TITANIC’S FORENSIC ANALYSIS COLLECTION

ITSSTILLTHINKING
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Introduction

Since her sinking in 1912, the Titanic has fascinated millions of people for over 100 years. And while the ship itself has always had a great interest; the sinking in particular is what most people are drawn too. Since that long-ago April, scores of people have tried to figure out how the ship behaved and sank during those two hours and 40 minutes.

With the advancement of technology and computers, the shipping industry has created tools to help simulate disasters and determine how ships will react to different types of flooding. Starting in 1996, naval engineers have used this technology to determine how much damage the ship attained and determine the ships trim and heel during the sinking.

This document will take all of the major forensics’ analysis done over the years and compile them into a readable and usable format for people to understand and use to help more accurately portray the sinking of the Titanic. This document will also compare it to survivor testimony and the famous 2012 animation found the Final Word documentary to see how they all differ from each other and find an average for the ship’s behaviour.

It should be stated that this document does not express how the ship sank for certain, but simply to help people understand the characteristics of the sinking better. While this document will compare each scenario, it is not the intent to bash or be negative to all of the hard work that clearly went into many of these simulations.

This document’s purpose is to simply allow people to have access to reliable information for understanding her sinking and portraying her movements.
History Of The Analysis

As stated in the introduction, Titanic's history with the modern-day tools of the shipping industry go all the way back as far as 1912. During the inquiries, Harland and Wolf architect Edward Wilding was called to ask technical questions on the Titanic. Some of his questions asked were relating to the flooding of the ship, and his thoughts on it.

To keep it short, Wilding using math, was able to get rough estimates of the ships damage by using survivor testimony on how fast areas of the ship were flooding. He was then able to use this to calculate how much water would have entered the ship for the early stages of the sinking. While not the most complete picture of the flooding, his calculations have been the basic framework for all future forensic analysis for the next 100 years.

The next major look into how the ship sank would not be attempted again until 1996. Using the NAPA flooding and hydrostatic programs, Harland & Wolff employees Hackett and Bedford released the paper *THE SINKING OF S.S. TITANIC - INVESTIGATED BY MODERN TECHNIQUES*, paper which laid out in 60 pages their findings on how the ship sank according to the simulations.

Using Wilding’s original work as a starting point, their work matched much of the survivor testimony in certain areas on how the ship behaved and how fast water flooded areas. They also ran a number of additional scenarios, which included flooding any two compartments, three compartments and leaving all the watertight doors open. Their conclusions not only supported the fact that the Titanic could be flooded in any two compartments, it was found that in several different scenarios, as many as three could be flooded and the ship would float. They also went out to test the theory that if all of watertight doors remained opened, the ship would have lasted longer due to the damage being retained only the initial 12 square feet and the ship would have settled on an even keel. It was found that the ship would have lost power far earlier and sank a half an hour faster than the actual event. With much of this time being unusable as the ship was listing heavily to port or starboard. While inaccurate in several ways, this paper remains the most complete look into the sinking of the ship.

Throughout the rest of the 90’s, William Garzke and others would use this data to do several stress analyses tests to determine at which point would the ship most likely have broken. Due to author not having these papers and since they do not add any new flooding tests, these will not be explored further.

The next set of major testing with the ship was conducted during 2005, in which JMS Naval Architects were asked to find the point at which the ship was under the most stress. This simulation was featured in *Titanic’s Achilles Heel* in which to test if the ship was poorly designed. While it did not go into very much detail in the companion paper, the footage in the documentary seems to allude that further sinking tests were done to calculate the finding in the paper. With only one published angle, this is not what one considers a very comprehensive look at the sinking.

The final analysis of the ship was conducted from 2010 to 2012, in which James Cameron initiated the most comprehensive study of the ships sinking to date. In addition to the paper, the results of this simulation were also feature in the *Final Word* documentary.
Concluding the 2012 analysis, no further research has been made public and with general interest in the ship slowly fading, it is seemingly unlikely that any more will be conducted in the near future.

**Hackett & Bedford Analysis**

The first modern look at the flooding of the Titanic was done in 1996 by Harland & Wolff employees Hackett & Bedford in cooperation with RINA. This was a milestone in Titanic’s history as it showed that by using modern tools, it was possible to get a whole new understanding on the flooding. Prior to this simulation, all people had to use for the ships trim and heel was survivor estimates. Now there were precise angles historians could work off and see how it compared to how people saw the ship sink.

This work also allowed other’s to then do stress estimates on the ship, allowing for the greater understanding of the forces involved in the break-up. This simulation was made famous in its inclusion in the documentary *Titanic: A Anatomy Of A Disaster* and future works until the early 2000’s.

Starting by creating a recreation of the ship in digital form, the duo went on to use the NAPA hydrostatic and stability software to complete their simulations. Using Wilding’s findings as a start and other survivor accounts, they began to estimate the hole in which the iceberg caused upon the initial collision with the ship. Their estimates showed that the ship had sustained damage around 12.60 square feet, and with an initial flooding rate at around 25,000 tons per hour (in contrast, the maximum pumping capacity was 1700 tons per hour). The simulations also showed a steady rush of water until the sinking slowed down, due to the ship nearing an equilibrium and then proceeds to speed up dramatically.

Their findings also show that flooding boiler #4 early causes the ship to become unstable, leading to the ships list to worsen until it capsizes. It was also found that raising the bulkheads as high as D deck would prove insufficient in keeping the ship afloat.

The following figures are remakes from the original paper, showing the progressing of water through conditions C1-C7. These are faithful recreations of the paper from the ships trim to the placement of water.

*Figure 1- C1*
This condition shows the ship at 11:50, or 10 minutes past the collision. Water is already at 8 feet high in boiler room #6 and the coal bunker in boiler room #5 is filling. The mail hold is rapidly filling while holds #1 & #2 are following each other closely.

![Figure 2-C2](image)

This condition shows the ship at 12:00. The flooding in the three compartments aft of the forepeak have equalized.

![Figure 3-C3](image)

This condition shows the ship at 12:20. With the ship settling lower in the water, the rate of flooding will slowly decrease, as the buoyancy in the remainder of the ship start to equalize the flooding.
This condition shows the ship at 12:40 or 1 hour after the collision. Water is now up to the ship’s lettering and heavy flooding of the forward D Deck is underway.
This condition shows the ship at 1:45. This will be the point at when the ship begins to lose her fight to stay afloat. Water is now almost atop of the forecastle and C deck in the tip of the bow is beginning to flood. Water is also now beginning to work its way down Scotland road into boiler room #4.

This condition shows the ship at 2:10. Time is now fast running out for the Titanic. All the ships collapsible’s has left the ship outside of the two stored next to the #1 Funnel. Water is now rapidly filling boiler room #4 in this simulation and the ship is about to make her final plunge. This is were the simulation begins to differ to the real event (As discussed later).
This condition shows the ship at 2:15. It is at this point in the real event when the ships final plunge begins as water floods the bridge. This simulation shows that more than 35000 tons of sea water has entered the ship at this point.

As will be discussed later, the initial flooding matches fairly closely to survivor accounts and other simulations for most of the sinking. It is not until the late stages of the sinking, in which the ships angle starts to increase dramatically were it begins to differ. Condition C7 is their estimates at 2:15, however this shows water up to the #2 funnel, when in reality, 2:15 is when the bridge goes under.

However, the angles when compared to the other simulations are remarkably similar, as will be discussed later on. And while this simulation is over 20 years old and is inaccurate in many ways, the similarities to other more recent analysis show that to a degree, the data located here should not be ignored.
JMS Naval Analysis

In 2005, a History Channel expedition was the first to thoroughly document the two double bottom pieces in their entirety. Previous expeditions had done some minor surveying of them in the 90’s, but not a complete picture of both. Using this data, Roger Long came up with a new theory of the break-up, of the ship hogging in the center and causing a V break at a low angle. He also made the claim that the Titanic was a poorly designed ship, and her poor design caused her to break up quicker than she should of, killing more people.

To support his theory, a new analysis of the ships flooding and load conditions were conducted at the JMS Naval Architects. Their aim was to test the hull in a variety of scenarios to see if Titanic could even handle a long life in the first place. Their results concluded that even with an unrealistic wave, Titanic was more than adequate to handle it, with the stress bearing being far less than her eventual sinking.

Unfortunately, while its alluded to in the documentary, and in the paper, there is no detailed look at the flooding of the ship. With the paper being only 11 pages long, it only very briefly goes over the flooding. The image below is a reproduction of the paper figure.

![Figure 8](image)

JMS came to the of a 10-degree trim angle before the peak stresses caused the hull failure.

Again, with a lack of clarification on how these results were obtained, this study will not be further looked at. The simulation also includes water in A, B & C deck as far aft as the second-class stairs. Why this was done is unknown and leads to one to doubt on the reliability of the flooding shown in this analysis.
GHS Analysis

With the mark of the 100th anniversary looming, James Cameron and his Blue Planet Marine Research Institute commissioned for a brand-new flooding, sinking & structural failure analysis of the ship. This was to be the most accurate and technical analysis of the ship done to date, with gained information of the structural and historical details added in wake of 20+ years of research and wreck diving since the ship’s initial discovery. This was also to use the most up to date and advanced forensic programs available, these being POSSE, GHS & MAESTRO with modifications made for them specific for this project.

The first step for the team was to create a digital recreation of the ship with far greater detail than originally conducted by Hackett and Bedford. This included open portholes as they were found on the bow section of the wreck and other data not known in the 1996 analysis. This would help provide far greater detail, as it would change the characteristics of the flooding.

While the initial flooding analysis was conducted using POSSE, it was eventually switched to the GHS system for greater accuracy in tracking the flooding. Using the flooding data, the team took the ship at any intermediate stage and input it into the MAESTRO program to determine at what angle would the ship reach peak stresses of initial failure. In short it was concluded that the ship fractured at around 23 degrees in the upper decks around the #3 funnel.

And unlike the Hackett & Bedford analysis, several scenarios were run with different degrees of initial damage with benchmarks of each. These ranged from 9.20 square feet to as much as 10 for the benchmarks, with other degrees of damage tested as well.

The problem with analyzing the data found in the paper is that it can’t be determined precisely what angles are found for each scenario, as they are represented in a line graph. In order to give usable information for the comparison (As found in this section), it was determined to use a cross line system to figure out what angle the ship was at any 10-minute interval. However, none of the tested scenarios ever came close to the agreed upon 160-minute time frame of the real event. The two closest scenarios were the “Best Estimate Permeability Benchmark” which showed the ship sank just before 190 minutes elapsed. The other was the “Max Permeability Benchmark”, which showed the ship sank just before the 150-minute mark. It was decided to focus on the scenario which most closely mimicked the real event.

With this decided upon, using a simple cross bar system in photoshop was sufficient to find the required angles and draft measurements. However, there was also another source for cross referencing the angles found in the paper. In 2012, National Geographic aired the Final Word Documentary with James Cameron, and in a segment of the doc, one of the GHS scenarios was shown in the upper corner. Using video editing software, its possible to enhance the footage and snippet enough to gather a near complete GHS sinking scenario. While not explicitly said, it was found to be a near match to the angles and draft calculated in the Max Permeability Benchmark found in the paper.

With this information in hand, a complete set of faithful recreation of the GHS sim was created in the following images, with particular note given to the location of flooding indicated by the software. It should be noted however that this model was run a locked 0-degree heel (How a ship leans from port to
starboard) due to the model capsizing and being unstable. This will be an important note when discussing the 2012 Final Word animation.

In the first 10 minutes of the sinking, the ship floods very quickly. The forepeak floods fast, as does the baggage and mail holds. Flooding in boiler room #6 slowly rises to 8 feet as described by firemen Fred Barrett, preventing any future work in this room.

In gathering the GHS data, there was no visual representation of the ship to compare to until the 50-minute mark. At this stage all the forward compartments have for the most part equalized with water now ready to make its way onto E deck, giving water access to Scotland road and allowing it to advance more easily aft.
Boiler rooms #5 & #6 are both flooded at this stage, with water flooding forward of the #1 hold. Water at this point has accessed the E deck landing of the grand staircase and is flooding the bunker for the #4 boiler room. Water at this point has flooded most of E deck in the bow, with water now primarily flooding areas above the forepeak.

Titanic’s bow is now well flooded, with water catching up to the ship’s exterior waterline. Flooding has now also moved aft of the E deck landing at the grand staircase, though no water has yet entered boiler room #4. It is after this point that the rate of flooding in the Titanic will increase dramatically as the bow loses all of its buoyancy.
Compared to the 50- & 100-minute mark, the 10 minutes following the 120-minute mark show a drastic increase of flood water. The forecastle on C deck is now flooding the forward areas, and water is filling the D deck landing of the grand staircase. Water is also now starting to fill the #4 boiler room, though its forward bunker has changed little. With its decks and the D deck shell door being submerged more and more, the surface area exposed to the sea will increase. This is also added due to several portholes being opened in the upper decks as observed on the wreck.
The ship is now losing her stability as all of C deck in the bow is completely flooded. The model indicates that the third-class dining room is also now filling as is the #3 boiler room, with the #4 filling more as well. Water can now also be seen entering the C deck landing of the grand staircase as well, with Titanic’s propellers now well above the water.

Figure 15- 145 Minute Mark

The Titanic’s final plunge has begun. Water has now filled the grand staircase up to the B deck level, and water is now completely filled the first-class dining room at this point. The #4 boiler room is also almost completely full of water, and #3 is filling faster than its forward coal bunker. The #1 funnel uptake is also not quite filled, this is interesting as it would help support second officer Lightoller’s testimony of some hot air blowing him off the forward vents as the bridge went under.
While the graph located in the paper is too small to make out the time this angle happened, it’s the author’s guess that it occurred around the 147-148 minute mark by eyeballing it. This is when the ship would have broken according to the MAESTRO finite model. The ship at this point would only have a few minutes to live, with the bow completely filled with water from the #2 funnel and forward. The model indicates light flooding as far aft as around the #3 funnel uptake, which would show that Scotland road would be completely flooded. Water has also begun to flood the forward coal bunker in the #2 boiler room and #3 is nearly full. The analysis suggests that as much as 60,000 lotn’s of water have entered the ship at this point.

The data gathered by GHS bears much of the same results as the 1996 simulation, just with far more detail and refining. Both suggest the general pattern that water initially flooded the ship at a high rate, then as the incoming water equalized with the ship’s remaining buoyancy, the rate of flooding slowed to a near stop. This all indicates that despite exceeding the design of the ship, the Titanic nearly survived her fatal collision. The slowing down of the flooding is what would have happened had the damage been contained to the first four compartments, or at best 5 if the damage in boiler room #6 had been controllable. However, as the Titanic began to stabilize and stop her flooding, the water reached the top of her watertight subdivision and began to flood slowing into boiler room #5 and then to #4 and so
forth. However as stated in the Hackett and Bedford analysis, even if the watertight bulkheads had been raised to D deck, it would have proved insufficient to keep the ship afloat.

**Final Word Animation**

This section might seem a bit odd, as this document primarily discusses the forensic analysis, not an individual animation. However, it was felt that the popular depiction of the ship sinking as shown in James Cameron’s *The Final Word* needed to be addressed in light of all of the data from the previously discussed simulations. It should be stated again that this is not meant to unfairly criticize or bash the hard work done here, but simply show it compared to other data.

The animation was created in light of all of the forensic and historical information that was not available to James Cameron during the production of his blockbuster film during 1995-1997. His goal was to create a computer animation that would serve as the most accurate one created and allow people to see a more up to date version of her sinking.

In order to do a proper comparison of this animation, a set of trim and heel angles were needed for recreations for both a mock-up recreation and for illustrations. To do this a simple process was used. Taking screenshots of different moments of the ship from the animation, these are then put into Photoshop. Using the horizon as a gauge, the difference between the horizon and the tilt of the decks was calculated, this can get some *estimates* of the angles used during the key frames of the animation. It cannot be understated the angles shown here are not 100% correct as seen in the original animation, however it was found when in creating 3D recreations, they seemed to fit closely to the original.

The following figures that feature water follow closely to what was shown in the animation. The lack of a port list in this 2D view can also change the position of the ship slightly.
Dubbed “First image of the bow” for this showing, this is the first view of the ship from the starboard side following the collision in the video. Water is shown much in the same as in the previous simulations. Though the water in boiler room #6 is shown fuller than before and the forepeak tank is not filled completely yet. There is also a lack of a noticeable 5-degree list to starboard reported just 5 minutes after the collision.

This is the profile of the ship just prior to it cutting away from the starboard bow view. The flooding has now completely flooded boiler room #6 and most of the forward F deck is now underwater. The ship in this showing has obtained a very small forward trim in relation to how far down she is.
The next usable view of the bow with the horizon as a reference point is when A deck is beginning to submerge underwater. The flooding shown in the ship is interesting as it does not match any of the previous data. This depiction shows water just now trickling into the most forward compartments and there is a lack of water on E deck. This profile of the ship would also make Boxhall’s lifeboat story impossible. In short, Boxhall stated after rowing some distance away from the ship in lifeboat #2, he obeyed Captain Smith’s orders to go to the aft starboard gangway. Boxhall decided to go around the stern, and he was not sure as he rounded the stern if he did not pass under the propellers as they were so visible at this point. Yet at this point in the sinking, the rudder is almost completely underwater, and as discussed later, the propellers would not be above the waterline until the #2 funnel touches the water.
The Titanic at this point is almost ready to do her final plunge as the bridge goes under. It is interesting then to see that water has not completely filled the bow nor has water even entered boiler room #4 at this point. There is also no water present on any cabins higher than D deck or aft of the grand staircase landing.

At this point in the animation, all visual showing of flooding of the ship has ceased. This angle of the ship was determined in a more complete shot seen in the *Final Word* documentary.
The ship at this point has been settling rapidly, with the propeller’s only now just reaching the waterline.

Figure 23: Hull Failure

This is the moment of the ship at the point the hull failure in the animation.

It does not take long to see that the movements and flooding of the ship found in this animation are not supported any of the data found in the previous simulations. The ship for most of the sinking shown here just settles lower and lower in the water, with the ship only having a 4-degree trim by the time A deck is going under, compared to the GHS in which 5 degrees is already reached upon the forecastle submerging.

The ship here also breaks one of the “Golden Rules” as it were when a vessel sinks. Historically, when ships sink that are caught on film, they will always sink faster in their drafts than in trim. This is because buoyancy is being lost faster than the ship can compensate in just trimming higher, and they do not obtain a magical “pivot point” that does not also lower as the ship sinking. This can be seen in the original sinking animation in the 1997 film, you will notice that as the bow sinks, there is a pivot point under the third funnel that stays almost perfectly still, allowing the stern to swing high as the bow sinks.

Titanic did have a pivot point for most of her sinking, just forward of the #4 funnel in the F deck region. This can be clearly seen in the lowering of boats #13 & #15. As lifeboat #13 was lowered at around 1:35, it got caught in the steady stream of water streaming from condenser as crew pumped water out. This discharge was usually located at the water line, and even this late in the sinking was still nearly at it. However shortly after this point the ships pivot point would no longer be able to keep up with the ships flooding, causing it to lower as the ship sank.
The 2012 animation however does not follow this, the ship as the number #2 funnel touches the water drastically changes her behaviour. The ship, which at this point had sunk nearly 70 feet in the previous two hours with only around a 12-degree trim, now reaches 23 degrees with only very little of a draft difference.

While it might seem weird that this animation with access to so much good information strays so far, there might be an explanation for this.

One of the contributors to the paper and Titanic historian Park’s Stephenson, has given some info that might explain it. Following the 2012 work, Park’s figured out what might be causing the ship to not behave in the simulation as it did in real-life (with the port and starboard list). It was known that due to the coal bunker fire, most of the coal was moved from the starboard bunker into the port one, causing a 2.5-3-degree list to port. With this additional data added to the simulation, the Titanic did not capsize, as at the point the Titanic’s starboard list would turn deadly, water spills over the firemen’s passage and once it reaches E deck, Scotland road provides easy access for the water to fill the port side, countering the starboard list. It is then reasonable that this also caused the ship to behave differently with the ships trim, which in turn would explain the odd angles chosen for the ship in the 2012 animation.

However, without any evidence of imagery to back this idea up outside of some comments, it cannot be proven. Given the fact that it differs so drastically from both previous analysis and survivor testimony, it of the author’s opinion that this showing of the ship is most likely not the most accurate showing of it, as discussed in the following sections.
Trim & Heel Collection

With all the major data over the past 20+ years assembled, it's possible to finally display it all in one place for people to compare and use for future showings of the ship with some reliable information.

But in order to properly compare the 2012 data and animate it for testing, a timeframe to work with was needed. Since the 2012 animation is not in real-time and there is no evidence available to the public on the specific times used in it, something was needed to use.

The solution was found in the updated animation created by Titanic Honor & Glory, which has one of the 2012 contributors, Park Stephenson as a consultant. While many are familiar with the famous real-time animation created by H&G in 2016, not as many are aware of a revised version created as a “pre vis” to the final version for the game. It should be noted that what is about to be presented here is not final to the project, and it should not be treated as such. Nor is this out to criticize the animation, but simply use it as a reference point.

While this updated animation was never shown to the public in full, enough has been shown for one to be able to reconstruct the angles and timeframe for the animation. The method for calculating the angles was the same as was used in the 2012 animation, and again is by no means 100% accurate.

Using these angles, it was possible to recreate the major key frames of the animation, and the heel of the ship as well. Using the shown timeline and final plunge footage, it's possible to determine when major events happened, such as the plunge, funnels falling, break-up and when the ship disappears. Upon completion of all this, it was found that the H&G followed very closely the trim and heel of the Final Word animation. As such it was determined that it would be useful for as a comparison for time stamps.

For the timing of events in the Final Word Animation, the H&G footage was used as a reference since no time stamp was ever given in animation. For this comparison, it was assumed the ship sank in the H&G animation at 2:20 AM and should not be used as 100% representation for their work. However, Parks Stephenson has given comments when discussing the sinking that might help enforce when the bridge goes under in the 2012 animation. Parks and the paper make multiple references to the time found on the bridge’s chronometer, which was recovered in 1996. The time commonly thought to originate from the instrument is 2:12, which is only 8 minutes from the accepted time the ship sank. This might be an open and shut case with the timeframe on when the ship’s final plunge began, however recent work found in the Time And Again-Titanic’s Final Hours by Mark Chirnside, Bill Wormstedt, Tad Fitch, Sam Halpern and others shine some new light into the validity of this accepted time.

In short, their findings show that the instruments hands were broken prior to recovery and should not be used as any historical reference. The paper then reinforces the generally accepted time of 2:15 as the ship makes her final plunge. Again, this is not to bash the hard work that uses the chronometer, but it simply seems that it can not be used as a time stamp.
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<td>30</td>
</tr>
<tr>
<td>160</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

*Table 2*
### 2012 Animation

<table>
<thead>
<tr>
<th>Description</th>
<th>Final Trim (Degrees)</th>
<th>Pre Vis (Degrees)</th>
<th>Author's 2012 Observations (Degrees)</th>
<th>Time (Ships Time)</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Image Of The Bow</td>
<td>1.2</td>
<td>?</td>
<td>Trim:1.2   Heel:2.9</td>
<td>?</td>
</tr>
<tr>
<td>Second Image Of The Bow</td>
<td>1.3</td>
<td>?</td>
<td>Trim:1.3   Heel:2</td>
<td>?</td>
</tr>
<tr>
<td>A Deck Slipping Under</td>
<td>3.7</td>
<td>?</td>
<td>Trim:4     Heel:8</td>
<td>?</td>
</tr>
<tr>
<td>A Deck Half Submerged</td>
<td>?</td>
<td>3.7</td>
<td>Trim 4.46 Heel:8</td>
<td>?</td>
</tr>
<tr>
<td>Boat Deck Going Under</td>
<td>4.7</td>
<td>?</td>
<td>Trim:5     Heel:8</td>
<td>?</td>
</tr>
<tr>
<td>Base Of The #1 Funnel Touching</td>
<td>?</td>
<td>7</td>
<td>Trim:7     Heel:8</td>
<td>?</td>
</tr>
<tr>
<td>Number #1 Funnel Collapse</td>
<td>9.4</td>
<td>10.4</td>
<td>Trim:9.4   Heel:9</td>
<td>2:12:18</td>
</tr>
<tr>
<td>Base Of The #2 Funnel Touching</td>
<td>10.4</td>
<td>14</td>
<td>Trim:12    Heel:7</td>
<td>2:14:18</td>
</tr>
<tr>
<td>Hull Failure</td>
<td>23</td>
<td>20</td>
<td>Trim:23    Heel:15</td>
<td>2:18:35</td>
</tr>
</tbody>
</table>

*Table 3*

### Titanic Honor & Glory

<table>
<thead>
<tr>
<th>Description</th>
<th>Trim (Degrees)</th>
<th>Heel</th>
<th>(Time (Ships Time))</th>
</tr>
</thead>
<tbody>
<tr>
<td>C Deck Going Under</td>
<td>4</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Windows Of Bridge Wing Touching The Water</td>
<td>5.2</td>
<td>9</td>
<td>?</td>
</tr>
<tr>
<td>Bridge Going Under</td>
<td>?</td>
<td>?</td>
<td>2:11:03</td>
</tr>
<tr>
<td>Number #1 Funnel Collapse</td>
<td>?</td>
<td>9</td>
<td>2:12:18</td>
</tr>
</tbody>
</table>
### Reaching The Base Of Funnel #2
- Time: 12.1
- Trim: 9
- Time (Titanic): 2:14:18

### Touching The Floor Of The Compass Platform
- Time: 16.639
- Trim: 9
- Time (Titanic): ?

### Break-Up
- Time: 24
- Trim: 9
- Time (Titanic): 2:18:35

#### Table 4

<table>
<thead>
<tr>
<th>Time (Minutes)</th>
<th>Time (Titanic Time)</th>
<th>Trim (Degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>11:40 PM</td>
<td>0</td>
</tr>
<tr>
<td>15</td>
<td>11:55 PM</td>
<td>0.8</td>
</tr>
<tr>
<td>23</td>
<td>12:03 AM</td>
<td>1.3</td>
</tr>
<tr>
<td>30</td>
<td>12:10 AM</td>
<td>1.8</td>
</tr>
<tr>
<td>45</td>
<td>12:25 AM</td>
<td>2.8</td>
</tr>
<tr>
<td>65</td>
<td>12:45 AM</td>
<td>3.1</td>
</tr>
<tr>
<td>70</td>
<td>12:50 AM</td>
<td>3.3</td>
</tr>
<tr>
<td>98</td>
<td>1:18 AM</td>
<td>4</td>
</tr>
<tr>
<td>125</td>
<td>1:45 AM</td>
<td>5</td>
</tr>
<tr>
<td>133</td>
<td>1:53 AM</td>
<td>5.7</td>
</tr>
<tr>
<td>145</td>
<td>2:05 AM</td>
<td>6.5</td>
</tr>
<tr>
<td>155</td>
<td>2:15 AM</td>
<td>10</td>
</tr>
</tbody>
</table>
With all of the trim history now in one place and with them compared to side by side, some interesting conclusions can be drawn.

First both table 6 & 7 must be explained in greater detail. Table 6 contains the Hackett & Bedford, GHS, 2012 & Samuel Halpern data shown side by side unaltered. Table 7 is slightly different, in order to compare all the sims side by side properly if one is not worrying about time, the data has to be altered slightly. To achieve this, the time stamps were broken into 5-minute intervals, any trim points that did not fit nicely were rounded off. Then each of these animations were animated in 3D with proper trim and heel, there was then three benchmarks used, this needs explaining on how they were found. When re creating these in 3D, its possible to stop the animation at any time and read what the computer averaged out in between the major key frames. With this in mind, each scenario was stopped at three major benchmarks and the angles were written down. These benchmarks were when the roof of the bridge went under (2:15 AM), when the second funnel was touching the water (2:16 AM ETA) and then the final calculated angle at 2:20. Comparing each in this way allows people to see how each sim differs more easily.

The data shown tells some interesting story’s that has only been seen by a few people. The results show that the H&B & GHS scenarios share much of the same data with the observed angles witnessed by survivors. The only one that is drastically different is the 2012 animation, which has a steep trim angle within the last few minutes.

These graphs also show how gradual the ship was settling for most of her sinking, and how the ships condition started to really change following the two-hour mark. This can help also to explain why it took people so long to realize the ship was in serious danger. Ken Marshall has described that while being on the 1997 movie set, which was at an angle of around 6 degrees, one got very used to the angle and soon forgot that the set was even tilted. The data here suggests that the ship never reached 6 degrees until the 140-minute mark, which was only 20 minutes before the ship sank.

One of the most interesting pieces of data from table 7 is at the 155-minute mark. Three of the four simulations show a near 10-degree angle as the ships final plunge begins. This is significant as while the H&B & GHS simulations are nearly 20 years apart, they are very similar when benchmarking features of the ship sinking. With these two forensic analysis following so closely to the observed trim angles by survivors, it is of the author’s opinion that these angles could be considered reliable information when simply accounting the ships behaviour when specific feature’s enter the water, while the 2012 animation has a lack of consistency and evidence to back it up.

What is not shown in any of these in detail is the listing from port to starboard throughout the sinking. The GHS sim was locked on a 0-degree heel as their model kept capsizing, the H&B mentions it but fails to go into much detail & the 2012 has a steady port list through most of the animation.

Further inspection of survivor testimony, however, clearly shows a ship that was moving constantly. It has been well established that the Titanic had a 5-degree list to starboard within the 5-minute mark. The ship is often portrayed to then slowly even out and then to develop a list to port as the D deck door begins to submerge and hold it all the way until the break-up, but is this the case?
Gracie mentions that he and many others were ordered to the starboard side to help with the port list estimated to be around 9-10 degrees, and it was reported that the ship righted herself slightly. However, when Hugh Woolner jumps for collapsible D from A deck, he reports the boat is around 9 feet away from the ships side. Jack Thayer also made clear mention as the ship took her initial plunge, that the ship righted herself to a near even keel. This would also support not only the funnel’s collapsing to starboard as people reported, but also help give the illusion that the boat deck “rises” as the ship momentarily recovered following the initial plunge. The key to all this might be found in Steward Edward Brown’s account as he is pushing collapsible A to the falls, "when we got halfway there, the Titanic then got a list to port". If this account is true, then it seems possible that in the last 20 minutes, the Titanic was listing from starboard to port multiple times, this could help explain different aspects of the sinking such as the forward two funnels collapsing to starboard and not port. Again, the true story will never be fully known, but it seems the ships movements were far more complex then previously believed.

The flooding shown here can also help when determining what happened to the ships lights in some ways. Both the GHS and H&B show that water was no were near the dynamo room until post break-up. It also shows that water was absent from boiler room #2, which would help give credibility that it was the room supplying steam. Some have argued that boiler room #1 was lit during the sinking and was supplying the emergency dynamo’s. However, footnotes in On A Sea Of Glass seem to show that it was not lit, or beginning the process of being lit prior to the collision. Considering that all of the boilers in the debris field have no damage or implosion damage at all, and there are implosion marks in the faces of those from boiler room #2, could help give evidence to the fact that the ones in #1 were not in operation at the time of the sinking. Some might argue though that the implosion marks found on the #2 boilers are from trapped air that could not escape at the bow plunged, but the fact that there are none of the #1 boilers that entered the water at the same time would seem to point for that not being the reason the faces of the #2 boilers being imploded.

Again, none of this is destined to set in stone how it happened, it simply shows that there is some considerable evidence on what might have happened and that there is always more to the story.

Effect’s On The Break-Up

It’s been stated earlier that this documents intention was primarily to display the data from these analyses, not necessarily dive deep into the historical side of the sinking. However, it was thought that a brief overview on how the flooding presented here might have impacted how the ship broke apart could be added.

The GHS and H&B simulations show that with certainty, flooding was present to a large degree in boiler room #4 and aft. The GHS data seems to suggest that water was entering the ship at such a large rate in the final minutes, that it did not have sufficient time to filter down to the bowl of the ship, and was mostly confined to the upper decks in the vicinity of the #3 funnel uptake.
By looking at figure 23, which shows the general layout on the major pieces of the break-up, the data would suggest that when the ship initially fractured, there was almost no water present in any of the areas compromised. It should be noted that Park Stephenson has said the data found in Roy Mengot’s break-up profile is out of date in some of the small details. The data shown in figure 23 should then be considered only as general layout on how the ship is broken today, however there is no other detailed information available to the public to study from the revised findings, his work remains the most complete one to look at.

With no water present in the stern when the break-up occurred, it is then logical to assume any major flooding done to the stern after this point would not originate with the initial impact of the iceberg.

The 2012 paper also went into detail about their structural analysis of the ship. H&B never went into it as that was never their goal, however for many year’s others used their results to accomplish it, such as William Garzke. These however have been not viewed as reliable information, as the mesh they used for the ship treated the superstructure as part of the hull, which would drastically alter the stresses of the ship.

The MASETRO program in short found that peak stresses were found at around 23 degrees with maximum stresses being 32,000 psi on B deck and 26,200 psi in compressive stresses in the double bottom.

This would support the conclusions of the Final Word documentary. Their conclusions were that the upper decks visibly failed, and the ship fractured right down to the double bottom. The stern relaxed its angle and a new flooding process began, it was then explained that the double bottom and keel remained attacked, forming the “banana peel” theory in which the bow began to pull the stern with it until the two pieces attached. At this point the stern’s flooding was dramatically increased from the tug, causing it to keel to port and going vertical as the poop deck goes under. The team then theorized that the major sections or “towers” detached in the water column as the stern rotated or as it imploded. This theory would seem to be backed up by survivor accounts. With Thayer and other clearly describing a visual parting of the upper decks and Charles Joughin, in which he describes a terrible list to port, allowing him to climb on the ships fantail and ride it down like an elevator.

This theory is the most popular, and many feel that this is the way it happened and no further research is needed. However, there is considerable evidence that there is more to this story than what the 2012 animation shows.

Take for example the two double bottom pieces featured in the Final Word, both were given evidence as the main section of the ship that remained connected before detaching, as were shown as such. However, upon close inspection of the two pieces reveals a far more detailed story than just that. The main documentation for these two pieces came in 2005 in a History Channel expedition, however at
least one of the double bottom pieces were photographed in detail during the 1998 expedition. The conclusions were that each section when put together matched perfectly to the break point in the bow and stern section’s of the Titanic, meaning the complete bottom of the ship is accounted for. However, it has been documented that the keel, the spine of the ship, was bent in a S-shape. Considering the size and strength of the keel, it would have to be an amazing force to cause it to deform the way it is today.

This caused Roy Mengot and Richard Woytowich in 2009 to complete a forensic analysis of the double bottom to determine what happened. Their findings located in the paper The Breakup of Titanic A Progress Report from the Marine Forensics Panel (SD-7) found that while the keel was in less compressive stress than what was found in the upper decks, the needed stress to compromise the tank was 18,000 psi for double riveted landings and 27,000 psi for the triple riveting with stresses found in the MASETRO to be 20,000-30,000 psi in this area. This would suggest that the keel might have failed first as its overall strength was less than the shell plaiting found were the peak stresses were located. This caused Mengot to come up with the theory that the ship might have broken from the bottom up, with the strength decks being the last part holding the ship together.

While the debate on which gave first will never be solved, it can be said that the double bottom would not be able to behave like a banana peel or shoe leather, it was designed to be rigid and solid as its supporting the entire ship, it if could do that then the whole ship would be able to flex like the expansion joints. Much like carboard, once the ships double bottom failed, its strength would be compromised and would not be able to bend the 15+ degrees to keep the bow attached. It is of the author’s opinion that more tests and research should be conducted to clarify matters to understand the double bottom better during the sinking.

Since it has been established that the stern settled back from the break-up, the flooding process would have to restart if it broke clean and this could in theory give the stern several minutes to live. However, it has been well established from survivors that after returning to a near even keel momentarily, the stern then started to sink. Since wreck exploration in 2001 showed the watertight door between the reciprocation & turbine rooms to be closed, some other force must have caused it.

The stern is often shown to capsize to port, allowing the accounts of Joughin to stand on the fan tail to be possible. However, a quick look at other accounts complicates things. Chief Baker Charles Joughin (Who had been drinking during the sinking) states that a motion caused everyone to get heaved to port, allowing him to stand on the fantail, and it was this that gave many people the illusion that the ship was nearing vertical. This is supported by others, such as Percy Keen “…afterwards we saw the fore part of the ship break away up to the foremost funnel, and it appeared to us that when the ship had listed heavily to port the engines fell out and crashed through the side.” and Eva Hart which in one interview said “she keeled over”.

But as with much of the sinking, there is other testimony that contradicts this idea. In addition to Joughin, there were two others who survived that were on the poop deck, these being Patrick Dillon & Frank Prentice. Neither of these men ever described such a port list, and if it did occur like how Joughin described, it would make Prentice’s account not possible. In one account, Prentice describes how “I felt
her go down, then come back up again” and jumped, by the time he got his sense and turned around “I looked up at the Titanic, her propeller were right out of the water, her rudder was right out and you could see the bottom. And then she glided away and that was the last of the Titanic”. In a BBC interview while looking at a model he described how “she was almost vertical when I left her... and on the sign Keep Clear Of The Propeller Blades at the very end I was lying on it and then I let go and I just missed the propellers”. Since he was hanging onto the stern by the port side sign (adjacent to the flag staff), this would mean several key items would have to take place.

1. The stern has to come to an even keel long enough for those on the stern to notice, but gradual enough not to immediately indicate to a hull failure.
2. The stern then must begin to rise out of the water.
3. By the time prentice leaves, the ship, it must be at a high enough angle for him to be nearly flat on the Keep Clear Of The Propeller’s sign and be in a position for him to nearly hit the propellers when he left the ship.
4. The stern must by the time he drops, get his senses and turns around to look at the ship be in a position where she has the propellers and the keel are still plainly visible.
5. The ship then glides steadily at this angle until it submerges.

Programming a mock-up 2012 animation and making it playable, it was determined that Prentice’s story would not be possible to achieve if the stern capsizes to port. Now this is not to say that there was no list to port as reported by people, but perhaps a combination of the listing to port and the ship going near vertical can be plausible.

Survivor accounts given by Richard Williams, Jack Thayer & Eugene Daly all tell a near identical story of the ship reaching of an angle of “60-degrees” or more, it paused and was rotating so that its propellers were above their heads. This I given even more credibility when one looks at the results of the crude model test done by James Cameron in 2017 for the 20 Year’s Later documentary. In their tank test, a basic model of the Titanic was sunk to see if the stern upon breaking could achieve 90 degrees. It was found in the model test that regardless on how the stern behaved, it always turned nearly 90 degrees as it sank. Once again, the mock-up demo found that with the stern capsizing, it would be impossible for any of the mentioned accounts to take place, even with the darkness as the stern capsized.

Another common comment by many people was that the stern prior to taking its final plunge, remained motionless as its air tried to keep it afloat. It remained still enough for Hugh Woolner about 150 yards away to make the following comment “she seemed to me to stop for about 30 seconds at one place before she took the final plunge, because I watched one particular porthole, and the water did not rise there for at least half a minute and then she suddenly slid under with her propellers under the water.”

Another aspect not investigated by any of these papers is the matter of how the ship broke up at the surface. As mentioned before, the 2012 animation depicts the major pieces leaving the ship after the stern left the surface, but there seems to be far more to this story than commonly shown. Carrie Chaffee “Just before going down it seemed to writhe, breaking into three parts into which it was divided”. Jack Thayer sated in one account that he saw the ship split in front of the #3 funnel while Frederick Scott said it broke as far aft as the #4 funnel.
When comparing this to the state of the stern, it seems possible that the break-up was far more complex in terms of what parts of the ship were compromised on the surface than previously thought. Both Frank Osman and Percy Keen talked about seeing the “engines slide out” during the break-up. Most people would scoff at this, as the reciprocating engines are located quite far aft in relation to the main fracture, not to mention even at a normal draft, they were not that far above the waterline. But these accounts might hold more weight when one considers the fact that both of the reciprocating engines are snapped off in the front, giving some credibility that the stern might have been riding higher in the water than previously thought, or something else left the stern.

Again, this document will not go into great depth on the historical side of things, but with the data of the analysis, model testing and survivor accounts, its possible to paint a basic picture of the break-up and the stern’s sinking.

1. The ship visibly split’s in the upper decks.
2. The stern settle’s back to an even keel long enough for some to think that it will float, but also be fast enough for some not to notice a huge interruption in the sinking.
3. The keel must be bent in a S shape.
4. The forward part of the stern must fracture in such a way that it can give an illusion of three or more pieces.
5. Some part of the bow is still connected to the stern to give it the necessary tug to move it and pull it under to some degree.
6. The stern tilt’s in such a way that it seems to be near vertical in different vantage points.
7. The propellers and bottom are clearly visible.
8. The stern rotates in a semi circle before foundering.
9. There is a long enough pause in the stern for people to take notice and have a porthole near the water stay stationary.
10. The stern speeds up as it goes for the final plunge, with it disappearing with minimal disturbance in the water.

Conclusion

The conclusions of these papers have traditionally put people off due to the nature of their content and how difficult they can be to obtain and understand. The document has brought all of the data into one place for full scrutiny and have it presented in a usable format for others to use in animations or future studies.

While many aspects of the Titanic’s sinking are unknown and never will be known, it is felt that this document can help clear up the confusion on the ships movements and help put people on the right path for showing it more accurately.

As James Cameron put it “We will never know exactly what happened, but we can say what is possible to have happened”.

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Special Thanks
Titanic Animations: For contributing information and always ready to discuss the sinking and break-up in detail.

Samuel Halpern: For making so much data available and always ready to help out.

Model for graphics was created by Sketchup user andrewsbestship.

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