No More Heads or Tails

The Adoption of Welding in U.S. Navy Submarines

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As we sit here at the dawn of the 3rd decade of the 21st century with all of our advanced technology and science, it is hard to imagine that the common and well understood process of welding in shipbuilding was once an unknown, or at best, a poorly understood and mistrusted science. Since the beginning of steel shipbuilding in the middle of the 19th century the only practical method of joining steel structures together was riveting, the forcing of a mushroom-shaped steel shank through a hole in two steel pieces, then flattening the opposite end so that the shank stayed in the hole. The idea of fusing two steel pieces together under a bead of intense focused heat seemed futuristic to say the least. Riveting, on the other hand, was a well-known process, fully trusted, and by the 1920s had been developed into a high art.

In any ship a solidly built frame and a water-tight hull is of primary importance. Riveting worked well in this regard, but it had disadvantages. As a ship moves through a seaway it will twist and bend both laterally and longitudinally and this movement tends to loosen the riveted seam. Constant caulking is needed to keep the seam between hull plates watertight. This was a particular concern in fuel tanks. After a period of time the working of the hull in a seaway loosened the riveted joints to the point that the fuel tanks would leak, sometimes badly. This has an immediate and obvious impact on the ship's range and combat capability. It was not uncommon see a miles-long petroleum slick trailing behind a ship underway.[1]

In a deep-diving pressure resisting submarine these concerns become paramount. Every time a submarine dives water pressure compresses every part of the boat's hull, evenly and relentlessly, distorting it from its designed shape. When the boat surfaces, that compression is released and the metal hull returns to its normal shape. This expansion and contraction cycle heavily stresses the steel of the hull and is analogous to repeatedly bending a paperclip. Bend that paperclip enough and it will eventually break. When combined with the normal seaway bending and twisting action, a submarine becomes particularly susceptible to metal fatigue, especially if it is riveted. Not only did riveted submarines leak fuel, but any gap in the pressure hull, no matter how small or insignificant, could allow high pressure seawater into the interior of the boat, often with disasterous results. The riveted submarine USS *S-28* (SS-133) was lost on a training mission off Hawaii in 1944. A leading theory in her loss was that 21-year-old rivets in the forward torpedo room area snapped under submerged pressure, and because the hull was stressed by the hydrodynamic forces of making a high speed turn. The hull catastrophically failed and the boat was lost with all hands.[2]

In the traditional shipbuilding riveting process, the typical solid steel rivet is a cylindrical shaft with a rounded "head" on one end. The opposite end is called the "tail" (Fig. 1). The rivet is heated in a furnace to white hot in order to make it malleable. It is then carefully inserted using tongs into a hole in two overlapping steel plates. One worker holds it in place using a heavy tool called a rivet set or dolly, then another hammers on the tail using a peening hammer until it is flattened or rounded similar to the head. As the rivet cools it also contracts, further tightening the joint. An improvement to the process was the use of a pneumatic peening hammer (shown here) which speeded the riveting cycle and provided a more uniform tail shape. Even with this improvement riveting was a comparatively slow process and was manpower-intensive. Shown in this photo (Fig. 2) are three of the four men in a typical riveting team. On the right is the *catcher,* who catches the rivet in a bucket after it was thrown to him by the *cook* (not shown). Next to the catcher is the *holder-on* with the rivet set, then the *riveter* himself. The process was also fairly dangerous. Burns, vibration-induced muscle and limb trauma, and loss of hearing were a constant concern.[3]

Fig 1. An example of a steel rivet (Courtesy Wikipedia)

Fig.2. Shipyard riveters at Hog island, PA 1919 (Courtesy James D. Andrew Jr. via americanhistory.si.edu)

In welding the frames are fused to the hull plates and the hull plates are fused together under the intense heat of an oxygen/gas flame or an electric arc (Fig. 3). There is no traditional seam to leak. Essentially the ship's hull and framework are one solid and homogeneous piece of steel. The advantages to welding are obvious to the modern reader, but to the Navy's engineers and shipfitters in the 1930s these advantages were far less understood, and the new science was mistrusted. The change came only with a great reluctance to give up the tried-and-true process of riveting.

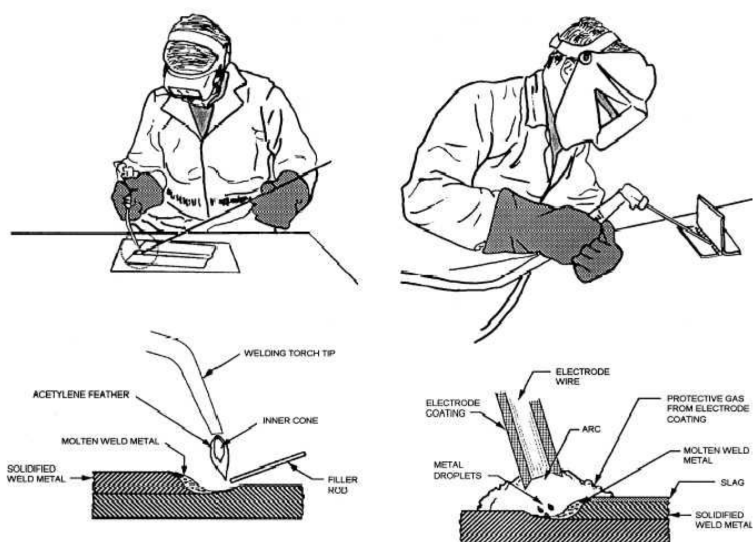

Fig. 3. Oxyacetylene and electric arc welding

Welding, in one form or another, has existed for hundreds of years, but technological limitations prevented it from being used on a widespread basis. Forge welding, where heated pieces of metal are continuously hammered until they fused together, has been around since the Middle Ages. Experiments continued until the end of the 19th century, and around 1900 the process of oxyacetylene torch welding came to the forefront of the efforts. This method used the combustion of oxygen and acetylene gas to produce a flame hot enough to melt metals. When run along a seam, this flame, along with a filler material, fused the two pieces together with no gaps. The later development of arc welding used a high temperature electric arc and a disposable electrode to fuse the pieces. Both processes greatly speeded ship construction, but arc welding came to be preferred because the equipment costs less, and it could be performed in a greater range of weather conditions -- wind and rain having minimal effect on the quality of the weld. It did, however, require more training and a greater skill set than the oxyacetylene process.[4]

If welding was a known process for several decades and its advantages over riveting in submarine construction were obvious, then why did it take the USN until 1936 to fully incorporate this paradigm changing process in submarine construction?

The traditional story starts with the government-owned Portsmouth Navy Yard[5] of Kittery, ME, the Navy's submarine design, development, and construction center. Stodgy and tradition bound, they resisted the change, convinced that riveting was the stronger and better method. In

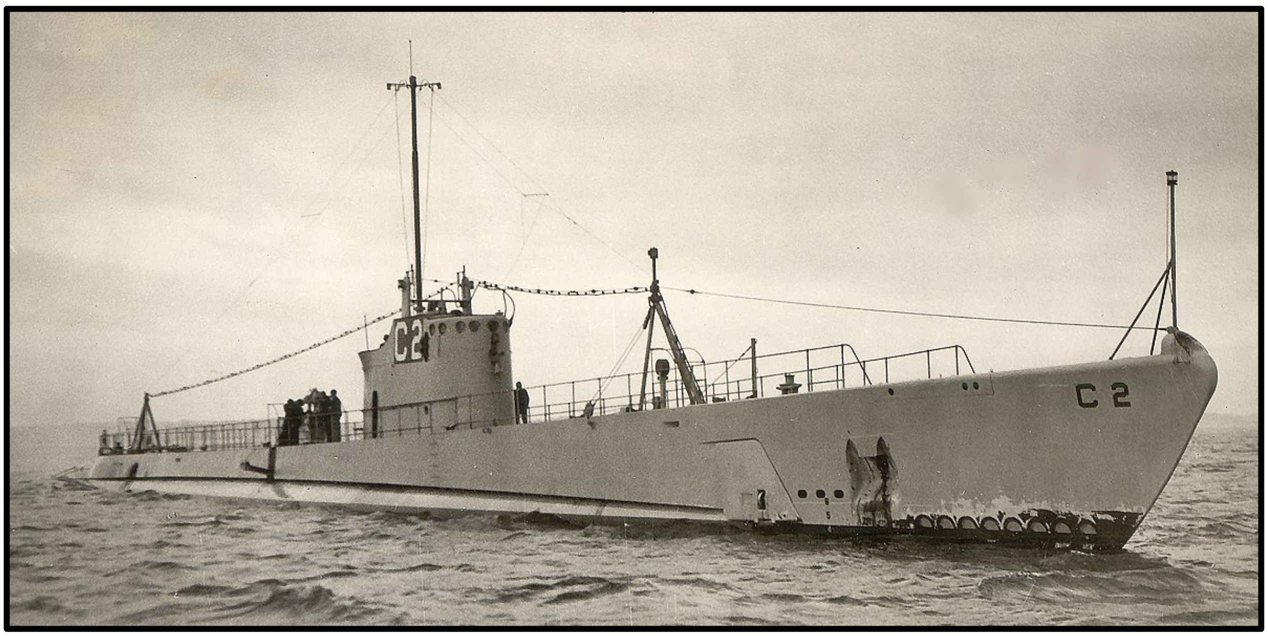

Fig. 4. USS Cuttlefish (SS-171), 27 March 1934 on builder's trials. She is traditionally thought of as the first boat on which welding was used. (Ric Hedman via PigBoats.COM)

1931 the Navy awarded the construction contracts for the last two of the so-called V-class submarines[6]. Construction of the USS *Cachalot* (SS-170) was given to Portsmouth, and USS *Cuttlefish* (SS-171) was awarded to the civilian Electric Boat Company of Groton, CT. (Fig. 4). The company's progressively-minded managers and engineers were very eager to showcase what the company could do for the Navy; their pride was smarting from a six-year hiatus in which the Navy had not awarded them any contracts. They managed to convince the Navy's Bureau of Construction & Repair (C&R), Portsmouth's parent command, to allow their company to incorporate the new and little understood process of welding in some portions of this boat while Portsmouth stuck to an all-riveting method for their work on the C*achalot*. The success of EB's pioneering use of welding became obvious during sea trials when the *Cuttlefish* proved to be a solid and leak-resistant boat, especially in the fuel tanks. Still bound to tradition, the Portsmouth engineers were not convinced of the efficacy of welding, and they steadfastly stuck to riveting for the five government-built boats of the follow-on Porpoise/Shark class despite the fact that EB used welding on their boats. It took until 1936 and the introduction of the Salmon/Sargo class for the government yards to jump into the modern era and make the wholesale switch to welding. Thus, Electric Boat has always been given the credit for introducing welding to the submarine service on the *Cuttlefish*.[7]/[8]/[9]

While there are elements of truth to this traditional story, the actual tale of this important shift in submarine construction methods has been obscured and distorted over time. Previous historians and authors missed important clues in the historical record, or simply did not fully understand the complex chain of events that led to the adoption of welding. Electric Boat, seeking to reestablish their corporate reputation, relentlessly promoted their role in this saga while the government shipyards did not, distorting the historical record. Historians like the eminent John D. Alden and Norman Friedman were faced with a mountain of data and photographs to sort through, and thus were forced by expediency to choose which to include. They couldn't look at or include everything and in this case, it was the information that remained on a shelf that proved important. They can't be overly faulted for these omissions in their narratives. This author does not possess any greater skill than those who have come before him, but by sheer providence came across drawings and photos that enabled the rewriting of this story. Recent discovery of these documents, long buried in the National Archives, have shown that the story told above is considerably different than previously believed.

In 2017 fellow submarine historian Ric Hedman and I were reviewing a batch of drawings that he had purchased. Hedman is the founder and editor of the submarine history website PigBoats.COM, and I have collaborated with him on the site for nearly 20 years. The drawings were reproductions of construction blueprints developed by the Portsmouth Navy Yard for the big minelaying submarine USS *Argonaut* (SF-7), built by the yard from 1925-1928, and predating the construction of the *Cuttlefish* by over five years (Fig. 5). One drawing caught our eye because of a reference to welding (Fig 6.). This drawing shows a cross section of the boat's forward

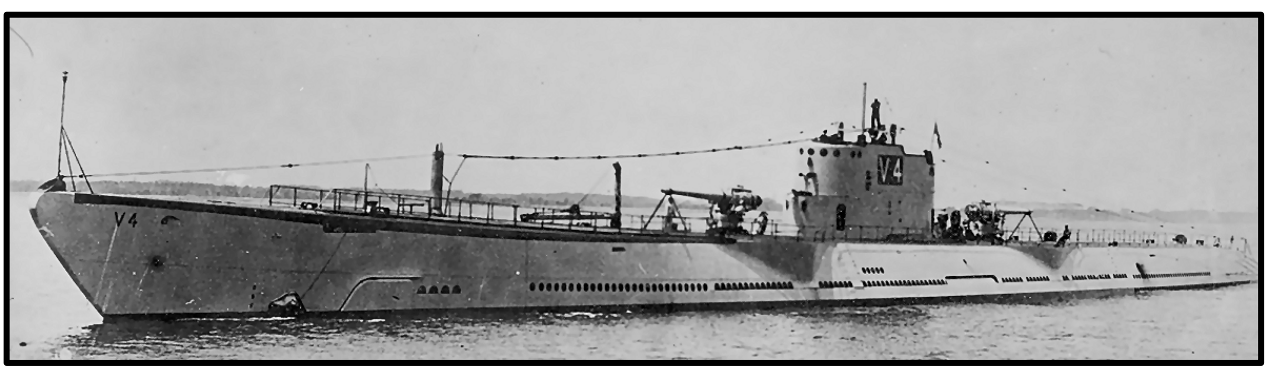

Figure 5. USS V-4 (SF-7) during sea trials off Provincetown, MA, June, 1928. This boat, not Cuttlefish, was the first submarine in the USN to incorporate welding in its construction. Three years after this photo was taken, she was renamed Argonaut. (USN photo via Pigboats.COM.)

superstructure at frame 13. In the center of the drawing is a reference to welding a clip to a support bracket. Curious, we reviewed the remainder of the drawings and found several more references

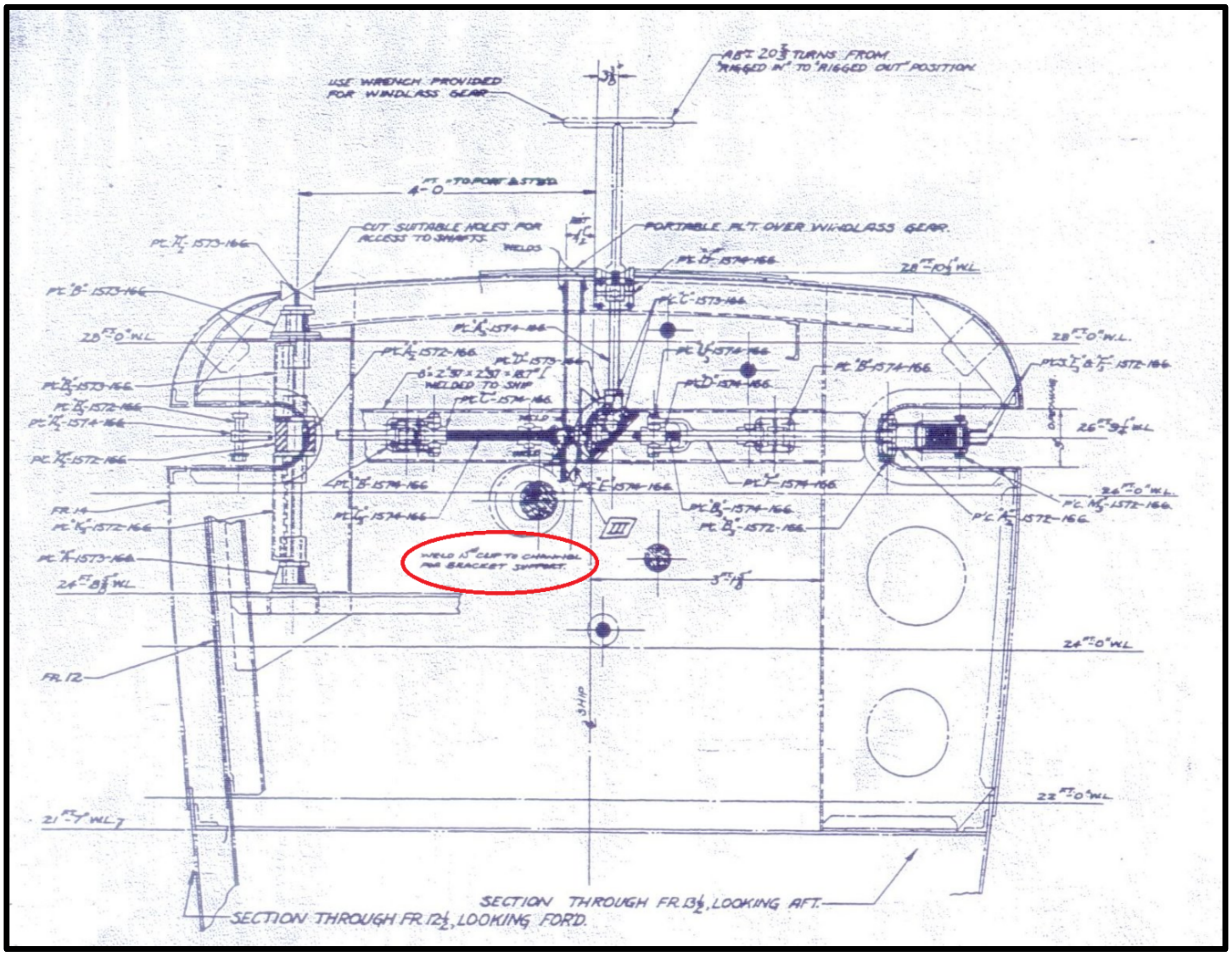

Figure 6. Construction drawing of the forward superstructure of Argonaut. Circled area contains reference to welding. (Drawing courtesy of Ric Hedman at PigBoats.com)

to welding, all in non-critical areas like the superstructure and support framing. Given the narrative above, we were both fully aware that the *Argonaut* had long been accepted as being of fully riveted construction; it was reported as such by Alden in his book.[10] At the time, however, busy with the task of developing the captions, the significance of the discovery did not register with us.

A year later, Hedman received a set of photos from researcher Roger Torgerson that he had discovered at the National Archives. The photos that Torgerson uncovered were from the builder's photo album for the USS *Dolphin* (SS-169), a boat built at the Portsmouth Navy Yard between 1930 and 1932 and the immediate predecessor to the *Cachalot* and *Cuttlefish*. High quality photos of this submarine are rare so Hedman and I eagerly poured over this new collection, arranging them into good order and studying them for additional features that would be of interest to our readers. One photo in particular caught Hedman's attention, the photo below of the *Dolphin* in drydock at Portsmouth on 30 September 1932 for her post-shakedown maintenance availability period.

Figure 7. View of Dolphin's keel area, showing welded flood port flange and welded bilge keel. (NARA photo courtesy Roger Torgerson and PigBoats.COM)

Fig. 7 shows a view of *Dolphin's* port side near the keel, aft of the bow and looking aft and to starboard. The square opening in the outer hull is a flood port for a main ballast tank. The triangular object attached to the hull is the boat's port side bilge keel, a stability device that is intended to reduce wave-induced rolling while on the surface. Along the edges around the flange for the flood port and on the edges of the bilge keel where it attaches to the hull, a welding bead can clearly be seen. Remarkably, the outer hull plating seam directly above the bilge keel displays the distinct round heads of rivets. The *Dolphin,* built at Portsmouth, preceded the construction of the *Cuttlefish* at Electric Boat by a full year. The undeniable presence of welding on a submarine that has long been listed as being of fully-riveted construction surprised both of us. This revelation prompted a review of all the photographs that are available to us, and that led to further research.

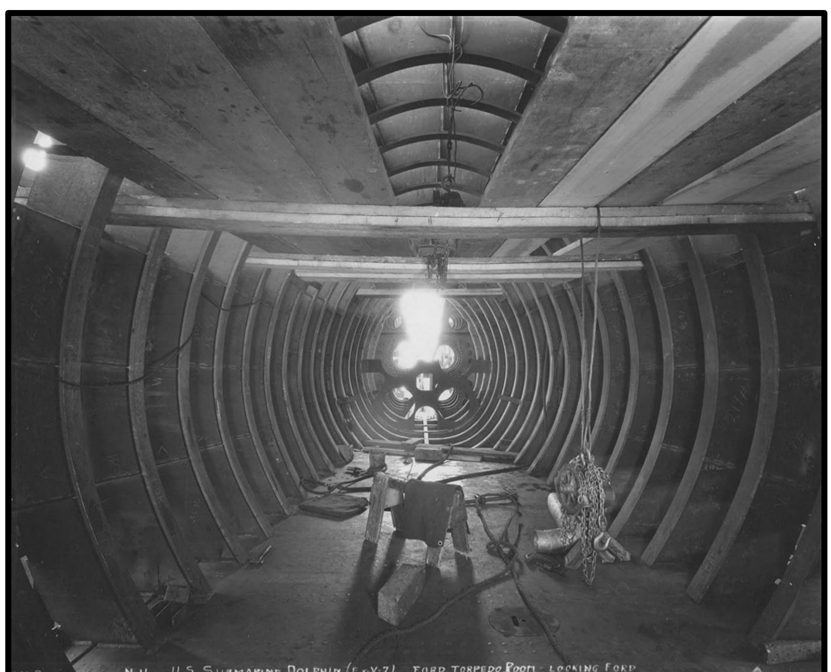
Figure 8. Dolphin forward torpedo room while under construction at Portsmouth, 1931. (NARA College Park photo courtesy of Tracey White and Navsource.com)

Recently, Hedman came across another photograph that gave us further confirmation (Fig. 8). This photo shows the *Dolphin's* forward torpedo room while she was under construction at Portsmouth in 1931. This is a very early stage of the construction process with just the basic framework and tankage completed. The four torpedo tubes that make up the forward portion of her main armament have yet to be installed. If you look closely in

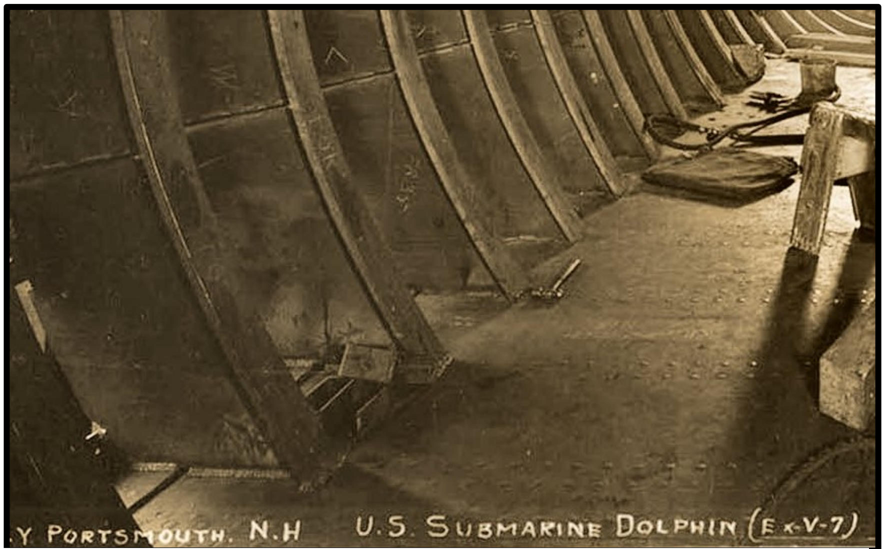

Figure 9. Closeup of Dolphin's forward torpedo room, clearly showing both welding and riveting. (NARA College Park photo courtesy Tracey White and Navsource.org

the lower left-hand corner, you will see that on the seams where the circular frames meet the deck, actually the top of the forward trim tank, the Portsmouth shipfitters have used welding (Fig. 9). You can also see a line of rivets running port to starboard across the top of the deck. It is now quite obvious that there was a mix of joinery styles used in the construction of this boat.

The fact that the Portsmouth Navy Yard was using welding in the construction of its submarines *several years before Electric Boat* "pioneered" its use on *Cuttlefish* runs counter to the conventional wisdom that it was Electric Boat that was the leader of this technology. So, how did this misalignment of the historical record come to be?

The exact origin is very hard to pin down. Some of it may be blamed on incomplete research by previous historians, but the bulk of the issue is related to the nature of what the authors and historians were writing about. In the 1970s solid technical information on U.S. submarines was difficult to obtain. Some of the WWII fleet submarines of the Gato, Balao, and Tench classes were still serving with the Navy, the last being decommissioned on 01 July 1975.[11] Because of this, much of the technical information was carefully stored away with some of it being classified until the later part of the decade. Many of the publications that came out during these years were derivative in nature and made use of already published material that had been carefully reviewed for security purposes and cleared by the Department of the Navy. Two references in the library of this author are actually completely wrong on the subject, missing the dates of the shift to welding by several years and several boat classes.[12]/[13] These relatively minor errors do not heavily detract from otherwise informative works, but may have contributed to the confusion.

The first author to take a deep dive into the historical records and technical data was the highly regarded Commander John D. Alden, USN (Ret.) in his 1979 seminal work *The Fleet Submarine in the U.S. Navy: A Design and Construction History.* Long considered the gold standard of USN submarine technical references, this book has served as the go-to source for many historians and researchers. Alden worked from data that he compiled from unpublished sources in several different archives, from personal interviews with key players and oral history collections, from personal collections of information accumulated during his career, and from other previously published sources. The breadth and depth of information that he worked from is vast. It is not hard to believe that he occasionally ran across contradictory information, or was forced by the sheer volume of material to omit some information that may have been helpful. With an emphasis on accuracy,[14] he did an incredible job of arranging, interpreting, and editing the information and in the end his text was in a very readable form. However, since this book has been heavily referenced by other authors, certain expediency forced omissions in Alden's text have contributed to this saga.

Despite the conventional wisdom, the use of welding on submarines actually originated with the U.S. Navy. In 1918 James W. Owens, an industrious 34-year-old British emigre from the Caribbean drew the attention of Commander H.G. Knox, shop superintendent of the Norfolk Navy Yard in Virginia. Owens' reputation as an expert in the relatively new field of welding caused Knox and the commandant of the yard to recommend to the Secretary of the Navy to get a brand-new civil service position created specifically for Owens, and he was hired as the Navy's first welding expert. Owens and Knox set up the Navy's first welding shop, they stood up an extensive research and development program, and they trained new welders. Owens' impromptu emergency repairs conducted on the battleship USS *West Virginia* (BB-48) after a 1924 grounding incident firmly cemented his reputation within the Navy.[15]

By the spring of 1925 the Navy had been evaluating the big new fleet submarine *Barracuda* for over seven months, and this pathfinder boat (and its two sister boats) with its fully riveted construction had been shown to have leaky fuel tanks, among other serious problems. Owens wrote a letter to the Secretary urging that welding be incorporated into future construction as a remedy to this problem.[16] Predictably, despite Owens' growing reputation, the Navy Department and the Bureau of C&R dithered on the issue. While enthusiastic about the new process, riveting was retained as the primary joinery method for the next several years. Undeterred, Owens and his staff soldiered on and continued to experiment when they could. He received approval to use welding in a limited fashion in non-critical areas on the *Argonaut*, starting construction in May 1925 at Portsmouth.

During research for his book, Alden uncovered anecdotal reports that Owens and his staff used welding to join the vertical keel plates on the giant new fleet submarine *Narwhal,* a follow on boat to *Argonaut*, also built at Portsmouth.[17] Given the revelations in the photos above of the later *Dolphin*, it can now be safely inferred that these anecdotal reports about the otherwise riveted *Narwhal* (and by default its sister boat *Nautilus*, built at Mare Island Navy Yard in California) are actually true. Eager to prove that his theories could solve known structural issues on submarines, Owens did what he could to push his work forward, and these limited examples on the *Argonaut, Narwhal, Nautilus* and *Dolphin* were the first steps. The boats ending up being built to a mixed method construction, with the majority of their hull and interior being riveted, but with certain low-criticality areas like the bilge keel, internal frame interfaces, and support brackets being welded. Newspapers of the time even picked up on this trend, with several reporting that *Dolphin* had been welded.[18]/[19] A chart in Alden's book indicates that the follow-on boat to *Dolphin* at Portsmouth, *Cachalot* (Fig. 10), also received this mixed method construction.[20] In a contradictory statement, Alden writes in an earlier chapter that "Portsmouth held strictly to riveting for its boat, the *Cachalot*."[21] Despite Alden's unambiguous statement and despite his listing the boats of the V-class as being of riveted construction, given the evidence from the *Argonaut* drawings, the

Dolphin photos, and the chart in the back of the book, it is now safe to state that the last six boats of the V-class were all built to a partial riveted, partial welded standard.

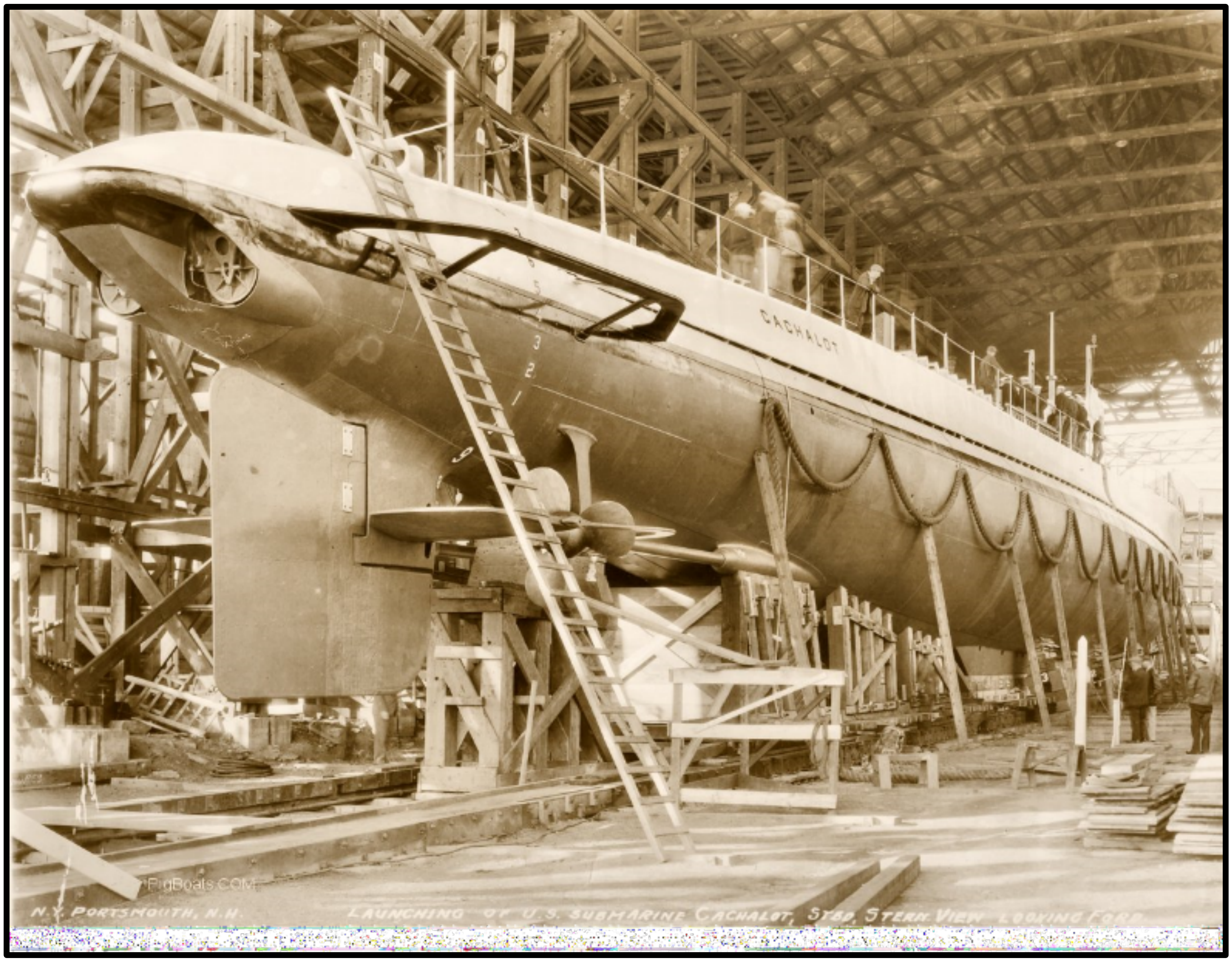

Figure 10. USS Cachalot (SS-170) on the ways at Portsmouth, 18 October 1933. While this picture is not detailed enough to verify the presence of welding, many of the seams on the outer hull appear to have been welded. (Rick Larson collection courtesy PigBoats.COM)

So, it has been established that as early as 1925, U.S. Navy personnel, led by James W. Owens, pioneered the use of welding in submarine construction, not the civilian Electric Boat Company. If this is the case, then why were the government-owned Navy yards still using riveting as the primary construction method as late as 1936? As stated above, the commonly accepted story was that the yard personnel resisted it on technical grounds, believing riveting to be the superior method. Once again while there is some kernel of truth to this story, the real explanation lies elsewhere.

As this issue was being pressed at Portsmouth by Owens, it was decided to run some tests so that the results could be empirically evaluated. Between 1931 and 1934 Portsmouth and the Mare Island Navy Yard in Vallejo, CA, welded a series of garbage lighters and wrecking derricks as a test and to train welders in non-critical welding. Portsmouth also built a full-size submarine hull section replica, sometimes referred to as a caisson, to a half-welded and half-riveted construction method. It was then towed to a safe location, submerged, and anchored. After being subjected to depth charge shock testing it was recovered and returned to the yard. Upon examination it was shown that the joints from both methods broke under the stress of the depth-charging. The welded seams held but some of the surrounding metal cracked. The riveted joints also popped, but according to Alden "this kind of damage was less drastic in most cases and *did not constitute enough of a disadvantage to warrant the abandonment of the long-established riveting method"*[22] (emphasis mine). Welding proponents argued that a simple change to the joint design would eliminate the problem.

The ambiguous results of this test provided fuel to the pro-riveting faction at Portsmouth. However, Navy management was not satisfied and ordered a follow up test; this time with two hull sections, one completely welded with a revised joint design, and one completely riveted. In this test the welded caisson did much better, bending but not breaking or leaking whereas the riveted caisson's seams popped and leaked profusely.[23] Convinced now of the efficacy of welding, C&R was ready to adapt to the method in whole, but ran headlong into the unmovable wall of the labor movement and the realities of the Great Depression.

As mentioned before, welding held numerous advantages over riveting, but from a management standpoint, one of these reasons stood out: a dramatic reduction in labor time and cost. A two-man welding team could do the same amount of work at a faster pace than a four-man riveting team, greatly reducing a large overhead in production time with (conservatively) half of the labor cost. The adoption of welding would result in a large reduction in the labor force at the government-owned yards at the very depths of the Great Depression. The Master Shipfitter at Portsmouth, a civilian old-timer by the name of Samuel D. Gilkey,[24] argued passionately to continue riveting. Employed at the yard since 1906, Gilkey was a traditionalist and had spent his

Figure 11. Samuel D. Gilkey (third from left) was a key player in the riveting vs. welding saga at Portsmouth Navy Yard in the 1920's and 30's. (USN photo courtesy of the Milne Special Collection, Univ. of New Hampshire and Navsource.org)

entire career using riveting to build ships (Fig. 11). He understandably was quite reluctant to change after such a long and respected career. In addition, at a time when loyalty in the workplace was a common virtue, he was highly respected by his workmen because he always had their best interests at heart.[25] He knew full well that if his riveters were laid-off they were likely to go straight to a bread line, as there was little industrial work, or work of any kind for that matter, in New England at the time.

The recalcitrant Gilkey wielded a great deal of influence at the yard, but it was the actions of the workers themselves that finally decided the issue. Delegations of workers from the yard were formed and they made the journey to Washington to take their case directly to their congressmen.[26] They lobbied strongly to preserve their jobs by retaining riveting, not necessarily because it was technologically superior to welding (after the second caisson test that viewpoint could no longer be supported), but because welding was *not yet superior enough to riveting to justify the essentially permanent loss of jobs.* Pressure was levied against the Navy Department by the legislators and eventually the managers at C&R and Portsmouth folded. When the authorizations for what would become the Porpoise/Shark class of submarines was approved for fiscal years 1934 and 1935, the contracts were awarded via a split decision. The boats of this class assigned to Portsmouth and Mare Island (a total of five) were built to a primarily riveted/partially welded method, while Electric Boat (who also received five contracts), was allowed to use an all-welded method, which is what C&R and the submarine force actually wanted. By 1936, with the National Industrial Recovery Act in full swing and the economy on the mend, there was far less labor opposition, so the Navy yards finally made the wholesale switch to all-welded submarines with great success.[27]

Should Electric Boat still receive some credit? Yes they should, in that their popularization of welding cleared doubt about the method in the minds of the public, the Sailors onboard the boats, and in the minds of C&R's managers and engineers. They also built the Navy's first *entirely* welded submarine, the USS *Shark* (SS-174) at a time when the Navy yards were still primarily using riveting.

Electric Boat managers shrewdly deduced that an opportunity existed to distinguish themselves from the navy yards by adopting welding on a large scale, taking advantage of the ground work laid by Owens and his staff and the good-will he had created towards the process within C&R. Electric Boat had struggled to survive the period of 1925 to 1931 when the nation's only civilian builder of submarines built not a single boat for the U.S. Navy. There were many reasons for this gap, and the company survived only by its willingness to diversify its manufacturing into other areas.[28] But by 1931 the company was eager and determined to get new Navy contracts and they seized on welding as one means to justify them. During the six-year gap, the company had reduced the size of their workforce to the bare bones, and when it came time to start work on the *Cuttlefish*, they did not have to lay off riveters; indeed, they actually hired new workers and expanded the company, sidestepping one of the major issues facing the government yards.

Welding was a paradigm shift in submarine construction and a change of that magnitude naturally caused some level of hesitation on behalf of C&R, despite the enthusiasm within the bureau created by Owens. When combined with the primacy of the issue of a reduction in labor during dark economic times, there is little wonder that the bureau and Portsmouth dithered. C&R needed time to develop a comprehensive labor management and technology insertion plan to address the issue. The continued use of riveting on their boats of the Porpoise/Shark class gave them that time. Electric Boat took advantage of both the enthusiasm for welding and the hesitation to use it to set itself apart. Company management keenly called attention to their adoption of the new paradigm and relentlessly promoted it.[29] The Bureau of C&R did not because as a government agency they didn't see the need to. Thus, Electric Boat received the historical credit, somewhat unfairly.

That such a seemingly trivial industrial process could have a disproportionate level of importance to later events can be surprising. Our submarines of WWII, the direct descendants of the submarines mentioned here, were renowned for their ruggedness. *Salmon, Kingfish*, and *Halibut* among several others, endured wartime ordeals that resulted in enormous amounts of damage to the boats, yet they survived with their crews intact. This speaks volumes to the skills of the workers at the Navy and civilian yards and the efficacy of the welding methods that were used. Our welded boats brought their crews home under conditions that may have been fatal if the boat had been riveted. James W. Owens and his adherents saved lives because of their foresightedness, their willingness to change, and their drive to persevere against entrenched thinking.

ACKNOWLEDGEMENTS

This article would not have been possible without the tireless efforts of my close friend Ric Hedman. With PigBoats.COM he has amassed one of the finest repositories of USN submarine history on the Internet, and his help and encouragement were key factors in the writing of this article. Many of the photos here were pulled from his site. John R. Alden, the son of historian John D. Alden, reviewed this text and gave his blessing, as this article was intended to be a supplement, and an homage, to his father's monumental work. Special thanks go to Roger Torgerson for finding the *Dolphin* photos on a back shelf in the Archives, and to Michael Mohl at Navsource Naval History for his efforts at preserving the photographic history of the USN Submarine Service. Joseph Gluckert and Gary Hildreth, historians with the Public Affairs Office at the present-day Portsmouth Naval Shipyard were very helpful and contributed important research. Author Craig McDonald provided needed encouragement.

Notes:

[1] *U.S. Subs in Action,* Robert C. Stern, 1979, Pg. 20. The partially riveted USS *Narwhal* lost approximately 20,000 gallons of fuel to leakage during a training cruise in 1941.

[2] *RECORD OF PROCEEDINGS of a COURT OF INQUIRY, For the purposes of inquiring into all the circumstances connected with the loss of the USS S-28,* By Order of the Commander in Chief, United States Pacific Fleet and Pacific Ocean Areas, 11 July 1944, Pg. 117 & 121. The Navy is careful in this document to not assign a definite cause for the loss, but the document reveals that rivets in the forward part of the boat were suspect. In addition, this conclusion was deduced from photographic and video evidence gathered after the discovery of the *S-28* wreck in 2017 by members of the Lost 52 Project lead by Tim Taylor.

[3] For further information on riveting see Wikipedia: https://en.wikipedia.org/wiki/Rivet

[4] For further information on welding see Wikipedia: https://en.wikipedia.org/wiki/Welding

[5] There is frequent confusion between this yard and the Norfolk Navy Yard, coincidently located in Portsmouth, Virginia.

[6] The Navy went through a major change in its submarine naming convention in 1931. Prior to this date submarine names consisted of a letter/number combination, i.e., *L-9, S-51, V-1,* etc. On the date of the change, all submarines built from the *V-1* forward were renamed using fish and marine creatures as the naming source. Submarines built prior to the V-class retained their letter/number names. Thus *V-1* became *Barracuda*, *V-2 Bass*, *V-3 Bonita*, *V-4 Argonaut, V-5 Narwhal*, and *V-6* became *Nautilus*. *Dolphin* had been laid down as *V-7*, but her name was changed before she was even launched. *V-8* and *V-9* refer to *Cachalot* and *Cuttlefish*, but the V-names appear only on the construction authorization documents. They were changed before construction even started on either boat. Only the post-1931 names will be used in this article, despite the fact that the V-names would be correct given the time frame in question.

[7] *The Fleet Submarine in the U.S. Navy: A Design and Construction History,* John D. Alden, 1979, Pg. 38 & 39.

[8] *United States Submarines,* David R. Hinkle, 2002, Pg. 109

[9] *U.S. Submarines 1941-45,* Jim Christley, 2006, Pg. 23

[10] Alden, Pg. 28.

[11] Alden, Pg. 141.

[12] *Warship Profile 34: USS Barb (SS-220) Gato Class Submarine,* William H. Cracknell, 1973, Pg. 226.

[13] *Jane's Pocket Book of Submarine Development,* John E. Moore, 1976, Pg. 34 & 35.

[14] Email to author from John R. Alden, son of John D. Alden, 24 March 2020.

[15] Article, *Daily Press,* Newport News Virginia, 15 May 1928.

[16] Alden, Pg. 16.

[17] Alden, Pg. 16.

[18] Article, *The Daily News,* Tarrytown New York, 10 March 1932

[19] Article, *Buffalo Evening News,* Buffalo New York, 11 March 1932

[20] Alden, Pg. 216. The chart was copied directly from Bureau of C&R Welding Sketch No. 1721 dated 14 February 1939.

[21] Alden, Pg. 39

[22] Alden, Pg. 46

[23] *U.S. Submarines Through 1945: An Illustrated Design History,* Norman Friedman, 1995, Pg. 200

[24] Email to author from Joseph J. Gluckert, Historian, Portsmouth Naval Shipyard, 10 March 2020.

[25] *Industrial Department Life Buoy,* Navy Yard Portsmouth, NH. July/August 1918, Pg. 12

[26] Alden, Pg. 46

[27] Friedman, Pg. 202. Alden, Pg. 65 & 216

[28] *The Legend of Electric Boat,* Jeffrey L. Rodengen, 2006, Pg. 79

[29] Rodengen, Pg. 85. This book, although well written and comprehensive, is an example of Electric Boat's continued promotion of what is largely a myth. It was written with the full cooperation of the Electric Boat/General Dynamics public affairs department and puts a very positive spin on the Electric Boat story. This company's contribution to the submarine service is significant and undeniable, but information that comes directly from them at times needs to be evaluated with a keen editorial eye.