

The Third Battle

Innovation in the U.S. Navy's Silent Cold War Struggle
with Soviet Submarines

Owen R. Cote, Jr.
Associate Director, MIT Security Studies Program

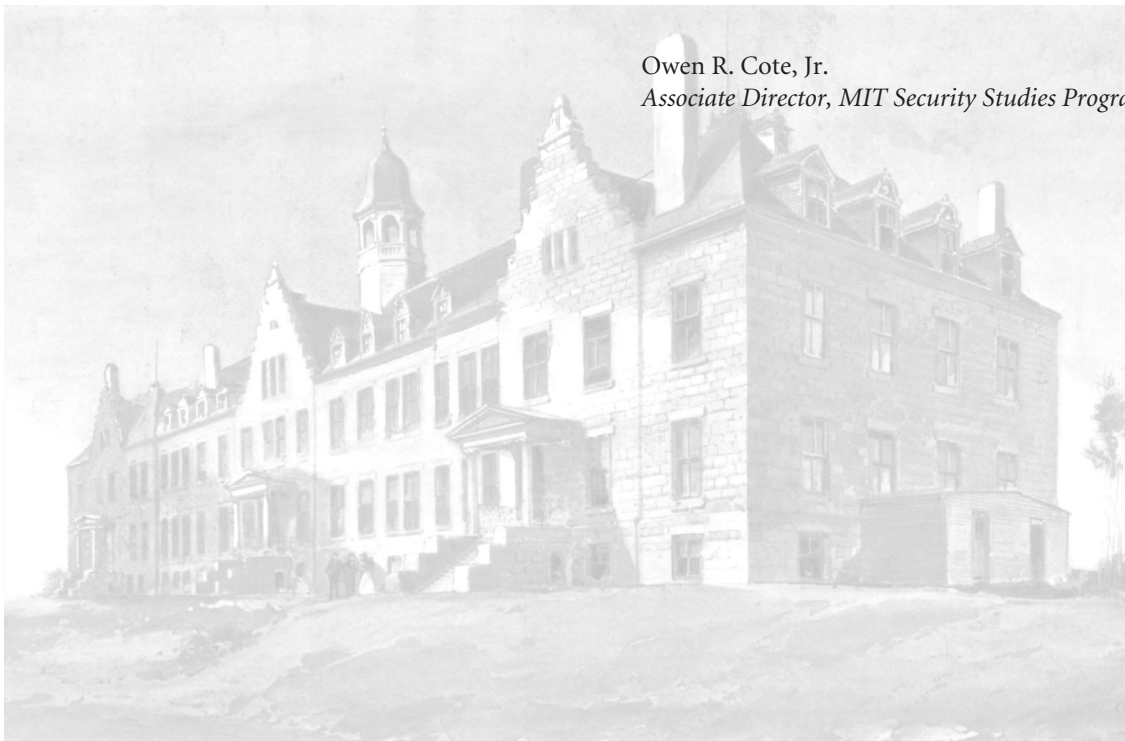
An aerial, sepia-toned photograph of a coastal city and harbor. The city features a prominent grid street pattern. The harbor is filled with numerous ships and boats. The surrounding landscape is hilly and green, with some buildings visible on the slopes. The sky is overcast with soft clouds.

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Foreword

We are pleased to launch the newly designed Newport Papers series with an intriguing case study, *The Third Battle*, by Owen Cote. In a manuscript developed under the editorial leadership of Dr. Thomas B. Grasse, then Press editor, Dr. Cote argues that the U.S. Navy's innovative response to the Soviet submarine fleet during the Cold War represents the third great battle for control of the seas in the 20th century. Technology was always the key factor in the continuing seesaw peacetime race between the two superpowers.

Dr. Cote, Associate Director of the Security Studies Program at the Massachusetts Institute of Technology, provides a critical groundbreaking perspective on this battle—quite different from the two that preceded it. During the two world wars, the then new and revolutionary submarine threatened the ability of the major naval powers to gain decisive control of the sea. In peacetime, the Allied powers were unable, or perhaps ultimately basically reluctant, to prepare innovative and effective measures to counter submarine use. In war, they then faced unrestricted submarine warfare and the attendant significant losses. Those antisubmarine measures that were eventually developed were short-lived because of the close technological arms race between the combatants. It was only with the development in the mid-1980s of truly quiet Soviet nuclear submarines that the U.S. Navy decisively confronted the antisubmarine warfare challenge. Cote details the events leading to that point and presents a critical study of technological innovation with clear implications for challenges in the 21st century.

This latest Newport Paper, the sixteenth in the generic series established in 1991, reflects the talents of the many who worked toward its production. David Chapman of Chapman and Partners, Warren, Rhode Island, is responsible for the overall design; the creative searching of Elizabeth Davis led to the discovery of the Newport map that will be the series' signature cover. Patricia Goodrich edited the manuscript with grace and style, under the thoughtful eye of Pelham Boyer, Managing Editor.

In the next several months, two additional Newport papers will be published. We welcome comments, suggestions, and proposals for this relaunched series

CATHERINE McARDLE KELLEHER
Editor, Naval War College Press
Newport, Rhode Island

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I would like to thank Vice Admiral John Grossenbacher for sponsoring this project and Admiral Richard Mies, Vice Admiral Ed Giambastiani, John Schuster, and Captain Karl Hasslinger for their support in getting it started. The Johns Hopkins Applied Physics Laboratory provided the administrative home for the project, and I thank Ernie Holmboe, Bill LaPlante, and Geoff Wilson of that organization for their support. I would also like to thank Admiral Henry Chiles (retired), Vice Admiral James Fitzgerald (retired), Rear Admiral Dan Wolkensdorfer (retired), Rear Admiral Jerry Holland (retired), and Commander Michael Poirier for reading and providing extensive comments on drafts of this paper. I am also indebted to the following for providing interviews or valuable source material: Harvey Sapolsky, Tim Wolters, Greg Koblentz, Ande Smith, Admiral Frank Bowman, Admiral Bruce Demars (retired), Admiral Carlisle Trost (retired), Vice Admiral Albert Baciocco (retired), Rear Admiral Richard Pittenger (retired), Rear Admiral John Morgan, Captain Jerry Ferguson, Paris Genalis, Commander Jamie Foggo, Frank Andrews, Ed Dalrymple, Fred Milford, Thaddeus Bell, Thomas Maloney, Juergen Keil, Dick Nadolink, Jeff Cohen, Bernie Myer, Hal Hultgreen, Dick Bonin, Colleen Leonardo, Bruce Rule, John Hanley, Dick Chapman, Greg Duckworth, Ted Wile, Captain Dave Schubert, Jan Breemer, John Brandes, Robert Frosch, and Commander Randy Craig. Finally, I thank my two assistants, Kristen Cashin and Harlene Miller.

Introduction

Since the beginning of the twentieth century, submarines have been the weapon of choice for weaker naval powers that wish to contest a dominant power's control of the seas or its ability to project power ashore from the sea. This is because submarines have been and are likely to remain the weapon system with the highest leverage in a battle for control of the ocean surface. Hence, antisubmarine warfare (ASW) will always remain the most important element of the U.S. Navy's core mission—sea control.

Since the middle of the twentieth century, submarines have also become a weapon of the strong, both because they became a major if not the dominant platform for performing ASW, and because they also became a dominant means of projecting power from the sea, first as a nuclear delivery platform, and now, at the end of the century, as a conventional precision strike platform.

For the U.S. Navy, maintaining superiority in ASW and maximizing its ability to project power from the sea will require innovative contributions by each of its platform communities in new mission areas, as it did during the Cold War. It is likely that the sources of victory in these future endeavors will be similar to those that gave the Navy a great victory in the Third Battle.

This paper seeks to establish the record of naval innovation in ASW during the Cold War so that an analysis of the sources of that innovation can proceed. It looks specifically at how ASW was conducted over time and at how the roles of the Navy's different platform communities changed over time. At the heart of this story is the transformation of the U.S. submarine force into the main ASW weapon in the struggle against Soviet submarines. The lessons of this transformation should be relevant to the task of meeting future ASW challenges, and they can serve as a guide to the submarine force and the Navy's other platform communities as they face demands to adopt new missions.

In two world wars, control of the sea by the major naval powers was threatened by the submarine. This resulted both from the inherent capabilities of a revolutionary new weapon of war, the submarine, and the inability or the reluctance of the major naval powers to anticipate this threat and prepare innovative and effective antisubmarine

measures during peacetime to counter it. When first faced with unrestricted submarine warfare, Britain in World War I, and Britain, the United States, and Japan in World War II all suffered grievous losses, especially to their merchant marines, which were to varying degrees their economic lifelines as well as their means of deploying military forces to distant shores. In two successive battles of the Atlantic against German submarines, the Allies eventually reestablished sea control after enormous effort, while in the Pacific during World War II, the Japanese never effectively countered American submarines, lost control of vital sea lines of communication, and were economically and strategically strangled as a result. Furthermore, the victory of antisubmarine over submarine forces in the Second Battle of the Atlantic proved short-lived, as the end of World War II saw the deployment of new German U-boats which largely returned to the submarine its recently lost advantages over antisubmarine forces. As the Cold War began, the Soviet Navy adopted these new submarine technologies and the U.S. Navy faced the task of developing an effective response to a new submarine challenge in peacetime.

The U.S. Navy's global Cold War ASW effort therefore constituted the third great battle for control of the seas against the submarine, albeit one that remained a peacetime effort. Prior experience predicted that this battle would not go well for the United States. For example, Great Britain's record of peacetime preparation and innovation in ASW before the two World Wars had not been a good one. Moreover, other new technologies spawned by the World War II mobilization, such as missiles and nuclear energy, promised both to tilt the balance between the submarine and ASW forces further in favor of the former and to increase the vulnerabilities that would result from ASW failure. For example, nuclear-powered submarines would be much more difficult to counter by ASW forces, and ballistic and cruise missiles would give submarines potent new offensive capabilities, allowing them to expand beyond commerce raiding into new mission areas.

This paper shows that the U.S. Navy's response over time to the threat posed by the Soviet submarine fleet during the Cold War was extremely innovative. The Navy kept its ASW posture responsive during the Third Battle to a series of peacetime challenges by the Soviet submarine force, including their first deployments of diesel submarines based on the German Type XXI, the first ballistic and cruise missile submarines, and then several generations of nuclear-powered submarines of all types. This edge remained largely intact through the mid-1980s, when the first truly quiet Soviet nuclear submarines were finally deployed, giving the end of the Third Battle the same "saved by the bell" character as the end of the Second Battle of the Atlantic. In its aftermath, the Navy once again found itself facing serious new ASW challenges, and the submarine force found itself looking for new missions.

In sketching an outline of the course of the Third Battle, this paper focuses on the technical and doctrinal innovations whose exploitation allowed the Navy to deal with successive generations of the Soviet undersea threat. It is part of a larger project that seeks the best explanation for why and how the Navy was able to maintain this record of innovation in a specific warfare area over so long a period in peacetime.¹ Better knowledge of the sources of innovation in peacetime is important in today's security environment. In some respects, this security environment resembles that which the Navy as well as the other services faced after World War II and before Korea, and it was in this period that the seeds of victory in the Third Battle were sown. A formidable foe had been defeated and a new peer competitor against which to plan had yet to clearly emerge. There are both interservice and intraservice debates about which missions to emphasize and about which platforms can best perform them. The pace of development in certain commercial technologies relevant to the military is accelerating with largely unpredictable consequences. And though the war on terrorism has led to increases in the defense budget, the long-term prospects for high levels of defense spending remain uncertain. Under these circumstances, many elements of the U.S. military's Cold War structure appear threatened with obsolescence and are struggling to adapt to the demands of the new security environment, and in many cases, success in this struggle will demand fairly radical innovation.

This paper is organized into six sections corresponding to distinct phases in the century-long battle between the submarine and its opponents. The first section provides a historical overview from the initial development of the modern submarine in 1900 through to the end of World War II. This is followed by a section on each of four phases of the Third Battle: meeting the challenge posed by Soviet adaptation of German Type XXI diesel submarines immediately after World War II; meeting the challenge posed by nuclear submarines and nuclear weapons; meeting the challenge of preserving an ASW barrier strategy based on a passive acoustic advantage; and meeting the challenge of passive acoustic parity. For each stage in this forty-year Cold War struggle, the paper describes the new demands placed by the Soviet submarine fleet on the U.S. Navy's ASW posture and the steps taken or not taken to meet those demands. Finally, the paper closes with a discussion of the current situation in ASW, with a focus on the dual challenge posed by the end of the Cold War and the wide availability of modern, non-nuclear submarines. Inevitably, this structure will give the reader a sense of cause and effect, with a Soviet challenge seeming to directly cause an American response; but the intent of the paper is only to describe what happened when, not to explain the sources of the behavior being discussed. Only when the record of the Third Battle is established with some clarity can the task of explaining it begin.

The rationale used for distinguishing successive phases of the submarine threat combines two elements. One is the evolution of submarine design, and the other is the evolution of its weapons and missions. The first element is what largely determines the operational and technical demands on antisubmarine forces, while the second largely determines the importance of ASW as a mission. Together with the maritime geography in which conflict occurs or is contemplated, they determine the ebb and flow of the balance between the submarine and its foes, and particularly those points in time when it is both most important and most difficult for a maritime power to gain and maintain control of the undersea battle space.

From *Holland* to the Second Battle The First Fifty Years

The first modern submarine was the *Holland*, which the U.S. Navy adopted in 1900, and the design for which was sold to other naval powers of the day. It was the harbinger of one of the two great naval innovations of the first half of the twentieth century, the other being the aircraft. In reference to this revolution, Bernard Brodie wrote in 1941:

The torpedo, the mine, and the submarine may be considered together because they have had a common origin and a closely associated development. . . . Closely related in function, these instruments comprise a distinct kind of naval warfare, one in which the attack, during some phase of its delivery, takes place beneath the surface of the sea. . . . By adopting these instruments, naval warfare entered a new dimension measured in fathoms of depth. The water which had previously only supported the vessels engaged in battle now became a medium for their concealment and for the transmission of their most powerful thrusts.²

By submerging, submarines became invisible, allowing them to approach the most powerful surface ship and deliver a torpedo, a weapon which outflanked the armor provided as protection against gunfire, striking a ship below its waterline where it was most vulnerable, allowing the smallest submarine to sink the largest battleship. This combination of stealth and offensive punch has from the beginning been the defining characteristic of the submarine.

The *Holland* is usually described as the first modern submarine because it was the first design in which an internal combustion engine for surfaced operation was combined with a battery-powered electric motor for submerged operation. Prior to this development, submarines either combined steam plants with batteries or relied on batteries alone. The former suffered from the tremendous heat generated by a steam plant in a small platform like a submarine, while the latter provided only very limited range and endurance. Submarines like the *Holland* were deployed by the major powers in the years before World War I with an eye toward two missions: coastal defense and fleet cooperation. As a coastal defense asset, submarines would greatly extend heretofore gun-based coastal defenses that were centered on major ports. Together with mines, submarines would therefore make close blockade of an enemy coast impossible,

regardless of the imbalance in traditional naval forces. By forcing the dominant navy away from the weaker adversary's coast, the submarine helped create a sanctuary for coastwise shipping and, more important in contemporary minds, the opportunity for blockade running by both merchant shipping and commerce-raiding cruisers.

World War I and the First Battle

Submarines were also conceived as a new arm of the battle fleet, an instrument that would operate in reasonably close concert with battleships. Again, in most schemes, the submarine would aid the lesser battle line, which in fleeing from its stronger opponent might lure the latter over a squadron of waiting submarines. Neither mission had the effect anticipated for it in World War I. Submarines and mines did succeed in making close blockade impossible, but distant blockade, depending increasingly on airborne scouting platforms and communications intelligence, proved almost equally effective. Thus, the Royal Navy was still able to effectively bottle up the German High Seas Fleet throughout World War I. Battle fleet cooperation also proved difficult because submarines had trouble keeping up with the battle line, and even when they did, coordination in battle was impossible to ensure with any certainty. Instead, the major role played by the submarine in World War I was as an independent commerce raider, a role which no major naval power had seriously anticipated.

The Germans started World War I with only twenty-four U-boats. Their campaign against Allied shipping did not begin until early 1915, and after several starts and stops, unrestricted submarine warfare did not begin until February 1917. Over the next year, the Allies lost more than 5.5 million tons of merchant shipping, a loss rate that substantially exceeded new construction.³ The U-boat threat was brought under control during the last year of the war, primarily through the implementation by the Royal Navy of escorted convoys, a measure that it had initially resisted. Convoying greatly complicated the open-ocean search problem for German submarines, because a group of ships was not much more likely to be found than a single ship, while escorts reduced the damage that submarines could cause when they did succeed in finding ships to attack. It is important to note that escorts were much less effective at actually destroying submarines than they were at limiting their effectiveness by forcing them to submerge after their initial attack, which generally allowed the rest of the convoy to escape.

The Allies, and particularly the Royal Navy, were unprepared for unrestricted submarine warfare by German U-boats for three reasons. First, submarines did not become capable of truly independent, long-range ocean patrols until their gasoline engines were replaced by diesels, which gave them much longer range and the ability to keep up with merchant ships while operating on the surface. Diesels were adopted by the major

navies only in the years between 1907 and 1912 and were not widely deployed until the war had already started.⁴

Second, international law barred unrestricted attacks in wartime against merchant ships that were not carrying war-related cargoes. In order to comply with the law, all warships, including submarines, had to first board and search a vessel and determine its cargo, and then allow its crew to safely disembark before attacking. Clearly these rules greatly hampered the submarine, and they were routinely violated by the Germans in operations near British waters aimed specifically at British ships even before unrestricted operations came into full swing. But these so-called “prize rules” remained largely in effect in operations against neutral shipping between 1914 and 1917, which gave the British access to the merchant fleets of powerful maritime countries like the United States. As long as these rules remained intact, it would be impossible for the Germans to blockade Britain, but their abandonment would bring the United States and other powers into the war. Thus, it was not unreasonable to expect the prize rules to remain in effect, as indeed they did for more than half the war.

Third, once unrestricted submarine warfare was instituted, the British were initially unprepared to take the steps necessary to counter it. An ASW strategy based on escorted convoys was a brute force method that reduced the efficiency of already strained merchant fleets by keeping them idle until convoys could be formed, and which produced demands for escorts out of all proportion to the growing number of enemy submarines. In the latter respect, the demand for convoy escorts competed with the demand for fleet escorts, which were still needed by the British Grand Fleet because the German High Seas Fleet remained in being.

In practice, the British were able to counter Germany’s resort to unrestricted submarine warfare only with the help of the Americans, who provided them with additional convoy escorts and merchant shipping, and who, with Britain, successfully pressured the large merchant fleets of countries that remained neutral to continue operation even after the prize rules were abandoned. Thus, Germany’s unrestricted submarine warfare campaign failed both because it brought the Americans into the war and because it failed to knock other neutral merchant fleets out of the war. Therefore, in an important sense, the political effects of the campaign negated its military effects, because Britain probably would not have survived the First Battle of the Atlantic if the Royal Navy and the British merchant marine had continued to face the U-boats on their own. As Arthur Hezlet has noted, “The defeat of the U-boats was not because the *guerre de course* (independent commerce raiding) could not by its nature be decisive: it was because the Allies were able to be strong everywhere and make a gigantic effort.”⁵

ASW in the Interwar Period

The submarines that fought World War I were surface ships which were expected to submerge only in order to attack and escape better-armed surface targets, but which also lost a considerable portion of their mobility and situational awareness when submerged and, therefore, much of their potential offensive power. This characteristic was of course based largely on technical constraints, but it was also a function of expectations about their primary mission, which was assumed in most cases to be coastal defense or fleet cooperation, both of which contemplated attacks against major naval assets, against which surface engagements were suicidal.

The German campaign against Allied merchant shipping demonstrated instead that attacks against merchant ships could be most effectively prosecuted at night, on the surface, at relatively close range, even in the face of escorts. The challenge was to maximize the effects of these attacks, escape the escorts alerted by these attacks, and reengage. Defined in this way, the operational demands placed on the “submersible” submarine were less in conflict with its basic technical limitations than when the challenge was to attack powerful naval vessels, as in the coastal defense or fleet cooperation missions. This lesson drove the German submarine force toward the operational and tactical methods it employed in its World War II *guerre de course*, which emphasized night surface attacks by groups of submarines which would pursue individual convoys and repeatedly attack them over a period of a week or two.

These “wolf pack” tactics were pioneered by German Nazi Admiral Karl Doenitz during the interwar years. Wolf pack tactics did not demand a radically new type of submarine, and German interwar submarine designs were evolutionary, emphasizing longer range and endurance and larger torpedo salvos and magazines. The most important technical development that made wolf packs possible was the maturation of high frequency (HF) radio as a command and control mechanism. HF radio provided over-the-horizon performance from a relatively small, low-powered transmitter, and allowed deployed submarines to report convoy sightings to a central command post, which could then broadcast this information to all other submarines in that broad ocean area, allowing them to marshal for a concentrated attack by a dozen or so submarines. Using night surface attacks, these wolf packs would strike the convoy simultaneously, from multiple azimuths, with multiple torpedo salvos, and then slip away. Many such attacks would be conducted over the course of several days, with the wolf pack using the daylight hours to separate from the convoy and race ahead of it on the surface to get into firing position for the following night.

The Royal Navy focused its interwar ASW development efforts on solving the World War I problem, which was to protect convoys from lone German U-boats. The heart of

the solution embraced was the first active sonar, originally called ASDIC after Allied Submarine Detection Investigation Committee. During World War I, hydrophones had been used by escorts to listen for submerged submarines. Sound traveled well underwater, and submarines could often be heard at ranges of several miles, but in order to use such passive sonar, escorts had to come to a complete stop to prevent their own noise from drowning out the submarine signal. Furthermore, under even the best of circumstances, passive sonar gave only a bearing to the target, not the range. Active sonar addressed both these problems and, combined with depth charges, appeared to give the convoy escort a killing capability against submerged submarines that it had lacked during World War I.

ASDIC produced confidence in the Royal Navy that it would be able to find submerged submarines and either prevent them from attacking convoys or, at a minimum, kill them after they did. This was ironic given that the German U-boat arm was preparing for a second battle of the Atlantic that would largely occur on the surface, where ASDIC would be irrelevant. The two opponents were preparing for quite different battles, but the consequences for the Royal Navy did not become immediately apparent until a year or two into World War II.

World War II and the Second Battle

The war began as World War I had ended, with the Germans waging essentially unrestricted submarine warfare, and the British convoying in response. But the intensity of the Second Battle was mitigated by the relatively low numbers of combatants available to both sides and by the competing operational demands placed on these forces.

The German U-boat arm began the war with fifty-seven submarines, only twenty-seven of which were oceangoing Type VIIs or IXs. With such a small force, wolf pack tactics were impractical, and their full implementation awaited delivery of the large number of submarines begun immediately before the war. Likewise, the Royal Navy again began the war with a shortage of escorts, and these shortages were exacerbated by losses in the Norwegian campaign and off Dunkirk in the spring and summer of 1940 as well as by the need to retain an anti-invasion force in being on the Channel Coast. This initially limited the area of convoy coverage to waters east of 15 degrees W.

Between June and October 1940, in the first real battles with German U-boats, the British lost 1.4 million tons of merchant shipping. These losses were alarming for several reasons, the most important being the fact that 30 percent of these losses were incurred by ships in convoy. With a still small force, the Germans were demonstrating that ASDIC-equipped convoys were not effective, even against individual submarines attacking on the surface at night. Matters quickly got much worse, as the U-boat force increased

in numbers, allowing it to implement its wolf pack tactics in 1941, and as it gained access in 1940 to French and Norwegian bases much closer to Allied shipping lanes. Moreover, the expedient of simply increasing production of escorts so that all merchant ships could be convoyed would no longer serve as a counter to German U-boats as it had in World War I. Thus, even though Canadian participation gave convoys continuous surface escorts all the way across the Atlantic starting in May 1941, losses continued at a rate sufficient to exceed new merchant ship production.

The outcome of these initial battles between ASDIC-equipped convoy escorts and U-boat wolf packs demonstrated that the Kriegsmarine had “won” the peacetime battle over doctrine for the Second Battle of the Atlantic during the interwar period. Fortunately, German submarines were not available in sufficient numbers at the outset of the war to execute their doctrine. The wartime victory of the Allies in the Second Battle resulted from ASW measures taken to counter the wolf packs after the war began. These measures turned the tide in the spring and summer of 1943, and the U-boat menace remained under control until the end of the war. The key to victory in the Second Battle was the introduction, beginning in 1942, of the radar-equipped ASW patrol aircraft. Just as in World War I, where shipping losses plummeted once all merchant shipping was organized into convoys with effective surface escorts, Allied shipping losses in World War II declined sharply once all convoys were provided effective surface and air escorts.

The necessity for effective air escorts became clear soon after the war began, when it became apparent that the German U-boat arm had adopted anti-convoy tactics that emphasized surface operations. Meeting this demand required both technical innovation and, perhaps more important, a commitment by political leaders to a strategy that emphasized both the European theater and the primacy of the battle for control of the Atlantic within that theater.

Technically, the success of air ASW in the Second Battle resulted from the marriage of microwave radar with very long-range bombardment aircraft. Radar allowed aircraft to detect surfaced submarines at ranges of twenty to thirty miles, and very long-range aircraft eliminated the gaps in air coverage over the Atlantic that existed during the first three years of the war. Air ASW patrols greatly expanded the radius around a convoy in which it was dangerous for a U-boat to surface, and it was the ability of U-boats to operate on the surface near convoys that was the basis for the wolf pack tactic. Forced to submerge, the U-boat lost much of its tactical mobility as well as its ability to communicate, and therefore lost much of its offensive punch as well.

Despite these advantages, it was still a struggle to close the air ASW gaps over the Atlantic because radar-equipped, long-range aircraft were also the means of prosecuting the strategic bombardment campaign, which was the core mission of both the Royal

Air Force and the U.S. Army Air Forces, the services which owned the very long-range aircraft in question, and because strategic bombardment was viewed by American, British, and Soviet political leaders as the only significant means of engaging in offensive operations against Germany in the West prior to the planned invasion of France. By the spring of 1943 the main Atlantic air gap was finally closed, primarily by radar-equipped B-24 Liberators flying out of Newfoundland, Iceland, and Northern Ireland.⁶

The central importance of closing the air gap should not be allowed to obscure the other almost equally important factors which influenced the outcome of the Second Battle. These can be broadly lumped into two general categories: the development of ocean-wide operational intelligence systems for ASW and the mobilization of civilian scientific and technical expertise in support of the overall ASW effort. The first development encompasses the broad area of electronic and communications intelligence (HF/DF and Ultra), its fusion ashore with other information in order to produce an up-to-date, ocean-wide picture of German U-boat operations, and the timely use of this information both as a means to redirect convoys away from wolf packs, and later as a mechanism for cueing offensive ASW assets against U-boats.

Wolf pack tactics depended on the central coordination of U-boat operations from a shore-based command center, and therefore entailed extensive two-way radio communications between deployed U-boats and headquarters. These transmissions could be located using shore and later sea-based direction-finding nets, thereby providing the rough locations of deployed U-boats, and the messages could themselves be decrypted using Ultra, intermittently, for the first three and a half years of the war and continuously thereafter. During the first three years of the war, the Germans were also intermittently reading messages concerning Allied convoy operations, but the British discovered this weakness at about the same point when it permanently solved the problem of decrypting German naval Enigma transmissions. By contrast, the Germans never accepted that their codes had been broken and never fully comprehended the degree to which radio transmissions by their submarines were exploited by Allied HF/DF nets.⁷

In addition to playing an important role in the establishment and operation of this operational intelligence system, mobilized civilian scientific and technological expertise also made two additional contributions to the Second Battle. It led to the panoply of increasingly sophisticated ASW weapons and tactical sensors that were developed and deployed after the war began, and the use of operations analysis as a tool for optimizing tactics and operations and for anticipating the effects of countermeasures.

Regarding weapon and sensor development, many of the tools of the Third Battle were born or first exploited by the Allies in the crucible of the early years of World War II, including obviously microwave radar, but also acoustic homing torpedoes such as the

air-delivered Mk. 24 “Mine,” magnetic anomaly detectors (MAD), sonobuoys, and ship-board HF/DF antennas. Operations analysis was a potent tool for combining and optimizing the effects of the complex combinations of platforms, sensors, and weapons at both the tactical and operational levels made possible by this technological cornucopia. In both cases, new weapons and new, more rigorous ways of analyzing their effects were key instruments in the prosecution of high technology warfare of which the Second Battle of the Atlantic was one of the harbingers, along with the strategic air war over Europe.

But victory by Allied ASW forces in the Second Battle masked the growing imbalance favoring the submarine over ASW forces that hunted it. In World War II, the Allied ASW effort necessary to defeat the U-boat was even more disproportionate to the size of the submarine threat than it was in World War I. At its peak in 1917, the German U-boat arm had 140 submarines in service, and they faced almost 200 operational Allied surface convoy escorts. In World War II, the peak number of U-boats operational was 240 in March 1943, and this force faced in the Royal Navy alone approximately 875 ASDIC-equipped escorts, 41 escort carriers, and 300 Coastal Command patrol aircraft.⁸ The price of sea control was growing substantially faster than the price of contesting it, and the growing asymmetry manifest in the aforementioned numbers ignored the fact that in technical terms a great leap forward in German submarine capabilities came just too late to affect the Second Battle.

Phase I of the Third Battle

The German Type XXI and the Early Cold War, 1945–1950

The Cold War ASW battle between the United States and the Soviet Union can be divided for our purposes into four stages, corresponding roughly to four major steps forward in Soviet submarine design. These major steps were their adaptation of the German Type XXI diesel-electric, their first nuclear-powered submarine, their first high-performance nuclear submarine, and their first very quiet nuclear submarine. Concurrent with these submarine design developments were a series of both real and anticipated submarine weapon developments, including the first introduction of nuclear weapons, their deployment on submarine-launched ballistic and cruise missiles for land attack, the development of first nuclear and then conventional antishipping missiles, and the development of long-range nuclear ballistic missiles. Finally, the Third Battle was constrained by a relatively constant maritime and political geography that also played an important role.

Each phase in the evolution of Soviet submarine capabilities created a new challenge for American ASW forces, and the next four sections briefly assess how well each such challenge was met, focusing on identifying innovations in technology and doctrine for ASW when they occurred.

The Second Battle ended as the Germans were deploying a new type of submarine designed to counter the ASW techniques used by the Allies to defeat their wolf packs operating on the surface. Known as the Type XXI, it combined three design changes to enable a radically new operational approach focused on submerged operations. These changes were greater battery capacity, a hull form more hydrodynamically suited to high underwater speed, and a snorkel allowing the main diesel engine to breathe from periscope depth.

The Type XXI undermined each element of the Allied ASW posture that won the Second Battle. The snorkel, which had a much lower radar cross section than a surfaced submarine, gave the submarine back its tactical mobility. That is, it could once again

move at speed on its main engine for great distances without molestation by air ASW forces. A more hydrodynamic hull and greater battery power allowed a completely submerged submarine to go faster for longer than before, allowing it to escape prosecution by sonar-equipped convoy escorts once it had revealed its position by attacking.

At the operational level, Type XXIIs deployed in sufficient numbers to blanket the North Atlantic shipping lanes would minimize the need for shore-based command and control, and, to the extent that two-way communications between deployed submarines and headquarters remained necessary, they could be executed using the new “kurier” burst transmission technology introduced by the Germans at the end of World War II. Burst transmissions compress HF signals enough to make it difficult to DF them. Combined with the likely absence of a code-breaking triumph, such as Ultra, a future battle of the Atlantic would therefore be prosecuted without much of the operational intelligence of opposing submarine operations that the Allies enjoyed in the Second Battle.

Type XXIIs had fallen into American, British, and Soviet hands after World War II, and the U.S. Navy rapidly discovered that it would face a major ASW challenge were the Soviet Navy to build large numbers of ocean-going Type XXIIs. In anticipation of this threat, Chief of Naval Operations Admiral Chester W. Nimitz identified ASW as equal in importance to dealing with the threat of atomic attack.⁹ The resulting ASW response to the fast snorkel threat initially unfolded in two basic directions: an evolutionary path that sought to repair the ASW team that won the Second Battle and a more revolutionary path that aspired to replace it.

The evolutionary response to the fast snorkel boat emphasized at the technical level better radars for air ASW assets, better active sonars for surface escorts, and better weapons for both, along with a tightly integrated tactical approach that sought to exploit the strengths and compensate for the weaknesses of each ASW platform. This approach took advantage of the fact that a snorkel boat still was not a true submarine in that it remained at least partially wedded to the surface, albeit in a fashion that greatly reduced its vulnerability.

The more revolutionary response introduced both a new sensor and a new platform into the ASW equation. The new sensor was the passive acoustic array, and the new platform was the ASW submarine, or SSK. American passive acoustic array development grew out of earlier German developments, in this case the GHG array first used on a limited basis as a torpedo-self-defense sensor on German surface ships, and later adapted for use by Type XXIIs as a means of tracking and targeting surface ships for torpedo attack while submerged. Fortuitously, the U.S. Navy discovered in early post-war exercises that submarines were quite loud when snorkeling. Compared to a surface ship, a snorkeling sub put all of its machinery noise into the water because it was

submerged, and if it was to make best progress during transits to and from its operating areas or keep up with a fast convoy, it needed to operate at speeds well past the onset of propeller cavitation at such shallow depths. For both reasons, it was an excellent target for a quiet platform deploying a large, low-frequency passive array.

The submarine, in turn, was ideal as such a platform for two reasons, one technical and one strategic. On battery, essentially hovering in place, a submarine introduced the least possible self-noise into the passive array, thereby maximizing the signal-to-noise ratio and therefore the detection range. Direct path detection ranges against snorkelers of 10–15 miles were achieved in this manner in exercises by essentially unmodified World War II fleet boats in the late 1940s. Equally important, the submarine's inherent stealth, combined with the maritime geography of the emerging Cold War, made it particularly suited for forward operations in the somewhat constricted waters through which Soviet submarines had to proceed with some dispatch in order both to gain access to the North Atlantic and to do so with transit times short enough to give reasonable endurance in the patrol area.

Both the evolutionary and revolutionary responses to the Type XXI threat began soon after World War II, when little was known about the nature of the Soviet submarine threat. It was simply expected that the Soviets, a continental power like Germany with both limited access to and dependence upon the sea, would focus their maritime efforts on interdicting Allied sea lines of communication by deploying a large force of modern submarines. Combined with this relative vacuum of intelligence was a period in the five years between World War II and Korea of very low defense spending in the United States. Despite the lack of intelligence and the extreme scarcity of resources, the Navy placed substantial emphasis on ASW and made significant progress.

The Evolutionary Response to the Type XXI

The evolutionary response focused on two technical challenges: the need to improve snorkel detection by airborne radar and the need to improve the performance of surface ship sonars against faster, deeper diving targets. Snorkels presented a much smaller radar cross section to a searching radar and were also harder to detect amongst sea clutter, while the fixed “searchlight” sonars of World War II could not be trained fast enough to keep up with a submarine moving at ten or fifteen knots. By 1950, the APS-20 radar had recovered much of the detection range lost when snorkels first arrived, and the QHB scanning sonar had improved the ability of a surface ship to hold a submerged contact, but the ASW situation remained troublesome, according to several contemporary analyses of the problem.

For example, the Hartwell report noted that despite its success, the performance of the APS-20 needed continued improvement because “we have no assurance that the ranges we are now obtaining against our own snorkels and copies of the German snorkel can be duplicated against the Soviet snorkel. Evidence regarding the efficacy of snorkel camouflage is still fragmentary, but we feel that a moderately vigorous Russian effort to exploit geometrical camouflage could probably reduce our range seriously. In the long run, then, we see the radar-vs.-submarine contest as an unequal one, with the submarine eventually the winner.”¹⁰ Similar pessimism attached to the active sonar-versus-submarine contest as well as to the equally important area of ASW weapons, where the capabilities of the Soviet systems produced by the imaginations of American engineers always exceeded the American systems actually available to counter them.

This pessimism helped leave the door ajar for other approaches to the ASW problem. Thus, one of the major conclusions of the Hartwell report was that small, tactical nuclear weapons should be developed so that carrier aircraft could strike Soviet submarines in port at the source, a strategy which had failed in World War II because of the fortifications produced by the Germans at their U-boat ports, which survived repeated and massive attacks by even the largest conventional bombs. It also discussed the possibility of ASW submarines and fixed surveillance systems utilizing passive acoustics to detect snorkeling submarines at long ranges of as much as 100 miles.

A More Radical Response to the Type XXI

Passive acoustic-based ASW methods grew out of discoveries about low-frequency sound propagation in the sea made during and immediately after World War II. One key discovery, made by Maurice Ewing and J. Lamar Worzel, was of a deep sound channel that trapped and focused low-frequency sound, allowing it to propagate over great distances. It was abstracted as follows when first discussed in the open literature in 1948:

Experiments are described to demonstrate a new method of sonic signaling at extremely long ranges in the oceans, utilizing the natural sound channel. Signals were made by causing a 4-lb. charge of TNT to explode at about 4000-foot depth. These signals have the following qualities:

- 1) Extremely long-range transmission (probably 10,000 miles).
- 2) Signal is positively identifiable.
- 3) Abrupt termination of the signal allows the arrival time to be read with an accuracy better than 0.05 second. This permits location of the source to within a mile, if the signal is received at three suitably located stations.
- 4) The relation of signal duration to distance is such that the distance may be estimated to 30 miles in 1000 from reception at a single station

The limitations are:

1. The great-circle path which the sound follows between source and receiver must lie entirely in deep water (probably at least 1000 fathoms).

2. Sound travels in water at about 1 mile per second, so that the interval between the origin of the signal and its reception becomes sufficiently great to be a handicap for some uses. . . .¹¹

The so-called SOFAR (SOund Fixing And Ranging) channel was first used as a means of locating downed aviators at sea,¹² then as a missile impact location system,¹³ but its most important application came in the form of SOSUS (SOund SURveillance System), the network of seabed listening arrays deployed by the Navy to listen for submarines in the deep, SOFAR channel. SOSUS began as a crash program by Bell Labs in October 1950 under the direction of the Navy's Office of Naval Research.¹⁴

But even before SOSUS was developed, the submarine force had begun looking explicitly at the utility of ASW submarines, or SSKs, using passive, low-frequency acoustic arrays. This effort began soon after World War II as part of a general search by the submarine force for new missions and was formalized under Project Kayo in 1949. Kayo included the establishment of Submarine Development Group 2 (SubDevGru 2), which was tasked with "solving the problem of using submarines to detect and destroy enemy submarines."¹⁵ In 1952, the first submarines explicitly designed for that mission—SSKs 1-3—became available. Their key attribute was a big, low-frequency bow array, the BQR-4. The first use of the BQR-4 in exercises produced stunning results. In the words of K-1's first skipper:

USS K-1, off Bermuda in 1952, picked up a snorkeling exercise submarine at 30 miles, a range previously unknown to me, its CO, and my fire control party. The K-1 stayed at battle stations for five hours expecting every minute, after the first 15 minutes of tracking, for the bearing-rate to break and the target to go by. Can you imagine it? JT ranges from 4000 to 10,000 yards until 1952: and then in one Fleet exercise period, BQR-4 ranges out to 30 miles.¹⁶

This was the convergence zone phenomenon, another characteristic of low-frequency sound propagation which led to concentric rings of increased sound pressure levels at 25 to 30-mile intervals around a sound source. With the ability to detect snorkelers at one or even two convergence zones, SSKs could be used to form barriers off enemy ports and across geographic choke points such as the Bear Island-Norway gap or the Greenland-Iceland-UK (GIUK) gap. Still, even with such long detection ranges, a barrier strategy would demand large numbers of submarines, and the K-1 and its two sisters were designed as mobilization ships to be produced in operationally significant numbers only in war. Meanwhile, existing fleet boats were given SSK conversions, using the somewhat less effective BQR-2.

The SSK led also to collaborative experiments with the maritime patrol VP community. This in turn led to the formation of VP/SSK barriers where a line of SSKs made the initial detection and cued the faster VP aircraft for the actual prosecution and kill of the contact. Such VP/SSK barriers were adopted in actual war plans during the early 1950s and were still part of CINCLANT's operational repertoire in October 1962, when a

sub-air barrier containing ten SSKs was established off Argentina, Newfoundland, during the Cuban Missile Crisis.¹⁷

The Lag in Soviet Submarine Development

Viewed over the same five-year period between the end of World War II and Korea, the Soviet Navy's exploitation of the Type XXI lagged significantly behind U.S. Navy intelligence forecasts, which initially foresaw in 1946 a force of 300 Soviet Type XXI equivalents by 1950.¹⁸ It was not until 1949 that the first postwar Soviet submarine designs went to sea. Two classes were deployed, the Whiskey and the Zulu. The Zulu was a true Type XXI, equipped with a snorkel, capable of 16 knots submerged, and possessing the size, habitability, and range necessary for long-range, blue-water interdiction operations. But only 21 Zulus were commissioned between 1949 and 1958. During the same period, 236 Whiskeys were commissioned, but the Whiskey was a smaller, less capable, shorter-range boat, designed more with an eye toward coastal defense and European littoral operations. Furthermore, it was not until the mid-1950s that Whiskeys were even given snorkels. Certainly the Soviet Navy was showing an emphasis on submarines during this period, but it deployed them neither in the numbers nor the quality expected.

This disconnect between the U.S. Navy's expectations and actual Soviet naval behavior helps to highlight several unexpected characteristics of the Navy's ASW response to the Soviet Type XXI threat during the first five years of the Third Battle. First, the fact that there was a response at all is somewhat of a puzzle, given the prior record of interwar ASW activity by the major Western navies. In a time of great budgetary scarcity and with a relative lack of hard intelligence about the threat, the U.S. Navy had identified ASW as one of its two most important missions and had taken steps in peacetime to counter a new challenge in that mission area. Second, the nature of the first steps taken to counter the new ASW challenge is also interesting in that those steps contained both evolutionary and more innovative elements. The U.S. Navy did not simply attempt to repair the damage done to its traditional air-surface ASW team by the Type XXI, but it also explored new ASW techniques and new ASW platforms, prominent among these being passive acoustics and the ASW submarine, or SSK. Third, by 1950 when the first Soviet Type XXIs were being deployed, both the traditional and the more innovative ASW approaches to this threat had already demonstrated considerable success. Thus, even as traditional air-surface hunter killer groups and convoy escorts began to recover some if not all of their capabilities against the snorkel boat, the submarine force was leading in the development of another set of passive acoustic-based methods that added a new tool to the ASW arsenal. This new tool grew dramatically in importance during the next phase of the Third Battle.

Phase II of the Third Battle

ASW and the Two Nuclear Revolutions, 1950–1960

The 1949–1950 time frame was arguably the most important period during the Third Battle for three reasons. First, it was in 1949 that the Soviets exploded their first nuclear weapon, well in advance of many American estimates of when that ominous event would occur. This was the first nuclear revolution. The significance of this event for ASW was that the submarine was an obvious delivery vehicle for nuclear weapons, which made ASW even more important than Admiral Nimitz had said in 1946, because ASW was now also an important element in the defense of the United States against nuclear attack. Second, it was also in 1949 that the U.S. Navy decided to go ahead with a project to develop the nuclear-powered submarine. This second nuclear revolution, when adopted by the Soviet Navy, would pose an even more daunting ASW challenge than had the Type XXI, making ASW much more difficult just as the first nuclear revolution was making ASW much more important. Third, it was in 1950 with the outbreak of the Korean War that the U.S.-Soviet Cold War truly began. One consequence was a permanent, fourfold increase in the steady-state level of defense spending that the United States would maintain throughout the Cold War, a necessary but by no means sufficient step towards toward fashioning a new ASW response to a much greater threat.

The body of this chapter will be devoted to a discussion of the significance for ASW of the second revolution, the nuclear submarine. Before turning to that discussion, it is important to explain the context established by the first Soviet nuclear detonation and the Korean War.

The Submarine as a Nuclear Weapons Carrier

The first nuclear revolution subsumed ASW in the larger problem of protecting the continental United States from nuclear attack. Strange as it may sound to a generation of Americans used to concepts such as nuclear deterrence and mutual assured destruction, the early Cold War years were witness to many attempts to preserve the societal invulnerability which geography and political isolation had bestowed on the United

States before the arrival of nuclear weapons. These attempts drew on national resources controlled by the highest political and military leaders, and when ASW became associated with that effort, it also became a national mission.

Once again, the relative lack of intelligence about Soviet efforts to make submarines into nuclear delivery vehicles did not prevent speculation that they were doing so. Thus, in 1950, the CIA noted an unconfirmed report “that the only atomic bomb the Soviets have been able to produce would have to be delivered by submarine.”¹⁹ Indeed, the U.S. Navy had already experimented successfully in 1947 with launching a V-1-type cruise missile from the *Cusk*, a converted Gato-class diesel submarine. The success of this experiment led to *Regulus*, a 400-mile, submarine-launched, nuclear cruise missile that began flight tests in 1951. Similar experiments by the Soviets were reported by the Office of Naval Intelligence during the 1950s, including conversions of Whiskeys into cruise missile submarines (SSGs) and *Zulus* into ballistic missile submarines (SSBs).²⁰ In the words of Project Nobska, a mid-1950s successor to the Project Hartwell study, “Confronted with quiet submarines of long endurance, a sufficiently accurate means of navigation, and suitable weapons, a defense against shore bombardment by submarines becomes a huge problem. Even the partial defense of a long coastline requires a very large effort.”²¹

In the event, the first Soviet missile submarine deployments by *Hotels* (SSBNs) and *Golfs* (SSBs) did not occur until the early 1960s, but it had already become U.S. national policy to counter such systems before they were deployed. For example, in discussions of whether it was necessary to speed up research and development on strategic ASW at the outset of the Kennedy administration, existing national policy was quoted as follows:

Until technology permits the deployment of an effective active defense against submarine-launched ballistic missiles, the principal measures of protection should be provided by the capability to attack prior to launch. . . . [Accordingly,] the United States should strive to achieve and maintain an effective and integrated sea surveillance system that permits detection and tracking of surface ships and submarines operating within missile-launching range of the North American continent; and should improve its related anti-submarine capability.²²

Thus, the prospect of Soviet nuclear-armed SSGs and SSBs arose in American minds soon after the first Soviet nuclear detonation, and this prospect elevated ASW to a mission of truly national importance during the 1950s. Because of Korea and the resources it made available, the DOD-wide budgetary penury that had characterized the previous five years also ended, and the services were able to fund projects which would have been impossible otherwise.

The True Submarine

Yet the growing importance of ASW and the resources now available to invest in it do not explain the roughly contemporary decision by the U.S. Navy to begin the naval reactor program. The decision in 1949, before Korea, to develop naval nuclear reactors had multiple, independent origins, some of which are of no concern to this story. But one important element in this decision concerned the obvious utility of a nuclear power plant for the achievement of a true submarine. The pursuit of the true submarine, one that needed no umbilical to the surface and could remain completely submerged while on patrol, had been a dream of submarine designers from the days of the *Holland*. On the other hand, the attraction of such a submarine to the U.S. submarine force lay not in its utility for ASW but in the immunity it would grant that force to opposing ASW forces. USS *Nautilus* was certainly not conceived by the U.S. Navy as a counter to the nuclear submarine. Instead, as its capabilities first became apparent, *Nautilus* provided an indication of how difficult ASW would soon become when the Soviets deployed their own nuclear submarines.

These fears were confirmed in 1955 when the U.S. Navy's ASW forces first encountered *Nautilus* in her initial post-commissioning exercises. In one such exercise her performance was described as follows:

Running at 24 knots and reattacking surface ships at will, she made simulated attacks on 16 ships. . . . On one occasion, she detected a carrier and her escorts steaming almost directly away at 20 knots. To reach an attacking position she steamed 219 nautical miles in 10.25 hours; 16 hours after this attack, she struck a lone destroyer 240 nautical miles away.²³

She was hard to find because she never had to snorkel and so fast that active sonars could not keep their beams focused on her. Her speed and three dimensional maneuverability also allowed her to simply outrun existing homing torpedoes, the design basis threat for which was a snorkeling diesel traveling at no more than 8 knots and maneuvering in only two dimensions. In short, she completely undermined almost all the ASW progress made in the previous ten years to counter the Type XXI snorkel boat. Key to this effort would be the more innovative approaches to ASW based on passive acoustics.

Passive acoustics became so important because *Nautilus* was loud, and unlike diesel-electrics, which were only intermittently loud because of their periodic need to snorkel, early nuclear submarines like *Nautilus* were loud all the time, particularly in the low-frequency part of the sound spectrum, because of items like reactor coolant pumps which operated continuously whenever the reactor was providing power, and reduction gears, which were needed to reduce steam turbine shaft output revolutions. This was a potential chink in the nuclear submarine's armor, and it would quickly become the key to a completely revamped U.S. Navy ASW posture in which nuclear

submarines, long-range patrol aircraft, and SOSUS arrays would be the dominant tools. Before describing the evolution of this posture, it is important to pause here for a brief general description of passive acoustics and its role in ASW. Following that will be sections devoted to the development during the mid and late 1950s of SOSUS, nuclear submarines optimized for ASW, and long-range maritime patrol aircraft (VP) optimized for prosecuting SOSUS contacts. The last section will discuss the surface community's ambivalent attitude toward the ASW challenge posed by nuclear submarines.

Passive Acoustics in ASW

Like radio and radar, sound occurs on a spectrum of frequencies.²⁴ High-frequency, short wavelength signals attenuate more quickly but can be detected with good angular resolution by small antennas, while low-frequency, long wavelength signals propagate further but require antennas with much larger apertures in order to achieve directional reception. To detect a signal, it must be distinguishable from any background noise, whether in the propagation medium, i.e., the ocean or in the receiver itself. The key variable that determines whether detection occurs is the signal-to-noise ratio. There are two basic approaches to maximizing the signal-to-noise ratios achieved by a sonar—antenna gain and processing gain.

Because the optimum diameter or aperture of an antenna varies directly with wavelength, very low-frequency sound reception is maximized by antennas with very wide apertures, which means that sonars designed to detect low frequency sound must be large. This explains the big bow arrays on the early SSKs, and it also explains the use of long line arrays for SOSUS. In the former case, the “gain” of the array was limited by the need to fit it on the bow of a submarine, whereas in the latter case, fixed, ocean floor arrays 1,000 feet in length were used, which maximized the antenna gain possible against even the lowest frequency signals.

High gain antennas increase the signal-to-noise ratio by nulling out reception of noise from all directions except that of the main beam of the antenna, but noise within the main beam remains. Thus, even when the main beam of such an array is pointing directly at a submarine, there is noise that competes with the submarine's acoustic signature, and at long ranges this noise can still mask the submarine signal and prevent detection. Further filtering of this noise depends on signal processing within the sonar itself.

This processing usually exploits the fact that a submarine's signature contains both a continuous, broadband spectrum of sound as well as discrete narrowband tonals at specific frequencies along that spectrum that rise above it.²⁵ These tonals are caused by specific pieces of rotating machinery within the submarine, such as pumps, generators, and gears, whereas the continuous broadband spectrum is caused primarily by flow

noise over the hull surface or by propeller cavitation. A submarine's broadband signature resembles background noise in that it contains a continuous spectrum of frequencies within which sound source levels at particular frequencies rise and fall in random fashion around a mean, over time. By contrast, the narrowband component of a submarine's signature generates sound at several specific frequencies continuously. Thus, compared to the background noise generated at these specific frequencies, which will average out over time to x , the signal plus noise received at the tonal frequency will average out over time to $x + y$, with y being the source level of the signal. In order to listen for these specific tonals, a sonar is given a spectrum analyzer that passes an incoming broadband signal through a set of narrowband filters tuned to the frequencies of interest. Narrowband processing will detect signal y as long as it remains high enough to be reliably distinguished from the background noise x .²⁶ When first used in the early 1950s, it was given the name LOFAR (LOW Frequency Analysis and Ranging).

The significance of LOFAR was that it provided an additional, very powerful tool for increasing acoustic signal-to-noise ratios. For example, at close range, a simple sonar will detect a submarine's broadband signal simply by pointing the main beam of its antenna at the submarine. The sonar is measuring all the sound it receives in a given direction, including both signal and background noise, and as it points in the direction of the target, the signal increases. As the range to the opposing submarine is increased, the relative strength of this broadband signature compared to the broadband background noise declines until it is drowned out and the signal-to-noise ratio drops below the detection threshold.

Using LOFAR, the same sonar would filter out most of the sound received by its main beam and focus only on those low-frequency tonals where the submarine's source levels were highest. In those narrow frequency bins, the part of the submarine's sound signature that propagates furthest is competing only with the background noise that exists at that frequency rather than the entire broadband noise spectrum, and the sonar can therefore detect that narrow component of the submarine's overall sound spectrum at much greater ranges before noise drowns it out.

The effectiveness of passive sonars depends also on the relative position of the sound source and the sonar, and on the self-noise generated by the sonar platform. In the first case, the important variable is the existence of layers in the ocean which both reflect and absorb sound that strikes them at any but the steepest angles. In particular, there is normally a so-called surface layer ranging from several tens to several hundred feet deep, depending on location and seasonal variations. Most sound generated above this layer stays trapped above it and rapidly attenuates as it bounces back and forth between the surface and the layer itself. Only the sound that strikes the layer at a steep angle

penetrates it. In deep water, this sound is then captured and focused by the SOFAR channel. A passive sonar below the layer is therefore far more effective than one that is above the layer, because the signal it seeks to detect will travel much further. Convergence zones, where sound from the SOFAR channel returns and is focused at the surface at approximately 25-mile intervals, are an important exception to this rule, and it is also possible to cover the area between the limit of direct path propagation and the first convergence zone using bottom bounce techniques.²⁷

Self-noise is also an important issue for sonar effectiveness for obvious reasons. Any sonar attached to a loud platform will perform less well than the same sonar attached to a quiet one. This is true regardless of whether one is seeking broadband or narrowband detections. Self-noise can be minimized both by reducing speed and through explicit attempts to design a more quiet platform. The methods used to quiet sonar platforms become more elaborate later in this story, but low speed was a factor from the beginning. Furthermore, speed and depth variations between target and source can reinforce each other.

Thus, one key to the passive acoustic approach to ASW at the outset of the Third Battle was the fact that Soviet diesel subs snorkeled on their diesels at 8 knots during long transits to and from ocean patrol areas. At speeds lower than 8 knots, the time spent in transit would simply grow too long, but while traveling near the surface at 8 knots and above, submarine propellers cavitate. By contrast, an SSK patrolling on battery at depth in the path of the snorkeler would neither be cavitating nor putting diesel machinery noise into the water, which would both maximize its detection range and minimize its counter-detection range. Under that particular set of circumstances, the SSK would have a formidable acoustic advantage.

To return to the ASW challenge posed by nuclear weapons and the nuclear submarine, passive acoustics, both broadband and narrowband, became an important element of the response in three areas—ocean surveillance, submarine versus submarine operations, and maritime patrol (VP) operations. Ocean surveillance for ASW was revolutionized by the development and deployment of SOSUS. Submarine versus submarine ASW underwent a similar revolution as a result of the rapid development and deployment of the *Thresher*, the first quiet nuclear submarine. And finally, the VP community underwent a revolution when it shifted from operations cued by HF/DF that used radar to search for surfaced or snorkeling submarines, to operations in which SOSUS provided the cueing data and acoustic sonobuoys were used to search the datum for submerged submarines.

Ocean Surveillance

SOSUS was initially developed to provide warning of Soviet submarines approaching the continental United States. Two groups led the initial developments: Project Jezebel at Bell Labs, and Project Michael at Columbia University's Hudson Lab.²⁸ The first test SOSUS array was installed by Western Electric at Eleuthera in the Bahamas in 1951. Its success led to a decision in 1952 to install arrays along the entire eastern seaboard, followed by a decision in 1954 to do the same along the Pacific coast and off Hawaii. By 1958, these efforts were completed, and in 1959, an array was installed off Argentina, Newfoundland.

SOSUS arrays consisted of hydrophones spaced along undersea cables laid at the axis of the deep sound channel roughly normal to the direction that the array was to listen. The cables were brought ashore at Naval Facilities (or NavFacs), where the signals they received were processed. Evaluation centers were established to assess the processed data from the NavFacs and combine it with other surveillance information, such as from HF/DF nets.

SOSUS was designed to maximize detection ranges of the low-frequency part of a submarine's spectrum. Deployed at the axis of the SOFAR channel, the arrays were optimally located to exploit its focusing effects. Their 1,000-foot apertures maximized array gain against even the lowest frequencies. And finally, SOSUS was the first ASW system to fully exploit narrowband signal analysis in order to maximize processing gain.

Initially, SOSUS was begun on the basis of experiments against surface ships in which broadband, low-frequency cavitation was detected at ranges of roughly 100 miles.²⁹ The introduction of narrowband signal processing gave the same arrays detection ranges that could extend clear across entire ocean basins under some circumstances. LOFAR also allowed for more sophisticated tracking techniques. For example, two of the most important tonals in a submarine's signature were those modulated by the propeller at the rate at which its blades turned and those associated with particular items of rotating machinery. Blade rate tonals were usually slightly lower in frequency than machinery tonals, and both were usually aspect dependent and speed dependent. Taken together, these gave SOSUS the ability to detect and classify targets at extreme ranges and to track them over time. SOSUS' ability to locate targets depended on a variety of factors, including the range of the detection, the number of separate arrays providing a bearing to the same target, and the length of the baseline separating them. Under the best of circumstances, SOSUS cued operational forces to probability areas, or SPAs, in which the tactical ASW asset then had to search for and reacquire the contact. SPAs could be very large, particularly when they were relatively distant from the nearest array, meaning that successful SOSUS cueing was not automatic. In addition, there was

a fairly high false alarm rate, meaning that ASW assets often spent considerable time “prosecuting” merchant ships and marine life.

SOSUS became a part of a larger ocean surveillance system, and inputs from other elements of this system remained important to the ASW problem. Certainly, HF/DF remained an important component of the ocean surveillance system, though unlike SOSUS, details about HF/DF and other forms of signals intelligence (SIGINT) during the Cold War remain classified.³⁰ The timely fusion of all of these inputs and diffusion of the resulting operation intelligence to the operating forces remained as important in the Third Battle as it had been in the Second Battle, where success had ultimately depended on organizations like the U.S. Navy’s Tenth Fleet.³¹ Yet, as in the Second Battle, effective ocean surveillance systems did not guarantee tactical success.

The Submarine as an ASW Platform

At the tactical level, as was discussed in the previous section, the submarine force was the first community to fully embrace the passive acoustic approach to ASW. The development of this approach during the 1950s culminated in the deployment in 1960 of the *Thresher/Permits*, the first quiet nuclear submarines. The *Permits* brought together in one platform what had initially been three largely independent strands of development in the submarine force.

First, the submarine force had emerged from World War II victorious but without a new enemy. The Soviet Union was a continental power which did not rely on the sea, and it lacked both a large surface navy and an oceangoing merchant marine. Therefore, the beginning of the Third Battle saw the U.S. submarine force searching for new missions, including troop carriers, radar pickets, SSGs, and SSBs. By 1949, with the formal establishment of Project Kayo, ASW was included among the potential new missions, and SSKs became a part of the initial response to the Type XXI threat.

The idea behind an SSK was to put the biggest, low-frequency array on the bow of the smallest, simplest submarine and send it forward to form barriers at choke points across the transit routes of Soviet XXIs leaving and returning from Murmansk and Vladivostok. The concept of operation was for the barrier to have SSKs spaced one or two convergence zones apart, such that each could cover its assigned station while essentially hovering on battery, providing the optimum conditions for maximum passive array performance. This generated a requirement for an enormous number of submarines, which explained the desire for a simple design that could be mass produced, the idea being that there would still be a mobilization approach to achieving the necessary number of ASW assets, as there had been in the past.

The first nuclear revolution helped to bury this concept, since countering nuclear-armed Soviet submarines would clearly require an adequate ASW capability when war began. But the potential value of the submarine as an ASW platform remained, and SubDevGru 2 retained its mission of fulfilling this promise.

The second axis of submarine development focused on the search for new power plant technologies that would enable the true submarine—one that was completely independent from the surface. The desire for a true submarine grew at least partly out of the submarine force's reaction to what had occurred during the Second Battle in the Atlantic. There, the Allies had marshaled ASW forces far in excess of both the numbers and the capabilities the Japanese had deployed during the war in the Pacific. Likewise, in response, the Germans had developed new technologies which resulted in submarines far superior to all those that had preceded them, primarily by approaching closer to the ideal of the true submarine. This included both the Type XXI and the more exotic Type XXVI Walther boat, which introduced the first truly air-independent propulsion (AIP) plant using hydrogen peroxide as an oxidizer. The U.S. submarine force was therefore quite interested in giving its own forces capabilities like these, even though their purpose was not always clear, except as a target against which friendly ASW forces could exercise. At any rate, one key to a true submarine was AIP, and the submarine force experimented with both Walther plants and, more importantly, nuclear power. The second key was a hull form designed for high-speed, submerged operation in three dimensions, rather than surfaced or near-surface operations in two.

Nuclear power was rapidly chosen as the optimum propulsion plant for a true submarine, and its first deployment on *Nautilus* helped spur a new phase of the Third Battle. But nuclear power did not begin life as an ideal power plant for an ASW submarine. Certainly, *Nautilus* was much louder than an SSK on its battery under all circumstances, and this asymmetry appeared at least initially to be inherent to the technology, given the need for reactor coolant pumps and other such machinery to be kept running at all times. Here, for example, is Project Nobska's view of this question in December 1956:

The reactor art is also likely to continue to move ahead rapidly, but it should be emphasized that until nuclear plants can be made quiet, they are not necessarily the optimum propulsion system for the true submarine. Any system of reasonable endurance that does not require air and that is really quiet could be a strong competitor.³²

Or later in the same report, with specific reference to the ASW mission:

Since the submarine is an excellent mobile sonar platform, maximum advantage should be taken of it as an ASW vehicle. We feel that the effectiveness of the submarine in this mission will be limited largely by the noise which it produces. Therefore, our first suggested pre-prototype is a submarine in which quietness of operation is made an over-riding consideration. As a point of departure this might be considered as a pre-prototype embodying size, speed, and equipment suitable for an SSK mission.³³

As with the earlier SSKs, another emphasis beyond quieting was on cost and ease of production in order to achieve sufficient numbers in peacetime, and nuclear power complicated that objective as well.

The point in these examples is that nuclear power began as a means of achieving the true submarine, a basic technological objective that transcended the requirements of any particular mission and which almost constituted an end in itself. Ironically, given what lay in the future, the fit between nuclear power and ASW was not a natural one.

More advanced underwater hull forms were the subject of the *Albacore* experiment, an FY 50 initiative designed to look at the control problems that would arise if submarines adopted hydrodynamically efficient, single-body-of-revolution hulls. So-called teardrop hulls with single screws were clearly the way toward maximum submerged speed, but designers had no way of knowing how to control them. *Albacore* was an experiment designed to answer this question and to determine whether teardrop hulls could be adopted for submarines with AIP plants—whether nuclear or closed cycle. *Albacore* was also the first U.S. submarine to use high yield (HY80) steel in her hull.

The third axis of submarine development during the first years of the Third Battle was less ambitious technically than the previous two, and sought simply to integrate Type XXI technology into a multipurpose diesel submarine that would constitute the near term backbone of the U.S. submarine force. The main challenge here was budgets. Even after Korea, the submarine force did not immediately benefit from the resulting surge in defense spending, as was demonstrated by the relatively small building program for new diesel attack boats begun in the first decade of the Third Battle. Only ten new diesel attack boats were purchased by the U.S. Navy through fiscal year 1956, six *Tangs*, one *Darter*, and three *Barbels*. The *Tang* class was an explicit attempt to improve on the Type XXI, and they were funded with high priority in FY48–49 with the support of the rest of the Navy, due to the need for modern ASW targets.

The main element of the force structure consisted of conversions. The GUPPY (greater underwater propulsion power) was an extensive conversion that gave fleet boats a snorkel, a more streamlined hull, much greater battery capacity, and a BQR-2. There were a total of fifty GUPPY conversions made between 1946 and 1960. The GUPPY SSKs were the best that the submarine force could do and still maintain a reasonable force structure. As late as 1965, there were still forty-eight SSKs in the force structure compared to twenty-four SSNs.³⁴ Compared to the BQR-4 SSK conversions, the GUPPYs traded some long-range detection capability for a greater probability of closing and attacking the targets they did detect, due to their greater underwater speed and endurance.³⁵

The SSKs can be considered the submarine force's response to the Soviet Type XXI threat, designed as they were to counter a snorkeling sub on a long-range transit. As

such, they constituted a major innovation in their own right. But the main point of describing diesel boat development in the submarine force is to establish a baseline to compare developments before and after the two nuclear revolutions. After 1955, there was an explosion of development in the submarine force, leading to the combination of the ASW submarine, the true submarine, and the multipurpose submarine into one dominant platform, the quiet, multipurpose SSN. During the same period, albeit as a result of pressure from outside the submarine force, Polaris ballistic missiles were developed for deployment on SSBNs based on modified SSN designs. Finally, with the focus on SSNs and SSBNs, the submarine force dropped its experimentation with other missions, including using the submarine as a radar picket for carrier battle groups and as launchers for the already developed Regulus cruise missile, which, in addition to several SSRs and SSGs, resulted in only one SSRN and one SSGN ever being deployed, USS *Triton* and USS *Halibut*.³⁶ Because of the national priority behind the Polaris program, nuclear submarine production initially focused on SSBNs, but a class of quiet, multipurpose SSNs still began deployment in 1960.

The initially independent steps toward this grand synthesis were the *Tang* (SS), the *Albacore*, the *Nautilus*, and the three SSKs, all of which were funded by FY52, before Korea, in a time of great budgetary scarcity. *Seawolf* was funded a year after *Nautilus* in FY53 as the platform to test a liquid metal-cooled reactor, which promised higher power densities than pressurized water. No submarines were authorized in FY54, and then four *Skates* (SSN) were authorized in FY55–56. The *Skate* class was a modest evolution on the basic *Nautilus* design. FY56 also saw three *Barbels* (SS) authorized. The *Barbels* combined the multipurpose orientation of the *Tang* with the first operational use of the *Albacore* teardrop hull form. In September 1955, after *Nautilus*'s initial exercises, Chief of Naval Operations Admiral Arleigh Burke declared that all further American submarines would be nuclear submarines, and the FY57 program contained five SSNs. These became the *Skipjacks* which first combined the *Albacore* hull with nuclear power and are reputed to be the first submarines to exceed 30 knots. In FY58, the USS *Tullibee* (SSKN) was funded along with three other SSNs, which originally were to be modified *Skipjacks* but which eventually became the all new *Thresher* class.

Tullibee combined the ASW focus of the SSKs with the smallest nuclear reactor then feasible, with an eye toward a relatively cheap, dedicated ASW asset that could be deployed in the numbers still considered necessary to fully populate the forward barriers. Compared to the 15,000 SHP S5W type reactor of a *Skipjack*, *Tullibee* had a 2,500 SHP reactor and turbo-electric drive.³⁷ She could barely make 20 knots, but she lacked the reduction gears whose loud tonals made prior SSNs so easy for SOSUS to detect at extreme range. She also continued the tradition established by the BQR-4 equipped SSKs

by mounting a large, bow-mounted, passive, low-frequency array, the BQR-7. On *Tullibee*, the BQR-7 was wrapped around the first spherical active sonar, the BQS-6, and together they formed the first integrated sonar system, the BQQ-1. As an ASW platform, her performance was unmatched, but almost as soon as the decision to deploy *Tullibee* was made, a further decision was made to avoid specialized platforms and pursue instead a multipurpose SSN that best combined the speed of *Skipjack* and the ASW capability of *Tullibee* into one platform. This became the USS *Thresher*.

All subsequent U.S. submarine classes derive from the *Thresher* class, sometimes referred to as the *Permit* class after the lead ship was lost in 1963. Both *Tullibee* and the *Threshers* were also the first submarines designed explicitly for ASW against nuclear submarines. The key was quieting. *Tullibee* represented an attempt to eliminate the sources of noise in the submarine, while *Thresher* represented an effort to insulate that noise from the hull and the water beyond. The basic solution adopted in the latter case was rafting, whereby the engineering plant of the submarine, containing all or most of its rotating machinery, was placed on a flexible mount or raft within the submarine. This dramatically reduced the amplitude of the mechanical vibrations coupling to the hull, and therefore the sound that was put into the water. It also drove up the size of the hull and, as a consequence, propelled by the same S5W as the *Skipjack*, *Thresher* lost a few knots of top end speed. Rafting and other quieting technologies also drove up the cost of the submarine, partly due to the increase in size, but also due to the fiendish engineering problems associated with requirements like circulating water at great pressure from outside the hull into the ship through flexible piping.

The benefit was a dramatic acoustic advantage over the prior *Skipjacks* and the *Skates*, and more to the point, the Soviet HENS—the Hotels (SSBN), Echos (SSGN), and Novembers (SSN) which began deploying alongside the *Threshers* in the early 1960s. Furthermore, this was a broadband acoustic advantage, which is to say that LOFAR remained a non-standard element of the U.S. submarine fleet's sonar suites until much later in the 1960s.³⁸ With the BQQ-1, which was designed in 1958, initial detections at the convergence zones were possible either with the BQR-7 using low frequency broadband starting at 150 Hz, or with the BQS-6. The higher frequency BQS-6 would then track the target through bottom bounce range into direct path, where a fire control solution could be made.

Torpedoes were the big remaining question mark in submarine versus submarine ASW for the U.S. submarine force. When the threat had been a snorkeling diesel, the ASW torpedo problem was not severe in that it was slow and two dimensional, akin to attacking a very loud surface ship moving at 8–12 knots. Thus, the first submarine-launched, passive homing torpedo, the 16-knot Mk. 27-4, deployed in 1949, was

effective in exercises both against snorkelers and fully submerged subs on battery as long as they did not exceed 10 knots.³⁹ In 1956, the 26-knot Mk. 37 followed. In general, a torpedo needs to be 1.5 times faster than its prey to assure that the latter will not have the ability to outrun it under some circumstances, which means that Whiskeys and Zulus surprised by a Mk. 27 while snorkeling would have been fair game and would have been vulnerable to a Mk. 37 under all circumstances. A 25–30 knot nuclear submarine was a different proposition. It would ideally require a high speed homing torpedo capable of 45 knots, something which was not provided until the Mk. 48's deployment in 1972. In the interim, two alternatives were pursued, one tactical and one technical.

The technical solution was to use nuclear torpedoes (Mk. 45) and later rocket-propelled nuclear depth charges (SUBROC). This was one of the major recommendations of the 1956 Nobska report, but it was never the optimal solution for the Navy, which preferred a conventional solution. This led to the tactical solution, which was to use the formidable acoustic advantage to obtain firing positions for the Mk. 37, whose geometry both minimized the chances of detection of the torpedo launch by the target, and the chances that the target could escape, even if it did detect the torpedo in the water.

Innovations in Air ASW

The VP community was a close second behind the submarine force in embracing the passive acoustic approach to ASW. Unlike the submarine force, the VP community was a major member of the ASW team that fought the Second Battle. After the war, it was part of the traditional response to the Type XXI threat mounted by that team. Thus, for the first five years after the war, the VP community continued its focus on the concept of operations in which SIGINT cueing was used to vector radar-equipped aircraft to surfaced or snorkeling submarines, where they would be attacked by acoustic homing torpedoes derived from the World War II Mk. 24. The main challenge to this approach posed by the Type XXI was its snorkel, which reduced radar detection ranges, so the major technical effort mounted by the air ASW community during this period was the large APS-20 radar, which by 1950 had recovered much of the detection range originally lost to the snorkel, but was not too big to be carried by long-range VP aircraft.

The embrace of passive acoustics by the VP community grew in stages and is largely a story of sonobuoy development. The first attempt to use sonobuoys came early in World War II and saw them as a ship-launched device to warn of U-boats closing a convoy from the rear. Developed by RCA (Radio Corporation of America) at the direction of the National Defense Research Council (NDRC), they were not adopted, but the technology was then used to solve another problem, the high false alarm rate experienced by blimps used in coastal ASW patrols using MADs as their primary search sensor. Again, sonobuoys were never actually adopted for this purpose, but were then used

by the Army in experiments where they were dropped by aircraft into the wakes of recently submerged submarines. These experiments were successful enough to cause the Army Air Forces to order 6,410 sonobuoys in 1942. These became the AN/CRT-1, and this interest by the Army caused the Navy to reconsider its position on sonobuoys, and by 1944 the Navy had ordered 59,700 of them.

After the war, sonobuoy development was largely put on the shelf with the exception of the omnidirectional SSQ-2, which first deployed in 1950, but which suffered through serious reliability problems for several years. In the years when the submarine force was first experimenting with SSKs carrying large, bow-mounted, low-frequency arrays, the potential role of passive acoustics in VP operations was less clear. Omnidirectional buoys like the SSQ-2 could detect targets at reasonable range but without the bearing resolution necessary for localization and attack, and the development of directional buoys had proven quite problematic. Thus, sonobuoys remained useful as a tool for classification, but were not yet ready to replace radar as the primary air ASW search sensor.

This began to change with the development of SOSUS, for several reasons. SOSUS and the low-frequency detection and signal-processing advances associated with it led both to a demand for better air ASW capabilities and the means to achieve them. The demand was for a means of quickly prosecuting a SOSUS detection before the contact grew stale, and the solution was to give VP aircraft the ability to search SOSUS probability areas and localize submarines within them using passive acoustics. The first answer to this tactical challenge was Jezebel/Codar/Julie, which were different signal processing techniques used with the same low-frequency sonobuoys for search and localization respectively. The first LF sonobuoy was the omnidirectional SSQ-23 deployed in 1957. Jezebel applied LOFAR processing to the output of an SSQ-23, which suddenly gave buoys extraordinary initial detection ranges, albeit with little or no bearing or range resolution. Codar was a means of passive localization of the LOFAR contact, while Julie was active.

Codar used two precisely spaced SSQ-23s to detect and correlate broadband LF signals using the time difference of arrival method. When successful, the first Codar pair gave an ambiguous bearing, and at least one other pair of buoys was necessary to resolve the bearing ambiguity. Julie used explosive sound sources called practice depth charges (PDCs). After planting an array of SSQ-23s, the aircraft would “bomb” each buoy with a PDC until it received an echo return. After localization using either or both methods, the aircraft would seek MAD contact as the final step before release of a homing torpedo.

The weak link in this chain was localization. As a broadband system, Codar lacked Jezebel’s range and often failed to detect the target that Jezebel had initially acquired. Even when it did, it took time for the four buoys to be placed, and against diesels, this

time often exceeded the snorkel period. Once the target was on battery, Codar became much less effective and the target would often be lost. As an active system, Julie was equally effective against snorkelers and subs on battery, but it had even less range than Codar, which made Julie localizations of Jezebel detections equally difficult.

Jezebel, Codar, and Julie demanded great skill of their operators, and normal personnel rotation policies therefore made it difficult for the average crew to gain and retain these skills. This was one of the impetuses behind the establishment of Task Force Delta in 1961, which sought to do for the VP/SOSUS ASW team what Project Kayo and SubDevGru 2 had done for submarine versus submarine ASW. Select crews in TF Delta would be immersed in the challenge of coordinating VP operations with SOSUS and mastering Jezebel/Codar/Julie. They would then be spread amongst the various fleet VP squadrons. TF Delta would also experiment with new tactics and new technologies. Jezebel/Codar/Julie was useful in other air ASW missions as well, and it played a role both in the VP-SSK forward barriers as well as in coordinated air-surface, Hunter-Killer (HUK) group operations. Thus, carrier-based VS squadrons flying the S-2 also adopted these techniques.

The deployment of the *Thresher* and the establishment of Task Force Delta in 1961 were the culmination of a decade of experimentation and development of passive acoustic ASW methods. At the same time, the evolution of the more traditional radar and active sonar-based methods used during the Second Battle continued. This line of development was centered in the destroyer and carrier-based air ASW communities, commonly organized for ASW purposes into a Hunter-Killer (HUK) group consisting of an aircraft carrier, its air wing, and a destroyer squadron.

The Evolution of Traditional ASW Methods

HUK groups had first been used in World War II, both as a means of closing the North Atlantic air gap and as a means of attacking U-boat concentrations revealed by Ultra decryptions and HF/DF. Special escort carriers (CVEs) were developed to support these groups, whose air wings consisted of naval attack aircraft converted to the ASW role. After the war, the Navy retained HUK groups in both the Atlantic and the Pacific. Their operational focus lay in three distinct ASW tasks: offensive area search based on offboard cueing, screening for carrier battle groups or amphibious task forces, and convoy escort. In 1958, the Navy took the additional step of permanently assigning one HUK group the task of accelerating tactical development and increasing readiness in each of these three ASW mission areas. These groups were named Task Force Alfa, Bravo, and Charlie respectively.

There are three strands to the story of the World War II ASW team which continued from the first phase of the Third Battle into the second one. The first two involve the evolution of the two platform communities, air and surface, while the third involves the evolution of their operation together as a team in the HUKs.

The evolution of the carrier-based, fixed-wing air ASW community (VS) during the first two phases of the Third Battle is the shortest story, because it merges beginning in the late 1950s with the developments in the VP community described in the previous section. Prior to that point, the developments unique to the VS community had been dominated by the pursuit of a better snorkel detection radar. This search was complicated by the need to mate that radar with an aircraft compatible with the relatively small and slow World War II ASW carriers.

The first solution to this tradeoff was the AF-2W (with radar) and the AF-2S (with weapons) hunter-killer team in which the hunter aircraft carried an APS-20, while the killer carried everything else, including a smaller radar, ECM, sonobuoys, and torpedoes. The team tactics generated by this pairing could be effective but demanded high crew skills and became difficult under many weather conditions, particularly for the killer aircraft. A presentation at the May 1952 undersea warfare symposium describes these tactics:

(1) The search plane obtains radar contact (2) It gives the attack plane a vector (3) The attack plane steers the heading (4) It descends to attack altitude of about 300 feet (5) Attack radar is energized when target is at 5 or 6 miles (6) Circuits energized for weapon release—bomb bay doors open (7) Sonobuoy circuit energized (8) At one mile, searchlight on—pilot still flying on instruments at 300 feet (9) Target detected by searchlight operator/bombardier (10) Target identified (11) Torpedo away (12) Pilot drops buoys and sea markers over submarine position—listens for explosion/cavitation sounds (13) Wire recorder turned on to record sounds (14) Pilot completes sonobuoy pattern in case it becomes necessary to track submerged submarine.⁴⁰

Though the team approach had advantages, including the fact that it allowed a more effective search radar, the disadvantages in terms of cost, all-weather capability, and dependence on radio led to a “single package” aircraft, the S-2F.

The S-2F was the first purpose-designed VS aircraft. It had a crew of four, an APS-33 X-band radar, and a smaller but similar payload as compared to its VP contemporary, the P-2V. It sacrificed some snorkel detection capability in higher sea states for the advantages described above. In addition, since the APS-20 was also used by air defense early warning aircraft, which a larger CVS would also normally deploy, the single package aircraft might still benefit from APS-20 cueing.

The APS-20 versus “single package” debate was rendered somewhat moot by the development in the mid-1950s of Jezebel/Julie, which promised a strong complement to the

radar for search. Thus, S-2Fs began adopting Jezebel/Julie alongside the VP community, and the sensor/weapon development paths of those two communities began to merge by the end of the 1950s.

The air ASW picture described above was far from sufficient to address even the Type XXI threat by itself much less the nuclear threat. At every stage of the generic air ASW engagement described above, the submarine might take countermeasures that would be effective in ending the engagement, or at least in forcing its repetition over many iterations. At the very outset, a submarine's ECM receiver was likely to detect the APS-20 at least one and a half times the range that the latter was likely to detect the submarine's snorkel. Given such warning, it would submerge, and the engagement would be returned to the search phase. In general, at any point in the engagement right up until just before weapon release, the submarine could submerge and usually get away. This was due to the almost complete inability of the air ASW community to detect a fully submerged submarine on battery. This was a tactical situation that demanded an active sonar, but fixed-wing ASW aircraft were not effective active ASW platforms, and even with Jezebel/Codar/Julie, which could detect a nuclear submarine, the tactical problem of the very quiet battery boat remained unsolved.

This is the all-important role that the destroyer (DD) community had played during the latter years of World War II and would continue to play most prominently as the other half of the HUKs, which each contained a destroyer squadron as well as a CVS. The key to this air-surface team approach was that a properly designed destroyer would be able to hold and track a submerged submarine on battery with its active sonar if it could be brought within the detection range of that sonar. Thus, the tactic that evolved was for the VS community to respond to all radar or ECM contacts and attempt at a minimum to classify them and, if they were submarines, stop them from snorkeling. This limited the submarine's rate of advance and kept it from fully recharging its battery. Most important though were two other results of such a classification. It would allow the protected asset, a carrier battle group for example, to take evasive action, and it would also constitute a datum toward which destroyers might converge. Over time, after several snorkel periods in succession in which such a datum was refreshed from the air, a track would develop and sufficient time would pass for the destroyers to close the target, at which point it might be attacked immediately or held down and trailed continuously until its battery was exhausted.

The other role for destroyers was to form active sonar screens around task forces or convoys. These inner screens relied on active sonar because passive sonar would be swamped by all the noise generated near a group of surface ships, and because the screen had to move at the speed of advance of the protected asset, which in the case of

a carrier would usually be above 20 knots, exceeding the tactical speed of any passive sonar platform. In both roles, the destroyer would benefit from longer range active sonar and, as with the submarine force, this drove the surface community toward larger, low-frequency arrays, but it proved more difficult for the surface force to get long-range active sonar than it was for the submarine force to get long-range passive sonar.

As with radar, active sonar depends on receiving an echo from the target, which means that the signal travels twice as far as with a passive system, which in turn means that there are greater propagation losses and therefore inherently shorter detection ranges for any active system compared to a passive system, all other things being equal. Furthermore, all other things were not equal, and the DD community faced four other obstacles in its quest for better sonar.

First, destroyers operated above the isothermal surface layer, and much of the energy from their active sonar remained trapped in that layer where propagation losses were high and detection ranges were limited to the direct path. Second, the hull-mounted active sonar arrays were exposed both to the turbulent flow of the hull and to machinery noise within the hull. Third, and perhaps most important, low-frequency, active sonar arrays were large enough and required enough power that they established a lower bound on the size of the ship that could carry them. For example, World War II fleet boats could be converted into SSKs with a convergence zone detection capability with the addition of a passive BQR-2 array, but as it would turn out, World War II destroyers could not be given an active sonar with a convergence zone range because the first system with that capability, the SQS-26, was too large.

Four generations of active sonar were developed for the DD community between the late 1940s and 1960. The QHB was the first scanning sonar, operating at 25 kHz using a 19-inch diameter transducer and giving a range of about 1,800 yards at 20 knots in 1950.⁴¹ By 1959, the SQS-4 operating at 15 kHz needed an array 4 to 5 feet in diameter, but was achieving maximum detection ranges of 8,000 yards. The SQS-23, first deployed in 1958 and operating at 5 kHz, required a transducer 8 feet in diameter. The expected payoff for such a large array was direct path detection ranges of no more than 10,000 yards and the possibility of bottom bounce detections that would finally eliminate the constraint of operating within the surface layer.

The SQS-23 encountered serious problems during its first decade in operational use and was never able to reliably achieve bottom bounce detection ranges, though it did extend direct path ranges out to the point where the destroyer once again became weapon limited rather than sensor limited in a tactical engagement against a submerged diesel on battery.⁴² The SQS-23 was also too large to be fitted to all but the largest fleet destroyers of World War II, and the anticipated follow-on to the SQS-23, the

3.5 kHz SQS-26, made matters even worse with an even larger transducer and greater power requirements. This demonstrated that new construction was going to be necessary to create an adequate surface ASW platform. Starting in 1960, seventy-five SQS-26 ships were authorized of the *Bronstein* (2), *Brooke* (10), *Garcia* (10), and *Knox* (46) classes, as well as eleven cruisers, including the nine *Belknaps*, but the SQS-26 also experienced problems similar to the SQS-23 and was not fully accepted for service use by the Navy until 1968.⁴³

Limited through the 1960s to the direct path detection ranges of the SQS-23 and the SQS-26 before its bugs were worked out, the destroyer community still had trouble developing weapons and fire control systems that could track and attack high speed contacts at the ranges that SQS-23/26 detected them. ASROC and DASH were alternative solutions to this problem. ASROC was a rocket that carried either a nuclear depth charge or a homing torpedo, while DASH was a small, unmanned helicopter. ASROC proved more reliable in operational use than DASH, but was limited to direct path ranges and would not be adequate when bottom-bounce (BB) and convergence-zone (CZ) sonars became available. DASH was designed with an eye toward these latter capabilities, but when they finally became available in the late 1960s, a manned helicopter proved a more reliable solution. Backing up ASROC and DASH, destroyers also deployed launchers for homing torpedoes to be used only at very close range in self-defense.

In order to achieve the minimum numbers believed necessary for its surface ASW force, the Navy chose in 1958 to modernize existing World War II destroyers by giving them the maximum ASW suite that would fit in their hulls. Known as the Fleet Rehabilitation and Modernization (FRAM) program, FRAM I saw seventy-nine *Gearing* class DDs given SQS-23, ASROC/DASH, and Mk. 111 digital fire control, while FRAM II saw fifty-two *Sumner/Fletcher*s given a more austere suite including SQS-4, DASH, and an SQS-9 variable depth sonar (VDS).

This represented an evolutionary development path focused on an active acoustic approach to the ASW problem. This path began when the threat was a Type XXI. Against that threat, the active acoustic approach complemented other techniques. For example, active acoustics was not the best way to detect snorkelers, but it was the only way to detect a Type XXI once it was on battery. This was the rationale behind the hold-down tactics pursued by the HUK groups, where aircraft detected snorkelers and surface ships held them down once they had submerged and tracked them until they exhausted their batteries. But hold-down tactics based on active sonar did not work against nuclear submarines. Because of their speed in all three dimensions and their underwater endurance, nuclear submarines could usually either outrun a surface ship if they

wanted to escape or outmaneuver its active sonar beam if it wanted to attack it or the platform it was screening.

This produced a great paradox in the development of U.S. ASW capabilities at the end of the second phase of the Third Battle. Passive acoustics became the key to dealing with almost all aspects of ASW against nuclear submarines; ASW against nuclear submarines, including especially nuclear missile submarines, was a mission whose difficulty and national importance justified the great expenditures on ASW that began in the 1950s. Active acoustics in this realm remained important as the last of several barriers that the nuclear submarine had to penetrate in order to attack high value surface targets, but was much less useful against nuclear submarines in open ocean search and forward barrier operations.

By contrast, active acoustics never ceased to play a large role in ASW against diesel-electric submarines, but the rise of the nuclear submarine eclipsed the threat posed by the Type XXI and its successors. The U.S. Navy focused on the high-end nuclear submarine threat, while its allies tended to focus on the diesel sub threat. Thus, as the U.S. Navy's ASW posture was optimized after 1960 for the nuclear submarine threat, resources flowed toward the platforms most suited to adopting the passive acoustic approach that had been chosen to counter it.

For surface ships, there were many obstacles in the path of exploiting passive acoustics, prime among them being the need for more quiet ships, both to increase their sensitivity as listening platforms and to decrease the prospect of counter-detection, and the need to find a way of putting a large listening array below the surface layer. As we shall see in the next section, it would not be until the late 1970s that the surface community would begin to take these steps, though attempts were made to do this sooner, the abortive, mid-1960s Project Sea Hawk being the main example. The result was that the destroyer community retained its exclusive focus on active acoustics during the period when the submarine and air communities were embracing passive acoustics.

American ASW and the First Soviet Nuclear Submarines

As ASW developments in the intelligence (SOSUS), submarine, air, and surface communities became focused to varying degrees during the 1950s on the threat of nuclear submarines, and particularly nuclear missile submarines, Soviet nuclear submarine development lagged behind American expectations, though not as much as it had in the years between World War II and Korea, when a large Soviet Type XXI force was the threat.

The first Soviet nuclear submarine was the November SSN, launched in 1958. Using basically the same propulsion system, Hotel SSBNs and Echo SSGNs were deployed soon after. Together, these were known in the West as the HENs, and between 1958 and

1968, a total of 55 were deployed, 13 Novembers, 8 Hotels, and 34 Echos. They all had two reactors, two fast-turning screws, and a double hull.

From an ASW perspective, the HENs were contemporaries of *Nautilus* and the *Skates*, which is to say that they could defeat traditional ASW measures based on radar and active sonar, but were extremely vulnerable to the new passive acoustic approach already being adopted by the U.S. Navy. At speed, their double hulls generated considerable flow noise and their two fast-turning screws cavitated loudly. Alongside this broadband signature was a pronounced LOFAR signature useful for both long-range detection and classification.

LOFAR detection ranges against both American and Soviet first generation nuclear submarines were astounding. For example, SSBN 598, USS *George Washington*, which was actually a lengthened *Skipjack*, on one of her first deterrent patrols in 1961, was tracked continuously across the Atlantic all the way to the United Kingdom by SOSUS arrays deployed along the East Coast of the United States. In July 1962, a SOSUS array off Barbados detected a Soviet HEN class submarine as it crossed the Greenland-Iceland-UK gap, the first detection of a Soviet nuclear submarine by SOSUS.⁴⁴ In both cases, SOSUS was able to exploit the fact that both propellers and rotating machinery mounted directly to a submarine's hull generated clear, predictable narrowband tonals at source levels high enough for large LOFAR arrays to detect and track them on an ocean-wide basis.

These surveillance capabilities were complemented by the new tactical ASW prosecution capabilities of the VP and submarine communities. In the VP community, in which LOFAR was first introduced during 1956–1957, there were initially troublesome tactical problems generated by the extreme detection ranges possible with omnidirectional LOFAR sonobuoys when they were first used against snorkeling submarines. Here is a description of some of those problems by Russ Mason, a key member of the technical community responsible for sonobuoy development:

(LOFAR) turned out to be so good under certain conditions in certain areas that it caused airborne ASW a major problem. Instead of detecting submarines only a few thousand yards away, Jezebel was consistently making detections in the tens or even occasionally hundreds of miles. The sensitivity of the system was not really recognized, known, or believed for years. . . . A LOFAR detection could not necessarily, as planned or hoped for, be turned into a CODAR bearing and fix because CODAR, being broadband, did not approach the sensitivity of narrowband Jezebel ranges.⁴⁵

This was a particular problem against diesel electric boats, which became vulnerable to LOFAR only when they snorkeled, which put an upper bound on the time the ASW aircraft had to accomplish a CODAR localization before the target went back on battery. But against nuclear submarines, whose LOFAR signatures were essentially

continuous, the problems associated with localizing long-range Jezebel contacts eased considerably because they were no longer intermittent.

In the submarine community, and particularly with quiet, second generation subs like *Tullibee* and the *Threshers*, because of the wide apertures of their low-frequency arrays, it was possible to get long-range detection of the broadband signature of first generation nuclear submarines like *Nautilus* or, more importantly, the Soviet HENs. The following is a now-declassified, contemporary description of this capability as it was first emerging:

The past year (7/60-6/61) has seen the introduction and the commencement of the evaluation of *Tullibee* (SSN-597) as a vehicle constructed specifically for anti-submarine warfare. Installed equipment and characteristics of this ship represent the most impressive advance in submarine ASW capability to date. Passive detection to over 100 miles and active ranging to the first convergence zone coupled with extremely low self and propagation noise bring us to a new era of submarine participation in the antisubmarine effort. These improvements are also characteristic of *Thresher* (SSN-593) and the follow-on ships of her class.⁴⁶

Unlike in the VP community, LOFAR was first used in the submarine force only as a classification tool because broadband sonar was sufficient for long-range detection and easier to use tactically.

To conclude discussion of the second phase of the Third Battle in the period between 1950 and 1960, two points stand out. First, as with the first phase of the Third Battle against the Type XXI, the U.S. Navy ended up nearly preempting the ASW challenge posed by the Soviet submarine force's anticipated exploitation of the two nuclear revolutions. In other words, by the time the HENs actually began going to sea, all the elements of an effective ASW response to them had already been demonstrated and were being deployed by the U.S. Navy. Second, once implemented, this ASW response was clearly going to necessitate a dramatic shift in the resources available to and the status of the Navy's different platform communities, and yet the specific programs that would cause this shift were not suppressed by those with the most to lose. Thus, the Navy continued to keep pace at the technical and tactical levels with the peacetime evolution of the Soviet submarine threat, even as that threat began to grow in a qualitative sense by leaps and bounds. The Navy was able to do this at least in part through the kind of technical and doctrinal innovation which is normally considered rare in military organizations in peacetime.

Phase III of the Third Battle

ASW and the Happy Time, 1960–1980

SOSUS, the quiet, ASW-optimized SSN, and Jezebel/Codar/Julie for VP and VS aircraft were all developed by the end of the 1950s. These were the key elements of a new approach to ASW emphasizing passive acoustics, and it was this approach which became central in the ASW battle against Soviet nuclear submarines. But to be fully exploited, these new tools needed to be integrated into a combined arms team that still included more traditional tools. Furthermore, once a new concept of operations was established, sufficient numbers of platforms needed to be deployed to support it in peacetime. Thus, where the 1950s was a period of radical technological ferment in the ASW mission area, the 1960s saw a series of doctrinal debates over how best to exploit the technological bonanza that resulted. As always, the chief protagonists in these debates tended to be the individual ASW platform communities.

The Barrier Strategy Embraced

The core of the new concept of operation was to place barriers between Soviet homeports and open-ocean patrol areas wherever maritime geography made them possible. Barriers were feasible in deep water wherever SOSUS arrays could be emplaced in such a way as to cover a choke point, and given SOSUS' range, these choke points could be quite wide. For example, the waters separating Greenland, Iceland, and the United Kingdom (GIUK) became a key choke point, and the 1965 decision to emplace SOSUS arrays and create a barrier there was part of a general strategy that sought to push SOSUS barriers as far forward as possible. NavFac Keflavik was established in 1966, and by 1974 a total of twenty-two SOSUS installations existed along the East and West coasts of the United States and at various forward choke points.⁴⁷ Another key expansion of the SOSUS network came with the establishment in 1964 of an array off Andoya, covering the entrance to the Norwegian Sea between Norway, Bear Island, and Spitsbergen.⁴⁸ By 1981, unclassified depictions of SOSUS described it as having thirty-six installations, including facilities located in the United States, the United Kingdom,

Turkey, Japan, the Aleutians, Hawaii, Puerto Rico, Bermuda, Barbados, Canada, Norway, Iceland, the Azores, Italy, Denmark, Gibraltar, the Ryukyus, Panama, the Philippines, Guam, and Diego Garcia.⁴⁹

Within such a choke point or barrier, submarines and/or VP could be cued by long-range SOSUS detections. In the earlier sub-air barriers, submarines spaced at twice the average range of their bow sonar provided the initial detections. This produced requirements for more submarines than could be afforded in peacetime, hence the interest in experimental designs like K-1 and, later, *Tullibee*, which could hopefully be produced in numbers large enough to man these barriers. Furthermore, even with the peacetime submarine force that could be afforded, forward barriers could not be maintained in peacetime because of the normal requirements for training, upkeep, and crew rotation. Therefore, warning was needed in advance to create a barrier, and the degree of warning received determined how far forward these barriers could be established. But this had always implied a certain circularity of logic, because forward barriers were one of the primary means of confirming a large Soviet submarine deployment. For example, five Soviet submarines deployed from the Kola peninsula area in early October to support Soviet naval operations in late October 1962, in the Caribbean during the Cuban Missile Crisis. They were not detected until they encountered American quarantine forces in the region; therefore, the sub-air barrier off Argentina that was established after the quarantine began missed them.⁵⁰

SOSUS directly addressed both of these problems. Because SOSUS made the initial detections, barriers now needed to be manned by platforms sufficient only to prosecute contacts, which was a much smaller number than that required to make the initial detections. Furthermore, SOSUS was a permanent peacetime installation that could and was in fact designed to provide advance warning of Soviet submarine movements. Thus, far forward arrays might give warning sufficient for barriers further back to be manned in time to interdict a deployment. For SOSUS-VP barriers, basing rights in the region would allow permanent detachments of air ASW aircraft to man barriers in peacetime.

The new concept of operations also envisioned independent, far forward operations by SSNs. In peacetime, these would provide intelligence and warning, and in wartime would constitute the first barrier that Soviet submarines would encounter when they left their bases. Even within the deep-water SOSUS barriers further back, SSNs would operate largely independent of VP forces. Sub-air tactics had always been hampered by communication and IFF problems. Because SOSUS eliminated the need for close cooperation between the two communities, both were happy to go off on their own. Thus, main barriers like the GIUK consisted of alternating layers in which VP and submarines

conducted the prosecutions. In the forward areas, submarines operated alone, and in the rear areas, along friendly coastlines, VP dominated and submarines were largely absent. These independent operations contrasted with the cooperative tactics that were central to the effectiveness of a HUK group's air-DD team.

The big doctrinal question created by the new barrier concept revolved around what was needed, if anything, in addition to the barriers. One view was that ASW strategy had fundamentally changed in such a way as to make those additional requirements much smaller than in the past:

Advanced nuclear attack submarines in barriers could exact considerable attrition as Soviet submarines surged into the North Atlantic shipping lanes, and as they attempted to return to their bases for replenishment. The evolving SOSUS network could direct long-range ASW aircraft and destroyer-carrier-hunter-killer (HUK) forces against submarines at sea in the North Atlantic; as shore-based aircraft performance improved, even the HUK units became less important. . . . Thus, the balance of the ASW effort would shift from escort operations to offensive patrol, with escort ships employed as a backup.⁵¹

In some eyes, this was fortunate, because, as the Chief of the Bureau of Ships, Rear Admiral R. K. James, argued in 1961:

. . . the time has come when we should seriously question the wisdom of continuing to emphasize the surface ship as our primary ASW vehicle. . . . [W]e are trying to accomplish the job the hard way, expending tremendous effort to get our sonars deep in the water where the acoustic problems will disappear. . . . [T]here is no question but that a surface platform is not a good sonar platform, nor, indeed, is it likely that we will ever succeed in making it anything more than marginal. A submarine, on the other hand, represents a near-optimum sonar platform.⁵²

For those who accepted this position, the consequence was a diminution in the importance of surface ship ASW programs and an overall reduction in the size of the destroyer force. In a war there would be some leakage of Soviet submarines through the barriers, and destroyers would be needed to protect those forces so valuable that even limited losses needed to be avoided, such as carrier battle groups. But early losses to merchant shipping would be accepted on the assumption that the submarine threat would soon become manageable due to steady attrition by the barriers.

By the mid-1960s, a consensus developed which embraced the passive acoustics-based barrier strategy, while also supporting investment in a two-tiered ASW escort force, with small numbers of multipurpose destroyers assigned to battle groups and other high-value units, and larger numbers of single-purpose destroyer escorts devoted largely to ASW for use in screening mid-ocean convoys. One cause of this consensus being reached was the establishment of Op-95 in 1964 as both the CNO's and the Secretary of the Navy's chief adviser for ASW. The first occupant of this office was Vice Admiral Charles Martell.

This office was formed in the midst of a Navy-wide review of ASW programs and of future Soviet submarine developments. At the most general level, this review led to

some relaxation in the near term concern over the Soviet submarine threat but continued anxiety about the more distant future. The following exchange in a 1964 congressional hearing on Navy research and development is illustrative. The main participants in the exchange are Congressman Robert Sikes and Rear Admiral E.B. Hooper, Director of ASW Research and Development.

Mr. Sikes. Do you think that defenses against submarines will ever catch up with submarine offensive capability?

Admiral Hooper. The question as to whether or not a submarine or antisubmarine force is ahead is a rather difficult one to evaluate. It is not a symmetrical situation. We certainly have a very good capability to counter submarines at the present time but it is a touch and go situation.

Mr. Sikes. Surely you would not indicate that submarine defenses can effectively cope with the offensive capability of submarines?

Admiral Hooper. Yes I would in a certain context. I believe right now we have good antisubmarine warfare.

Mr. Sikes. If that were true, our Polaris submarine would be jeopardized.

Admiral Hooper. That is why I say this is not a symmetrical situation. The capabilities we have developed help make this give us [sic] these capabilities. Geography is greatly in our favor.

(Discussion off the record)

Admiral Hooper. When one projects this very serious competition well into the future and sees the number of nuclear submarines the Soviet Union will probably build, one notes the improvements that he can make, although some of these improvements are going to cost him a lot of resources he has to pull away from something else. Then the situation is a very serious one. . . .

Mr. Sikes. Let me rephrase my question. If the Soviet defensive or offensive capability were as great as ours, would your ASW capability be sufficient to cope with it?

Admiral Hooper. I would prefer to say we are able to stay ahead of the submarine menace. I personally believe that if we can make the fullest use of the information we are gaining of the environment, if we pursue an aggressive and imaginative program with enough emphasis on the basic things, I personally believe that we can and will stay ahead.⁵³

The motivation behind the aggressive program Admiral Hooper referred to in this extended colloquy seems to have been based on a tendency to base future ASW requirements on what would be needed to counter submarines of the quality the United States was currently building deployed in the numbers that the Soviets were capable of producing in the future.

Already, it was becoming clear that this approach could lead to great success when Soviet efforts did not live up to this expectation. For example, Secretary of the Navy Paul Nitze testified in 1965 that “our antisubmarine warfare effort of past years has been more effective than we have sometimes realized. We have had the advantage of training against our own submarine forces, which, as you know, have been in the forefront of both development and operational know-how since World War II. Thus, our own peacetime opposition has perhaps been more effective than a real enemy would be.”⁵⁴

The same dynamic at a more technical level was described by Assistant Secretary of the Navy for Research and Development Robert Morse in an effort to explain the source of the tremendous acoustic advantage American submarines enjoyed in 1965 over their Soviet counterparts. He noted that:

It came about, I think, by just a general overall attention to sound reduction, in every possible way, looking at every piece of machinery, how it was mounted, looking at the connections to the outside, that is of cooling pumps and so on which can then pump noise out along with the water, looking at the sources or the ways in which sound is generated and is transmitted from the submarine. . . . One of the reasons that we have been benefited so much is that we had made great progress in antisubmarine warfare. I think that without the ability to make good measurements on our own submarines and without having the stimulation to do it by knowing that that was an Achilles' heel to the submarine, that we would not have made that progress. That is, the quieting of your own submarines comes in many ways from a consciousness of the antisubmarine problem.⁵⁵

But would not the Soviets take the same steps sometime in the future, Morse was asked?

Oh, yes; yes sir. There are no secrets or no real magic in the technology that we have used. The translation of this into engineering practice, though, is not necessarily easy. That is, one has to go through many evolutionary steps. We have gone through them and if you looked at our own quieting program, I think you will see that it rarely took big jumps. That is, it tended to be an evolutionary thing. That isn't to say theirs won't be.⁵⁶

Thus, if the United States continued to solve the ASW problem against its own submarines and continued to push the development of its submarines past those "solutions," it would always stay just ahead of the Soviets, whose submarines would always lag in capability because their development was not informed by the same consciousness of the ASW problem but rather was driven only by a focus on the prosubmarine problem. But if the United States relaxed in its efforts to solve the ASW problem against its own submarines, the Soviets would quickly catch up because the American lead in quieting and other prosubmarine technologies was evanescent, in that it was based mostly on dogged attention to engineering detail rather than any fundamental technical breakthrough.

This approach to consolidating and preserving the passive acoustics-based approach to ASW was relatively successful for almost twenty years, from 1960 to 1980. During this period, mostly evolutionary improvements in passive acoustic capabilities were pursued, and until near the end of this period these efforts remained confined largely to the SOSUS, SSN, and VP communities. Their success was based at least partly on the fact that the Soviets did not focus on quieting as much as planners had expected they would in the early 1960s. Thus the second generation Charlie/Victor/Yankee (CVY) classes, which began deploying in 1968, remained quite vulnerable to a passive acoustic approach. In fact, by some measures, the American acoustic advantage against the CVYs had actually deepened by the early 1970s.

More turmoil attended the evolution of the carrier-based air and surface ASW communities during this period. By the late 1960s, the HUKs had lost their open ocean search role to the VP community, and were focused on screening for carrier battle groups. By the early 1970s, the expense of providing dedicated CVS groups for this purpose led to the multimission CV concept, which eliminated the CVS, and assigned half of its VS and HS aircraft to the attack carrier wing. The surface community focused during the 1960s on making the SQS-26 work. When by the end of the decade it finally had a true bottom-bounce and convergence zone sonar, it finally abandoned DASH and embraced the manned helicopter as the main destroyer-based ASW weapon.

The main challenges to the U.S. Navy's ASW posture during this third and longest phase of the Third Battle turned out not to be the one that was most feared—the truly quiet nuclear submarine. Instead, the Navy was surprised to varying degrees during this period by fast, deep-diving submarines (Alfa and Papa); submerged launch, antiship missile submarines (Charlie I and II SSGNs); and the long-range, ballistic missile submarines (Delta SSBNs). In each of these three cases, a major element of the passive acoustic barrier strategy was threatened, and therefore a major response was perceived to be necessary, even though in the first two cases, the threat that was initially imagined never fully materialized, or came much later than anticipated. The fast, deep-diving submarine threat provoked a major ASW torpedo improvement program. The Charlie SSGN, with its submerged launch SS-N-7s and 9s, was one of several catalysts leading the surface force to embrace ship quieting and passive acoustics. And the Delta SSBN with its circa 4,000-mile range SS-N-8s caused a fundamental shift in the U.S. Navy's approach to strategic ASW, one that involved a major expansion in the role of its SSN force.

The rest of this chapter is divided into three parts. First is a discussion of developments in passive acoustics in the SOSUS, SSN, and VP communities. Second is a discussion of developments in the ship-based air and surface ASW communities. Third is a discussion of the three Soviet challenges to the passive acoustic barrier strategy and the U.S. Navy's responses. The last section will be brought through to the late 1970s, when the very quiet Soviet nuclear submarine threat did finally begin to appear.

Protecting the Passive Acoustic Advantage

Having embraced the passive acoustic approach to ASW, the SOSUS, submarine, and VP communities set about improving it in anticipation of much quieter Soviet submarines. A simple way of describing this evolution is to think in terms of array gain and processing gain. The ideal detection system combines these two techniques to maximize the signal-to-noise ratio. From the beginning, the SOSUS system employed both techniques. Its seabed arrays were not limited in aperture and could achieve the

maximum array gain possible for even the lowest frequencies. Likewise, its shore-based processing facilities had access to computational capacity unlimited by volume constraints, and were able to perform the computationally-intensive fourier transforms needed for spectral analysis at a time when computers were quite large and user unfriendly.

Over the course of the 1960s and 1970s, upgrades to the SOSUS system focused on evolutionary improvements in array gain, processing gain, and timeliness. The original arrays had 40 elements spaced equally along 1,000 feet of cable (1x40). No more than 40 elements could be supported by a single cable, and it turned out that acceptable performance could be achieved under many circumstances using fewer elements. To extract more value from each cable, 2x20 and 3x16 arrays were deployed in which the elements on one cable were divided into two or three separate arrays looking in different directions. This allowed one cable to focus along two or three separate acoustic paths where surveys had demonstrated optimal deep sound channel propagation. These arrays also reduced the bearing ambiguity that could exist when using only a single array. During the same period, improvements in computer processing allowed for more processing gain by integrating over smaller and smaller frequency bins.⁵⁷

As the geographic reach of SOSUS expanded into forward areas, there were also debates about its purpose. Originally conceived as an intelligence asset, SOSUS first gained support as a means of warning national political authorities of the approach of Soviet submarines. This was important information in its own right, as Soviet submarines were themselves considered nuclear delivery vehicles. But it was important as well on a larger level, as such a submarine deployment was also considered a reliable source of warning of a larger, general attack. For these reasons, like all other intelligence assets, SOSUS information was always closely held by the intelligence community, and there was considerable reluctance to release it to tactical ASW forces.

This instinct to protect intelligence sources and methods clashed with the need for large area undersea surveillance for ASW. The barrier strategy was premised on the availability of SOSUS cueing for SSNs and VP, and these techniques needed to be practiced in peacetime, but unrestricted use of SOSUS in peacetime would in all likelihood reveal its capabilities to the Soviets. Thus, for many years, as with Ultra during World War II, the exploitation of SOSUS data was done in such a way as to mask the exact location of its arrays and their capabilities. For example, tactical forces used only passive techniques when they prosecuted SOSUS contacts of Soviet submarines, and many training exercises were conducted against either friendly or neutral targets. One common SOSUS/VP exercise was to train against diesel trawlers, which had signatures similar to a snorkeling submarine.

From the beginning, the technical community that supported SOSUS understood that it could be rendered largely ineffective by quieting. In fact, SOSUS played a major role in the accelerated quieting program adopted by the American submarine force. This contribution had both an engineering and an operational aspect to it.

From an engineering perspective, American submarine designers sought to build submarines that could not be detected by SOSUS. This resulted in a technical competition between listeners and hiders in which both sides benefited. The submarine quieting program was centered at the David Taylor Model Ship basin (now known as the Naval Surface Warfare Center, at Carderock, Maryland), while the research and technical support for SOSUS was done at Bell Labs, Columbia's Hudson Lab, Scripps, and Woods Hole. One example of this interaction was the discovery of mechanical, blade rate tonals on *Thresher* during her early trials.⁵⁸ The benefits of this internal competition extended to the operational realm as well. SOSUS often detected unwanted spikes in the signatures of American submarines, due in some cases to wear and tear in a particular piece of machinery.

But these experiences also made the U.S. Navy sensitive to SOSUS' vulnerability to Soviet quieting. One consequence was an attempt from almost the very beginning to incorporate active echo-ranging into ocean-wide undersea surveillance. Project Artemis of the early and mid-1960s was such an attempt. As with all attempts to develop low-frequency, active sonar, the main obstacles encountered in Artemis were in designing a powerful enough transducer and in countering reverberation, the phenomenon of receiving multiple echoes, both from the initial signal returning over multiple paths, and from spurious echoes caused by other objects and variations in the sea bottom.

The submarine community emphasized improvements in quieting, both array and processing gain, better sonar system integration, and formal tactical and operational analysis. Beginning with the *Thresher/Permits*, American SSN design demonstrated a continuing willingness to emphasize quieting over other valuable operational capabilities such as speed and diving performance. Therefore, in the progression from *Skipjack* to *Thresher* to the *Sturgeon* class in 1967, one sees significant improvements in quieting with each generation, and a loss in several knots of top speed. Fourteen *Permits* (plus *Tullibee*) were built between 1961 and 1967 and thirty-seven *Sturgeons* between 1967 and 1975. In the latter period, USS *Narwhal* and USS *Lipscomb* were also built as experimental platforms for, respectively, natural circulation reactors and electric drive.

USS *Sturgeon* (SSN 637) was originally conceived as a modest upgrade to the *Permits*. She was larger, both because quieting and size tend to accompany each other, and because she was given more space to accommodate a more advanced acoustic and SIGINT sensor suite. With the 637s, the submarine force began to embrace LOFAR

signal processing as a tool for both detection and classification. Experimental spectrum analyzers like the BQQ-3 were replaced in the early 1970s by digital systems and were deployed on all submarines rather than only those engaged in special missions.⁵⁹ The 637s were also the vehicle for early experiments with towed arrays. Towed arrays were line arrays of omnidirectional hydrophones much like SOSUS arrays that used electronic beamformers to achieve array gain. Long, towed arrays could provide more aperture than could bow or hull-mounted arrays, and also suffered less from self noise and flow noise.

The first towed array used by the submarine force was the Submarine Tactical Array Sonar System (STASS), which was used experimentally in the mid-1960s and began deployment on a regular basis in the late 1960s. STASS could not be reeled in and out of the submarine, so it was employed as a clip-on array, meaning that the array was attached to the submarine at the beginning of a deployment and towed for the duration of that deployment. Later, so-called “thin line” arrays were developed which could be reeled in and out. The first such was the TB-16, which in turn was followed by the TB-23 and 29; the increasing numbers representing the increase in acoustic aperture provided by each succeeding generation.⁶⁰

One of the first and most important uses for both LOFAR and the towed array in the submarine force was the creation and maintenance of a library of Soviet submarine signatures. Each class of submarine, and indeed each submarine, generated its own unique blend of narrow and broadband sound at varying levels. Knowledge of these signatures was fundamental to the effective use of LOFAR and to predicting the performance of passive sonars.⁶¹ Even the most advanced computers of the day were limited in the number of spectral lines that they could process, meaning that prior knowledge of the frequency of those lines was necessary in order to maximize LOFAR capabilities.⁶² Likewise, predicting the performance of passive sonars demanded knowledge of the strength of the target signal.⁶³ Knowledge of sonar performance was fundamental to the barrier strategy because expected detection range was the key variable in determining the number of platforms needed to man a given barrier. Submarines were uniquely able to collect and maintain this database of opposing submarine signatures, which served both their own operations as well as the other ASW communities.⁶⁴

Another unique capability provided for the first time on a large scale by the 637s was an enhanced ability to covertly track an opponent.⁶⁵ Prior SSNs could certainly track their Soviet counterparts, but the tactical challenges involved were high. Tracking operations demanded the ability to approach the target covertly and establish and maintain a position to its rear in its so-called “sound baffles.” The situational awareness required to do this was high, because the distance from which the track was maintained was at

relatively short, direct path ranges where counter detection was most likely. Alongside the fact that it was quiet, a 637's large, spherical, bow sonar array gave its crew a wider angle view in both azimuth and elevation of its target than did a *Skipjack* or a *Skate*. The analogy in visual terms would be to removing a set of blinders which constrained one's field of regard to a narrow cone looking forward.⁶⁶ The 637s made it feasible to develop tactics for routine, covert tracking operations that could be implemented on a force-wide basis.

Many of these operational and analytical activities continued to be centered in Submarine Development Squadron 12 (SubDevRon 12), formerly known as Submarine Development Group 2 (SubDevGru 2). DevRon 12 was the home of the Tactical Analysis Group (TAG), which played a major role in the "Big Daddy" exercise series; its submarines were also assigned many forward intelligence missions.

The TAG was set up to develop analytical techniques for examining exercise results and to use them to predict operational performance. Big Daddy was an annual SSN versus SSN ASW exercise which the submarine force used in part to develop and validate the models developed by the TAG. These models could then be used in war planning, in setting force requirements, and in assisting in the design of new systems. Big Daddy and TAG were key tools for the Navy to use in convincing both itself and the national leadership of the viability of its ASW posture. The TAG also developed into a formidable tool for justifying new submarine development to the civilian leadership, particularly in the years the Office of the Secretary of Defense was infected with enthusiasm for the quantitative methods first introduced by Robert McNamara in the early 1960s. In this capacity, the TAG played a major role in the justification for the *Sturgeon*, the first SSN class produced in large numbers.

DevRon 12 also played a major role in the introduction of new sensor technology. Part of its charter was to test new equipment, but because it also had an operational role, these tests often occurred in real world operations. Once the value of an experimental system was established in this way, it tended to be retained for further use in the DevRon, rather than returned to its manufacturer for further development. This low-level melding of the technical and operational communities provided an informal path for new technology like LOFAR and the towed array to be inserted into the submarine force.

The last major submarine community activity was the development of a new, heavy-weight ASW torpedo designed for use against nuclear submarines—the Mk. 48. This story merges with the story of the Navy's response to the Alfa/Papa threat, which will be discussed below.

The VP community focused on solving the localization problem created by initial, long-range, LOFAR detections by Jezebel omnidirectional buoys and on deploying and modernizing Lockheed's P-3 Orion. The key to solving the localization problem was DIFAR, a directional LOFAR buoy. DIFAR was not a new concept, but its development had been postponed in the years after Jezebel's introduction on the assumption that CODAR and Julie would suffice. The latter two had the advantage of using existing, omnidirectional, broadband buoys, whereas DIFAR required a new, more advanced buoy. One of the first steps taken by Admiral Martell when he became OP-95 was to direct that DIFAR buoys be developed on a priority basis.⁶⁷

DIFAR replaced CODAR as the means of localizing a Jezebel contact. Unlike CODAR, which used broadband processing, DIFAR used narrowband processing and could easily match the detection of omnidirectional Jezebel buoys. A plant of several DIFAR buoys with a long enough baseline provided several bearings to the target that could be used to triangulate the range. Flying that distance down the target bearing would usually bring the P-3 within range to achieve a fire control solution.

The deployment of the P-3, beginning in the early 1960s, gave the VP community a faster aircraft than the P-2 it replaced and one that was capable of carrying a much larger suite of equipment and crew. P-3 operating bases were established at locations that allowed them timely access to SOSUS barriers, and as those barriers expanded during the 1960s, the SOSUS/VP team developed an ocean-wide reach in the Atlantic and the Pacific. It was this development that led to the demise of the mid-ocean, hunter-killer role for CVS task forces, relegating them to the battle group and convoy escort roles. The P-3C, originally known as the A-New project, was an explicit attempt to modernize the avionics in the P-3, integrating their various functions and making them more user friendly through automation. This was considered necessary against faster nuclear submarines, which imposed a much faster decision cycle on system operators, who on the P-3A performed the integration function themselves and had already reached task saturation when faced with slower diesel-electric boats.

One role for which the SOSUS/VP team developed a unique aptitude was to stay on top of forward deployed Soviet SSBNs. This contributed to the strategic ASW role that had played such an important part in the rise of ASW to the status of a national mission. According to Admiral Hooper, Director of ASW Research and Development, one of the principles underlying the strategic ASW mission was:

. . . that one would like to destroy these missiles (Soviet SLBMs) or the means of launching them before they are launched, if possible, and if so launched we would like to destroy the missiles immediately and then get those which have not been launched. In other words, missile destruction is considered as associated with the anti-submarine warfare program.⁶⁸

In application, this principle argued for a means of holding forward-deployed SSBNs at risk of prompt destruction, and the SOSUS/VP team was already prepared to adopt this mission when the first Yankee deployments occurred in the late 1960s.⁶⁹

The submarine community was also prepared for strategic ASW against forward-deployed Soviet SSBNs because of its capability to track them covertly in their deployment areas. Because Soviet SSBNs of the Hotel and Yankee classes had to pass through Allied barriers before getting within range of their targets, American SSNs could be vectored by SOSUS to intercept them as they passed through those barriers. The SSN would then maintain continuous contact with its quarry, in some cases for the entire duration of the SSBN's forward patrol. Also, a powerful synergy existed between SSN tracking operations and the SOSUS/VP team. In those cases, when the former lost contact with its target, the latter was often able to quickly reacquire it and hand it back off to the SSN, which could then resume tracking.⁷⁰

This was a significant capability because the assumption on both sides appears to have been that Soviet SSBNs not already forward deployed on the far side of NATO's ASW barriers when a war started would never even get into position to deliver their missiles against the United States, either because they would come under immediate nuclear attack if still in their ports or be destroyed at NATO ASW barriers before they got within missile range of their targets. This is one reason why the Soviets may have considered their non-deployed SSBNs as theater nuclear assets for use against European and/or Asian targets.

Traditional ASW Communities and the Barrier Strategy

As the SOSUS, submarine, and VP communities consolidated the passive acoustic approach to ASW during the 1960s and early 1970s, the carrier-based air and surface ASW communities struggled with the technical challenge of making themselves relevant to the problem of ASW against nuclear submarines. This technical challenge was combined with the political challenge of justifying investments in ASW in communities where other mission priorities were higher. As noted, this period saw the demise first of the open-ocean, hunter-killer role for combined, CVS-destroyer ASW groups and then the elimination of those groups altogether and the adoption of the all-purpose CV air wing. It also saw great turmoil in destroyer ASW programs, including technical problems with active sonar and long-range ASW weapons, and doctrinal debates over the future role of the surface combatant force.

The HUK mission for CVS groups died because the land-based P-3 could do it more cheaply once SOSUS arrays and VP bases were forward deployed. VS and VP aircraft used essentially the same sonobuoy systems to detect and localize nuclear submarines,

and by the mid to late 1960s, a land-based P-3 could go almost anywhere a sea-based S-2 could. CVS groups certainly had the ability to more densely cover a given area with air ASW assets than did more distant VP bases, and their destroyers provided an active sonar platform with more endurance than a P-3, but these capabilities were more relevant to the radar flooding and hold-down tactics used against diesel-electric boats, and ASW against diesel boats was increasingly becoming the responsibility of Allied navies.

The CVS groups also died because after Vietnam the cost of maintaining separate CVA and CVS groups was deemed unaffordable given that the latter now existed primarily to screen the former. This resulted in the multipurpose CV concept which saw half of a CVS wing—one VS and one HS squadron—added to each existing attack carrier wing, replacing a dozen fighter, attack, and reconnaissance aircraft, and requiring ship alterations by installation of ASW facilities and equipment.

Amidst these major doctrinal changes, technical developments in the VS and HS communities continued. The highlights here were the transition from the S-2 to the S-3, and the development of the SH-3. The S-3 was an ambitious attempt to integrate a new, carrier-compatible, jet platform with an avionics suite that included a very powerful new periscope detection radar, onboard acoustic sonobuoy processing, MAD, ESM, and homing torpedoes. First deployed in 1974, the S-3A's autonomous onboard sonobuoy processing capability was one of its key attributes, giving it the ability to operate beyond the range of line-of-sight data links back to the carrier. But this highly automated and sophisticated avionics suite shared the major reliability problems that other contemporary systems had in the period during the early 1970s when advanced digital electronic systems were first introduced into the U.S. military. As a result of these problems, the VS community was hampered in its operations until the development in the 1980s of the S-3B.

Fewer problems attended the evolution of carrier-based, helicopter ASW platforms. Interestingly, this was one of the first areas where the ASW communities using the radar and active sonar ASW methods, which won the Second Battle, were responsible for a major technical innovation in Cold War ASW—the introduction of the ASW helicopter with an active, dipping sonar. Beginning in the 1950s, the carrier-based air ASW community was one of the driving forces behind helicopter development, and within the HUK groups, HS squadrons deploying active, dipping sonars became a key addition to the combined arms ASW team.

HS squadrons gave the HUK group an active sonar platform with the speed and mobility of an aircraft. The original attraction of helicopters with an airborne dipping sonar was to cooperate with radar-equipped aircraft in operations against snorkelers. The latter would often detect a snorkel, but the submarine would submerge and be lost when

it went on battery because no destroyers were within range to hold the contact with active sonar. The ASW helicopter, with a dipping sonar, filled this gap by holding contacts until destroyers, with the endurance to hold the submarine down until its batteries were exhausted, arrived. As ASW against nuclear submarines became more important, HS squadrons also were useful because they could operate in noisy environments where passive acoustics were much less effective, but where screening forces were still necessary, as in the inner screen of a carrier battle group or within a convoy.

The culmination of this first phase of the helicopter's use as an ASW platform was the SH-3 Sea King. The Sea King was too big to be deployed on all but the largest surface combatants of its time, which limited the ASW helicopter to being a carrier-based platform. This would change in the early 1970s with the development of LAMPS (Light Airborne Multipurpose System) ASW helicopters, which leads into a discussion of the surface ASW community.

The key technical issue that dominated surface ASW during the 1960s was to get the SQS-26 to achieve its full potential as a bottom bounce and convergence zone active sonar. As long as the surface community was limited to direct path, above-the-layer submarine detections with its active sonar, it was going to have limited utility as an ASW platform against any modern submarine, whether conventional or nuclear. With a fully capable SQS-26, it would become a more formidable anti-diesel ASW asset, but against a nuclear submarine it would still suffer from the lack of a weapon to match the range of its main sensor.

By the close of the 1960s, as the SQS-26 finally emerged from its extended development phase, the weapon issue became acute. During that decade, long-range, surface ship ASW armament development had focused on ASROC and DASH. ASROC was fairly effective out to the 10,000-yard, direct-path ranges achievable by the SQS-4 and SQS-23, but large range extensions for such a rocket-propelled weapon were difficult to implement because of the "time late" (i.e., how long after the last contact it was fired) of the weapon and the speed of the target.

In theory, DASH solved both the range and the time late problems, but in practice never achieved the operational reliability needed for effective operation. Often described as a technical failure, DASH's problems were almost certainly of a more organizational nature.⁷¹

The eventual success of the SQS-26 get-well program led the surface community to finally abandon DASH in 1968 and embrace a manned helicopter option. This led to the LAMPS I program, a conversion of a lightweight, commercial utility helicopter, which first deployed in 1972. LAMPS I was small enough to operate from many DASH ships and it gave SQS-26 ships a reliable, first convergence zone weapon. In the words of Bob

Frosch, “(LAMPS) finally gave surface ships a final location and detection system to go with its convergence zone sonar so that we could finally use SQS-26 and towed arrays for purposes other than deciding when to pray.”⁷²

The LAMPS/SQS-26 combination was widely deployed in the *Garcia*, *Brooke*, and *Knox* class destroyer escorts (later redesignated FFs and FFGs), sixty-two of which were deployed between 1960–1967. These were arguably the first truly successful, postwar ASW ships, and at the same time, certainly the least popular members of the destroyer community. This inverse relationship between ASW effectiveness and acceptance in the destroyer community highlights the fundamental doctrinal turmoil that community was experiencing during this period.

As was true in the particular case of DASH, where inherent technical problems were often used to explain what were really organizational weaknesses, it was generally believed during the 1960s and much of the 1970s that surface ships were incapable of being effective ASW platforms against nuclear submarines. In most cases, it was more accurate to say that given the multimission demands facing the surface community and its own doctrinal priorities, ASW was always going to be a lower priority compared to antisurface (ASUW) and anti-air (AAW) warfare. Destroyer officers wanted fast, seaworthy ships armed with guns and, later, antiship missiles, able to defeat their like in direct combat.⁷³ This internal doctrinal proclivity was leavened by the powerful carrier aviation community’s need for surface-to-air missile-armed, anti-air escorts for carrier battle groups.

Juxtaposed alongside these powerful pressures was the need for large numbers of ocean-going ASW escorts for battle groups, underway replenishment groups, amphibious groups, and merchant convoys. Truly multipurpose destroyers combining all three capabilities were too expensive to build in the numbers necessary for all ASW missions, and single purpose destroyer escorts like the *Knox* class were therefore built to provide the numbers needed for the ASW missions like amphibious group and convoy escort, where the submarine threat was potentially high, but the air and surface threat was reduced or being handled by other platforms.

These ships were heroically unpopular in much of the destroyer community because of their explicit design emphasis on ASW at the expense of AAW and especially ASUW.⁷⁴ Given the attitude of the destroyer community toward dedicated ASW escorts, it is not surprising that ASW advocates within that community had difficulty obtaining the resources needed either to solve existing technical problems in ASW or to fund new, more innovative approaches.

Another problem was that the ASW R&D and acquisition community was increasingly dominated by practitioners of the passive acoustic approach, and particularly by the

submarine community. Members of this community tended to view surface combatants as poor passive sonar platforms, which they were initially. On the other hand, efforts to make surface combatants better passive sonar platforms could be viewed by the same community as unnecessary and even competitive with other ASW platforms like the submarine, and therefore to be opposed. Indeed, this is how some explain the demise of Project Sea Hawk in the mid 1960s, a program that had been designed to produce an advanced ASW escort combining quiet gas turbine propulsion with an advanced, integrated sonar suite that included a new VDS capable of independent operation.⁷⁵

After Sea Hawk was canceled, development of its key components continued, and indeed most elements of Sea Hawk were later included in what became the *Spruance*, which began deploying in 1975. The later success of *Spruance* as a passive acoustic platform, which will be discussed below, demonstrated that it was probably organizational and funding issues more than technical constraints which prevented the surface force from expanding its role in ASW sooner. Certainly it was not technical constraints which prevented the Navy from developing a destroyer that combined a towed array like STASS, Sea King, and a rafted propulsion plant, whether using the new gas turbines or not. Such a platform could have provided a passive, two convergence zone, submarine detection and prosecution capability to the surface force, and the technology to do so had already been demonstrated by the mid-1960s.

Thus, by the mid-1970s, the surface force had finally succeeded in deploying a force capable of providing a reasonably effective active screen out to one convergence zone around high value assets, but it had yet to embrace the passive acoustic approach necessary to extend its reach out to two or three convergence zones.

On the other hand, beginning in the early 1970s, the passive acoustic-based, barrier ASW strategy began to encounter unexpected challenges. The great fear and anticipation of Soviet development of quiet nuclear submarines remained largely unrealized in practice. Thus, continuing efforts to counter this expected challenge tended to further reinforce the American acoustic advantage when they met with a mostly static threat measured in acoustic terms. This was a reassuring development, but it was accompanied by the three other challenges described earlier that will be referred to below as the Alfa, Charlie, and Delta threats, after the eponymous Soviet submarine classes. The Alfa threat was primarily a challenge to American ASW weapons, while the Charlie threat challenged the surface ASW community, and the Delta threat challenged the SOSUS, submarine, and VP communities.

The Alfa Threat

ASW weapon development after World War II largely focused on acoustic homing torpedo development, building on the success achieved by the air-launched Mk. 24 “mine” and the submarine-launched Mk. 27 anti-escort torpedo in the Second Battle. Quickly, a distinction developed between light and heavyweight torpedoes:

Although modern lightweight and heavyweight torpedoes had their respective origins in the very similar Mk. 24 and Mk. 27 torpedoes of World War II, they have become very different not only in size and weight, but also in their attack paradigm. A heavyweight torpedo is launched thousands of yards from its target, well beyond the acquisition range of the homing system. . . . A lightweight torpedo is normally delivered to the near vicinity of its target by the launch platform.⁷⁶

Lightweight torpedoes became the weapon of choice for the air ASW community, while heavyweight torpedoes were developed for submarines. Surface ships initially carried both, but came to rely mostly on “thrown” (ASROC) or air-delivered (DASH, LAMPS) lightweight torpedoes.

The first postwar lightweight torpedo was the Mk. 43. It was the first active homing torpedo (Mks. 24 and 27 had been passive), and originally was capable of 15-knot speed and 650-foot depth when first deployed in 1951. Later versions were able to reach 20 knots and 1,000 feet. The Mk. 44, which entered production in 1956, was designed to counter Type XXIs with submerged speeds of up to 20 knots. It had a range of 6,000 yards and a speed of 30 knots. Over 10,000 were produced and some remain in service with foreign navies.

Even as the Mk. 44 entered production, it was clear that it would be inadequate against the faster nuclear submarines which were already on the horizon. The basic problem was that an ASW torpedo needs a 50 percent margin of superiority in speed over its target in order to assure that the target does not escape once alerted to the attack. Nuclear submarines were expected to achieve 30-knot speeds at 1,000 foot depths, creating the need for a 45-knot torpedo. A development program to achieve this for both light and heavyweight torpedoes was begun in 1956. In the first case, this resulted in the Mk. 46, which began deploying in 1965.

The same size as a Mk. 43, the Mk. 46 apparently met its performance goals.⁷⁷ Dropped from an aircraft, it created against a submerged submarine a no-escape zone shaped like a cylinder several thousand yards in diameter and roughly 1,500 feet deep. The cue for dropping the torpedo was usually the aircraft’s magnetic anomaly detection MAD gear, whose range was often less than the search volume of the torpedo itself. During the mid and late 1960s, the Mk. 46 was deployed widely in the VP community and on ASROCs deployed on surface ships.

Heavyweight torpedo development followed a similar path. The first submarine-launched ASW torpedo was the Mk. 27-4, a 1948 modification to the World War II anti-escort weapon. It had a speed of 16 knots and a range of 6,200 yards, and was an interim weapon designed primarily for attacking snorkelers. The more permanent solution was the Mk. 37, begun at roughly the same time, but with more ambitious requirements. When first deployed in 1957, the Mk. 37 was a 26-knot weapon with a 10,000-yard range. As with the Mk. 27, when launched the Mk. 37 would run out for a set distance along a fixed bearing and then begin a passive circular search, but terminal homing was active. The 1960 Mk. 37-1 added wire guidance, which allowed the submarine to control the torpedo during the run out, making it more effective against faster, more maneuverable targets. The 37-1 was effective against targets with speeds up to 20 knots and down to depths of 1,000 feet, which was only minimally satisfactory against first generation Soviet nuclear submarines which could exceed 20 knots.

Therefore, the same 1956 torpedo development program provoked by the nuclear submarine threat that produced the Mk. 46 also included a heavyweight torpedo program. Formal requirements for this latter program were established in 1960, aiming at a 55-knot speed, 35,000-yard range, and 2,500-foot depth.⁷⁸ In 1967, it was decided to make this an antisurface weapon as well, which mandated a larger warhead. In 1971, production of what had become the Mk. 48 started, and the first torpedoes were delivered in 1972, some seven years after the lightweight Mk. 46 was delivered.

The extended gestation experienced by the Mk. 48 and, to a lesser extent, the Mk. 46 is a reflection of two factors. First, these were very advanced weapons designed to very ambitious requirements. Second, these requirements were clearly designed to drive conventional torpedo technology as much as they were designed to meet a particular, near-term Soviet submarine threat. Thus, in both areas, nuclear alternatives existed and were deployed, using lethal radius to substitute for weapon performance. This second factor was particularly apparent in the Mk. 48 program, which included the development of a massive, instrumented torpedo testing facility and firing range off Andros Island in the Caribbean—and which was not conducted on a crash basis.⁷⁹

These two factors led to a mixed picture in the years from the mid-1950s through the end of the 1960s. American ASW torpedo development had certainly kept up with the Type XXI threat during the early part of this period, but by at least some measures, primarily speed, it appears to have fallen behind the nuclear submarine threat, particularly in the submarine force, where 25-knot Mk. 37s were used through 1972 against a threat that approached 30 knots. Certainly stealthy tactics designed to minimize warning of attack could go a long way toward easing these concerns, and given the enormous acoustic advantage that had emerged by the 1960s, it was not hard to design such

tactics for American SSNs using Mk. 37s. Meanwhile, the disparity in speed between the Mk. 46 and its prey was less troublesome, which made sense because the Mk. 46 used active search and was therefore bound to alert its opponent as soon as it hit the water.

This reasonably happy state of affairs was upset in 1970 with the deployment of the Alfa SSN, whose estimated 45-knot speed and 2,000–2,500 foot operating depth surprised the U.S. Navy. Alfa used a high-power-density, liquid metal reactor plant to increase the power-to-weight and volume ratios of her propulsion plant, while simultaneously reducing the hull weight needed for extreme operating depths by using a titanium pressure hull. Alfa had a sister, the Papa SSGN, which appeared to employ these same submarine design technologies for the antiship mission. These submarines, assuming they were the lead boats of new submarine classes, threatened American ASW weapons with obsolescence.

Any assessment of the American response to this Soviet challenge is complicated by the fact that the fast, deep-diving nuclear submarine threat proved in many ways to be a false alarm. Certainly Alfa was fast, demonstrating a 41-knot speed, but her titanium hull had actually been used to decrease displacement rather than increase operating depth, which was more like 1,100 feet. Finally, Alfa's liquid metal reactors used molten lead-bismuth as its primary coolant, which generated formidable maintenance requirements, including the need for a continuous stream of superheated steam from shore when the submarine was in port to keep the metal coolant from "freezing."⁸⁰ Thus, Alfa did not enter serial production until later in the 1970s, and a total of only six were deployed before the program was canceled. Likewise, only one Papa was ever deployed. Instead, the Soviets focused on building the more traditional CVYs, which were 30-knot submarines, with the exception of Charlie, of which more is offered in the next section. Nevertheless, Alfa and Papa were viewed as impressive achievements that might return in more reliable and cost-effective form at a later date, and weapon development programs were begun in 1972 in anticipation of that event.

The result of these programs reversed in some ways the experience of the earlier effort to preempt the Soviet nuclear submarine threat begun in 1956. In the later case, steady improvements in the Mk. 48 were made, first with the Mk. 48-3 in the late 1970s, which gave the submarine a track-via-torpedo capability through the guidance wire, and then with the envelope extension program deployed in the early 1980s with a deeper operating depth, and finally with a series of ADCAP (Advanced Capability) modifications beginning in the late 1980s that apparently culminated in a 63-knot torpedo.⁸¹ ADCAPs were bought in significant numbers and deployed by the submarine force.

Lightweight torpedo developments designed to counter the Alfa threat appear to have gone more slowly in that the Mk. 50 replacement to the Mk. 46 did not finally deploy

until the late 1980s, and was never produced in great numbers. On the other hand, many interim modifications to the Mk. 46 were implemented, including the 46-5 NEARTIP (Near Term Improvement Program), which deployed in the late 1970s. Lightweight torpedo development was complicated by multiple concerns beyond speed and depth performance, including warhead lethality, shallow water performance, and vulnerability of the active seeker to stealthy anechoic tiles, all of which were also addressed to varying degrees by NEARTIP and the Mk. 50.

It is hard to avoid the conclusion that the Alfa did more for the U.S. Navy's ASW posture than it did for the Soviet Navy's prosubmarine posture. The Alfas were clearly a programmatic failure, whether for technical or budgetary reasons, or some combination thereof. Yet they provoked massive investments in ASW weapons by the U.S. Navy, and these investments resulted in dramatic improvements in the Mk. 46 and Mk. 48, improvements which helped ensure their continuing effectiveness against the much more widely deployed CVYs. In some ways, this experience would be repeated with the Charlie threat.

The Charlie Threat

The Charlie SSGN was the first Soviet submarine to deploy submerged launch, anti-ship missiles. Twelve Charlie Is were deployed beginning in 1969, each carrying eight SS-N-7s of approximately 30-mile range. Six Charlie IIs followed, beginning in 1973, each with eight SS-N-8s of 60-mile range. The total of eighteen Charlie SSGNs eventually deployed constituted by far the smallest class of the second generation of Soviet nuclear submarines which, depending on one's definition, also included forty-nine Victor SSNs and seventy-six Yankee/Delta SSBNs.⁸² In order to understand the effect the Charlie had on the U.S. Navy, one needs to look at the capabilities of its predecessor in the HEN class, the Echo.

The Echo SSGN, along with its non-nuclear contemporary, the Juliett SSG, deployed in its antiship version 400-mile-range SS-N-3 cruise missiles designed originally for the land attack role. SS-N-3s were like the U.S. Navy's Regulus in that they demanded that the submarine platform surface for launch, deploy and activate a tracking radar, and remain on the surface linked to the high altitude cruise missile in flight via datalink, providing guidance commands based on the submarine radar's tracking data. In its antiship version, the Echo depended on prior cueing by a radar-equipped maritime patrol aircraft and terminal homing by a radar seeker on the SS-N-3 itself.

Echo antiship SSGNs were primarily anti-carrier weapons, intended originally as a response to the threat of nuclear strikes against the Soviet Union by carrier-based aircraft like the A-3 Skywarrior. As such, their SS-N-3s came in both nuclear and conventional

versions. Outside of this nuclear, homeland defense mission, the Echo's concept of operation had many problems. In blue water, anti-carrier operations using conventional warheads, the Echos were vulnerable to long-range tracking by SOSUS; the maritime patrol aircraft that cued them were limited in endurance and range and vulnerable to the carrier's air defenses; the submarine itself was vulnerable while on the surface operating its radar; the high altitude, relatively slow SS-N-3 was vulnerable to air defenses in flight; and its radar seeker was vulnerable to jamming and deception measures. Thus, in many respects, the Echo was an ASW challenge that could also be countered using ASUW and AAW methods, which is largely what happened.⁸³

Charlie seemed to eliminate many of these vulnerabilities. Though it still relied on offboard cueing, it was deployed along with the first Soviet ocean surveillance satellites, which were designed to replace the vulnerable and range-limited maritime patrol aircraft force with a space-based system, and whose limitations were not yet fully apparent in the early 1970s.⁸⁴ The shorter range of the SS-N-7, and later the SS-N-9, compared to the SS-N-3 reduced the flight time of the missile and eliminated the need for mid-course guidance, thereby eliminating the need for a radar on the launcher and in turn allowing a submerged fire-and-forget launch. Finally, the missiles were faster and flew at low altitude, complicating the air defense problem.

Of course, Charlie was still vulnerable to passive acoustic barriers; but unlike Echo, it appeared that even in mid-ocean, blue-water operations carrier battle groups would not be able to defend themselves against Charlies that leaked through the barriers, as some inevitably would in wartime, or which had predeployed in peacetime. Finally, Charlie appeared clearly more effective than Echo in the homeland defense mission in which it would operate against American carriers deploying forward of the fixed ASW barriers.

Much of this promise was not realized in practice for several reasons. The Soviet space-based, ocean surveillance system never fully achieved its original promise for reasons that go beyond the scope of this discussion, which kept Soviet antiship SSGNs dependent on maritime patrol aircraft cueing, which remained a major weakness in blue-water operations. Another option was to create a more autonomous concept of operations in which SS-N-7s and 9s were cued by the SSGN's own passive sonar, which certainly could detect, localize, and classify fast surface ships at 30 or even 60 miles distance, as indeed Western submarine forces later did with Sub-Harpoon.⁸⁵ More important, the Charlie was apparently the victim of a bottleneck in Soviet reactor production during the busy years of CVY construction. Unique among Soviet combatant submarines, Charlies had only one reactor driving a single screw; their top speed was limited to 24 knots, which was not sufficient to keep up with a carrier battle group in blue water.

These weaknesses help explain the limited Charlie production run, but they were not entirely apparent to the U.S. Navy when the Charlie first appeared. One element of the Navy's response to the Charlie threat was the long-postponed embrace by the American surface ASW community of the passive acoustic approach to ASW.

The rationale for this was that submerged-launch, sea-skimming, antiship cruise missiles were much less vulnerable to ASUW or AAW countermeasures by a carrier battle group, and that the ASW screen therefore needed to be expanded in both scope and capability. SSGNs would not suffer from limiting lines of approach against fast carrier battle groups in the same way that torpedo-armed SSNs did, and they could therefore attack from all azimuths. Furthermore, their weapons would allow them to stand off beyond the range of a destroyer screen using active sonar and also eliminate the need for exposing a periscope within the carrier's screen, as Soviet SSNs were wont to do during high-speed approach runs despite the threat of detection by airborne radars. In order to defend itself, the battle group would need to be able to quickly detect and prosecute submerged targets at greater ranges and over wider azimuths. Because a carrier's sound signature propagates through water to the first and second convergence zones—hence the ranges of SS-N-7s and SS-N-9s—the only answer was for surface escorts to expand the reach of both their sensors and their weapons out to multiple rather than single convergence zones.

The result was that the surface force slowly evolved from a sensor/weapon suite based on the SQS-26, ASROC, and LAMPS I to one that included by the late 1980s a passive towed array and the longer range LAMPS III. The LAMPS/towed array combination revolutionized surface ship ASW capabilities by combining the detection ranges heretofore only achieved at the tactical level by submarines deploying large, below layer, passive arrays with the rapid, long-range prosecution capabilities provided only by air ASW assets.

Waypoints in this transformation included: first experiments and initial deployments with a towed array surveillance system (TASS) surveillance array (SQR-14/15) towed from the variable depth sonar (VDS) fish on USS *Patterson* (DE-1061) in the early 1970s; the deployment of four TASS-equipped *Knox* class frigates in 1973, primarily to the Mediterranean for acoustic surveillance because of that sea's lack of a deep sound channel for use by SOSUS; first experiments and deployments with an interim tactical towed array sonar system (ITASS) array (SQR-18) on USS *Joseph Hewes* (FF 1078) in 1978; and first experiments and deployments of a higher speed tactical array (SQR-19) on USS *Moosbrugger* (DD 980) in 1982. By 1987, there were some forty SQR-18s deployed, with SQR-19 about to deploy on *Spruances*.⁸⁶ These critical tests repeated the earlier experience of the submarine force as it progressed through various experiments

like the SSKs, *Albacore*, and *Tullibee*. Another analogy was the assignment of a special unit to the task of conducting at-sea evaluation of laboratory concepts: SubDevGru 2 in the case of the submarine force, and in 1984 the San Diego-based Destroyer Squadron 31 for the surface ASW force.⁸⁷ Unlike the submarine force though, surface ships remained multimission platforms, and the surface community retained its instinct to focus on ASUW and AAW, never committing as aggressively to exploiting the ASW potential of its assets as the submarine force had.

For example, funding constraints forced *Spruance*'s developers to use a "build it and they will come" strategy, with "it" being the ship and "they" being the bulk of its combat systems. In the ASW mission area, the first *Spruances* deployed in 1975, with only SQS-53, a digital, solid state version of the SQS-26, and ASROC. In the early 1980s, these ships were upgraded with LAMPS I, a digital spectrum analyzer, and torpedo decoys, which added a passive, single convergence zone capability. Only in the late 1980s did the fully integrated SQQ-89 ASW suite arrive, including LAMPS III and the SQR-19 towed array, which gave a passive, two to three convergence zone capability.⁸⁸

Certainly other pressures besides the Charlie SSGN threat were responsible for this evolution. But the SSGN threat did play an important role, and it is hard not to see analogies in this process to the contemporary story of the rise of the Alfa threat and the Navy's response to it. Unlike the Alfas and the lone Papa, Charlies were deployed in meaningful numbers, but they did not decisively threaten U.S. carrier formations; yet the U.S. Navy responded to the Charlie threat with, among other measures, a vigorous program to improve the ASW capabilities of its surface escorts. By the mid 1980s, the surface community was finally demonstrating in practice the ASW potential which it had always possessed. On the other hand, unlike in the case of the fast, deep-diving nuclear submarine threat, the Soviet antiship SSGN threat did eventually materialize, albeit a decade after it was originally identified with the 1981 deployment of Oscar, armed with twenty-four autonomous, 300-mile-range, submerged launch SS-N-19s. The improvements in the intervening period in American surface ASW capabilities therefore proved fortuitous, although, as with the original Echo SSGN threat, the answer to the Oscar transcended ASW alone and demanded a multifaceted approach that included counter-surveillance and AAW as well.

The Delta Threat

The third challenge to the Navy's passive acoustic barrier strategy was the deployment of long-range Soviet SLBMs on the Delta SSBN, a modification of the Yankee. A total of forty-two Deltas deployed in four classes, beginning in 1973, with missiles that had ranges of 3,500 to (in the case of the SS-N-8 Mod 2) nearly 5,000 miles. These ranges were sufficient to allow SSBN alert patrols in the marginal ice seas of the Soviet Arctic

littoral, including the Norwegian and Barents Seas, and later, under the permanent ice of the Arctic Ocean. This had two dramatic effects. First, Soviet SSBNs no longer needed to pass through SOSUS barriers in order to get within range of their targets. Second, deployed close to home, they could now be protected in so-called bastions by the rest of the Soviet Navy.

The one element of the U.S. Navy's strategic ASW posture, in its original formulation, that demanded explicit attention was the need to threaten with prompt destruction forward-deployed SSBNs that menaced the United States with surprise, short-warning attacks against its nuclear forces and national command authorities. Otherwise, at a tactical and operational level, strategic ASW was a lesser included case of the overall ASW posture. This was so because the range of first and second generation Soviet SLBMs was insufficient to allow attacks against the continental United States without prior passage by the launch platform through at least one and sometimes several ASW barriers. These barriers were established to keep all Soviet submarine forces from deploying into mid-ocean areas in a war, and they did not discriminate among platforms. Thus, assuming that forward deployed SSBNs could be held at risk, the rest of the task of protecting the United States from Soviet SLBMs was performed by the barriers.

Delta eliminated this natural convergence of ASW tasks, forcing the Navy and higher political authorities to consider whether a new strategic ASW posture needed to be fashioned in which explicit steps would be taken to counter Soviet SSBNs able to strike American targets from the far side of Western ASW barriers. One position in the ensuing debate, first associated with the Nixon doctrine and the tenure of Admiral Elmo Zumwalt as Chief of Naval Operations, emphasized the U.S. Navy's sea control mission and its role in assuring the reinforcement of conventional forces assigned the defense of Western Europe. Focusing on sea control would mean the abandonment of any thoughts of trying to place at risk Delta SSBNs withheld in Soviet littoral waters. As one naval historian has written, "Zumwalt consciously chose to avoid offensive operations in strategically sensitive regions where the enemy ballistic missile submarines were on patrol. On one occasion, the State Department even announced that this was declared U.S. strategy."⁸⁹

An alternative view, and the one eventually adopted, was that an explicit attempt should be made to go forward and hold Soviet SSBNs at risk. This would be done by surging American SSNs into Soviet SSBN patrol areas in a crisis or at the outset of a war. Over the thirty to sixty days that such a war could be surmised to last in its conventional phase, American SSNs would search Soviet submarine operating areas and attack those Soviet submarines, especially SSBNs, which they might find. The rationale for this approach was twofold. First, it would steadily change the strategic nuclear

balance in the United States' favor over the course of a conventional war in Europe. This might simultaneously reduce the Soviets' incentives for continuing to fight conventionally if they had met stalemate, reduce their incentives to escalate in order to break that stalemate, and increase the credibility of Western escalation in the alternative case, where the Soviet conventional attack seemed on the brink of success.

Second, and perhaps more important from the Navy's point of view, a forward strategic ASW campaign would actually serve American sea control efforts by forcing the Soviet Navy to divert many of its sea denial assets to the SSBN bastion defense mission. Here, the approach was an inversion of the normal relationship between the dominant and weaker naval powers regarding the submarine, with the U.S. Navy exploiting the fact that its submarines could also divert Soviet naval assets to the ASW mission in disproportionate numbers.

Evidence that such a diversion would be possible already existed by the mid-1970s. From the beginning, forward deployments of Yankee SSBNs by the Soviets had put them in the teeth of a formidable array of U.S. Navy and other Western ASW assets. Aware of this vulnerability, analogous in the words of one U.S. Navy admiral as that of a "tethered goat," the Soviet Navy "pulled some of its best torpedo-armed nuclear-powered submarines out of the Mediterranean and deployed them to the western Atlantic, perhaps in an effort to provide protection for patrolling missile subs which until now have operated alone."⁹⁰ Both rationales for the forward strategic ASW mission were described publicly by Admiral James Watkins, the Chief of Naval Operations, in 1986, although most if not all elements of this strategy were in place by the late 1970s.⁹¹

Forward strategic ASW could only be performed by SSNs, especially when it involved under-ice operations.⁹² Therefore, as the mission grew in importance, this fact was reflected in both force structure and platform design decisions, including a steady rise in SSN force levels, culminating in the hundred-SSN-force requirement of the 600-ship navy and the design of USS *Seawolf*. The cost of growing SSN force levels and the focus on far forward operations contributed to a relative decline in the share of investments in other ASW communities.⁹³ It also led to *Seawolf*, whose emphasis on fast tactical search speeds and a massive torpedo magazine were reflections of its design mission, which was to independently search for and kill Soviet submarines in the relatively confined and target rich northern waters of the Soviet Arctic littoral.

There are several differences in the story of the U.S. Navy's response to the Delta threat compared to the Alfa and Charlie threats. First, the Soviet long-range SSBN threat actually developed as expected. It did not turn out to be an experiment that failed or was dramatically delayed in its execution, but instead was implemented rapidly and on a large scale. Second, there was some degree of open political controversy over whether a

response to this Soviet challenge was even needed, whereas in the previous cases any controversy that occurred was largely internal to the Navy and the Department of Defense, focused on finding the best technical and operational means of responding to a challenge that all agreed had to be met. Third, it is also more difficult to assess how effective the Navy's response was to the Delta challenge.

It is difficult to determine whether the Navy's SSN-based, forward strategic ASW posture would have been effective at the tactical and operational levels or whether it would have had its anticipated political effects. The uncertainties here are basic, given both the large scale of the anticipated strategic ASW campaign and the lack of documentation for the sources of Soviet behavior.

Unclassified tactical and operational assessments of the Navy's forward strategic ASW campaign were and remain almost universally pessimistic concerning the Navy's capabilities in this mission.⁹⁴ The main reasons given for this skepticism are the dual effects of shallow water and quieter submarines on acoustic search rates. Shallow water eliminates the deep sound channel and convergence zone propagation paths that minimize sound absorption over long distances; it limits detection ranges to the direct path, and quiet submarines amplify this effect by reducing the source level of the original signal. Forward strategic ASW would therefore be conducted in an environment that reduced the effect of the acoustic advantage that American SSNs had traditionally enjoyed versus Soviet submarines, and more important, quiet Soviet SSBNs would begin to eliminate that acoustic advantage.

The assumption in these analyses that Soviet SSBNs were becoming quieter and would achieve further reductions in source levels in the future reflected the fact that a serious and unambiguous Soviet submarine quieting effort had finally become manifest by the early 1980s. Such an effort had been anticipated for twenty years.⁹⁵ Even as late as 1976, the Navy was still being surprised at how loud successive generations of Soviet submarines remained. For example:

Those of us who are in the technical community had staked our reputations on the fact that when the Delta-class submarine(s) went to sea in 1976 they were going to demonstrate a fundamental quieting program, and we said that to the rest of the world and they did not do it and we lost a lot of credibility.⁹⁶

This turned out to be the last of many such pleasant surprises, because soon after Delta's deployment came the Victor III in the late 1970s. Regarding the Victor III, Admiral Watkins testified that "we had misjudged the absolute sound and pressure levels of the Soviet Victor III. We had made an estimating error and found that they were quieter than we thought. . . . We learned that they are very hard to find."⁹⁷ The Victor III was the first Soviet submarine that surprised the Navy with its acoustic stealth, and

its deployment was a harbinger of worse to come. Thus ended the Navy's two-decade long "happy time," and began the fourth and final phase of the Third Battle—the struggle against the very quiet nuclear submarine.

Phase IV of the Third Battle

ASW and Acoustic Parity, 1980–1990

The Victor III was a harbinger of the Akula, the first Soviet submarine that approached or achieved acoustic parity with its American contemporaries. Though first deployed in 1978, it was in 1981 that the full significance of the Victor III's quieting sank in.⁹⁸ From public testimony, it is possible to describe broadly the quieting steps finally taken in this class. In a 1984 reference to operations against Victor IIIs, Chief of Naval Operations Admiral Watkins testified:

What we also learned was that where we had the towed array that covers the low frequency band it was effective every time. The lesson is . . . we need to get the low frequency end developed and accelerate its introduction into the fleet. Now we are working on that. We have put extra dollars into the low frequency end so that we can go after the propeller blade rates and the other things we have to get on a quiet submarine.⁹⁹

The significance of this statement is in its reference to the importance of propeller blade rate tonals for detecting Victor IIIs, which indicates that other, higher frequency, narrowband tonals like those generated by a ship's service turbo-generators had been reduced.

This in turn indicates that rafting and other, more advanced quieting techniques first adopted by *Thresher* in the United States were probably adopted by the Soviets only with Victor III. It also demonstrates the significance of the Toshiba nine-axes milling machinery obtained by the Soviet Union, which gave them the ability to make the kind of skewback propellers that reduce blade rate tonals.¹⁰⁰ This technology, combined on Akula with the quieting technologies already demonstrated on Victor III, gave the Soviets by the mid-1980s a nuclear submarine that could elude SOSUS and frustrate efforts by tactical ASW platforms using passive sonar to establish and maintain contact with it.¹⁰¹ Akula's narrowband, low-frequency tonals had been reduced below the source level of its continuous broadband signature, and the source level of that broadband signature was close or equal to that of American *Sturgeons* and early 688s.¹⁰² Absent a strong narrowband tonal structure, and with low broadband source levels,

passive acoustic detection, classification, and localization of submarines becomes quite difficult at long range, and counter-detection becomes more likely at shorter ranges.

In time-honored fashion, the threat of the truly quiet Soviet nuclear submarine really registered in the larger political environment only when it was associated with an accompanying nuclear weapon threat. In this case, the combination of these two threats occurred in the “Analogous Response” deployments of Akulas armed with nuclear land-attack variants of the SS-N-21 sea-launched cruise missile (SLCM).¹⁰³ Like the U.S. Navy’s TLAM-N version of the Tomahawk SLCM, SS-N-21 could not be detected reliably by existing early warning systems, which raised the specter of “no warning” nuclear attacks against important time-urgent targets like national command centers and bomber bases.¹⁰⁴ At the same time, American ASW forces found it quite difficult to detect and maintain continuous contact on forward deployed Akulas in the way that they had with prior generations of louder submarines.¹⁰⁵ This resulted in several incidents in which, as one participant put it, “the entire Navy had to deploy in order to find and maintain contact on one submarine.”¹⁰⁶

Two responses to the quiet submarine threat emerged during the 1980s. Both were driven by the fear that very long-range, passive acoustic detection of Soviet submarines would soon be a thing of the past. The first response increased the emphasis on the diversion strategy that had first developed in response to the Delta threat, by increasing the U.S. Navy’s wartime emphasis on forward SSN operations. The second response sought to prepare the Navy’s ASW posture for a world in which barriers, open ocean search, and diversion were all less effective. In this world, the only answer was a return to the cooperative ASW tactics that had been largely abandoned after the passive acoustic revolution of the early 1960s.

The Diversion Strategy

The diversion strategy sought to use submarines offensively in forward operations in such a way as to divert the Soviet Navy, and particularly its best SSNs, away from other, more offensive missions. It was classically associated in the Navy’s Maritime Strategy of the 1980s with forward SSN operations in Soviet SSBN bastions, but the decision to deploy TLAM-N on American SSNs may also have been motivated in part by the diversion strategy. In the first and most important case, the argument was that the Soviets would be forced to protect their SSBNs with their best SSNs.

This strategy relied on the unique diversionary effects of forward SSN operations. It was based on the view that the Navy could best exploit its dwindling acoustic superiority through offensive operations, but that eventually, when true acoustic parity arrived, ASW would become essentially impossible. This view was most clearly expressed in

1986 by Admiral Kinnard McKee, then Director of Naval Nuclear Propulsion, when he opined that:

Eventually, U.S. and Soviet submarine capabilities will converge. Then we will have to think about different applications for submarines because ASW is only going to become a defensive business for submarines in my judgment. It will be blind man's bluff with other submarines. . . . Many of the other roles for submarines will become more predominant as we go further into the future, because at some point, nobody will be able to find a submarine with anything.¹⁰⁷

In order to avoid acoustic parity for as long as possible, it was important to wring out the last improvements in passive acoustics and deploy them on a new submarine optimized to exploit them. This would be *Seawolf*. In order to best exploit the acoustic superiority that remained, submarines like *Seawolf* and improved *Los Angeles*-class 688s should be used offensively.

As noted, *Seawolf* was designed with forward operations in mind.¹⁰⁸ Its three key characteristics were a much faster tactical speed than the 688, a much larger weapon load, and eight rather than four torpedo tubes. Tactical speed is the maximum speed at which a submarine can operate and still detect and classify an opposing submarine without being counter-detected. High tactical speeds give high search rates, and high search rates are necessary for independent, forward ASW operations. A larger weapon load gave *Seawolf* more endurance in its operating area by reducing the need to return to port for replenishment. Finally, eight torpedo tubes gave *Seawolf* a larger Mk. 48 multishot capability. Forward ASW operations in the relatively narrow seas of the Soviet Arctic littoral were expected to produce a target rich environment, and in such an environment, torpedo load-outs rather than crew endurance were likely to be the limiting factor on patrol length. Also, the distance back to port or to a submarine tender was longer the further forward were American submarine patrol areas, increasing the base-loss factors involved with multiple sorties.

The benefits in terms of diversion of these forward ASW operations were described by Admiral McKee as follows:

We build a submarine that can stay ahead of the threat and can operate alone and unsupported wherever it wants to go. It provides the fleet commander significantly improved offensive and defensive leverage. . . . It gives him the ability to dictate where the opposition must commit forces to protect themselves. . . . When they have to deal with submarines they cannot handle, it gives them an increased ASW force level requirement, forces them to commit resources to ASW forces that they would rather put in other places, and reduces their tactical flexibility because the amount of forces required to meet a competent submarine threat increases his risk dramatically. . . . Finally, an attack submarine can modify the entire strategic posture and it has. The Soviet strategic sea-based deployment posture is based on his concern for the opposition of U.S. submarines. . . . We would like them to continue to have to deal with that. The bottom line is leverage.¹⁰⁹

The resulting leverage imposed on the Soviets was the asymmetric price paid by any force that must exercise sea control against submarines, diverting the best Soviet SSNs

away from offensive missions where they could otherwise extract the same price from U.S. and Allied ASW forces.

One key to the success of this diversion strategy was a certain minimum level of acoustic superiority. In the long run, Admiral McKee himself had expressed pessimism about whether such an advantage could be maintained. In the near term, even with Akula, forward ASW operations by SSNs might remain effective for several reasons.

First, the levels of quieting achieved by Akula would not be representative of the overall Soviet force for some time. In the meantime, American SSNs could exploit the fact that they retained an acoustic advantage over earlier Soviet submarines, including their SSBNs. That such an advantage still existed is clear from statements that Akula was both quieter than Delta and louder than the latest 688s, giving the latter a still significant acoustic advantage over the bulk of the Soviet SSBN force.¹¹⁰

Second, there is some evidence that the cost of achieving and maintaining acoustic parity for the bulk of its submarine forces might exceed what the Soviets were willing to pay, both financially and politically. In the latter case, the Soviet Navy had to convince Soviet shipyards to incur the costs involved with a serious quieting program. The U.S. Navy discovered those costs in the 1960s, when it was forced to institute a serious quality control program. One catalyst was the USS *Gurnard*:

USS *Gurnard*, the first (Sturgeon) built at Mare Island, was surprisingly noisy. It was determined that no particular flaw existed in the design. Instead, the ship's relatively high noise level was traced to a large number of minor imperfections in equipment supplied by contractors and insufficiently checked by the yard. Silencing had to be a combination of very careful design and very tough—and costly—quality control at the subcontractor and shipyard levels.¹¹¹

The Soviet Navy clearly had more trouble than did the U.S. Navy in winning similar battles with its own shipyards, which in the Soviet system were part of other independent and powerful central ministries. Another problem was the historic Soviet emphasis on land-based nuclear forces, which had a particular impact on investments in Soviet SSBNs. Whatever the reasons, it remained the case in the 1980s, and still does today, that Soviet SSBNs are louder than the quietest Soviet SSNs.¹¹²

More important in judging the effectiveness of the diversion strategy, there is considerable evidence that the Soviets themselves believed it would be effective. Beginning in the mid 1970s, some American analysts of the Soviet Navy had already begun arguing that its contemporary naval buildup was largely defensive, and that the Soviet Navy saw “Sea Control on behalf of missile submarines [as] not a secondary but, along with strategic strike, a main goal, to be carried out using surface ships, aviation, and general-purpose submarines as the first and main task from the very beginning of the war.”¹¹³ In the face of worldwide Soviet naval power projection exercises like Okean 75, many in and out of the Navy disputed this argument about Soviet intentions. But it gained

great credibility by the mid 1980s after Soviet exercises during the intervening period had clearly demonstrated a focus on pro-SSBN operations.

In contrast to the major 1975 worldwide Soviet naval maneuvers called Okean 75, when Soviet tactics emphasized projecting power into distant waters and cutting Western sea lanes, more recent maneuvers have focused on finding and destroying enemy submarines and protecting their own missile subs. . . .¹¹⁴

This radical change in Soviet behavior was a mystery to U.S. naval intelligence analysts when it first began to occur in the mid and late 1970s, but the mystery was resolved in 1985 when the Navy first broke the Walker espionage ring, whose information had shown the Soviets how vulnerable their SSBNs were.¹¹⁵

As noted earlier, the Navy's forward ASW strategy attracted considerable skepticism when it was declared publicly in 1986. The contrast between this skepticism and actual Soviet behavior is striking, in that the latter clearly behaved as if the skeptics were wrong. Classification still prevents a detailed discussion and assessment of forward SSN operations in Soviet SSBN bastions during the last decade of the Cold War, but certain observations can be made with confidence based on the discussion to this point. These suggest possible explanations for Soviet fears regarding American strategic ASW capabilities.

First, though the relatively shallow Barents Sea foreclosed convergence zone detection ranges, it had a relatively smooth bottom which produced superb bottom bounce propagation and a sound-velocity profile almost uniformly favorable to surface ducting. This provided for fairly long propagation paths for low-frequency signals often far exceeding normal direct path ranges, even if these paths were still much shorter than the convergence zone or deep-sound channel propagation paths available in deeper water. Thus, one finds those who have actually conducted submarine operations in these waters often speaking of the excellent sonar conditions they experience there.¹¹⁶

Second, given the lingering acoustic advantage that American SSNs retained over Soviet SSBNs (as opposed to Akula), logic would certainly argue that peacetime tracking operations remained viable. Though there was no substitute for the cueing function provided by the passive acoustic barriers through which older Soviet SSBNs had to deploy to reach targets in the United States, tracking operations in forward areas might nevertheless remain viable if SSNs could pick up their prey soon enough after they left port. In this case, geography provided a focal point that offered the cueing function formerly delivered by SOSUS. Because 80–90 percent of the total fleet of about sixty-five Soviet SSBNs continued to remain in port in peacetime, the peacetime requirements for forward deployed American SSNs would remain manageable, especially as their force structure grew toward a goal of one hundred beginning in the early 1980s, and their forward-deployed operations tempo remained equal to or even a little higher than, at 20 percent, Soviet SSBNs.

But third, the assumption that Soviet SSBNs not already forward deployed at the outset of a war would not survive in significant numbers to deliver their missiles against U.S. targets would no longer be viable. Commensurate with the Soviet development of longer range SLBMs and the establishment of their SSBN bastions was a renewed emphasis by NATO on raising the nuclear threshold on the central front of Europe. A direct goal of these efforts was to extend the duration of the conventional phase of a NATO-Warsaw Pact conflict from days to weeks or even months. In this scenario, Soviet SSBNs in port at the outset of a NATO-Pact conflict would not be exposed to immediate nuclear attack when the war started. Furthermore, if and when they surged into their operating areas soon after the war started, there would not necessarily be any NATO ASW barriers to penetrate before they were in range of their targets. The key determinant of American strategic ASW effectiveness would therefore no longer be only peacetime tracking operations but also wartime operations. These would aim either to pick off Soviet SSBNs as they surged from port or for those SSBNs that escaped port safely, to search for, find, and attack those SSBNs in their patrol areas.

The more pessimistic analyses of American strategic ASW capabilities emphasized the problem of finding a Soviet SSBN force that had successfully surged into its patrol areas without being tracked or attacked as it exited port. Here, one is looking at a search problem over an area spanning, at a minimum, the Barents, the Sea of Okhotsk, and under the permanent ice in the Arctic. The searchers would be American SSNs which had surged forward after the Soviet deployment. The important independent variables other than the search area and the number of searchers were the search rate of individual SSNs and the tactics of their prey, and the important dependent variable was time. How many Soviet SSBNs could American SSNs kill during the conventional phase of a war whose length could not be foretold?

The other side of the equation concerned the vulnerability of American SSNs to counterattack. Here it is important to note the tactical constraints associated with a long-range, wire-guided torpedo like the Mk. 48. When a wire-guided torpedo is launched, it is under the control of the launching submarine via the wire, which requires that the launching submarine stay slow and remain pointed toward the target. The torpedo remains wire-guided until it reaches the acquisition range of its own active sonar. When the weapon operators determine that the torpedo has acquired the target submarine, they cut the wire and the weapon becomes autonomous, freeing the launching submarine to maneuver without constraint. Assuming for the sake of argument that the Mk. 48 had a ten-mile range, a two-mile active acquisition range, and a maximum speed of 60 knots, certain parameters of the resulting engagement become clear.

First, an engagement begun at ten nautical miles will take roughly ten minutes to complete, and because a fast torpedo like the Mk. 48 is quite loud, the target submarine will know that it is under attack essentially as soon as the torpedo is launched. Second, for the first eight minutes, the control of the torpedo will remain with the launching submarine. A standard Soviet tactic would be for the target submarine to launch an active homing torpedo down the bearing of the incoming Mk. 48 in the hope that it might cause the American submarine to cut the Mk. 48 wire and run, or that it might kill the American submarine if it stayed to complete the engagement, albeit in the latter case, probably too late to prevent the incoming Mk. 48 from going active and killing the Soviet submarine first.

The nature of such an engagement provides one explanation of why the Soviets might have begun escorting their SSBNs with SSNs on a routine basis once they established their barrier strategy, as they are alleged to have done. In this scenario, an attacking American submarine might not detect the escort when it attacked, or would be faced with the need to launch multiple Mk. 48s simultaneously, either case representing less encouraging odds of survival for the attacking submarine. It also explains the Soviet interest in rocket-propelled torpedoes, whose speed would allow a counterattack to strike home before the “go active” range of the Mk. 48 had been reached, assuming of course that some form of guidance and fuzing could be arranged for a super-cavitating torpedo. On the American side, this tactical scenario demonstrates the logic behind *Seawolf*, especially her eight-tube multishot capability and large magazine, and it also demonstrates the great tactical value of a quiet torpedo, and indeed the submarine force was pursuing a quieter Mk. 48 as the Cold War came to an end.¹¹⁷

A more positive assessment of American strategic ASW capabilities would start with more optimistic assumptions about the respective timing of the surge deployments of the two forces and whether they occurred prior to or after the start of the war. For example, American SSNs might win a race to the Barents and the Sea of Okhotsk such that numbers of them were in place off Soviet ports before Soviet SSBNs had surged. This might occur in a case where the Soviets had withheld their SSBNs in port until after the war started so as not to provide NATO strategic warning of its imminence. Under these circumstances, strategic ASW would be less of a wide area search problem and more of a barrier problem in a target rich environment, where the two most important independent variables were the exchange rate in engagements between Soviet and American submarines, and the latter’s supply of torpedoes.

The important question concerns Soviet perceptions about American strategic ASW capabilities. There is considerable evidence that American political and military leaders understood this. In fact, some of them speak in retrospect of the mission of “perception

management” regarding the Soviet Navy and its political leadership. For example, on at least three occasions during the 1980s, the entire American attack submarine force was flushed out of port and sent to sea in a matter of days. These demonstrations of the U.S. submarine force’s ability to surge forward quickly on a moment’s notice were designed in part as a perception management device, and one message that was probably received by the Soviets concerned the possibility that their SSBNs would lose a race to the Barents with American SSNs.¹¹⁸ This would certainly be one explanation for the disparity between most outside analyses of American strategic ASW capabilities and Soviet behavior.

Even to its supporters, the seeming success of this strategy at diverting the best Soviet SSNs to pro-SSBN missions was not a long term source of comfort, because acoustic parity at very low source levels between all American and Soviet submarines appeared inevitable in the long term. This led to a resurgence of interest in coordinated ASW employing multiple sensors and multiple platforms.

The Return of Coordinated ASW

When the passive acoustic barrier strategy was embraced during the 1960s, the need for coordinated ASW declined, the final death knell sounding with the elimination of the HUKs after Vietnam. Relatively loud nuclear submarines could be continuously tracked on an ocean-wide basis, while diesel-electric submarines could be interdicted at forward barriers, through which they needed to move at reasonable speed in order to reduce base-loss factors, and where they therefore needed to snorkel to keep their batteries charged, exposing themselves to long-range passive detection.¹¹⁹ Diesels that leaked through the barriers could be countered by battle groups with speed and an inner ASW screen, but the problem of protecting slower merchant shipping in the open ocean and in focal areas near allied ports remained. Merchant convoys would be escorted by ASW frigates in the open ocean, and these retained the kernel of a coordinated ASW approach in their use of organic helicopters and supporting VP. But this mission and the more ambitious mission of protecting shipping in focal areas near debarkation ports were largely delegated to Allied navies, the clearest example being the Royal Navy, which retained HUK groups organized around their small deck carriers. Because it largely delegated this part of the ASW problem to its allies, the U.S. Navy let its ability to find and maintain contact with truly quiet submarines atrophy.

Thus, when Analogous Response brought this problem back to the fore, the Navy made an effort to reacquire this expertise. One center of this activity was in Destroyer Squadron 31, which experimented with more coordinated approaches to finding and maintaining contact with Akulas on Analogous Response patrols in the Pacific.¹²⁰ These exercises relied on much greater coordination at both the operational and tactical levels

between the Integrated Undersea Surveillance System, submarine, VP, and DesRon assets involved.

For example, much more vigorous interaction between the IUSS community and the operating forces was instituted, both in advance of and during an exercise. In the former case, operators were given a much fuller picture of what the intelligence community knew about its target, including the history of its past deployments, and its expected movements. During the exercise, more communication occurred between the shore-based and at-sea assets, allowing, among other innovations, the reverse cueing of SOSUS by operating forces. This required much greater access to crowded ultra high frequency satellite communications circuits and highlighted the importance of real time connectivity in coordinated ASW.

This innovation was enabled by an organizational change in the management of the IUSS community. Historically, the IUSS community had been managed by the intelligence community and therefore had shared the intelligence community's bias towards protecting its sources and methods. This reduced its tactical utility to the operating forces, and real improvements in that utility only occurred in the 1980s because the operating forces gained greater managerial control over IUSS.¹²¹

Another innovation which gained momentum during these exercises was the use of negative search information to better assign search patterns for scarce, relatively short-ranged sensors. Using statistical models, the absence of detection by a given sensor or sensors over time could be used to build up a wide area picture of those areas where the probability was highest that a real target lurked, allowing the concentration of available sensors there. This method was initially developed in support of the first battle group deployments to the Indian Ocean and the Arabian Sea in the late 1970s, where it was the hostility of the acoustic conditions rather than the quietness of the targets which drove this development.¹²²

Because the Akulas did not produce powerful, continuous, narrowband tonals, transient tonals often provided the best initial detection opportunities at long range. Prosecution of these contacts required quick closure of the datum by air ASW assets, because only they could reduce the time lag enough to bring broadband sensors within detection range of the Akula's continuous sound spectrum. Also, air ASW assets provided the only means of quickly classifying these contacts, thereby reducing the time wasted prosecuting false contacts. These tactics were platform intensive, and one result was the first operational use of two-helicopter LAMPs III detachments on DDs and FFGs. This allowed the DesRon to maintain contact on an Akula over extended periods. These exercises also saw the surface ASW community finally in its element, in that it combined

the endurance and long-range passive acoustic towed arrays of the SSN with the ability to coordinate with or organically deploy a high-density air ASW capability.

Contemporary with exercises like those conducted by DesRon 31 were other efforts to repair or replace damaged elements of the Navy's passive barrier strategy. The technical side of this effort included systems such as the Fixed Deployable System (FDS), the Surveillance Towed Array Sonar System (SURTASS), and various efforts to use explosive sound sources with existing passive sensors in a repeat of the earlier Julie system.

SURTASS was conceived as a kind of mobile SOSUS array. It employs a very long, very wide aperture array towed by a civilian-crewed ship. The ship, designated T-AGOS, utilizes the high bandwidths available through super high frequency satellite communications to uplink its data back to shore, where increasingly complicated signal processing is conducted with essentially unlimited computing assets. SURTASS, and particularly its active version known as Low Frequency/Active (LFA), was an attempt to recover some open ocean search capability and constituted the renaissance of work begun and then abandoned with Project Artemis. In many respects, SURTASS was and remains the cutting edge of the traditional long-range, passive acoustic approach to ASW.¹²³

FDS was an attempt to repair the barrier strategy by using many simple passive sensors in an upward looking array that used the reliable acoustic path (essentially the direct path) rather than the deep-sound channel. Each sensor would cover a small cone of the ocean column, and fiber optic cable provided the bandwidth to network a vast array of these small sensors and bring their output ashore for processing. But neither the diversion strategy, nor the reembrace of operational and tactical coordination in ASW, nor the prospect of new sensor and signal processing technologies came close to promising a return to the happy time of Cold War ASW when the U.S. Navy enjoyed a major passive acoustic advantage over its opponent. Instead, the Navy again faced a future in which the balance between pro and antisubmarine efforts would once again shift decisively in favor of the former. It is for this reason that the demise of the Soviet Union and the end of the Third Battle seems highly reminiscent of the "saved by the bell" end of the Second Battle of the Atlantic. And these similarities carry forward into the post-Cold War era, the first decade of which makes clear that a Fourth Battle for control of the seas against modern, non-nuclear submarines looms.

The Fourth Battle?

Submarines and ASW After the Cold War

Current trends in America's external security environment may confront the U.S. Navy with new ASW challenges not unlike those it avoided when the Soviet Union collapsed, albeit in a radically changed security environment. This environment may also demand that the U.S. Navy's submarine force adopt additional missions beyond its traditional focus on ASW. In both respects, the future security environment is likely to challenge the Navy much as did the one it faced at the outset of the Cold War.

Antisubmarine Warfare after the Cold War

Three specific aspects of this future environment create problems for the Navy's ASW posture: the capabilities and relatively wide availability of modern non-nuclear submarines; the United States' extreme aversion to casualties in post-Cold War conflicts over less than vital interests; and the U.S. Navy's doctrinal focus on power projection from the sea at the expense of sea control.¹²⁴

First, a technical challenge to the Navy's ASW posture analogous to that resulting from the first Soviet deployments of the Akula in the mid 1980s may recur in today's security environment with the increasingly wide proliferation of modern non-nuclear submarines.¹²⁵ Deployed relatively close to their homes, in or near littoral waters through which the United States may need to project power from the sea, these submarines pose a potentially formidable threat. With a competent crew and the kind of advanced weapons that are now widely available in global arms markets, a modern non-nuclear submarine deployed in its own backyard might become a poor man's Akula. Of even more concern is the fact that modern weapons—wake homing torpedoes, for example—tend to reduce the demands on submarine crews, making even less competent crews too dangerous to ignore.

Modern non-nuclear submarines are both better than those deployed by the Soviets during the Cold War and more widely available as defense industries that served their

home markets during the Cold War now struggle to use exports to stay alive. One reason that the submarines are better is because many decades of continual investment by countries like Germany and Sweden have finally paid off in the form of non-nuclear submarines with air independent propulsion (AIP) systems that make them true submarines rather than mere submersibles. These submarines still do not provide the mobility and endurance of a nuclear submarine, but they greatly reduce the “indiscretion rate” of a traditional diesel-electric submarine, which must expose a snorkeling mast to recharge its batteries every few days at a minimum, and much more frequently if forced to operate at high speed.

Modern submarines are also armed with better weapons and fire control systems. One particularly alarming development is the marriage made possible by the end of the Cold War of the air independent, non-nuclear submarine with the submarine-launched antiship missile. Armed with sophisticated antiship weapons available from several Western and Russian suppliers, these platforms can launch fire-and-forget missiles from over the radar horizon without the need for the noisy and battery-draining approach run necessary for a traditional, torpedo-armed, diesel-electric boat. This threat circumvents the time-honored ASW approach to dealing with very quiet diesel-electrics, i.e., to flood the ocean surface with radar and use speed to force the submarine to either run down its battery and expose itself in an attack run or stay quiet and defensive.

The primary ASW challenge has always been wide-area surveillance, and the main challenge initially posed by the new security environment in this mission area is a wide area search problem. Sound propagates better in deep water than in shallow water, and non-nuclear submarines can remain silent for extended periods when allowed to patrol small areas near their home ports at low speed. Using passive acoustics to search for such submarines is much more difficult than it was to search for relatively loud Soviet submarines operating in deep water during the Cold War. On the other hand, active sonars encounter serious problems with clutter in shallow water, much as early radars did when forced to look down at targets flying over land. And even in shallow water, the water column still remains relatively opaque to non-acoustic energy, limiting the role of RF and laser radars as long-range sensors.

Two new systems stand out as first steps toward gaining a wide area search capability in the littorals. The first is called the Advanced Deployable System (ADS), and the second is called Distant Thunder. ADS is a passive ocean bottom array that can be deployed by a surface ship and whose output is currently collected and processed ashore via fiber-optic cable. Distant Thunder is primarily a signal processing adjunct to existing ASW combat systems, combined with legacy, air-droppable, active sound sources and a relatively simple data link that uses existing UHF radios on participating platforms.

Unlike the Cold War Sound Surveillance System (SOSUS) arrays, which listened for low-frequency, narrowband tonals propagating outward horizontally along the deep-sound channel, nodes in an ADS array look upward along what is called the reliable acoustic path. ADS is a derivative of the Cold War Fixed Distributed System (FDS) program, which was an attempt to repair the ASW barrier strategy by using many simple passive sensors in an upward-looking array that used the reliable acoustic path rather than the deep-sound channel. Each sensor in the ADS would cover a small cone of the ocean column.

Distant Thunder adds commercial off-the-shelf (COTS) processing to existing towed arrays on ships (and potentially, submarines) and air-deployed sonobuoys, and links the processors together using legacy radios with modems to form a network that can do bistatic or multistatic processing of the echoes from the air-dropped sound source. The essence of Distant Thunder is that it uses both spatial and temporal processing to extract a submarine's echo from the clutter and reverberation of a specific explosion deliberately introduced in the water. Long wavelength towed arrays allow spatial processing that can eliminate clutter and reverberation entering the array's sidelobes, and temporal processing allows reverberating echoes from the same object to be compared over time, thereby exploiting the fact that a submarine's echo loses less of its higher frequency spectrum in that time than do objects sitting on the bottom or floating on the surface.

One of the original concerns about Distant Thunder was that variations in bottom topography and content would interfere with its temporal processing capability, but worldwide experiments have demonstrated excellent performance over a wide range of environments. Like all acoustic sensors, performance will vary in practice, depending on many circumstances, yet Distant Thunder promises to return a substantial portion of the detection ranges initially lost when the Navy first shifted its focus to shallow water ASW. Another benefit of Distant Thunder is that it demonstrates long-range performance under a wide variety of acoustic conditions, including the very common case in the littoral where sound is refracted away from the surface, a condition which drastically reduces the performance of a traditional, hull-mounted sonar.

Distant Thunder is also a great example of the incredible power of networked sensors, and the relative ease of backfitting such a capability onto legacy platforms once the substantial initial challenge of developing the necessary signal processing algorithms is completed. Distant Thunder can be backfitted onto any towed-array ship or submarine and onto LAMPs helos and P-3s. For example, on surface ships with the SQQ-89 ASW system, the physical footprint of a Distant Thunder backfit consists of one server and two laptops.

Specialized periscope or mast detection radars can also play an important role in the ASW search problem. Even during the Cold War, Soviet nuclear submarines regularly exposed a periscope when seeking a torpedo fire control solution against the fast ships of a battle group. And, of course, radar has an important role to play in preventing diesel submarines from snorkeling to recharge their batteries. Thus, a combination of speed and radar deployed to search within the limiting lines of approach created by that speed have always been an important ASW tactic against all submarines. Likewise, radar flooding—in which a large area is continuously illuminated with RF energy so as to set off a submarine's radar warning alarm whenever it exposes a periscope with a radar warning receiver on an ECM mast designed to detect and warn of an enemy's search radars—is also a traditional tactic against diesel submarines. But specialized mast detection radars like the APS-137 used on the S-3 and the P-3 experience tremendous false alarm rates caused by both sea state and other floating objects and debris when their detection threshold is set low to maximize range or sensitivity.

The Automatic Radar Periscope Detection and Discrimination (ARPDD) program is developing the capability to process the S-3B's APS-137 returns in such a way as to allow very low detection thresholds (i.e., long range and high sensitivity) and very low false alarm rates. Very impressive results have already been demonstrated in shipboard experiments, but unlike Distant Thunder, ARPDD needs further development time to simplify the massive processing capability it now requires before it can be backfitted onto legacy P-3 and LAMPs platforms.

Second, consideration must be given to a political challenge associated with conflicts in which the United States is fighting over less than all-out stakes. In such conflicts, there will be a very low tolerance for shipping losses, but the presence of even a small opposing submarine force will make it extremely difficult for the Navy to quickly eliminate the possibility of such losses.

Regarding casualties, even in a major regional contingency the stakes for the United States are limited, while those of its opponents are very high indeed. The opponent may be willing to run great risks and sustain high losses, while the United States will not. Faced with the possibility or the reality of losses at sea, the Navy will be forced to stop and eliminate that threat before proceeding, and when that threat is submarine-based, its elimination will not be immediate and may take weeks.

A good analogy is to the great Scud hunt of Desert Storm. Thousands of sorties were diverted over several weeks from the air war during Desert Storm to hunt for Scud missiles to little or no effect. From an ASW perspective, this experience is illuminating for both operational and political reasons.

Operationally, Scud hunting was like ASW against a quiet target. A large area needed to be searched for objects that easily blended into the background and only intermittently exposed themselves. Thus radar was used to flood Scud operating areas, unattended field sensors were also deployed, and aircraft were used to pounce on potential contacts. This was a protracted, extremely asset-intensive endeavor, characterized by false alarms, high weapon expenditures, and low success rates. In short, a Scud launcher was most likely to reveal itself by successfully launching its weapon, just as sinking ships are often the only reliable indication that there is a submarine in the neighborhood.

The political lessons of the Scud hunt also apply to ASW. Before the war, the Scud had rightly been dismissed as a serious military threat, but once they began landing in Israel, the political imperative to allocate scarce resources to at least appear to counter this threat rapidly overwhelmed these narrow military calculations. The same political pressures would be brought to bear on ASW forces facing active enemy submarines, but unlike Scud missiles, which remain terror weapons without much military utility, submarines are a deadly serious military threat as well a political one. Therefore, it will not do to simply appear to be addressing the ASW problem with a major allocation of resources. Real results will have to be forthcoming before political and military leaders will be willing to risk valuable seaborne assets, be they Navy aircraft carriers, amphibious force ships carrying Marines, or Army sealift ships.

A delay of several weeks during the halting phase of a major regional conflict might not be a war stopper all by itself, but it is important to understand the consequences for current time-phased force deployment list timelines, which assume the arrival of millions of square feet of pre-positioned sealift within the first two weeks of the commencement of hostilities. This would transform a rapid deployment into a slow one, throw the deployment timelines of all the services askew, and open a window of indeterminate size at the outset of a conflict in which the enemy can operate unmolested except by those opposing forces already in theater, assuming they do not need an open sea line of communication to sustain themselves.

Third, the Navy confronts a doctrinal challenge as it attempts to increase its ability to project power from the sea. The Navy faces a new operating environment in which it is increasingly relevant and therefore in demand. Unlike in the post World War II era when the Navy was searching for a mission, the Navy has been inundated with new missions in the post-Cold War era, and these new missions compete with ASW for resources.

This has serious consequences for ASW because, as noted above, ASW is a multi-platform mission area performed by multi-mission platforms. As the Navy's strike warfare, anti-air warfare, missile defense, and amphibious warfare capabilities have grown in importance in the nation's military strategy, the Navy has shifted its focus away from

an emphasis on blue water sea control toward power projection and land control in the littorals. Yet these missions must be performed by the same platforms that perform ASW—the air, surface, and submarine communities, all supported by the ocean surveillance community. It is natural that the Navy’s platform communities should shift their focus; but in a time of declining resources, this shift inevitably comes at the expense of other missions performed by those platforms.

This “multi-mission pull” increasingly makes ASW compete with strike warfare and theater air and missile defense for the same resources and training opportunities. The other mission areas are winning these battles and pulling the Navy’s major platform communities away from ASW, particularly in the aviation and surface warfare branches.

This shift in orientation is occurring at a time when technology increasingly demands that ASW be a coordinated, “combined arms” exercise if it is to succeed. All elements of the Navy’s ASW posture must be maintained to succeed in the fight against quiet submarines, but all three of the Navy’s major platform communities perceive that their survival in the new security environment depends to some extent on their success in performing other missions.

New Missions for Submarines after the Cold War

The U.S. Navy’s submarines have not been immune to the pressure to look at new missions, and this pressure has arguably been greatest in the area of strike warfare. One manifestation of this pressure is the Trident SSBN to SSGN program, which, when completed, will dramatically increase the submarine force’s capabilities in this mission area.¹²⁶ A Trident SSGN program will also demonstrate a repeat of the submarine force’s post World War II experience, when radical innovation made it a key player in a new mission, assuring its continued relevance in a new security environment.

Trident SSGNs are being converted because new precision weapons, new platforms for launching them, and new concepts for using them are needed to help the U.S. Navy meet the demands created by new geopolitical and technological trends in America’s external security environment. Geopolitics and technology are conspiring to pull the Navy ashore from the sea, without eliminating the traditional and irreducible need for a navy that is capable of controlling the sea. The tension between “From the Sea” and controlling the sea is real, but a wholehearted embrace by the Navy of one orientation to the exclusion of the other is neither desirable nor necessary. New ways of performing precision strike from the sea, if vigorously exploited, will reduce the need for trade-offs between sea control and power projection.

Long-range precision weapons can dramatically reduce the mass that must be projected from the sea in order to produce a given effect ashore, while at the same time expanding the power that can be projected by a given naval force. They reduce the requirements for mass by making target destruction possible with one or two precision weapons rather than ten or a hundred unguided bombs; in addition, by allowing long standoff ranges from the target, they increase the number of platforms that can serve as precision weapon launchers. This means that both surface ships and submarines can join aircraft carriers to form a triad of naval strike warfare assets. It also means that each weapon launcher, whether it be an aircraft or a ship's vertical launch system for missiles, is capable of achieving much greater and more precise effects. Future improvements in long-range precision weapons will occur at the steep rate characteristic of technologies still in their infancy, as compared to the more sedate rate at which more mature systems improve.

In principle, these new capabilities can be used in one of two ways. At one extreme would be an effort to maximize the Navy's overall contribution to the precision strike from the sea mission area. This is tempting, because it gives each of the Navy's major platform communities a role in a mission that is clearly of central national importance in the new security environment and which, therefore, is easier to fund in a time of declining or steady budgets. At the other extreme, the Navy could aim only to meet the minimum demands for precision strike from the sea, and exploit new precision weapons to minimize the investment in this mission area rather than maximize capabilities. The advantage of this approach would be that it would allow the Navy to focus more on sea control, as well as other missions which only it can perform, leaving greatly increased precision strike largely to the other services.

It is impossible today to predict with certainty where on this continuum the Navy will be tomorrow, but there are two variables which will largely determine the need. First is the question of access to overseas bases, and second is the evolution of future threats to American sea control. Assuming continued access to a robust overseas base structure in both crisis and war, the other services (notably, the Air Force) will continue to be able to provide the bulk of the required precision strike assets in a future contingency. If, on the other hand, that assured access ashore is denied or sharply limited, the Navy will be forced to fill the void from the sea.¹²⁷ At the same time, future adversaries may continue to cede the United States control of the seas, as Iraq did during Desert Shield/Desert Storm, which in turn would allow the U.S. Navy to continue its current deemphasis on sea control. Alternatively, these adversaries might discover that the best way to blunt American power projection capabilities is at sea, and that the highest leverage sea denial capabilities are provided by modern, undersea warfare weapons, as both the

Iranians and the Chinese may have already decided, as suggested by their recent purchases of Russian Kilo-class submarines.

The most challenging scenario for the Navy is one where U.S. access to overseas bases is greatly reduced, and where the proliferation of relatively low cost and easy to use access denial weapons—such as modern diesel-electric submarines, anti-ship and anti-aircraft missiles, and naval mines—continues to grow. This is a world in which the Navy will have to provide a larger portion of national power projection capabilities, while also placing much more emphasis on sea control than it does now. Indeed, it is arguable that this is the security environment the United States is already beginning to face along the great arc of the Indian and Pacific Ocean littorals. In it, the U.S. Navy's relevance is likely to exceed its currently projected capabilities by a wide margin, and dealing with this “crisis of relevance” will demand innovation, particularly in precision strike from the sea.¹²⁸

This has led the Navy to explore how best to improve its submarine force's capabilities in precision strike from the sea; deepen its commitment to developing improved precision weapons for use on all naval platforms—and notably its submarines and surface combatants; and ensure that all naval platforms enjoy connectivity sufficient to link into future intelligence, surveillance, and reconnaissance nets. The combination of submarines and long-range precision weapons is particularly relevant to this problem, because it links a weapons platform whose inherent stealth makes it easy to defend and a weapon against which defense is extremely difficult. It is this combination of inherent survivability and lethality which the SSBN force brought to the nuclear deterrence mission; given the rapidly growing lethality of modern precision weapons, this is what makes a conventional SSGN force such an important opportunity.

The size of this opportunity can be measured directly in terms of the added strike warfare and special operations capabilities it provides, and indirectly in terms of the capabilities it liberates in the other platforms with which it shares missions, since they are normally multimission platforms as well. In the first case, an SSGN assigned to a battle group would double or triple its strike assets and give the battle group commander a means of suppressing opposing air defenses and shore-based sea denial forces from a stealthy, secure, forward-based platform. Used in this way, an SSGN would increase the effectiveness of and reduce the danger to other battle group strike assets early in a conflict.

Less obviously, by improving the submarine force's contribution to precision strike from the sea, an SSGN would also help create additional ASW, air, and tactical ballistic missile defense capabilities in the air and surface forces by giving the Navy more flexibility to focus on those mission areas should the need arise. This could be reflected physically in terms of finite magazine space allocations, by allowing other platforms to

carry fewer strike weapons, or tactically and operationally, by giving other platforms more freedom of maneuver in space and time early in a contingency when multi-mission pull is highest.

Conclusions

During two world wars in the first half of the twentieth century, submarines were the weapon of choice for naval powers needing to contest the control of seas dominated by stronger navies. In their peacetime preparations for these conflicts, the stronger navies tended to underestimate this threat to their sea lines of communication. In both world wars, submarines therefore tended to win the first battles between pro and anti-submarine forces. ASW success for the major naval powers depended upon urgent wartime adaptation at the technical, operational, and tactical levels. Even for those powers that were relatively quick to adapt, as were the British in World War I and both the British and the United States in World War II, their eventual ASW success was tempered by the radically asymmetric levels of effort by the contestants in favor of the submarine. The one major naval power that failed to adapt to a wartime submarine challenge, the Imperial Japanese Navy in World War II, lost control of its oceanic supply lines to American submarines with catastrophic consequences.

The Third Battle, beginning roughly in the middle of the century, had a different pattern. First, the U.S. Navy was much more aggressive in its Cold War efforts to counter Soviet submarines than any of the major naval powers were before the two world wars. It developed innovative new ASW techniques based on passive acoustics which reduced the historic disparity in investment favoring the submarine over ASW forces. This happy state of affairs lasted until the Soviet Union finally deployed truly quiet nuclear submarines in the early 1980s, but the Cold War was already on its last legs by then. Thus, in many respects, the U.S. Navy was the first great power navy to win a peacetime battle for ASW supremacy with the submarine force of a major competitor.

On the other hand, the post-Cold War security environment presents some of the operational and technical challenges in ASW that the unanticipated end of the Third Battle allowed the Navy to avoid. This security environment is also placing pressure on the submarine force to adopt new missions, particularly in the area of precision strike. In

both cases, innovation will be necessary by both the U.S. Navy and its submarine force if the demands of this new security environment are to be met.

In describing the innovations underlying the U.S. Navy's Cold War ASW effort, this paper has also sought to lay the groundwork for further research and writing along two additional paths. First, as an unclassified discussion, it has by necessity left out much that is relevant to the Cold War ASW story. That story does need to be fully developed in all its breadth and detail. For example, non-acoustic means of ocean surveillance, particularly those based on signals intelligence, undoubtedly played a major role in the Third Battle, as they did in the Second Battle, but remain classified because of the continuing relevance of the sources and methods involved. The same constraints apply to details about tactical, operational, and technical developments in the undersea surveillance, submarine, surface, and air ASW communities. The Navy should have a great interest in sponsoring rigorous historical studies of these areas at whatever classification level is necessary in order to preserve its institutional memory of events now often residing only in the individual minds of a shrinking cadre of actual participants.

Second, this paper seeks only to establish the record of innovation in the Cold War ASW battle and does not attempt to explain its causes. The motivation for this effort was to develop an important series of case studies of successful, peacetime innovation by a major military organization. The case studies here described are important for academic researchers for two reasons: cases of rapid, peacetime innovation in military doctrine are rare, and the Navy's success in the Third Battle was largely untold. This paper, therefore, provides additional case material for research on the sources of peacetime military innovation.

In addition, the particular case of the U.S. Navy's submarine force's role in the Third Battle, especially in the early years from the late 1940s to 1960, constitutes a puzzle for existing theories of the sources of peacetime innovation. These theories explain innovation as the result either of outside intervention by high-level political leaders, protracted struggles for control within a service among its branches, or interservice competition between independent military services in areas of mission overlap. It is difficult to explain the post World War II evolution of the submarine force in any of these terms—high-level political leaders seem largely absent from the story at the outset; the changes appear too quickly and decisively to be the result of the normal pulling and hauling on a generational timescale between internal Navy platform communities; and ASW was a mission area that the Navy had largely to itself, unlike carrier aviation and missiles, which did become major bones of interservice contention. Identifying the factors which caused both the submarine

community and the Navy as a whole to so quickly recast their entire mode of ASW operation in peacetime and in the immediate aftermath of a great victory will help to develop better theories about the sources of military innovation. Such theories, in turn, can help U.S. political and military leaders with the practical task of adjusting to the demands of a radically new, post-Cold War security environment.

Notes

1. For a summary of this larger project, see Owen Cote and Harvey Sapolsky, "The Navy and the Third Battle of the Atlantic," *Submarine Review*, July 1997, pp. 40–2.
2. Bernard Brodie, *Sea Power in the Machine Age* (New York: Greenwood Press, 1969), p. 261.
3. George R. Lindsey, "Tactical Anti-submarine Warfare: The Past and the Future," *Adelphi Paper No. 122*, p. 30.
4. On the significance of the adoption of diesel propulsion see Captain Harry A. Jackson, USN (Ret.), Commander William D. Needham, USN, and Lieutenant Dale E. Sigman, USN, "ASW: Revolution or Evolution," U.S. Naval Institute *Proceedings* (hereafter *Proceedings*), September 1986, pp. 64–5.
5. Vice Admiral Sir Arthur Hezlet, *The Submarine and Sea Power* (New York: Stein and Day, 1967), p. 106.
6. Very Long Range (VLR) B-24s were first deployed to Iceland in late 1942, but only in small numbers. The decisive step came in March 1943 when two VLR squadrons—one American and one Canadian—were deployed to Newfoundland. March 1943 also saw the first use of small escort carriers (CVEs) as ASW escorts in the air gap. CVEs later played a larger role when German submarines fled the North Atlantic and shifted their attention to the sea lanes linking the United States and North Africa. See Henry Probert, "Allied Land-Based Antisubmarine Warfare," pp. 378–9, and David Hobbs, "Ship-borne Air Anti-submarine Warfare," pp. 392–5, in Stephen Howarth and Derek Law (eds.), *The Battle of the Atlantic 1939–1945* (London: Greenhill Books, 1994). See also, Alfred Price, *Aircraft Versus Submarine* (London: Jane's Publishing Co., 1973), pp. 127–53.
7. On American use of HF/DF, see Kathleen Broome Williams, *Secret Weapon: U.S. High-Frequency Direction Finding in the Battle of the Atlantic* (Annapolis, Md.: Naval Institute Press, 1996).
8. Lindsey, "Tactical Anti-submarine Warfare," pp. 30–1.
9. Michael A. Palmer, *Origins of the Maritime Strategy: American Naval Strategy in the First Postwar Decade*, Contributions to Naval History, No. 1 (Washington, D.C.: U.S. Government Printing Office [hereafter GPO], 1988), pp. 24–5.
10. Massachusetts Institute of Technology, Project Hartwell, *A Report on Security of Overseas Transport*, 21 September 1950, Volume I, Appendix D, p. D–55.
11. Maurice Ewing and J. Lamar Worzel, "Long-Range Sound Transmission," *Geological Society of America Memoir 27*, 15 October 1948, p. 1.
12. See, for example, W. W. Stifler and W. F. Saars, "SOFAR," *Electron*, 21:98, 1948.
13. H. H. Baker, "Missile Impact Locating System," *Bell Telephone Laboratory Record*, 39:195, 1961.
14. Chief of Naval Research to Assistant Chief of Naval Operations for Undersea Warfare, "Bell Telephone Laboratories' Contracts - Low Frequency Detection," 4 May 1951, J15-11, U.S. Navy Operational Archives.
15. Frank Andrews, "The Evolution of SubDevGru 12," *Submarine Review*, April 1983, p. 4.
16. *Ibid.*, p. 9. One of the members of the fire control party on this historic occasion was K-1's chief engineer—Lt. Jimmy Carter. Interview by the author with Frank Andrews, 16 July 1998. In 1955, K-1, K-2, and K-3 were named *Bass*, *Barracuda*, and *Bonita*. Each displaced less than half the tonnage of a World War II fleet boat.
17. Joseph F. Bouchard, *Command in Crisis: Four Case Studies* (New York: Columbia University Press, 1991), p. 117.
18. On this point, see Jan S. Breemer, "The Submarine Gap: Intelligence Estimates 1945–1955," *Navy International*, February 1986, pp. 100–5.
19. U.S. Central Intelligence Agency, "Bacteriological Warfare and Radioactive Material" (Information Report), 30 December 1950, p. 1 (Top Secret), as cited in Norman Polmar and Jurrien Noot, *Submarines of the Russian and*

- Soviet Navies, 1718–1990* (Annapolis, Md.: U.S. Naval Institute Press, 1991), p. 149.
20. On this reporting by ONI, see Jan Breemer, “Submarine Missile Developments, 1947–1962,” *Navy International*, March 1985, pp. 171–9.
 21. Committee on Undersea Warfare, National Academy of Sciences, *Project Nobska: The Implications of Advanced Design on Undersea Warfare*, Final Report, Volume 1: Assumptions, Conclusions, and Recommendations, p. 34.
 22. Memorandum to McGeorge Bundy from Robert Johnson, “The FY 1962 Budget – Issues Relating to the U.S. Military Program,” 30 January 1961 (Second Draft), pp. 2, 3, and 6, John F. Kennedy Library, National Security Files, Box 273, Folder: Department of Defense, General, 1/61. I am indebted to Greg Koblenz for this document.
 23. Norman Friedman, *U.S. Submarines Since 1945: An Illustrated Design History* (Annapolis, Md.: U.S. Naval Institute Press, 1994), p. 109.
 24. A good textbook on the subject of the following discussion is Albert W. Cox, *Sonar and Underwater Sound* (Lexington, Mass.: Lexington Books, 1974).
 25. On tonals and other aspects of a submarine’s acoustic signature, see William S. Burdic, *Underwater Acoustic System Analysis* (Englewood Cliffs, N.J.: Prentice Hall, 1991), pp. 339–45.
 26. For a detailed, quantitative discussion of narrowband signal processing, see Tom Stefanick, *Strategic Antisubmarine Warfare and Naval Strategy* (Lexington, Mass.: Lexington Books, 1987), pp. 293–306.
 27. On layers, convergence zones, and sound channels, and their effects on sound propagation, see Robert J. Urick, *Principles of Underwater Sound for Engineers* (New York: McGraw-Hill, 1967), pp. 122–59.
 28. Two authoritative unclassified sources on the history of SOSUS are available online at <http://www.spawar.navy.mil/commands/comunderseasurv/pages/SOSUS.htm> and <http://c4iweb.spawar.navy.mil/pd18/pd18hist.htm>. The latter was authored by Ed Dalrymple and I am indebted to Captain Gerry Nifontoff for alerting me to it.
 29. Interview by the author with Robert Frosch of Project Michael.
 30. For the reader who wishes to pursue further research on the role of signals intelligence (SIGINT) in the Third Battle, the best place to start is pp. 25–52 of Appendix D in Volume I of the Project Hartwell report, referenced above in note 10. This is a discussion of the design of an HF/DF network able to intercept very short “burst” or “flash” communications. The Germans had developed a burst transmission system named Kurier for use by their submarine force near the end of World War II. Kurier compressed a standard operational message down to a half-second HF transmission, defeating traditional DF techniques which relied on multiple stations tuning to a signal and gaining a bearing on it after the transmission had commenced. The Hartwell Team expected that the Soviets would adopt this technology for their submarine force, and therefore designed a system to counter it. For an account of when the Soviets did adopt burst transmissions and what the U.S. response was, see W. Craig Reed with William Reed, *Crazy Ivan* (Lincoln, Neb.: iUniverse.Com, Inc., 2000), pp. 185–208.
 31. On the Tenth Fleet, see Ladislav Farago, *The Tenth Fleet* (New York: Paperback Library, 1962).
 32. *Nobska*, p. 6.
 33. *Ibid.*, p. 29.
 34. I am indebted to Fred Milford for this point. One of the reasons for the relatively low number of SSNs was of course the Polaris program, which essentially consumed all nuclear submarine production during the first half of the 1960s.
 35. For a discussion of Navy ASW capabilities during the SSK era, see Frank Andrews, “Submarine Against Submarine,” *Proceedings*, May 1966, pp. 43–57.
 36. *Triton* was the first nuclear submarine to be retired, while *Halibut* was converted into a special mission submarine.

37. On reactor shaft horsepower figures, see Friedman, *U.S. Submarines*, p. 142.
38. Until the late 1960s, LOFAR was normally used only as an adjunct to a submarine's sonar suite when it was assigned to special missions. Later, LOFAR became an integral part of the digital sonar suites that came into the force in the early 1970s.
39. Frederick J. Milford, "U.S. Navy Torpedoes: Part Eight, Torpedoes in the Cold War," *Submarine Review*, April 1998, p. 81.
40. Commander T.F. Schneider, "The Role of Carrier Aircraft in Anti-Submarine Warfare," in *Air Aspects of Antisubmarine Warfare*, presented at Seventh Undersea Symposium, May 1952, DTIC # AD 5088, p. 9.
41. Norman Friedman, *U.S. Destroyers: An Illustrated Design History* (Annapolis, Md.: Naval Institute Press, 1982), p. 279.
42. Interview by the author with Rear Admiral Richard F. Pittenger, 10 December 1996. See also Frank Massa, "Sonar Transducers: A History," *Sea Technology*, Vol. 30, No. 11 (November 1989), pp. 46–7.
43. On the SQS-26, I am indebted to Thaddeus Bell for providing me a copy of his unpublished manuscript, *Probing the Oceans: A History of the AN/SQS-26 Long-Range Echo-Ranging Sonar Development*, Revision 4, 29 March 2001. See also, Norman Friedman, *U.S. Naval Weapons* (London: Conway Maritime Press, 1983), p. 264.
44. Both of these vignettes are described in the SOSUS program history cited in note 28.
45. Russ Mason, "The Evolution of Airborne Anti-submarine Warfare," p. 47, an unpublished manuscript provided the author by Rear Admiral Dan Wolkensdorfer, USN (Ret.).
46. Commander in Chief U.S. Atlantic Fleet, "Annual Report of the Commander in Chief U.S. Atlantic Fleet, 1 July 1960—30 June 1961," 16 January 1962, p. 37, CINCLANTFLT command files, Navy Operational Archives, Washington Navy Yard.
47. U.S. Congress, Senate Appropriations Committee, *Department of Defense Appropriations, Fiscal Year 1975, Part 3* (Washington, D.C.: GPO, 1974), p. 444.
48. On the cooperation between the United States, Great Britain, and Norway in developing, deploying, and exploiting SOSUS, see Olav Riste, *The Norwegian Intelligence Service, 1945–1970* (London: Frank Cass, 1999), pp. 164–90.
49. Joel S. Wit, "Advances in Antisubmarine Warfare," *Scientific American* (February 1981), pp. 36–7; Jeffrey Richelson, *The U.S. Intelligence Community* (Cambridge, Mass.: Ballinger, 1985), pp. 148–9.
50. See letter from Fred Korth to John Stennis on the subject of ASW operations during the Cuban Missile Crisis, 29 November 1962, Navy Operational Archives, 00-Box 11-1962, Folder S.F. #5.
51. Norman Friedman, *U.S. Destroyers*, pp. 363–4.
52. *Ibid.*, p. 363.
53. U.S. House of Representatives, Subcommittee of the Committee on Appropriations, *Department of Defense Appropriations for 1965, Part 5, Research, Development, Test, and Evaluation*, 16 March 1964, pp. 275–6.
54. U.S. House of Representatives, Subcommittee of the Committee on Appropriations, *Department of Defense Appropriations for 1966, Part 3*, 11 March 1965, p. 674.
55. U.S. House of Representatives, Committee on Armed Services, *Hearings on Military Posture and H.R. 4016, to Authorize Appropriations during Fiscal Year 1966*, 2 February 1965, pp. 1079–80.
56. *Ibid.*, p. 1080.
57. Interview with Ed Dalrymple, 13 July 1998.
58. Mechanical blade rate tonals occur at very low frequencies. Provided an array with sufficient aperture and narrowband signal processing, they can be detected at great distances. The Soviet Navy did not eliminate these tonals from their submarines until Akula deployed in the early 1980s. For an early technical description of the source of these tonals, see Donald Ross, *Mechanics Of Underwater Noise*

(New York: Pergamon Press, 1976), pp. 101, 293–5, 297–8.

59. Thus eliminating the burning smell so familiar to a generation of American submariners, caused by the BQQ-3's use of a heat stylus to literally burn narrowband tonals onto a moving sheet of paper.
60. Friedman, *U.S. Submarines*, pp. 67–8.
61. An example of the importance of these signatures to sonar performance prediction was provided by then CNO Admiral Watkins in 1984, when he noted less than predicted ASW performance in exercises involving Victor IIIs because “we had misjudged the absolute sound and pressure levels of the Victor III. We had made an estimating error, and found that they were quieter than we had thought.” See testimony of Admiral James D. Watkins, Committee on Armed Services, U.S. Senate, *Department of Defense Authorization for Appropriations for Fiscal Year 1985, Part 8*, 14 March 1984, p. 3889.
62. A window into the importance of individual submarine fingerprints for SOSUS performance is provided in: Memorandum, Rear Admiral Richard G. Colbert and W. E. Gathright, Policy Planning Council, to Walt W. Rostow, Director, Policy Planning Council, “The ChiCom ‘G’ Class (Missile-Launching Submarine),” 4 May 1965, enclosing U.S. Naval Intelligence Paper, “ChiCom ‘G’ Class,” 11 April 1965, Top Secret, National Archives, RG 59, Policy Planning Council Subject and Country Files, 1965–1969, box 328, Misc. folder. The problem outlined in this memo is the imminent deployment of a Soviet Golf Class SSB by the Chinese, and the question of whether SOSUS would be able to distinguish this submarine from its Soviet cousins.
63. On the value of knowledge of the strength of the target signal, see Frank Andrew's comments in William Browning, “Submarine Warfare and Tactical Development: A Look – Past, Present, and Future,” *Proceedings of the Submarine Development Group TWO & Submarine Development Squadron TWELVE 50th Anniversary Symposium 1949–1999*, U.S. Naval Submarine Base New London, 20–22 May 1999, pp. 35–6.
64. Later, the VP community developed its own capability to obtain opposing submarine signatures. Interview by the author with Rear Admiral Dan Wolkensdorfer, USN (Ret.), 17 November 1998.
65. I am indebted to Thomas Maloney for a discussion of the relative merits of the 594s and especially the 637s in tracking operations compared to their predecessors. Interview, 18 November 1997.
66. The flip side of this enhanced field of view was a more complex set of propagation paths between the target submarine and its hunter. Broadband sound from a Soviet sub could take the direct path to the spherical array in the bow of a trailing American submarine, or it could first bounce off the surface or, in shallow water, the bottom. The direct path signal might not always be the most powerful, which could sometimes confuse the automatic tracker in the bow sonar into thinking that the submarine being trailed was shallower or deeper than it actually was. This is just one example of how trailing operations could go awry even when the U.S. sub had a tremendous acoustic advantage over its prey. See “Synopsis of Interview With Donald Ross, San Diego, California, 1998” in Reed, *Crazy Ivan*, pp. 209–20.
67. Russ Mason manuscript.
68. U.S. House of Representatives, Subcommittee of the Committee on Appropriations, *Department of Defense Appropriations for 1965, Part 5, Research, Development, Test, and Evaluation*, 16 March 1964, p. 279.
69. On the calm official reaction to the first Yankee deployments, see William Beecher, “Soviet Missile Submarines on Patrol off U.S. Coasts: But Pentagon Aides See Deployment as Only Defensive,” *New York Times*, 10 May 1968, p. 3.
70. Two submarine patrol reports, recently declassified by N77, the Undersea Warfare Division of the Office of the Chief of Naval Operations, describe trail operations during the “Happy Time”: Commanding Officer,

USS *Guardfish* (SSN 612) to Commander in Chief, U.S. Pacific Fleet, "Trail of Soviet Echo II nuclear submarine (case PAPA 07) during the period 12 May 1972 – 6 June 1972"; Commanding Officer, USS *Batfish* (SSN 681) to Chief of Naval Operations (OP-95), "Report of Mission LS-26, 2 March 1978 – 17 May 1978." The first describes a trail of an Echo by a *Permit* in the Pacific in 1972. The second describes a trail of a Yankee by a *Sturgeon* in the Atlantic in 1978. For a recent description of the later operation, see Thomas B. Allen, "Run Silent, Run Deep," *Smithsonian*, March 2001, pp. 50–61.

71. Interview with Rear Admiral Richard Pittenger, USN (Ret.), 12 December 1996.
72. R. F. Cross Associates, *Sea-Based Airborne Antisubmarine Warfare, 1940–1977, Volume II 1960–1977*, Prepared for Op-095 Under ONR Contract N00014–77–C–0338, Second Edition, 28 April 1978, p. 173.
73. Thus, mainstream surface warfare officers were fondly referred to as "cannon cockers" by those in the surface community who had developed expertise in ASW. Pittenger interview.
74. A widely noted, contemporary expression of this unpopularity was Captain Robert H. Smith, "A United States Navy for the Future," *Proceedings*, March 1971, pp. 18–25.
75. On Sea Hawk's cancellation see Michael Potter, *Electronic Greyhounds: The Spruance Class Destroyers* (Annapolis, Md.: Naval Institute Press, 1995), p. 21; Friedman, *U.S. Destroyers*, pp. 366–9; and Vice Admiral John Hayward (Ret.), "Comment and Discussion," *Proceedings*, August 1976, p. 71.
76. Dr. Fred Milford, "U.S. Navy Torpedoes: Part Six," *Submarine Review*, October 1997, p. 42.
77. *Ibid.*, p. 46.
78. For all torpedoes the U.S. Navy attests only to speeds in excess of 28 knots, depths to 1,000 feet and range to 10,000 yards. The requirements described here are from Milford, "U.S. Navy Torpedoes: Part Five," *Submarine Review*, July 1997, pp. 78–9.
79. Known as the Tongue of the Ocean because of its unique underwater canyon configuration, the Andros range was chosen for Mk. 48 development largely in order to hide that development from prying Soviet ears. Interview at the Naval Undersea Warfare Center with Dick Nadolink, Jeff Cohen, Bernie Myer, Hal Hultgreen, Dick Bonin, and Colleen Leonardo, 13 March 1998. For more on what came to be known as the Atlantic Undersea Test and Evaluation Center (AUTECE), see John Merrill and Lionel D. Wyld, *Meeting the Submarine Challenge: A Short History of the Naval Underwater Systems Center* (Washington, D.C.: GPO, 1997), pp. 250–60.
80. On Alfa and Papa, I am indebted to Bruce Rule for providing me a translated synopsis of R. Shmakov, "Ahead of Their Time (Design Projects 705 and 705K SSNs)," *Morskoy Sbornik*, 7 November 1996.
81. Mk. 48 performance specifications remain classified. The reference to a 63-knot speed for ADCAP is from Milford, "U.S. Navy Torpedoes: Part Five," *Submarine Review*, July 1997, p. 81.
82. The twenty-six Victor IIIs and later versions of the Delta are sometimes treated as a separate, third generation of Soviet submarines because of their quieting. One Charlie I sank in the Bering Sea off Kamchatka in 1983; though raised, it was not returned to service.
83. Indeed, Harpoon began life as an anti-SSGN weapon. See Malcolm Muir, Jr., *Black Shoes and Blue Water: Surface Warfare in the United States Navy, 1945–1975*, Contributions to Naval History No. 6 (Washington, D.C.: Naval Historical Center, 1996), pp. 184–5.
84. On the Soviet space-based ocean surveillance system, see Norman Friedman, *Seapower and Space* (Annapolis: U.S. Naval Institute Press, 2000), pp. 155–72.
85. John E. Moore and Richard Compton-Hall, *Submarine Warfare Today and Tomorrow* (Bethesda, Md.: Adler & Adler, 1987), pp. 88–9.
86. On this evolution, see Merrill and Wyld, *Meeting the Submarine Challenge*, pp. 78–80, and Bell, *Probing the Oceans*, pp. 143–4, 194.

87. See Merrill and Wyld, *Meeting the Submarine Challenge*, pp. 74–85 for a longer discussion of these developments in surface ASW.
88. Potter, *Electronic Greyhounds*, p. 146.
89. Robert W. Love, Jr., *History of the U.S. Navy, Volume Two, 1942–1991* (Harrisburg, Pa.: Stackpole Books, 1992), p. 612.
90. The tethered goat analogy was attributed to Vice Admiral Lee Baggett by several interviewees. The quote concerning Soviet SSNs being diverted to protect SSBNs was attributed to knowledgeable sources in William Beecher, “The Submarine Game,” *Boston Globe*, 19 December 1975, p. 2. Before becoming the *Globe*’s defense correspondent, Beecher had been an Assistant Secretary of Defense in the Nixon and Ford administrations.
91. Admiral James D. Watkins, “The Maritime Strategy,” *Proceedings*, January 1986, pp. 11–4. On the origins of the Maritime Strategy in the late 1970s, see Michael Palmer, *Origins of the Maritime Strategy: American Naval Strategy in the First Postwar Decade*, Contributions to Naval History No. 1 (Washington, D.C.: Naval Historical Center, 1988); Admiral Thomas B. Hayward, “The Future of U.S. Sea Power,” *Proceedings*, May 1979, pp. 66–71; and John B. Hattendorf, “The Evolution of the Maritime Strategy: 1977–1987,” *Naval War College Review*, Summer 1988, pp. 7–38.
92. On under-ice operations, see Captain T. M. Le Marchand, “Under Ice Operations,” *Naval War College Review*, May–June 1985, pp. 19–27.
93. Interview by the author with Rear Admiral Dan Wolkensdorfer, USN (Ret.), 14 July 1998.
94. The best examples of this genre are: Donald C. Daniel, *Anti-Submarine Warfare and Superpower Strategic Stability* (Urbana, IL: University of Illinois Press, 1986); Tom Stefanick, *Strategic Antisubmarine Warfare and Naval Strategy* (Lexington, Mass.: Lexington Books, 1987); Mark Sakitt, *Submarine Warfare in the Arctic: Option or Illusion? An Occasional Paper of the Center for International Security and Arms Control*, Stanford University, May 1988; and E. V. Miasnikov, *The Future of Russia’s Strategic Nuclear Forces: Discussions and Arguments*, Center for Arms Control, Energy, and Environmental Studies, Moscow Institute of Physics and Technology, 1996.
95. See note 50 for example.
96. Gerald A. Cann, Assistant Secretary of the Navy for Research and Development, in testimony before U.S. House of Representatives, Appropriations Committee, *Hearings on the FY 1985 Defense Budget, Part 5*, p. 204.
97. U.S. Senate Armed Services Committee, *Hearings on the FY 1985 Defense Budget, Part 8*, p. 3889.
98. *Ibid.*, p. 4169.
99. *Ibid.*, p. 3889.
100. On Toshiba, skewback propellers, and blade rate tonals, see Norman Friedman, “Technology and the New Attack Submarine,” Critical Issues Paper, Center for Security Strategies and Operations, Techmatics, Inc., Arlington, Va., p. 31.
101. On Akula and SOSUS see “In the News,” *Submarine Review*, January 1987, pp. 79–80.
102. On the high degree of acoustic parity in the mid-1980s between Akula and all but the improved 688s in the American submarine force, see testimony of Vice Admiral Lee Baggett, Jr., in Committee on Armed Services, U.S. Senate, *Department of Defense Authorization for Appropriations for Fiscal Year 1986, Part 8*, 26 February 1985, p. 4373.
103. Analogous response began with an “interim” forward deployment of Deltas and Echo IIs in early 1984, but even then the Navy was anticipating the later deployment of SS-N-21s on more quiet SSNs. See the prepared statement of Rear Admiral John Butts in Committee on Armed Services, U.S. Senate, *Department of Defense Authorization for Appropriations for Fiscal Year 1986, Part 8*, 26 February 1985, pp. 4364–5.
104. On the threat of no warning SLCM attacks, see George N. Lewis and Theodore E. Postol, “Long-Range Nuclear Cruise Missiles and Stability,” *Science & Global Security*, Vol. 3, Nos. 1–2 (1992), pp. 49–99.

105. Vice Admiral James Fitzgerald, "About ASW," *Submarine Review*, April 1997, p. 6.
106. Interview with Thomas Maloney, 18 November 1997.
107. Subcommittee of the Committee on Appropriations, U.S. House of Representatives, *Department of Defense Appropriations for 1987, Part 4*, 24 April 1986, p. 456.
108. On *Seawolf*, see testimony by Vice Admiral Nils Thunman in Committee on Armed Services, U.S. Senate, *Department of Defense Authorization for Appropriations for Fiscal Year 1986, Part 8*, 15 March 1985, p. 4590.
109. House Subcommittee on Appropriations, *DOD Appropriations for 1987*, pp. 447–8.
110. On Akula compared to Delta, see the statement by Admiral Butts, referenced in note 103, where he stated that the Navy anticipated the Soviets would replace Deltas on interim analogous response patrols "with quieter, SS-N-21 equipped submarines," p. 4365. On submarines like Akula and Sierra compared to older 688s, see Admiral Baggett's testimony later in the same hearing, p. 4373.
111. Friedman, *U.S. Submarines*, pp. 146–7.
112. See Miasnikov, *The Future of Russia's Strategic Nuclear Forces*, especially pp. 16, 17 (note 17), and 35.
113. James M. McConnell, "Strategy and Missions of the Soviet Navy in the Year 2000," in James L. George, ed., *Problems of Sea Power As We Approach the Twenty-First Century* (Washington, D.C.: American Enterprise Institute, 1978), p. 47.
114. Robert C. Toth, "Change in Soviets' Sub Tactics Tied to Spy Case," *Los Angeles Times*, 17 June 1985, p. 3.
115. Comments by Rich Haver at DevRon 12 symposium, 20–22 May 1999.
116. I am particularly indebted to written comments provided me by Rear Admiral W. J. Holland, Jr., USN (Ret.), on this point, dated 10 October 1999.
117. On the requirement for a quieter Mk. 48, see U.S. General Accounting Office, *Navy Torpedo Programs: MK-48 ADCAP Upgrades Not Adequately Justified*, Letter Report, 12 June 1995, GAO/NSIAD-95-104.
118. On perception management, I am indebted to an interview with Admiral Bruce Demars, USN (Ret.), 19 June 1999.
119. During the Cold War, the Soviet Navy never chose to raft the engineering and propulsion spaces of their diesel subs, guaranteeing loud narrow-band tonals when they snorkeled. This is unfortunately no longer true of modern nonnuclear submarines, of which more below.
120. My discussion of DesRon 31 is based on a 24 November 1998 interview with Vice Admiral James Fitzgerald, USN (Ret.), who was in command during much of this period.
121. Interview with Ed Dalrymple, 13 July 1998 and comments provided to the author by Rear Admiral W. J. Holland.
122. Interview with Admiral Carlisle Trost, USN (Ret.), 15 June 1999, who was then Pacific Fleet commander. These negative search methods were supported by the Center for Naval Analyses, continuing the tradition begun by the Operations Evaluation Group during World War II of using sophisticated operations analysis methods in support of the ASW effort. These Indian Ocean deployments also saw the first routine direct support operations by SSNs in the battle group, again because of the atrocious acoustic conditions.
123. On future developments in SURTASS and in passive acoustics in general, see Naval Studies Board, National Research Council, *Technology for the United States Navy and Marine Corps, 2000-2035, Volume 7, Undersea Warfare* (Washington, D.C.: National Academy Press, 1997), pp. 12–21.
124. For a longer discussion of antisubmarine warfare after the Cold War, see Owen Cote, *Anti-submarine Warfare after the Cold War*, An MIT Security Studies Program Conference Report, June 1997. A text only version of the report is available at <http://web.mit.edu/ssp/>.
125. One of the first references to this challenge is in "Report of the Advisory Panel on Submarine and Antisubmarine Warfare," House

Armed Services Committee, 21 March 1989, p.4.

126. On the Trident SSGN conversion, see Owen Cote, *Precision Strike from the Sea: New Missions for a New Navy*, An MIT Security Studies Conference Report, December 1997. See also, Owen Cote, *Mobile Targets from Under the Sea: New Submarine Missions for a New Security Environment*, An MIT Security Studies Conference Report, December 1999. A text only version of both reports is available at <http://web.mit.edu/ssp/>.
127. On the consequences of such limited access ashore, particularly for the Army and the Air Force, see Owen R. Cote, Jr., "Buying '... From the Sea': A Defense Budget For a Maritime Strategy," in Cindy Williams (ed.), *Holding the Line: U.S. Defense Alternatives for the Early 21st Century* (Cambridge, Mass.: M.I.T. Press, 2000).
128. On the required innovations, see Owen R. Cote, Jr., *Assuring Access and Projecting Power*, An MIT Security Studies Program Conference Report, April 2001; text only version is available at <http://web.mit.edu/ssp/>.

Abbreviations

A	AAW	anti-air warfare
	ADCAP	advanced capability Mk. 48 torpedo
	ADS	advanced deployable system
	AIP	air independent propulsion
	ARPDD	automatic radar periscope detection and discrimination
	ASDIC	Allied Submarine Detection Investigation Committee
	ASROC	antisubmarine rocket
	ASUW	antisurface warfare
	ASW	antisubmarine warfare
	AUTEC	Atlantic Undersea Test and Evaluation Center
B	BB	bottom bounce
C	CIA	Central Intelligence Agency
	CNO	Chief of Naval Operations
	CODAR	correlation detection and ranging
	CONUS	continental United States
	COTS	commercial off-the-shelf
	CV	aircraft carrier
	CVA	attack aircraft carrier
	CVE	escort aircraft carrier
	CVS	antisubmarine aircraft carrier
	CVY	Charlie/Victor/Yankee
	CZ	convergence zone
D	DASH	drone anti-submarine helicopter
	DD	destroyer

	DESRON	destroyer squadron
	DIFAR	directional LOFAR
E	ECM	electronic countermeasures
	ESM	electronic support measures
F	FDS	Fixed Distributed System
	FF	frigate
	FFG	guided missile frigate
	FRAM	fleet rehabilitation and modernization
G	GIUK	Greenland-Iceland-UK
	GUPPY	greater underwater propulsion power
H	HEN	Hotel/Echo/November
	HF	high frequency
	HF/DF	high frequency direction finding
	HS	carrier-based, rotary wing ASW aircraft
	HUK	hunter-killer
I	IFF	identification friend or foe
	ISR	intelligence, surveillance, and reconnaissance
	ITASS	interim tactical towed array sonar system
	IUSS	integrated undersea surveillance system
L	LAMPS	Light Airborne Multipurpose System
	LF	low frequency
	LFA	low frequency/active
	LOFAR	low frequency analysis and ranging
M	MAD	magnetic anomaly detection
	MPA	maritime patrol aircraft

N	NavFacs	naval facilities
	NDRC	National Defense Research Council
	NEARTIP	Near Term Improvement Program
	NUWC	Naval Undersea Warfare Center
P	PDC	practice depth charge
R	R&D	research and development
	RCA	Radio Corporation of America
	RF	radio frequency
S	SIGINT	signals intelligence
	SLBM	submarine launched ballistic missile
	SLCM	submarine launched cruise missile
	SLOC	sea line of communication
	SOFAR	sound fixing and ranging
	SOSUS	sound surveillance system
	SS	submarine
	SSB	ballistic missile submarine
	SSBN	nuclear ballistic missile submarine
	SSG	cruise missile submarine
	SSGN	nuclear cruise missile submarine
	SSK	hunter-killer submarine
	SSN	nuclear submarine
	SSR	radar picket submarine
	SSRN	nuclear radar picket submarine
	STASS	submarine tactical array sonar system
	SubDevGru	Submarine Development Group
	SubDevRon	Submarine Development Squadron

	SUBROC	submarine launched rocket
	SURTASS	surveillance towed array sonar system
T	TAG	Tactical Analysis Group
	TASS	towed array surveillance system
	TF	task force
	TLAM-N	tactical land attack missile-nuclear
V	VDS	variable depth sonar
	VP	land-based patrol aircraft
	VP/SSK	patrol aircraft/hunter killer submarine
	VS	carrier-based, fixed wing, ASW aircraft

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