U-boat Predators in the Great War: "A Problem of Physics, Pure and Simple"

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That a solution to U-boat predation during World War I (WWI), also known as The Great War (1914–1918), was "a problem of physics, pure and simple" occurred in a conversation between British Nobel Laureate Sir Ernest Rutherford and American physicist Robert Millikan. Millikan then added: "It was not even a problem of engineering, although every physical problem, in general, sooner or later becomes one for the engineer" (Yerkes, 1920, p. 39). Technologies of the industrial revolution found new applications, many of which were about to converge on the battlefields of Europe. Scientists placed their discoveries into the hands of engineers, who then put their inventions into the hands of the military. The president of Western Reserve University (Cleveland, Ohio), Charles Thwing (1920, p. 115), was unequivocal: "The two new chief forms of attack, the submarine and the airplane, had their origins in the science of physics."

The War to End All Wars

Within weeks of Germany's onslaught through Belgium and Britain's declaration of war on August 4, 1914, H. G. Wells wrote *The War That Would End War*, pleading with the world to intervene: "There is no going back now to peace; our men must die, in heaps, in thousands; we cannot delude ourselves with dreams of easy victories" (Wells, 1914, p. 41). The title was soon popularized as *The War to End All Wars*.

As Wells had envisioned, the course of the war would become a four-year stalemate along the Western Front. European battlefields were overrun by mechanized infantry; the killing fields were made even more deadly with the introduction of rapid-fire weapons, poison gas, and bombing by aircraft. Long-range cannons bombarded Paris from 75 miles where targeting calculations included rotation of the earth.

Prior to 1914, none of the future belligerents understood the scale of devastation that The Great War would bring. Neither did they foresee the role of submarine warfare nor the need for effective anti-submarine technologies. This all changed on September 22, 1914. Germany's nearly obsolete Unterseeboot *U-9*, on a scouting mission in the North Sea, encountered three armored British cruisers. The reality of asymmetrical naval warfare arrived when *U-9*, with a compliment of only 29, fired torpedoes into the *Aboukir*, *Cressy*, and *Hogue*, sending the ships to the bottom with a loss of over 1,400.

Vulnerable to this invisible predator, a shocked and unprepared British Admiralty realized that The Grand Fleet was not so grand. Germany, however, immediately expanded submarine construction for extended operations into the Atlantic and Mediterranean. U-boats rose to periscope depth to aim and fire a torpedo, set to run below six feet, striking the soft underbelly of a ship. So-called "armored" vessels were only protected above the waterline against cannon fire, not against a well-aimed torpedo.

Allied destroyers, alerted to the presence of a U-boat by the explosive destruction of a merchantman, had one option, follow the trail of bubbles left by the torpedo and run through the U-boat's hull before submerging deeper than the destroyer's keel. Crude depth charges were available but were simply hit or miss. Once submerged and speeding from the scene, attacking the predator was futile. Time was better spent rescuing survivors.

"[T]he submarine problem was the problem of the war" (Millikan, 1919, p. 288), certainly the understatement of the war. From the start, however, naval planners understood a U-boat's vulnerability, and that is where our story begins.

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Urgent Need For Anti-Submarine Technologies

Admiral William Sowden Sims, commander of US Naval Forces in Europe, described the situation Allies faced (**Figure 1**) as "an enemy we could not see," adding "warfare upon the submarine was still largely a game of blind man's buff. If our men could not detect the submarine with their eyes, could they not do so with their ears. The enemy could make himself unseen at will, but he could not make himself unheard." Admiral Sims recognized the key to finding a solution to the "submarine problem" but only the key, not the solution itself. Sims (1920, vol. 39, pp. 357-358) set the stage: "[U-boats] produced sound waves that resembled nothing else in art or nature. It now became the business of naval science to take advantage of this phenomenon to track the submarine after it had submerged."

U-boats arrived on the scene in 1914, yet more than two-and-a-half years passed before the United States entered the war. Transforming the sounds of a submerged, transiting U-boat into a fatal vulnerability fell to the British. The Admiralty, unmoved by efforts from the scientific community to seek solutions, turned to a recently retired officer, Commander (later Captain) C. P. Ryan. Ryan left retirement in August 1914 and was assigned to an island naval base in the Firth of Forth, an estuary (Firth) of Scotland's River Forth flowing into the North Sea. The urgency of his assignment occurred in September when *U-21*, hunting British warships, entered the Firth. Recognized by the Admiralty during his prior service developing naval radio communications, Ryan was well suited to the task at hand, exploiting that U-boat vulnerability with electronic devices, microphones in particular. Beyond applications in undersea warfare, microphone-based acoustics also became essential on battlefields to locate and subdue enemy artillery fire (Costley, 2020).

Figure 1. *Locations of the vessels lost to U-boats in April 1917 (**open circles**), the month Admiral Sims arrived (Sims, 1919, vol. 38, p. 497). **Closed circles**, locations of small islands. **Inset:** British steamer* Maplewood *attacked by* U-35*, April 7, 1917. Reproduced from Wikimedia Commons, Bundesarchiv, Bild 102-00159 ([bit.ly/3Vs2J68](bit.ly/3Vs2J68)); licensed under a Creative Commons Attribution ShareAlike 3.0 Germany (CC-BY-SA 3.0, creativecommons.org/licenses/by-sa/3.0/de/deed.en) license.*

At the onset of WWI, the "hydrophone" was a technology that evolved in the late nineteenth century (see bit.ly/3RAIi5i). Not readily available in 1914, Ryan initially enclosed microphones in watertight housings and began "listening" for vessels operating in the Firth of Forth. The Admiralty, pleased with the results of his experiments, considered the pragmatic Ryan their golden child for submarine detection, a distinction he held throughout the war, to the chagrin of British scientists.

The British Board of Invention and Research

On February 18, 1915, Germany, having declared the waters around the British Isles a war zone, accelerated U-boat predation, increasing their range of operations. Open-ocean submarine hunting became a priority. Listening devices needed to become more sophisticated, focusing on range and bearing accuracy. Sir Arthur James Balfour, who had replaced Winston Churchill as First Sea Lord of the Admiralty, instituted a Board of Invention and Research (BIR). Balfour insisted that it be free of Admiralty control so it would draw in civilian scientists who could operate independently.

Meanwhile, Ryan continued to improve his hydrophone designs. He developed a shore station connected via cable to a bottom-mounted hydrophone. Initially in the Firth of Forth, shore stations were placed at the approaches to naval bases and high-value strategic locations. The Admiralty was delighted, establishing the Hawkcraig Experimental Station (described in Wilson, H. W., 1920) near the entrance to the Forth. Equally delighted, Ryan was provided with buildings, a staff, and vessels to conduct his system development, including the submarine *B-3*.

BIR scientists, however, were now in the game. Understanding the fundamentals of underwater acoustics became an important design tool, and Balfour began inserting civilians into the work at Hawkcraig. Ryan was not delighted with this influx of scientists. His lack of enthusiasm became evident in several communications between one of the civilian scientists, Albert B. Wood, and the BIR. He said this to Sir Ernest Rutherford: "[A]t the time of our arrival at Hawkcraig the state of our knowledge of underwater sound propagation in the sea was very primitive. [T]he serving officers at the station were not generally interested in the physical properties involved" (MacLeod and Andrews, 1971, p. 20).

When Admiral John Rushworth Jellicoe became the new First Sea Lord in November 1916, he created the Admiralty's Anti-Submarine Division (ASD), with directions to maximize research and development focusing on U-boat detection. Soon, the civilian scientists at Hawkcraig were reassigned to the Parkston Quay Experimental Station, allowing the BIR better access to vessels and facilities. Commander Ryan could now continue his approach to submarine detection unhindered.

Despite their differences, much was accomplished at Hawkcraig. The same Albert Wood who had complained to Rutherford was more generous when writing in 1962, citing examples of successful experiments. "Prior to the formation of the BIR, the Navy had not been very successful in their efforts to counter enemy submariners," Wood (1962) admitted, adding "on some experiments in August 1916 [at Hawkcraig], we located the [British] submarine *G.4* at a range of four miles."

Wood recognized that his colleagues at Hawkcraig learned much about sound source characteristics, but science was their role. Wood was less generous describing Commander Ryan: "Ryan's observations were empirical. He made no measurements," adding that Ryan "had made valuable initial progress in the art of listening underwater [but] knew little or nothing about the theory of sound or the possibilities of designing equipment" (Wood, 1962, pp. 10-14). There had been progress, but as 1916 came to a close, Admiral Jellicoe (1921, p. 49) lamented: "[The] hydrophone had been in the experimental stage and under trial for a considerable period, but it had not so far developed into an effective instrument for locating submarines."

Ruthless Submarine Warfare: America Enters the War

In February 1917, Germany announced a policy of *unrestricted* submarine warfare, declaring the waters "around Great Britain, France, Italy and in the Eastern Mediterranean" war zones, adding: "All ships met within the zone will be sunk" (Horne, 1923, vol. 5, p. 14). Although the possibility of the United States entering the war had been considered, the German Admiralty and Reichstag concluded that "there is no possibility of bringing the war to a satisfactory end without *ruthless* U-boat warfare" (Scheer, 1920, p. 247) (my emphases).

Triggering America's entry into the war, the Zimmerman telegram, intercepted by the British in January 1917, was intended to create an alliance between Mexico and Germany, claiming that "employment of ruthless submarine warfare now promises to compel England to make peace in a few months" (Horne, 1923, vol. 5, p. 43). On April 2, 1917, US President Woodrow Wilson addressed Congress, emphasizing Germany's use of submarines, adding that vessels "have been ruthlessly sent to the bottom without warning and without thought of help or mercy for those on board" (Horne, 1923, vol. 5, p. 108). Four days later, in a joint resolution, America declared war on Germany.

Americans, even those who wished for neutrality, knew that war with Germany was inevitable. Preparations began soon after the sinking of *Lusitania* in May 1915 (see bit.ly/3Ps8SLX), with the loss of 128 Americans. US Secretary of the Navy Josephus Daniels envisioned having a small group of industrial experts consider approaches to solving the "submarine problem." In July, Daniels contacted Thomas Edison to head what would become the Naval Consulting Board (NCB). During an October meeting, one of Edison's engineers stated that: "[I]t was [Edison's] desire to have this Board composed of practical men who were accustomed to doing things, and not talking about it." Edison later "privately advised Daniels that he did not think 'scientific research' would be necessary to any great extent" (Kevles, 1978, p. 106).

There was no room for scientists in the NCB, and that upset members of the US National Academy of Sciences.

George Ellery Hale, in particular, was certain that President Wilson would welcome assistance from the Academy. It was not until June 1916 that plans were underway to establish a National Research Council (NRC). Members of the Academy crossed the Atlantic to discuss wartime issues with their European counterparts, the information gained being presented at the initial NRC meeting in September (Millikan, 1950, p. 126). Science would now have a role in solving the "submarine problem."

The NCB would provide the inventive know-how; the NRC would apply scientific principles. But that had not worked in Britain where Ryan, the pragmatic inventor, vied with the BIR scientists, a situation that Secretary of the Navy Daniels was aware of. Daniels sought a working relationship between the NCB and NRC, realizing that cooperation would have to be mandated. That June, Daniels formed the Special Board on Anti submarine Devices, led by an admiral with civilian and military members. "The department [of the Navy] has approved the plan to coordinate and organize the efforts of various groups now considering submarine and anti-submarine devices," adding that the Special Board "shall have complete charge of the carrying out of experiments on submarine and anti-submarine devices" (Scott, 1920, p. 82).

The Navy Establishes Experimental Stations

By early 1917, the NCB received authorization to create an experimental station at Nahant, Massachusetts, on a peninsula extending into Boston harbor. Laboratory facilities were completed on April 7, with an engineering staff from General Electric, Western Electric, and the Submarine Signal Company. A scientific mission from Europe, primarily England and France, arrived in Washington in June to share anti-submarine concepts at meetings with American scientists and engineers. Technologies included passive listening, echolocation, and electromagnetic systems.

At the beginning of July, NRC members met in New London, Connecticut. Soon thereafter, the Naval Experimental Station was established on the grounds of Fort Trumbull near the entrance to the Thames River in New London. Throughout the war, the scientific and engineering staff was drawn from multiple universities. Those remaining at armistice are shown in **Figure 2**. Work at the Nahant and New London stations began immediately, expanding on many of the ideas from the June meetings with European scientists. With oversight by Daniels' Special Board, science and technology could, and would, be blended together.

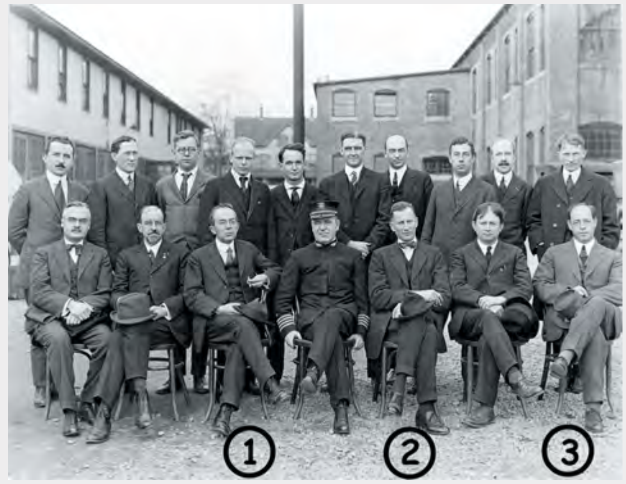


Figure 2. *Naval Experimental Station scientific staff at Armistice, three of whom are referred to in this article: 1, Ernest Merritt; 2, Max Mason; 3, Harvey Hayes. Courtesy of the Harvey Hayes Family archive.*

It is impossible, within the limits of this article, to fully describe the extent of the innovation from these experimental stations, but here is a summary. For details, see Manstan, 2018.

Binaural Listening and Broca Tubes

When Sir Ernest Rutherford addressed the June meeting in Washington, he brought an example of the Broca tube, describing its use in binaural listening. One of the attendees, H. A. Wilson, wrote: "[The Broca tube] consisted of a flat circular metal box, one of the circular sides of which was made of a thin metal plate. A tube fixed to the center of the opposite side led to the ears of the observer" (Wilson, H. A., 1920, pp. 178-179). Referred to as an "acoustic receiver," the Broca tube was readily adapted to passive listening.

What finally emerged after initial experimental successes at Nahant and New London was the binaural C-tube, an easily constructed device that "any plumber's helper could have duplicated" (Thompson, 1937, p. 59). Initially installed on 110-ft vessels designed specifically for U-boat hunting, submarine chasers (or subchasers) (see Woofenden, 2006) became essential to the anti-submarine effort. The C-tube (and SC-tube) was a T-shaped device mounted through the hull and lowered below

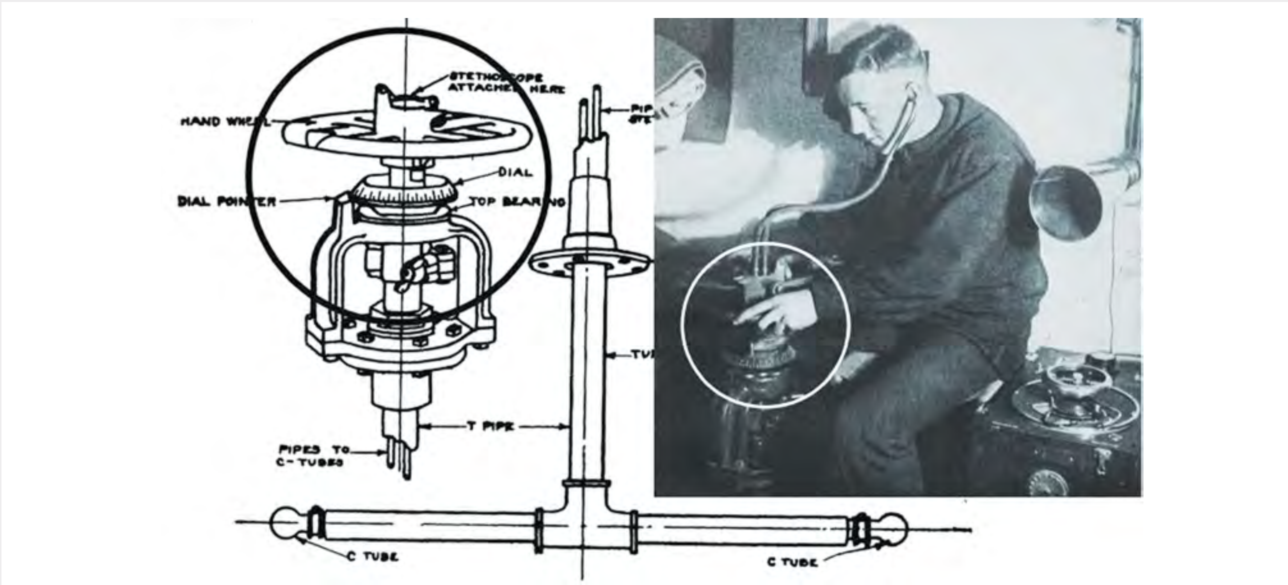


Figure 3. *With the subchaser at rest, the C-tube (Hayes, 1920, p. 30) was lowered below the keel (**left**) and rotated until the listener received equal sound levels in each ear (**right**). The bearing to the source relative to that of the subchaser was indicated on the dial (Sims, 1920, vol. 39, p. 355).*

the keel. A Broca tube receiver was placed at each end of the "T" at a separation based on the speed of sound in water re-creating in-air human binaural hearing. The thin metal Broca tube plates were replaced with rubber spheres, the underwater sounds transmitting more efficiently into air-filled metal tubes and eventually to the stethoscope worn by the listener (**Figure 3**).

Acoustic receivers based on the Broca tube remained common on many vessels operating in the war zone. An MV-tube design by Max Mason was composed of a line of multiple Broca tubes. Tested on destroyers and along the keel of a submarine, the device functioned with the ship underway (see Mason, 1921). Mason was sent to England and France to oversee their installations.

Hydrophone-Based Listening Devices

By 1917, multiple hydrophone designs were in use by all countries in the conflict. The choice was resonant (used by Germany and initially by Ryan) or nonresonant. The advantage of a resonant hydrophone was that if the sound source was at that resonant frequency, a U-boat could be detected at greater distances. Nonresonant hydrophones, in general use among the Allies but needing electronic amplification, were sensitive over the broad range of frequencies associated with submarines.

Figure 4. *The streamlined shape of this three-element OV-tube enabled towing by a blimp. A hydrophone was housed at the end of each wing and at the tow point.* ***Inset:*** *one of the wing tips disassembled, exposing the hydrophone. See Manstan (2018) for this image and a variety of listening devices.*

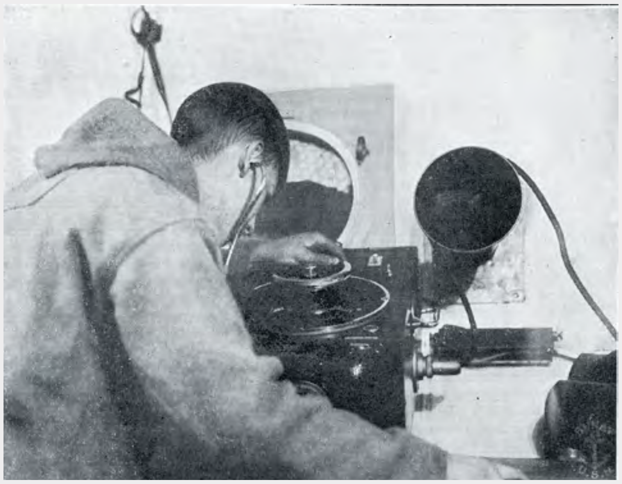


Figure 5. *A subchaser listener is shown at the handwheel of a K-tube compensator. The bearing was passed to the bridge via the speaking tube on his right (Stockbridge, 1920, p. 221).*

Prior to World War II (WWII), passive detection technologies were referred to as "listening devices" and the operators "listeners." Also, the word "tube" of Broca tube receivers became standard for all passive devices, even after hydrophones where the air-backed tubes were replaced with wires were employed. The first of those was the K-tube.

The K-tube was composed of a triangular frame with a hydrophone at each corner. Lowered from a subchaser while the vessel drifted in the current, the engines were shut down to eliminate the vessel's own noise. The listener switched between pairs of hydrophones, the loudest pair indicating within which 120° sector the U-boat was transiting. This three-element system proved effective, and multiple variations were created; there were OV-tubes (**Figure 4**); OK- and OS-tubes; and PB-, Delta-, X- and Y-tubes, some designed to be towed by a destroyer or a blimp. A three-element, bottom-mounted shore station system was also used. None, however, used a tube.

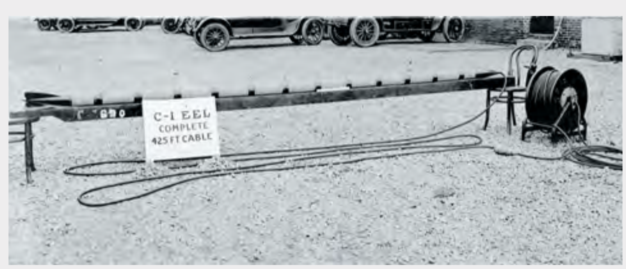
Prototype systems tested at Nahant and showing promise were sent to New London for further development. Determining an accurate bearing to within 5° was essential, requiring an additional technology, a compensator. Regardless of the device, a listener had to make adjustments with the compensator such that sounds, transmitted acoustically or electronically, would reach both ears in phase (see Manstan, 2018, chs. 19-20).

For Broca tube systems, underwater sounds arrived at the listener's ears via an air path. Hence in multireceiver, nonrotatable systems, each air path had to be adjustable. Compensator air paths were lengthened or shortened along circular grooves on plates within a housing. The listener turned a handwheel; the amount of rotation needed to equalize the path lengths provided an indication of bearing. For hydrophone systems, turning the handwheel added electronic time delays between sensors equalizing the phase, with bearing indicated on the listener's compensator. In either case, the listener passed the relative bearing to the vessel's captain and navigator (**Figure 5**).

Towed Line Arrays

The desire for towable systems became another priority at New London. The result was a 12-element flexible line array, referred to as an electric eel or simply an eel (**Figure 6**). Line arrays were tested on seaplanes that would taxi on the surface and on blimps that could move along a few feet above the surface, but the most promising application was towing from the stern of a destroyer. A pair of eels could account for the left/right ambiguity associated with omnidirectional hydrophones. The British designed baffles for their single-element devices, rotatable mounts providing directionality within a streamlined tow body. American hull-mounted port- and starboard-mounted arrays depended on the hull serving as a baffle.

Figure 6. *During the closing months of the war, Harvey Hayes was evaluating towed arrays at New London, Connecticut, and on September 21, 1918, wrote: "Comparative tests between C-1 eels and O-S and O-V and O-X tubes on a slow-moving submarine as a sound source showed that the eels were superior as a detecting device. The observations are taken more rapidly and with less interference from other boats. The eels also outranged any of the listening devices with which it was compared. Selectivity proved comparable to MV [Broca tube] lines on [the test ship]* NARADA.*" Courtesy of the Harvey Hayes Family archive.*

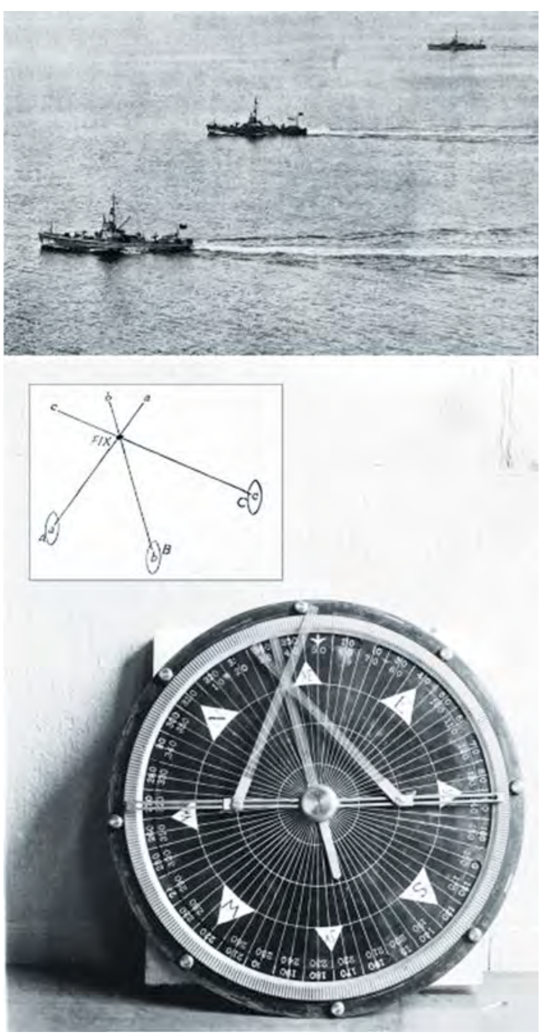


America, Ready to Join The War

The work at the Naval Experimental Station had progressed 24/7 for 6 months. Subchasers began arriving at New London that fall. Crews received rigorous training in Long Island Sound (south of the Connecticut coast) where seasonal winds created conditions close to those in Europe. By December 1917, prototype listening devices were in the English Channel hunting U-boats.

The Special Board was also responsible for ensuring that devices deployed to the war would survive harsh combat operations. Station staff who were designing the devices were therefore required to join the listeners when training at sea. "In those days," proclaimed subchaser commander Ensign George Wallace, "few of us had our sea stomachs and many a seaman locked arms with a civilian inventor or two over the rail" (Nutting, 1920, p. 85). The listeners, two per vessel, had to be well prepared. "To qualify as a listener it was necessary to locate the direction of a submarine within five degrees. Practice tests were made daily to familiarize the students with various noises encountered" (Bean, ca. 1920). Listeners had to distinguish the target among multiple underwater sounds.

Figure 7. ***Top:*** *hunting unit en route to its search area.* ***Bottom:*** *bearings were set on the position plotter.* ***Inset:*** *where they crossed indicated the location or "fix" on the target.* ***Top*** *and* ***inset*** *from Sims, 1920, vol. 39, pp. 362, 458; position plotter, courtesy of the Harvey Hayes Family archive.*



By February 1918, convoys of subchasers began the 12-week Atlantic crossing, arriving at bases in England, Ireland, and the Greek island of Corfu at the entrance to the Adriatic. Subchasers operated in hunting units of three (**Figure 7**), two wing boats and the central flagship. When a U-boat was detected, each subchaser radioed bearings to the flagship navigator. The hunting unit now had both elements for targeting, bearing *and* range.

An example of a U-boat hunt (**Figure 8**) is from an Office of Naval Intelligence (1918) report. The 30-hour chase ended when listeners heard unfamiliar sounds, as recounted by Admiral Sims: "[A]t about five o'clock on the afternoon a sharp piercing noise came ringing over the [hydrophone] wires. It was a sound that made the listeners' blood run cold. In all, twenty-five shots came from the bottom of the sea. As there were from twenty-five to thirty men in a submarine crew the meaning was all too evident. Nearly all of them had committed suicide" (Sims, 1920, vol. 39, p. 468).

Armistice and The War That Did Not End All Wars

In a postwar interview, Frederick Körner, an officer on *U-155*, made this observation: "the wide expanse of the Atlantic was not enough to keep us from the coast of far-off America. To those who can see into the future, surely this is a warning of what later wars may bring" (Thomas, 1928, p. 332).

With expectations on both sides that the conflict would continue another year, a number of anti-submarine technologies were nearing readiness for deployment. In October 1918, a conference was held in Paris to discuss the use of supersonics (a term commonly used at that time), already considered for active echo detection by

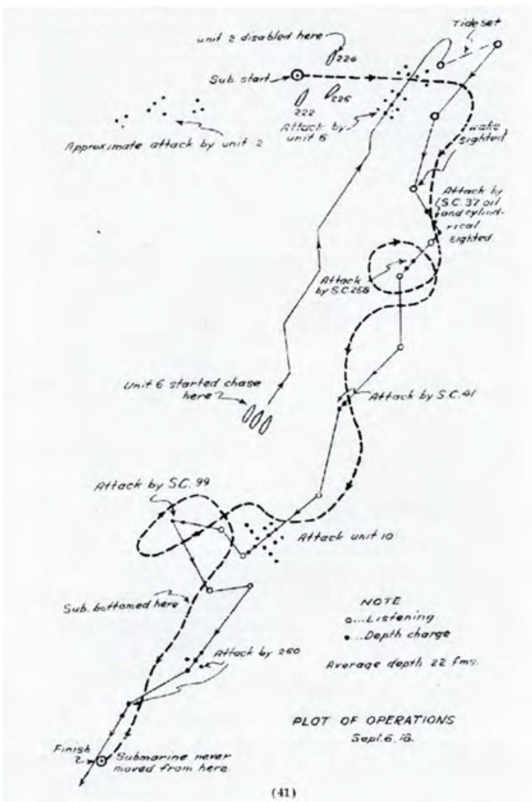


Figure 8. *On September 6, 1918, listeners detected a U-boat operating within the English channel (**top right**). **Dashed line:** path of the U-boat attempting to evade the subchaser units (**solid line**) (Office of Naval Intelligence, 1918, p. 41).*

the Americans, British, and, in particular, French Professor Paul Langevin. He had been experimenting with piezoelectric transmitters at Toulon, France, receiving an echo from a submerged submarine at a range of one mile. What was also discussed among the scientists in attendance, however, was the need for increased knowledge of the properties of seawater affecting sound propagation, specifically "the viscosity of the water, its temperature, the presence of marine life and debris" (Weir, 1997, p. 88).

Armistice occurred at the 11th hour on the 11th day of the 11th month in 1918. Many of those whose monumental effort of science and innovation defeated the U-boat, continued to imagine a dangerous future as prophesized by Körner. On November 9, Ernest Merritt briefed the Special Board on Antisubmarine Devices, recommending systems that should continue to be pursued, one in particular: "Echo methods whether using waves above the audible range or, if practicable, longer waves," stressing that "the development of antisubmarine devices should continue even after peace is declared with the idea of obtaining such devices as will make it extremely difficult for submarines to be used in the future." In a postwar briefing (December 27, 1918), Merritt again looked to the future, concerned about the "echo method" and if "some material might be found which absorbs underwater sound waves as completely as black paint absorbs light" (Merritt, 1917–1918).

The Great War was not the war to end all wars, as H. G. Wells had hoped in 1914. Only two decades passed before Germany's intentions toward Europe rose again. In the summer of 1939, U-boats returned to a policy of unrestricted submarine warfare, approved by Germany's Chancellor Adolph Hitler.

Acoustics Today [Well, Almost]: World War II and the Cold War

It is thought that there are six degrees of separation between any two humans on the planet. When warfare technologies are involved, the degrees of separation between warfare system designers and the warfighters must be reduced to zero.

This essential collaboration reappeared during WWII when ASW was the mission of another generation of civilian scientists. Fort Trumbull in New London became the home of the Columbia University Division of War Research, while another group, the Harvard Underwater Sound Laboratory, was established in Cambridge, Massachusetts. On the US West Coast, San Diego hosted the University of California Division of War Research. Active and passive submarine detection devices, now "sonar," evolved at these research centers throughout WWII. Submarine warfare was far more lethal than in the past; yet once again, it would take scientists and engineers to turn the oceanic predators into prey.

In 1946, sonar development by Columbia and Harvard was consolidated in New London to form the United States Navy Underwater Sound Laboratory. Soviet submarines had to be detected at ranges and depths far exceeding the U-boats of WWI and WWII. The October 1918 conference in Paris predicted the inevitable, that to exploit the physics of underwater sound, the properties affecting propagation had to be studied and incorporated into Cold War sonars as, for example, that of sonar pioneer Thaddeus Bell (2011) and the SQS-26 surface ship sonar. See Manstan (2014) for an overview of Cold War ASW technologies developed in New London and operational within the fleet from a field engineering perspective.

Then and Now

This from Sir Ernest Rutherford in 1918: "If the Navy is to retain its supremacy in the future, methods must be devised for systematic scientific investigations [between] Naval Officers who have shown marked scientific ability [and] highly trained and technical civilians" (MacLeod and Andrews, 1971, p. 35).

Maintaining the Navy's supremacy into our future, dominated by antisubmarine technologies, require those same systematic scientific investigations involving knowledgeable civilian and naval staffs. Nuclear-powered submarines dive deeper, move faster and quieter, remain submerged longer, and will continue to be a technological challenge to locate in a three-dimensional undersea battlespace.

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About the Author

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Roy Manstan began his field engineering career in 1967 at the US Navy Underwater Sound Laboratory, retiring in December 2005 from the Naval Undersea Warfare Center. He received degrees in mechanical engineering from Lafayette College, Easton, Pennsylvania (BS) and the University of Connecticut, Storrs (MS) and in zoology from Connecticut College, New London (MA). Qualifying as a Navy diver in 1974, he was later appointed command diving officer, working with antisubmarine warfare technologies worldwide. After retirement, he volunteered at Old Saybrook High School, Old Saybrook, Connecticut, creating a working replica of the Revolutionary War submarine *Turtle*. Photo shows him emerging through its hatch (Manstan and Frese, 2010).