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The American Sound Surveillance System: Using the Ocean to Hunt Soviet Submarines, 1950-1961

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The most ambitious and effective defense project undertaken during the Cold War next to the hydrogen bomb succeeded completely, made not a sound, and remained invisible for a half-century.[1] Dreading an increase in the capability and geographical reach of a Soviet deep-water submarine force,[2] the U.S. Navy decided in 1950 to turn the ocean itself against the Soviet Navy. Over the next three decades there emerged a sophisticated surveillance network with global reach that used the ocean's own characteristics to identify submarine activity. SOSUS, as the sound surveillance system became known, gradually made it impossible for the Soviets to sortie a submarine anywhere in the world without detection. The present historical analysis of this system highlights the importance of the environment in naval warfare, further illuminates the relationship between naval and civilian ocean science, and reveals significant challenges to naval culture and habits directly related to the nature of SOSUS.

In hot or cold war, the natural environment holds warriors and weapons captive and warring adversaries traditionally beg technology to set them free. Driven by the Great War of 1914-1918, technological innovations such as the submarine and airplane emerged as major players in armed conflict by permitting adaptation to the natural environment. In these and many other cases through history, the technology either opened doors to an unexploited environment or enabled better performance in a difficult natural setting. These observations offer nothing new. This analytical assessment appears across the entire spectrum of military and naval historiography and has become commonplace, underpinning a great many effective historical efforts.

However, the creation of global ocean surveillance by the United States during the Cold War overthrows this interpretive commonplace. The navy needed no novel or dedicated technology to accomplish this goal. The necessary components initially came, completely tested, off the vendor's shelf. All of it existed to support the telephone communication system in the United States or the efforts of energy companies to locate ocean-bottom oil deposits and to define potential drill sites. Even the LOFAR actuator, which recorded on paper the submarine detection data for SOSUS, emerged from a desire at AT&T Bell Laboratories to examine more closely human voice patterns with an eye toward enhancing basic customer services.

> When analyzed historically SOSUS turns the familiar Great War adaptive paradigm on its head. In this case new technology did not make the environment more accessible. Rather, environmental understanding enabled the technology. Truly knowing the ocean made effective submarine surveillance conceivable, and that cast the available technology in a new light, revealing unrecognized potential in existing methods and means.

Suddenly the ocean became the most critical factor. In the early Cold War the overwhelming power of the Red Army on the European continent remained a constant threat to NATO. With American personnel on the ground in Europe and allies to support, the U.S. Navy once again became concerned about the safety of the sea-lanes that extended from North America to the United Kingdom and Western Europe . If the Soviet Union developed a Navy with a significant deep-ocean submarine component, the NATO allies would face a potential replay of the battle of the Atlantic against the Germans. Only this time they would probably face high-speed Russian submarines capable of prolonged submergence without the benefit of Ultra signals intelligence. By any standard this constituted a nightmare neither the U.S Navy nor the Royal Navy wished to revisit. Taking a chapter from the history of the undersea clash with the *Kriegsmarine*, knowing the environment in which the battle might take place seemed wise. Thus the fledgling Office of Naval Research (ONR) continued after 1946 the systematic wartime effort to sponsor oceanographic research on a global scale. It also relentlessly pursued the fundamental technical skills and private-sector partners necessary to make surveillance possible.[3]

In this case the most critical component of a high-priority naval mission required a sophisticated understanding of an environment that covers seventy percent of the Earth’s surface. While the navy would certainly fund this effort for its rich treasure of submarine intelligence, it held even greater promise for those who looked more closely. Given some thought, the possible civilian and environmental advantages that might derive from the knowledge generated to enable SOSUS passed imagining. Turning the ocean itself into the most important part of a global defense system would reveal the Earth to humanity in a way heretofore impossible.

Driven by ideology and a consistent strategic goal, the consequent naval mission to locate, classify, and track soviet submarines, enabled by the power of environmental knowledge, gave rise to both a specialized system and a historically unique community within the Navy. This community, their methods, and their distinctive task lasted as long as the threat remained constant and the world bipolar.

For the past half-century SOSUS has certainly attracted historians, if only for its alleged extraordinary capability and the mystery of hunting a deadly adversary deep in the ocean. Time and again highly classified and therefore unavailable sources have made it impossible to evaluate the system and its support community properly. Unlike secret programs emerging from World War 2, ocean surveillance has remained hidden by security measures that protect the intelligence community’s means and methods of operation. Evaluations of the system and portrayals of its capability, both under and overstated, have appeared mostly through the courtesy of journalists and imaginative screenwriters. As the first historical effort made possible by access to the necessary sources this effort will complement the particularly fine work on acoustic anti-submarine warfare by Willem Hackmann, the author's own work on the navy, oceanography, and deep submergence, as well as analyses of social change in the naval service, especially in works by Paul Stillwell, Robert Schneller, and Kathleen Williams.[4]

Origins:

Concerned in 1950 with supporting European allies and American forces across the Atlantic Ocean , American Chief of Naval Operations, Admiral Forrest Sherman requested the assistance of the National Academy of Sciences to explore the problem further. The introduction of high-speed submarines with increased submerged endurance by the Germans in the form of the Type 21 U-boat during World War 2 raised a concern that these technical advances would inform the Soviets in the same way they did the United States Navy.[5] If the Soviet Navy attempted to compensate for its immediate lack of an effective blue water surface fleet with Type 21 emulations, they might compromise any convoy system envisioned as a lifeline for the new NATO alliance.By arrangement with Sherman , Professor Jerrold Zacharias of MIT agreed to lead a summer study of this overseas transport problem, focusing on the submarine threat.[6] According to local lore, the project derived the name *Hartwell* from a popular faculty watering hole near the MIT campus.

Given wartime advances in oceanography and the insights brought to the study by acousticians and representatives from the telephone industry, Hartwell suggested looking into the possibility of an acoustic detection system based upon a recently enhanced appreciation of long-range sound transmission in the ocean. In 1937 Lehigh University physicist William Maurice Ewing hypothesized the existence of a natural channel that would permit the transmission of sound in the ocean at a minimum velocity over hundreds of miles with minimal attenuation.[7] Ewing and his student J. Lamar Worzel went on to confirm the existence of the channel experimentally in 1944. [8] For the postwar scientists at Project Hartwell the suggested ranges made a sound surveillance network tantalizingly possible. In the autumn of 1950 Mervin Kelly of AT&T entered into discussions with Admiral Sherman, resulting in Office of Naval Research contract 210[00] of 12 December with Western Electric. This arrangement provided for a thorough research program in underwater sound with an emphasis on designing and installing a system to detect and classify low-frequency sound radiation from submarines.

Shortly after the contract signing, AT&T submitted a report outlining the general details of a new low frequency signal analyzer. Called Low Frequency Analysis and Recording, or LOFAR, the new technique and its hardware emerged from research conducted by Ralph Potter and David Winston at Bell Laboratories. The Navy first took delivery of LOFAR on 2 May 1951 as a production model that promised both submarine detection and classification.[9]

From Concept to Reality:

In 1952 construction began on the first surveillance facility, or NAVFAC, in the highly secret Caesar series, as well as its supporting submerged arrays. The facility initiated effective listening from Puerto Rico by February 1955.[10] The Naval Hydrographic Office, the Woods Hole Oceanographic Institution, and Hudson Laboratories did the ocean bottom surveys necessary to assure the best placement for both the hydrophone arrays and the connecting cables feeding the LOFAR-equipped Navfacs on shore.[11] Both the Navy and AT&T laid the cable that enabled the system.

The CNO originally specified six Caesar stations, but this mandate expanded quickly. The final first generation NAVFAC went on line as part of the Caesar program in 1961.

In the charged political atmosphere following the Cuban Missile Crisis in 1962, the system’s identity changed from experimental Soviet submarine tripwire to a national strategic asset. The entire technical implementation emerged from the Navy’s partnership with AT&T and its Western Electric subsidiary.

The system design and architecture invited the operators, mostly enlisted ratings, to partner with the ocean in an effort to discover Soviet submarines on patrol. Fixed, rigid arrays lay at a variety of advantageous positions and angles on the ocean bottom, each attached to a NAVFAC on shore. The system's officers and ratings, the latter called Ocean Technicians or OTs after 1969, monitored the paper Lofargrams generated by the actuators, which recorded graphically the acoustic signals captured by the arrays, enabling visual detection and interpretation.

SOSUS required of those who read and interpreted the Lofargrams a working intimacy with ocean acoustics and Soviet submarine systems. SOSUS personnel acquired this familiarity in very rigorous classes conducted in the highly classified area located behind a large green security door at the Fleet Sonar Sound School in Key West . In the early years barely half of the twenty-five people in each successive training class passed the course and joined the system. For those who qualified, they never lost the knowledge they needed to understand what the Lofargram had to offer. If any part of the boat moved, pumped or circulated, the resulting sound radiated into the ocean and formed part of the trail that enabled the system to find the submarine and track it.[12]

The detection process relied on nature, both environmental and human, rather than mechanical devices. Only after discovering and confirming a potential target deep in the ocean, beyond visibility, did the mechanical processes take over. Describing his on-the-job training at Point Magu California in 1963 a retired OT master chief recalled a very ambitious training regimen for students barely twenty years old.

> Well, you were expected to maintain your position on the watch, which was doing Lofargram analysis, learning plotting techniques, learning how to track contacts, studying nautical slide rules, one-arm protractors, and . . . learning all these various things as far as plotting and location and geography. . . you had to know how to do very extensive maneuvering board solutions in order . . . to detect localize, track, and report threat contacts. . .And you also had to learn . . . the dynamics of props and sound propagation, and underwater factors . . .as well as

apply the tools to do the jobs and report the contacts. . . You had all these things. . . to learn.[13]

The naval personnel who made this system work clearly understood the theory upon which it rested and never simply relied on "black boxed" methods. The Navy trained OTs and their officers in acoustic theory as it related to submarines and drilled them in every aspect of Soviet submarine hardware. By the time an operator completed his or her training at Key West or, in later years, in Norfolk , they knew the physics, the adversary, and exactly how the system addressed the problem of long range, deep-water submarine detection and classification. They could identify submarines, all manner of surface vessels, marine life, and submerged seismic events immediately upon seeing the acoustic signals as rendered by LOFAR or in post detection analysis of magnetic tape recordings made of the sounds captured by the hydrophones. Beyond that, they helped install and regularly maintain the equipment at the SOSUS Navfacs in conjunction with Western Electric and other commercial ventures committed to the system's growth and refinement. As it turned out, the human being in this detection system did not merely play the role of observer, collector, or reporter. In reality, the machine did not achieve the goal. With SOSUS an OT moved beyond the role of device operator.

In some cases, advanced technologies did not require much of an alteration in the appreciation of the individual's role. Wartime development of radar-enhanced fire control systems designed to target and destroy hostile ships and aircraft carefully took into account the affect human beings would have on the system, its integration, and effectiveness. In this model, however, the "human factor" and the system still stood apart. The system would perform a function if properly operated and maintained; the human being enabled the system as machine operator and monitor.

Operators assumed a very different role in SOSUS. The individual proved an integral part of the system itself, merging the officers and ratings at the SOSUS stations so completely into the process of detection that the acoustic and mechanical systems became extensions of the ocean technician's sensory capability. This did not compare to driving an automobile. Rather, it seemed as if the SOSUS operator physically became part of an intelligent or "smart" vehicle. The sound surveillance system projected the intellect and senses of the operators well beyond their personal space, at times thousands of miles across the ocean and hundreds of fathoms into its depths. As a result, SOSUS permitted first-hand, real-time human interpretation and analysis at a very high technical and interpretative level, something that not even the advent of the early digital age would radically change or improve.

In designing the critical link between the operator and the system technology, the architects of this type of surveillance designed the LOFAR actuator to provide an image of acoustic energy in transit through the ocean.[14] The Lofargrams, generated by a stylus tracking across constantly moving heat-sensitive, carbon based paper, provided a graphic sketch of the acoustic signals in black, white, and grey, offering an image of aural reality while filling the operations spaces in the Navfacs with a carbon powder haze that only a small stylus-mounted vacuum would later subdue.

While a perfectly natural expression of scientific method and process, communicating data with this type of imagery achieved a result that went far beyond immediate utility. Embedded within the many varied graphic images operators found themselves able to discern subtle nuances in sound signals via intensity, color, shape, and shade that often made the difference between seeing a school of fish or a submarine on a Lofargram.

This approach also enabled hundreds of SOSUS personnel to master the technique of detection using artistic skills that would not play a role if the acoustic contacts emerged as numbers on a spreadsheet or a contact point on an early warning radar screen. For some, it actually raised conditions commonly perceived as physical handicaps to prized assets, very effective for interpretation. Color blindness, which made people exceptionally sensitive to fine shades of black and white, emerged as one of these. The colorblind world played out in the same varied shades of gray that appeared on the

Lofargram. Operators looked beyond the data, the physics, and the engineering, to the ways the LOFAR trace betrayed the personality and attitude of the detected signal that very often revealed its nature. In short, the use of graphic images enabled SOSUS personnel in a way similar to the effect the graphic-user interface commercially exploited by Steve Jobs in the Apple “Mac” had on the average computer user thirty years go.[15] It drew them into a comfortable relationship with the system that promoted ease of use while enhancing the final product.

The nature of the task and the acoustic imaging techniques employed by LOFAR made a well-trained and intellectually able operator with an artistic eye a necessity. Understanding the behavior of sound in seawater and submarines represented only part of the challenge. With detection and identification of the target the primary goal, the SOSUS watch-standers tapped their technical knowledge of Soviet submarines and their appreciation of the ocean’s influence to provide the proper interpretation of the signal graphically represented on the Lofargram. Some signals appeared in such a regular and familiar ways that, after initial detection; future identification did not present a problem. These visual patterns became the much-vaunted “signatures” which betrayed particular targets or classes of targets.

Signatures and peculiar image variations suggesting a submarine threat, emerged with far greater ease to those with an artistic flair or with personal visual talents or gifts. If it became necessary to resort to the audio recordings, the NAVFAC staff would listen to the tapes and review the Lofargrams in a post-detection analysis session to determine the nature of the contact. This approach permitted naval officers and ratings, some of them rather junior, to play a role in the fine particulars of threat analysis and system development. The latter became possible because those who actually used the system daily, developing an intimate appreciation of its capabilities, eccentricities, and possibilities could effectively communicate that knowledge to their scientific and engineering counterparts. In this particular case, for this unique system, they communicated nearly as equals. This became particularly evident in the repeated attempts to adapt signal-processing techniques to detect and identify targets. Very often the naval personnel appreciated more quickly than anyone the possible effectiveness of the technique under consideration and the reasons for potential failure or the possible degree of success.

In every case, informed personal opinion led to confirmed targets, regularly highlighting the importance of individual knowledge and the visual interpretation of Lofargrams. SOSUS also encouraged competition among increasingly expert OTs, and the entire community became consumed by a hunger to dominate the object of the hunt. That object always seemed close and immediate. They appeared in black and gray on the Lofargrams near at hand for every hunter to see, if he or she knew the signs.

The competition to know the signs, to find the elusive target first, and to know that a threat existed even before the president himself, created an intense and competitive atmosphere. Occupied by a rigorous watch schedule, not even sleep seemed more important than the hunt and its signs. A veteran of multiple tours at NAVFAC Keflevik, established in 1966, Commander James Donovan remembered his early service as an enlisted OT and the importance of watching a target's signature and sound characteristics emerge for the first time on LOFAR. If a new Soviet boat passed over one of the Keflavik arrays, very few remained in their beds. As he recalled, the action lay elsewhere.

> I remember a submarine being detected and it was coming toward a SOSUS array. It was really interesting. And I know when I was on watch in the daytime that we knew it was coming and probably at midnight. So I would wake myself up and come in at a quarter 'til midnight to be there, and sure enough there would be five or six guys from my watchteam doing the same thing; to watch the submarine. Then we would go back home and go back to bed.[16]

Unexpected Challenges:

This unique naval experience also laid the groundwork for fundamental social change, almost unwittingly opening an important door for women. Admitted to the community from a very early stage, women played an important part in the success of SOSUS only because the mission departed so frequently from the normal naval cultural and operational routine. In this case, detection and analysis would not require women to serve on board ship because the system asked operators to reach out into the ocean and retrieve the necessary data from Navfacs ashore via LOFAR. In this professional community, living accommodations could remain separate and ashore, talented women could easily rise to the demands of the training, and the Navy needed large numbers of operators to keep pace with the system's promise and growth. Inviting women to join the community simply made good sense and had great immediate utility. In 1970 Norah Anderson received her assignment to NAVFAC Eleuthera, becoming the first woman to take a place on the operations floor.

The advantage of this choice for women went well beyond the obviously interesting work. Since the Navy classified SOSUS activity as a warfare specialty, the door opened for hundreds of women to a Navy career outside of medicine, education, or administration. SOSUS work appeared on your fitness report and record as combat experience equal in value to time at sea. The Navfacs qualified as one of the Cold War's front lines. Thus, SOSUS presented the possibility of advancing to a very senior enlisted grade or, for officers of both sexes, it offered the holy grail of command. Lieutenant Commander Peggy Frederick became the first woman to attain the latter, taking command of NAVFAC Lewes in Delaware in 1977.

For the entire history of the OT rating, extending from 1969 to 1997, any day would find as many women on a NAVFAC operations floor as men. For most of the Cold War this represented the only way a woman could claim warfare experience and compete with her male counterparts on a nearly equal basis. SOSUS required intellect, nearly artistic discernment, and good judgment, diminishing the significance of physical strength and size. By removing many of the traditional barriers to female front-line service, this effort provided a common denominator for both sexes in the context of a mission capability the navy leadership prized very highly.

In a much broader sense, providing qualified personnel represented one of the most difficult cultural challenges for those commanding SOSUS. Early experience demonstrated that it took a great deal of time to train operators. A Navfac's capability suffered when one of its trained staff finished a tour and returned to a traditional fleet experience. When the system began the Navy attracted people through recruitment and from a variety of ratings and officer experiences. Many of the assigned officers came from the reserves, a naval community with a style of staffing flexibility that initially served the system's needs. Finding and retaining talent remained haphazard and difficult.

By the mid-1960s short term commitments and tours lasting only two or three years left the SOSUS system regularly short of qualified personnel. In 1964, Commander Ocean Systems Atlantic [COSL], the senior officer in the system, launched an appeal to create a rating for the SOSUS enlisted community, with a complete career track from able seaman through master chief. His effort benefited from a report composed by a panel expressly created at COSL in Dam Neck, Virginia to design all aspects of the proposed rating.[17] In spite of meticulous preparation it took nearly five years of rather intense debate between Ocean Systems Atlantic and the Bureau of Personnel to agree on the need for the Ocean Technician [OT] rating. This innovation preserved a cadre of well-trained and experienced enlisted operators for the duration of a career rather than just an extended tour. Standards for the rating appeared in print to inform the enlisted community by early 1970.[18]

The dramatic debate that created the OT rating paled in comparison with the Bureau of Personnel reaction to suggestions that similar measures might retain highly qualified officers or permit OTs to aspire to oceanographic warrant officer positions while remaining within SOSUS. Retaining trained officers who wanted to stay with the system by means of service tour extensions did not properly address the need for informed and expert leadership at the Navfacs.

The SOSUS leadership began their appeal in 1973 that officers might make a career of specialized service in this non-traditional system. They never succeeded. The bureau refused to entertain the possibility that this kind of exclusive work would provide the proper background to help shape an officer who would expect to rise in the ranks. The rarity of sea duty among officers serving in SOSUS alone seemed to make the suggestion absolutely foreign. For the remaining years of the Cold War officers who wished to remain with SOSUS extended their tours as long as possible and then left the service, staying with the system in a civilian capacity. The closest SOSUS ever came to a reliable source of trained officers eventually took the form of possible promotion to Limited Duty Officer or LDO. In this case, individuals with experience in the system had their records marked accordingly and through their very traditional careers might find themselves called upon to return to a Navfac to fill a pressing need for experienced leadership. More frequently, the strong appeal of the work and the strict traditional definition of the way a naval officer developed drove very skilled personnel out of the Navy and into the civil service or private companies.[19]

SOSUS demanded unique knowledge, methods, relationships, and a need for secrecy equaled by few other defense projects. From the earliest months of SOSUS activity, its operators kept secret the nature and existence of their "black" program. Knowledge of their mission could not go beyond their professional circle. Their workspaces remained non-descript and only carried the outward title Navfac. Watch bills kept them on duty for long periods of time on a twenty-four hour clock, but unlike the rest of the Navy, never at sea. Upon transfer from one Navfac to another, a new arrival would usually know at least one third of the people at the new site, because he or she had worked with all of them before at other locations. Varying slightly in number over time, roughly 1800 OTs and 150 SOSUS officers only had a small number of Navfacs in the United States and abroad to populate.[20]

They lived, worked, ate, smoked, worried, and hunted Soviet submarines together and did it in very close personal proximity. In spite of the stated Navy policy against fraternization, many senior OTs married their watch officers and the official Navy turned a blind eye.[21] Thus families grew, prospered, and occasionally split within the confines of this professional culture. In spite of this kind of surveillance qualifying as a warfare specialty, in the beginning they did not have, and later could not wear, their uniform insignia in the same way a submariner might display gold or silver dolphins over his uniform breast pocket. This community had to live the secret.

Conclusion

Examining SOSUS forces the ocean environment into the analytical foreground, inviting new connections and suggesting questions that would not present themselves otherwise. The systems and methods that contributed to SOSUS strongly suggest a symbiotic relationship between independent civilian science and the national defense as it pertained to the ocean. Ocean surveillance encouraged investigation that advanced the science of acoustics and produced seminal research and essential publications. Given the fact that much of it remained classified and threatened the need for professional communication led the Navy laboratories to create the classified *Journal of Underwater Acoustics* to permit the kind of community awareness necessary for science to prosper, even within a professional group closed by security concerns. In recent years some physicists and oceanographers have collected seminal scientific articles published in this fashion and submitted those still classified for security review to develop a widely available library of basic research and analysis in support of the current state of the art.[22]

Indeed, a close look at oceanography's recent past suggests that a very powerful and ever-present civilian obverse of defense ocean science emerged from World War 2. In serving their own interests, the naval and civilian ocean science communities naturally, but often reluctantly, served one another as well. The SOSUS experience built on these developments and benefited from them. The emergence of acoustic tomography provides a case in point. After retiring from Bell Laboratories John Steinberg embarked on an academic career at the University of Miami in the early 1960s and pursued acoustics research in the Florida Straits sponsored by ONR. In the process of supporting the submarine community and SOSUS operators with his work, Steinberg discovered a way of acoustically monitoring various physical attributes of the ocean. Dubbed tomography, this technique has helped scientists understand the extent and effect of global warming through many productive civilian scientific projects including ATOC.[23]

The importance of the ocean to the detection equation drove the Navy to learn as much as it could about depths well beyond the limits imposed by a submarine's capability. This imperative drew Navy sponsorship and personnel into every aspect of oceanography, to the extent of funding the creation of programs in universities around the country and offering support to those pioneering centers of ocean science already in existence. SOSUS and anti-submarine warfare did not create oceanography as an independent university-based science in the United States , but it certainly made a major contribution. The system's increasing significance and the importance of undersea warfare in general guaranteed a continuing level of patronage for certain lines of scientific investigation, particularly physical oceanography and underwater acoustics.

SOSUS historically emphasizes the importance of the environmental factor in understanding naval professional communities as well. Surveillance practitioners remained unique and separate, an intelligence subculture within a Navy that often found them disturbingly different. Their relationship with the ocean and what it had to offer took a completely different form from those who sailed on its surface and that difference had social as well as operational consequences. Women found unexpected opportunity and the enlisted community discovered new alternatives in a career track that defined their professional purpose in a satisfying manner. For officers, relentlessly held by the Navy to the tradition of diverse experience and sea duty, the appeal of SOSUS ended or redefined careers, affirming, for better or worse, the traditional road to senior naval leadership.

In the context of the relationship with science that made SOSUS possible, regardless of current personal opinions or cultural attitudes, both the naval and civilian science communities actually worked toward the same goal. Understanding the ocean in all of its complexity became the common denominator that bound them together, making it impossible for historians to understand one without knowing the other.

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[1] The author wishes to thank the reviewers, particularly Dr. John Guilmartin of Ohio State University , for their comments and insight. A version of this article was delivered at the 2006 meeting of the Society for Military History. Some of the sources for this article are still classified and cannot be made available to the public for reasons of national security. Those sources are marked with a "Class" for identification at the beginning and end of the particular source citation.

[2] Study of Undersea Warfare (The Low Report), 22 April 1950, Post 1 January 1946 Command File , U.S. Navy Operational Archive, Washington D.C.

[3] Gary E. Weir, An Ocean in Common: American Naval Officers, Scientists, and the Ocean Environment (College Station : Texas A&M University Press, 2001), chapters 10-17.

[4] Willem Hackmann, *Seek and Strike: Sonar, Anti-Submarine Warfare, and the Royal Navy, 1914-54* (London: HMSO, 1984); Paul Stillwell, ed., *The Golden Thirteen: Recollections of the First Black Naval Officers* (Annapolis: Naval Institute Press, 1993); Robert Schneller, *Breaking the Color Barrier: The U.S. Naval Academy's First Black Midshipmen and the Struggle for Naval Equality* (New York: NYU Press, 2005); Kathleen Broome Williams, *Grace Hopper: Admiral of the Cyber Sea* (Annapolis: Naval Institute Press, 2004); Kathleen Broome Williams, *Improbable Warriors: Women Scientists and the U.S. Navy in World War II* (Annapolis: Naval Institute Press, 2001).

[5] Type 21 U-boats emerged from a very intensive development program within the wartime *Kriegsmarine* to create a boat that could stay submerged longer and move much

faster. Employing the schnorchel to draw in air for propulsion and to dispose of exhaust, increased battery power for greater submerged speed, and a streamlined hull, by the end of the conflict the Germans produced a vessel capable of staying submerged longer and moving through the water at a sustained 17 knots for thirty minutes without a battery recharge. If this kind of submarine became the rule, it could easily defeat the anti-submarine capabilities of the victorious powers. In the immediate postwar years it presented the ultimate threat. Eberhard Rössler, *Geschichte des deutschen Ubootbaus* (Munich: J.F. Lehman Verlag, 1975).

[6] [Class] Project Hartwell, MIT, "A Report on Security of Overseas Transport," 21 September 1950, post-1 January 1946 Command File, AR/NHC.[Class] In an effort to magnify the effect of the fluid professional dialogue that characterized the relationship between the Navy and the civilian scientific community during World War 2, the National Academy of Sciences and various universities employed summer studies to address critical defense and scientific problems. These experiences brought scientists, engineers, and naval professionals together for most of a summer at a fixed location to achieve a critical mass of intellect and experience in an effort to address the problem and compose possible solutions. Summer Studies took place with relative frequency during the Cold War and also gave rise to regular consulting groups occupied with particular aspects of the defense problem, like the Jasons. Weir, *An Ocean in Common*, Interpolation 2, Chapter 18.

[7] Weir, *An Ocean in Common*, 172-178; 298; 315.

[8] Weir, *An Ocean in Common*, 172-178; 298; 315. Maurice Ewing, G.P. Woollard, A.C. Vine, and J.L. Worzel, "Recent Results in Submarine Geophysics," *Bulletin of the Geological Society of America*, LVII, October 1946, 909-934, box 4; "Sofar," Radio broadcast made over WGY, Schenectady, N.Y. 17 April 1946, box 232, W. Maurice Ewing Papers, Center for American History Archives, University of Texas, Austin; Maurice Ewing and J. Lamar Worzel, "Long Range Sound Transmission," *The Geological Society of America Memoir 27*, 15 October 1948. Ralph Potter was a veteran

of Project Hartwell. He brought the immediacy of the Navy's ASW needs back to Bell with him after the summer study concluded. He and Winston adapted an effort at Bell to analyze voice patterns for telephone transmission to the Navy's needs with LOFAR.

[9] [Class] Project Jezebel: Final Project Jezebel: Final Report on Developmental Contract NObsr-57093, 1 January 1961 [covering the period 1 November 1951 to 1 January 1961] (These records are now resident at the U.S. Navy Operational Archive); ASW Surveillance, Phase 1, Volume II, Appendix A - History of ASW Surveillance, 28 June 1968, TRW Underwater Surveillance Office Archive, McLean, VA. Interview with Captain Joseph Kelly by David K. Allison and John Pitts, 9 November 1984, Navy Laboratories Archive, David Taylor Research Center, Carderock, Maryland. [Class]

[10] This was Navfac Ramey in Puerto Rico .

[11] [Class] Oral History with Mr. Ramon Jackson by Gary E. Weir, 9 October 2001, U.S. Navy Operational Archive, Washington D.C. [Class] Jackson was one of the ocean bottom surveyors and cartographers with the Navy Hydrographic Office.

[12] [Class] Oral History with Michael Duggan by Gary E. Weir, 7 November 2001, U.S. Navy Operational Archive, Washington D.C. [Class]

[13] [Class] Oral History with Phillip Brown, USN (Ret.) by Gary E. Weir, 2 June 1997, U.S. Navy Operational Archive, Washington D.C. [Class]

[14] Peter Galison, Image and Logic: A Material Culture of Microphysics (Chicago and London: University of Chicago Press, 1997), chapter 1. Galison's analysis of the material culture of microphysics examined largely through the nature of laboratory practice and instrumentation illuminated for this study the importance of the nature of LOFAR and the choices made in its creation. The decision to employ a *graph* plotting time versus frequency combined with the means of rendering the graph, a stylus contact essentially burning its trace into heat sensitive carbon based paper, satisfied the need to collect data

on the sound detected but also provided an image with sufficient character and attributes to permit threat analysis based upon the graph-as-image as opposed to its usual function as a simple picture of related datapoints. This characteristic opened great possibilities for both the scientist and the system operators. For the most part, the latter treated the Lofargrams as images one could interpret as numerical value and as art, each with its own unique “brushstrokes“ suggesting that each contact had its own signature.

[15] Michael Hiltzik, Dealers of Lightning: Xerox PARC and the Dawn of the Computer Age (New York: Harper Collins, 1999), see especially chapter 23.

[16] [Class] Oral History with Commander James M. Donovan, USN by Gary E. Weir, 24 May 2001, U.S. Navy Operational Archive, Washington D.C. [Class]

[17] [Class] COSL to Chief of Naval Personnel, 9 June 1964, Classified Records Vault Shelf, Code N16, Commander Undersea Surveillance, FCTC Dam Neck, VA.[Class]

[18] [Class] Proposed Occupational Standards, OT Rating, c 1970; Revised 1975, Classified Records Vault Shelf, Code N16, Commander Undersea Surveillance, FCTC Dam Neck, VA.[Class]

[19] [Class] Commanding Officer, Navfac Keflavik to Chief of Naval Personnel, 20 February 1973; Chief of Naval Personnel to Commanding Officer, Navfac Keflavik, 26 November 1973; COSL and COSP to CNO, 15 February 1973, Classified Records Vault Shelf, Code N16, Commander Undersea Surveillance, FCTC Dam Neck, VA.[Class]. See also: [Class] Donovan Oral History by Weir [Class].

[20] [Class] Donovan Oral History by Weir [Class]

[21] [Class] Donovan Oral History by Weir [Class] Many others interviewed for this project made this same point.

[22] Author correspondence with Dr. Fred Spiess, Marine Physical Laboratory [San Diego] and the Scripps Institution of Oceanography [LaJolla], 2005, 2006.

[23] Weir, An Ocean in Common, 298-315; Oral History with Professor Harry DeFerrari, RSMAS conducted by Gary E. Weir, 21 January 2000, Contemporary History Branch, U.S. Naval Historical Center; John C. Steinberg and T.G. Birdsall, "Underwater Sound Propagation in the Straits of Florida," *Journal of the Acoustical Society of America* (volume 39 No.301, 1966), 301. ATOC is an acronym for Acoustic Thermometry of Ocean Climate. Gary E. Weir, From Surveillance to Global Warming: John Steinberg and Ocean Acoustics, *International Journal of Naval History*, volume 2, number 1 (April 2003), www.ijnhonline.org (accessed 18 September 2006.).

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