USCG MARINE SAFETY CENTER

POST-SINKING STABILITY ANALYSIS OF F/V EMMY ROSE

EXPLANATION OF ANALYSIS AND ASSUMPTIONS

March 2, 2022

1. Introduction:

The F/V EMMY ROSE (ex. SASHA LEE), O.N. 909149 is an uninspected fishing vessel constructed in the 1987. The vessel sank off the coast of Provincetown, Massachusetts while transiting back to port on the morning of November 23, 2020 with all four crew members missing. At the time of incident (TOI), a gale warning was in effect with southwest winds and a 6-9 foot sea state in the vicinity of the sinking. The temperatures that week were in the mid 40's and vessel icing was not a threat.

In reference (a), the Marine Safety Center (MSC) was asked to review evidence and conduct a technical analysis to assist the formal investigation in determining possible causes of the incident. From the evidence gathered, MSC evaluated load conditions throughout a typical voyage with a focus on the estimated load condition at the time of incident. A technical analysis of stability at each load condition was conducted to determine if the vessel was in compliance with applicable stability regulations.

2. Lines Plan and MSC Computer Model Development

From information gathered for the investigation, computer models from past stability analyses were not available for this post sinking analysis. The original build plans for the vessel were not available from when the vessel was originally built as a shrimp fishing vessel. However, when the vessel was converted to a trawler, a new stability analysis and lines plan, reference (b) and (c) respectively, were created. These plans were used to conduct MSC's analysis.

McNeel Associates 3-dimensional technical drawing software "Rhinoceros" was used to expand the 2-dimensional lines plan into a 3-dimensional model. This process involved importing the three different views from the lines plan, positioning them at the origin, and scaling them to match the vessel particulars in reference (b). Then the profile, plan, and body views were rotated along the axis to be positioned in perpendicular planes. The points from each view were then manually moved into the correct positions creating a 3-dimensional framework. A surface was then fitted over the framework to create the outer skin of the vessel.

At this stage the surface of the vessel's hull was converted into a geometry file to be used in Creative Systems' stability analysis program General Hydro Statics (GHS). The 3-diminsional model in Rhinoceros was further developed based on available pictures to create the rendering seen in Figure 2.1 and enclosure (2).

Figure 2.1: MSC Rhinoceros 3-D Model created from 2002 Lines Plan.

In GHS, the geometry file of the vessel's hull was imported and scaled again to ensure the dimensions matched the vessel particulars of reference (b). Figure 2.2 is an isometric view of the hull in GHS. To conduct this analysis, MSC assumed that the hull below the bulkhead deck is the only buoyant volume of the vessel. No portions of the vessel above the bulkhead deck, such as the superstructure and bulwarks, were considered as buoyant volume. The watertight integrity of the superstructure was unknown along with if the doors into the superstructure were open or closed during the time of incident. The vessel modeled with only the buoyant volume of the hull is the most conservative approach. The portion of the vessel above the bulkhead deck was counted towards the sail area. Additional views of the GHS model can be found in enclosure (3).

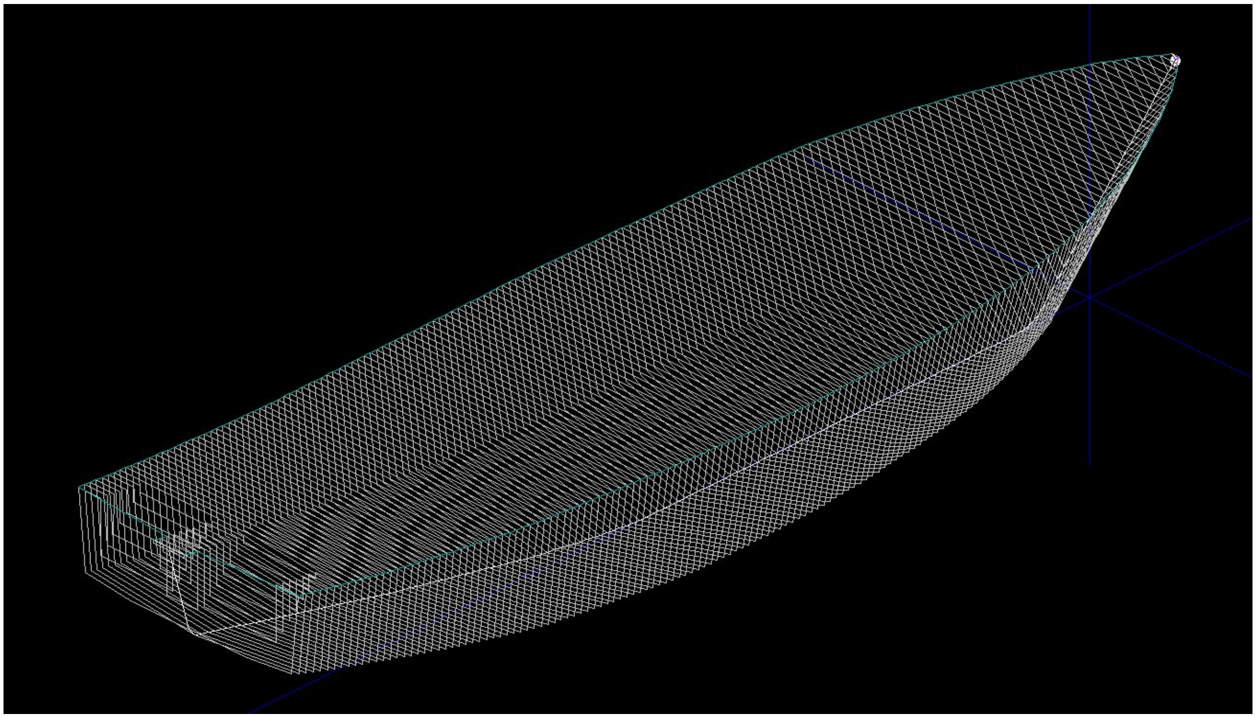

Figure 2.2: Isometric View of Hull Model in GHS

Based on the lines plan, watertight bulkheads were placed into the model creating three compartments plus a forepeak tank for fresh water. The tank capacity plan located in reference (b) was used to create the four tanks on board; forepeak fresh water tank, hydraulic oil tank, port fuel oil tank and starboard fuel oil tank. A complete list of dimensions for the tanks was not available, therefore some dimensions were approximated. The priorities for creating the tanks was to match the overall capacity and listed dimensions for each tank. Table 2.1 shows the final tank capacity of the model and the difference from the tank capacity plan in reference (b).

Tank	Reference (b) Tank Capacity	MSC GHS Model Tank Capacity	Percentage Difference
Fresh Water Tank	1,638.5 gals	1,625.0 gals	0.82%
Hydraulic Oil Tank	156.0 gals	152.0 gals	2.56%
Port Fuel Oil Tank	7,117.5 gals	7,178.0 gals	0.85%
Starboard Fuel Oil Tank	7,117.5 gals	7,178.0 gals	0.85%

Table 2.1: Tank Capacity Difference

After the tanks and compartments were created, the superstructure and bulwarks of the vessel were added to the model. The superstructure and bulwarks contribute wind surface area to the model, but do not add buoyant volume. For expediency, the wind profile is generated as a 2-D surface on centerline composed of all structure above the bulkhead deck. This includes any bulwarks, superstructure, outriggers, spars, net reels and miscellaneous equipment. The dimensions of the bulwarks and house were taken from the lines plan. Dimensions for the outriggers, spars, net reels, and miscellaneous equipment were estimated from pictures by scaling based on known item dimensions prior to taking measurements. Because information was not available to model all windage details precisely, the rough outline was obtained to capture small details resulting in a conservatively high wind profile area. The final GHS model can be seen in Figure 2.3 with all compartments, tanks, and sail area added.

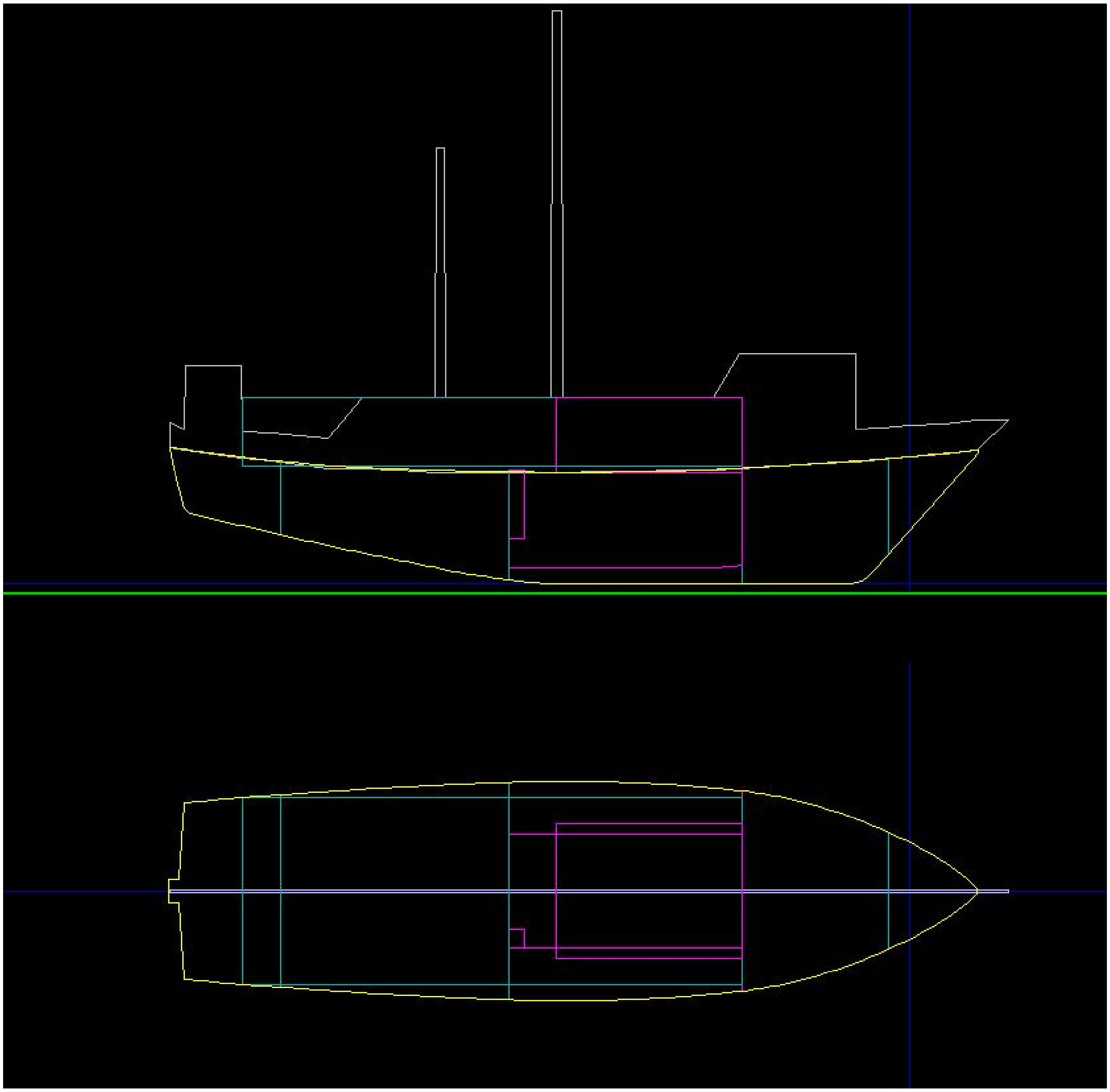

Figure 2.3: Profile and Plan View of GHS Model.

3. Model Validation and Lightship Characteristics

With the GHS model completed, MSC validated it by comparing hydrostatics to the data listed in reference (b). Reference (b) provides a hydrostatic table listing the vessel's displacement based on an increasing range of drafts. A hydrostatic table was created for the GHS model based on the same range of drafts to compare the displacement. Table 3.1 is a comparison of the hydrostatics from reference (b) and the GHS model hydrostatics in enclosure (4). The displacements of the MSC model is within 2 percent of that noted in reference (b) with the exception of when the draft is 12 feet. This is of note because the lowest point of the deck edge is 11.51 feet, which could possibly indicate the model in reference (b) has more buoyant volume above this point. For conservatism, our model only included the buoyant volume of the hull since the watertight integrity of the super structure was unknown.

Draft (ft)	Reference (b) Displacement (LT)	MSC Model Displacement (LT)	Percent Difference
6.0	122.50	121.29	-0.99%
6.5	140.55	138.64	-1.36%
7.0	159.62	156.79	-1.77%
7.5	179.31	175.71	-2.01%
8.0	199.45	195.28	-2.09%
8.5	219.85	215.27	-2.08%
9.0	240.43	235.55	-2.03%
9.5	261.31	256.13	-1.98%
10.0	282.72	276.97	-2.03%
10.5	304.34	297.96	-2.10%
11.0	326.27	319.14	-2.19%
11.5	348.13	340.49	-2.19%
12.0	367.88	353.02	-4.04%

Table 3.1: Comparison of Model Displacements based on Draft

To establish weight and center of gravity of the model, MSC used the stability test data from reference (b). This data is based on the latest inclining experiment that was conducted on the vessel in 2002 to determine the new lightship characteristics after completion of modifications. MSC independently calculated lightship characteristics using the raw data from the test to identify any discrepancies between MSC calculations and reference (b).

During the 2002 stability test, freeboard measurements were taken on both port and starboard sides to calculate an average measurement at each longitudinal location. MSC calculated drafts at specified longitudinal locations by subtracting the corresponding freeboard measurements from the molded depth dimensions. The calculated drafts matched those in reference (b) for the as inclined condition. With measurements on both sides and a known beam, the vessel's heel angle can be determined. Based on the measured freeboards, the heel angle determined in references (b) was incorrectly applied to starboard vice port. However, the effect of this discrepancy is negligible since the magnitude of the heel is only 0.05 degrees.

Next, in GHS, the calculated drafts were used with MSC's model to obtain the displacement, longitudinal center of gravity (LCG) and transverse center of gravity (TCG) for the as inclined condition. MSC's calculated as inclined displacement was 1.81% lower than that calculated in reference (b). The vertical center of gravity (VCG) is determined by the inclining process of measuring the vessel's heel angle for a given weight shift. MSC independently calculated a VCG of 9.70 feet above baseline, which is within 0.15% of the VCG calculated in reference (b). The comparison of as inclined vessel characteristics is shown in Table 3.2.

As Inclined	Reference (b)	MSC GHS Model	Difference
Displacement (LT)	216.28 LT	212.36 LT	3.92 LT
LCG (aft FP)	35.68 ft	36.44 ft	0.76 ft
TCG (Starboard of CL)	0.00 ft	0.00 ft	0.00 ft
VCG (above baseline)	9.72 ft	9.70 ft	0.02 ft

Table 3.2: As Inclined Vessel Characteristics

To determine the lightship vessel characteristics, the weights to be added, removed or relocated need to be factored into the as inclined characteristics. The list of these weights and their centers of gravity are included in reference (b). The information for these weights is assumed to be correct and used in MSC calculations to resolve lightship. Resolving lightship is critical because the lightship characteristics will be the foundation for creating the different load conditions for the analysis. The comparison of the lightship vessel characteristics is shown in Table 3.3 and the detailed lightship information is found in enclosure (5). The difference in lightship displacement between reference (b) and the MSC model is only 2.11%, which is an acceptable difference for general plan review. The difference in LCG is 0.89% based on length between perpendiculars and is within an acceptable range.

Lightship	Reference (b)	MSC GHS Model	Difference
Displacement (LT)	185.69 LT	181.77 LT	3.92 LT
LCG (aft FP)	37.98 ft	38.69 ft	0.71 ft
TCG (Starboard of CL)	0.00 ft	0.00 ft	0.00 ft
VCG (above baseline)	10.55 ft	10.55 ft	0.02 ft

Table 3.3: Lightship Vessel Characteristics

Since eighteen years had passed since the last stability test, the lightship of the vessel likely increased overtime with small modifications. The lightship was assumed to not have changed and a growth factor was not applied to lightship. However, with limited information, we were able to identify and apply the weight of a known modification in load condition 9 through load condition 12 as an itemized weight. The effect of known and unknown modifications can drastically alter the stability characteristics of the vessel.

4. Downflooding Points

Downflooding points allow water to enter the buoyant volume of the vessel when they are submerged below the waterline. They must be added to the computer model to track the angle at which downflooding occurs because they are used by the stability criteria.

Downflooding points are typically identified during the stability test and described in the field notes or analysis with pertinent information such as location and watertight integrity properties. There was a lack of information to properly identify possible downflooding points for this analysis. In reference (b) the only downflooding point noted is the engine room vent located 50 inches off the bulkhead deck, however, the longitudinal and transverse location of the vent are omitted. The location of the engine room vent was assumed to be the vent located on the forward portside of the pilot house, see Figure 4.1. The location of this downflooding point was estimated by using scaled measurements from pictures and reference (c).

Figure 4.1: Engine Room Vent downflooding point

Additional points of interest include the four corners of the fish hold hatch and aft lazarette hatch located on the bulkhead deck. The sill height of the fish hold was assumed to be 29 inches above the deck at the forward point and 28 inches above the deck at the aft point. The lazarette sill height was assumed to be 3 inches above the deck. The location of each of these points were estimated using scaled measurements from pictures. The lazarette was considered watertight since it had a hatch and the fish hold was considered weathertight since it was assumed to have a hatch covering. Weathertight points are considered as downflooding points only when they are below the initial equilibrium waterline. Once the vessel is heeled in the analysis, the weathertight point is not considered a downflooding point. A list of the critical points used in the analysis is presented in Table 4.1.

Critical Points	LCP (ft aft FP)	TCP (ft off CL)	VCP (ft above base)	Integrity
(1) Hold Forward	51	2.5 P/S	14.25	Weathertight
(2) Hold Aft	55	2.5 P/S	14.25	Weathertight
(3) Blower Vent Port	7.5	4.4 P	15.75	Downflood
(4) Lazarette Hatch	71	12 S	13.5	Watertight

Table 4.1: Critical Points, Location, and Designation

5. Load Conditions

Sample load conditions used during analysis should closely match the voyage and operations a vessel regularly conducts. Common items to be included in the load conditions are crew, consumables such as food, spare parts for maintenance, liquid loading, and cargo. In this case, the fishing vessel's catch would be the cargo. The liquid load of the vessel also factors into the load conditions and is dependent on the stage of the voyage. The burn sequence of fuel tanks, use of freshwater, and filling of sewage tanks are all captured in the liquid load.

Reference (b) load conditions and stability analysis were used to create the stability instructions to the master. MSC used the loading conditions in reference (b) for analysis as load conditions 1 through 7 (LC1-LC7). These load conditions also provide points of comparison during the stability analysis. Five additional load conditions are defined in load conditions 8 through 12 (LC8-LC12). These load conditions are created to capture the information provided in evidence or testimony from past crew estimating typical operation of the vessel that could have been a factor in the incident. Table 5.1 describes the load conditions used in the analysis and enclosure (6) provides the detailed itemized list of each load condition.

Load Condition	Description
LC1	Departure from Port
LC2	Arrival at fishing grounds
LC3	50% Catch at fishing grounds
LC4	100% Catch departing fishing grounds
LC5	40% Catch departing fishing grounds
LC6	Port arrival with 100% catch
LC7	Port arrival with 40% catch
LC8	Port arrival with 0% catch, Transit trip
LC9	Time of Incident (TOI)
LC10	Time of Incident with ¼ more fuel in starboard fuel oil tank
LC11	Time of Incident with ½ more fuel in starboard fuel oil tank
LC12	Time of Incident with uneven paravane (bird) deployment

Table 5.1: Load Condition Numbers and Description

Load condition 1 represents the condition the vessel is in when departing port fully outfitted and loaded for a voyage to engage in fishing with fuel and water tanks pressed up. Load condition 2 represents arrival at the fishing grounds with 80% fuel load and the start of fishing with cargo on deck. Load condition 3 has 50% catch onboard with a 60% fuel load. Load conditions 4 and 5 both represent the vessel leaving the fishing grounds with 40% fuel load but with 100% and 40% catch onboard, respectively. Likewise, load conditions 6 and 7 are arrival to port at 20% fuel load with 100% and 40% catch onboard, respectively.

Load condition 8 represents the vessel in transit with no catch onboard. Load condition 9 represents the estimated condition of the vessel at the time of the incident based on the reported catch onboard and typical liquid load for that point in the voyage. The additional weight of the known larger trawler door modification was added in load condition 9. The equilibrium condition of the vessel at load condition 9 can be seen in Figure 5.1.

Load conditions 10 through 12 used the time of incident condition (load condition 9) as a foundation and modified certain portions of the load based on evidence and testimony. Load condition 10 represents a quarter tank more fuel in the starboard fuel tank compared to the port fuel tank. Load condition 11 is the same as 10 but with a half tank difference to starboard instead of a quarter. Load condition 12 includes the wire weight for the port paravane being paid out four times further than the starboard paravane.

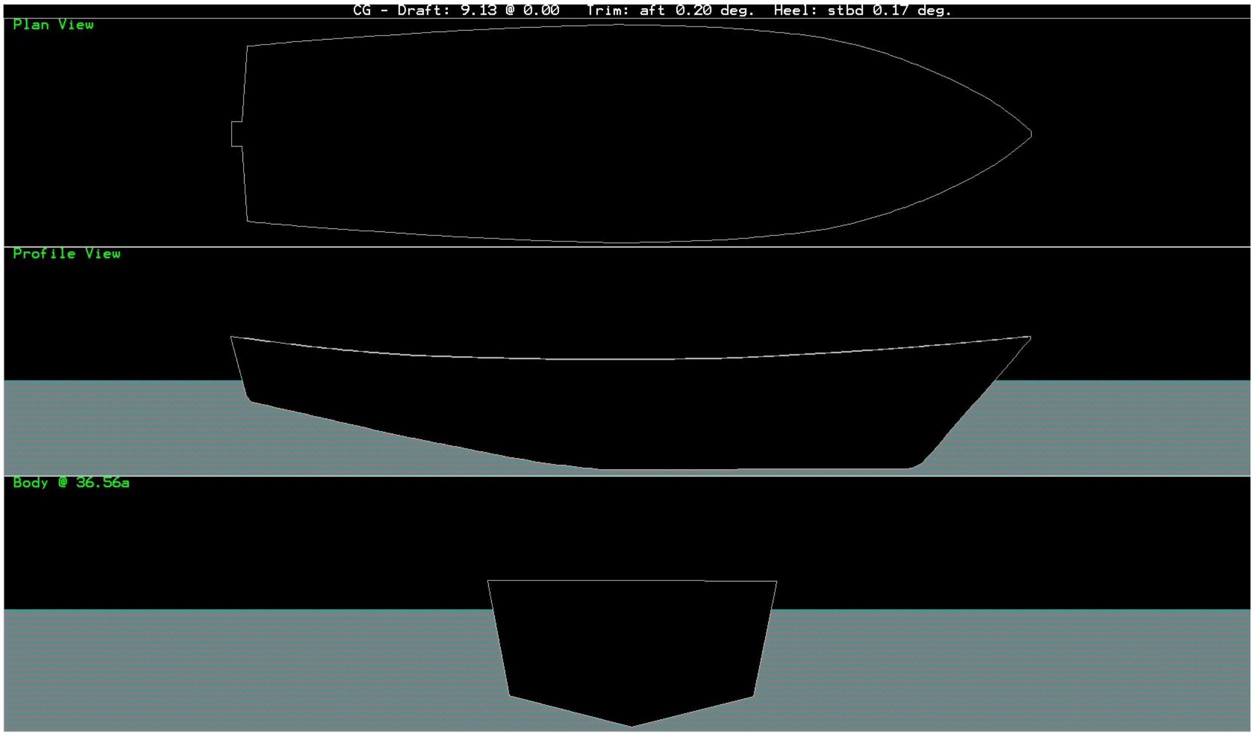

Figure 5.1: Equilibrium Condition at Time of Incident (Load Condition 9)

6. Intact Stability

EMMY ROSE was classified as an uninspected vessel subject to the regulations of 46 CFR Subchapter C. Stability regulations for commercial fishing vessel industry vessels are contained in of 46 CFR Part 28, Subpart E, including:

- 46 CFR 28.550 Icing
- 46 CFR 28.565, Water on Deck
- 46 CFR 28.570, Intact Righting Energy
- 46 CFR 28.575, Severe Wind and Roll

MSC did not evaluate the vessel for compliance with 46 CFR 28.550 Icing standards since the temperatures at the time of the incident were above freezing. Each of the twelve load conditions were evaluated to the other three stability criteria noted above. A vessel's failure to meet minimum regulatory static stability standards does not necessarily imply that it would capsize in any particular dynamic wind and sea condition.

The 46 CFR 28.565 Water on Deck criteria is intended to evaluate a vessel's ability to remain stable when a large wave fills the deck with seawater to the top of the bulwarks without draining through the freeing ports. This criterion requires the residual righting energy (the difference between heeling and righting energy) to be greater than the heeling energy of the water on deck at the downflooding angle or 40 degrees, whichever is least. MSC's analysis showed the vessel passed the water on deck criteria for all load conditions except load conditions 10 and 11. In these conditions, a large list exists due to unequal loading of port and starboard fuel tanks.

Next, the vessel was evaluated to the 46 CFR 28.570 Intact Righting Energy criteria. These criteria evaluate the righting arm curve for seven distinct limits. These limits are listed in Table 6.1 and correspond to the limits of the analysis found in enclosure (7). MSC analysis indicates that the vessel failed the intact righting energy criteria in all loading conditions: in each condition, the maximum righting arm is achieved at an angle of heel less than 25º, and the minimum righting energy and range of stability requirements are not met. Specifically, all load conditions failed limits 2 through 7 with the exception of passing limit 5 for load conditions 5 through 9. All load conditions passed limit 1.

46 CFR 28.570 Intact Righting Energy	
Limits	**Description**
Lim (1)	GM upright > 1.15 feet
Lim (2)	Righting arm at 30 degrees > 0.66 feet
Lim (3)	Angle at max righting arm > 25 degrees
Lim (4)	Area from 0 degrees to 40 degrees or Flood > 16.9 foot-degrees
Lim (5)	Area from 0 degrees to 30 degrees > 10.3 foot-degrees
Lim (6)	Area from 30 degrees to 40 degrees or Flood > 5.6 foot-degrees
Lim (7)	Angle from 0 degrees to vanishing righting arm > 60 degrees

Table 6.1: Limits for 46 CFR 28.570 Intact Righting Energy

Finally, the vessel was evaluated against 46 CFR 28.575 Severe Wind and Roll criteria. This quasi-static criterion accounts for the effects of the vessel being subject to a gust of wind and subsequent roll. This criterion is composed of the three limits defined in Table 6.2. The vessel failed the criteria in all load conditions except load conditions 5 through 8. In all conditions that failed, limit 2 was the limiting factor. The list of the vessel in load conditions 10 and 11 resulted in additional failures in limits 1 and 3.

46 CFR 28.575 Severe Wind and Roll	
Limits	**Description**
Lim (1)	Equilibrium angle < 14 degrees
Lim (2)	Residual ratio from roll to 50 degrees or Flood > 1
Lim (3)	Residual area ratio from roll to vanishing righting arm or Flood > 1

Table 6.2: Limits for 46 CFR 28.575 Severe Wind and Roll

A summary of the results from the three regulatory criteria is shown in Table 6.3. The degree of failure at the time of incident was most significant for intact righting energy. The righting arm at 30 degrees was 0.4 feet, only 60% of the required righting arm, and maximum righting arm occurred at 20 degrees versus the required 25 degrees. Positive righting energy extended to 42 degrees, only 70% of the required 60 degrees. Additionally, the righting energy from 0 degrees to 40 degrees or flood is 79% of the requirement with 30 degrees to 40 degrees or flood only 45% of the requirement. These results indicate failure in contrast to the passing results found in the of 2002 stability analysis, reference (b). The difference in results could be attributed to the allocation of buoyant volume. MSC used the most conservative model that modeled the observed sheer of the vessel (from the lines plan) with no additional buoyant credit given to bulwarks or the superstructure (sheer is the downward curvature of the main deck). However, MSC did explore giving buoyant credit to the superstructure, along with the hull, but this case still showed significant failure of the stability criteria. Even with the assumptions and conservative nature of the analysis, the failure of the criteria is so large the vessel was determined not to be in compliance with the standards at the time of incident.

Load Conditions	**28.565 Water on Deck**	**28.570 Intact Righting Energy**	**28.575 Severe Wind & Roll**
LC1- Departure from port	Pass	Fail (2-7)	Fail (2)
LC2- Arrival at grounds	Pass	Fail (2-7)	Fail (2)
LC3- Grounds 50% catch	Pass	Fail (2-7)	Fail (2)
LC4- Grounds 100% catch	Pass	Fail (2-7)	Fail (2)
LC5- Grounds 40% catch	Pass	Fail (2-4, 6-7)	Pass
LC6- Port 100% catch	Pass	Fail (2-4, 6-7)	Pass
LC7- Port 40% catch	Pass	Fail (2-4, 6-7)	Pass
LC8- Port 0% catch	Pass	Fail (2-4, 6-7)	Pass
LC9- TOI	Pass	Fail (2-4, 6-7)	Fail (2)
LC10- ¼ fuel diff	Fail (1)	Fail (2-7)	Fail (2-3)
LC11- ½ fuel diff	Fail (1)	Fail (2-7)	Fail (1-3)
LC12- Paravanes	Pass	Fail (2-7)	Fail (2)
*Fail (#) indicates specific limit of the criteria that failed			

Table 6.3: Results Summary of Regulatory Stability Analysis

7. Drainage

In addition to Subchapter C intact stability, fishing industry vessels must meet the drainage requirements of 46 CFR 28.555 Freeing Ports. The vessel was equipped with six freeing ports on each side of the vessel. The main deck was separated by a transverse bulkhead just aft of the pilot house. Two of the twelve freeing ports were located in the bow section to provide drainage of the forward bulwarks while the remaining ten freeing ports service the aft deck. The required freeing port area is a function of bulwark length with the required freeing port area calculated to be 48.94 square feet in enclosure (10).

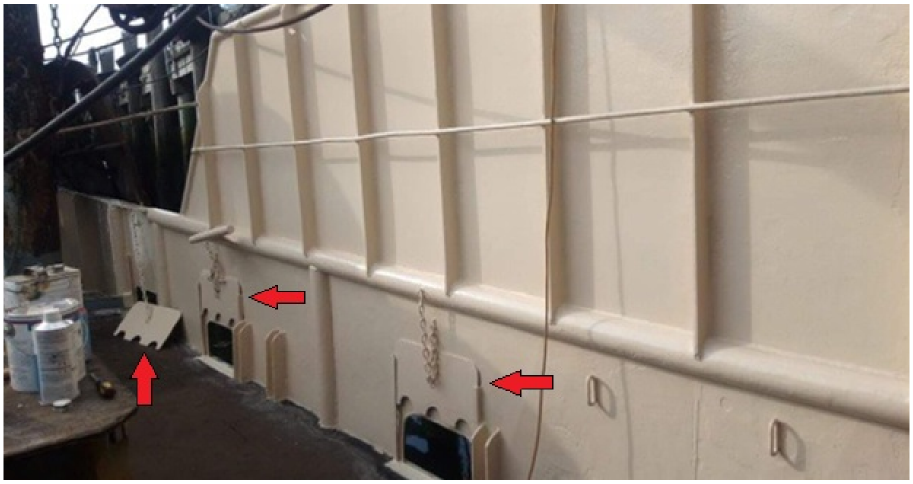

Figure 7.1: Freeing Port Restrictor Plates

Measurements were taken from photos to approximate the dimensions of the freeing ports. Due to the skew of the photograph, MSC approximated dimensions conservatively high. The dimensions of an individual freeing port was estimated to be 1.75 feet long by 1.25 feet high and all freeing ports were assumed to be identical. Using this estimate, the total freeing port area of the vessel was estimated to be 26.25 square feet, much less than the required 48.94 square feet. Additionally, the vessel had restrictor plates installed that could cover the freeing ports (see Figure 7.1), and drastically restrict deck drainage. Each restrictor plate has three semicircular openings that measure approximately 4 inches in diameter. If all twelve restrictor plates were installed and in the closed position, the total freeing port area would have been reduced to only 1.57 square feet. The vessel was also fitted with removable “storm gates” in the bulwark under the aft net reels, see Figure 7.2. With the “storm gates” removed additional drainage would be gained, but this area was not included in the freeing port calculation since the gates are typically in place during inclement weather.

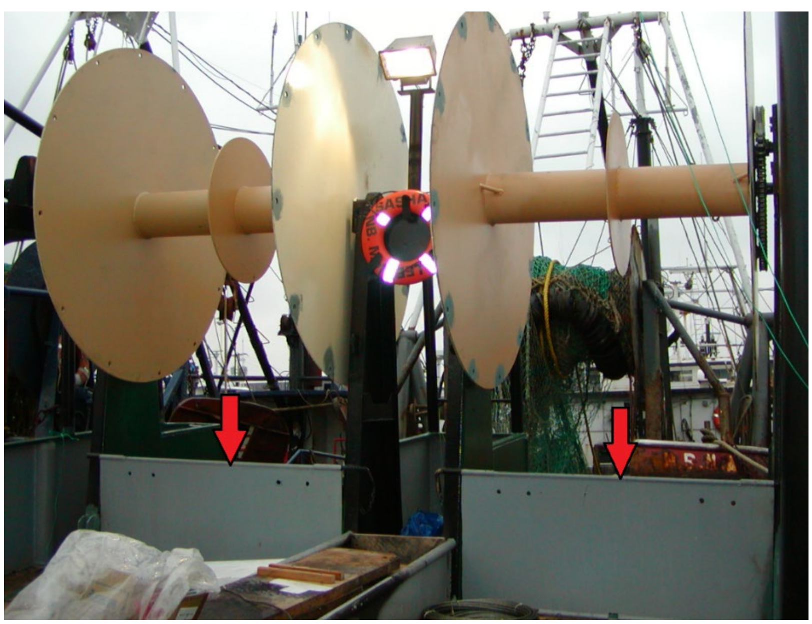

Figure 7.2: Aft Storm Gates

Table 7.1 is a summary of the required and actual freeing port areas. Insufficient deck drainage has the potential to retain water on deck, increasing the vessel's displacement, reducing its freeboards and righting arms, and reducing the effective height of downflooding points. Off-center pocketing and shifting of water on deck also reduces the vessel's stability.

Freeing Port Area 46 CFR 28.555	
Required Freeing Port Area	48.94 sqft
Total Estimated Freeing Port Area without Restrictor Plates	26.25 sqft
Total Estimated Freeing Port Area with Restrictor Plates	1.57 sqft

Table 7.1: Summary of Required and Estimated Total Freeing Port Area

8. Damage Stability

Although the vessel was not subject to 46 CFR 28.580 Unintentional Flooding standards since it was constructed prior to 1991, MSC was asked to evaluate possible damage scenarios using these standards. The vessel is comprised of three main watertight compartments plus the potable water tank in the forepeak. The first compartment aft of the potable water tank is the auxiliary space followed by the engine room. Photographs from evidence indicate that these two spaces share a non-watertight bulkhead, thus making the two spaces one effective watertight compartment. For the purpose of MSC's analysis, these spaces were considered both as separate auxiliary and engine room compartments as well as a larger combined auxiliary/engine room compartment. Aft of the engine room is the fish hold compartment followed by the lazarette compartment all the way aft.

Damage in each compartment was analyzed in load condition 9. Using the MSC model, each compartment was allowed to flood until it reached equilibrium with the outside waterline or the vessel capsized. Detailed results are provided in enclosure (11) and summarized in Table 8. The results indicate that the vessel failed 46 CFR 28.580 Unintentional Flooding standards for all damage cases and resulted in capsize when the auxiliary/engine room or fish hold compartments were flooded. When the lazarette was flooded, the vessel reached an equilibrium condition with 3 degrees of trim aft but remained upright and afloat.

Damage Results		
Damage Cases	**46 CFR 28.580 Unintentional Flooding**	**Equilibrium Condition**
DC0: Auxiliary	Fail	Capsize
DC1: Engine	Fail	Stable Equilibrium
DC2: Aux/Eng	Fail	Capsize
DC3: Fish Hold	Fail	Capsize
DC4: Lazarette	Fail	Stable Equilibrium

Table 8.1: Summary of Unintentional Flooding

Additionally, a quasi-static flow rate analysis was conducted to determine the time required to flood the compartments damaged above. The focus of the flow rate analysis was on the lazarette and auxiliary/engine room compartments since they contained the majority of the through hull fittings, which present the greatest risk for flooding. The exact size of through hull fittings was unknown, therefore the analyses consider various size holes ranging from 1 to 6 inches. The ingress point of each compartment was placed at the lowest point in the compartment, which is representative of the maximum hydrostatic pressure. This approach results in the shortest/worst-case flood times. The lazarette flooding time ranged from 350 minutes to 9.5 minutes, (see Table 8.2). The auxiliary/engine room flooding time to capsize ranged from 360 minutes to as little as 10 minutes (see Table 8.3). Based on these flooding times, the crew may have been alerted to the signs of degrading stability with little response time, or gradually with the crew not noticing before capsizing.

Lazarette Compartment (1,150 cubic feet)		
Hole Size (inches)	**Time to Equilibrium (minutes)**	**Equilibrium Condition**
1	350	Stable Equilibrium
2	87.5	Stable Equilibrium
3	38	Stable Equilibrium
4	20	Stable Equilibrium
5	13.5	Stable Equilibrium
6	9.5	Stable Equilibrium

Table 8.2: Lazarette Flood Times with Various Size Holes

Auxiliary/Engine Room Compartment (7,167 cubic feet)		
Hole Size (inches)	**Time to Equilibrium (minutes)**	**Equilibrium Condition**
1	360	Capsize
2	90	Capsize
3	40	Capsize
4	22	Capsize
5	14.5	Capsize
6	10	Capsize

Table 8.3: Auxiliary/Engine Room Flood Times with Various Size Holes

MSC was also asked to predict the required heeling moment to submerge the downflooding points that would cause progressive flooding. However, when applying a heeling moment, the vessel capsizes before the downflooding points are ever submerged.

9. Side Scan Sonar and ROV Survey

A side scan sonar search was conducted by MIND Technology on May 17-21, 2021 to locate the F/V EMMY ROSE. The vessel was found in the vicinity of the last known EPIRB transmission and can be seen in Figure 9.1 resting on the seabed in an upright position with the outriggers deployed. The sonar image shows the paravanes, also known as "birds," are paid out forward of the vessel, indicating the vessel possibly sank stern first through the water column. There is also a difference in cable length for the paravanes with the port side paid out four times further at 62 meters. A possible cause for this could be winch failure from water intrusion during the sinking. It was also explored that the paravane snagged bottom, but this is not possible since the vessel is in over 200 meters of water. The sonar scan does not indicate any damage from an allision or collision.

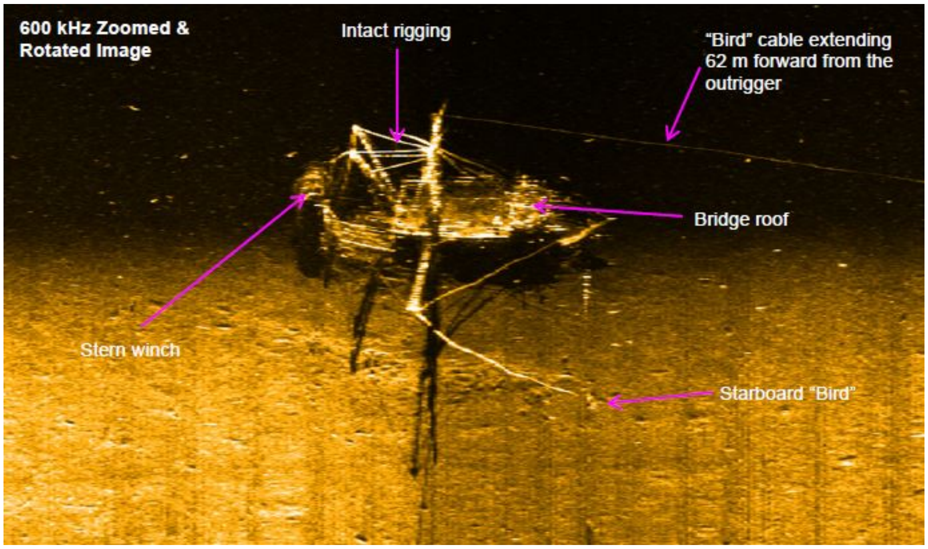

Figure 9.1: Sonar image of F/V EMMY ROSE from MIND Technology

A closer look of the vessel was conducted by Woods Hole Oceanographic Institution (WHOI) with an underwater survey using remotely operated vehicles (ROV). No damage was found to the hull or superstructure but the propulsion gear and underside could not be seen due to the vessel orientation and sediment. On the starboard side it was discovered that the freeing port restrictor plates were in place on the aft two freeing ports while the middle three freeing ports had line and chain hanging out of them. On the port side, only one aft freeing port had the restrictor plate in place and no debris was hanging out of the freeing ports. This could be indicative of a list to starboard causing gear on deck to shift to the starboard side and wash out the freeing ports.

10. Conclusion

MSC was asked to review evidence and conduct a technical analysis into possible causes of the sinking of F/V EMMY ROSE. The information gathered and necessary assumptions made were used to create a model from the provided lines plan and validate that model against an existing stability test and lightship data. An independent stability analysis was then conducted to the applicable stability regulations and possible damage scenarios.

Based on the analysis, the vessel lacked sufficient stability in all loading conditions, specifically at the time of incident, per the regulatory criteria in 46 CFR Subchapter C. The limiting criteria in all cases was 46 CFR 28.570 Intact Righting Energy. At the time of incident, the vessel failed by 20% or more in each failure of this criteria. The failure percentage exceeds any expected differences from assumptions made in the analysis, therefore indicating the vessel was not in stability compliance per the regulations. Although failure of the criteria does not necessarily indicate capsize, the likelihood is increased. Additionally, any off center loading or weight shifts that would cause a list would have reduced the vessel's stability further. This could be caused by large shifting weights on deck, shifting catch in the fish hold, or internal liquid transfers. The lack of sufficient drainage could also cause entrapment or pocketing of water on deck, producing a heeling moment and list.

Damage scenarios were analyzed even though the vessel was not subject to damage stability regulations. MSC's analysis indicates that unintentional flooding of the fish hold or auxiliary/engine room compartments would result in capsize. When the lazarette is flooded, the vessel remains afloat but with significant trim aft. The time required for flooding induced capsize ranged from hours to 10 minutes based on various sized holes with diameters from 1 inch to 6 inches. The smaller diameter holes represent small through hull fittings or ruptured auxiliary piping while the large diameter holes represent large fittings such as a sea chest or propeller shaft.

The sonar scan and ROV surveys do not indicate any external damage to the vessel that would cause a damage case. An internal or underside survey of the vessel to check for damage was not possible. The ROV pictures revealed debris hanging out the starboard side freeing ports and no debris in the port freeing ports, indicating a starboard list likely occurred causing deck gear to wash out the starboard side freeing ports.