right time to solve an emerging strategic problem.

The emerging problem was how to maintain a secure deterrent force and thereby a low risk of nuclear war.[66] Immediately after the advent of nuclear weapons at the end of World War II, the Western powers saw American nuclear forces as a means to deter Soviet agression in Europe and prevent a major war. The Soviet Union developed its own nuclear weapons and had deployed a bomber force with intercontinental range by the end of 1956. At about this time, both superpowers were also adding thermonuclear weapons to their arsenals. The tremendous destructive power of each thermonuclear weapon and the intercontinental range of new bomber aircraft meant that from the late 1950s, each superpower could deal the other a direct and devastating blow. Thus began the age of mutual nuclear deterrence. However, the stability of this situation appeared to be threatened by the emergence of intercontinental ballistic missiles (ICBMs), which, when deployed, would give each side the capability to destroy the other's bombers on the

65. Norman Friedman, *Modern Warship Design and Development* (Greenwich: Conway Maritime Press, 1979), pp. 121–135; and Norman Friedman, *U.S. Naval Weapons* (Annapolis: Naval Institute Press, 1982), pp. 99–140, 256–269, 272–273.

66. Summaries of these developments can be found in Jerome H. Kahan, *Security in the Nuclear Age: Developing U.S. Strategic Arms Policy* (Washington, D.C.: Brookings, 1975), pp. 9–98; David Alan Rosenberg, "The Origins of Overkill: Nuclear Weapons and American Strategy, 1945–1960," *International Security*, Vol. 7, No. 4 (Spring 1983), pp. 3–71; and Lawrence Freedman, *The Evolution of Nuclear Strategy* (New York: St. Martin's, 1981), pp. 22–68, 76–90, 134–171, 227–256.

ground at their bases in a preemptive first strike. In order to avoid a strategy that would require hair-trigger response in a crisis situation, the nuclear deterrent forces had to be able to survive a nuclear attack and still strike their targets.

A strategy of assured destruction meant giving nuclear forces a second-strike capability in order to reduce the risks of nuclear war in a crisis situation. The first step was to put part of the bomber force on 15-minute ground alert, so that it could become airborne (but not necessarily proceed to its targets) upon warning of an attack. A few years after ICBMs were introduced, they were put into hardened silos, which gave them the capability to survive a first strike, a capability only recently in doubt with the deployment of many ICBMs with multiple warheads of very high accuracy.

Even before ICBMs were based in hardened silos, submarines acquired a capability for assured destruction that has remained intact in spite of many technological developments. In the United States, the Polaris program produced a submarine that carried sixteen intermediate-range (1,200 nautical miles) ballistic missiles. The first of these submarines went on patrol in late 1960. Successive models of the missile brought increases in range to 1,500 and then 2,500 nautical miles, and by 1967 the U.S. Navy had 41 Polaris ballistic missile submarines (SSBNs) in commission.[67] With two-thirds of this force at sea, there were sufficient numbers of submarines on station at all times to launch missiles against the 300 largest cities in the Soviet Union. With 27 of the 41 boats on station and some degradation for system failures, the Polaris submarine missile force alone could deliver the 400 megaton equivalents assumed necessary for unacceptable damage of Soviet industry under the McNamara definition of assured destruction.[68]

Further improvements in assured destruction capability came with the introduction of technologies that brought multiple independently targetable reentry vehicles (MIRVs) in the American Poseidon C-3 missile in 1971 and intercontinental range in the Soviet SS-N-8 missile in 1974.[69] At the same

67. Harvey M. Sapolsky, *The Polaris System Development; Bureaucratic and Programmatic Success in Government* (Cambridge: Harvard University Press, 1972); and Norman Polmar, *The Ships and Aircraft of the U.S. Fleet*, 12th ed. (Annapolis: Naval Institute Press, 1981), pp. 20–23, 336–337. Detailed data on commissionings, conversions, and first deterrent patrols of each boat are given alphabetically by ship's name in United States Navy Department, *Dictionary of American Naval Fighting Ships* (Washington: U.S. Government Printing Office, 1959–1981).

68. Alain C. Enthoven and K. Wayne Smith, *How Much is Enough? Shaping the Defense Program, 1961–1969* (New York: Harper & Row, 1971), especially pp. 174–178, 207–208; and William W. Kaufman, *The McNamara Strategy* (New York: Harper & Row, 1964).

69. The evolution of the Soviet SLBM force is described in Robert P. Berman and John C. Baker,

time, developments in ASW technology do not appear to threaten the survivability of ballistic missile submarines in the foreseeable future.[70]

The Future

Future capabilities of submarines in naval warfare will be determined by new developments in technology and ongoing trends in building programs as they change or sustain existing force structures. In the near-term future, submarines will acquire a new capability and see the decline of one existing capability and the enhancement of another.

STRATEGIC COUNTERFORCE

The high accuracy of the D-5 Trident II submarine-launched ballistic missile will bring a new capability to submarines when it is deployed in 1989 by enabling them to destroy precise, hardened targets such as missile silos.[71] If building and retrofitting schedules proceed according to current projections, the U.S. Navy will have a 20-ship force by the year 2000 and be able to maintain two-thirds of it on station. The Soviet ICBM force, if maintained in its current configuration of 1,398 fixed silo launchers, could be destroyed by the Trident force in a first strike.[72]

The capability to destroy small, hardened targets with nuclear warheads is a function of warhead yield and the accuracy of the delivery system. This kind of accuracy is becoming possible through improvements in navigation and guidance technology. Since submarine-launched ballistic missile (SLBM)

Soviet Strategic Forces: Requirements and Responses (Washington, D.C.: Brookings, 1982), pp. 55–59, 62–65, 93–96, 106–108.

70. Richard L. Garwin, "Will Strategic Submarines Be Vulnerable?," *International Security*, Vol. 8, No. 2 (Fall 1983), pp. 52–67; and Donald C. Daniel, "Antisubmarine Warfare in the Nuclear Age," *Orbis*, Vol. 28, No. 3 (Fall 1984), pp. 527–552.

71. D. Douglas Dalgleish and Larry Schweikart, "Trident and the Triad," U.S. Naval Institute *Proceedings*, Vol. 112, No. 6 (June 1986), p. 76; and Roger F. Bacon, "Strategic Employment Concepts," *The Submarine Review*, Vol. 2, No. 3 (October 1984), pp. 4–9.

72. Unclassified estimates of missile performance vary. Against a nominal Soviet ICBM silo hardened to 3,000 psi, the C-4 Trident I would have an 8 percent single shot kill probability (SSKP), assuming a 1,500-foot CEP and a yield of 100 KT for each of its warheads. The D-5 Trident II would have a 77 percent SSKP, assuming accuracy as good as a 600-foot CEP and a nominal yield of 500 KT for each warhead. If each D-5 missile carried 8 warheads in a delivery system with these hypothetical characteristics and the number of submarines on station was increased from 13 to just 15, the force would have a 94 percent chance of disabling each of the 1,398 Soviet ICBMs in its silo. Data from International Institute for Strategic Studies, *The Military Balance*, 1985–86, p. 158; Couhat and Baker, *Combat Fleets of the World*, 1986–87, pp. 593, 616; and General Electric, Defense Electronics Division, *Missile Effectiveness Calculator*, 1965.

systems deliver long-range missiles from a moving underwater platform, the launch position as a reference point for the guidance system has been less precise than for an ICBM, which is launched from a fixed silo. Early SLBM systems had accuracies of from 3,000 to 6,000 feet, circular error probable (CEP).[73] More precise submarine navigation systems and the introduction of a stellar system that takes at least one star sighting to refine the missile's trajectory in the post-boost phase reportedly reduced the CEP of the C-4 Trident I missile to 1,500 feet, in spite of an increase in range to 4,000 miles, over three times that of the Polaris A-1 of 1960.[74] Improved stellar-corrected inertial guidance in the D-5 Trident II could decrease the CEP further even with a range goal of 6,000 miles.[75]

The new capability in submarines will increase strategic targeting options, and it will mean broader nuclear warfighting capabilities. It may or may not enhance the deterrent effect of the U.S. submarine force. Deterrence can be primarily the result of better warfighting capability, but this is not necessarily the case, particularly in the realm of strategic nuclear war, where what deters is subject to debate and impossible to measure. By opening a "window of vulnerability" on the Soviet land-based ICBM force, a hard target kill capability bestowed on submarines may well undermine stable mutual deterrence between the superpowers.

Counter-ICBM capability in submarines will have profound strategic effects far beyond a better warfighting capability that may or may not mean a more effective deterrent. By giving the essentially immune SLBM force the capability to destroy an adversary's land-based ICBM force in a single first strike, we raise a more serious version of the vulnerability problem that many in the late 1970s sought to eliminate from the Minuteman force by replacing it with a mobile version of the MX. The strategic implications of deploying a highly accurate version of the D-5 SLBM will become clear when the Soviets give their own SLBM force the capability to destroy the U.S. land-based ICBM force. If land-based ICBMs are to be retained after the introduction of highly accurate SLBM systems, both superpowers will inevitably develop

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73. Circular error probable is usually based on test data indicating that 50 percent of the bombs from an aircraft delivery system or warheads from a missile delivery system will fall within a circle having the radius given as CEP.

74. Bill Gunston, *The Illustrated Encyclopedia of the World's Rockets and Missiles* (New York: Cresent, 1979), pp. 92–95; and Thomas B. Cochran, William M. Arkin, and Milton M. Hoenig, *Nuclear Weapons Databook*, Vol. 1, *U.S. Nuclear Forces and Capabilities* (Cambridge, Mass.: Ballinger, 1984), pp. 69, 74, 134–143.

75. Cochran, Arkin, and Hoenig, *Nuclear Weapons Databook*, Vol. 1, pp. 144–146.

countermeasures to make land-based missiles more survivable, and this will probably lead both sides to deploy exclusively mobile ICBM forces and ballistic missile defenses to protect them.

COMMERCE WARFARE

A second major capability being affected by developments in technology and force structures is the ability to wage commerce warfare using submarines. Current trends point to declining capability and little likelihood for a commerce warfare campaign of the magnitude experienced in World War II. In the unlikely event of future war between the superpowers, the obvious naval scenario would be a Soviet submarine campaign against Western maritime nations, which depend upon shipping to deliver essential raw materials and to move troops and military supplies. It is this scenario that will best serve to illustrate the current trend.

Most basic of several trends that make commerce warfare a thing of the past is the size of the objective: the overwhelming numbers of merchant ships operated by the Western maritime nations. The merchant marines of the Western Alliance currently number 38,000 ships totaling 183 million tons. This represents four times the shipping available at the beginning of World War II. The carrying capacity available to the Western Alliance is much greater if neutral powers are induced to keep their ships at sea. Liberia and Panama alone have 7,500 ships totaling 100 million tons, most of which is Alliance shipping registered under neutral flags of convenience.[76] The availability of neutral shipping cannot be assumed in a future war, but since it was a critical factor in the World War I submarine campaign, the Soviets cannot ignore it in their assessments of a future submarine campaign against shipping.

A second reason to question future capabilities for waging an effective commerce warfare campaign is numbers of available submarines. Sophisticated submarines cannot be built rapidly in large numbers, and the new capabilities have brought essential new missions, leaving fewer numbers to wage commerce warfare. Submarines are much more capable today than they were in the two world wars, but in commerce warfare, numbers are as important as capabilities. Even the most advanced submarine in the world can only be in one place at one time. It must expend at least one missile or torpedo to sink a ship, and with the size of today's merchant ships and past

76. Numbers of merchant ships and aggregate tonnage are given by country in Couhat and Baker, *Combat Fleets of the World*, 1986–87. Data is taken from *Lloyds Register of Shipping*, 1984.

experience as a guide, more than one weapon will be required to sink each one. After expending a typical load of 24 torpedoes, the submarine must return to base for more. Stalking targets, attacking each one, transits to and from base, reprovisioning and maintenance all take time. Therefore numbers are essential if the campaign is to have effect. To seriously threaten the survival of the maritime nations by destroying a good portion of their shipping, the experience of three campaigns in two world wars indicates that hundreds of submarines would be necessary just to start an effective campaign, and that monthly production rates would have to be in the dozens. Yet the trend today is to build ever larger and more sophisticated submarines, and as complexity has increased, force levels and building rates have declined significantly.

A projection of the makeup of Soviet submarine forces in 1995 shows serious limitations in numbers required for a commerce warfare capability if current trends continue. Not only are Soviet building rates down to about 7 or 8 boats a year compared with between 60 and 80 in the late 1950s, but the force has taken on several competing but essential missions.[77] Eliminating submarines that will be over 30 years old from the force and assuming an optimistic building rate of 10 new boats per year, the Soviet navy will have about 240 submarines in the mid-1990s. Reflecting both the current makeup of the Soviet submarine force and the most likely trends in its development, these 240 submarines will probably be assigned as follows. About 60 will be ballistic missile submarines, with a modest complement of 40 SSNs to protect them against American SSNs, although more are likely to be assigned to this mission. Another 20 submarines will probably be armed with land-attack cruise missiles, as replacements for the current theater strategic forces, such as the "Golf II" SSBs deployed in the Baltic. Countering a nominal 15 U.S. and French carrier battle groups with just 4 cruise missile submarines each would require another 60 submarines, and Soviet prudence would dictate that more be assigned to this mission.[78] Even these optimistic assumptions

77. Building rates were derived from completion dates for all Soviet submarines built since 1945. Sources are Budzbon and Friedman, *Conway's All the World's Fighting Ships 1947–1982*, Vol. 2, pp. 468, 492–499; Polmar, *Guide to the Soviet Navy*, 3rd ed., pp. 84–123; Couhat and Baker, *Combat Fleets of the World*, 1980–81, pp. 540–552; 1982–83, pp. 602–615; 1984–85, pp. 695–711; 1986–87, pp. 498–510.

78. Norman Polmar with Norman Friedman, "Their Missions and Tactics," U.S. Naval Institute *Proceedings*, Vol. 108, No. 10 (October 1982), pp. 34–44; Paul J. Murphy, ed., *Naval Power in Soviet Policy* (Washington: U.S. Government Printing Office, 1978), pp. 78–84, 112–117, 155–168; and Milan Vego, "Their SSGs/SSGNs," U.S. Naval Institute *Proceedings*, Vol. 108, No. 10 (October 1982), pp. 60–68.

leave the Soviet navy with only 60 SSN and diesel-electric boats to wage a campaign against *either* the ballistic missile submarines *or* the merchant shipping of the Western Alliance, and this takes no account of subs in each category that will be in transit to operational areas, used for training, and in the yard for refit. Given the notorious reputation Soviet submarines have for breakdowns and low availability, these last factors are significant.

In order to wage a campaign that would seriously threaten Western sea lines of communication, the Soviets would need a total of 450 to 500 submarines if the other commitments listed above are to be met as well. Regardless of the impressive achievements of the Soviet shipbuilding industry over the past two decades, there is little evidence that the Soviets will be able to produce such a force or to make good the losses they would suffer in what would be an intensive struggle.

Anti-submarine warfare has also improved significantly since World War II. Numerical strength in a submarine force is no longer sufficient. To wage a major campaign against shipping today, a submarine force needs both numbers and the best capabilities in each unit. Yet the kind of technical sophistication required to overcome advanced ASW techniques must come at the price of numbers, because again, the more sophisticated a submarine, the greater its cost in resources and manpower and the longer its building time.

There are several developments that not only enhance ASW capability but change the nature of such a campaign compared to its historical antecedents.[79] The advent of seabed sensor arrays makes barrier ASW an effective complement to localized ASW built around the convoy system. Another development, the towed sonar array, not only provides a complementary surveillance system for seabed sensors, in a slightly different configuration, it allows surface ships to acquire tactical data directly from the operating medium of the submarine, within thermal layers rather than through them. A third development is the ASW helicopter, which extends sensor coverage and represents a weapon delivery platform that moves three times as fast as any submarine. Since helicopters can easily operate from the decks of large merchantmen as well ASW escorts, future arming of merchant ships would be with helicopters, instead of deck guns as in the two world wars.

79. Joel S. Wit, "Advances in Antisubmarine Warfare," *Scientific American*, Vol. 244, No. 2 (February 1981), pp. 31–41; B.W. Lythall, "The Future of Submarine Detection," *Naval Forces*, Vol. 2, No. 2 (1981), pp. 41–49; and Norman Friedman, "The Evolution of Towed Array Sonar Systems," *Naval Forces*, Vol. 4, No. 5 (1983), pp. 76–81.

Finally, there is the problem of just how the Soviets would be able to wage a major submarine campaign against Western commerce for many months without an escalation to general nuclear war. Such a struggle is frequently postulated, but to be prolonged, the assumption must be that it could become bitter without the use of a single nuclear weapon. Setting aside political calculations on whether the West would engage in such a campaign without resort to nuclear weapons, there are at least two direct linkages between antisubmarine warfare and general nuclear war. First, Soviet dependence on radar and electronic ocean reconnaissance satellites (RORSAT and EORSAT) for submarine operations means that the Western navies would inevitably try to destroy these space platforms. However, the employment of antisatellite weapons also threatens early warning satellites that are an integral part of strategic nuclear forces. Second, aggressive ASW operations by American SSNs in the Norwegian Sea and Arctic Ocean to preempt Soviet attacks on shipping would also threaten Soviet ballistic missile submarines, an essential element of strategic nuclear forces. The sinking of Soviet SSBNs in the course of ASW operations to preempt an anti-shipping campaign could appear to be deliberate attrition of Soviet SSBNs as a preliminary step to a strategic nuclear offensive against the Soviet Union. This would provide a strong incentive for the Soviets to escalate immediately to nuclear war.[80]

Assuming the war remains conventional, the Soviets would make better use of their limited numbers of submarines by attacking troop and supply convoys attempting to reinforce NATO forces rather than waging protracted warfare against ocean commerce. But given the risks of general nuclear war, the Soviets would gain even more by attacking the channel ports with bombers and intermediate-range ballistic missiles instead.

These trends reduce the potential impact of using submarines against commerce, but they will not make it disappear. We might say that commerce warfare capability in submarines is regressing to commerce harassment. In a major war, the Soviet navy would undoubtedly send some submarines to attack military and merchant convoys as part of a general war of attrition. Given the fortunately low likelihood of war between the superpowers, a more probable scenario is a maverick Third World country using its small force of submarines to strike at its enemies, large or small, by sinking some

80. Barry R. Posen, "Inadvertent Nuclear War? Escalation and NATO's Northern Flank," *International Security*, Vol. 7, No. 2 (Fall 1982), pp. 28–54; and Desmond Ball, "Nuclear War at Sea," *International Security*, Vol. 10, No. 3 (Winter 1985–86), pp. 16–21, 22–23.

of their shipping. Both of these cases indicate the need for considerable ASW capability in Western navies. While recognizing a decline in capabilities and probabilities of a major commerce warfare campaign, Western ASW forces are essential to prevent the Soviets from having a "free ride" in a limited attrition campaign and to counter third power assaults on vital shipping, such as tanker traffic from the Persian Gulf.

DECISIVE BATTLE?

As submarine forces are losing the capability to wage commerce warfare, they are gradually gaining in the capability to engage first-line naval forces. Once able to destroy the modern equivalent of a surface battle fleet, submarines will have acquired their eighth basic capability. This represents much more than wearing down enemy naval forces through gradual attrition of ancillary, obsolescent, and independently steaming warships, and it gives submarines more combat potential than the essentially hit-and-run tactics of fleet engagement that came with the introduction of high-performance nuclear submarines in 1959. It is the advent of classical battle capability for the undersea arm of navies. It is also the integration of submarines into some kind of fleet-type targeting, command, and control system, with all of the associated tactical problems long avoided by keeping submarines dispersed and independent.

At the beginning of the 1980s, Soviet and American submarines began to be armed with anti-ship cruise missiles that could be launched from underwater and hit moving ship targets hundreds of miles away.[81] This means that they can hide in hundreds of thousands of cubic miles of ocean until the instant of weapon launch. Many of the requisite technologies are common to the new generation of compact, land-attack cruise missiles recently coming to maturity. As more submarines are armed with long-range, anti-ship missiles, they will acquire the ordnance delivery capability to destroy a large combat formation of surface warships.

However, against maneuvering targets, the added capability of real-time tactical reconnaissance and targeting information is essential. In this respect, the new generation of cruise missile submarines will be subject to the capa-

81. Michael MccGwire, "The Tomahawk and General Purpose Naval Forces," in Betts, *Cruise Missiles*, pp. 231–247; and John Jordan, "'Oscar': A Change in Soviet Naval Policy," *Jane's Defence Weekly*, May 24, 1986, pp. 942–947.

bility/vulnerability paradox.[82] The obvious platforms for the required sensors are aircraft and low-orbit satellites. Both are vulnerable to attack by any fleet with modern carrier-based aircraft. A high-performance fighter with a small anti-satellite (ASAT) missile has been shown to be effective, making ocean reconnaissance satellites probably more vulnerable to carriers than carriers are to weapons systems served by these satellites.[83] Aircraft can also provide target acquisition and tracking data, but surveillance aircraft are defenseless against carrier-based fighters. If the reconnaissance and targeting aircraft are protected by fighters, then we have come full circle to the requirement for carriers to counter carriers, and submarines are just one part of an integrated battle situation. Thus, although the submarines themselves will be extremely difficult to counter with fleet ASW defenses at missile launch range, they must have outside support, not only from tactical reconnaissance platforms but also for the protection of those platforms. At least for the anti-warship mission, it appears that as submarines move closer to the capability for decisive battle, they will also have to become more integrated with and dependent upon fleet surface and air units.

Conclusions

After 125 years of technical experimentation, submarines joined the navies of the world as warships, and in the next 60 years they evolved from unimportant ancillary craft into a central element of national security. A rapid synthesis of technologies during the last decade before World War I gave submarines the basic capabilities of coast defense, naval attrition, and commerce warfare. There followed three decades of sustained equilibrium in submarine technology and basic capabilities. World War II brought the first and only successful submarine campaign against merchant shipping and precipitated many new technical developments. Another period of relatively rapid technological synthesis gave submarines three more basic capabilities between 1957 and 1967: projection ashore, fleet engagement, and assured

82. Norman Friedman, "C^3 War at Sea," U.S. Naval Institute *Proceedings*, Vol. 103, No. 5 (May 1977), pp. 124–141; and R.B. Laning, "Air Support for Submarine War," *The Submarine Review*, Vol. 3, No. 3 (October 1985), pp. 77–81.

83. "Defense Dept. Readies Asat Weapon for Third Test Firing in Space," *Aviation Week & Space Technology*, September 2, 1985, pp. 20–21; and "Defense Dept. Plans Next Test Firing of Air-Launched Asat System," *Aviation Week and Space Technology*, September 23, 1985, pp. 20–21. The effectiveness of satellite ocean surveillance is also probably overestimated. See Frank Cranston, "USN Carrier 'Disappeared' for Two Weeks," *Jane's Defence Weekly*, July 26, 1986, p. 112.

destruction. The near-term future will bring a seventh new capability, strategic counterforce. It will continue a decline in the capability to wage major commerce warfare campaigns, and it will enhance the submarine's new capability to engage and destroy first-line fleet units. Decisive battle therefore could possibly become an eighth major capability for submarines in coming years.

Both the successes and the problems of submarines are directly related to their separateness. Their effectiveness as a weapon platform and their survival in the face of countermeasures depend upon operating in a separate medium, and their most effective employment, whether as a means of naval attrition, a commerce destroyer, or a nuclear deterrent, has been while operating essentially in isolation from surface forces. Although naval establishments persist in their attempts to combine the roles and missions of submarines with those of the surface fleet, submarines have had no need to integrate. For their entire history, they have operated best in parallel to but separate from the surface fleet. The most bothersome aspect of this separateness is that it seems to challenge the basic tenets of Anglo–American naval doctrine, because the most successful submarine strategies do not conform to the classical model of naval warfare.

None of this need represent the challenge to established doctrine that is often assumed by proponents and opponents alike. In adding a new operating medium, new modes of operation, and new strategic concepts, submarines are not an alternative but an addition to the more traditional instruments of naval power. If submarine strategies and force structures are developed in this context, they can contribute even more effectively to the exercise of naval power in the future.