THE QUEST TO ACHIEVE "ONE ACCURATE SHOT"[1]: U.S. NAVY TORPEDO DEVELOPMENT AND TESTING, 1896-1917

An Essay

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The Faculty of the

United States Naval War College

In Partial Fulfillment

of the Requirements for the

Graduate Certificate in Maritime History

[1]Albert Gleaves, *Torpedoes, U.S. Naval War College Lecture* (Naval Torpedo Station Records, MSC-031, Box: July 1906, Newport, RI), 30.

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THE QUEST TO ACHIEVE "ONE ACCURATE SHOT"[2]: U.S. NAVY TORPEDO DEVELOPMENT AND TESTING, 1896-1917

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[2]Gleaves, *Torpedoes, U.S. Naval War College Lecture*, 30.

The invention of the torpedo in the eighteenth century, initially referred to as the naval mine, kicked off decades of challenges in technological and strategic developments. The weapon system altered naval history, impacting countless battles and influencing strategy and decisions throughout the last three centuries. Lessons learned from torpedo development can be applied to better understand the research and development (R&D) cycle and struggles the United States (U.S.) faced in fielding the complex weapon system. Since its invention in the eighteenth century, the concept of the torpedo has shifted from a stationary area-denial tool to a propelled offensive weapon system. Understanding the shifts and advances in torpedo design concepts throughout the centuries is vital because, as torpedo development progressed, its projected utility and impact on strategy changed. Given the intricacy of design, with early iterations boasting hundreds of components, fielding this new capability relied heavily on developing a robust testing matrix. Since torpedoes are complex, and even early designs boasted hundreds of components, it is not surprising that as their strategic importance evolved, the reliance upon developing a more robust testing matrix grew as well. The U.S.'s journey through torpedo development laid the groundwork for future testing standards and requirements. Lessons learned from the early developmental timeline can be leveraged to avoid similar mistakes and optimize testing cycles in future weapon systems.

As stated, throughout torpedo development, testing was vital in maturing and integrating the design with the fleet. In 2018, the Naval Historical Collection (NHC) at the U.S. Naval War College in Newport, Rhode Island, began processing records of the Naval Torpedo Station (NTS) at Goat Island from 1883 through the 1920s. The records chronicle the administration, test data, torpedo design developments, and scientific studies at the NTS. During these years, the U.S. fought in two major wars while observing and drawing lessons from several other conflicts.

Analyzing the early history of torpedoes' development, testing, and evolution during these dynamic years illustrates the complexity of fielding a novel weapon system during a period of expansion.

From 1896 to 1917, the U.S. struggled to conduct operational tests and exercises consistently. Throughout this time, funding levels for the Navy fluctuated, technical priorities shifted, and the nation oscillated between periods of conflict and peace. The quantitative magnitude of tests, methods, specifications, and requirements of torpedo test reports from this period can be utilized to analyze the U.S. Navy's evolution in understanding the development and fielding of one of its first complex weapon systems. Although the Navy made significant progress in conducting testing, the organization as a whole did not grasp the value of the following three areas: proactive and consistent guidance for required capabilities, repetitive testing and qualification of individual components, and fleet training to build operational experience with the all-up-weapon system. In order to illustrate the Navy's struggle and progression with testing and fielding the torpedo, first, a historical analysis of the weapon system, design iterations, and its shifting battle tactics will be explored. Next, an overview of the organizations and agencies involved with advancing the technology, along with their roles and responsibilities, will be outlined. Finally, an analysis of the testing data and a critique of the testing process will be conducted.

EARLY TORPEDO DEVELOPMENT & BATTLE TACTICS

Torpedoes, also known as naval mines, can be traced back to 1777 with the invention of the Bushnell keg by the American inventor David Bushnell during the American Revolution. The design included a charge of gunpowder in a submerged keg supported by a float on the surface.

The devices were to be released upstream and drift slowly towards a stationary target, exploding upon contact. Due to weather constraints, a lack of high explosives (which had not been invented yet), and a poor targeting mechanism that relied on water currents, the invention failed to make an impact and did not receive significant recognition or attention.[3] Twenty years after the creation of the Bushnell Keg, Robert Fulton, another American inventor, expanded on the concept, kicking off years of innovation by the British, French, and U.S. Though promising, Fulton's ideas were ahead of his time due to limitations of current technologies and the desire of nations to maintain traditions of honor and decisive battles at sea. It took decades for the concept to be accepted and fielded for battle.[4]

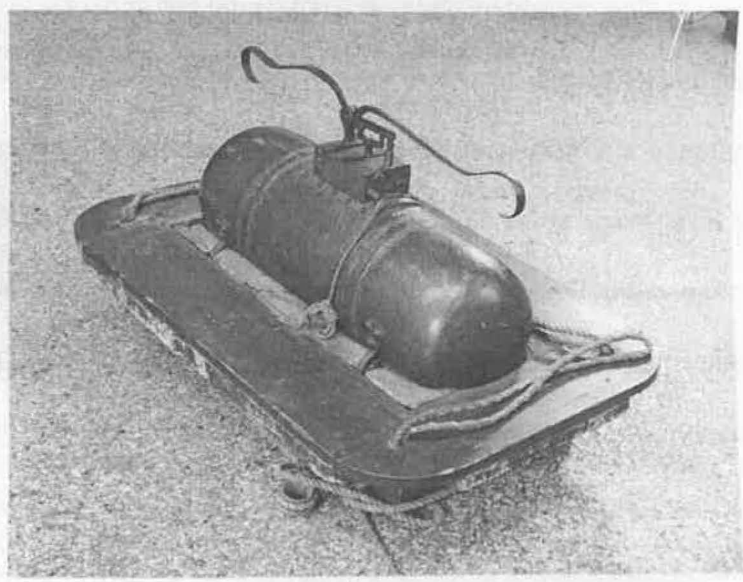

Figure 1. Model of underwater mine based on designs of Robert Fulton, circa 1818.[5]

[3] Gregory K. Hartmann, "NSWC Technical Report: Mine Warfare History and Technology" (Maryland: White Oak Laboratory, 1975), 7-8.
[4] Andrew Patterson Jr., "MINING: A Naval Strategy" *Naval War College Review*, Vol. 23, No. 9 (May 1971): 53.
[5] Fig. 1, Anonymous, *Fulton-Type Mine*, Color Photograph, circa 1818, (Naval History and Heritage Command, NH 85684-KN, Courtesy of The Marine Museum, Karlskrona, Sweden), https://www.history.navy.mil/content/history/nhhc/our-collections/photography/numerical-list-of-images/nhhc-series/nh-series/NH-85000/NH-85684-KN.html.

In the early years of development, navies perceived the torpedo as a capability that could challenge sea control through denial. While countries with weaker navies viewed the technology optimistically, the British naval establishment, comfortable with being the dominant sea power of the era, was cautious of funding the technology due to the fear of its ability to take away command of the sea.[6] Fulton leveraged the curiosity and fear surrounding the technology to convince the British, French, and U.S. to conduct tests and fund the development of naval mine technologies, along with submarine trials, under his guidance.[7] In spite of the strong views on the promises and risks of torpedoes, no navy placed a high priority on its development.

Since the naval mine introduced a new mode of warfare, challenging the honor of traditional battles at sea, many countries were hesitant to leverage the capability fully. For example, the British naval administration was intimidated by its power. It feared this new warfare mode would take away their command and power at sea. Lord St. Vincent of the British Admiralty even remarked that funding this new technology was foolish as it "encouraged a mode of warfare which those that commanded the sea did not want, and which, if successful, would deprive them of it."[8] Additionally, Sailors felt these new weapons undermined their power and command. To sailors, their honor was their legacy, as demonstrated by Admiral Nelson's message to the fleet before the battle commenced at Trafalgar, "England expects that every man will do his duty,"[9] and his final words before he died in the same battle, "Thank God I have done my duty."[10] Even before his death, Nelson had regarded torpedo technology as a waste of time,

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[6] Richard Dunley, *Britain and the Mine, 1900–1915: Culture, Strategy, and International Law* (Cham, Switzerland: Palgrave Macmillan, 2018) 17-18.
[7] Tom Ricci, "Robert Fulton" *The American Society of Mechanical Engineers* (May 14, 2012): 2.
[8] Hartmann, "NSWC Technical Report: Mine Warfare History and Technology", 8.
[9] N.A.M. Rodger, *The Command of the Ocean: A Naval History of Britain, 1649–1815* (New York and London: Penguin, 2004), 539.
[10] Davey, *In Nelson's Wake: The Navy and the Napoleonic Wars*, 101.

writing, "I depend more upon my hunger for driving them [the French] out, and upon the gallant officers and men under my command for their destruction, than any invention."[11] Other sailors echoed this sentiment, even referring to the weapon as 'unmanly,' 'assassin-like,' and 'dastardly.'[12]

Following Fulton's push to develop the technology, significant progress was not made until the advent of the American Civil War in 1861 with the development of spar torpedoes. The spar concept, invented by John L. Lay, featured an intricately complex detonation mechanism controlled by two lanyards.[13] An explosive charge of gunpowder was attached to the end of a long pole, projected from the bow of a small steamer. Unlike naval mines, spar torpedoes were not to be released and drifted to the target; instead, the steamer's crew rammed the device against its target and then retreated before detonation. Since spar torpedoes required the crews to maneuver within close proximity to the target, most attacks were launched at night, which elevated the chances of running aground or missing the target completely. On the night of October 27, 1864, a Union force led by Lieutenant William B. Cushing launched a successful surprise attack with a spar torpedo on the Confederate ironclad ram *Albemarle* while under construction on the Roanoke River at Plymouth, North Carolina.[14] The success of this attack led to widespread recognition of Cushing's battle tactics, and decades later, the U.S. Navy's first class of torpedo boats was named after him. The Confederates also developed spar torpedoes, and both sides used variations of Fulton's early torpedo concepts. On the Confederate side, *H.L. Hunley* was the first submarine to sink an enemy ship, the Union vessel *Housatonic*, with a spar

[11] Davey, *In Nelson's Wake: The Navy and the Napoleonic Wars*, 76.
[12] Davey, *In Nelson's Wake: The Navy and the Napoleonic Wars*, 76.
[13] Anthony Newpower, *Iron Men and Tin Fish: The Race to Build a Better Torpedo During World War II* (Annapolis, Maryland: Naval Institute Press, 2006), 11.
[14] Richard Simpson, *Goat Island and the U.S. Naval Torpedo Station: Guncotton, Smokeless Powder and Torpedoes* (England: Arcadia Publishing, 2016), 14.

torpedo.[15] By the war's end, twenty-eight ships on both sides were lost due to spar and stationary torpedoes. Although achieving notable impact in war, the spar torpedo was ultimately replaced by the towed and automobile torpedoes due to its limited range of fewer than 40 feet and risk of injury or death to its executing crew.

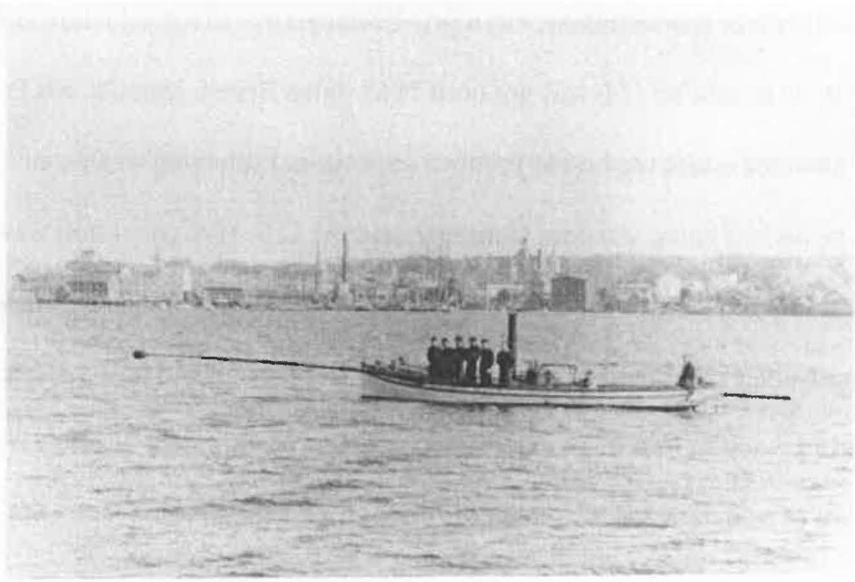

Figure 2. Spar Torpedo Rigged Out, circa 1865.[16]

With the advent of novel naval weapon systems and growing interest in naval capabilities due to the Civil War, Congress re-established the Bureau of Ordnance (BuOrd) in 1862 to replace the Bureau of Ordnance and Hydrography created two decades earlier. With its hydrographic functions transferred to the Bureau of Navigation, BuOrd assumed responsibility for advancing, procuring, storing, and deploying all naval weapons. After the war, the bureau continued to exist and helped drive plans to explore advanced torpedo technology further. With

[15] "H.L. Hunley." Encyclopedia Britannica (03 December 2018), https://www.britannica.com/topic/H-L-Hunley.
[16] Fig. 2, Anonymous, *Spar Torpedo Rigged Out*, BW Photograph, circa 1865, (Naval History and Heritage Command, NH 82827, Courtesy of Naval Underwater Systems Center, Newport, Rhode Island), https://www.history.navy.mil/content/history/nhhc/our-collections/photography/numerical-list-of-images/nhhc-series/nh-series/NH-82000/NH-82827.html.

support from BuOrd, in July 1869, the Secretary of the Navy, George M. Robeson, announced the NTS establishment on Goat Island in Newport Harbor.[17]

The revival of BuOrd and the creation of the NTS coincided with significant oversea advances in explosives and ordnance. In 1833, French chemist Henri Bracounot invented wet guncotton, also known as nitrocellulose, but it proved dangerous to manufacture and utilize in explosives due to its instability.[18] It was not until 1865 that a British chemist, Sir Frederick Abel, developed and patented a safe method to produce guncotton. Following this patent, Abel sold the manufacturing rights to France, Austria, Germany, and the U.S. Wet guncotton was not incorporated into torpedo designs until the invention of automobile torpedoes. The development of these high explosives correlated to improvements in ship design and hull material. As ship armor shifted from wood to iron, high explosives became a requirement in offensive weaponry.[19] The development of ironclads led to a greater need for high explosives.

In the late 1860s, Captain John Harvey of the Royal Navy invented the first towing torpedo, the Harvey, which was intended more for defense than offense. It was designed to be dragged by a cable off the quarter of a vessel and dive under an enemy's hull.[20] Small steamers would drag the torpedoes into place, requiring skill to position the device accurately. The towed torpedo was an improvement from the spar regarding range as it increased the standoff distance of the executing crew from 35 feet to 250 feet.[21] Russia adopted the design in 1869, followed by Britain and other European countries. In 1872, the U.S. purchased the Harvey for experimental purposes and issued it to a few ships for trial. For ten years, this torpedo was further tested and

[17] Simpson, *Goat Island and the U.S. Naval Torpedo Station: Guncotton, Smokeless Powder and Torpedoes*, 14.
[18] Karl Rohr, "Guncotton – History, Manufacture & Use," *U.S. Naval Institute* (July 1889): 2.
[19] E. B. Potter, *Sea Power: A Naval History, 2nd Edition* (Annapolis, MD: U.S. Naval Institute Press, 1981), 158.
[20] Simpson, *Goat Island and the U.S. Naval Torpedo Station: Guncotton, Smokeless Powder and Torpedoes*, 35.
[21] Gleaves. *Torpedoes, U.S. Naval War College Lecture*, 2.

developed. BuOrd dropped both the Harvey and Spar torpedoes from the U.S. inventory in the 1880s following the invention of the automobile torpedo.[22] Rear Admiral Alfred Thayer Mahan viewed these devices as offensive-defensive measures utilized only for harbor defense, with significant drawbacks due to their reliance on night attacks at close range to the target.[23] While spar and towed torpedoes added additional tactical options, the concepts did not eliminate ship-to-ship engagements and were primarily intended for use against stationary and anchored targets until they were removed from the fleet.

In 1866, Robert Whitehead released the first iteration of his eponymous torpedo, invented from a design first conceived by Giovanni Luppis of the Austro-Hungarian Navy. A three-cylinder, compressed-air engine propelled the Whitehead torpedo and did not have horizontal control in the first iterations of the concept. In addition to horizontal control drawbacks, the first version of the Whitehead was plagued with depth control issues that were not resolved until 1870 with the introduction of a balance chamber. This pendulum-and-hydrostatic control system monitored resistance and adjusted to external water pressure.[24] These earliest automobile torpedoes had a speed of 18 knots and a range of 830 yards, a significant improvement over previous torpedo designs. The invention of the first self-propelled automobile torpedo marked a critical turning point in torpedo development; shifting the weapon from a defensive sea denial tool to an offensive weapon that could travel undetected underwater from a distance to strike its target.[25]

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[22] Gleaves, *Torpedoes, U.S. Naval War College Lecture*, 3.
[23] John Hattendorf, *Mahan on Naval Strategy* (Annapolis, MD: Naval Institute Press, 2015), 126.
[24] Newpower, *Iron Men and Tine Fish: The Race to Build a Better Torpedo During World War II*, 13.
[25] Newpower, *Iron Men and Tine Fish: The Race to Build a Better Torpedo During World War II*, 12.

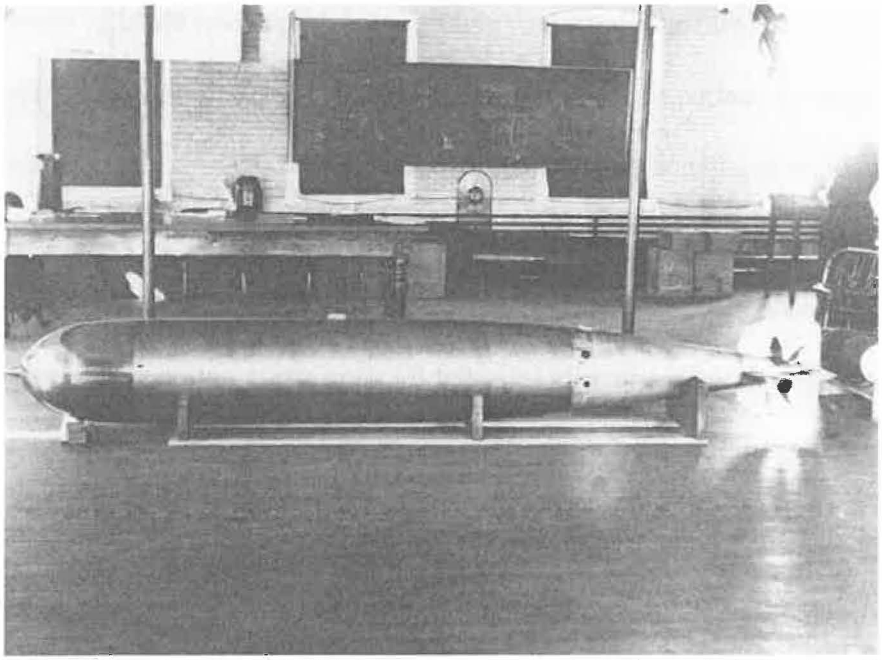

Figure 3. Whitehead Torpedo, MK I at the Newport Torpedo Station, R.I., in October 1892.[26]

The automobile torpedo quickly became the primary type for all navies across the globe. In 1871, England, France, and Russia bought the design and rights to manufacture the Whitehead torpedo, followed in 1873 by Italy. Germany, however, did not purchase the design; they stole it. Whitehead's Fiume Torpedo Works Manufacturing Plant was a meeting place for potential customers, and when Germany's Robert Schwartzkopff visited, a copy of the Whitehead design disappeared. A few months later, in 1877, Schwartzkopff's company unveiled a new product, the Schwartzkopff torpedo, which looked similar to the Whitehead torpedo and even featured Whitehead's "secret" pendulum-and-hydrostatic control system.[27] In summary, England, France, Russia, Italy, and Germany all had the Whitehead design before 1880.

[26] Fig. 3, Anonymous, *Whitehead Torpedo, MK 1*, BW Photograph, October 1892, (Naval History and Heritage Command, NH 84482, Newport, Rhode Island), https://www.history.navy.mil/content/history/nhhc/our-collections/photography/numerical-list-of-images/nhhc-series/nh-series/NH-84000/NH-84482.html.
[27] Gleaves, *Torpedoes, U.S. Naval War College Lecture*, 3.

Meanwhile, in 1869 the U.S. declined an offer to purchase the design and the right to manufacture the Whitehead. Several years later, a former employee of the Whitehead Company offered to sell complete working drawings to BuOrd, but again this offer was refused as the U.S. was busy pursuing domestic solutions. Instead, the U.S. worked to produce a superior domestic automobile torpedo. In 1871, Lieutenant Commander J.A. Howell invented a two-cylinder reciprocating engine, fly-wheel propelled torpedo. The design required an air flask to hold air pressure in the hull of the device, which proved difficult for the U.S. to manufacture consistently.[28] With the fly-wheel design, the Howell torpedo had both vertical and horizontal control, but difficulties with leaking air flasks caused inconsistent vertical control. Although invented in 1871, the Howell was not patented and contracted for production by the U.S. Navy until 1884.[29] It was not until May 1891 that the Navy Department officially adopted the Whitehead torpedo when it formally entered into a contract with the E. W. Bliss Company to manufacture the Whitehead design.

The Howell torpedo was a viable competitor to the Whitehead, and both designs were pursued by BuOrd under a risk-reduction strategy.[30] By pursuing two solutions, the BuOrd was not relying on the success of one design, instead reducing risk by pursuing both. When the Obry Company invented gyroscopic steering gear in 1896, solving the horizontal control issues of the Whitehead, BuOrd decided to remove the Howell from its portfolio.[31] The stumbling block of the Howell was its lack of directive force vertically. Had this problem been as successfully worked

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[28] Newpower, *Iron Men and Tine Fish: The Race to Build a Better Torpedo During World War II*, 13.
[29] Stephen Stein, *From Torpedoes to Aviation: Washington Irving Chambers and Technological Innovation in the New Navy, 1876-1913* (Tuscaloosa: The University of Alabama Press, 2007), 122.
[30] Katherine Epstein, *Torpedo: Inventing the Military-Industrial Complex in the United States and Great Britain* (Cambridge, Massachusetts: Harvard University Press, 2014), 38.
[31] Stein, *From Torpedoes to Aviation: Washington Irving Chambers and Technological Innovation in the New Navy, 1876-1913*, 123.

out as had the corresponding problem for the Whitehead horizontally, there is no doubt that the Howell would have given it even a longer and closer race than it did.[32] Additionally, the fly-wheel design required extra time to spin up before launching, which was not ideal for use in battle. BuOrd removed the Howell torpedo from its portfolio in 1904 due to the integration and success of the Obry gyroscope in the Whitehead torpedo. Although developing the Howell and Whitehead torpedoes parallel to each other was an adequate strategy, reducing risk by not focusing on one solution and removing the Howell from the portfolio based on one component's success was a premature decision.

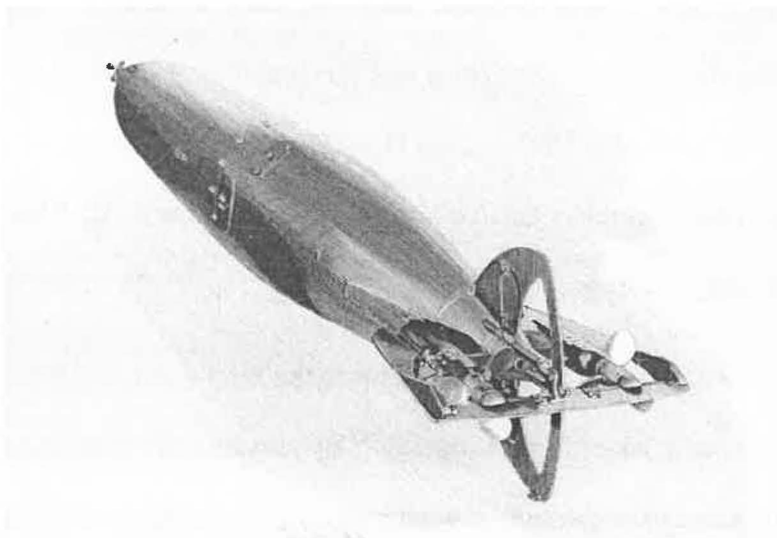
TAIL OF THE HOWELL AUTOMOBILE TORPEDO, SHOWING TWIN PROPELLERS AND STEERING MECHANISM.

Figure 4. Howell Automobile Torpedo, 1898.[33]

Although BuOrd actively pushed torpedo development forward on the international stage, its impact remained limited. Foreign navies had little success in their early uses of Whitehead

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[32] Gleaves, *Torpedoes, U.S. Naval War College Lecture*, 10.

[33] Fig. 4, Anonymous, *Howell Automobile Torpedo*, BW Photograph, October 1898, (Naval History and Heritage Command, NH 73953, Copied from the Journal of Scientific American Coast Defense Supplement), https://www.history.navy.mil/content/history/nhhc/our-collections/photography/numerical-list-of-images/nhhc-series/nh-series/NH-73000/NH-73953.html.

torpedoes, but the U.S. Navy fared no better, scoring no confirmed hits with torpedoes in the Spanish-American War.[34] Due to the Navy's underwhelming performance in the conflict, Secretary of the Navy John D. Long established the General Board in March 1900. The board was the Navy's first centralized planning institution that sought to unite the bureaus to form rational, coherent naval policy.[35] BuOrd, the primary decision point for advancing torpedo concepts up until this point, now had to seek approval and planning consensus from the General Board. In the early 1900s, BuOrd's requests to the General Board were often overshadowed by the fierce debate surrounding shipbuilding and battleship development.[36] Even though the goal of creating the General Board was to streamline naval technology development, BuOrd received fluctuating support for torpedo initiatives until the Russo-Japanese War.[37]

In the Russo-Japanese War, both sides used Whitehead torpedoes extensively and proved their value as a weapon of offense beyond all questions of controversy. While the torpedo had not yet attained the notoriety of the gun, its striking effect, shot for shot, was significant. Similar to gunnery at the time, the weaknesses in precision and accuracy were overcome by launching higher quantities of shots, understanding only a few will hit the target. In the night attack on Port Arthur on February 8, 1904, a Japanese flotilla of twelve destroyers entered the Russian anchorage and, at a range of 200 yards, torpedoed two battleships and one protected cruiser. The night was calm and dark, and the conditions were ideal for torpedo work. Incredibly, of the twenty-four torpedoes fired, only three hit their targets, but all three torpedoes caused significant

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[34] Gleaves, *Torpedoes, U.S. Naval War College Lecture*, 12.

[35] Stein, *From Torpedoes to Aviation: Washington Irving Chambers and Technological Innovation in the New Navy, 1876-1913*, 139. See also John T. Kuehn, *America's First General Staff: A Short History of the Rise and Fall of the U.S. Navy's General Board, 1900-1950* (Annapolis, MD: Naval Institute Press, 2017).

[36] Kenneth Hagan and Michael T. McMaster, *In Peace and War: Interpretations of American Naval History, 30th Anniversary Edition* (Westport, CT: Praeger Security International, 2008), 136.

[37] Craig Symonds, *Historical Atlas of the U.S. Navy (*Annapolis, MD: The Naval Institute, 2001), 121-123.

damage to Russian ships. The Japanese could have inflicted even more damage were it not for operator error; in a number of the torpedoes found floating in the harbor after the attack, the safety pin had not been removed, causing them to not explode on impact.[38]

This torpedo attack produced a great sensation throughout the naval world and proved conclusively what the automobile torpedo could do. The use of the Whitehead torpedo during this war allowed the U.S. to study the effects of the novel technology and its impact on strategy and battle tactics without engaging in combat. In a lecture by Commander Albert Gleaves to the U.S. Naval War College in Newport in 1906, he concluded, "it is evident that the loss of a number of torpedoes is repaid a hundred-fold by the results of one accurate shot."[39] Remarks from this lecture demonstrated the Navy's awareness that the torpedo had drawbacks in function and performance, but continued development was justified due to the impact of one accurate hit.

During the same year the Russo-Japanese War began, the U.S. fielded another new design, the Bliss-Leavitt torpedo, invented by F.M. Leavitt, a leading engineer at the E.W. Bliss Company. Since the E.W. Bliss Company also manufactured the Whitehead torpedo at the time, the Bliss-Leavitt torpedo had a similar propulsion system. In this torpedo, a turbine replaced the reciprocating engines of the Whitehead.[40] This change, utilizing the turbine, did away with the necessity for a starting lever, which simplified the design. The Bliss-Leavitt torpedo also did not include a safety pin to be removed before launch, eliminating the potential for operator error as demonstrated by the Whitehead design in the Russo-Japanese War. The Bliss-Leavitt and Whitehead torpedoes continued to advance in the years leading up to World War I; with each iteration, the range, speed, and explosive charge also increased. The explosive charge in designs

[38] Gleaves, *Torpedoes, U.S. Naval War College Lecture*, 12.
[39] Gleaves, *Torpedoes, U.S. Naval War College Lecture*, 13.
[40] Gleaves, *Torpedoes, U.S. Naval War College Lecture*, 14.

before the Bliss-Leavitt Mark VII utilized wet guncotton. Trinitrotoluene (TNT) was adopted for use in the warhead in the Bliss-Leavitt Mark VII and future iterations. Table A1 in Appendix A summarizes the torpedo types the U.S. Navy fielded in the years leading up to and through World War I.

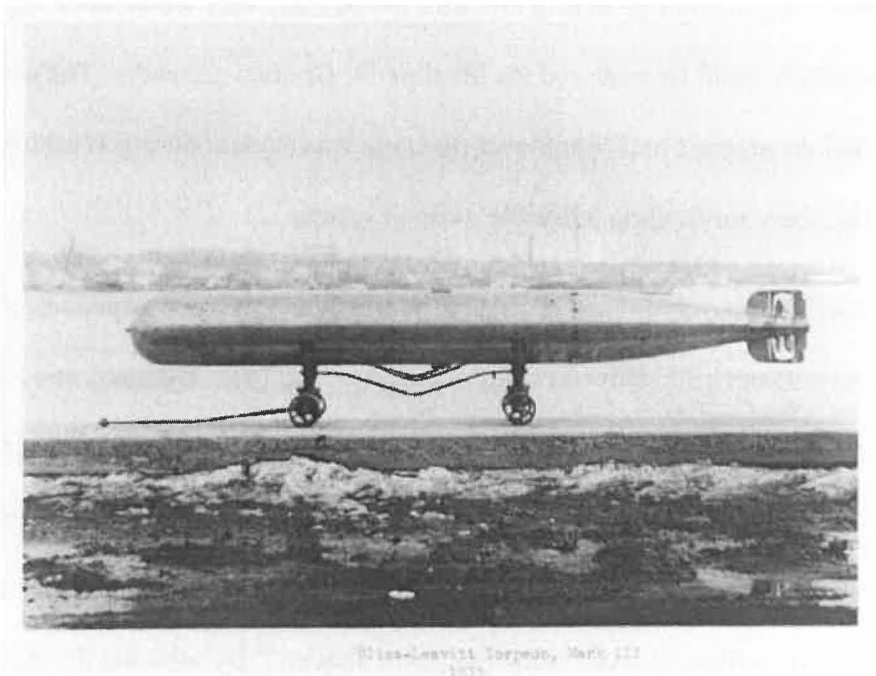

Figure 5. Bliss-Leavitt Torpedo MK 3, 1911.[41]

In World War I, torpedoes displayed both direct and indirect effects in battle. Indirectly, the threat of the torpedo had a significant impact on psychology, impacting decision-makers at the strategic level. For instance, the British decided to set up a distant blockade of the North Sea due to the threat of mines and torpedoes along the German coast.[42] The British, the dominant sea power during the war, were threatened by Germany's novel advances in naval weaponry.

[41] Fig. 5, Anonymous, *Bliss-Leavitt Torpedo Mark 3, 1911*, BW Photograph, 1911, (Naval History and Heritage Command, NH 82836, Copied from an original negative held by Naval Underwater Systems Center, Newport, Rhode Island), https://www.history.navy.mil/content/history/nhhc/our-collections/photography/numerical-list-of-images/nhhc-series/nh-series/NH-82000/NH-82836.html.

[42] Nicholas Lambert, *Sir John Fisher's Naval Revolution* (Columbia, SC: University of South Carolina Press, 2002), 122.

Torpedoes, utilized effectively, had the potential to deteriorate the British fleet and contest their sea control. Since the British understood the significance of one accurate hit from a torpedo, a distant blockade and strategy of prolonged attrition were selected. The torpedo demonstrated its capacity to wage psychological warfare in influencing adversary decisions. If Germany did not have torpedo and mine technology during this war, the British likely would have opted for a close blockade, which could have altered the timeline for German surrender. The psychological toll torpedoes had on strategic and operational planning was evident during World War I, furthering the necessity for fielding a reliable weapon system.

Aside from their psychological impacts in World War I, various torpedoes, including the Whitehead, Schwartzkopff, and Bliss-Leavitt, saw operational use. Germany successfully demonstrated the direct impact of effective torpedo use during the war by leveraging U-boats, or submarines, as launch platforms. Throughout the war, the Germans employed numerous variants of the Schwartzkopff automobile torpedo. In the first year of the conflict, Germany sunk thirty-nine ships and lost only three U-boats launching these attacks.[43] By utilizing the weapon, the Germans could threaten British Sea Lines of Communications (SLOCs) and significantly impact merchant shipping. Due to the weapon's success, German leadership expected the torpedo to deliver a decisive advantage in the war. Although warfare with U-boats allowed the Germans to challenge the Royal Navy, the novel tactics also ended up provoking the U.S. to join the war. It was the targets, not the tactics, that caused the problem. Since the German High Seas Fleet was not strong enough to challenge the Royal Navy in a decisive battle, they were forced to develop asymmetric warfare and novel battle tactics. After the Germans announced unrestricted

[43] Li Zhou, et. al. "This Map Shows the Full Extent of the Devastation Wrought by U-Boats in World War I," Smithsonian Magazine, 7 May 2015, https://www.smithsonianmag.com/history/map-shows-full-extent-devastation-wrought-uboats-world-war-i-180955191/.

submarine warfare in 1915, a U-boat torpedoed the British-owned steamship Lusitania, killing 1,195 people, including 128 Americans.[44] Due to the employment of U-boats and torpedoes, the U.S. joined the war on the Allies' side.

When the U.S. entered the war, the Navy deployed the Bliss-Leavitt Mark VII torpedo, which had a range of 4,000 yards at 32 knots. Opposite to Germany's success, of the eleven torpedoes fired by the U.S., zero hit their target.[45] Unfortunately, the complete failure of Bliss-Leavitt Mark VII torpedoes in the war is often overlooked. The image of thousands of American troops coming home after victory over the Central Powers overshadowed the ineffectiveness of the U.S. torpedo. Additionally, the scale of the land war drew attention away from the naval portion of the war, especially after the neutralization of Germany's U-Boats. By the time the U.S. entered the war, torpedo concepts were ready for demonstration on the battlefield after years of development, prototyping, and fleet testing. Although a rudimentary framework for developing and testing design iterations had been broadly established, testing from the component level to a fully integrated torpedo was inconsistent. While Captain William S. Sims of the Atlantic Fleet's Torpedo Flotilla had realized the importance of fleet testing and the development of tactics and doctrine, his influence had not yet ensured the successful use of torpedoes in World War I, though it did pave the way for success in the future.[46] Fleet testing and the development of tactics and doctrine are important but useless if the technology does not perform consistently.

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[44] Annette McDermott, "How the Sinking of Lusitania Changed World War I," HISTORY Channel, 17 April 2018, https://www.history.com/news/how-the-sinking-of-lusitania-changed-wwi.
[45] Frank Blazich, *Newport's 90-Pound Rube Goldberg Device: Reexamining the Mark 6 Mod 1 Exploder* (National Museum of American History, September 2022), 7.
[46] Trent Hone, *Learning War: The Evolution of Fighting Doctrine in the U.S. Navy, 1898-1945* (Annapolis, MD: Naval Institute Press, 2018), 120.

From the inception of the torpedo through World War I, various solutions and innovative concepts were invented and fielded. The concept started as a stationary, area-denial tool focused on defensive measures and morphed into an advanced threat with high explosives, capable of traveling quickly underwater to strike and sink a target. As the weapon system progressed, the U.S. struggled to develop an R&D infrastructure capable of producing a superior torpedo on the global stage while preparing sailors to utilize the novel technology in battle. Realizing the challenges associated with fielding the complex weapon system, the U.S. Navy created a facility on Goat Island to assist in the continued development of the torpedo.

THE NAVAL TORPEDO STATION AT GOAT ISLAND

As outlined, the U.S. raced to develop and field an internationally superior torpedo throughout the latter half of the 19th century and into the 20th century. At the center of this arms race was the NTS on Goat Island in the Harbor of Newport, established in 1869. The War Department initially controlled the island following its purchase from the city of Newport in 1799 until the establishment of the NTS. Within the first two decades of the creation of NTS, the Navy constructed a guncotton plant, a seaman gunner's school, and fire control support.[47] Leading up to, throughout, and after World War I, the station manufactured torpedoes, conducted experiments, and trained sailors on torpedoes and tactics. During the decades following the station's establishment, Goat Island also housed several buildings and barracks supporting the Naval Academy in Newport. Although the Naval Academy eventually returned to Annapolis, the Navy's presence in Newport remained permanent with the institution of the NTS.[48]

[47] Simpson, *Goat Island and the U.S. Naval Torpedo Station: Guncotton, Smokeless Powder and Torpedoes*, 15.
[48] Simpson, *Goat Island and the U.S. Naval Torpedo Station: Guncotton, Smokeless Powder and Torpedoes*, 21.

While the creation of the NTS was a significant event in the torpedo's developmental timeline, it also marked the beginning of the U.S. establishing specialized technical activities to advance specific technology areas, the impact of which can be seen across the nation in national laboratories and research centers today. Upon its inception, the station served as the Navy's research and experimental center for developing torpedoes, explosives, and electrical equipment.[49]

In addition to being a research center, the NTS also functioned as a school for training sailors on torpedoes. In the early years of schooling, courses were developed to teach students about the design, development, and fleet use of stationary (moored) mines, spar, towed, and automobile torpedoes. Additionally, courses included instruction on explosives in the warheads and the corresponding manufacturing process and electrical devices in torpedoes, including fuses, batteries, lighting systems, generators, and wire-guided systems. Initially, all students at the NTS were in the military and, in addition to coursework, participated in the research and development of various underwater weapons. The station continuously refined and focused its instruction as novel concepts were introduced, developed, and tested. Over the years, as the station grew, its workforce became a mixture of military professionals and civilians. Civilians provided support primarily in conducting research and filling roles in production facilities on the island.

During torpedo development, having a facility explicitly dedicated to R&D, training, and experimentation was vital to enhancing the integration and deployment of the weapon. From its inception, the NTS at Goat Island conducted a wide variety of experimental tests on numerous

[49] Simpson, *Goat Island and the U.S. Naval Torpedo Station: Guncotton, Smokeless Powder and Torpedoes*, 26.

torpedo types throughout their development and provided vital training and schooling for the fleet. Although the NTS came under fire for the negative performance of the torpedo during World War II, it also served as one of the first U.S. specialty facilities for developing, testing, and manufacturing a complex weapon system.[50] While the reputation of the NTS at Goat Island is clouded by the early performance of torpedoes in both world wars, the station's overall impact on torpedo development, fleet training, and readiness cannot be disputed.

THE NAVAL HISTORICAL COLLECTION'S NAVAL TORPEDO STATION RECORDS

Since the inception of the NTS on Goat Island, records chronicling the administration and scientific studies of the research facility have been logged and archived. The NTS began sending these records to the National Archives and Records Administration (NARA) in 1947 per federal record management guidelines.[51] The records started in 1883 and were collected at NARA until 1957; they chronicled the administration, test data, torpedo design developments, and scientific studies at the NTS. After sitting untouched for years, the Naval Underwater Systems Center (NUSC) hired a firm to review the records in 1977. Due to the size of the collection, which comprised over 500 banker boxes, and the various types of records in it, the firm NUSC hired concluded they were unqualified for the job. The collection then sat untouched until 1984, when custody of the records was transferred to the Naval War College Archives, known as the Naval Historical Collection (NHC). With this transfer, the records again sat untouched until 1991, when they were inventoried and re-boxed, then sent to off-site storage. The collection remained in off-

[50] Wallin McBurney and Kennedy Conley, *World War II Rhode Island* (Charleston, SC: The History Press, 2017), 19.
[51] Naval Historical Collection, "Torpedo Station Records Processing" U.S. Naval War College, accessed February 7, 2023, https://digital-commons.usnwc.edu/exhibit/nts-progress/?page=2.

site storage until 2018, when the NHC made the records available to researchers. Still, since the records had not been fully processed and arranged chronologically, researchers were causing damage to the documents by sifting through multiple boxes while searching for specific information. In 2021, the NHC closed the collection and began a large-scale processing project to perform conservation, stabilize the materials and arrange them chronologically to facilitate research. When the first review of the collection occurred in 1977, there were 518 boxes of documents. In 2018, the NHC noted 23 boxes unaccounted for during inventory. Thirteen of these boxes were determined to be missing before the collection's return. The remaining ten boxes may not have been checked off during inventory due to human error.[52] The contents of the missing boxes were not tracked, and there is no way of knowing what is missing until the entire collection has been inventoried and organized. The NHC plans to have its in-depth processing complete by 2024.

Understanding the history of the records is essential when analyzing test data gathered from the collection. As of March 2023, records from 1883 through the 1920s had been processed and organized chronologically. The records analyzed in this research are specifically from the collection between 1896 to 1917. Although the collection has not been fully processed, analyzing the data from the years leading up to the U.S. joining World War I is vital to understanding the early history of torpedoes' development, testing, and evolution. While over time, some reports and documents have been lost in custody due to changes and movement of the collection, the quantitative magnitude of tests, methods, specifications, and requirements of torpedo test reports

[52] Stacie Parillo, "NTSR Survey" Naval Historical Collection, August 2018.

can be utilized to analyze the U.S. Navy's evolution in understanding the development and fielding of one of its first complex weapon systems.

DEVELOPING THE TESTING CONTINUUM

"It is possible that if a perfect weapon were supplied, perfection might be obtained, but it is hardly fair to expect the service to overcome faults which torpedo experts cannot, and these faults cannot be known unless the torpedo is actually tested."[53] – Lieutenant Charles Belknap, 1911

In the years leading up to World War I, the U.S. Navy conducted various tests on torpedoes to evaluate designs, performance specifications, and weapon system reliability. In the era before the Department of Defense (DoD) was established and terms such as Technology Readiness Level (TRL), Integration Readiness Level (IRL), and Manufacturing Readiness Level (MRL) came into use, the U.S. Navy developed the backbone of the guidelines and paved the way for their creation. The NTS was pivotal in this testing continuum and maturing torpedo technology. At the facility, engineers, scientists, and technicians worked on design optimization while developing production and maintenance capabilities.[54] The NHC's collection of NTS records chronicles the assortment of tests, repairs, and production progress at the facility in the years before the U.S. joined the first World War. These documents are vital in illustrating the vital role of the NTS in torpedo development and production, as well as the importance of various testing methods in maturing a complex system. Moreover, Lieutenant Belknap's quote above foreshadowed the Navy's long struggle to deploy the torpedo successfully and drew

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[53] Naval Torpedo Station Records, MSC-031, Box 1911 Dec. Naval War College Archives, U.S. Naval War College, Newport.

[54] Norman Polmar, *The American Submarine* (Nautical & Aviation Pub Co. of America: January 1983), 13-14.

attention to the necessity to understand the correlation between testing and successful integration and use by the fleet. The Navy needed to establish a strategy for technological innovation.

Without an established method or guidelines for developing, integrating, and fielding a complex weapon system, the Navy utilized a number of tests to mature torpedo technology. Notable methods included range, depth, speed, explosive and operational testing. Range testing was conducted by launching a torpedo from a testing site and measuring the distance it traveled before running out of fuel and sinking or surfacing. Range testing was generally conducted in a bay under somewhat controlled environments but also occurred in open water at sea. Variables such as water current and pressure, as well as varying torpedo speed throughout runs, make it difficult to track and measure the distance traveled.[55] As the achievable range increased, field testing in the open sea and bays became more difficult because of the difficulty in keeping the factors in the equation constant when comparing various aspects of torpedo performance. Range testing was significant in understanding torpedoes' distance limitations, which helped develop tactics and target sets.

Depth testing was conducted to ensure the torpedo could maintain a constant depth throughout the entirety of its operation. One method of depth testing included wire-guided torpedoes in which a wire was used to guide the torpedo during its run and monitor its depth.[56] Another method for monitoring depth was to mount a hydrostatic depth-measuring device to a torpedo during its run that measured water pressure as the torpedo traveled.[57] A third and low-fidelity method was visually monitoring the torpedo with a periscope throughout its run.

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[55] Naval Torpedo Station Records, MSC-031, Boxes 1896 Jan – 1917 Dec. Naval War College Archives, U.S. Naval War College, Newport, RI.
[56] Polmar, *The American Submarine*, 14.
[57] Polmar, *The American Submarine*, 14.

Although limited by human visual tracking ability, this method avoided mounting a device to the torpedo or guiding it with a wire, both of which could affect its performance. Depth testing was crucial for ensuring the torpedo would not surface or sink during a run. Early depth mechanisms, such as the pendulum-and-hydrostat design, were often inconsistent and resulted in depth errors and missed targets due to several variables, including varying torpedo speed and water temperature and pressure.[58] Frank Leavitt refined the pattern-type depth mechanism in the early 1900s and incorporated it as the standard mechanism in U.S. Navy torpedoes through World War I. The pattern-type design improved upon the pendulum-and-hydrostat design in terms of performance but was much more complex, making them difficult to manufacture and maintain, and required highly trained operators.[59] In the early years of torpedo development, creating a reliable depth mechanism was a significant challenge.

Additionally, torpedoes were tested to develop requirements for their speed and acceleration. Both laboratory and field test methods conducted speed testing. In the laboratory, experiments were conducted at the NTS with wind tunnels and other testing equipment to evaluate the performance of torpedo components, such as propellers and engines.[60] In the field, torpedoes were launched and timed via stopwatches or mechanical speedometers, then the speed was calculated with the run's distance. By starting in the laboratory and then transitioning to field testing, the NTS could repetitively demonstrate the capability and reliability of components and the weapon system as a whole. Understanding the capable speeds of different variants of torpedoes was significant in developing tactics and strategies for employing the weapons in battle. As shown by Table A1 in Appendix A, the range decreased as speed increased for torpedo

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[58] Epstein, *Torpedo: Inventing the Military-Industrial Complex in the United States and Great Britain,* 38.
[59] Epstein, *Torpedo: Inventing the Military-Industrial Complex in the United States and Great Britain,* 46.
[60] Robert Gardiner, *The Naval War of 1914-1918* (Maryland: Naval Institute Press, 1995), 12.

modifications of the same variant. Given this relationship, correlating torpedo variants to target sets based on the results of speed testing was vital for successfully fielding and utilizing the weapon in battle.

Explosive testing was also conducted to understand a torpedo's explosive power and ability to damage a target. The testing occurred by detonating the torpedo against a target and quantifying the extent of the damage. Explosive testing was conducted in a laboratory as well as in the field. The detonator mechanism and timing were tested in the laboratory while war shots were fired at targets in the field. Field tests with war shots were conducted with the all-up weapon system and were not conducted often due to budgetary constraints. In the field, devices measuring the shockwave after detonation, as well as damage to the target, were methods of collecting data.[61] Targets were generally retired and unusable ships. Additionally, aging tests on explosive materials were also conducted to develop an understanding of the lifespan of the materials. As the characterization of explosives increased, explosive charges were enhanced, and the capable battle damage increased. The Navy collected monthly guncotton testing data and reports outlining results and progress in the years leading up to World War I. Explosive testing enabled warhead enhancement and increased battle damage capabilities as torpedo variants progressed.

Operational testing combined all of the above methods to evaluate the overall performance and effectiveness of torpedoes in combat situations. Both NTS and the fleet conducted operational testing. Operational tests included exercise runs and war shots. Exercise runs utilized inert warheads, or exercise heads, while war shots were live fires with explosive

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[61] Epstein, *Torpedo: Inventing the Military-Industrial Complex in the United States and Great Britain,* 42.

warheads. When NTS conducted operational testing, it occurred in the seas surrounding Goat Island by various launcher systems that correlated to the platforms the torpedoes were to be integrated. In fleet operational testing, torpedoes were launched from the platforms targeted for their integration and fielding, such as destroyers, torpedo boats, and submarines. These tests were conducted at sea, usually in bays or harbors. When conducting exercise runs, the tests were usually in bays to ease retrieval, whereas the war shots were generally completed in open seas. During fleet testing, the crews recorded the speed of the torpedo, speed of the ship, depth of the torpedo, speed of the target, range of the run, condition of the torpedo, and accuracy of the run (distance from target).

Unlike the testing outlined above conducted by NTS, crews aboard warships performed fleet operational tests. Fleet operational tests not only built-up reliability in the torpedoes but also enhanced military experience. The collection of NTS records from the NHC includes fleet and NTS operational test reports. Per guidelines of the era, the fleet was to record each exercise conducted with torpedoes and was expected to conduct exercise runs monthly for torpedo boats and submarines and quarterly for destroyers and other ships. The reports were sent to and compiled by the NTS into quarterly reports documenting the results of runs. The data gathered from these tests was used to refine torpedo designs and improve their performance, ultimately leading to the development of more effective and reliable torpedoes in the years leading up to World War I. The data also helped develop specifications for achievable speeds and accuracies.

OPERATIONAL TESTING DATA

While extensive work has been published around the historical narrative of torpedo development, there is a gap in understanding the importance of operational testing on successful use in battle. Generally, when a weapon does not work properly in the field, the failure is tied to a specific component failure or operator error. While these reasons may be adequate, digging deeper, both can be attributed to testing or the lack thereof. For this research, the analysis will be focused on operational testing. Operational testing was selected as the focus to identify correlations between all-up weapon system exercises and effectiveness in battle. Operational testing is the final step before fielding and integration. The results of analyzing the NTS's operational data from 1896 to 1917 illustrate that there were issues in torpedo development well before World War II, which is when historians typically focus their attention on U.S. Navy torpedo failures.

With the data presented in the following sections, keep in mind the following assumptions and constraints: analysis is based on the reports in the collection, meaning some could be missing; testing reports and the format of data collection varied over the years; and variables chosen for analysis were selected based on uniform appearances in reports across the selected years. Furthermore, from 1896 to 1907, the recorded operational exercises were completed entirely by the fleet, not the NTS, whereas in 1907, there was a shift to both the fleet and NTS conducting operational testing. The shift from fleet only to the fleet and NTS will be discussed further in the following section; the charts, however, include both the fleet and NTS operational tests and do not delineate the two. Additionally, the operational tests in this analysis are for exercise runs only and not war shots. The conclusions drawn from this data do not relate to the warhead's effectiveness during this era.

Table I and II on the following page illustrates the total number of operational exercises completed yearly from 1896 to 1917. Notable spikes can easily be correlated to significant historical events. In 1898, torpedo exercises nearly doubled from the previous year due to the

Spanish-American War. Although both sides were equipped with variations of the Whitehead torpedo in the war, there were no confirmed hits with the weapon. The psychological effect and impact of the threatened capability of the weapon are demonstrated in the increased exercises. After the Spanish-American War, as the Navy sought to rectify lessons learned from the conflict, it also impacted the increased quantity of exercises and tests. Leading up to 1904, the number of tests gradually increased yearly, with a minor dip in 1900. The dip can be correlated to BuOrd receiving fluctuating support for torpedo initiatives until the Russo-Japanese War when the Whitehead torpedo proved its place in warfare.[62]

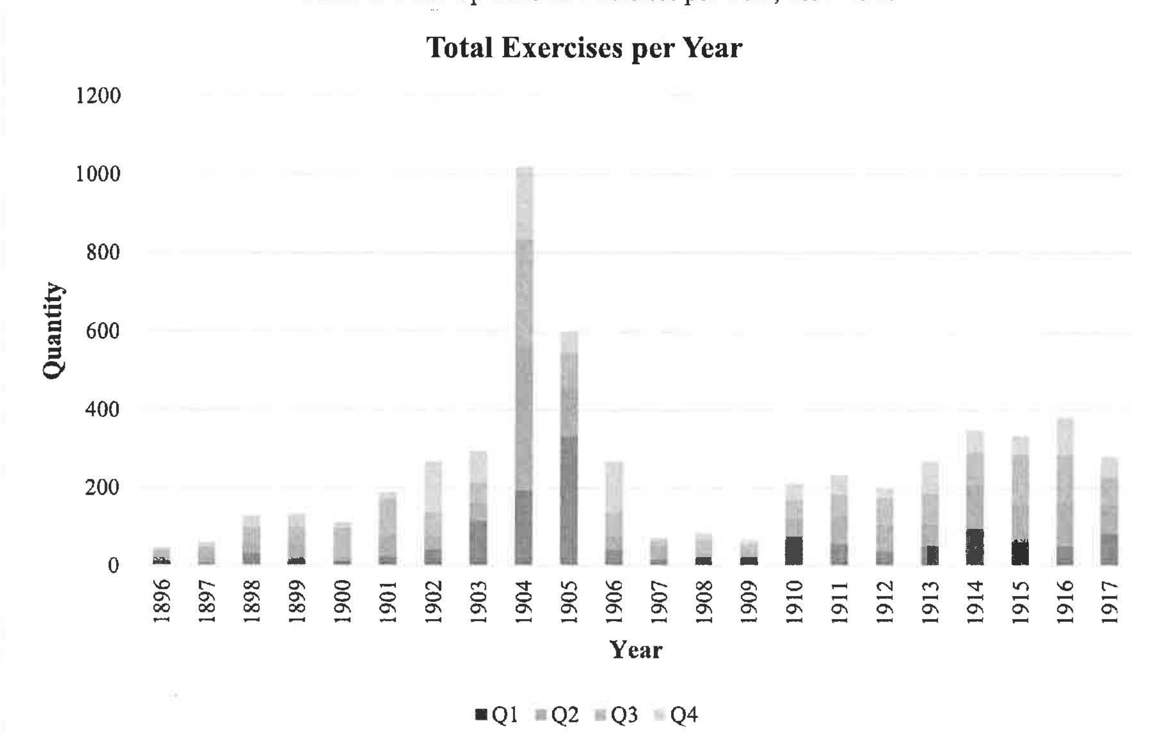
As discussed earlier, the Russo-Japanese War led to a torpedo development and production surge. Along with the increased attention on the weapon system, operational testing tripled from 1903 to 1904. In the years following the war, operational torpedo tests declined as production and fleet quantity increased. During these years, the U.S. struggled to reach a consensus on Navy funding and the allocation of those funds, especially during peacetime. There were two camps, one supporting the build-up of a peacetime Navy and the other against it, placing other developmental initiatives higher in priority than the Navy.

In December of 1907, President Theodore Roosevelt sent the "Great White Fleet" on a voyage around the world. The voyage spanned until February of 1909 and consisted of sixteen battleships from the Atlantic Fleet. The fleet was named after the battleships were painted white, except for the gilded scrollwork on their bows.[63] In the first stage of the voyage, the fleet was accompanied by a torpedo flotilla of six destroyers and other auxiliary ships from the Atlantic Fleet. This voyage and the preparation for the voyage led to a drop in fleet torpedo exercises and

[62] Craig Symonds, *Historical Atlas of the U.S. Navy (*Annapolis, MD: The Naval Institute, 2001), 121-123.
[63] "The Great White Fleet" Naval History and Heritage Command, January 2022.

tests. Since most of the fleet was occupied with the voyage, the priority to test torpedoes decreased. As mentioned above, from 1896 to 1907, the recorded operational exercises were completed entirely by the fleet, not the NTS, whereas after 1907, there was a shift to the fleet and NTS operational testing. The shift resulted from BuOrd realizing the need to continue operational tests even when the fleet was engaged in higher-priority operations. After the return of the Great White Fleet, the number of exercises again fluctuated until the start of World War I in 1914. From 1914 until the U.S. joined the war in 1917, torpedo exercises and tests remained consistent. When the U.S. joined the war, operational tests were completed almost entirely by the NTS, which accounts for a drop in the number from the previous year.

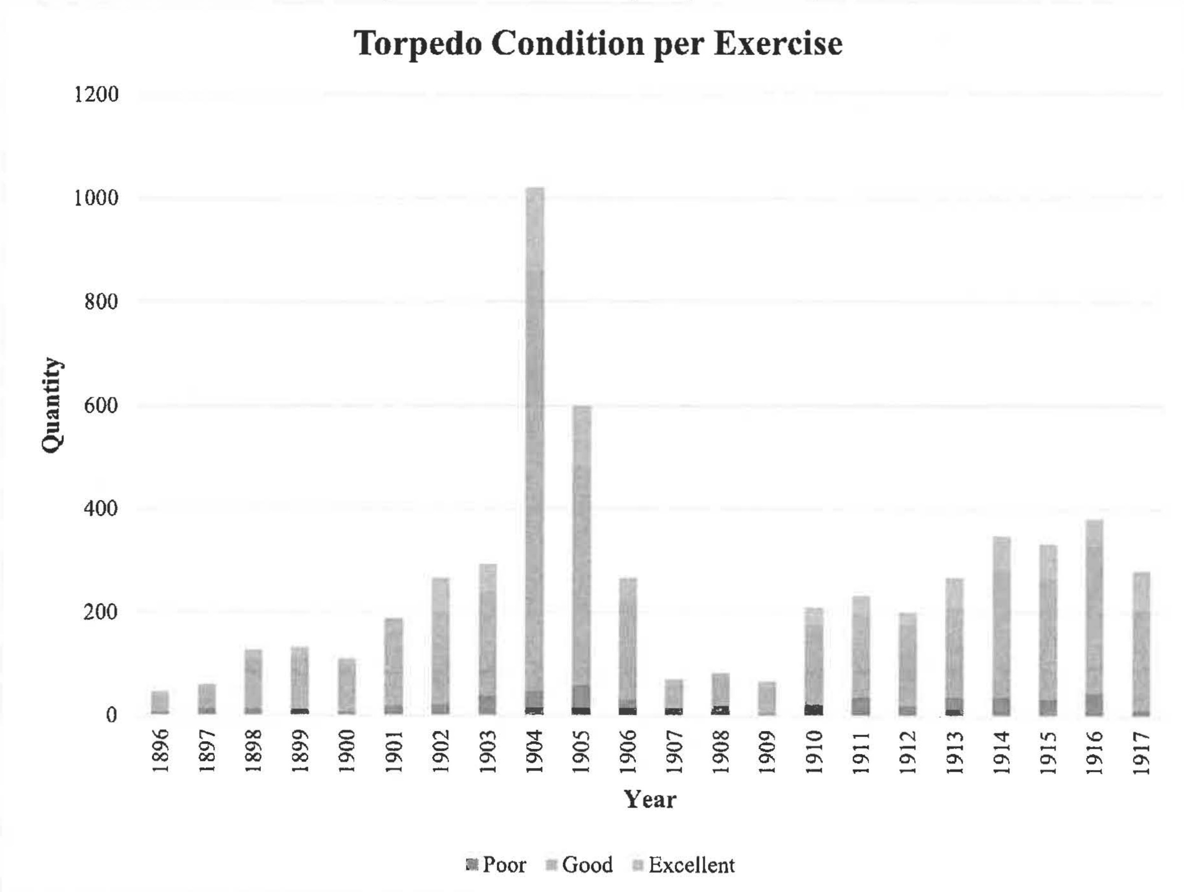
Table I. Total Operational Exercises per Year, 1896-1917[64]



[64] Naval Torpedo Station Records, MSC-031, Boxes 1896 Jan – 1917 Dec. Naval War College Archives, U.S. Naval War College, Newport.

In Table II, the reported condition of torpedoes per exercise is illustrated. The inspection was conducted visually. Comments on the torpedoes labeled as "poor" condition included significantly rusted components, missing parts, and damaged exercise heads. Also, the torpedoes labeled as "poor" accounted for under ten percent of the total exercises conducted (this metric will be significant when analyzing the following charts). The remaining "good" and "excellent" torpedoes accounted for ninety percent of those tested in runs. When testing and fielding a complex weapon system, tracking the integrity of the units is vital when analyzing results.

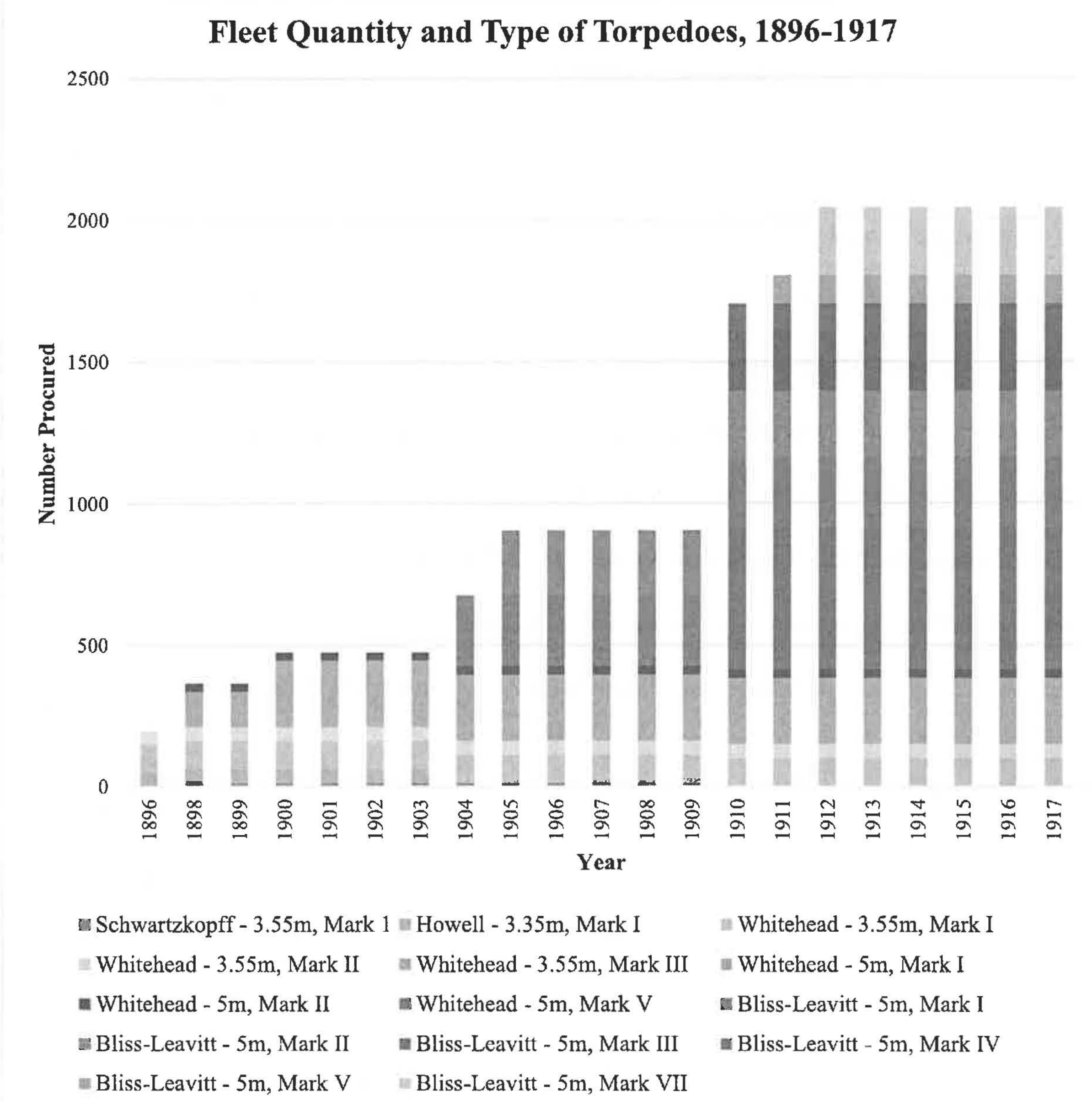
Table II. Reported Condition of Torpedo per Exercise, 1896-1917[65]



[65] Naval Torpedo Station Records, MSC-031, Boxes 1896 Jan – 1917 Dec. Naval War College Archives, U.S. Naval War College, Newport.

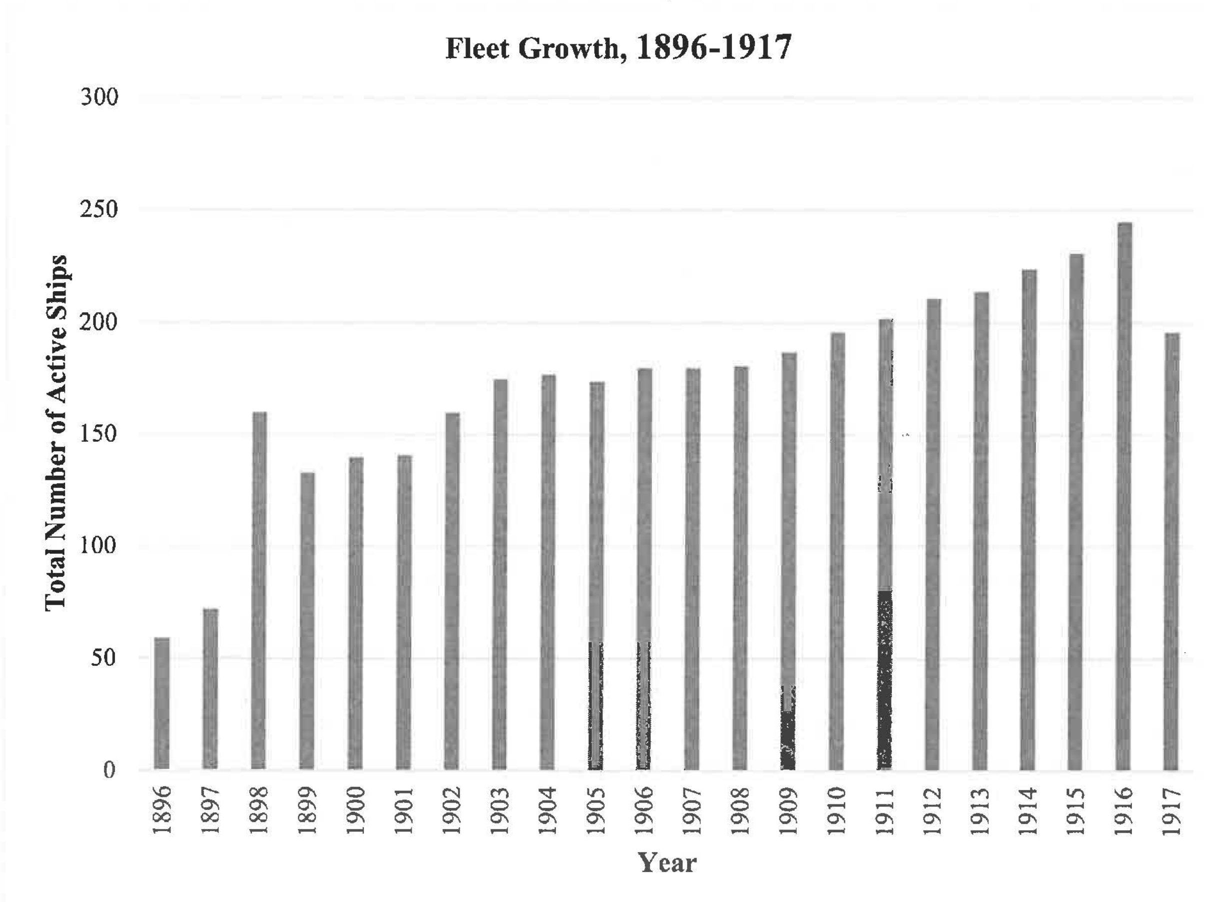
In Tables III and IV below, the number and type of torpedoes in the fleet, as well as the growth of the fleet each year, is illustrated. As shown, the frequency of tests does not clearly correlate to the growth of the fleet and the number of torpedoes procured. In 1904 and 1905, following the Russo-Japanese War, an increase in the procurement of torpedoes occurred along with the increase in tests. As torpedoes were procured in 1904, 1910, and 1911, the number of exercises in that year also increased. On the contrary, the same trend was not displayed in 1905 or 1912 as additional torpedoes were added to the fleet. Additionally, from 1901 on, the fleet continued to grow as the nation realized the importance of maintaining a powerful navy with the influence of President Theodore Roosevelt. A drop in fleet size and the number of torpedo exercises is notable in 1917, correlating with the U.S. entering World War I, decommissioning ships, and shifting focus away from torpedo testing. Overall, torpedo procurement correlates directly to fleet growth, although trends between the two concerning the number of exercises are not consistent.

Table III. Quantity and Type of Torpedoes in the Fleet, 1896-1917[66]



[66] Naval Torpedo Station Records, MSC-031, Boxes 1896 Jan – 1917 Dec. Naval War College Archives, U.S. Naval War College, Newport.

Table IV. Fleet Growth, 1896-1917[67]



Results were compiled after collecting the total number of tests conducted per year. Table V illustrates the overall results from comments noted in reports and the documented error in target accuracy. Results were documented as one of the following: good run, curved left, curved right, sank/lost, surfaced early, or no comment. The good runs hit the target and operated as expected. The runs that curved left or right missed the target but did not surface or exhibit depth issues during the exercise. The tests noted as sinking or lost did not hit the target and either ran into the ground and were retrieved or lost without recovery. Tests that were completed in bays

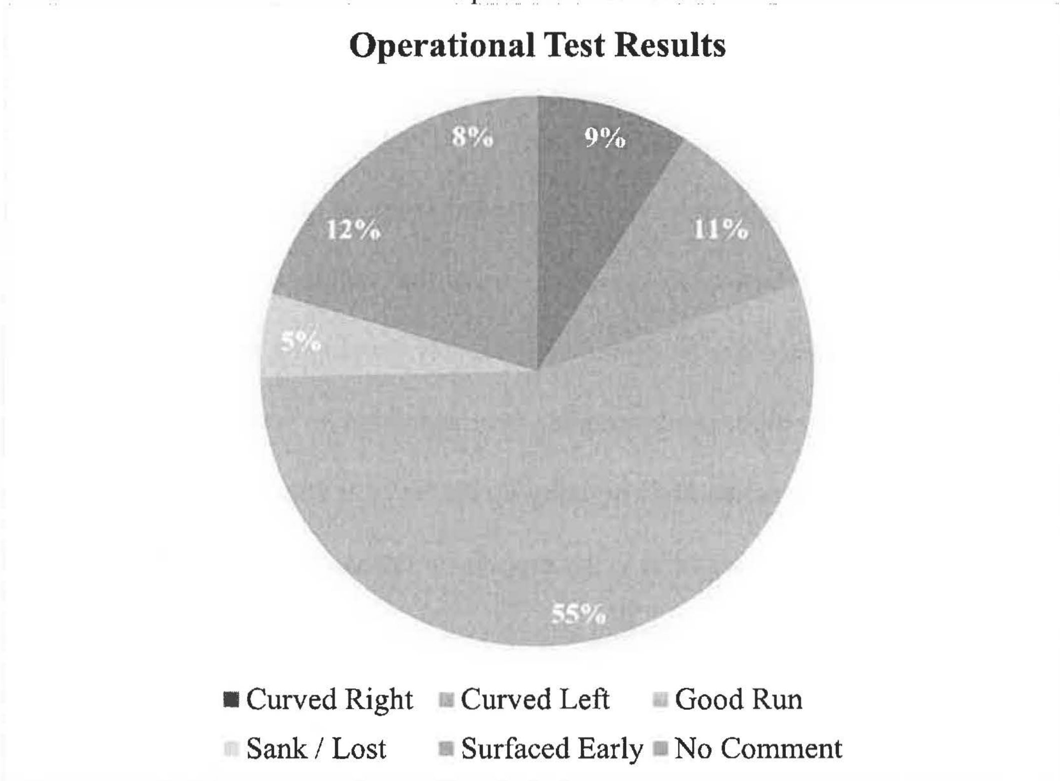
[67] Naval Torpedo Station Records, MSC-031, Boxes 1896 Jan – 1917 Dec. Naval War College Archives, U.S. Naval War College, Newport.

generally allowed for the retrieval of sunken torpedoes in shallow waters. Runs labeled as surfaced early were generally attributed to an error in the depth mechanism and were recovered, examined, and reused after modifications. The runs labeled with no comment represent the reports that did not include information on the outcome. No comment could mean the run was good and the torpedo hit its target, but this assumption was not made for this analysis.

As illustrated, fifty-five percent of the exercises were classified as good runs, while eight percent had no comments and likely were also good runs. The remaining thirty-seven percent of the runs had negative results. That means a torpedo would fail during battle nearly forty percent of the time. A forty percent failure rate is significant and clearly denotes design and production errors. Statistical analysis of the results found the runs resulting in sinking or surfacing early decreased after 1904 when the pattern-type depth mechanism, which was refined by Frank Leavitt, was improved and integrated into all torpedo variants.

Additionally, the analysis found that as torpedo speed increased, the number of runs curving left and right decreased. Components were further refined with each new torpedo variant, and capability increased. At higher speeds, projectile stabilization could be achieved, lining up with the decrease in curved trajectories. Also, the Obry gyroscope, which was integrated into torpedo variants in the early 1900s, led to a decrease in curved runs, though not eliminating them altogether. Given the statistical analysis results, the thirty-seven percent of negative resulting runs decreased as components were modified. While testing focused on repetitive exercise runs are beneficial for evaluating navigation and propulsion components, the lack of war shots testing the explosive capabilities, detonators, and firing mechanisms could not be completed by only exercised runs.

Table V. Operational Test Results[68]



THE EVOLUTION OF TESTING

"A good Navy is not a provocation to war. It is the surest guarantee of peace." – President Theodore Roosevelt, 1902[69]

From 1896 to 1917, the U.S. struggled to conduct operational tests and exercises consistently. Although the Navy made significant progress in conducting testing, the organization as a whole did not grasp the value of the following areas: proactive and consistent guidance for required capabilities, repetitive testing and qualification of individual components, and fleet training to build operational experience with the all-up-weapon system. An all-up

[68] Naval Torpedo Station Records, MSC-031, Boxes 1896 Jan – 1917 Dec. Naval War College Archives, U.S. Naval War College, Newport.

[69] Theodore Roosevelt, "Message of the President of the United States Communicated to the Two Houses of Congress at the Beginning of the First Session of the Fifty-Seventh Congress," (Washington, DC: Government Printing Office, 1901): 29.

weapon refers to an entirely integrated system with all related equipment, materials, services, personnel, and launch platform components required for operational use. During this time, funding fluctuated, priorities shifted, and the nation oscillated between periods of conflict and peace. As the nation grew in size, industrialized, and enhanced its military power, it faced many new challenges. President Theodore Roosevelt, aware of the challenges facing the nation, advocated for building a peacetime Navy and continuously developing naval technologies. He realized that to successfully mobilize the country from peacetime to wartime; the nation needed to be prepared, which meant deliberately building up the Navy and its capabilities. Although President Roosevelt remained consistent in his support for expanding the fleet as well as developing new weapons systems, including torpedoes, Congressional appropriations for the service grew but fluctuated from year to year, likely affecting the pace and frequency of torpedo testing.[70] Additionally, the bureaus and R&D facilities established to oversee the development of the torpedo did not have adequate power to advocate for the initiatives and funds necessary to ensure consistent support of the weapon's development. Due to this unreliable support and lack of guidelines for developing and maturing complex weapon systems, the U.S. Navy struggled to field and integrate the torpedo with the fleet.'

As mentioned in the previous sections, the National Military Establishment was not formed until 1947, and the DoD in 1949 by an act of Congress. Until this point, there was no centralized entity that ensured a solid foundation of national policy and supervised military

[70] Matthew Oyos, *In Command: Theodore Roosevelt and the American Military* (Lincoln, NE: Potomac Books, 2018), 118-44, 216-43, 247-60, 276-94; Paul E. Pedisich, *Congress Buys a Navy: Politics, Economics, and the Rise of American Naval Power, 1881-1921* (Annapolis, Maryland: Naval Institute Press, 2016), 141-179; "Budget of the US Navy: 1794 to 2014," Naval History and Heritage Command, last updated 23 August 2014, https://www.history.navy.mil/research/library/online-reading-room/title-list-alphabetically/b/budget-of-the-us-navy-1794-to-2004.html.

forces and capabilities.[71] During torpedo development, BuOrd represented the closest agency to the DoD. Additionally, DoD guidance for developing weapon systems and other equipment for the military had not been created. The NTS and BuOrd, in their testing continuum described previously, paved the way for the DoD and TRL guidelines and enhanced understanding of testing requirements when developing new technology. As reflected by the various types of tests mentioned above, torpedo development was stepping through similar milestones per current DoD TRL guidelines. However, the process of repetitively testing individual components in the same controlled environment to enhance reliability before all-up system integration was not robust during torpedo development. While repetitive testing utilizing exercise heads was conducted, destructive testing was neglected. Destructive testing was more expensive to complete due to the tests expending energetics. Budgetary constraints on torpedo development led to the neglect of the firing mechanism. Since no defined and uniform process with milestones existed, torpedo developers struggled to develop a high-fidelity testing matrix for the system and all of its components, including the firing mechanism and warhead.

The following is a brief summary of each TRL and its associated milestones according to current DoD guidance: TRL 1: Basic principles observed and reported: This is the earliest stage of technology development. TRL 2: Technology concept and application formulated. TRL 3: Analytical and experimental critical function and characteristic proof of concept. The technology has been tested in a laboratory environment to prove its critical functions and characteristics. TRL 4: Component validation in a laboratory environment. TRL 5: Component validation in the relevant environment. TRL 6: System/subsystem model or prototype demonstration in a relevant

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[71] Roger Trask and Alfred Goldberg, "The Department of Defense 1947 – 1997," (Washington DC: Office of the SECDEF, Historical Office: 1997): 2.

environment. TRL 7: System prototype demonstration in a realistic environment. TRL 8: Actual system completed and qualified through test and demonstration. TRL 9: Actual system proven through successful mission operations.[72] Although the NTS did not outline these steps specifically in torpedo development, their testing continuum resembled today's guidance, although qualification and accepted risk levels were higher for systems in the 1900s than today.

In today's national security environment, qualification tests and experimental results are held to a higher rigor for several reasons. The possibility of programmatic failure is a risk the military services seek to minimize today, as political processes often determine budgets based on success and failure.[73] Additionally, in the current high-tech age, with rapid advances in emerging technologies, the margin for error is small, meaning fielded technologies are held to higher standards given the chain reaction one failure could cause to systems relying on other systems. When analyzing the NTS operational testing data above, understanding that uniform technology development guidelines were not invented yet gives some clarity to the significant number of runs that failed. As Lieutenant Charles Belknap noted in a speech to the President of the U.S. Navy in 1911 about torpedo development, "It is possible that if a perfect weapon were supplied, perfection might be obtained, but it is hardly fair to expect the service to overcome faults which torpedo experts cannot, and these faults cannot be known unless the torpedo is actually tested."[74] The Navy realized its testing continuum was lagging during the development of the torpedo, and the lessons learned throughout the process are reflected in the standards and R&D infrastructure

[72] Office of the Director, Defense Research and Engineering. *Technology Readiness Assessment Deskbook* (Department of Defense: 2009), 1-1.
[73] Matthew Fay, "Understanding the Role of Risk in Military Innovation" Niskanen Center, September 2016.
[74] Naval Torpedo Station Records, MSC-031, Box 1911 Dec. Naval War College Archives, U.S. Naval War College, Newport.

that has been developed today. To adequately set the fleet up for success, testing and building reliability in the system is a necessity.

From the invention of the naval mine to numerous automobile torpedo concepts, the U.S. struggled to be proactive in fielding the complex weapon system ahead of adversaries. In the midst of an era surrounding technological advancement, the U.S. began to develop the R&D cycle, enhance domestic industry and increase experimentation and testing of novel concepts at the NTS. Balancing strategy, training, and manufacturing of a novel weapon system that was consistently advancing in capability and introducing novel modes of warfare proved challenging for the U.S. Throughout the 19th and 20th centuries, the weapon system altered naval history, impacting countless battles and influencing strategy, psychology, and decisions. Since its invention, the concept of the torpedo shifted from a stationary area-denial tool to a propelled offensive weapon capable of traveling quickly, at range to strike a moving target. Although the performance of the torpedo is often correlated to its failures early in World War II, the problems were noted decades earlier and reflected the U.S. struggle to define an optimal R&D infrastructure. Furthermore, wartime experience in World War I exposed numerous limitations of the current torpedo technology and triggered the requirement for more sophisticated doctrine in technology and strategy development.[75]

Analyzing torpedo development leading to World War I adds an essential piece to the narrative and emphasizes the need for a defined innovation and fielding process with complex weapon systems. The R&D community, along with the DoD, must deliberately and consistently conduct testing of complex technologies and their components. While the U.S. Navy conducted

[75] Hone, *Learning War: The Evolution of Fighting Doctrine in the U.S. Navy, 1898-1945*, 120.

significant exercises with inert heads, the same attention was not given to live war shots. Although conducting war shots at the same magnitude as exercise runs is not maintainable, warhead design and validation are necessary for successful operations in battle. Finally, operational testing is vital to gaining fleet experience and trust as technologies become increasingly complex. While testing is essential, it must be balanced with timelines, fleet training, and fielding schedules. The means and infrastructure to conduct repetitive tests on components and all-up weapon systems must be developed and planned for early in the inception of novel technologies. Thorough planning at all stages of technology maturity, coupled with an adequate understanding of testing capabilities and guidance, were missing variables in the early development of torpedoes. Although agencies such as the DoD have been created and infrastructure, industrial capacity, and technology have been enhanced significantly since the early 1900s, analyzing torpedo development during that period provides guidance and lessons that can still be applied today. Maintaining an emphasis on proactive and consistent guidance for required capabilities, repetitive testing and qualification of individual components, and fleet training to build operational experience with all-up-weapon systems are lessons learned that apply to developing today's complex weapon systems.

Appendix A

Table A1. U.S. Fleet Torpedo Types & Characteristics through WWI[76]

Kind	Mark	Range [yds]	Speed [knots]	Explosive Charge [lbs.]	Procurements [qty]
Schwartzkopff - 3.55m	I	800	28	119	12
Howell - 3.35m	I	400	25	96	50
Whitehead - 3.55m	I	800	26	119	100
Whitehead - 3.55m	II	800	28	119	50
Whitehead - 3.55m	III	800	28	119	109
Whitehead - 5m	I	1,000	28	220	125
Whitehead - 5m	II	1,500	29	132	30
Whitehead - 5m	V	Mod 1: 4,000 Mod 2: 2,000 Mod 3: 1,000	Mod 1: 27 Mod 2: 36 Mod 3: 40	200	500
Bliss-Leavitt - 5m	I	Mod 1: 4,000 Mod 2: 4,000	Mod 1: 27 Mod 2: 26.5	200	250
Bliss-Leavitt - 5m	II	3,500	26	207	230
Bliss-Leavitt - 5m	III	4,000	26	218	210
Bliss-Leavitt - 5m	IV	Mod 1: 2,000 Mod 2: 3,000	Mod 1: 30 Mod 2: 29	200	100
Bliss-Leavitt - 5m	VI	2,000	35	200	100
Bliss-Leavitt - 5m	VII*	4,000	32	205**	240
Bliss-Leavitt - 5m	VIII	Mod 1: 10,000 Mod 2: 12,500 Mod 3: 13,500	27	320	***

*After World War I, all iterations before the Bliss-Leavitt Mark VII were discontinued from fleet use.
**TNT replaces guncotton in the warhead.
***Torpedoes of this kind were not produced until after WWI.

[76] Naval Torpedo Station Records, MSC-031, Boxes 1896 Jan – 1917 Dec. Naval War College Archives, U.S. Naval War College, Newport.

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Fig. 2, Anonymous, *Spar Torpedo Rigged Out*, BW Photograph, circa 1865, (Naval History and Heritage Command, NH 82827, Courtesy of Naval Underwater Systems Center, Newport, Rhode Island), https://www.history.navy.mil/content/history/nhhc/our-collections/photography/numerical-list-of-images/nhhc-series/nh-series/NH-82000/NH-82827.html.

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