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The Sinking Of the Titanic

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ABSTRACT

The Titanic was a British luxury passenger ship completed in 1912 that was one of the largest of its kind at the time. When built it was widely deemed to be virtually unsinkable, but the ship met with disaster after hitting an iceberg on its maiden voyage. This resulted in the sinking of the vessel and the deaths of over 1,500 of the 2,224 passengers and crew.

Although impact with the iceberg was the catalyst, investigation has suggested that material failures and design flaws, as well as outdated safety requirements, all played a role in the large scale destruction and loss of life. In particular, this paper will focus upon the impact of the brittle steel used for the hull, the failure of key rivets, the flawed design of the watertight compartments, the inadequate number of life boats onboard, and the excessive speed of the vessel under the conditions. It will also review changes to marine design and safety requirements that resulted from the tragedy, including the formation of the International Ice Patrol (IIP).

1 INTRODUCTION

The Titanic was among the largest and most luxurious ocean liners to have ever been built to date in the year 1912. It was owned by the White Star Line and was constructed by Harland and Wolff, a ship building company located in Belfast, Ireland. She was nearly 275m long, 54ft tall, had a tonnage of over 46,000, and was billed as the largest moving object ever made by man. At the time, Britain was the world leader in ship building and the Titanic was said to have incorporated the best traditions of British shipbuilding and the latest techniques of design and construction. [1] It was a common held opinion that the Titanic was an "unsinkable" ship and the Titanic's Captain Edward Smith was quoted as saying "I cannot conceive of any condition which would cause a ship to founder" and that "modern shipbuilding has gone beyond that". [2] According to the Titanic's builders, even in the worst possible case of two ships colliding, the vessel should stay afloat for at least two to three days, providing adequate time for passengers to be ferried to safety. [3] Unfortunately for the Titanic this was not the case.

On April 11th of 1912, the Titanic set out from its final European port on its maiden voyage to New York carrying 2,224 passengers and crew. Over the period of April 11th to 14th, warnings of icebergs and ice flows were being transmitted by at least twenty ships along the Trans Atlantic route. Although the Titanic did not receive all of these, there was "irrefutable evidence that enough were picked up that Captain Smith was well aware of the potential danger". [2] Despite this, on the night of April 14th the Titanic sideswiped a large iceberg several hundred miles southeast of Newfoundland and sank in less than three hours. The collision damaged the hull and allowed water into six of the sixteen watertight compartments, more than the ship could handle. Of the 2,224 passengers and crew, only 705 survived, making the sinking of the Titanic one of the worst maritime disasters in human history. [3]

2 MATERIAL FAILURES

The quality of several of the materials used in the construction of the Titanic is believed to be a major contributing factor in the vessel's demise. The impact from the Titanic's collision with the iceberg caused both the hull steel and the rivets holding the steel plates together to experience brittle failure. Brittle failure occurs in structural materials very quickly and without plastic deformation. This type of failure is often caused by low temperatures, high impact loads and high concentrations of sulphur. All three of these criteria were present at the time of the Titanic sinking. [3]

2.1 Hull Steel

In 1991, a piece of the hull material of the Titanic was recovered for the first time since the vessel went down. The mechanical properties of the steel were tested by several institutions on behalf of the Maritime Museum of the Atlantic. The results of Charpy impact tests, used to gauge the brittleness of a material, indicated that the hull steel would act in a completely brittle fashion at the icy water temperatures that the Titanic was exposed to. This led to wide spread speculation that the lack of ductility in the steel may have been a major contributing factor in the rapid flooding of the ship.

Figure 1 below shows a comparison of Charpy test results of modern steel compared to the test sample from the Titanic's hull. The modern steel on the left bent without breaking when struck by an impact, while the Titanic's sample on the right is shown to have broken into two pieces in a brittle fashion under the same impact load. [4]

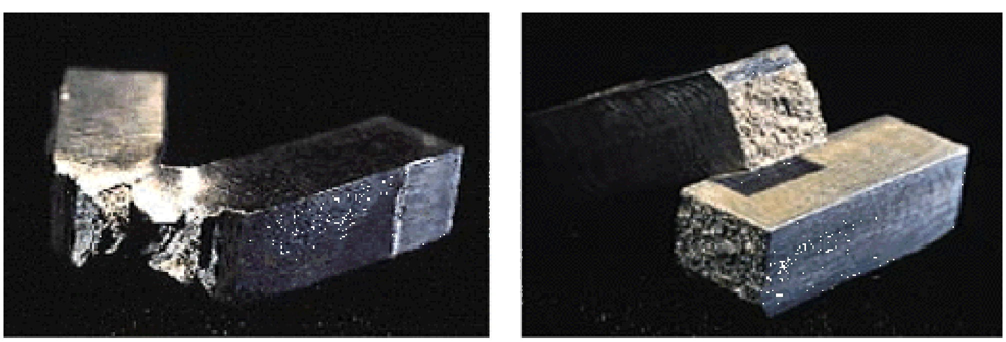

Figure 1: Results for Charpy Test of Modern Steel & Titanic Hull Steel [3]

Although the composition of the hull steel would be considered excessively brittle by today's standards due to the excessive amounts of sulphur and phosphorus, specifications at the time only called for "a range of tensile strength and tensile ductility, which is a poor indicator of fracture toughness." The Charpy tests had only been devised approximately five years prior to the construction of the vessel and few materials were tested for fracture toughness at that time. In fact, there was little theoretical information about steel notch sensitivity and it would not have been intuitive for the designers of the Titanic to test for a property that was so little understood. [4]

2.2 Rivets

The Marine Forensics Panel published a report stating that the damage to the Titanic consisted of a parting of the hull seams rather than a large iceberg induced gash. This would imply that failure of the rivets may have contributed to the sinking of the vessel. Two hull rivets were recovered from the wreck site in 1997 and were analyzed to determine if their metallurgic makeup may have been a factor to the sinking of the Titanic. The two rivets were found to contain approximately 3 times the usual amount of slag expected in wrought iron and were missing their interior heads. Due to the slag orientation, these rivets may have lost their interior heads upon impact causing them to pop out of the holes within the hull. Although this was a small sample, the Titanic was constructed with approximately 3,000,000 hydraulically driven, wrought iron rivets. Failure of even a fraction of the rivets would transfer load onto the remaining intact rivets and could bring stress levels to a failing point. [4]

In 2008, a book was released by Dr. Timothy Foecke and Dr. Jennifer Hooper McCarty outlining the results of analysis of 48 more rivets recovered from the wreck of the Titanic, as well as information about rivet material quality found in the original ship builder's achieves. The analysis of these 48 rivets was similar to the two rivets originally tested. They also contained extremely high concentrations of slag present in the iron. The scientists argued that findings from the archival research imply that a lower grade of material was used than was typical for rivets, and that less skilled riveters and forgers were employed due to the pure magnitude of the project and a shortage of skilled labour. However the Titanic's ship building company, Harland and Wolff, has gone on record stating that the "there was nothing wrong with the materials" used in the Titanic's construction and the findings are circumstantial in proving that the hull openings were caused by rivet failures. [5]

3 DESIGN FLAWS

Along with material failures, design flaws also played a contributing role in the sinking of the Titanic. Of these, the poor design of the watertight compartments had the largest affect on the time it took for the vessel to fill with water.

3.1 Design of Watertight Compartments

When designing the Titanic and its sister vessels, the Harland and Wolff building company set out to provide an exemplary level of safety for the current times. They did this mainly through subdividing the hulls of the vessels into watertight compartments. Fifteen transverse bulkheads divided the hull into sixteen watertight compartments, and each could be sealed off from the adjoining compartments through mechanized doors in the case of an emergency. [6] However, although these compartments were considered watertight, they were only effectively so in a horizontal direction. The bulkheads were not capped at the top and extended only several meters above the waterline. [7] The ship's builders claimed that four of the compartments could be filled without adversely affecting the vessel's buoyancy. However, at least six of the watertight compartments towards the bow were ruptured after the Titanic scraped along the iceberg. [2] As one compartment filled, it spilled over into the next due to the tilt of the sinking vessel. [7] Figure 2 below shows a layout of the watertight compartments with the thick horizontal black lines representing the approximate locations of the damage to the hull.

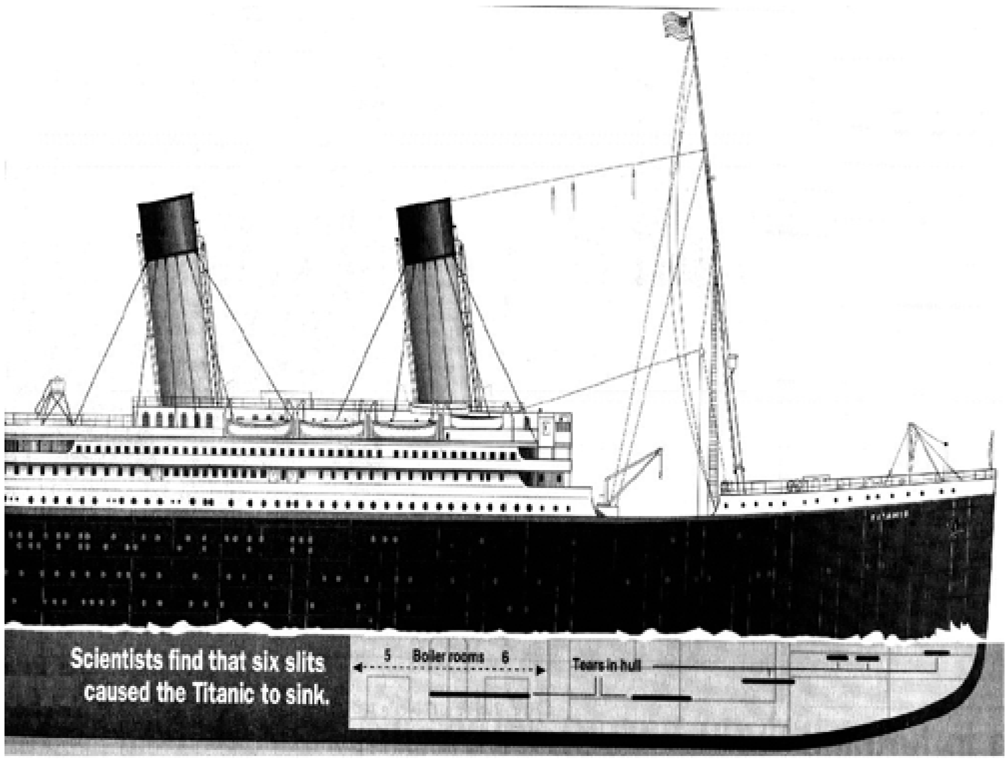

Figure 2: Approximate Locations of Damage to Titanic's Hull [3]

Five of the six breached compartments flooded within an hour after impact with the iceberg, and the Titanic sank to the bottom of the Atlantic Ocean in less than three hours. [8]

4 OUTDATED SAFETY REQUIREMENTS

The shipping industry of 1912 had a somewhat cavalier attitude towards maintaining safety standards and practices, neglecting to update as technology advanced. Two prime examples of this were the Board of Trade's minimum requirements for lifeboats aboard a vessel, and the standard practice of maintaining speed and course through ice treacherous waters when the weather was clear. People mistakenly believed that the improving advancements in construction and safety features made it unnecessary to update regulations that no longer strictly applied. A Nautical Advisor under the Board of Trade gave a statement that prior to the sinking of the Titanic he "found that [sailing] was the safest mode of travel in the world, and [he] thought it was neither right nor the duty of a State Department to impose regulations upon that mode of travel as long as the record was a clean one." [9]

4.1 Life Boats

Although the Titanic carried 2,224 passengers and crew, the capacity of the lifeboats onboard was only sufficient to handle slightly more than half of that number. Despite this, the vessel was fully compliant with all current marine laws. The British Board of Trade required all vessels over 10,000 metric tons carry a minimum of sixteen lifeboats. The Titanic had twenty lifeboats aboard, exceeding the requirement by four devices. However, the Titanic's total mass was over 40,000 metrics tons, considerably more than the classification criteria. The British Board of Trade had not updated the lifeboat requirements in over twenty years, and the discrepancy was due to regulations designed for a time before vessels of the pure magnitude of the Titanic. Additionally, there had not been a significant loss of life at sea in forty years. Lifeboats were considered more as a tool to simply ferry passengers to rescuing ships rather than being "designed to keep all the ship [passengers] and crew afloat while the vessel sank". There was a misconception that any sinking vessel would have enough time to be evacuated, as reinforced by fatally crippled ships in recent history of the time. [10]

Furthermore, although there was potentially enough capacity for 1,178 people, only 705 were saved. Almost 500 empty seats were left unused on the launched lifeboats. This was partially due to the lack of training of staff with evacuation procedures. No official drill was ever conducted during the voyage and only one had been completed prior to launching, when not all staff were present. This was compounded further by the lack of experienced seamen aboard the vessel in ratio to support staff. [11]

4.2 Vessel Speed

After leaving Queenstown, the vessel's final stop in the UK, the speed of the Titanic was gradually increased every day. The distance travelled the first day was 745km, the second day was 835 km, and the run the third day was 879 miles. The ship was making the maximum speed of the voyage just prior to colliding with the iceberg, at a pace of 21 knots or 39.9 kilometres per hour. [12] Although the Titanic's captain was informed of ice fields ahead by several other vessels, he did not decrease his speed. He was following the standard procedure of the last quarter century to "keep course in clear weather, to maintain speed, and trust to a sharp look-out to enable them to avoid danger". The disastrous results proved this to be a dangerous practice, whose roots likely originated in "competition and the desire of the public for quick passages, rather than in the judgement of navigators". [13] It has been speculated that if the Titanic had been travelling at half as fast it would not have suffered such extensive damage and fewer of the ship's compartments would have flooded. It is even likely that although injured, the Titanic would have completed her maiden voyage and arrived safely in New York. [14]

5 RESULTS OF THE DISASTER

The sinking of the Titanic on her maiden voyage led the shipping industry and the public to realize that some of the industry's requirements and practices had serious flaws. Several existing vessels were modified to fix design issues that were believed to have contributed to the Titanic's demise, and new ships also incorporated these changes. [3] Following investigation into the incident by both American and British authorities, various safety recommendations were made concerning updates to maritime requirements. The first International Convention for Safety of Life at Sea (SOLAS) was held in 1913 and many of these recommendations were formalized into regulations. This also lead to the establishment of the International Ice Patrol (IIP) in an attempt to decrease the danger associated with icebergs and ice flows in the Atlantic Ocean. [2]

5.1 Marine Design

The White Star Line modified the hull design of several of their existing vessels in two major ways in response to the disaster of the Titanic. The double bottoms of the ships were extended further along the hulls, and the watertight compartments were raised so that they were watertight vertically as well as horizontally. A double bottom is constructed from two layers of steel, separated by a 1.5m gap, spanning the entire length of the ship. If the outer layer of the hull is breached, the inner layer would likely remain intact. By raising the height of the transverse bulkheads, water is prevented from flowing over the top of one compartment into the next in the case of a breach in the bow compartments. This allows flooding to be isolated and contained to damaged sections. [3]

Although the first SOLAS Convention was first held in 1913, it has been hosted several times since in order to keep maritime safety measures up to date. The current version is SOLAS 1976 which is still in effect but has been updated many times. [15] It was during the 1948 convention that specifications for the orientation, length, and number of watertight compartments were first established in relation to passenger vessels. It was determined that compartments should be oriented across the width of the ship so any flooding would be evenly distributed and allow a nearly level position to be maintained. The length of the watertight compartments is to be determined by the length of the ship, and the number of compartments is also based on size. [3] All of these factors served to improve the safety of vessels in the case of a collision.

5.2 Safety Requirements

While the sinking of the Titanic lead to many modifications to marine design, it also drastically changed the degree to which safety was considered in the shipping industry. The SOLAS convention required more stringent safety practices in many areas including, continuous radio watch, vessel speed around ice, the number of lifeboats on a vessel, and the training and implementation of lifeboat drills, among others.

There was great controversy surrounding a vessel that had been less than thirty kilometres away from the Titanic when it sank, but the radio controller onboard had already gone off duty by the time distress signals were sent. This led to the requirement of continuous radio watch at all hours so that future distress calls would not go unnoticed as in the case of the Titanic.

The official investigation into the sinking of the Titanic determined that excessive speed in proximity to ice had led to the vessel's demise. Under SOLAS, when ice has been reported near a planned course, the Captain of the ship is required to either keep a moderate speed or alter the course of the vessel.

The Titanic carried only enough lifeboats to accommodate slightly more than half of her passengers and crew in accordance with the British Board of Trade's minimum requirements for vessels over 10,000 metric tons. However, following this incident the SOLAS convention ruled that passenger ships must carry enough lifeboats for all passengers aboard, as well as providing life rafts for an additional 25%. It was also determined that there must be regular practice drills in the use of a ship's lifeboats for both crew and passengers. The lack of training and practice in this area contributed towards the confusion surrounding the launching of lifeboats from the Titanic, leading to the deaths of many.

All of these factors, as well as several others implemented from the SOLAS convention, are intended to give passengers and crew the greatest chance of survival in the case of a catastrophe at sea. [15]

5.3 International Ice Patrol

On January 30th, 1914 a treaty was signed at the first SOLAS conference that lead to the formation and international funding of the International Ice Patrol. An agency of the United States Coast Guard, the IIP monitors and reports the locations of icebergs that could potentially be a threat to vessels along the transatlantic seaways. [16]

Currently the IIP and the Canadian Ice Service (CIS) issue one daily iceberg analysis under a collaborative agreement titled the North American Ice Service (NAIS). Analysis is presented in the form of text bulletins and graphical charts and the collaboration serves to improve ice formation monitoring and service to mariners.

Neglecting the years of the two world wars, the IIP has been active during each ice season since 1913. In this time it has compiled an exemplary safety record and no vessel that has followed the IIP iceberg limits has yet to collide with an iceberg. [17]

6 CONCLUSION

The sinking of Titanic was one of the worst maritime disasters of recent history with large scale loss of human life. Many theories circulate about the major contributing factors leading to the loss of the largest ship of its time. The most probable theories based on recent evidence have been presented in this paper.

The material composition of the steel plates and iron rivets used to construct the Titanic’s hull was predominantly at fault for the rapid flooding of the vessel. Brittle failure of the steel hull upon impact with the iceberg, along with failure of the rivets due to high concentrations of slag greatly increased the degree of damage and the speed at which it occurred.

Additionally, industry safety requirements at the time were not sufficient to prevent the large scale loss of life. The British Board of Trade only required lifeboat capacity to be sufficient for approximately half of the passengers and crew onboard, and drills in evacuation were not mandatory. It was also the standard procedure of the time to maintain constant speed and course in clear weather under warnings of potential ice, relying on lookouts to avoid any danger. Neither of these practices adequately considered the safety of all aboard.

Following the tragic events of April 14th, 1912 there was widespread modification to existing marine design, as well as the implementation of new and more stringent safety requirements. Ship hulls were modified to extend double bottoms further and raise the height of the watertight bulkheads. Specifications were also established concerning the orientation, length and number of watertight compartments. In addition, the first SOLAS convention, as well as others after, established increased safety practice requirements to give passengers and crew the best chance of survival in the case of a catastrophe. These included requiring 24 hour radio watch, more moderate speeds or adjusted courses in the case of ice warnings, sufficient lifeboats for all passengers plus an extra 25%, and mandatory drills in lifeboat evacuation procedures. The first SOLAS convention also led to the establishment and funding of the International Ice Patrol, an agency who tracks and distributes information about the location of icebergs along the transatlantic seaways.

Understanding the factors that led to the sinking of the Titanic is vital to preventing similar incidents from occurring again. The lessons learned from this tragic loss have had great impact on society’s views on the danger of overestimating new technologies and the importance of maritime safety. Although it required a horrible tragedy to bring these changes about, many lives have since been saved because of these modifications to marine design and safety, and the creation of the International Ice Patrol.

REFERENCES

[1] L. Marriott, “Titanic”, 1997.

[2] “Titanic: The Unsinkable Ship”, Encyclopaedia Britannica, 1998.

[3] V. Bassett, “Causes and Effects of the Rapid Sinking of the Titanic”, 1998. http://www.writing.eng.vt.edu/uer/bassett.html. Retrieved March 5 2013.

[4] T. Foecke, “Metallurgy of the RMS Titanic”, NIST-IR 6118, 1998

[5] W. Broad, “In Weak Rivets, A Possible Key to Titanic’s Doom”, The New York Times, April 15 2008.

[6] A. Clarkson, “Titanic’s Watertight Compartments”, 2013. http://www.titanic-titanic.com/titanic_watertight_compartments.shtml. Retrieved March 6 2013.

[7] R. Gannon, “What Really Sank The Titanic”, Popular Science, February 1995.

[8] BBC, “More Information About: Titanic”, 2013. http://www.bbc.co.uk/history/titanic. Retrieved March 9, 2013.

[9] “Report on the Loss of the S.S. Titanic”, 1990 (original report date 1912).

[10] C. Berg, “The Real Reason for the Tragedy of the Titanic”, The Wall Street Journal, April 12 2012.

[11] A. Nicholas, “To the Lifeboats – Evacuating Titanic”, American Daily Herald, April 15 2012.

[12] S. Spignesi, “The Complete Titanic”, 1998.

[13] “The Titanic Disaster, Due to Excessive Speed”, The Connaught Telegraph, August 3 1912.

[14] S. Wells, “Titanic: Legacy of the World’s Greatest Ocean Liner”, 1997.

[15] “Surviving Disaster – The Titanic and SOLAS”, International Maritime Organization, 2013. http://www.imo.org/OurWork/Safety/regulations/documents/titanic.pdf. Retrieved April 9, 2013.

[16] M. Levinson, “A General Semantics Analysis of the RMS Titanic Disaster”, 2012.

[17] “International Ice Patrol”, 2012. http://www.navcen.uscg.gov/?pageName=IIPHome. Retrieved March 10, 2013