ABSTRACT

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The US Navy's move to high-pressure and -temperature steam propulsion, otherwise known as "high steam," has been viewed in the postwar period as a critical advance that made long-range operations possible during World War II. This position, which is almost entirely reliant on the autobiography of Rear Admiral Harold G. Bowen, has neglected to consider the complex and problematic nature of the supply chain required to produce high-steam turbines. Archival research has revealed that the US Navy's insensitivity to these changes after 1938 caused severe bottlenecks in wartime destroyer production. Also overlooked was the aggressive administrative action on the part of the Navy's Bureau of Ships and its turbine subcontractors required to mitigate this crisis. Together, these events formed an important example of the need to adapt administratively to match the advance of technology.

ADAPTING TO INNOVATION: THE US NAVY, HIGH-STEAM DESTROYERS, AND THE SECOND WORLD WAR.

By

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Introduction

Invention is one thing, manufacture is another. The US Navy’s transition to high-pressure and -temperature steam propulsion in the 1930s is a striking reminder of the truth of this axiom. The employment of high-pressure and -temperature boilers and turbines, collectively known as high steam, provided US Navy warships with a significantly increased range. Historians have described this advantage as a critical innovation that made possible long-range operations in the Pacific Theater of World War II. However, no innovation has ever come without its own challenges. Postwar scholars, like the prewar US Navy before them, have overlooked the transformation of material requirements and production methods that accompanied high steam. The benefits of this technology actually came at a high cost. The Navy’s insensitivity to these changes between 1938 and 1942 nearly precipitated a collapse of wartime destroyer production, maintenance, and repair. It was aggressive action on the part of the Navy's Bureau of Ships that averted disaster. Specifically, the Bureau's efforts to assert control over turbine manufacturers and their suppliers after 1941 were critical in this endeavor. The complete story of high steam was not just a tale of mechanical invention, but also one of production management.

Understanding Steam Power

For the US Navy, high steam was simply the next logical step in the evolution of shipboard propulsion which began in the latter half of the 19th century. The earliest marine steam engines consisted of a single or small number of boilers that burned wood or coal fuel in an open furnace, heating water into steam in a manner very similar to a steam locomotive. This steam was fed to a reciprocating engine, a device resembling a massive piston (or later a series of pistons). The engine in turn drove a paddle wheel or simple propeller through a direct connection such as a crankshaft.

The advancing industrial revolution of the 19th century brought with it improved materials and precision production techniques for the manufacture of complex engines. Cast iron was superseded by various steels, particularly carbon steel, which significantly improved the strength and durability of engine components. Mass-produced cast steel in particular allowed for steam boilers with fewer seams and higher temperature tolerances. This allowed for steam pressures to increase from around 50 pounds per square inch (psi) to around 200 psi by 1900.[1] Temperature in these boilers was unregulated, meaning that on average the steam produced would remain at or very near the boiling point of water for the pressure in use.

At the beginning of the 20th century, the reciprocating engine was replaced in most major navies by the marine turbine, a modified engine originally created for land-based power stations. The turbine was a cylindrical engine that contained alternating rows of fixed "guide" blades and rotating "moving" blades, the latter of

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[1] Hans Naegeli and A. C. Jones, "Carbon-Molybdenum Cast Steel for Steam Service" in *Journal of the American Society for Naval Engineers* 47 (May, 1935), 198-201.

which were affixed to a central rotor. Steam was forced through the length of the turbine, spinning the rotor and expending temperature and pressure in the process. The temperature and pressure change within a turbine were collectively known as the "heat drop." The greater the drop, the greater the efficiency.[2] There were two types of turbines developed in the 1880s, differentiated by the location of the heat drop. The reaction turbine, pioneered by Charles Parsons, evenly divided the heat drop between the guide and moving blades for a constant rate of change. This required a long turbine and a very large number of blades to achieve maximum efficiency.[3] The other was the impulse turbine, invented by Gustaf de Laval. In this engine, the entirety of the heat drop was contained in the alternating rows of stationary guide blades, allowing the moving blades to receive the greatest possible impulse from the expanding steam. Although the impulse turbine required significantly fewer blades than the reaction turbine, the latter was significantly more common in the early 20th century.[4] Despite the fact that turbines were much more complex than the reciprocating engine, both types were quieter, caused less vibration, and were more efficient. Dangers associated with steam engines were universal—steam in an enclosed system must be pressurized; boiler or pipe ruptures were capable of causing catastrophic damage.

The adoption of the turbine to naval use posed a unique problem to engineers: how to efficiently connect the turbine rotor to a propeller. Turbines are generally

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[2] Ingvar Jung, *The Marine Turbine, Part 2 1928-1980: Development of Naval Turbines and the Engines of the Great Atlantic Liners* (Greenwich, London: National Maritime Museum, 1986), 6-10.

[3] The first turbine powered vessel was actually the *Turbinia* (1894), Parsons' own vessel. He used it to turn up unannounced at the Royal Navy review of June 1897 in a dramatic demonstration of the speed and power the turbine promised. Given that the Royal Navy was unable to stop him with its own slower vessels and thus began ordering turbines for itself by 1899, it is safe to say Parsons was successful in this endeavor.

[4] Jung, *The Marine Turbine, Part 2*, 6-7.

highly efficient at velocities in the range of several thousand revolutions per minute (rpm). Conversely, propellers are only efficient at much lower speeds of a few hundred rpm. In order to allow a turbine rotor to efficiently turn a propeller, a reduction gear was interposed between the two.[5] The reduction gear was a relatively simple innovation; a small gear attached to the turbine rotor turned a much larger gear wheel linked directly to the propeller shaft. However, despite the simple concept, this component was difficult to manufacture due to the precision required. The complexity increased markedly when more than one turbine had to be attached to the same propeller.[6]

By the 1930s, navies the world over were considering or experimenting in a limited fashion with raising both the pressures and temperatures of steam in an attempt to produce vessels with more speed, horsepower, and range. Though high steam was clearly desirable for a greater heat drop, a number of technical barriers existed. To be properly utilized, high steam required reliable pressure and temperature control, a steel alloy capable of withstanding greater stresses than cast steel, an improved method allowing turbines and their linked propellers to rotate at vastly differing speeds to maintain peak efficiency, and extreme precision in the manufacture of turbine blades and casings. These obstacles were widely regarded as not only prohibitively expensive, but also dangerous. Without proper use of steel alloys, for example, rapid load changes due to the need for warships in combat to frequently change course and speed would very quickly cause high steam turbines to overheat and fail. In short, high steam required a level of industrial advancement that

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[5] A propeller rotating at too high a speed causes excessive cavitation, which in turn causes excessive wear and inefficiency.

[6] Jung, *The Marine Turbine, Part 2*, 9-10.

was considered beyond the major naval powers of the 1920s. As a result, pressures and temperatures had remained relatively constant since the advent of the marine turbine. This trend continued for most navies until the postwar period. Other than a handful of Japanese and German warships, the only notable exception was the post-1930 US Navy.[7]

The story of how the US Navy's near monopolization of high-steam technology came about, and its impact on the outcome of the Second World War, is summarized in relatively brief sections of general works. These include Norman Friedman's well-regarded *US Navy Destroyers: An Illustrated Design History* (2004), David C. Evans and Mark R. Peattie's *Kaigun: Strategy, Tactics, and Technology in the Imperial Japanese Navy, 1887-1941* (1997), and Albert A. Nofi's *To Train the Fleet for War: The U.S. Navy Fleet Problems, 1923-1940* (2010).[8] There is general consensus that vast improvements in cruising radius attributable to high steam, particularly in the case of the US Navy's destroyer force, made long-range operations in the Pacific Theater feasible by cutting down on fuel, refueling time, and the additional bases that otherwise would have been required to fight the Imperial

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[7] The Japanese in particular experimented with 426 psi, 662°F, and eventually standardized these numbers for the *Kagero* class destroyers and *Shokaku* class carriers, according to David C. Evans and Mark R. Peattie, *Kaigun: Strategy, Tactics, and Technology in the Imperial Japanese Navy, 1887-1941* (Annapolis, MD: Naval Institute Press, 1997), 246-48.

[8] Friedman brings up the issue of high steam briefly using Bowen's story in Chapter 5 ("Leaders and the Interwar Period, 1917-1940") and in Chapter 7 ("The Destroyer Escorts, 1941-1945"), in which he makes a rare mention of the shortage of turbines and reduction gears during the Second World War, but goes no further. Evans and Peattie naturally focus primarily on the Japanese experimentation with high steam and only briefly visit upon the capabilities of the US Navy for point of comparison. For his part, Nofi relates the story of the range deficiency of US Navy destroyers rather than the change to high steam itself throughout his work. This is particularly apparent in the case of Fleet Problem XIV in 1933, during which many of the Navy's destroyers were afforded only a limited role due to their range. Norman Friedman, *U.S. Destroyers: An Illustrated Design History* (Annapolis, MD: Naval Institute Press, 2004), 88, 95-97, 143-44, Evans and Peattie, *Kaigun*, 246-48, and Albert A. Nofi, *To Train the Fleet for War: The US Navy Fleet Problems, 1923-1940* (Newport, RI: Naval War College, 2010), 168.

Japanese Navy. However, all renditions of high-steam development and employment closely follow the language of a single primary source: Rear Admiral Harold G. Bowen's *Ships Machinery, and Mossbacks: The Autobiography of a Naval Engineer* (1954). Bowen, who was head of the Navy's Bureau of Engineering from 1935-39 when the controversy over the speedy adoption of high steam reached its critical stage, appears at first glance to be a knowledgeable and reliable source for this information. In this book, the reader is presented with statements such as, "high pressure high temperature [steam] formed the background of propulsion engineering during World War II. According to Vice Admiral Earle W. Mills, later Chief of the Bureau of Ships, our operations in the Pacific would not have been possible without it."[9] All new technology brings with it benefits and drawbacks, yet Bowen presented only sunshine and rainbows. He neglected to discuss the immense challenges, namely the impact of this next-generation technology on the war effort itself. Why? The battle over implementation of high steam proved to be a pyrrhic victory that eventually cost Bowen, its chief advocate, his job as head of the bureau. It is only natural that he would seek to emphasize the resounding successes of the cause he championed. What has been lost as a result, however, is that the history of high steam is not just a tale of technological success, but also an instructive case study of administrative adaptability.

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[9] Rear Admiral H.G. Bowen, *Ships, Machinery, and Mossbacks: The Autobiography of a Naval Engineer*, (Princeton, New Jersey: Princeton University Press, 1954), 111.

Bowen's Story: Evolution and Controversy

The two-part story surrounding high steam involved warships of all classes, but focused primarily on destroyers, considered the smallest significant fleet unit. This class was ordered in greater numbers than all other types of vessels fitted with geared-steam turbines, and thus required production en masse. Conversely, cruisers, battleships, and aircraft carriers, with their smaller numbers and long construction times had their equipment specially constructed. Since the time required to produce a destroyer was considerably shorter, demand for subcomponents such as engines was accelerated. The evolution of high steam would focus squarely on the destroyer.

The early 1930s became a period of significant change for the US Navy, not only because of the adoption of high-pressure and -temperature steam, but also due to the preceding decade-long break in naval construction. Prior to the destroyers of the *Farragut* (DD-348) class, ordered in 1932, the Navy had not constructed any new destroyers since 1922.[10]

Ship construction by the world's major navies was limited severely throughout most of the interwar period by a series of treaties initiated by the Washington Naval Conference of 1922. The treaty system, put in place to stop an ongoing naval arms race primarily between the United States and Britain, limited almost every aspect of each signatory nation's navy from the numbers of each ship class to a maximum tonnage and gun size. Not every nation was permitted to have the same total tonnage either; the total size of the world's major navies was fixed at a

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[10] The prior *Clemson* class had many minor variations, and is thus sometimes considered as a number of separate classes. Engineering performance, however, was largely the same across all of these vessels.

ratio of 5:5:3:1.7:1.7 for the United States, Great Britain, Japan, France, and Italy, respectively. Accordingly, new naval construction was only permitted to replace "obsolete" vessels once a nation had reached its allotted tonnage. For this reason, very few ships were completed by any nation between 1923 and 1932.

A typical destroyer of the US's pre-treaty *Clemson* class displaced 1,215 tons and had a maximum speed of about 35½ knots. The class was powered by four boilers that drove a pair of low-pressure turbines for a maximum of about 27,500 shaft horsepower and a range of about 2,500 nautical miles at 20 knots or 4,900 nautical miles at 15 knots. Built primarily by what Admiral Bowen referred to as the "Big Three" shipyards of Bethlehem Steel, Newport News Shipbuilding, and New York Shipbuilding, these ships were constructed entirely on site along with all their requisite machinery and spares. The turbines for these vessels were also produced by the shipyards utilizing a British design under license from Parsons, Ltd, along the same lines as those that Parsons produced for the Royal Navy.[11]

Technical specifications of the *Clemson*'s low-steam installation were typical of those found in pre-1932 US destroyers. Such a system utilized saturated steam oil-burning boilers powering (mostly) reaction turbines linked by a single reduction gear to the propeller shafts.[12] The turbines themselves were low-speed and -pressure machinery that possessed 17,500 blades and utilized steam at around 260-275 psi. The use of "saturated" steam meant that steam generated for power by the boilers was

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[11] See Table 1 for comparative details. Friedman, *U.S. Destroyers*, 462.

[12] The *Clemson* class had a mix of different turbines depending on which yard manufactured a given ship. The majority used Parsons reaction turbines, but some used subcontracted impulse turbines. Jung, *The Marine Turbine, Part 2*, 12.

very near the minimum temperature required for it to remain a dry gas at that pressure.[13] This temperature typically remained around 450°F.

The period between design of the *Clemson* class (1918-19) and the resumption of destroyer production to replace ships considered "obsolete" by the treaty system in 1932 witnessed significant advance in the field of land-based, power-generating turbines, which caught the attention of the Navy's Bureau of Engineering. Chief among these improvements was the employment of higher pressures and temperatures resulting in more efficient use of steam, and by extension, fuel.[14] Although the Navy (and Parsons, Ltd. in Britain) had not been willing to take the risks of developing high-steam technology in the 1920s, the American civilian firms of General Electric, Westinghouse, and Allis-Chalmers had accepted the challenge and succeeded. Beginning late in the 1920s, but only in earnest in the early 1930s, the Bureau of Engineering, charged with providing specifications for power plants of every new Navy warship, was keen to increase what had been perceived by numerous commanders in the US fleet as the woefully inadequate range of destroyers then in service.[15] That range, about 4,900 miles at 15 knots for the *Clemson* class, is cited often as a major deficiency in records of the General Board of the Navy, particularly

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[13] Bowen, *Ships, Machinery, and Mossbacks*, 53.

[14] Ibid, 53.

[15] Claims to this effect are everywhere in the General Board's records. Several examples are Chairman of the General Board to the Secretary of the Navy, "1936 Building Program – Characteristics of Destroyers and Submarines," 19 March 1935; General Board Study 420-9 "1935"; Records of the General Board of the Navy, Record Group 80.7.3; National Archives Building, Washington, DC, Gibbs & Cox, Inc. to Chairman of the General Board, "Memorandum supplementing the Testimony to be given by Mr. William Francois Gibbs in accord with Invitation to the firm of Gibbs & Cox, Inc. from the General Board for its opinion with respect to Pressures and Temperatures," 1938; General Board Study 420-13 – December 1, 1938: Steam Conditions of Pressure; Records of the General Board of the Navy, Record Group 80.7.3; National Archives Building, Washington, DC, and Bureau of Engineering Memorandum to the General Board of the Navy, "General Engineering Matters," 30 November 1938; General Board Study 420-13 – December 1, 1938: Steam Conditions of Pressure; Records of the General Board of the Navy, Record Group 80.7.3; National Archives Building, Washington, DC.

in reviews following fleet exercises.[16] Beginning with the *Farragut* class of destroyers in 1932, the Bureau of Engineering gradually stepped up its pressure and temperature requirements for each successive design. The first major landmark stage in this process, however, was not the small step taken by the *Farragut* class, but the leap made by the *Mahan* class.

The 18 *Mahan* class destroyers, which were produced from 1934 to 1937, were a 1,500-ton design constructed largely by smaller shipyards either incapable or unwilling to build their own propulsion machinery. They were, as a consequence, fitted with two sets of General Electric-built impulse turbines producing about 49,000 shaft horsepower and possessing 10 times fewer blades than the reaction turbines of the *Farragut* class. These turbines were arranged so that each propeller shaft was linked via a double-reduction gear to a high-pressure, low-pressure, and declutchable cruising turbine. Replacing the single gear-and-pinion, a double-reduction gear was a series of gear-and-pinion linkages permitting high turbine rotation speeds while occupying space smaller than a comparable single-reduction gear.[17] The *Mahan*'s boilers, designed by Babcock & Wilcox, operated at 450°F and 650 psi and gave the destroyer a range of 7,300 miles at 12 knots during her trials.[18]

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[16] Bowen also includes instances of this complaint, citing one exercise review as stating that the first action they took was to steam several hours west and then immediately refuel all destroyers. Though this issue does appear in the records of the General Board, it is only indirectly discussed by Nofi. Bureau of Engineering to the General Board of the Navy, 30 Nov 1938; General Board Study 420-13 – December 1, 1938: Steam Conditions of Pressure; Records of the General Board of the Navy, Record Group 80.7.3; National Archives Building, Washington, DC, and Nofi, *To Train the Fleet for War,* 168.

[17] Jung, *The Marine Turbine, Part 2*, 31-35.

[18] See Table 1 for comparative details. Friedman, *U.S. Destroyers*, 462.

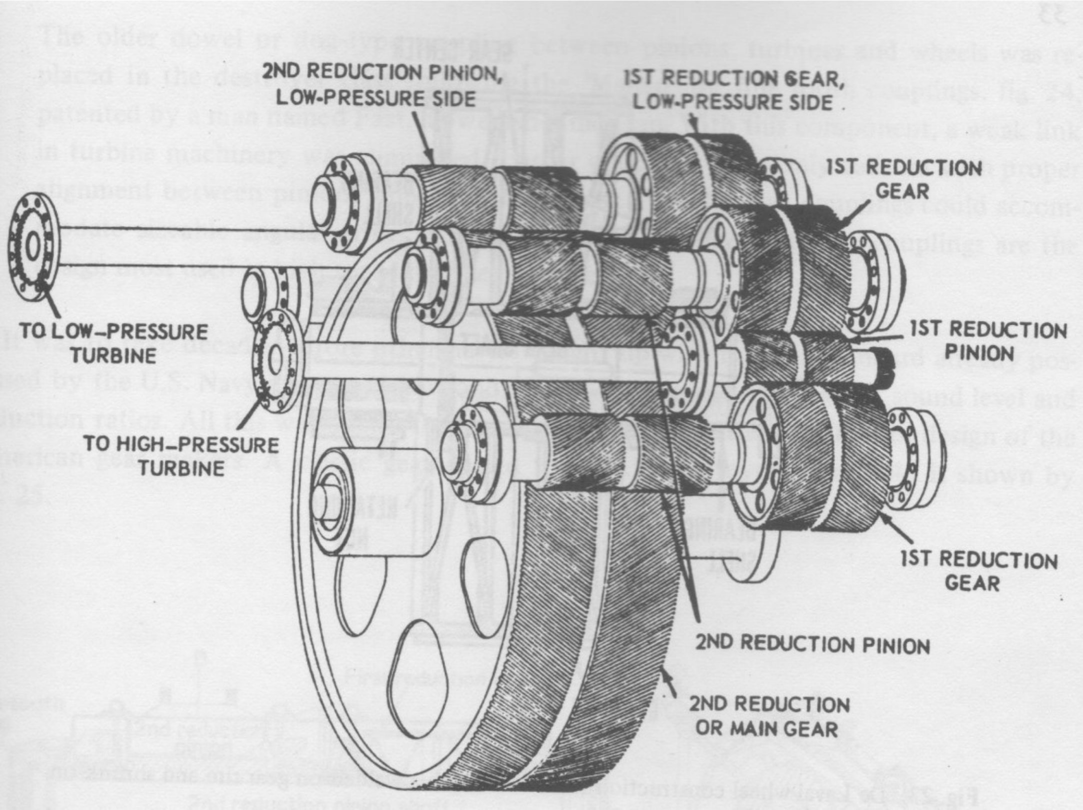

Figure 1: Locked-train, double-reduction gear designed for the *Mahan* class destroyers (1933), from Jung, *The Marine Turbine, Part 2*, 32.

By the mid-1930s, it was clear to the Bureau of Engineering that the "Big Three" shipyards were not keeping pace with advancing steam technology.[19] In 1935, the Bureau acted aggressively to initiate change. The "Big Three" shipyards were informed that the Navy had decided to enforce the Espionage Act in regards to their contracts with Parsons. The Navy claimed that these contracts required the "Big Three" to share crucial details of US warships with a foreign power.[20] These shipyards were thus given the choice to either surrender their ability to bid on future Navy contracts or void their agreements with Parsons. As Bowen and the Bureau expected, this act forced a major change in the engineering status quo. The effect,

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[19] Bowen repeatedly mentions this throughout his autobiography, but particularly focuses on this situation here. Bowen, *Ships, Machinery, and Mossbacks,* 56-59.

[20] Ibid, 57, and Friedman, *U.S. Destroyers*, 88.

however, was not to press the "Big Three" yards to build their own versions of high-pressure and -temperature steam plants. Rather, it forced them into a cheaper alternative—purchasing said plants from companies already proficient in production of land-based turbines.[21]

As might be expected, records indicate that the increase in destroyer range accompanying these changes was welcomed in the fleet.[22] However, the pressures and temperatures in use in the *Mahan* class were not, according to Admiral Bowen and the Bureau of Engineering, the best that could be achieved. The next stage of development for high steam, which Bowen later claimed was simply a natural step forward, lay at about 850°F and 650 psi.[23] These levels were first issued as part of the requirements for the *Somers* class in 1935.

Table 1: The Development of High Steam in US Navy Destroyers.

Class (Design Year)	Displacement (Tons)	Turbines per Shaft	Reduction Gears	Pressure & Temperature	Range (NM)
***Clemson* (1918)**	1,215	Low Press.	Single	260-275 psi 450°F	4,900 @ 15 knots
***Farragut* (1931)**	1,365	Low Press. High Press.	Single	400 psi 650°F	8,968 @ 12 knots
***Mahan* (1933)**	1,460	Low Press. High Press. Cruising	Double	400 psi 700°F	7,300 @ 12 knots
***Somers* (1935)**	1,850	Low Press. High Press. Cruising	Double	600 psi 850°F	10,540 @ 15 knots *

***Sources*: Bowen, *Ships, Machinery, and Mossbacks*, 62-70, Friedman *U.S. Destroyers*, 462-5.**

****Somers* achieved this range on her trials using only 600 psi, 700°F.**

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[21] Bowen, *Ships, Machinery, and Mossbacks*, 66-67.

[22] Bureau of Engineering to the General Board of the Navy, 30 Nov 1938; General Board Study 420-13 – December 1, 1938: Steam Conditions of Pressure; Records of the General Board of the Navy, Record Group 80.7.3; National Archives Building, Washington, DC.

[23] Bowen discusses this issue at length. Bowen, *Ships, Machinery, and Mossbacks*, 52-54, 92, 125.

High-steam plants went through a number of rapid iterations in the mid-1930s, but the stage embodied in the USS *Somers* (DD-381, 1937) was the first to include all the innovations required for effective employment of high steam: high-pressure and –temperature impulse turbines, double reduction gears, a cruising turbine, and effective superheat control. Superheat, the excess heat present past the point at which steam remains "dry," is desirable in larger quantities at higher turbine speeds. It can be dangerous to machinery at low speeds however, making accurate control absolutely critical to avoid damaging the turbines.[24] *Somers* possessed superheating boilers which required pressurized "closed" type boiler rooms which, though functional, were highly uncomfortable for their crews. These superheated boilers, capable of producing steam at 600 psi and 850°F, were coupled to a three-turbine setup per propeller shaft: a high-pressure turbine, a low-pressure turbine, and a cruising turbine (these three are often referred to as a "set" per shaft, or even, confusingly, as a single unit at times). These turbines were linked to propeller shafts by double wheel-and-pinion reduction gears to allow for maximum efficiency. A steam plant like this provided the *Somers* with a significant range advantage over every previous US destroyer class; during its trials *Somers* managed to steam 10,540 miles at 15 knots, or more than twice the endurance of a *Clemson* class unit.[25] Only one additional prewar high-steam innovation would come after the completion of *Somers*: the air-

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[24] Ibid, 64-65.

[25] See Table 1 for comparative details. Gibbs & Cox, Inc. to Chairman of the General Board, "Memorandum supplementing the Testimony to be given by Mr. William Francois Gibbs in accord with Invitation to the firm of Gibbs & Cox, Inc. from the General Board for its opinion with respect to Pressures and Temperatures," 1938; General Board Study 420-13 – December 1, 1938: Steam Conditions of Pressure; Records of the General Board of the Navy, Record Group 80.7.3; National Archives Building, Washington, DC, and Friedman, *U.S. Destroyers*, 463.

encased boiler, which provided *Benson* (DD-421, 1938) class destroyers and their successors with reliable superheat control in the comfort of “open” boiler rooms.[26]

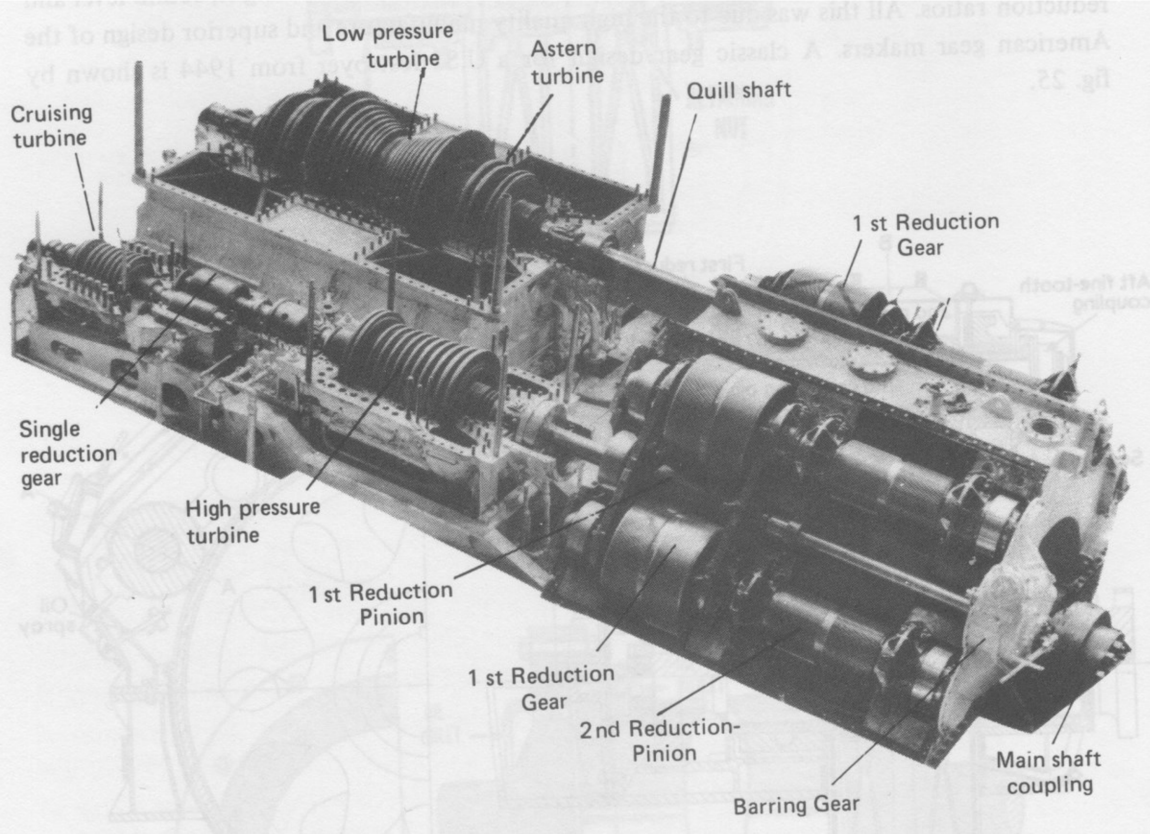

Figure 2: One turbine and gear “set” for an Essex-class aircraft carrier. Though intended for a different ship class, this machinery differed little from that installed in US destroyers. The turbine casings have been lifted to expose the rotors for this photograph. From Jung, *The Marine Turbine, Part 2*, 35.

Although this proved to be the highest stage of development realized until after the war, it was not where the Bureau of Engineering wished to stop. Admiral Bowen referred to the 600 psi and 850°F of the *Somers* and later as merely a stepping stone, like the *Farragut* and *Mahan* before it.[27] However, although the Navy briefly toyed with the re-engined USS *Dahlgren* (DD-187) in 1939, no further serious progress was made in increasing pressures and temperatures until after 1945.[28]

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[26] Jung, *The Marine Turbine, Part 2*, 17.
[27] Bowen, *Ships, Machinery, and Mossbacks*, 92.
[28] Ibid, 125.

Unfortunately for the Bureau of Engineering, it was with the introduction of the *Somers* class that critics attempted to apply the brakes to this breakneck pace of engineering advancement. Resistance to the Bureau of Engineering's ambitious specifications actually began to materialize with the resumption of destroyer construction in 1932 and escalated with the divided *Gridley*/*Bagley* class in 1935. It was with this split class, of which the four smaller yard-built *Gridley*s received higher pressure and temperature plants than the eight "Big Three" *Bagley*s, that the Bureau of Engineering decided to enforce the Espionage Act, setting off the Navy's steam engineering controversy of the late 1930s. The outcry from the "Big Three" and Bureau of Construction and Repair over this matter meant that the Bureau of Engineering found serious opposition to its objectives.

The high-steam controversy came to a head in the spring of 1938 with what Admiral Bowen refers to as the "Bath change," a design decision resulting in the construction of a large number of destroyers from different contract years to a nearly identical high-steam design. So named for the implementation of the design changes beginning with USS *Gleaves* (DD-423) and USS *Niblack* (DD-424) built by Bath Iron Works, the entire process was opposed by Bethlehem Steel, who was also contracted to build 1938 class destroyers.[29] Bethlehem, apparently convinced that it could produce destroyers using less advanced machinery that would prove to be just as efficient as those envisioned by the Bureau of Engineering, requested and was granted permission to build its share of the contract to different specifications to decrease production costs. Instead of a high-steam installation akin to the *Somers*' three-turbine-per-shaft system, Bethlehem installed one low-speed, low-pressure

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[29] Ibid*,* 79, 82.

turbine in addition to one high-speed, high-pressure turbine per shaft, omitting a cruising turbine. In addition, the boilers utilized a less advanced "integral" type superheater (rather than one of the "controlled" type used by ships built to a design similar to the *Somers*).[30] The first destroyer completed under this design, USS *Benson* (DD-421), failed to meet the fuel consumption rates originally specified in Bethlehem's contract.[31]

The acceptance of these changes to Bethlehem's contract encouraged the company to attempt the same design change in its bid for the later 1939 class destroyers. However, even though Bethlehem's bid was lower than those of Bath and Federal, it was rejected on the basis of Admiral Bowen's recommendation to the Secretary of the Navy.[32] To some in the Bureau of Engineering and the Bureau of Construction and Repair this was a daring move, as it ran the risk that the "Big Three" might be unresponsive to further high-steam contract opportunities. Naturally, this concern was amplified by the fact that Bethlehem and its compatriots were the only private yards capable of constructing battleships.[33]

Following the "Bath change" and the subsequent specification of 600 psi, 850°F for the contracts for new battleships #57-60, the high-steam debate was taken up by the General Board of the Navy, which began hearings on the matter on 25 October 1938. The proceedings, featuring testimony from the commanders of *Somers* and her sibling USS *Warrington* (DD-383), presented arguments of those for and

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[30] Ibid, 83.
[31] Ibid, 83, and Friedman, *U.S. Destroyers*, 95-97.
[32] Bowen, *Ships, Machinery, and Mossbacks*, 88.
[33] Ibid, 91.

against high steam.[34] As might be expected, proponents of the change to 600 psi, 850°F emphasized the fuel efficiency of the new installations in the *Somers* class, equipping the ships in question with a cruising radius 21% greater than the USS *Porter* (DD-356), a 400 psi, 700°F destroyer ordered only a year earlier.[35] Additionally, proponents of high steam emphasized the reliability of the new power plants, along with the simplicity of the turbines.[36]

For its part, the opposition accused the Bureau of Engineering of moving too rapidly in its power specifications without adequate testing. The new plants, it was claimed, were too expensive to manufacture and maintain, were bulky, and were potentially dangerous should failure occur with pressures and temperatures reaching twice that of older destroyers in the fleet.[37] The Bureau of Engineering later countered in a formal memorandum following the live testimony. It associated the perceived "bulkiness" of the plants with design flaws of the *Mahan* class, which did indeed have cramped engineering spaces, but added that no successive designs had generated any complaints about space problems. As far as maintenance and danger, the Bureau asserted that new plants were in fact no more complex than a typical low-steam

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[34] "Testimony of Lieutenant C.M. Dalton, Engineer Officer, USS *Warrington*, and Lieutenant C.J. Hardesty, Engineer Officer, USS *Somers*," 20 October 1938; General Board Study 420-13 – December 1, 1938: Steam Conditions of Pressure; Records of the General Board of the Navy, Record Group 80.7.3; National Archives Building, Washington, DC

[35] Bowen, *Ships, Machinery, and Mossbacks*, 70.

[36] Ibid, 92-96. Bowen's points are also emphasized in nearly identical phrasing in his testimony in the General Board's records on the hearing as recorded in General Board Study 420-13 – December 1, 1938: Steam Conditions of Pressure; Records of the General Board of the Navy, Record Group 80.7.3; National Archives Building, Washington, DC. Additional support for high steam is provided by "Statement from Commander J. E. Maher, Commanding Officer, USS Somers," 20 November 1938; General Board Study 420-13 – December 1, 1938: Steam Conditions of Pressure; Records of the General Board of the Navy, Record Group 80.7.3; National Archives Building, Washington, DC.

[37] "Testimony of Commander E.B. Thompson, Office of Naval Intelligence," 21 October 1938; General Board Study 420-13 – December 1, 1938: Steam Conditions of Pressure; Records of the General Board of the Navy, Record Group 80.7.3; National Archives Building, Washington, DC.

installation in the Royal Navy, and dangers resulting from high-steam leakage were already present and no less severe in low-steam plants.[38]

Lacking conclusive evidence for either argument apart from the increase in range gained from high steam, the General Board issued nothing more than an "opinion based on opinions." It agreed with the "Big Three" and its associated opposition to rapid advancements in high steam on the grounds that the Bureau of Engineering was moving far too quickly without adequate testing.[39] However, it permitted the Bureau to continue with its higher pressure and temperature requirements for future designs.[40] According to Admiral Bowen, this was a victory for progress and an important advance which made long-range destroyer operations in the Pacific possible, streamlined US naval strategy in the Pacific Theater and, due to the decreased number of refueling bases thus required, very likely shortened the war.[41] Of course, these conclusions assumed a seamless transition to high steam. Unfortunately, this was not the case.

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[38] Bowen, *Ships, Machinery, and Mossbacks*, 92-96, and Bureau of Engineering Memorandum to the General Board of the Navy, "General Engineering Matters," 30 November 1938; General Board Study 420-13 – December 1, 1938: Steam Conditions of Pressure; Records of the General Board of the Navy, Record Group 80.7.3; National Archives Building, Washington, DC.

[39] General Board of the Navy to the Secretary of the Navy, "An Estimate on Temperature and Pressure," 1938; General Board Study 420-13 – December 1, 1938: Steam Conditions of Pressure; Records of the General Board of the Navy, Record Group 80.7.3; National Archives Building, Washington, DC.

[40] Such a progressive decision was apparently not at all unusual for the General Board during the interwar period. Recent scholarship has portrayed the board as an opportunistic body during the treaty era that sought every available advantage during a time of limited budgets and tonnages. For more information, see John T. Kuehn, *Agents of Innovation: The General Board and the Design of the Fleet that Defeated the Japanese Navy* (Annapolis, MD: Naval Institute Press, 2008).

[41] Bureau of Ships, "An Administrative History of the Bureau of Ships During World War II," p. 31-33, vol. I (89a-b); Rare Book Room (RBR); Navy Department Library, Washington, DC (NDL-Washington, DC).

What Bowen Did Not Tell Us

Putting aside its influence on warship range and military strategy, the US Navy's adoption of high steam brought dramatic change to ship construction and, by extension, maintenance and repair. As has been stated, prior to the adoption of high-pressure and -temperature steam, the primary yards contracted by the US Navy (apart from their own), the so-called "Big Three" of Bethlehem Steel, Newport News Shipbuilding, and New York Shipbuilding, built power plants and spares for their own ships on site under license from Parsons, Ltd.[42] Severance of these licenses as a result of the enforcement of the Espionage Act in 1935 leveled the playing field. It forced the major yards to compete with smaller ones that purchased independently built, high-pressure boilers and turbines from contractors such as General Electric, Westinghouse, and Allis-Chalmers. Lacking expertise, the "Big Three" resorted to the practice of their competitors—they, too, began contracting off-site for their turbines and associated engine components. This expedient was encouraged by the Bureau of Engineering during its high-steam initiative as a means to achieve higher pressures and temperatures. The Bureau even went so far as to offer to provide the "Big Three," at its own expense, the high steam machinery for the new battleships contracted in 1938.[43] This shift in methodology is cited as a major milestone by Admiral Bowen himself—he points to this change as the transition of the shipyard from construction

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[42] Bowen, *Ships, Machinery, and Mossbacks*, 56-57.
[43] Ibid, 89.

site, where everything was built from scratch, to assembly yard, where pre-built components were brought together.[44]

Reliance on outside contractors for turbines, however, had its own set of challenges which went largely unmentioned by Admiral Bowen: it fostered stagnation of private shipyard power-plant investment and development. Naturally, with outside acquisition of pre-built turbines and spares as the new standard in ship construction, there was no longer a need for the "Big Three" (or any private yard for that matter) to continue maintaining up-to-date machining equipment and personnel for the rapid manufacture of precision components necessary to build and use turbines. The capacity for all major yards to construct turbines on-site rapidly vanished after 1935-38.[45]

On the other side of this new production paradigm were turbine suppliers, particularly General Electric and Westinghouse. By 1937-38, these manufacturers might have been expected to increase production capacity substantially for high-pressure and -temperature naval turbines in response to the enforcement of the Espionage Act. There is, however, no evidence of their having done so.

Why not? The answer might be related to the 1938 General Board hearing—that largely noncommittal ruling regarding the use of higher-pressure and -temperature steam. The Board's indecision over the matter hardly guaranteed future naval contracts to these companies; at the time it was just as likely that the major shipyards might again begin building their own turbines, particularly if the Navy

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[44] Ibid, 130-39. This point is also reiterated in Friedman, *U.S. Destroyers*, 88.

[45] Bowen actively encouraged this, believing that it was the only way to guarantee efficient production in the event of war. Ironically, it was the same stagnation of turbine development by shipyards which he had criticized previously. Ibid, 56-57.

changed course and adopted the more conservative approach to engineering advances advised by the General Board.[46] Additionally, with the treaty system still in effect until 1938, it was highly unlikely that any major contract orders would materialize in the near future. Existing capacity was adequate to manufacture turbines for the small numbers of destroyers then being built to replace those considered "obsolete" under the treaties—typically warships over 20 years old. The net result was a shipbuilding industry increasingly reliant on independent turbine contractors with limited experience and capacity for military construction.

Compounding this situation was a general lack of appreciation for supply mobilization planning on the part of the US Navy prior to World War II. Unlike the US Army, the Navy had no single agency that monitored the service's current and future needs, nor did it have any sort of contracting oversight. The Navy's supply system was highly decentralized and had been ever since its success during the First World War. Six separate bureaus were charged with procurement during the interwar period: Engineering, Construction & Repair, Supplies & Accounts, Aeronautics, Ordinance, and Yards & Docks. These organizations were nominally supervised by the Secretary of the Navy and the Chief of Naval Operations, but neither was actually equipped or willing to do so before 1941.[47] Like any bureaucracy left to its own devices, the individual Navy supply bureaus had thus become set in their ways and highly territorial by 1939, and conflicts of interest between them were quite common.

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[46] General Board of the Navy to the Secretary of the Navy, "An Estimate on Temperature and Pressure," 1938; General Board Study 420-13 – December 1, 1938: Steam Conditions of Pressure; Records of the General Board of the Navy, Record Group 80.7.3; National Archives Building, Washington, DC.

[47] Paul A.C. Koistinen, *Arsenal of World War II: The Political Economy of American Warfares, 1940-1945* (Lawrence, Kansas: University Press of Kansas, 2004), 44.

They had no significant coordination and no will or ability to accurately predict their future needs.[48] In this sort of environment, it is therefore no small coincidence that naval contractors would be unwilling to take a risk on expansion.

The end of the treaty system, the rising threat posed by Japan in the Pacific, and the rearmament of Germany combined to change this situation entirely after 1937-38. Beginning with the *Benson* and *Gleaves* destroyer classes in 1938, destroyers were ordered in ever-increasing quantities in an attempt to provide adequate numbers of escorts to a fleet facing the prospect of war on two oceans. While the US Navy had ordered 106 destroyers between 1932 and 1940, 412 contracts would be issued between January 1941 and December 1945—four times as many destroyers in half the time.[49]

The system for ordering new vessels was not substantially changed between the General Board hearings on high steam and the end of the Second World War, but the bureau system itself was altered in order to streamline the vessel design phase. In 1939-40, in an attempt to reduce department redundancy and conflicts of interest such as that which resulted in the high-steam controversy, the Bureau of Engineering and the Bureau of Construction and Repair were unified to create the Bureau of Ships, now responsible for all stages of the vessel design, procurement, and maintenance processes.[50] In the interest of maintaining continuity, Rear Admiral Samuel M. Robinson, Bowen's successor (and predecessor) as chief of the Bureau of

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[48] Ibid, 106.

[49] While 12 units of the preceding class (*Sims*) were built between 1937 and 1940, 92 ships of the *Benson* and *Gleaves* classes were completed in total between 1938 and 1943. See Table 2 for details on destroyer contracts by year.

[50] Bureau of Ships, "An Administrative History of the Bureau of Ships During World War II," p. 31-33, vol. I-II (89a-b); RBR; NDL-Washington, DC.

Engineering, was appointed chief of the Bureau of Ships. The new organization was charged with managing an already unwieldy network of contractors now crucial to the “shipyard as assembly yard” process. This would prove to be an enormous task.

As World War II approached, two major complications had emerged that threatened to choke the Navy’s expansion program. The first of these was inadequate Bureau control over subcontractors now relied upon for turbine production; the second was the availability of special-purpose machine tools necessary for the mass production of high pressure turbines.

At the onset of naval expansion in 1938, contracts for warships were awarded to the lowest bidding entity that in turn was expected to hire its own subcontractors for raw steel, power plant components, and other materials required to fulfill their contracts. Under this process, the Bureau of Ships directly controlled the allocation of work to upper-level contractors, but had no direct influence over the successive lower tiers of material production. Yards were thus free to set delivery dates and priorities for each of their subcontractors based on their own schedules. Naturally, such a situation resulted in order pileups with turbine manufacturers as demand accelerated, setting off panic at the first major signs of production trouble in reports appearing at the Bureau of Ships in the middle of 1941.[51]

In its postwar review, the Bureau of Ships highlighted its failure to exercise direct control over both material procurement and component subcontracting as a

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[51] G.B. Ogle, Bureau of Ships, to Chief of the Bureau of Ships, “Main Turbine Delivery & Requirement Dates for Navy Destroyers,” 11 June 1941; Destroyers; Records of the Shipbuilding Division, Records of the Bureau of Ships 1794-1972, Record Group 19.8.5; National Archives at College Park, MD.

major cause of delays in turbine manufacturing that began to crop up in 1940.[52] The Navy's interwar disregard for supply oversight meant that fundamental changes in how ships were built had gone completely overlooked. The transition to high steam was not merely a change in temperatures and boiler pressures, but a radical shift encompassing numerous innovations. As Admiral Bowen himself stated, the term "high steam" refers to all those technological advances that were combined into what became the Navy's principal means of propulsion during World War II.[53] Although many within the Bureau of Ships understood this as it related to machinery (boilers, superheat control, high pressure turbines, and reduction gears), they failed to grasp fully the extent of this transformation as it affected material requirements. High-pressure and -temperature steam propulsion was only made possible by the commercial development of high tensile alloys, particularly carbon molybdenum steel, which was able to withstand the enormous stresses caused by prolonged exposure to high steam.[54] These materials were not available in adequate amounts during the Second World War due to a limited production capacity combined with competing orders from the Navy, the rest of the US military, and the civilian economy.[55] Although this shortage was eventually recognized and eased through the creation of the Navy's Office of Procurement and Material in 1942, the initial damage was severe. Surprisingly, this lack of oversight was also problematic in the areas of

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[52] Bureau of Ships, "An Administrative History of the Bureau of Ships During World War II," p. 134, 182-83, 204-6, vol. I-II (89a-b); RBR; NDL-Washington, DC.

[53] Bowen, *Ships Machinery, and Mossbacks*, 51.

[54] Ibid, 68, and Bureau of Ships, "An Administrative History of the Bureau of Ships During World War II," p. 134, 182-83, 204-6, vol. I-II (89a-b); RBR; NDL-Washington, DC.

[55] An enlightening overview of carbon molybdenum steel as it related to turbine production can be found in an article from a 1935 issue of the Journal of American Society for Naval Engineers. Turbine casing production was a difficult and time-consuming process for low steam, but high steam and its requirement of the difficult-to-handle carbon molybdenum steel significantly complicated the process. Naegeli and Jones, "Carbon-Molybdenum Cast Steel for Steam Service," 205-219.

more common steel and bronze casting. Unforeseen and conflicting demands, exacerbated by a lack of even expansion of production capacity caused widespread shortages both real and perceived. Such an issue demonstrates both a lack of familiarity with long chains of industrial production on the part of the Bureau of Ships and the shortcomings of the Navy's decentralized supply structure. While these issues are cited by the Bureau of Ships' postwar review as major failures, they were compounded by another major factor that prevented the rapid expansion of these industries to match demand—machine tool shortages.[56]

Machine tools are vital components of any major production line. These are divided into two primary types: general-purpose and special-purpose. While general-purpose machine tools can perform many roles in different industries, special-purpose tools are designed with a very specific task in mind and cannot easily be put to other uses. In the United States both before and during the Second World War, special-purpose machine tools were produced via a lengthy cooperative process between the tool producers and product manufacturers. As one might expect, this practice was not well-suited to rapid expansion.[57]

Unfortunately for the US Navy, the use of special high-tensile steel alloys and the need for precision manufacturing meant that high-steam turbines and reduction gears required special-purpose machine tools for their manufacture. The length of time required for new tools to be produced meant that, despite early orders, it was not

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[56] Bureau of Ships, "An Administrative History of the Bureau of Ships During World War II," 134, 182-83, 204-6.

[57] Some insight into the importance of machine tools to armament production is provided by Alan S. Milward. Though the US produced a surplus of machine tools prior to the Second World War, a significant percentage of those were special-purpose tools. Alan S. Milward, *War, Economy, and Society 1939-1945* (Berkeley, CA: University of California Press, 1979), 187-90.

until late in the war that the turbine industry could even hope to be able to meet demand.[58] At the same time, areas of warship production that could get by with general-purpose tools were able to expand with relative ease to accommodate Navy contracts. This included the shipyards themselves, which were no longer required to manufacture their own turbines.[59] Such a capacity mismatch between the yards and their turbine suppliers, by this time principally General Electric, Westinghouse, and Allis-Chalmers, exacerbated the shortage of raw materials necessary for turbines and high-steam valves.

The perfect storm was brewing for the Navy with its dependence on private shipyards utilizing independent subcontractors, lack of Bureau oversight of warship component production, limited capacity of turbine manufacturers, and shortage of machine tools. Unless significant action was taken, the Navy's plans were poised for collapse with the onset of war. The Navy's supply system, already stressed from the simultaneous production of several dozen destroyers in 1941, was subsequently expected to massively increase its output.

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[58] Interestingly, this shortage is briefly mentioned by Friedman in his examination of the Destroyer Escort Program, but is not elaborated upon. According to Milward, US and German exports represented nearly 80% of the value of all machine tools involved in international trade prior to World War II. Massive increases in demand in 1940-1941, as well as the termination of trade with Germany, meant that US turbine contractors were required to rely wholly upon domestic production for their special-purpose machine tools once the war began. Friedman, *U.S. Destroyers*, 143-44 and Milward, *War, Economy, and Society*, 35.

[59] Bureau of Ships, "An Administrative History of the Bureau of Ships During World War II," 179-181, 204-6.

Table 2: US Navy Destroyer Production from 1932-45.

Year	Laid Down	Launched	Commissioned
1932	3	0	0
1933	8	0	0
1934	21	6	2
1935	13	13	6
1936	9	17	22
1937	12	9	15
1938	14	16	5
1939	15	15	17
1940	11	18	18
1941	87	24	23
1942	101	119	81
1943	89	101	130
1944	87	85	86
1945	48	72	72

***Source*: Friedman, *U.S. Navy Destroyers*, 488-513.**

Storm on the Horizon

Although the wartime problems associated with high steam were already manifest well before the outbreak of war, the recognition of their existence by the Navy only came gradually as conflict approached and orders for spares and new ships rapidly escalated. The conventional story of high steam terminates just before this point with the Bureau of Engineering's victory in the General Board hearing. But this was only the first act in the story of making high steam a viable system for general use.

The first tangible signs of turbine trouble for the US Navy surfaced as early as 1940 with a major recall of defective turbine blades in 22 destroyers.[60] Although significant in that it raised concerns that a major high-pressure turbine contractor—Westinghouse—was unfamiliar with the stress requirements of marine turbines, as opposed to land-based ones, even more disturbing was the process required to overhaul and replace defective blades. This replacement order suffered numerous delays caused by Westinghouse's already overloaded schedule, as one delivery of 17 sets of turbine blading was 30 days late. With large-scale destroyer procurement well underway by 1940, the ability of one of the Navy's major turbine subcontractors to produce new engines and spares on time was already questionable. Fortunately for the Navy, the delays at this stage were not considered to be critical. No radical action was required to deal with the delay outside of running these destroyers a few extra weeks with their defective turbines on reduced power.[61] Though this practice severely

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[60] Commandant, Navy Yard, Boston, to Bureau of Ships, "DD397-399; DD402-408; DD409-414; DD415-420 – Main Turbines – Correction of Defects in," 20 August 1940; Destroyers; Records of the Shipbuilding Division, Records of the Bureau of Ships 1794-1972, Record Group 19.8.5; National Archives at College Park, MD.

[61] Ibid.

limited the performance of the ships in question, it prevented the defective blades from damaging the rest of the engine. This was a viable option since America was not officially at war; so the ability to steam at full speed was not essential. For the time being, turbine delivery priority could continue to be given to those contracts that had been under order longest (usually those for equipment for new ships) over contracts for spares. However, it was not to be long before the lack of turbine production capacity was felt on a larger scale.

By the first half of 1941, the turbine shortage was spreading to ships under construction. Prior to naval expansion in the early 1940s, destroyers built by larger shipyards, such as the "Big Three," typically took two to three months to commission after launch, while smaller shipyards with less experience generally took three to five months.[62] It was during this interim period that engines, electronics, and armaments were installed. Beginning around May 1941, records of the Bureau of Ships indicated that turbine components for 24 destroyers being constructed by Bethlehem Steel were encountering significant delays that would substantially extend the launch to commission time of these vessels. While schedules for deliveries for four of these ships had been made, the production delays were such that the company was unable to promise individual turbine delivery for the rest of the hulls in question by a specifiable date. Instead, engines would be assigned, "according to when they are needed most," with hopes of preventing any significant delays.[63]

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[62] Though not explicitly stated, this average can be clearly seen in Friedman's work. Some anomalies exist in this data due to other design deficiencies that were discovered late; some members of the *Sims* class (DD-409—DD-420) failed their inclining tests and had to have their armament altered. Friedman, *U.S. Navy Destroyers*, 488-513.

[63] Captain C.M. Simmers, Supervisor of Shipbuilding, calling Mr. Neuhaus, Progress Branch, Bureau of Ships, "Prospective Shipment Dates for Turbines – Destroyers – 1650-Ton – Bethlehem Steel Co,"

Large private shipyards such as Bethlehem were not alone in their problems with turbine contractors in mid-1941. By June, the Bureau of Ships' records noted a further 43 destroyers expected or already delayed due to the failure of their turbine manufacturers, General Electric and Allis-Chalmers, to meet their respective yard delivery dates. The estimated delays in question for these yards—Consolidated of Orange, Texas, Gulf S.B. Company, and various US Navy yards—ranged from one to 16 months. The Bureau of Ships recognized there was the tendency of some yards, in this case Consolidated, to request components "much earlier than [actually] required."[64] While the Bureau did not believe pushing back or simply ignoring the requested turbine delivery dates would result in the on-time delivery of Consolidated's 12 destroyers, it would theoretically reduce the delay to two to six months rather than the claimed 12 to 16. The Bureau acknowledged, however, that there was a bottleneck in turbine production that had resulted from both the lack of overall capacity and low availability of machine tools for the creation of turbine blading.[65] It added that delays caused by this problem tended to be underestimated and were likely to be more severe than predicted. This information precipitated the earliest attempts by the Bureau of Ships to mitigate the turbine production problem. The Bureau reassigned to Charleston Navy Yard and Norfolk responsibility for completing turbines assigned to two of the destroyers in question. Although this

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2:30 PM, 13 May, 1941; Destroyers; Records of the Shipbuilding Division, Records of the Bureau of Ships 1794-1972, Record Group 19.8.5; National Archives at College Park, MD.

[64] G.B. Ogle, Bureau of Ships, to Chief of the Bureau of Ships, "Main Turbine Delivery & Requirement Dates for Navy Destroyers," 11 June 1941; Destroyers; Records of the Shipbuilding Division, Records of the Bureau of Ships 1794-1972, Record Group 19.8.5; National Archives at College Park, MD, and Bureau of Ships, "An Administrative History of the Bureau of Ships During World War II," p. 183, 217, vol. I-II (89a-b); RBR; NDL-Washington, DC.

[65] Ogle to Chief of the Bureau of Ships, "Main Turbine Delivery & Requirement Dates for Navy Destroyers," 1.

action would result in these particular units being about six months late, the Bureau expressed hope that this would reduce the delay in subsequent vessels. Fortunately for the Navy, it eventually would.[66]

Clearly, the Bureau of Ships was beginning to realize the severity of its emerging turbine- and gear-production problems. In November of 1941, Bureau chief Robinson issued a directive to all supervisors of shipbuilding and navy yard commandants to cease the manufacture of shore spares for all new warships and devote all possible efforts to completing primary turbines and reduction gears as swiftly as possible.[67] Shore spares, essentially duplicate steam plants typically delivered in tandem with components to be mounted on newly constructed warships, were critical in both war and peace for keeping engines well maintained and minimizing repair time. Thus, suspending production of shore spares was an extremely risky expedient considering the outbreak of war soon seemed likely if not certain. This was a clear sign of trouble for the US Navy in late 1941. Unfortunately, even this measure would not be enough to reduce mounting production delays.

Such was the climate for the Destroyer Escort Program in late 1941, a program characterized by the Bureau of Ships itself as simultaneously one of the greatest successes and greatest failures of the war.[68] Although destroyer escorts in general were roughly half the displacement of a fleet destroyer and much less well armed, they required the same kind of propulsion machinery as their larger

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[66] Ibid, 1-2.

[67] Chief of the Bureau of Ships to all Supervisors of Shipbuilding, USN and all Commandants, US Navy Yard, “Shore Spares – Suspension of Manufacture of,” 17 November 1941 as reproduced in Bureau of Ships, “An Administrative History of the Bureau of Ships During World War II,” p. 83-84, vol. I-II (89a-b); RBR; NDL-Washington, DC.

[68] Bureau of Ships, “An Administrative History of the Bureau of Ships During World War II,” p. 183-84, vol. I-II (89a-b); RBR; NDL-Washington, DC.

counterparts. As a result, this program was adversely affected not only by the turbine shortage, but also by the accompanying less-severe shortage of reduction gears required for high-steam plants to function efficiently. Naturally, this gear shortage was also a potential threat to the timely completion of full-size destroyers and was often mentioned in tandem with turbine delays in correspondence of the Bureau of Ships. However, delays with gears were typically not as severe as those associated with the turbines themselves and were usually much more easily accommodated or eliminated. Unfortunately for the Navy, shortages in both turbines and gears were acute enough that a sudden order of several hundred destroyer-type engineering plants was more than sufficient to overwhelm the capacity of the turbine manufacturers.[69] As a result, many ships of the Destroyer Escort Program were ultimately completed using propulsion methods substantially different from and significantly less efficient than traditional steam-power plants.[70] Although compromised from a design perspective, this decision allowed all ships of the initial order batch to be delivered to the Navy by the end of 1943.[71] Additionally, the compromise in design forced the Bureau to increase its investment in diesel propulsion and production, thereby significantly advancing that field but at a cost of

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[69] G.B. Ogle, Bureau of Ships, to Chief of the Bureau of Ships, "Main Turbine Delivery & Requirement Dates for Navy Destroyers," 11 June 1941; Destroyers; Records of the Shipbuilding Division, Records of the Bureau of Ships 1794-1972, Record Group 19.8.5; National Archives at College Park, MD, and W.J. Kastor, Order Service Manager, Steam Division, Westinghouse Electric & Manufacturing Co., to Inspector of Machinery, US Navy, "Propulsion Equipment – 2150 Ton Destroyers," 2 February 1942; Destroyers; Records of the Shipbuilding Division, Records of the Bureau of Ships 1794-1972, Record Group 19.8.5; National Archives at College Park, MD both mention that subcontracting could rectify the shortages, but such a move would not entirely eliminate the delay.

[70] Again, this issue is mentioned by Friedman, but is not elaborated upon outside of allusions to this issue as the reason for the initial use of diesel engines in destroyer escorts. Friedman, *U.S. Destroyers*, 143-44.

[71] Bureau of Ships, "An Administrative History of the Bureau of Ships During World War II," p. 182, vol. I-II (89a-b); RBR; NDL-Washington, DC.

fielding a fleet of escort ships with "inferior speed."[72] By the war's end, about 229 destroyer escorts had been completed with various diesel drives, while another 124 were completed with steam turbo-electric drives that did not require reduction gears. Only 87 were equipped with traditional geared-steam turbines, all of which were available only after March of 1944.[73]

A moratorium on the manufacture of shore spares and the alteration of the design of destroyer escorts was not enough to eliminate the turbine shortages faced by the US Navy. To make matters worse, the Bureau of Ships' policy of giving production priority to new shipping over maintenance was not a viable wartime solution. Such an act would virtually ensure the rapid degradation of the fleet's combat power due to battle damage and heavy wear. Thus, desperate measures were required to reverse the escalating turbine shortage and to ensure the fleet both maintained its current strength and continued to expand. Problems from this combination of circumstances would become so acute that by April 1942 a 30% reduction in the entire naval construction program was considered a definite possibility unless solutions could be found.[74]

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[72] The diesel classes were typically only able to produce enough power to run up to 19 or 21 knots, while the steam classes could make 24. Ibid, 182-84.

[73] Interestingly, Admiral Robinson was a major proponent of the DE program throughout this period despite the production problems all destroyers encountered.

[74] Ibid, 179-181, 206.

War, Shortages, and Damage Control

The outbreak of war brought home the need for a shift in turbine policy. The attack on Pearl Harbor on 7 December 1941 presented the Navy with its first large-scale emergency need for spares and posed the certain prospect of further spikes in demand in the near future. Maintenance of the Navy's existing warships took priority over new construction. Additionally, with the Navy's primary turbine suppliers falling increasingly behind in their contracts by 1942, the Navy finally moved in earnest to counteract the turbine production shortfall. In January of 1942, Robinson was promoted to vice admiral and placed in charge of the newly created Office of Procurement and Material (OP&M). Conceived by Secretary of the Navy Frank Knox, this office was charged with supervising and coordinating procurement efforts for every bureau in the Navy. OP&M served to both centralize control over the "shore establishment" of the bureaus as well as provide a means by which accurate supply statistics and projections might finally be calculated and utilized. It was under Robinson's watch that OP&M handled the rationing of critical raw materials and conflicting demands with other branches of the military.[75] Although bureaucratic infighting would continue to cause production ripples, the period of direct competition between the bureaus for raw materials was finally over.[76] Succeeding

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[75] Koistinen, *Arsenal of World War II*, 106-108.

[76] The activities of the Office of Procurement and Material were critical to the overall war effort and, accordingly, fill 18 volumes at the Navy Department Library. Much has and still can be written about this agency, but its activities are beyond the scope of this essay. For more information, see Office of Procurement and Material, "Office of Procurement and Material: Industrial Mobilization," vol. I-II (2a-b); RBR; NDL-Washington, DC, Office of Procurement and Material, "Office of Procurement and Material: Production Branch," vol. I-IV (4a-d); RBR; NDL-Washington, DC, and Office of Procurement and Material, "Office of Procurement and Material: Coordination of Material Procurement," vol. I-VII (6a-g); RBR; NDL-Washington, DC.

Robinson as chief of the Bureau of Ships were Rear Admiral Alexander Van Keuren (January 1942-November 1942) and Rear Admiral Edward L. Cochrane (November 1942-46). This centralized control by a mostly civilian, business-savvy OP&M pressed the Bureau of Ships to take a much more directed approach to counteracting the turbine shortages plaguing new destroyers. What followed was the implementation of three primary policies, some of which had already been put to limited use. All three included direct intervention by the Bureau of Ships in the affairs of both their contractors and subcontractors.[77]

Given the wartime stresses on the economy, it should come as little surprise that the Bureau of Ships' ability to counter the turbine shortages was limited to the resources it already had available to it. Therefore, the first method utilized to minimize turbine production delays was to shuffle partially completed turbines and turbine components between manufacturers as they completed contracts, freed up production space, or found themselves suddenly unable to cope with orders. This policy resulted in a few front-end delays due to the shuttling of partially completed turbines around the country and the extensive paperwork involved, and there were other impediments as well. Instances of confusion regarding exchanges are apparent in the records of the Bureau of Ships and are particularly evident in the early days of this practice (late in Robinson's tenure at the Bureau from 1941-42).[78] Even worse, in several instances entire contracts were mistakenly dropped due to simple

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[77] Ibid, 134, 182-83, 204-6.

[78] Chief of the Bureau of Ships to Inspector of Machinery, USN, "DD445 Class Destroyers – High Pressure and Cruising Turbine Spindle Forgings for – Shipment of From Allis-Chalmers Manufacturing Company to Westinghouse Company," 20 October 1942; Destroyers; Records of the Shipbuilding Division, Records of the Bureau of Ships 1794-1972, Record Group 19.8.5; National Archives at College Park, MD.

miscommunication between the various companies involved in an exchange. Fortunately, in most severe cases, the problem was quickly discovered by the Bureau.[79] In general, these efforts helped decrease some of the longer turbine-related delays.[80]

The second method employed by the Bureau of Ships was, ironically, to facilitate the contracting of both Navy and private shipyards to build engines or engine components for turbine manufacturers. Initiated on a large scale in partnership with Allis-Chalmers in 1941, this method had a major shortcoming—virtually none of the private yards possessed the tools or expertise to produce even low-pressure turbines after 1938.[81] As a result, the turbine manufacturer or the Navy had to provide the shipyards with the necessary personnel and, often, tools as well as funding for this endeavor.[82] As might be expected, the use of Navy yards for this type of subcontracting was far more commonplace than private yards. Not only were the Navy yards easier for the Bureau of Ships to supervise, but the Navy typically had better access to the resources required for turbine blading, casings, and final

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[79] Inspector of Machinery, USN, to Westinghouse Electric & Mfg. Company, "Substance of Telephone Conversation – Lt. Commander Ogle, Bureau of Ships to Captain Wille, USN, 2:50 PM, 29 May 1942; Destroyers; Records of the Shipbuilding division, Records of the Bureau of Ships 1794-1972, Record Group 19.8.5; National Archives at College Park, MD. Fortunately for the Navy, the issue was quickly resolved. Inspector of Machinery, USN, to Westinghouse Electric & Mfg. Company, "Substance of Telephone Conversation – Lt. Commander Ogle, Bureau of Ships to Captain Wille, USN, 3:20 PM, 29 May 1942; Destroyers; Records of the Shipbuilding Division, Records of the Bureau of Ships 1794-1972, Record Group 19.8.5; National Archives at College Park, MD.

[80] Ibid, and F.J. Wille, Inspector of Machinery, USN to Chief of the Bureau of Ships, "Main Propulsion Equipment – 2150 Ton Destroyers," 4 February 1942; Destroyers; Records of the Shipbuilding division, Records of the Bureau of Ships 1794-1972, Record Group 19.8.5; National Archives at College Park, MD.

[81] G.B. Ogle, Bureau of Ships, to Chief of the Bureau of Ships, "Main Turbine Delivery & Requirement Dates for Navy Destroyers," 11 June 1941; Destroyers; Records of the Shipbuilding Division, Records of the Bureau of Ships 1794-1972, Record Group 19.8.5; National Archives at College Park, MD.

[82] Commandant, United States Navy Yard, New York, to Chief of the Bureau of Ships, "Manufacture of Turbine Blading by Navy Yard, New York for Westinghouse Elec. & Mfg. Co.," 17 April 1942; Destroyers; Records of the Shipbuilding Division, Records of the Bureau of Ships 1794-1972, Record Group 19.8.5; National Archives at College Park, MD.

assemblies. As a result, the various Navy yards became a major source of turbine components (and even in numerous cases entire turbines) for the turbine manufacturers.[83] This was the most effective of the three methods employed by the Bureau of Ships.[84]

The third approach to combat the severe turbine production delays was to cultivate additional production sources from companies not yet involved in turbine production but in possession of adaptable capacity. This involved contacting various owners of machinery similar to that used by the turbine suppliers, as they had the potential to be repurposed for producing turbines. With Westinghouse falling increasingly behind in its orders in early 1942, the Bureau contacted DeLaval, a company that already produced reduction gears for the Navy, the Elliott Company, and Murray Iron Works. [85] Unfortunately, the response to this initiative was poor, as most companies lacked the capacity to take on any new types of work without significant retooling well into 1943—an insurmountable obstacle in light of the

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[83] Numerous examples of this appear in the records of the Bureau of Ships, including Inspector of Machinery, USN to Westinghouse Electric & Manufacturing Company, "Manufacturing of Turbine Blading of DD-445 Class, 2150-Ton Destroyers, High-Pressure and Cruising Turbines for the Account of the Westinghouse Electric & Manufacturing Company," 27 May 1942; Destroyers; Records of the Shipbuilding Division, Records of the Bureau of Ships 1794-1972, Record Group 19.8.5; National Archives at College Park, MD.

[84] Bureau of Ships, "An Administrative History of the Bureau of Ships During World War II," p. 182-83, vol. I-II (89a-b); RBR; NDL-Washington, DC.

[85] Captain N.L. Rawlings, USN, "Development of Additional Sources for the Manufacture of High Pressure Main Propulsion Turbines for 2100 Ton Destroyers," 16 February 1942; Destroyers; Records of the Shipbuilding Division, Records of the Bureau of Ships 1794-1972, Record Group 19.8.5; National Archives at College Park, MD. In regards to Norfolk, Inspector of Machinery, USN to Westinghouse Electric & Mfg. Co., "Norfolk Navy Yard," 8 January 1942; Destroyers; Records of the Shipbuilding Division, Records of the Bureau of Ships 1794-1972, Record Group 19.8.5; National Archives at College Park, MD, and Commandant Norfolk Navy Yard calling Chief of the Bureau of Ships, "Manufacture of Turbine Blades at Norfolk Navy Yard for Allis-Chalmers and Westinghouse Electric & Mfg. Co. on usual deposit basis," 19 January 1942; Destroyers; Records of the Shipbuilding Division, Records of the Bureau of Ships 1794-1972, Record Group 19.8.5; National Archives at College Park, MD.

nationwide shortage of precision machinery.[86] This approach by the Bureau was so underproductive that the Navy was forced to rely largely on its other patchwork methods of subcontracting its own yards and component swapping between turbine suppliers to minimize effects of delays.

As efforts to stabilize turbine production progressed, the Navy was busy fighting a war that constantly required the Bureau of Ships to provide maintenance on vessels which had either taken enough damage to require turbine or component replacements or had simply worn out their engines. War had a curious effect on equipment of all types; despite all preparations and expectations, very rarely did anything work quite as intended. Ships were no exception to this rule—they were loaded down more heavily, steamed faster, maneuvered more aggressively and, of course, took damage from bombs, torpedoes, and gunfire. All of these factors had the effect of decreasing the range and expected lifespan of a warship's engines, and thus particular care and attention had to be given to keep a warship combat ready. Maintenance was indispensible to the wartime US Navy and accordingly overrode new construction in priority throughout the Second World War, despite the fact that new vessels continued to be commissioned without their matching shore spares after November 1941. To combat this shortage, three methods of acquiring spares on demand were put to use by the Navy—seizing engines completed for new vessels, issuing emergency priority contracts, and finally issuing pre-emptive contracts that could be escalated should circumstances demand it.

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[86] Elliott Company to the Bureau of Ships, "Development of Additional Sources for the Manufacture of High Pressure Main Propulsion Turbines for 2100 Ton Class Destroyers," 3 March 1942; Destroyers; Records of the Shipbuilding Division, Records of the Bureau of Ships 1794-1972, Record Group 19.8.5; National Archives at College Park, MD.

At the onset of the war, spares could be obtained from engines already completed for new or existing warships. Though obviously quick and effective options as far as repairs were concerned, there were two problems with this course of action. First, if the Navy chose to seize an engine from a ship nearing completion, then that vessel was set back considerably in the contract queue. It would be useless to the Navy until a new contract could be issued and filled, setting back ships already delayed by the wait for their turbines by an even larger margin. The second issue was that despite the relative standardization of engine specifications prior to the Second World War, turbines were not always interchangeable between different ship types and classes. As a result, the options for this repair method were at times quite limited. Fortunately for the Navy, the fleet opened the war in the Pacific with a large number of destroyers still in possession of their spares. It was primarily these units that were seized.[87]

As the war in the Pacific progressed, major battles and changing priorities caused contracts for spare turbine components to be regularly displaced from the order queues of the turbine manufacturers. This is evidenced by the manner in which Midway and the battles of the first half of 1942 pushed carrier turbines ahead of destroyers in Westinghouse's production orders.[88] By and large, however, by the middle stages of the war, the Navy was issuing contracts for spares primarily on an

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[87] Engines were not installed in destroyers in particular until after their launch as one of the final stages of production. Thus, seizure of an engine from a nearly completed vessel was not a well-liked practice, though it did occur for all types of vessels, such as shown in Commandant, Norfolk Navy Yard, calling the Chief of the Bureau of Ships, "Consolidated Steel Corporation – Spare Parts for Type DA Engines," 22 June 1943; Destroyers; Records of the Shipbuilding Division, Records of the Bureau of Ships 1794-1972, Record Group 19.8.5; National Archives at College Park, MD.

[88] Inspector of Machinery, USN, to Westinghouse Electric & Mfg. Company, "Substance of Telephone Conversation – Lt. Commander Ogle, Bureau of Ships to Captain Wille, USN, 2:50 PM, 29 May 1942; Destroyers; Records of the Shipbuilding Division, Records of the Bureau of Ships 1794-1972, Record Group 19.8.5; National Archives at College Park, MD.

emergency basis only, immediately displacing all other orders for priority-repair orders. This policy was no less disruptive than seizing engines from nearly completed vessels. It, too, was quickly dropped in favor of the third method of ensuring the readiness of spare parts, which rose to prominence as the war progressed.

This final method for providing spare turbines and components for the US Navy's vessels, particularly its destroyers, was to issue contracts for components whenever possible far in advance of the expectation that they would be needed. The catch was these contracts were issued with the understanding that they could be escalated in size or priority should circumstances demand it. Unlike the issuance of emergency contracts on the spot which displaced other orders significantly and worsened the overall turbine situation, this method ensured that the effects of sudden contract changes were minimal. By latter half of the war, raw materials were significantly less of a problem for turbine manufacturers than manpower and capacity thanks to efforts of the Navy. Issue of a contract in this manner therefore ensured that the contractor immediately began allocating the materials necessary to fulfill the contract conditions. Everything would be on hand were it to be abruptly needed, thereby minimizing the time required to retool and make other changes necessary to shift production. Instances of this method of contracting for spare parts became quite common.[89]

Despite these improvements however, evidence suggests that turbine production capacity was still not at an acceptable level for the Bureau of Ships in 1944. The Navy's displeasure is demonstrated within contract negotiations between it

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[89] Nearly every case in the records of the Bureau of Ships contains unprovoked direct assurances by the contractor that the contract may be moved forward immediately should battle damage require it.

and primary turbine suppliers for the production of replacement turbines and reduction gears for destroyers damaged in combat. These negotiations, conducted by the Bureau's Contract Negotiation Board, produced official transcripts covering precise content, nature, and proposed delivery dates of each job, as well as the Navy's understanding and position for each. Common are statements such as, "We would like to have that equipment much earlier than March-April 1945, but we understand that it cannot be completed earlier without disturbing existing schedules."[90] The Bureau of Ships appears to have accepted that private turbine production would continue to be a bottleneck in warship construction despite the vast production increases elsewhere and its relatively successful attempts to counteract delays.

The Navy never hit upon a perfect solution to the turbine production shortfall, but the Bureau of Ships' patchwork approach of subcontracting and disbursing available components to locations where they were most needed began to draw turbine delivery dates ever closer to their yard requirements as 1943 drew to a close (see Appendix). Production orders after the middle of 1943 avoided significant delays as increasing machine tool availability finally brought up precision production capacity, while patchwork measures enacted by the Bureau to meet deadlines became standard practice. Although production concerns persisted throughout the war, wide-scale disaster due to the new technology and its associated production methods had been averted.

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[90] Bureau of Ships, "Negotiations with Westinghouse Electric & Manufacturing Company for One Set of Main Propulsion Turbines and Reduction Gears for the DD231 Class of Destroyer," 7 January 1944; p. 2; Destroyers; Records of the Shipbuilding Division, Records of the Bureau of Ships 1794-1972, Record Group 19.8.5; National Archives at College Park, MD.

Conclusion

Although it may not seem apparent to a casual observer, a shortage of destroyers was a critical problem for the US Navy. While smaller than carriers, cruisers, and battleships, destroyers were generally the most numerous class of warship in any mid-20th century navy. They were required as escorts or as the primary force for virtually every naval mission imaginable. The US Navy was no exception; almost nothing moved in the Navy without the support of destroyers.[91] Fewer destroyers meant fewer or delayed operations, heavier wear on those already in service from extensive use, and increased impact of ships lost in combat. In short, the US Navy needed as many destroyers as it could get as fast as the yards could build them.

Fortunately for the Navy, the proposed large-scale cuts in naval construction due to problematic shortages of machine tools, steel, and turbines proved to be unnecessary. Although turbine production for destroyers in particular was a serious problem right up to 1944, the Navy managed to acquire enough equipment to fight effectively and win the war against Japan. What was compromised, however, was the proper and timely maintenance and repair of ships prior to the war, as well as on-time delivery of new ships once hostilities had begun. Generally, the shortage of spare turbines and turbine components and significant delays imposed on fleet destroyer production as a whole conspired to place a hard limit on destroyer availability through 1944 and left the Bureau of Ships scrambling.

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[91] Friedman discusses this issue in brief when considering the Navy's ideal role for the destroyer. Friedman, *U.S. Destroyers*, 93.

It would be incorrect to assert that no one anticipated problems associated with the adoption of high-pressure and -temperature steam at the height of its controversy in 1938. Admiral Bowen himself stated in his autobiography the potential for production difficulties in precision industries in a time of war. But clearly the complexity of the turbine bottleneck came as a nasty surprise to the Navy.[92] No one at the Bureau of Ships, as late as 1940, appears to have appreciated the obstacles presented by the production of a high-steam plant as opposed to its low-steam counterpart, particularly during a time of high demand. The Navy paid a stiff price for this oversight.

"According to Vice Admiral Earle W. Mills, later Chief of the Bureau of Ships, our operations in the Pacific would not have been possible without [high steam]."[93]

After careful examination, Admiral Bowen's assessment of high steam should be viewed in a different light. While high steam certainly gave the US Navy superior range against its Japanese counterpart, it simultaneously proved to be a serious impediment to the buildup of the Navy's assets. Without the Office of Procurement and Materials' administrative successes in handling steel, valve, and machine-tool shortages and the Bureau of Ships' creative management of turbine contracts, this advanced technology may have crippled the construction and maintenance of destroyers. It was effective administrative improvisation on the part of the Navy that allowed the United States to take advantage of this technology at all. The complete story of high steam is something far more unique than a tale of innovation. High

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[92] Bowen, however, thought that the switch to sub-contractors would largely solve the issue. Bowen, *Ships, Machinery, and Mossbacks*, 124.
[93] Ibid, 111.

steam was an example of traditional "American ingenuity," just not in the manner Admiral Bowen's memoirs led us to believe. Of the many factors that led to the allied victory in World War II, we must count the ability to solve major supply problems as significant.

Although high steam represented a substantial technological advantage for the United States Navy, it was in all likelihood not critical to the US victory in the Pacific Theater. In industrial capacity alone, the United States dwarfed Japan, and in any protracted-war scenario, the Japanese could not hope to match their opponent. Considering many of the production problems stemming from high steam had roots in the inexperience of the Navy in dealing with the new technology, one cannot help but wonder what impact earlier or later adoption would have had on the course of the war. The only insight we have into the strategy of a war without high steam can be drawn from US war plans that predated widespread employment of this technology by the Navy.[94] What can be stated for certain is that fewer destroyers were available to the United States at all stages of the Second World War than might have been available had the Navy fully grasped the implications of high steam or even taken a pass on it. That the Navy was able to maintain and, eventually, expand production of high-steam vessels at all during the war was a remarkable accomplishment and by no means inevitable.

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[94] For how such a conflict might have turned out, our best starting point would likely be Edward S. Miller, *War Plan Orange: The US Strategy to Defeat Japan, 1897-1945* (Annapolis, MD: Naval Institute Press, 2007).

Appendix

Delayed Destroyers Reported to the Bureau of Ships

The following tables show the projected delays in the delivery of turbines for destroyers as they were reported to the Bureau of Ships. As turbines had to be delivered by the time a ship was launched in order to ensure its commissioning on schedule, the effectiveness of the Bureau of Ships' efforts to reduce the delays can be seen by checking how much time passed between a delayed ship's launch and its commissioning in the Navy. This period, typically two to three months for major yards and three to five for minor ones, was the time during which engines, electronics, and weapons were installed.

Table A-1: Projected Delays in the Delivery of Allis-Chalmers (A-C) and General Electric (GE) Turbines for Destroyers as of June 1941 and the Effectiveness of the Bureau of Ships' Efforts to Counter Them.

Hull No.	Yard	Turbine Contractor	Yard's Projected Delay in Months with (Navy Est.)	Launch	Commissioning	Approx. Difference (Launch to Commissioning) in Months
472	Navy	A-C	4-5.5	2/20/42	12/15/42	10
473	Navy	A-C	4-5.5	4/16/42	2/9/43	10
474	Navy	A-C	4-5.5	4/16/42	2/9/43	10
475	Navy	A-C	4-5.5	6/3/42	4/13/43	10.5
476	Navy	A-C	4-5.5	2/20/42	11/17/42	9
477	Navy	A-C	4-5.5	5/2/42	9/15/42	4.5
478	Navy	A-C	4-5.5	5/12/42	10/15/42	5
479	Navy	A-C	4-5.5	6/24/42	2/1/43	8
480	Navy	A-C	4-5.5	10/29/42	4/10/43	5.5

481	Navy	A-C	4-5.5	10/29/42	3/4/44	16
550	Gulf S.B.	GE	2-6	5/31/42	6/23/43	13
551	Gulf S.B.	GE	2-6	7/4/43	9/18/43	2.5
552	Gulf S.B.	GE	2-6	10/4/42	12/11/43	14
553	Gulf S.B.	GE	2-6	11/15/42	2/2/44	14.5
569	Consolidated	GE	12-16(2-6)	3/2/42	10/27/42	8
570	Consolidated	GE	12-16(2-6)	3/16/42	11/24/42	8
571	Consolidated	GE	12-16(2-6)	4/1/42	12/8/42	8
572	Consolidated	GE	12-16(2-6)	4/15/42	12/30/42	8.5
573	Consolidated	GE	12-16(2-6)	5/7/42	1/25/43	8.5
574	Consolidated	GE	12-16(2-6)	5/7/42	2/9/43	9
575	Consolidated	GE	12-16(2-6)	8/2/42	3/31/43	8
576	Consolidated	GE	12-16(2-6)	8/16/42	4/20/43	8
577	Consolidated	GE	12-16(2-6)	8/31/42	5/19/43	8.5
578	Consolidated	GE	12-16(2-6)	9/13/42	6/16/43	9
579	Consolidated	GE	12-16(2-6)	9/27/42	7/6/43	10
580	Consolidated	GE	12-16(2-6)	10/11/42	7/31/43	9.5
581	Navy	A-C	1.5-4	6/3/42	5/18/43	11.5
582	Navy	A-C	1.5-4	7/18/42	6/8/43	11.5
583	Navy	A-C	1.5-4	7/18/42	7/6/43	11.5
584	Navy	A-C	1.5-4	3/19/43	8/19/43	5
585	Navy	A-C	1.5-4	3/19/43	9/16/43	6
586	Navy	A-C	1.5-4	7/4/43	11/10/43	3
587	Navy	A-C	1.5-4	6/24/42	3/4/43	8.5
588	Navy	A-C	1.5-4	8/8/42	4/3/43	8
589	Navy	A-C	1.5-4	8/8/42	5/15/43	9
590	Navy	A-C	1.5-4	4/7/43	10/25/43	6.5
591	Navy	A-C	1.5-4	4/7/43	11/4/43	7

592	Navy	A-C	1.5-4	1/10/43	4/3/44	15
593	Navy	A-C	1.5-4	1/10/43	5/4/44	16
594	Navy	A-C	1.5-4	9/25/44	11/4/44	1.5
595	Navy	A-C	1.5-4	9/25/44	11/18/44	2
596	Navy	A-C	1.5-4	9/25/44	2/8/45	4.5
597	Navy	A-C	1.5-4	9/25/44	2/22/45	5

Sources**: Bureau of Ships Memorandum, "Main Turbine Delivery & Requirement Dates for Navy Destroyers", 11 June 1941 (RG 19) and Friedman, *U.S. Navy Destroyers*, 488-507.**

Table A-2: Projected Delays in the Delivery of Westinghouse Turbines for Destroyers as of February 1942, and the Effectiveness of the Bureau of Ships' Efforts to Counter Them.

Hull No.	Yard	Yard's Turbine Req. Date	Westinghouse's Projected Turbine Delivery	Launch	Commissioning	Approx. Difference (Launch to Commissioning) in Months
449	Bath	--	Feb 1942	2/19/42	6/4/42	3.5
450	Bath	1/23/42	Feb 1942	3/14/42	6/26/42	3.5
451	Bath	3/5/42	Mar 1942	4/11/42	7/20/42	3
467	Bath	3/20/42	Apr 1942	5/17/42	8/7/42	2.5
468	Bath	4/5/42	May 1942	6/7/42	8/28/42	2.5
469	Bath	4/16/42	June 1942	6/28/42	9/21/42	3
470	Bethlehem	11/1/42	July 1943	7/7/42	11/14/42	4
471	Bethlehem	12/1/42	July 1943	8/24/42	12/23/42	4
507	Bath	5/7/42	Aug 1942	8/16/42	10/9/42	2
508	Bath	6/10/42	Nov 1942	8/20/42	10/30/42	2.5
509	Bath	7/10/42	Dec 1942	8/30/42	11/20/42	2.5
510	Bath	8/10/42	Dec 1942	8/20/42	12/4/42	3.5
511	Bath	9/9/42	Feb 1943	10/11/42	12/22/42	2.5
512	Bath	10/10/42	Apr 1943	10/27/42	1/8/43	2.5
513	Bath	11/5/42	May 1943	11/22/42	1/27/43	2

514	Bath	10/30/42	June 1943	12/6/42	2/10/43	2
515	Bath	11/30/42	July 1943	12/20/42	2/26/43	2
516	Bath	12/27/42	Aug 1943	1/10/43	3/16/43	2
517	Bath	1/30/43	Sept 1943	1/31/43	4/3/43	2
518	Bethlehem	1/15/43	Aug 1943	9/24/42	2/3/43	4.5
519	Bethlehem	2/15/43	Sept 1943	10/24/42	3/10/43	4.5
520	Bethlehem	4/1/43	Oct 1943	11/24/42	4/12/43	4.5
521	Bethlehem	7/1/43	Jan 1944	2/4/43	5/22/43	3.5
522	Bethlehem	8/1/43	Feb 1944	3/6/43	6/21/43	3.5
526	Bethlehem	10/1/42	June 1943	8/18/42	2/5/43	5.5
527	Bethlehem	11/1/42	July 1943	8/17/42	3/12/43	7
528	Bethlehem	1/1/43	Aug 1943	10/10/42	5/10/43	7
529	Bethlehem	3/1/43	Sept 1943	10/27/42	5/10/43	6.5
530	Bethlehem	4/1/43	Oct 1943	10/22/42	5/28/43	7
531	Bethlehem	5/1/43	Nov 1943	11/20/42	6/18/43	7
532	Bethlehem	6/1/43	Dec 1943	12/5/42	7/6/43	7
533	Bethlehem	7/1/43	Dec 1943	12/19/42	7/29/43	7.5
534	Bethlehem	8/1/43	Feb 1944	1/10/43	8/19/43	7
535	Bethlehem	9/1/43	Feb 1944	2/15/43	8/31/43	6.5
536	Bethlehem	10/1/43	Mar 1944	3/21/43	9/20/43	6
537	Bethlehem	11/1/43	Apr 1944	4/4/43	9/30/43	5.5
538	Bethlehem	12/1/43	Apr 1944	4/28/43	10/21/43	6
539	Bethlehem	1/1/44	May 1944	5/28/43	11/25/43	6
540	Bethlehem	2/1/44	May 1944	7/11/43	12/1/43	4.5
541	Bethlehem	4/1/44	June 1944	7/25/43	12/30/43	5
567	Sea-Tac	4/1/44	--	12/31/43	4/29/44	4
568	Sea-Tac	5/1/44	--	1/29/44	4/24/44	3
629	Bath	3/1/43	Sept 1943	2/17/43	4/23/43	2

630	Bath	4/1/43	Oct 1943	3/7/43	4/23/43	1.5
631	Bath	4/30/43	Nov 1943	3/21/43	5/28/43	2
642	Bath	5/30/43	Nov 1943	4/4/43	6/15/43	2.5
643	Bath	6/30/43	Dec 1943	4/24/43	6/29/43	2
644	Bath	7/30/43	Jan 1944	5/8/43	7/16/43	2
657	Bethlehem	9/15/43	Mar 1944	4/3/43	7/23/43	3.5
658	Bethlehem	10/15/43	Apr 1944	5/3/43	8/23/43	3.5

***Sources*: Correspondence, W.J. Kastor, Westinghouse Electric & Manufacturing Co. to Inspector of Machinery, USN, "Propulsion Equipment – 2150 Ton Destroyers", 2 February 1942. (RG 19), and Friedman, *U.S. Navy Destroyers*, 488-507.**

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