# Material Transition: How Naval Materials Improved Over Time

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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**Studying Innovation**

"Evolutionary innovation depends on organizational focus over time, rather than guidance by one individual" (Murray, 1996). True innovation requires the right circumstances and many setbacks, which makes the eventual success all the more exciting. This quote from Murray, a military historian, comes from him writing about the lack of innovation in military culture between the World Wars. He speaks about how difficult change can be due to seemingly external factors, which come from humans creating barriers to change or creating a culture that supports experimentation. With this in mind, I believe that all past innovations are amazing, given the barriers that they had to overcome. Although, some might say that some technological innovation is inevitable, given the way technology always seems to improve. I would agree in a basic sense, but given how hard it is for people to embrace change when they don't know what the innovation will do to everyday life, power balances, and established structures (Shane, 1995), we can never be sure of when innovation will happen, and the timeframe for innovation is something I wish to explore.

Specifically, this paper will study the change in ship materials over time, by examining some of the factors that enabled or held back the transition. I wish to look into what ship materials because the importance of correct material choice for an application intrigues me. Material selection can be the difference between a system working correctly or causing catastrophic failure, thus I am interested to see how the material of choice for ships has evolved over time, and what factors or groups of people were involved in the change. I suspect that war and economics were major factors that drove this. It has been seen through history that war has bred all sorts of technological innovation (Van Creveld, 2010), and we know from everyday life that economics drive many major decisions. I am researching ships because I believe it is not an overstatement to say that ships were the primary system that allowed humans to travel, trade, fight, and otherwise drive history. In the words of Trevor Blakely, Chief Executive of the Royal Institution of Naval Architects, “Without them to provide for the safe and efficient transport and recovery of the world’s raw materials and products, modern society as we know it could not exist” (Walker, 2010, p. 9).

**Research Methods**

I am looking into the evolution of ship materials, but would like to expand beyond just their technical aspects. I will be using an STS framework to examine the material as a technology, in its greater societal, cultural, and historical context. My approach to this discussion is inspired by the Technological Frame framework, which suggests that a given technology is seen and used differently by different groups of people, and we can explore the true end product of a technology by studying the cumulative feelings towards it as well as how it was eventually used (Sovacool, 2006). I wish to find the most important shipbuilding materials throughout history, and explore what factors and social groups where at play in order for the research, development, utilization, repair, and/or regulation of the material to exist the way that it did. The most important factors will change depending on the material, and I will try to include a variety of viewpoints throughout the paper, in order to illustrate how different groups were involved in the evolution of ship materials.

In terms of resources, I will mainly be using historical reference material since this topic will have little to do with current events. Many resources already exist on the history of ships, and I plan to use as many of these as possible to get details on when and how material transitions happened. A broad search will be needed to find information on different social groups involved with the different ship materials, since I do not believe that many authors specifically set out to explore these relationships. Getting first-hand accounts would help with maintaining historical accuracy, as well as aid in the search for important social groups, since these primary authors could mention a factor that a later historian might skip over. Depending on the time period being looked at, resources will be used to study it in terms of big historical events that were happening, like important wars/battles or changes in important industries. An important note to make here is that I will be focusing on the transition in ship material in Great Britain (unless otherwise stated), since this is the area with the most published literature, as well as this area having large worldwide impacts. Scientific literature will be used to generate data on the material properties needed as well for any physical explanations.

**Brief Material Background**

I also wish to give further details on the materials of interest. The most obvious is wood, which we all see in some form or another, most commonly as trees. Wood has been used for pretty much all of human history in an uncountable number of ways, and it just so happens that wood is naturally less dense than water, meaning no matter what you do with it, it will most likely produce a structure that floats (Ray, n.d). Iron is a historic material as well, given the fact that it is one of the most abundant elements in the Earth's crust, and has been known since around 3500 BCE (Royal Society of Chemistry, 2023). Iron is taken from its naturally occurring forms throughout the ground and heated until it forms a pasty substance, when it can then be forged/shaped into usable parts. Iron parts made in this way, known as wrought iron, usually have impurities within them, meaning that the parts are not really pure iron, as the impurities, like traces of oxygen and carbon, are not allowed to diffuse out during the forging process. We inherently know that metal is stronger than wood, but to quantitatively compare them, the elastic moduli of wood and iron are about 12.4 and 185 GPa, and the yield strengths of these materials are about 51.8 and 210, respectively (Ansys GRANTA, 2023). Elastic modulus tells us about the stiffness of the material, and yield strength describes how much force can be applied to a material before it starts to deform. Without getting too technical, we can quite clearly see how the performance of ships was helped by the upgrading of materials used, without even considering all of the properties at play.

**Starting Off With Trees**

As we know, the very first widely used ships were made of wood (Boyce, 2018). For many groups that took part in shipbuilding, wood was pretty amazing – it made structures that floated, it was able to be shaped in intuitive ways, and the resource was all around them. By consequence, it supported people's livelihoods in many different ways, like the first social group that I would like to highlight within the technological frame of wooden ships, the shipbuilders. These men worked a difficult manual profession, with work at the mercy of the elements, and working during all seasons as the profession got more sophisticated (Working Class Movement Library). The work was not only difficult, but could also be dangerous, with many reports of injuries associated with cutting their legs with tools or back injuries because of the positions they would put themselves in (Dunn & Leggett, 2012). Regardless, these talented and hardworking individuals made the profession their own, developing amazing techniques and making shipbuilding into a real art (Pritchard, 1987). This is exemplified by the fact that shipbuilding, for most of its history, was taught by apprenticeships or through family owned businesses, meaning the skill was kept in small circles, and it took a while for their knowledge would be put into any scholarly form (National Parks Service). Shipbuilders also used their work to support many other trades, from engineers, rope makers, and sail makers. These trades literally could not have existed without the work of the wooden shipbuilders. The shipbuilders themselves were dependent on other actors within the technological frame, namely the trees themselves. Shipbuilders needed quality wood to do their job effectively, and thus were reliant on this natural resource, which down the line would pose an availability issue in some places.

A second group within the technological frame are the many different types of traders that needed shipping to do business. These people traded pretty much anything from food to natural resources like coal. They were also involved in transporting items like mail or military equipment, making traders inherently tied to the economy and government of their nation. Traders and their companies would commission ships for their specific needs, and interacted with shipbuilders to find compromise between optimizing cargo space, speed, and stability depending on the specific items that needed to be transported, utilizing the vast expertise of the shipbuilders. A trader viewed a ship as a means to make money rather than an art, with very specific goals in place about how fast they could go and how much they could carry. This presented great opportunity if successful, as more money from the trade would mean the ability to buy a bigger ship, thus transport more goods and make more money, and repeat. Traders were more likely to accept any proven improvements to ships than the shipbuilders, since they had this goal-driven mindset of doing anything to make more money. This economic drive for bigger and better ships was a major factor in the material transition that would eventually happen.

**Iron's Massive Impact**

Now we get to the historic material transition. As seen from the highlighted material properties, the transition to iron ships drastically improved the performance of ships by making them stronger, stiffer, more durable, as well as in the end more cost effective, safer, and allowing an increase in ship efficiency. Using our modern knowledge, it seems like an obvious change to make in this field; why wouldn't people have done this earlier, given that iron had been known for most of history? I find this barrier to acceptance particularly intriguing, and we will explore this by looking at it from the perspectives of the groups that were doubtful or rejected iron, and the view from those that supported it.

Firstly, we cannot talk about the iron ships without mentioning the influential Industrial Revolution happening at the time. The Industrial Revolution was a period of huge economic growth and technological innovation that broadly occurred between 1760 and 1830 (Ashton, 1964). The industrial revolution is widely considered a major turning point in human history, because of how all of the new innovations impacted the world and led us to where we are today. We could delve into the details of all the results of this time period, but the main thing that needs to be understood about this time period is the effect of the steam engine. The innovations in this type of engine throughout the years was the main enabler of the whole industrial revolution. Given that the steam engine was a provider of energy, providing the means for machinery to operate, it was a natural thought to place steam engines onto ships. This idea evolved into ship designs as steam engines connected to propellers placed at the rear of the ship. Ships were still important as vessels that enabled trade and communication, and engineers of the time correctly assumed that steam would not only make ships go faster and thus decrease overall travel times, but critically, the dependence on an engine for power would render the need for traditional sails obsolete, since now it wouldn’t matter where the wind was blowing.

Once steam engines were compatible with ships, shipbuilders and designers were quick to plop them aboard and assume everything would work fine. There are two things that happen right away – they realize the potential of this new engine and realize they need more space for the engine and its fuel, and simultaneously they enter unknown territory in terms of how large they could build without any adverse side effects. Because of this new powerful engine, the ships could be made bigger for additional cargo and passenger space. As the ships got larger however, certain structural design factors became apparent, as the larger ships undergo much larger stresses when in rough waters or when turning, as well as undergo large stresses within the structure when trying to accommodate the force from the steam engine and propeller. These considerations were discovered during trial and error in the ship design phase, and it took many years to smooth out all of these details, eventually leading to the use of iron, and updated structural designs, to withstand these effects.

Viewing the new iron ships as within a technological frame, we see that many actors were involved. One group of actors was skeptical and/or completely against the use of iron for ships. The actors in this point of view were the older generation of shipbuilders, that were previously mentioned, and skeptical lawmakers and business owners, not convinced at iron's utility and favoring the known material. The concerns of the older generation were very important, as many of these people held important positions within the navy, and within a naval power like Great Britain, they were major influences. Alongside this, since naval power was still closely intertwined with trade and the economy, politicians held the ultimate say in what to use government spending on, and would only do so for things that posed minimal risk. People with established businesses were also hesitant to allow their goods to be shipped on iron ships at first, given how new and unproven the technology was. The main concerns were that a heavy structure built of iron would not float, that iron was too brittle to survive impacts from grounding, that compasses would be affected, and that fouling of the hull would be too much of a hassle (Fougner, 1922). These concerns came from centuries of working with wood and becoming experts in this subject, and not wanting to dive into the unknown. They also brought up the fact that the quality of iron at the time was not ideal and required specialized laborers, and the fact that at the time iron was more expensive than wood, because of this increase in labor but also the longer process involved with mining, transport, forging, and construction of iron ship pieces. Once the initial iron ships started being used, the older generation of shipbuilders were especially worried about the thinness of the iron hulls being used, citing them as nerve-inducing and unsafe, as well as the new buckling problems that iron brought with it, which needed different support structures than wood (Coates & Coates, 1999). In the end, old shipbuilders were probably worried that if iron came into full force, their industry would die, since the new ships didn't use wood to nearly the same extent, if at all. The conservative lawmakers, supported by older shipbuilders, initially made it hard for iron ships to be mass produced and refused to spend substantially. Sir Howard Douglas was even able to lobby a law into effect that limited iron ships to troop transports, rather than the revolutionary warships that the advocates had been pushing for (Lambert, 2011). It took consistent pressure from proponents of iron and positive results from early iron ships in harsh situations to convince these two groups to change their minds, and then the money started pouring in to the iron shipbuilding industry.

On the other side of the technological frame were engineers and ship designers, who cited their new understanding of how to use this metal, which came from their belief in testing and science, as evidence for why they should use it. These tests, as well as early field results, allowed this group to answer all of the concerns of the critics. Because of the newly studied phenomena known as buoyancy, iron ships were found to indeed float, and in addition be used smaller relative amounts of material than wood, leaving iron ships effectively lighter than wooden ships. In regards to the brittleness concern, which came from the fact that pure iron isn't very tough, there was an incident where an iron ship, the *Garry Owen*, ran aground with the rest of its accompanying wooden ship fleet due to harsh winds, and all the other ships were either destroyed or seriously damaged, with no damage done unto itself (Fougner, 1922). The compass objection was a genuine problem, shown by the time the *Lord Dundas* got lost for several days from a known path due to faulty compass readings, and this was eventually fixed by compass correcting, which was the process of placing corrective magnets around the compass to neutralize the iron's effect on the local magnetic field (Walker, 2010). The fouling problem, when sea organisms would attach themselves to the ship's hull and cause deterioration, was found to be an easy fix once more research was done on repelling these organisms, leading to the development of new anti-fouling paints, and was found to be about the same amount of work compared to fixing wooden ship fouling (Geels, 2002). The thinness of iron hulls was proven to not be a problem through the proven durability, and was defended by engineers as a helpful result of the strength of iron. The one concern that did take some time in addressing was the quality of iron being used, but as iron became more and more viable, the techniques involved in forging iron became more sophisticated and controlled, leading to vast improvements on quality. Another major reason cited by engineers, especially in Great Britain, was the rising price and decreasing availability of quality wood for the ships, and using a mined ore that was more available would lead to a more stable supply of material. One warship alone needed about 2000 trees to build, and not all trees were equally good for ship uses (Royal Museums Greenwich). Overall, engineers used their knowledge of science and math to vouch for iron, and were motivated by the financial bonuses they would get if their designs worked successfully, as well as the rising status of engineers in society.

Coming back to the traders mentioned earlier, they had an interesting "in-between" outlook on the situation. On the one hand, taking part in the early transition to iron was risky, and they did not want to risk their products when they could use proven wooden ships. Some traders, as well as people that had naval power, had contracts and investments within the timber trade as well as wooden-specific industries, and thus were reluctant to see this industry decrease in use (Goodwin, 1997). On the other hand, some saw the revolutionary ideas coming and jumped on them, making full use of the increased cargo space and decreased travel times, and they thus played a key role in making iron ships, in addition to steam engines, commercially viable because of their increased demand. The increased use of iron ships in trade was also a key role in the overall adoption of iron ships, since the boosted economy influenced government officials to increase regulations and push more money into the industry. This was highlighted in the end in 1861, when the House of Commons passed a law that prevented capital ships above a certain size to be made of wood, signaling that iron had won.

**Case Study: The Effect of War**

To give more perspective on the material transition, I wish to highlight the Battle of Hampton Roads that occurred in early March, 1862 (Milton, 2012). This battle occurred during the American Civil War, and was fought between the *CSS Virginia* and the *USS Monitor*, when the Confederacy was trying to break the Union blockade of its ports. The Confederacy had just upgraded the *Virginia* to an ironclad ship, it being their first iron ship, and during the first day of the battle, sunk 2 union ships and grounded a 3rd, with all the Union ships that day being made of wood. The Union soldiers aboard their ships could only watch with dread as all of the firepower they had laid into the *Virginia* with little damage and minor casualties, as the *Virginia* rammed into one ship and tore another apart with cannon fire. The Union had been quickly working on their own ironclad, the *Monitor*, and the very next day the *Monitor* engaged the *Virginia*. The two battleships circled each other and fired on one another for about 3 hours, with both ships undergoing barely any damage from each other’s cannons. This battle was the first time iron ships fought against each other, and it ended with a draw; in the end the Confederacy was unable to break the blockade due to the presence of the *Monitor*. Looking at the bigger picture, this breaking news was spread all over the world, and was a huge driving force behind the rationale of switching to iron ships (Andrews, 2018). Wooden ships were now objectively inferior to any decently built iron ship.

**Conclusion**

Studying past innovation is really interesting, especially looking back through history using frameworks that need you to find effects from different social groups. Doing this really highlights the fact that technology does not exist in isolation; all technology is the product of its people and culture, as well as past innovations in its field. I believe the material transition from wood to iron in ships really exemplifies this process, especially since the Industrial Revolution is at the heart of what happened. It is also incredible, looking through a modern perspective, that people would ever doubt the effectiveness of an objectively better material. This really highlights the importance of perception in technology; many people in different social groups need to buy into a technology for it to truly be successful. This is by no means a comprehensive examination of the material transition, as I am sure there were other important actors within the technological frame of the iron ships that played roles, big or small, in their eventual adoption.

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