FIXED SONAR SYSTEMS
THE HISTORY AND FUTURE OF THE UNDEWATER SILENT SENTINEL

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Executive Summary

One of the most challenging aspects of Anti-Submarine Warfare (ASW) has been the detection and tracking of submerged contacts. One of the most successful means of achieving this goal was the Sound Surveillance System (SOSUS) developed by the United States Navy in the early 1950's. It was designed using breakthrough discoveries of the propagation paths of sound through water and intended to monitor the growing submarine threat of the Soviet Union. SOSUS provided cueing of transiting Soviet submarines to allow for optimal positioning of U.S. ASW forces for tracking and prosecution of these underwater threats. SOSUS took on an even greater national security role with the advent of submarine launched ballistic missiles, ensuring that U.S. forces were aware of these strategic liabilities in case hostilities were ever to erupt between the two superpowers. With the end of the Cold War, SOSUS has undergone a number of changes in its utilization, but is finding itself no less relevant as an asset against the growing number of modern quiet submarines proliferating around the world.

Introduction

For millennia, humans seeking to better defend themselves have set up observation posts along the ingress routes to their key strongholds. This could consist of something as simple as a person hidden in a tree, to extensive networks of towers communicating with signal fires. Regardless of the means, the goal was the same: to gain advanced notice of the approach of one's enemies to allow for defensive forces to be prepared in a timely manner.

This strategy continues to hold today, though the technological means to do so are radically different. Many of our tools for long-range observation are now based on orbiting satellites. Instead of keeping watch from a high tower, we use photographic reconnaissance. Instead of using signal fires for communication, we use radio signals that are relayed through satellites. However, one area of great concern with which satellites continue to have difficulty is the detection of submerged vessels approaching our shores.

Since World War I, sonar has been used with varying degrees of success to detect submarines. By the end of World War II, it was considered the premier sensor to locate submarines that were able to stay below the surface of the ocean for longer periods of time. Keeping forces constantly at sea to maintain a continuous patrol, however, is expensive and very time consuming. A method was sought that could provide the detection capability of sonar without the prohibitive cost of seagoing time and resources. That method was the fixed sonar system, an array of hydrophones deployed along the ocean floor in strategic areas, designed to detect an enemy submarine as she either left her home waters or approached ours. These silent tripwires came to play a vital role in the rapid buildup and undersea forces of the 1950's and beyond. They still have an important role even today, as their capabilities continue to be refined to meet growing acoustic detection challenges.

Early Designs

The first sonar hydrophones, developed during World War I, could detect submarines from several miles away. However, self-noise was a very limiting factor (and still is today to a lesser degree). These early convoy escorts had to come to a complete stop to be quiet enough to listen for an enemy submarine, greatly hampering their effectiveness in protecting a convoy. (Cote, 2003) Having seen the effectiveness of the lone submarine against commercial assets, the Royal Navy spent several years after the end of the war developing a new technology to aid in the detection of a single submarine at sea. This new development—called ASDIC—was one of the most closely guarded secrets of any military program at the time. The meaning of ASDIC is still debated, but could possibly mean Allied Submarine Detection Investigation Committee or Anti-Submarine Division Supersonics. ASDIC was the first active sonar and provided a step-jump improvement over earlier passive arrays by providing not only bearing to a contact, but also the range.

Once the United States entered World War II, the British began sharing the technology behind their new secret asset. The United States used it to set up high frequency active sonar transducers—known as the Herald system—mounted on submerged tripods outside of several commercial ports. The Herald transducers were operated via cable run to nearby shore-based stations. They could be trained as needed to detect and track a target. The Heralds also incorporated a magnetic tripwire detector that was a precursor to modern Magnetic Anomaly Detectors. (Gerken, 1986)

Acoustic Research Makes Major Strides

Further research into passive acoustic arrays and sound propagation through the water, both during and after World War II, resulted in a breakthrough discovery. Maurice Ewing and J. Lamar Worzel located the presence of a deep-water sound channel that trapped and focused low frequency sound waves, allowing them to propagate over distances of thousands of miles. (Cote, 2003) At the direction of the Office of Naval Research, this Sound Fixing and Ranging (SOFAR) channel was exploited by Bell Labs in late 1950 to begin development on the Sound Surveillance System (SOSUS). SOSUS was to be a vast network of seabed acoustic hydrophones that would utilize the characteristics of the SOFAR channel to detect submerged adversarial submarines at long ranges.

Detecting contacts underwater, particularly from long range, is a difficult task given the interference of acoustic noise in the signal reaching the hydrophone being monitored. Two methods of improving the signal-to-noise ratio (SNR) are antenna gain and processing gain. Given the relatively limited processing power of then-current computer technology, improvements in processing gain were difficult to achieve at the time. Antenna gain, however, was already being exploited in the design of the large hydrophone arrays being installed in the bows of hunter-killer submarines (SSKs). In addition, as the array length grew, the minimum frequency that could be detected also improved. This made SOSUS very well suited to aid in the detection of submarines at long distances. Its 1,000 foot long hydrophone arrays could detect even the lowest frequencies being generated by submarines at ranges of hundreds of miles. To maximize their low frequency detection capability, the SOSUS arrays were installed perpendicular to the expected direction of sound arriving from submarines transiting at the axis of the SOFAR channel.

The realization that the broadband nature of the noise signature of submarines also contained measurable narrowband components led to the next step-increase in submarine detection capabilities. These narrowband components are usually associated with a particular piece of machinery, be it a pump, generator, or gearbox. Using a tunable set of frequency filters, these tonals could be picked out of the general signal being received by the array. The process of sorting out these narrowband tonals was termed Low Frequency Analysis and Ranging (LOFAR). LOFAR gave sonar array designers a way to dramatically improve the processing gain of their systems. As intelligence about adversarial submarine design improved, the aspect-dependent nature of many narrowband tonals could provide even more detailed information about a submarine's general direction of transit. It was later realized that these tonals can also act as a form of acoustic fingerprint for identifying a given class of submarine and sometimes even a specific boat.

The Beginnings of the Network

Bell Labs' first design for SOSUS – named Project Jezebel – was installed off the coast of Eleuthera, Bahamas in 1951. This test installation was so successful that 1952 saw the decision to install SOSUS arrays along the entire Eastern coastline of the U.S. Two years later, SOSUS arrays were planned along the Western coastline and in the waters surrounding Hawaii. These systems were completed and began operations in 1958. The next installation was completed in 1959 off the coast of Argentia, Newfoundland, demonstrating the incorporation of allied nations into the ever-expanding Anti-Submarine Warfare (ASW) detection network.

In use, the detection network entailed a multi-stage process. The SOSUS arrays were connected to land-based Naval Facilities (NavFacs) that received and processed the acoustic information. The refined data was then passed to evaluation centers that incorporated other cueing sources, such as high-frequency direction-finding radars, to generate a submarine probability area (SPA). ASW forces were then directed to the SPA to attempt to gain local contact with the submarine. Completing this sequence of events entailed an inevitable time delay. It also suffered from a relatively high false alarm rate, adding further difficulty to the task of locating and tracking the target. (Cote, 2003)

SOSUS Comes Into Its Own

LOFAR was a great development in the ability to detect submarines. However, against diesel submarines, it was hampered by the fact that the target low frequency tonals were only emitted while the submarine was snorkeling. Thus, a sub could be tracked as it transited to its patrol area, but further localization was at the mercy of the sub's operating routine for recharging its batteries. The advent of nuclear power in submarines, though, showed the great potential of the SOSUS arrays.

Nuclear submarines have numerous pieces of machinery supporting the operation of the reactor that are required to run at all times. The acoustic stealth of early nuclear designs was further compromised by the continued practice of mounting engineering equipment directly to the hull, as well as the use of traditional, but noisy, propeller designs. Their tell-tale narrowband tonals were a constant noise source while they were at sea, making them prime targets for SOSUS. SOSUS also helped to highlight the noisy signatures of the U.S. nuclear subs. The most noted example of this involved USS GEORGE WASHINGTON (SSBN-598) as she transited for one of her first deterrent patrols in 1961. East coast SOSUS stations tracked her during her entire trip across the Atlantic Ocean to the United Kingdom. Another first in long distance detection was achieved in 1962, when the SOSUS station in Barbados detected a Soviet Hotel/Echo/November (HEN)-class submarine as it passed through the Greenland-Iceland-United Kingdom (GIUK) gap.

SOSUS was also proving its value to the aviation-based ASW community. Using the cueing from SOSUS and their own LOFAR-based sonobuoys, ASW patrol aircraft were becoming more effective at tracking adversarial submarines. Coordination with SOSUS, however, caused their tactics to undergo a good deal of refinement. Detections were being made at much longer ranges, and so the area of location uncertainty for the target sub was much larger by the time the ASW aircraft arrived at the original detection point than had been experienced before. This was particularly troubling when attempting to track diesel submarines, as they would only be snorkeling for a finite period of time. Nuclear submarines and their constant noise signatures made this problem much less significant. The growing effectiveness of SOSUS continued to spur development of new ASW tactics in the coming years.

Bringing the Fight to the Enemy

The ability to detect and track Soviet submarines almost at will emboldened the Navy's vision of ASW operations. In 1965, Navy leadership decided to install SOSUS arrays in locations as close to the Soviet home waters as possible. This strategy would offer as much lead time as possible to position U.S. and Allied surface, submarine, and aviation ASW assets to best prosecute the coming threat. The Navy began by looking for natural choke points where the Soviets would have to transit to reach their open-ocean patrol areas. An array was built in the Norwegian Sea in 1964 to watch for submarines leaving their bases on the Kola

Peninsula, and NavFac Keflavik was established in 1966 to supervise the GIUK gap. By 1981, thirty-six stations were keeping watch for submarines of the Soviet Union and their allies around the world. These barrier stations provided the cueing data needed by ASW prosecution vessels. The constant monitoring capability of SOSUS reduced the need for ships, subs, and aircraft to maintain the barrier watch for Soviet subs. The granting of basing rights in places like Rota, Spain and Keflavik, Iceland greatly increased the proximity of ASW aircraft to the expected Soviet transit lanes. SOSUS also freed up American attack submarines (SSNs) to be able to forward deploy in Soviet waters to conduct intelligence gathering, as well as provide the first line of defense in case hostilities were to break out.

The need for a permanent advanced warning system was highlighted by the deployment of four Soviet Foxtrot-class submarines to the Caribbean Sea during the Cuban Missile Crisis in October 1962. The detection of one of the Foxtrots by SOSUS and its subsequent prosecution by ASW patrol aircraft marked another milestone in the program's continuing development. (Association, 2010) SOSUS provided the ideal combination of round-the-clock watchfulness without alerting the adversary to the presence of the sentries.

SOSUS Continues its Evolution

One of the great concerns of the ASW community, and thus one of its primary driving factors, was maintaining its established acoustic advantage over the Soviet Navy. Leaders in the community predicted that it was a matter of when, not if, the Soviets would improve the noise silencing on their submarines to eliminate the early-warning capabilities provided by SOSUS. A primary focus in maintaining that edge was the continuing refinement of acoustic and computing hardware to further enhance array and processing gains.

One of the innovative enhancements to SOSUS was altering how it processed the data from its hydrophone strings. Instead of linking all the hydrophones on a string into a single array, it was determined that splitting the hydrophones into two or even three arrays on a given string would still provide an acceptable level of acoustic detection. The advantage to this technique is that these arrays could be steered to look at separate acoustic arrival paths, which helped to resolve the issue with bearing resolution that was present when a string was configured as a single array. The computers that processed the acoustic data saw continuing improvements as well, allowing for frequency spectra to be resolved at a finer level. This development of passive acoustic detection capability also helped to improve the quieting efforts of American submarine designers. (Cote, 2003)

Navy leadership recognized the vulnerability of SOSUS's passive detection to quieting efforts by the Soviets shortly after the system was first implemented. As a means to prevent the possibility of future obsolescence, SOSUS designers took up where the Herald system left off and tried to develop active echo-ranging capabilities that would work across entire ocean basins. The most notable of these efforts was Project Artemis, which ran during the first half of the 1960's. Artemis, like most other large-scale active echo-ranging systems, had difficulty in developing a low frequency active transducer powerful enough to operate over the desired ranges. It was also inhibited by an inability to perform enough signal processing to account for the effects of reverberation on the outgoing pulses. Ultimately, the idea of an ocean-wide active sonar network was abandoned as unfeasible. In the meantime, technological improvement in passive acoustics continued. However, the biggest challenges to the viability of SOSUS were on the horizon.

SOSUS Meets Its Match

The 1970's saw the introduction of two significant—and different—threats to the ability of SOSUS to fulfill its early-warning detection role. The first, introduced in 1973, was the Delta-class ballistic missile submarine (SSBN). The second, introduced in 1978, was the VICTOR III SSN. These two Soviet submarines were the harbingers that the days of overwhelming

U.S. ASW superiority over the Soviet Union were drawing to a close.

The Delta was not a remarkably new design for Soviet SSBNs. In fact, it was viewed by American intelligence analysts as yet another example of the Soviets failing to improve their quieting techniques. One analyst was quoted as saying:

> 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. (Cote, 2003)

What made the Delta so formidable to SOSUS was its submarine launched ballistic missile (SLBM), which had sufficient range to reach the continental United States from the waters in the vicinity of the Barents Sea and the Sea of Okhotsk. This meant that Soviet SSBNs no longer had to transit through the elaborate series of choke points and acoustic barriers to be able to endanger the U.S. with their nuclear payload. At the same time, the United States publicly declared that one of its first goals upon the commencement of hostilities with the USSR would be the destruction of all Soviet SSBNs. These two factors—the Delta's long-distance launch capability and the announced targeting of their SSBN fleet in the event of hostilities—caused a fundamental shift in the strategic and operational policy of the Soviet Union. They implemented their bastion strategy, in which their SSBNs would conduct their patrols within friendly home waters or under the protection of the marginal and permanent Arctic ice. There were even reports of Deltas conducting strategic patrols while still in port. The bastion strategy meant that U.S. SSNs would have to pass through Soviet ASW barriers to reach their prey in the event of war.

Despite this radical shift by the Soviet strategic forces, SOSUS could still operate against the other classes of Soviet subs, which were still at a noticeable acoustic disadvantage. 1978 was another milestone in the improvements to the Soviet submarine program. This time, it was the introduction of VICTOR III SSN, a measurably quieter nuclear submarine. VICTOR III and its mid-1980's descendent, the even-quieter AKULA, put the U.S. Submarine Force on notice that its acoustic advantage was coming to an end. The Victors and Akulas incorporated numerous technological improvements, from equipment rafting to improved propeller design, to reduce their acoustic signatures. The Akulas, in particular, achieved the long sought-after goal of being quiet enough to evade detection by SOSUS. These dramatic improvements in acoustic quieting technology were the direct result of the classified information collected by SOSUS that was leaked to the Soviet Navy by the Walker/Whitworth spy ring. (Whitman, 2005) Prior to that compromise of information, U.S. intelligence indicated that the Soviet Submarine Force had little indication of the degree to which their submarines were acoustically vulnerable. Despite the setback, proponents of SOSUS could take some comfort in knowing that it would be some time before the rest of the Soviet Submarine Force would reach the acoustic silence standard set by Akula, if such a program was even feasible for the Soviet Union to undertake.

New Life and New Developments

The Navy was not willing to resign SOSUS to the annals of Cold War history. Through efforts led chiefly by Destroyer Squadron (DESRON) 31 as it worked to restore its long-dormant coordinated ASW skills, operational commanders were given more ability to access and incorporate SOSUS and other elements of the Integrated Undersea Surveillance System (IUSS) into their planning and tactical employment. Specifically, DESRON 31 developed techniques for the reverse cueing of contacts to SOSUS operators. This involved sending contact data back to SOSUS monitoring stations to prompt their review to look for the vessel in question and allowed the operators at sea to take advantage of the significantly greater acoustic processing capability of SOSUS base stations.

The 1980's also saw the fielding of two new sonar systems. The first was the Surveillance Towed Array Sonar System (SURTASS), which was essentially a SOSUS-like array towed from a DOD-contracted civilian ship. This array, incorporating the use of a low frequency active (LFA) transducer, achieved the goal of open-ocean active sonar search envisioned by Project Artemis. Further experiments with LFA may be able to incorporate both SOSUS and SURTASS arrays as receiving stations to track quiet modern submarines. The second new development was the Fixed Distributed System (FDS), which used an array of hydrophones designed to take advantage of shorter-range direct path acoustic signals. These sensors would then be networked together through fiber optic cables and routed to an operating station on shore for signal processing. The advantage to FDS is that it can be deployed in both deep and shallow areas because it does not depend on sound propagation through the SOFAR channel. The successor to FDS was the Advanced Deployable System (ADS). ADS operated in much the same fashion as FDS, except that it was intended to be deployed from a ship on an as-needed basis in a forward operating area. The development program for ADS was cancelled in 2006, though remotely-operated, forward-deployable systems continue to be under development. These new systems, now known as Distributed Netted Systems (DNS), are taking on an increasingly important role in the emerging field of Subsea Warfare. DNS perform some of the same monitoring functions as SOSUS, but also have more advanced communications capabilities, such as being able to communicate directly with ships at sea without a shore-based relay station, as well as a growing variety of non-acoustic sensors.

The future of SOSUS is likely heading in a much different direction from what its designers originally envisioned. While it is still considered an important national security asset, the opportunity is also being granted for civilian use of the array and its data collection capabilities. SOSUS has been used in several areas of research, including seismology, marine mammal migration, and looking for global warming trends in oceanographic conditions. Users are required to possess a security clearance, as the data is still in use by Defense Department personnel, but it provides an excellent infrastructure that might not otherwise be feasible for development and deployment by research and academic institutions. SOSUS has also been used by law enforcement personnel, most notably in drug interdiction efforts for over-water supply routes from Central and South America.

Conclusion

SOSUS has had a storied service record over the last fifty-plus years, though many of those stories are only recently being declassified for public consideration and analysis. It was a revolutionary system that provided a significant technological advantage to the United States in its conflict with the former Soviet Union. For all the secrecy associated with the information it provided, SOSUS had a profound impact on the growth and development of modern ASW techniques and tactics. It directly contributed to the acoustic advantage that the U.S. Submarine Force enjoyed for many years, allowing U.S. subs to operate with near-impunity in virtually every region of the world with water deep enough to accommodate them. Even as SOSUS has been pushed towards obsolescence by continuing advances in submarine design, such as air-independent propulsion and ultra-quiet nuclear submarines, its legacy of technological innovation has continued. SOSUS continues to be a valuable resource as its capabilities are applied to new areas of study, ensuring its relevance for years to come.

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