The Designing of *Titanic*

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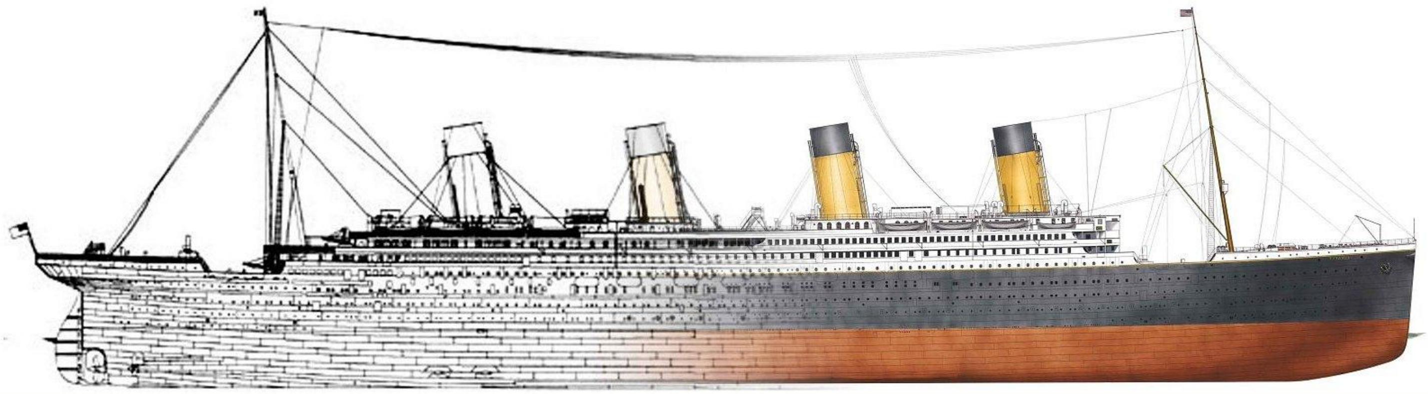

Photo courtesy of Robert Hahn, Titanic Research and Modeling Association

ABSTRACT

This paper examines the design process of RMS Titanic with a point of view of what naval archetects knew about designing ships in the early 20th century. The process of designing it also points out some of the engineering related mythsand questions about the Titanic story that have persisteded through the last century.

The business proposition

In the summer of 1907, J. Bruce Ismay, Managing Director of the White Star Line, attended a business dinner at the London home of Lord Pirrie, a partner in the Ship building firm of Harland & Wolff in Belfast. Together they hatched a plan to build a pair, probably more, of the largest ocean liners in the world to recapture an advantage in the burgeoning trans-Atlantic passenger trade. Those two ships became the *Olympic* and the *Titanic*. The task of designing something that had never been built before fell to senior naval architects such as Thomas Andrews and Edward Wilding at Harland & Wolff.

Understanding a little of the process used to design these ships provides an understanding of why *Titanic* looked the way it did, but also shines some light on lingering questions whose answers are lost in engineering details. In deconstructing Titanic's design, we will reference the 1905 text book ***"Theoretical Naval Architecture"*** by Edward Attwood, a member of the Royal Corps of Naval Constructors. It will hereafter be refered to as **"*The Book*". "*The Book*"** will serve as a lense on what was known about ship building at the time, without the historical contamination of modern means. Thomas Andrews and Edward Wilding may have had copies of this book on their book shelves.

While the engineering discussions may be of little interest to most readers, the ramifications of decisions made in the design process answer a number of lingering questions that have persisted in the Titanic story through the years.

The Requirements

J. Bruce Ismay left Lord Pirrie with 4 basic requirements:

1) The ship must be 100 feet longer than Lusitania (his largest competitor's crown jewel),
2) It must have 50% greater displacement than Lusitania,
3) It must be economical in service, and
4) There were requirements for a list of lavash accommodations and special features such as a 1st class lounge, smoke rooms, gymnasium, etc.

How do you design the largest ship in the world to requirements like those? We shall see. The flowdown of these basic requirements are what made the Olympic class ships appear as they did. And don't forget, nobody had ever built a ship this large before.

Requirements 1) and 2) are relatively easy. Lusitania was 790 feet long (240.8 meters) and displaced roughly 30,000 tons. The new ships would be around 890 feet long and displace in the neighborhood of 45,000 tons. Scaling up an existing, proven design is a good start but preliminary calculations have to be made for weight of the ship's structures and loading to determine the proper width to ensure the design will be stable in the water. Simply scaling up the ship will provide most of the desired new displacement but additional calculations might alter the design.

For requirement 3), what does *economical* mean? This drives most of the design decisions. One of the main cost factors for a voyage was coal. How much coal the ship will burn is a function of speed. The Atlantic is 3000 miles wide. To cross it in 6 days requires sailing 500 miles a day, or around 20-21 knots average speed. To cross it in 5 days means sailing 600 miles a day or at some 25-26 knots. Even days give the line owners some fudge factor for storms or incidents in meeting their time tables. Half days requiring a night time departure or arrival and were generally not considered. Having staff there to off-load baggage and reprovision the ship were problematic in night time hours and lighting was poor in the early 20th century. Most of the passenger would sleep until morning anyway or otherwise be out of sync with transportation in port.

What would American folklore be if half the tired, poor, and hopeful immigrants to New York woke up to beeping cars and said, "Where's the Statue of Liberty!?" "Sorry fella. Ya missed it."

The chief rival of the White Star Line was the Lusitania that could cross in 5 days. She and her sister ship Mauritania held the Blue Ribband, the prize for being the fastest ships on the ocean.

So why wasn't Titanic designed to take the Blue Ribband AND be the biggest ship on the ocean? See requirement 3). The Olympic class ships sacrificed speed for comfort. They would be built for 6 day crossings, but in style. The resistance of water on a ship increases geometrically as you increase speed. "***The book***" highlights an 1871 experiment in which the HMS Greyhound was towed at different speeds and it's resistance to the water was carefully measured. From this, a more imperical and mathematical understanding of speed, resistance and horsepower aided naval architects as the 20th century approached.

Doubling a ship's speed doesn't mean doubling the horsepower. It takes 2 **cubed** more horsepower or 8 times the power to double the ship's speed at low speeds and more as speed increases. That difference of 5 extra knots to save a day meant Lusitania burned more coal to produce the needed speed than Titanic would burn in 6 days, even though Titanic was a larger ship. Coal costs money and takes a longer time to coal the ship between voyages, which might impact schedule as well. Titanic would burn about 50 tons of coal per day more for each half knot above the 21-22 knots for which she was designed. See requirement 3).

So how do you figure out how big an engine you need for something nobody ever built before? It's mostly formulas. ***"The book"*** describes four basic formulas that will size the power plant.

First we need to know the "wetted surface" or how much of the ship is actually in the water. That's calculated and estimated based of the shape of the hull using geometry and successive approximations.

Second, if we know the wetted surface, there's another formula to calulate the resistance of the hull to water. Longer ships with smoother hull surfaces have the best coefficient of resistance. This is also why Titanic had all flush rivets (rivets with no protruding heads) below D-deck over the entire lower hull.

Third, if we know the resistance, yet another formula is used to calculate how much power is needed to propell the ship at a given speed.

And fourth, if we know the amount of steam horsepower we need, a final formula is used to calculate the amount of boiler surface needed to produce a steady flow of adequate steam.

In short, the H&W naval architects came up with about 45,000 shp to move the ship at the desired speed. After that, selecting 2 reciprocating engines with 15,000 hp each and a turbine with 16,000 hp was an exercise in convenience. The boiler arrangement was also made to have enough boiler surface to provide that much steam, and not much more. To get that much boiler surface in the space available, the double ended boilers of that size were chosen.

So, was Titanic trying to set a speed record or win the Blue Ribband? It couldn't if it tried. Titanic's top speed was about 24 knots. Despite the coal strike, Titanic carried enough coal to make the crossing with about a two day reserve at normal speed. It could have finished the voyage at 24 knots at the cost on another 100 tons of coal, but that's well short of the speed of the Lusitania. Without the extra boilers to maintain the steam needed for anything faster, setting any records was impossible.

J. Bruce Ismay was kept apprised of the coal storage and consumption figures. He also knew Titanic could never much exceed the design speed limit so there was never a point in trying.

Yeah, but after Capt Rostron heard the distress call, he set a speed record for Carpathia in reaching the life boats! No. He didn't. Carpathia was a 14 knot ship. Captain Rostron caculated they were 58 miles from Boxhall's position of Titanic and figured it would take 4 hours to get there. He enountered the lifeboats in about 3 hours and everyone hailed the record setting speed.

Actually, Carpathia started south east of Boxhall's position and headed straight for it. Titanic didn't sink there. It sank some 13 miles east of Boxhall's position. The diagram belows shows that the lifeboats were in the circled area just off Capt. Rostron's course. After the collision, Titanic and then the lifeboats drifted south closer to his course and lights from the survivors were seen by Carpathia. At that point, nobody aboard Carpathia would have bothered trying to get a tedius accurate fix. They **must** have reached Boxhall's position because the boats were there!

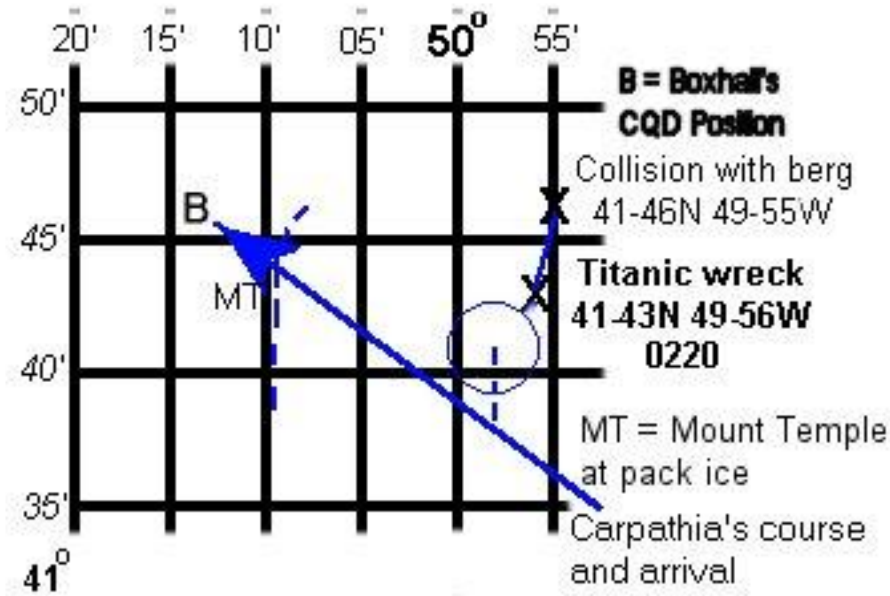

Figure 1: Carpathia never reached Titanic's CQD position

The fact is, Carpathia traveled 13 miles less than Capt. Rostron thought. Despite the best efforts of Carpathia's engineering crew, it didn't have the horse power and boiler capacity to exceed it's design speed. It was still a 13-14 knot ship. If this had been considered in the early 1980's, perhaps Jack Grimm and the French-American expedition that found Titanic would have started their searches much farther east.

How did Thomas Andrews know Titanic would sink? And when? The same way modern naval architects would know. John Bedford and Chris Hacket used computers at H&W to do the very same things Thomas Andrews and Edward Wilding did 90 years earlier and got similar results. "***The Book***" describes how to do stability calculations for a ship's design.

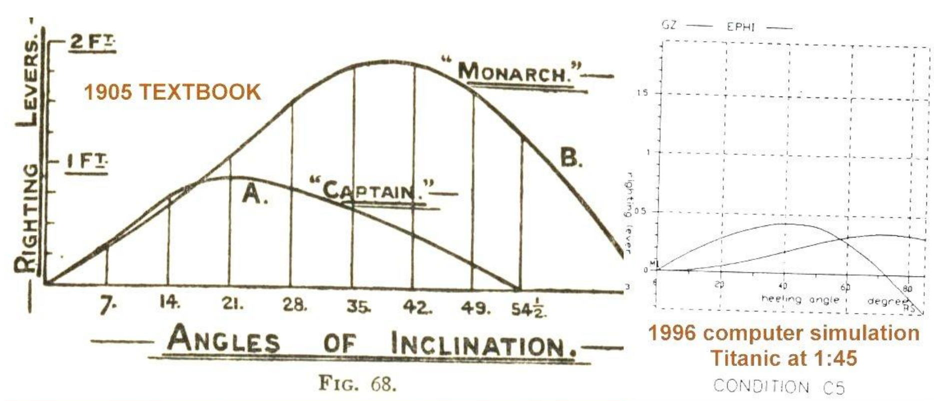

Figure 1: 1905 and 1996 Damage Stability calculations

These graphs are created by naval architects to determine the damage stability of a ship. As a ship takes on water, it changes the center of gravity of the ship. As water comes in, the line on the stability graph curve goes down. When the line goes negative, the ship doesn't want to float upright anymore. It will tip or roll over and either would be bad. The principles and methods have changed little since "***The Book***" was written.

Tom Andrews knew where the tipping point would be because he calculated the ship's volume in detail and that helped him decide how many watertight bulkheads to design in and where to put them. He knew that 30-odd thousand tons of water anywhere in the ship would be fatal and Titanic could handle any two compartments or the front four compartments being flooded.

When Tom Andrews surveyed the damage to Titanic, he knew 6 compartments flooded was fatal. Those damage stability curves **would** go negative. The question of *when* depended on how fast the water was coming in. By looking at the water level in each compament after the first 20 minutes, he could easily calculate the volume of seawater. He knew the compartment dimensions. From that, it's a back-of-the-envelope calculation to determine the rate of inflow. From that, he knew Titanic would reach 30-odd thouand tons in about an hour and a half.

He was close to right on the time. At about 2am, Titanic's damage stability curves went negative. When that happens, things happen quick. It took Titanic over two hours to tip down about 10 degrees. Once the damage stability curves went negative, the ship would have tipped the next 70 degrees in a few minutes had it not broken in two first. Paul Quinn wrote "Titanic at 2am" highlighting these sudden changes.

Why did Titanic have to break-up? Titanic was designed to sail the stormy North Atlantic, not sink gracefully. ***The book*** highlights the Trochoidal Wave method of determining how strong to build a ship, which Edward Wilding of H&W stated at the UK hearings was used in designing Titanic. A trochoidal wave is an imaginary ocean wave that is the worst wave the ship could theoretically encounter. This wave has a period (distance between peaks or troughs) equal to the length of the ship and 1/20th it's length in wave height. When the ship is on top of the peak, the ends bend down with the least support (called hogging). When the trough is in the middle, the ends are pushed up the most (called sagging). No other combination of waves that occur in nature will stress the design more than that.

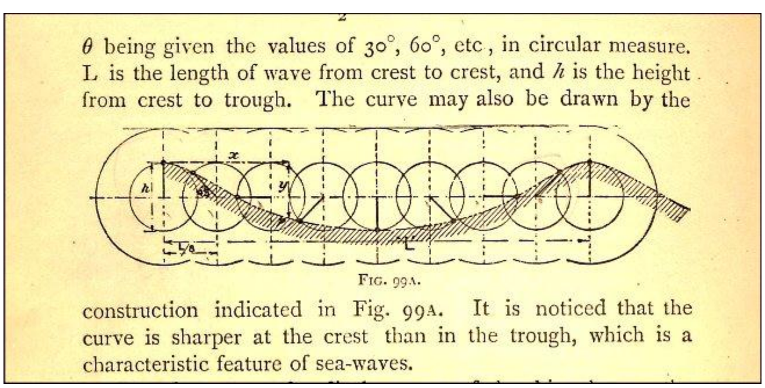
θ being given the values of 30°, 60°, etc, in circular measure. L is the length of wave from crest to crest, and h is the height from crest to trough. The curve may also be drawn by the

FIG. 99A.

construction indicated in Fig. 99A. It is noticed that the curve is sharper at the crest than in the trough, which is a characteristic feature of sea-waves.

Figure 2: Trochoidal waves in Theoretical Naval Architecture

Naval architects like Tom Andrews and Ed Wilding could calculate the loads associated with the maximum hogging and sagging conditions of a trocoidal wave and select appropriate structures for the ship. Just before the break-up, Titanic was loaded by more than half its own weight at one end, lifting a third of the ship out of the water at the other end. People may argue about whether Titanic broke up at a 16 or 23 or 45 degree angle, but anything after the first 10 degrees places loads and stresses on Titanic's design far in excess of anything in a trocoidal wave scenario. The only way to *avoid* breaking up would be to capsize sideways.

Why did they put that funny octagon shaped thingy on the side of the "Big Piece"? To help protect against trocoidal waves.

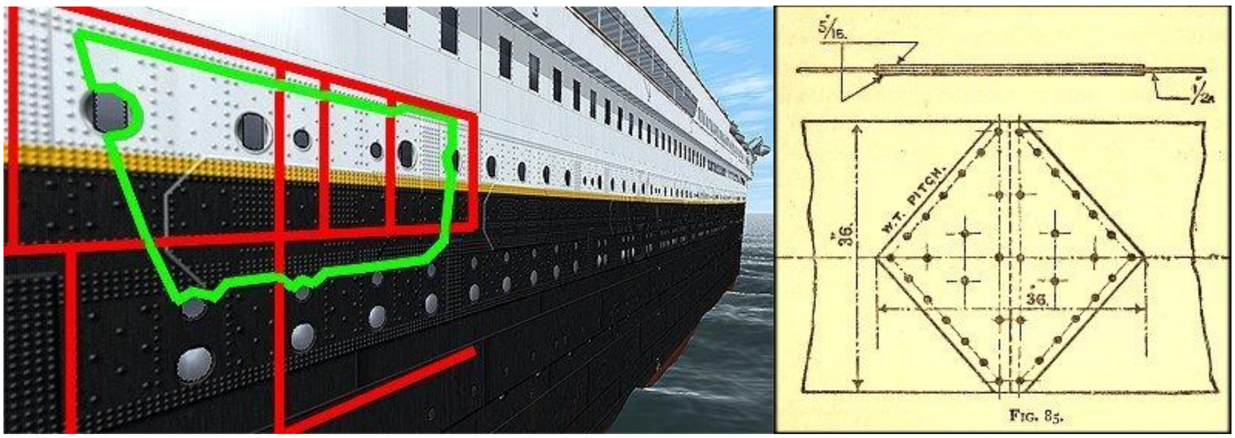

Figure 3: The octagon shape on the Big Piece and elsewhere on Titanic

When a ship is sagging in the middle, the greatest compression stress is on the top of the structural hull (which was the bottom of B-deck and all of C-deck). Rather than have two plates overlap, "***The book***" says it's better to have the plates butt up together end to end, and you cover the joint with a strap across the joint on both sides. You want enough rivets to account for the length of the joint, but you don't want to drill too many rivet holes close together to where a crack can run straight through all the row of holes. The solution is to have a strap on each side of the plates with a diamond shape. That way you can space out the rivets and not have many long lines of very close rivet holes.

Titanic had double 1" plates so they butted together at slightly different points and one *long* strap covered both joints. The octagon shape is a compromise on the diamond shape suggested in "***The book***". They only did this along the top of the structural hull. The double bottom solved the stress problem differently. The reason the Big Piece is so heavy is because you have two 1" plates, plus the octogon is 1" steel, and there's two slightly smaller 1" rectangular plates over the two joints on the inside. That's 4 inches (100mm) of steel there. They decided to raise probably the heaviest section of hull that size out there.

Conclusion

While ship building techiques and methods have changed dramatically since 1905, the basic principles of naval architecture have not. Those principles were very well understood as Titanic was designed. “***The Book***” provides useful technical insight into the Titanic story.