In Tribute to Riveted Ships

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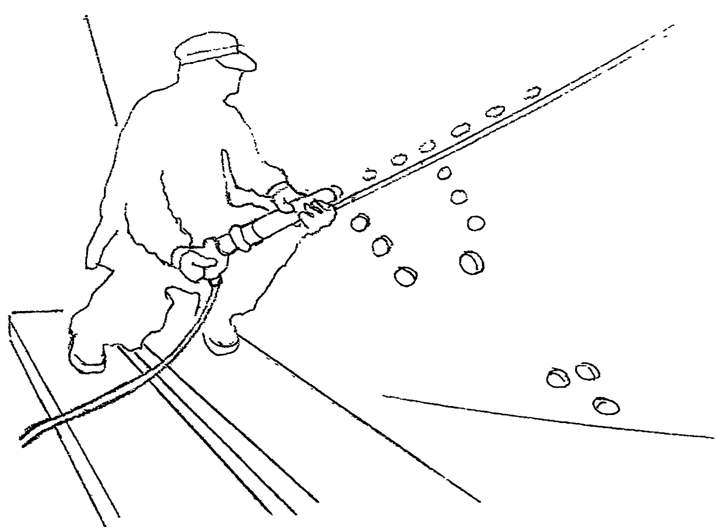

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In Tribute to Riveted Ships

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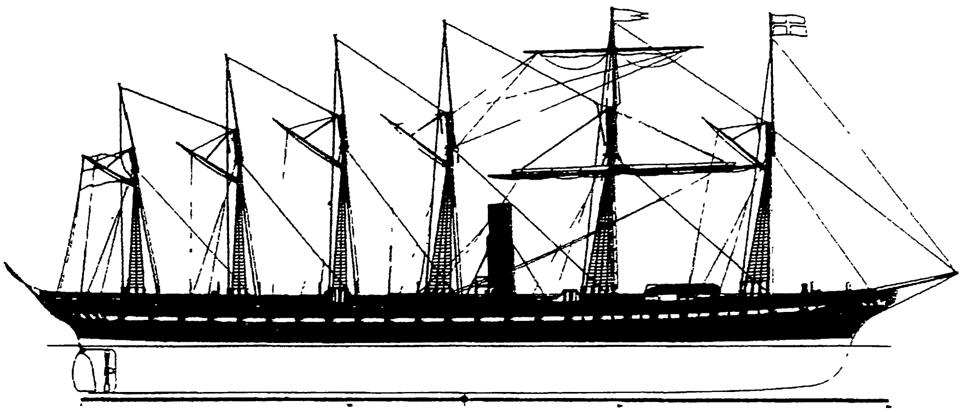


Fig. 1: Brunel's *Great Britain*

Preface

England is a land packed with interesting and historic sites. To a naval architect, probably the best example is to be found in Bristol. Displayed there is the lovingly reconstructed steamer *Great Britain*, an admirable example of I. K. Brunel's engineering genius. That ship, launched in 1843, was the world's first ocean going ship driven by a screw propeller. It was also the first large ship to be built of iron or steel. Virtually all of the plates and shapes were held together by rivets [1], and riveting remained the standard shipbuilding technique for most of the following century. In our country the first all-welded ships came along in the early 1940's, during World War II. At that time our maritime authorities wisely concluded that our wartime needs for merchant ships could best be met if we used the relatively simple methods associated with welding instead of riveting. The United States Navy, on the other hand, without time for complete change-overs, stuck to riveting at least in the main hull girder of its conventional ships. In new concepts such as landing craft, however, welding was quickly adopted.

My shipbuilding career was spent at the Newport News Shipbuilding & Dry Dock Company between 1939 and 1948. I found myself engaged in building or repairing a wide variety of ships, both merchant and naval, and thus I lived through the transition from riveting to welding. A couple of years ago I came to realize that, owing to my advanced years, I might be one of the few naval architects still around who could recall the days of riveting. Thus, when I was invited to present a paper before this meeting, I thought it might be appropriate to describe the steps involved in riveting, and go on to discuss some of the pros and cons of welding versus riveting.

If nothing else, I hope this exposition will engender in today's naval architects some degree of appreciation for the skill and dedication required to build a riveted ship.

Riveting Technology

In the days of riveting, naval architects had rational, well established rules for selecting the size and spacing of rivets in each of the various parts of the hull [2]. This information was plainly expressed on the drawings sent to the mold loft. There skilled loftsmen added the information to their templates, showing the exact location and hole diameter for every single rivet (thousands of them!). That information, in turn, was transferred to each actual plate or shape by center-punch and paint. Each of the thinner plates (up to ¾-inch) was then taken to a massive machine that punched a suitable hole at each of the indicated points. Those machines had a throat of four feet, so that plate widths were limited to eight feet (appropriate to turning the plate both ways). In the case of the thicker plates, machine drilling was used in place of punching [2]. In either case the hole diameter was slightly larger than that of the intended rivet.

Rivets were made from flanging quality steel, having slightly greater ductility, but slightly less tensile strength, than ordinary mild steel. They varied in diameter from 1/2 inch to 1¼ inch in 1/8 inch increments, and they were needed in great numbers. Buxton [7] for example cites the case of an 8600 gross ton passenger ship built around 1897 with 795,000 rivets. He adds that the venerable *Queen Mary* is still firmly held together after all these years by more than a million steadfast rivets.

As each plate or shape was added on the shipway, it was aligned with the previously erected adjacent components, and coaxed into place with spud wrenches (Fig 2), a convenient procedure largely unavailable in welded work.

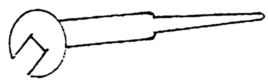


Fig. 2: Typical spud wrench

Once in place, the added item was temporarily held in position by fitting a few nuts and bolts at convenient locations. As shown in Fig. 3, the adjacent holes were not necessarily exactly aligned; moreover, the punching process tended to leave holes that were not 100 percent perfect cylinders. These minor discrepancies were largely eliminated by applying a power-driven fitting, the *ream,* leaving near-perfect cylindrical holes accurately aligned as shown in Fig. 4.

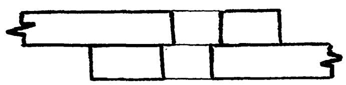


Fig. 3: Slight mis-alignment

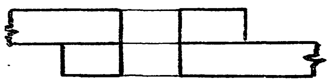


Fig. 4: Reamed holes

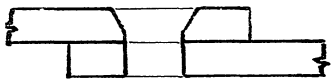


Fig. 5: Countersunk hole

Next, a power-driven counter-sinking tool left a pair of holes ready to be fastened together by a suitable rivet (Fig. 5). Now the riveting team could go to work. The typical team comprised a quartet: the head riveter and the rivet heater stationed at the point end of the rivet, and the assistant riveter and his helper stationed at the head end. The riveter was equipped with an air-powered riveting hammer with various working ends. The heater was responsible for bringing each rivet point (the end opposite the head) to a red heat. For this he was equipped with a little cast iron pot filled with burning coals and arranged with a supply of air brought in from below. As each rivet was judged ready, it was passed along to the assistant riveter and his helper, who were stationed near the inboard end of the hole; the assistant would grab it with a set of tongs and start it into the hole. Then the assistant riveter went to work with an air-powered tool (much like that held by the riveter). He made sure the rivet was driven in as far as the head would allow. Then the riveter and his assistant applied their air hammers simultaneously to pound the rivet until it filled the countersunk void and squeezed out any little gaps that might occur between the shank of the rivet and the hole into which it was fitted.

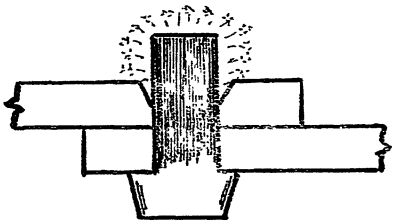


Fig. 6: Ready to be hammered down

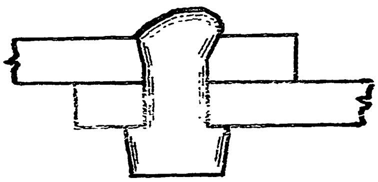


Fig. 7: Newly hammered down

Turning back to the step in which the heated rivet was passed to the assistant riveter, that might be as easy as using tongs to pick up the rivet and toss it into a bucket in the hands of the assistant riveter's helper. Caldwell [3] recalls with admiration "the remarkable dexterity of the rivet squad, who could catch a flying rivet as well as any slip-fielder in our national sport of cricket." On the other hand, no such picturesque tossing was possible when the helper and his assistant had to do their work cramped down in the double bottom; in such situations the rivet was shot to them through a flexible metal tube.

Since one could not expect to find a rivet of the exact length necessary to fill the countersunk hole, it was purposely left a trifle too long; and so, when driven, had an excess hump, as shown in Fig. 7. The riveter's next step then was to apply an air chisel to skim off the hump, leaving a neat, slightly convex point as shown in Fig. 8. In encore of his performance the riveter would finally apply a few more rapid blows from his hammer and thus assure a smooth, slightly convex surface while also adding to the tightness of the fit.

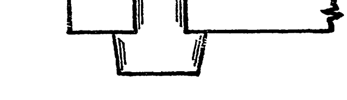


Fig. 8: Finished product

Fig. 9: Faulty fit

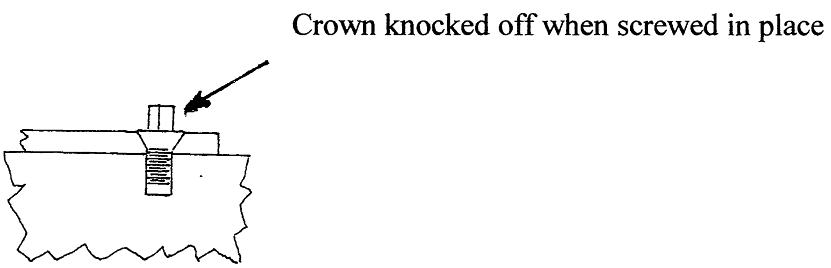
Figure 9 shows an ill-fitting rivet that would probably be rejected. It would be removed and a better fit effected by vigorous application of the ream to produce a more satisfactory hole.

Although the riveter and assistant riveter held similar tools, the assistant had the easier task because the working end of his tool was shaped to encase the rivet head and so was unlikely to slip out of place. The riveter himself needed muscle and skill to manipulate his awkward tool over the slippery surface of the red hot, malleable point.

While the assistant's task required less skill, it required greater stamina because, in general, it was carried out in far more uncomfortable situations. I have an abiding sympathy for the assistant riveter and his helper who had to work in the imprisoning confines of the double bottom. In their senior years I dare say they found an early and continuing need for hearing aid batteries in great supply.

Tap Rivets

Connecting shell plates to castings or forgings, such as stern frames, was usually effected by means of tap rivets, as shown in Fig. 10, below.



Fig, 10: Tap Rivet

Attaining Tight Plating

Making a riveted hull water-tight, or oil-tight, required skillful, conscientious workmanship. No matter how tightly the rivets might have held the shell or deck plates together, special measures had to be taken to keep water from seeping in. This was most efficiently accomplished by giving special attention to the exposed plate edges. First, a chisel-point was used to split the edges as shown in Fig. 11, then a blunt tool was used to upset the interior edge and thus force metal-to-metal contact as shown in Fig. 12. This procedure had to be carefully followed to provide endless water-tight loops. In certain complex structural arrangements tightness could be achieved only by recourse to applying soft materials, such as canvas soaked in white lead paint, to the faying (overlapping) surfaces. In other cases injector guns were used to force thick red lead paint, or thin putty, into troublesome seams [2].

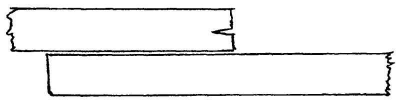


Fig. 11: Split plate edge

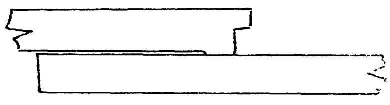


Fig.12: Forced contact

These preceding sketches are misleading. Tight seams were not to be expected when no binding rivet was close at hand. This was illustrated by a doubler plate I saw on the main deck of the battleship *Indiana*, where the naval architect had used scalloping to bring the doubler's edges into closest possible proximity to the nearest rivets.

Joggling

Riveting plates together required at least a few inches of overlap, thus the finished surfaces did not all lie on one plane. Either the frames or the plates had to be joggled. In general, plates could be run through a machine and joggled without heating. Alternatively, the frames might be joggled, but that usually required furnacing to make them malleable. Fig. 13 shows joggled plating, while Fig. 14 shows joggled framing. A third alternative was to fit a liner at each frame, but that was not considered good form, as it required the complication of added pieces of steel and wasted weight [6].

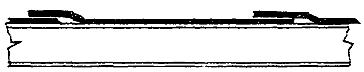


Fig. 13: Joggled plating

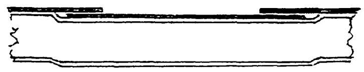
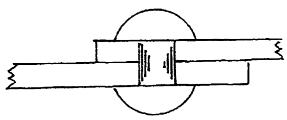


Fig.14: Joggled framing

Where two joggled joints coincided some hand chiseling or filing was required for scarfing to prevent an awkward structural pile-up.

Snap Rivets

To this point we have concentrated our attention on the traditional rivet with pan head and countersunk point, the variety that must be considered the unchallenged chieftain of the Clan MacRivet. They hold the ship's main hull girder together and provide its watertight envelope. Lesser parts of the hull require less exacting rivets, and this is where the snap head variety comes in. Fig. 15 shows a typical snap head/snap (button) point rivet. Requiring no countersinking, and no need for making watertight, it is far easier to install than the traditional rivets discussed above.



Note: Head & point are essentially identical

Fig. 15: Snap head/snap (button) point rivet

How the term "snap" arose is a question that seems to have evaded the careful lexicographers of the OED [4]. Perhaps it pertains to the relative ease of their installation.

Longitudinal Strength

Riveted butt joints in shell and decks deserved special attention if those structures were to do their part in contributing to the longitudinal strength of the hull girder. Despite the best of the designer's skill, a riveted butt could never overcome the fact that every rivet hole would reduce the extent of plating that resisted tearing apart. Every butt joint was thus suspect, so efforts were made to stagger their locations and thus avoid any concentration of weakness.

Neutral Axis

Since lines of rivets were thought to be weak in tension, longitudinal plating in shell or uppermost deck was assumed to lose a small fraction of its effectiveness in preventing complete hull failure when subjected to tensile loads. Thus the hull's assumed neutral axis would be raised while in the sagging condition and lowered when hogging. My recollection is that those assumptions were abandoned in the final years of riveted ship structures when authorities came to realize that hulls never seemed to pull apart along lines of rivets.

Transverse Bulkheads

Each watertight (or oil tight) transverse bulkhead presented a special problem. Tightness required closely spaced rivets in the angle irons connecting bulkheads to shell or deck. The resulting line of weakness had to be offset by means of doubler plates or perhaps large internal brackets. Therefore one of the first applications of welding was to replace those riveted connecting bars. I recall standing next to a dry dock admiring the hull of a newly built ship back in about 1947. Every shell frame was made evident by its neat vertical line of rivets. I noticed a group of three important looking inspectors who became severely agitated upon observing that one line of rivets was missing. Had the builders forgotten to install a frame? They moved in some haste to board the ship for a close-up look from inside, which amused me because I was aware of that welded bulkhead.

Closing Strakes

In spite of great skill and care, when all the component parts were assembled, the riveted hull's finished depth might not coincide with the designed specification. To overcome that potential problem, a strake of side shell plating would not be pre-fabricated, but would be tailor-made to fit the remaining gap after all else was firmly in place (and the ship's depth confirmed by careful measurement). In short, the size and shape of the closing plates would be lifted off the surrounding structure, as would its rivet holes. The same procedure would be true of a pair of strakes in each deck.

Advantages of Riveting

The advent of welding brought some unpleasant surprises, each of which may be interpreted as an advantage of riveting. First was the matter of all-welded hulls showing an embarrassing likelihood of breaking in two. Even the slightest flaw in welding, or sharp discontinuity in structure, could trigger a brittle fracture that might go right on around the hull in an instant. Cracks in riveted hulls generally stopped when reaching a seam because the stress concentration would be dispersed as affected rivets yielded slightly and distributed the load over their neighbors. This was recognized by the classification societies which asked that each existing Liberty Ship be fitted with a crack-arrestor strap: a riveted flat bar placed over a long slot burned in the shell a few feet below the main deck, port and starboard.

In the design stage of all-welded ships the authorities now require moderately expensive changes in the steel specification, making the hulls tougher and less notch sensitive. Greater care is also taken in design in order to avoid stress-raising discontinuities in hull structures.

The soundness of rivets could usually be ascertained by sharply rapping on each rivet head with a little hammer, but poor welding is harder to detect without recourse to expensive X-ray procedures.

In general, as riveting proceeded, the hull became more and more like the naval architect intended. In welding, however, a starved-horse look tends to develop, and special measures are required to keep the keel from arching up at bow and stern.

Breaking In

A riveted hull, when first placed in service had to undergo a period of breaking in. Initially, some rivets would be more highly stressed than others. As wave action and cargo distribution placed new loads on the structure, those overstressed rivets would yield just enough to pass some of their load along to their less stressed neighbors. This would allow the affected plates or shapes to shift some microscopic distance. I had no first hand experience in such a new ship, but they were reported to give evidence of such shifts through frequent squeaks or squeals. Indeed, Kipling was inspired to write "The Ship That Found Herself," an eloquent short story along those lines [5]:

> "Every inch of her [speaking of a ship fresh from the Clyde], ye'll understand, has to be livened up and made to work wi' its neighbor – sweetin' her we call it technically."

Then, after enduring a rough Atlantic crossing that produced complaints from all the component parts (and accommodating shifts by every rivet):

> There was just as much groaning and straining as ever, but it was not so loud or squeaky in tone; and when the ship quivered she did not jar stiffly, like a poker hit on the floor, but gave a supple little waggle, like a perfectly balanced golf club.
>
> When the ship finds herself all the talking of the separate pieces ceases and melts into one voice, which is the soul of the ship.

Conclusion

I am not advocating a return to riveting in ship construction. I only want to encourage some understanding of the art and science of riveting, and engender an appreciation of the pride, the skill, and the teamwork that went into that exacting technology.

Acknowledgements

I am grateful to Stephen Kemp for providing the sketch on the front cover, and for his helpful encouragement along every step of the way. Prof. John Caldwell [3] kindly gave permission to use his profile of the *Great Britain*, from Ref. 1 as my first figure. He also submitted useful comments on an early draft, as did the eminent marine historian Fred M.Walker [6], while my former student William Hickman merits credit for unique editorial service.

I must acknowledge the careful proofreading skills of my ever-patient wife, Kathy. I should also give credit to that highly skilled scrutinizer Anne S. Benninghoff; one of her suggestions was that I append one more reference [8] to clear up various potentially mysterious terms.

Finally, I am especially grateful to Susan Evans Grove, SNAME's Publications Director, for her patient perseverance in helping me put all this into its ultimate form.

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