National Transportation Safety Board

Office of Marine Safety

Washington, D.C. 20594

Group Chairman's Factual Report

Naval Architecture Group

SS ***El Faro***

DCA16MM001

Eric Stolzenberg

TABLE OF CONTENTS

Redacted- V2 [redacted]

1 ACCIDENT INFORMATION

Vessel:	SS *El Faro*
Accident Number:	DCA16MM001
Date:	October 1, 2015
Time:	0739 eastern daylight time (EDT) [1]
Location:	North Atlantic Ocean, 40 nautical miles northeast of Acklins and Crooked Island, Bahamas 23.3925˚ N, 73.9029˚ W
Accident type:	Sinking
Accident complement:	27 crew, 6 supernumeraries

2 NAVAL ARCHITECTURE GROUP

Group Chairman	Eric Stolzenberg Office of Marine Safety National Transportation Safety Board Washington, DC 20594
Member–US Coast Guard	Dr. Jeffrey W. Stettler Naval Architect, Salvage Engineer US Coast Guard Marine Safety Center, Salvage Engineering Response Team (SERT)
Member–TOTE Services, Inc.	Dennis O'Meara Director of Ship Management for Military Sealift Command, TOTE Services
Member–American Bureau of Shipping	Thomas M. Gruber, Naval Architect Chief Engineer, Statutes
Member–Herbert Engineering Corporation	Spencer Schilling, Naval Architect President

[1] Times in this report are eastern daylight time according to the 24-hour clock. EDT is 4 hours behind Universal Coordinated Time (UTC).

3 ACCIDENT SUMMARY

On Thursday, October 1, 2015, about 0715 EDT, the US Coast Guard received distress alerts from the 790-foot roll-on/roll-off container (Ro/Con) ship *El Faro*. The US-flagged ship, owned by TOTE Maritime Puerto Rico (formerly Sea Star Line, LLC) and operated by TOTE Services, Inc. (TOTE), was 40 nautical miles northeast of Acklins and Crooked Island, Bahamas, and close to the eye of Hurricane Joaquin. The ship was en route from Jacksonville, Florida, to San Juan, Puerto Rico, with a cargo of containers and vehicles. Just minutes before the distress alerts, the *El Faro* master had called TOTE's designated person and reported that a scuttle had popped open on deck two and that there was water entering down into the No. 3 hold. He said the crew had controlled the ingress of water but that the ship was listing 15° and had lost propulsion. The Coast Guard and TOTE were unable to reestablish communication with the ship. Twenty-eight US crewmembers, including an off-duty engineering officer sailing as a supernumerary, and five Polish workers were on board.

The Coast Guard, US Navy, and US Air Force dispatched multiple assets to the ship's last known position, but the search was hampered by hurricane-force conditions on scene. On Saturday, October 3, two debris fields were discovered, and on Sunday, October 4, a damaged lifeboat and liferaft were located. The same day, the Coast Guard found a deceased crewmember wearing an immersion suit. A Coast Guard helicopter dropped a locator buoy near the body in the immersion suit and left to investigate reported signs of life elsewhere but then could not relocate the immersion suit. No signs of life were found, and on Monday, October 5, two oil slicks were discovered. The Coast Guard determined that *El Faro* was lost and declared the event a major marine casualty. The Coast Guard suspended the unsuccessful search for survivors at sundown on Wednesday, October 7.

4 INVESTIGATION

The National Transportation Safety Board (NTSB) learned of the accident from the Coast Guard on the afternoon of October 1. A team of five investigators, a board member, and support staff launched from NTSB headquarters on October 6 and arrived on scene in Jacksonville later the same day. The investigation was led by the NTSB. Parties to the investigation were the Coast Guard, TOTE, the American Bureau of Shipping (ABS), the National Weather Service, Harding Safety USA (Palfinger), and Herbert Engineering Corporation (HEC). Company officials, off-duty crewmembers, Coast Guard inspectors, ABS surveyors, and other witnesses were interviewed. The on-scene part of the investigation was completed on October 15.

The Naval Architecture group was not convened on scene but was formed about a month after the accident. The purpose of the group was to examine the stability, structure, flooding events, and governing rules and history of *El Faro*. The group first convened by telephone conference on November 13, 2015. The group conducted naval architecture-based interviews and met periodically throughout the remainder of the fact-finding part of the investigation.

The Coast Guard convened three sets of Marine Board of Investigation (MBI) hearings in Jacksonville, Florida: in February and May 2016, and in February 2017. The Naval Architecture group chairman participated in the second and third hearings, and some party members of the Naval Architecture group served on the MBI as members or witnesses. Investigators visited *El Yunque*, a sister ship to *El Faro*, on four occasions (October 9 and December 1, 2015, in Jacksonville; September 20, 2016, in Tacoma, Washington; and January 10, 2017, in Brownsville, Texas). Representatives of the Coast Guard, ABS, and TOTE were present at each visit.

On October 31, 2015, the Navy ship USNS Apache, fitted with underwater detection equipment located the wreckage of *El Faro* at a depth of about 15,400 feet. The Naval Architecture group chairman requested and led contracting for a dynamic analysis of the sinking and a forensic analysis of the wreckage. In April 2016, the research vessel RV *Atlantis* from the National Science Foundation and the Woods Hole Oceanographic Institution traveled to the accident site and located *El Faro*'s voyage data recorder (VDR) but could not retrieve it. In August 2016, the *Apache* revisited the site and on August 8, recovered the VDR capsule using the unmanned submersible CURV, which yielded 26 hours of data. In December 2016, the NTSB released a transcript of the audio recordings made on the vessel's bridge during the last 10 hours before the sinking. The transcript is more than 500 pages long.

The Naval Architecture group chairman participated in the April 2016 voyage in search of *El Faro*'s VDR and requested contracting with Woods Hole Oceanographic Institution for detailed debris-field maps, a point cloud (three-dimensional data), and photomosaic images of the hull and other wreckage. The group chairman also requested a wreckage review in coordination with the NTSB's Office of Research and Engineering. All Naval Architecture Group members (or designees) participated in the review and had an opportunity to comment on the draft report.

5 VESSEL HISTORY AND DESCRIPTION

Figure 1. *El Faro* under way in March 2006, loaded with containers. (Photo TOTE website)

El Faro was an oceangoing cargo vessel in regular weekly liner service between Jacksonville, Florida, and San Juan, Puerto Rico. The vessel carried trailers, automobiles, containers, and miscellaneous cargo. Shoreside ramps were fitted in port to allow loading and unloading of cargo below the main deck (roll-on/roll-off, or Ro/Ro), while shoreside cranes loaded containers above the main deck (load-on/load-off, or Lo/Lo). As a vessel carrying both Ro/Ro and Lo/Lo containers, *El Faro* was both a Ro/Ro and a container vessel, or more simply, a Ro/Con.

5.1 *El Faro* Details

Table 1. Particulars of *El Faro*

Vessel Name	***El Faro***
Owner/operator	TOTE Maritime Puerto Rico/TOTE Services, Inc.
Port of registry	San Juan, Puerto Rico
Flag	United States
Type	Freight ship- Ro/Con
Builder	Sun Shipbuilding, Chester, Pennsylvania, hull No. 670
Delivery date	January 16, 1975
Official number	561732
International Maritime Organization (IMO) number	7395351
Classification society	American Bureau of Shipping

Class notification	ABS: ✠A1, Vehicle Carrier, (E), ✠AMS
Construction	Steel, welded
Draft, full Load (extreme[2])	30′-2 3/8″ (9.2 meters)
Displacement, full load (saltwater)	34,677 long tons (LT)[3]
Displacement, lightship (saltwater)	19,943 LT
Length, overall	790′-9″ (241.0 meters)
Length, between perpendiculars	733″-9″ (223.7 meters)
Beam, hull (molded)	92′-0″ (28.0 meters)
Beam, at main deck	105′-0″ (32.0) meters)
Depth, to main deck (molded)	60′-1 5/8″ (18.3 meters)
Depth, to 2nd deck (molded)	42′-1 5/8″ (12.8 meters)
Depth, to 3rd deck	24′-1 5/8″ (7.4 meters)
Gross tons, registered/international	17,527/31,515
Net tons, registered/international	11,399/21,473
Engine, power and type	Steam turbine, 30,000 shaft horsepower, single screw
Propulsion type	Single fixed-pitch propeller
Service Speed	20 knots
Fuel oil, total capacity (98%)	1,742.4 LT (11,552 barrels)
Cargo	Containers and rolling cargo (automobiles and trailers)
Container capacity, main deck[4]	1,414 TEUs[5]
Ro/Ro auto capacity, 2nd deck/3rd deck/tanktop	323/237/173 (733 total)
Ro/Ro trailer capacity, 2nd deck/3rd deck/tanktop	93/71/52 (216 total)
Complement, total	42 maximum (33 crew, 9 others)

1

2

[2] Extreme draft is to the bottom of the keel plating, while molded draft is to the top of the bottom or keel plate.

[3] One long ton = 2,240 pounds.

[4] Container and Ro/Ro capacity found in S.S. *El Faro*, Capacity Plan, Dwg. SSL-670-100-027 Alt. C, HEC, April 27, 2006 (MBI exhibit 133).

[5] The 20-foot equivalent unit, or TEU, is a standard unit for describing a containership's cargo-carrying capacity, or a shipping terminal's cargo-handling capacity. A standard 40-foot (40 x 8 x 8 feet) container equals two TEUs (each 20 x 8 x 8 feet).

5.2 *El Faro* General Arrangement

As a Ro/Con vessel, *El Faro* carried containers on its main deck and trailers and automobiles on its semi-enclosed second deck and in holds on its third deck (tween) and tanktop (lowest deck). Two working internal ramps and an elevator distributed Ro/Ro cargo throughout the vessel. Two internal ramps from the second to the main deck were blocked off.

A simplified inboard profile of *El Faro* and its deck, as configured at the time of the sinking, is found in **appendix A**. Earlier vessel profiles are reproduced below.

5.3 Vessel Ownership and History of Sun Shipbuilding Hull 670

El Faro was launched on November 1, 1974, as hull 670 by Sun Shipbuilding and Drydock Company, Chester, Pennsylvania (south of Philadelphia). The vessel was the seventh in the 700-foot-long Ro/Ro (originally, trailership) class from Sun Shipbuilding.[6] The ships are known as *Ponce*-class, after the first vessel launched in 1967, the *Ponce de Leon*. Hull 670, originally named the SS *Puerto Rico*, was the last of the 700-foot *Ponce*-class vessels. The final three (hull 673, *Great Land*; hull 674, *Westward Venture* and shortly after renamed *Saudi Bear* then *Atlantic Bear*; and hull 675, *Westward Venture*) were all built 790 feet long and with an additional spar deck above the main deck. Hull 673 was built to plans for 700-feet, but lengthened before delivery from Sun Shipbuilding.

The *Puerto Rico* began service as part of the now-defunct Navieras de Puerto Rico Steamship Company and sailed between Puerto Rico and the US East Coast from 1975 to 1991. In 1975, Sun Shipbuilding established Totem Ocean Trailer Express (TOTE),[7] offering Ro/Ro

[6] Sun Ship Historical Society website and Homepage, http://www.sunship.org.

[7] TOTE Inc. website, http://toteinc.com/about/history.

trailer service from Seattle, Washington, to Anchorage, Alaska. In October 1982, newly formed Totem Resources Company (currently Saltchuk Resources) purchased TOTE from Sun Shipbuilding.

In 1991, TOTE purchased the *Puerto Rico* and renamed it the *Northern Lights*. In 1992–1993, TOTE modified the vessel at Atlantic Marine, Inc., lengthening it 90 feet at midbody and adding a spar deck, in a configuration similar to its two other *Ponce*-class vessels (*Great Land* and *Westward Venture)* that were in service between Tacoma, Washington, and Anchorage. TOTE added the *Northern Lights* to its service between Tacoma and Anchorage in 1993. [8]

TOTE retired the *Great Land*, *Westward Venture*, and *Northern Lights* from the Tacoma-to-Anchorage run in 2002–2003, when the company took delivery of two new Orca-class vessels for a similar service. In 2003, the *Northern Lights* was chartered by the US Military Sealift Command, traveling to and from the Mideast to support Operation Iraqi Freedom.[9]

Sea Star Line was founded as Sea-Barge line in 1985, with two tugs and barges operating from south Florida. In 1998 Sea-Barge became Sea Star Line, LLC, when it was purchased by Totem Resources, owner of TOTE, and other investors. Totem Resources became Saltchuck Resources in 1998. Expanding routes and services, Sea Star added freight ships, and in 2002 Sea Star Line acquired the assets of Navieras de Puerto Rico and increased its sailings to Puerto Rico.

In 2005, TOTE transferred the *Northern Lights* to Sea Star Line and modified it to carry containers on and above the main deck, matching the configuration of two other *Ponce*-class vessels in Sea Star's Florida-to-Puerto Rico service: the *El Yunque* (Sun Shipbuilding hull 674)

[8] TOTE Inc. website, http://toteinc.com/about/history.

[9] TOTE Inc. website, http://toteinc.com/about/history.

and *El Morro* (Sun Shipbuilding hull 666). The three ships all carried both Ro/Ro and Lo/Lo container cargo.

In March 2006, Sea Star Line renamed the *Northern Lights* as *El Faro*. The vessel sailed under charter, was in East Coast-to-Puerto Rico service, was laid up for about 2 years (2012–2014), and was last in regular service between Jacksonville and San Juan.

In September 2015, just before *El Faro* sank, the Saltchuck subsidiaries Sea Star Line and TOTE (Alaska service) were renamed TOTE Maritime Puerto Rico and TOTE Maritime Alaska.

5.4 1975 Original Configuration

El Faro was originally built with similar dimensions to the other 700-foot *Ponce*-class vessels, including the *Ponce*, as indicated by an undated Sun Shipbuilding configuration schematic for its Ro/Ro vessels.[10] *El Faro*'s original general arrangement drawings could not be found. Investigators obtained drawings, however, indicating that the design of hull 647, the *Ponce*, was used in the original construction of the *Puerto Rico* and in its modifications as the *Northern Lights* and *El Faro*, substantiating similarities between the hulls.

The *Puerto Rico* had cargo holds below the second deck, the freeboard, and the bulkhead deck (see **figures 2 and 3**).[11] It carried additional trailers on the semi-enclosed second deck and the exposed main deck. It was designed as and functioned purely as a Ro/Ro, loading trailers, automobiles, and other cargo by rolling them onto the vessel through three access ports on the

[10] Sun Trailer Ships, undated Ro-Ro configuration schematic, provided by the US Maritime Administration (MARAD) via email to NTSB on 19 April 2016.

[11] The terms *freeboard* and *bulkhead deck* are often used interchangeably. The bulkhead deck is the highest deck up to which the transverse watertight bulkheads and shell are carried. The freeboard deck is normally the uppermost continuous deck exposed to the weather and the sea. It has permanent means of closing all openings weathertight, and below it all openings in the sides of the ship are fitted with permanent watertight closings.

starboard side of the second deck and then throughout the ship using four internal ramps and an elevator.

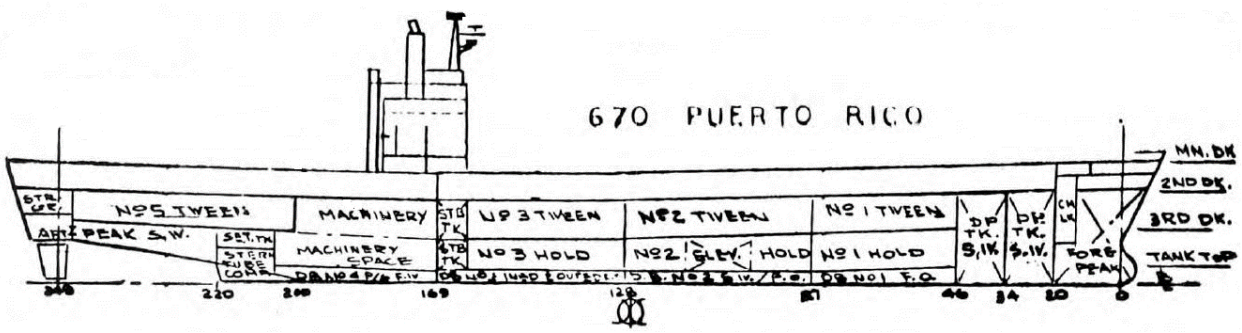


Figure 2. Simple inboard profile of Sun Shipbuilding hull 670 as originally constructed. (Source: MARAD)

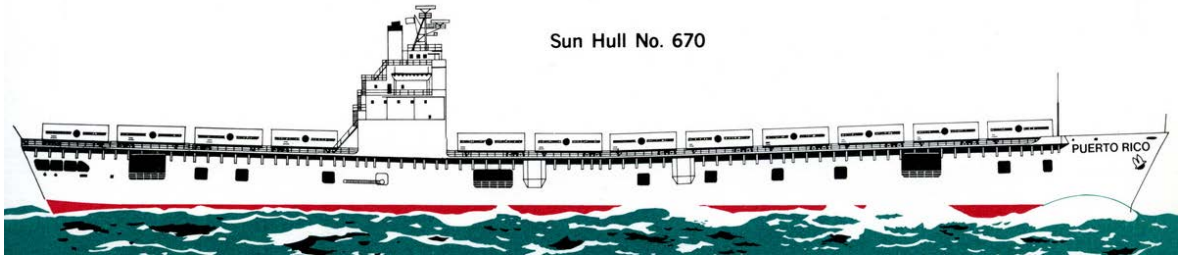


Figure 3. Hull 670 shown on Sun Shipbuilding launching Invitation. (Sunship.org)

Vessel parameters for the *Ponce* are shown in **table 2** (see section 5.6, below). Dimensions for beam and depths to decks are the same as in *El Faro*'s final Ro/Con configuration. The original length is 90 feet, 9 inches shorter and the full-load draft is 2 feet, 1 1/4 inches less than in *El Faro*'s final configuration.

5.5 1992–1993 Lengthening and Addition of Spar Deck

As early as 1982, plans were made to increase the Ro/Ro capacity of the *Puerto Rico* and make it similar to the longer *Ponce*-class hulls. ABS supplied investigators with a 1982 preliminary general arrangement drawing for a lengthened hull 670, showing the addition of an upper (spar)

deck extending from the house forward to the No. 2 hold.[12] The plan also shows a new 90-foot-long No. 2A hold, which was created by fitting a 90-foot, 9-inch midbody section (**figure 4**). The hull was not lengthened until 1992–1993, and was the last *Ponce*-class ship to be so altered.

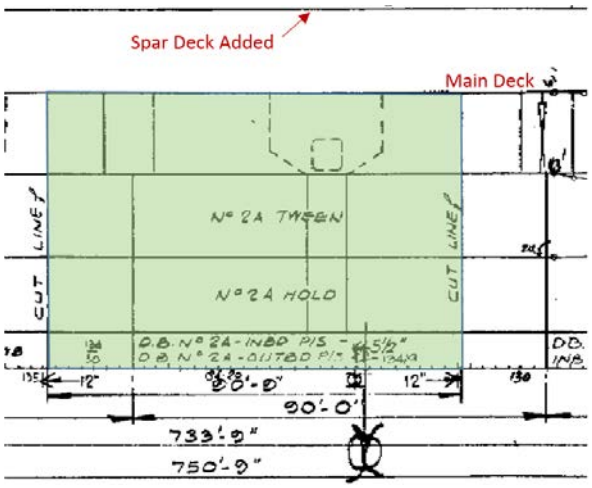


Figure 4. Hull cut and 90 foot, 9 inch midbody added between frames 134 and 135 (shaded green), from 1982 lengthening plan.

The modified vessel was renamed SS *Northern Lights* on September 24, 1991.[13] A simplified profile of the modified vessel is shown in **figure 5**. The added deck area allowed the vessel to carry a third more trailers and automobiles. The spar deck and the additional trailers and automobiles it would carry raised the vessel's center of gravity (CG), which required 1,830 LT of QCM[14] fixed ballast to be fitted in the No. 2 outboard port and starboard double-bottom tanks. Before the lengthening, the No. 2 double-bottom tanks were designated for saltwater ballast.

[12] Lengthening of Roll-On/Roll-Off Trailership S.S. *Puerto Rico*, Sun hull 670, general arrangement (contract plan) prepared by H.T McVey & Associates, approved September 10, 1982. Drawing prepared for Navieras De Puerto Rico, Apartado 71105, San Juan, Puerto Rico, 00936.

[13] ABS Survey manager survey status report, El Faro, p. 5, printed October 1, 2015 (MBI exhibit 112).

[14] QCM is a finely crushed iron ore concentrate with a density of about 190 lb/ft^3 (Coast Guard Navigation and Inspection Circular 5-82, Subject: Fixed Ballast).

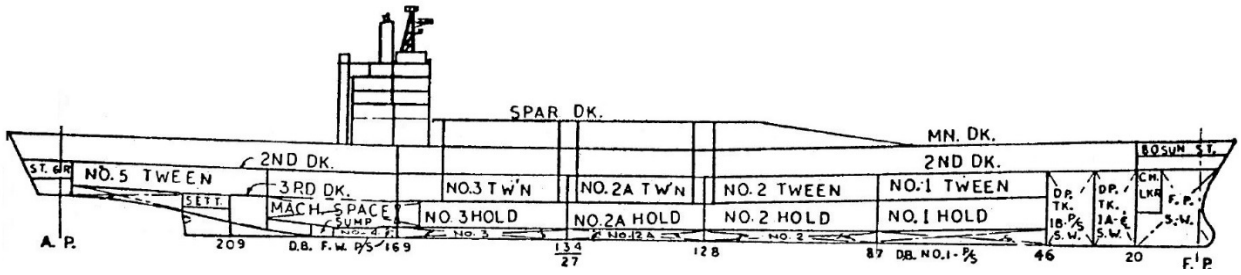


Figure 5. Simple inboard profile of hull 670 as lengthened with spar deck in 1993.[15]

Vessel parameters for the lengthened vessel are shown in **table 2** below. Dimensions for length, beam, and depths to decks are the same as for *El Faro*'s final Ro/Con configuration. The 1993 full-load draft was 1/16 inch less (nearly the same) than the original 1975 draft, which was 2 feet, 1 5/16 inches less than the vessel's full-load draft in its final Ro/Con configuration.

The Coast Guard determined the 1992–1993 conversion to be a major conversion. For a general discussion and details about the major conversion determinations for *El Faro*, see Section 11, "Major Conversion."

5.6 2005–2006 Removal of Spar Deck and Conversion to Carry Containers

As the *Northern Lights*, the vessel was converted in 2005–2006 to carry Lo/Lo containers in addition to Ro/Ro cargo. The spar deck was removed, both ramps to its main deck were blocked, and the main deck was modified to carry containers of varying lengths (53 feet, 45 feet, 40 feet, and 20 feet) rather than trailers. The alteration added up to twelve containers transversely, stacked as many as five high above the main deck. To support the additional weight of the containers, the main deck was strengthened by adding reinforcement and supporting structure. Transverse deck beams with container fittings were also added.

[15] Trim & Stability Booklet, rev. A1, SS Northern Lights, JJH Inc., 5 June 1993 (MBI exhibit 251).

The altered vessel lost over 40 percent of its Ro/Ro trailer and auto capacity, but it gained the capacity to carry 1,414 more TEUs of container cargo. The vessel's profile after the conversion is shown in **figure 6**.

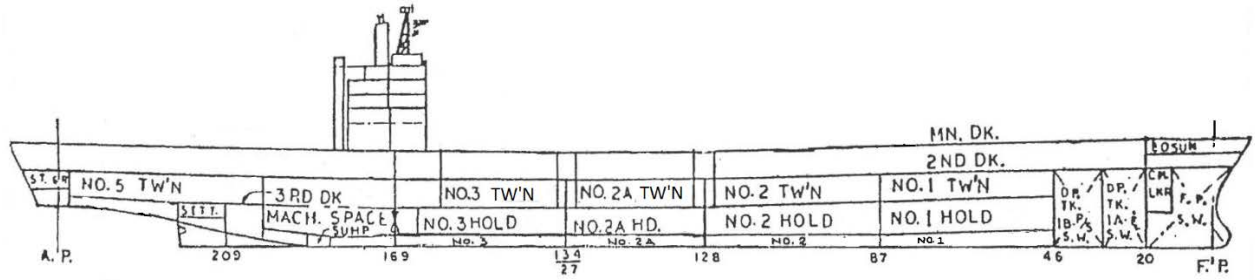


Figure 6. Simple inboard profile of hull 670 after spar deck was removed in 2006.[16]

The carriage of cargo containers above the main deck again raised the vessel's CG, requiring 4,875 LT of additional QCM fixed ballast to be fitted in the No. 2A and No. 3 port and starboard outboard double-bottom tanks. Before the modification, the No. 3 outboard tanks were designated for fuel oil or saltwater ballast, while the No. 2A outboard tanks were designated for fixed and saltwater ballast. Some double-bottom tanks that had held fuel oil were designated for other uses, and all double-bottom saltwater ballast tanks were changed to freshwater ballast tanks. Only forward deep tank 1A and the aft peak tanks remained designated for saltwater. The vessel was renamed SS *El Faro* on January 18, 2006.[17]

Table 2 compares selected vessel parameters of *El Faro* to its previous two hull configurations. *El Faro*'s main dimensions were unchanged from its configuration after it was lengthened (as the *Northern Lights*). Its draft increased by 2 feet, 1 1/4 inches, however, and its full-load displacement increased from 31,502 LT to 34,677 LT, or by just over 10 percent.

[16] Trim & Stability Booklet, rev E, SS *El Faro,* HEC, 14 February 2007, p. 9 (image simplified by NTSB).

[17] ABS survey manager survey status report, *El Faro*, p. 5, printed 1 October 2015 (MBI exhibit 112).

Table 2. Comparison of parameters for hull 670 in its three historical configurations.

Parameter	Hull 647, *Ponce*[18] (similar to *Puerto Rico*)	*Northern Lights*[19]	*El Faro*[20]
Years in service	1975-1992	1993-2005	2006-2015
Draft, full load (extreme)	28'-1 1/8" (8.6 m)	28'-1 1/8" (8.6 m)[21]	30'-2 3/8" (9.2 m)
Freeboard, type B[22]	14'-2 3/4"	14'-2 1/4"	12'-0 15/16"
Displacement, full load (S.W.)	25,350 LT	31,502 LT	34,677 LT
Displacement, lightship	10,721 LT	15,743 LT	19,943 LT
Length, overall	700'-0" (213.4 m)	790'-9" (241.0 m)	790'-9" (241.0 m)
Length, between perpendiculars	643'-0" (196.0 m)	733'-9" (223.7 m)	733'-9" (223.7 m)
Beam, hull (molded)	92'-0" (28.0 m)	92'-0" (28.0 m)	92'-0" (28.0 m)
Beam, at main deck	105'-0" (32.0 m)	105'-0" (32.0 m)	105'-0" (32.0 m)
Depth, to spar deck (molded)	No Spar Deck	78'-6 3/8" (23.9 m)	No Spar Deck
Depth, to main deck (molded)	60'-1 5/8" (18.3 m)	60'-1 5/8" (18.3 m)	60'-1 5/8" (18.3 m)
Depth, to 2nd deck (molded)	42'-1 5/8" (12.8 m)	42'-1 5/8" (12.8 m)	42'-1 5/8" (12.8 m)
Depth, to 3rd deck (molded)	unavailable	24'-1 5/8" (7.4 m)	24'-1 5/8" (7.4 m)
Fixed ballast (QCM)	-	1,830 LT	6,705 LT
Number of automobiles	102	139	74
Number of 20-foot trailers	0	28	24
Number of 40-foot trailers	294	369	190
Number of containers (TEU)	-	-	1,414

Unlike the 1992–1993 lengthening, the Coast Guard eventually determined that the vessel's alteration in 2005–2006 to carry containers was not a major conversion (see section 11).

[18] Trim & Stability Booklet, rev. _, SS *Ponce*, C.R. Cushing & Co., Inc., June 1977.

[19] Trim & Stability Booklet, rev. A1, SS *Northern Lights*, JJH Inc., 5 June 1993 (MBI exhibit 251).

[20] Trim & Stability Booklet, rev E, SS *El Faro*, HEC, 14 February 2007.

[21] The ABS 6 May 1993 ABS stability letter for *Northern Lights* gives 28'-1 1/16" as extreme draft, while the 1993 stability book gives 28'-1 1/8". Using 28'-1 1/16" as the 1993 extreme draft calculates the draft increase in 2006 was 2'-1 5/16".

[22] ABSID 7500285, *El Faro* Stability Timeline, November 23, 2015. All freeboards are from "summer" line.

5.7 Static Stability Data—Historical Comparison

Table 3 compares basic stability data for the three historical configurations of *El Faro* at full-load departure condition (full fuel oil and cargo). The intact stability weather criteria at Title 46 *Code of Federal Regulations* (CFR) 170.170 were applied to all three configurations to determine minimum metacentric height (GM) requirements.[23] The *El Faro* data are from its most recent stability book. The *Northern Lights* data are from the 1993 ABS-approved trim and stability (T&S) booklet produced by JJH (John J. Henry Naval Architects) for the vessel as lengthened and converted by Atlantic Marine.

Investigators could not locate the original T&S booklet for *El Faro* (then the *Puerto Rico*), but MARAD provided the nearest found equivalent: a copy of the booklet for the *Ponce,* dated June 1977 (the year its named was changed from the original *Ponce de Leon*). Although it was not the original T&S booklet for hull 670 (*El Faro*), the *Ponce*'s booklet showed a similar configuration and similar main dimensions to those of the *Puerto Rico.* MARAD personnel indicated that the booklet would generally be applicable to the *Puerto Rico* because of the similarities.[24]

[23] Although the vessel's 1993 and 2005 configurations were subject to damaged stability requirements, the weather criteria were found to be the limiting GM for all loading cases in the stability booklets (and therefore the minimum GM given in table 3 is for intact requirements).

[24] Email, MARAD D. Heller to NTSB E. Stolzenberg, MARAD Program Vessels, *El Faro* Design Letter 3 damage criteria, 19 April 2016.

Table 3. Stability parameters for vessel's three configurations, departure condition at full load.

Parameter	Hull 647, *Ponce*[25]	Hull 670, *Northern Lights*[26]	Hull 670, *El Faro*[27]
Years in service	1975–1992	1993–2005	2006–2015
Displacement (LT)	23,430.3	31,493.8	34,667
Vertical center of gravity (VCG) (feet above baseline)	37.03	36.65	35.36
Longitudinal center of gravity (LCG) (feet to forward perpendicular)	297.7	397.3	395.2
Free surface (LT-feet)	21,155	21,473	15,474
Longitudinal center of buoyancy (LCB) (feet to forward perpendicular)	302.6	388.03	391.46
Draft, at aft perpendicular/forward perpendicular (feet)	27.96/24.91	30.39/25.43	31.05/29.00
Transverse metacentric height (KMt) (feet)	42.15	41.63	41.68
GM (feet)	5.12	4.98	6.31
Free surface corrected (feet)	0.90	0.68	0.45
GM corrected (feet)	4.22	4.30	5.87
Minimum required GM (feet)	2.85	3.14	3.92
Draft at marks, forward/aft (feet)	–	30.21/25.46	29.01/30.97

6 APPLICABLE RULES AND REGULATIONS

Both the Coast Guard and marine classification societies (including ABS) develop and produce rules, standards, and guides for the design, construction, surveying, and operation of vessels. In general, when a vessel is intended to be certificated by the Coast Guard and "classed" by a given classification society, it must meet when constructed the relevant Coast Guard

[25] Trim & Stability Booklet, rev. _, SS Ponce, C.R. Cushing & Co., Inc., June 1977.

[26] Trim & Stability Booklet, DWG No. 1252-700-602, rev. A1, SS Northern Lights, JJH Inc., 5 June 1993 (MBI exhibit 251).

[27] Trim & Stability Booklet, rev E, SS *El Faro*, HEC, 14 February 2007.

regulations, found in the CFRs, and class society rules. When modifications are made, the Coast Guard determines whether the vessel, or selected parts of it and its systems, must comply with the newer regulations in place on the modification date, or whether the vessel can continue to comply with the regulations in place when it was built. Similarly, the classification society will make a determination of what class rules apply to the vessel based upon the modification date. In the case of US-flagged ships like *El Faro*, if the Coast Guard determines that alterations are deemed a "major conversion," the vessel or portions and systems of it may have to meet newer rules and regulations in place at the date of modification. For further information, see section 11.

To ascertain what rules and regulations ABS and the Coast Guard would have previously found applicable to *El Faro*, investigators determined pertinent dates in the ship's configuration history. The most recent Coast Guard certificate of inspection (COI) for *El Faro* gives a delivery date of January 16, 1975. ABS gave investigators a slightly earlier delivery date of January 1, 1975.[28] The Sun Ship website shows a launch date of November 1, 1974. Investigators could not determine the contract date of the originally constructed vessel, which would determine the applicability of most regulations in 46 CFR Subchapter I. Because some regulations may have been modified between 1973 and 1975, the exact contract date might change the applicable CFRs.

The vessel was ABS-classed on delivery in 1975. According to ABS, the 1973 ABS steel vessel rules would most likely have been applicable to *El Faro* as it was constructed.[29] The vessel was inspected and certified by the Coast Guard at delivery as well. Based on the build date, the 1973 or the 1974 CFRs or both most likely applied.

[28] Email, *El Faro* construction question, ABS assistant chief surveyor, 30 June 2016.

[29] Email, *El Faro* construction question, ABS assistant chief surveyor, 30 June 2016.

Coast Guard correspondence showed that they considered 1992 lengthening to be a "major modification" and based on the date of the vessel lengthening, the vessel was to comply with recent changes to the SOLAS damaged stability standards.[30] The 1992 regulations (as opposed to those from 1975) were applicable to the vessel and its systems because the Coast Guard deemed the conversion a "major modification." Similarly, ABS would make a determination of what class rules apply to the vessel based upon the modification date. Even with the "major modification" designation, new class rules and regulations were applied as reasonable and practicable, by either ABS or the Coast Guard (see section 11 for further details on major modifications).

For new construction and Coast Guard determined "major modification" designated alterations occurring in 2005, the 2005 CFRs and ABS Steel Vessel Rules would have been applicable for the vessel and its systems. The Coast Guard determined that the 2005 conversion was not a major conversion. If the Ro/Con conversion had theoretically been determined to be a "major modification" new class rules and regulations would still be applied as reasonable and practicable by ABS and Coast Guard (see section 11).

6.1 Applicable Rules for Alternate Compliance Program

According to the final enrollment letter from the Coast Guard dated December 21, 2010, *El Faro* was enrolled in the Coast Guard's Alternate Compliance Program (ACP) on.[31] The effective date of enrollment was listed as February 27, 2006, on the enrollment letter, without explanation.[32] According to ABS[33], the *El Faro* entered into the ACP in December 2010. ABS

[30] Correspondence, Northern Lights Lengthening, MSC to Atlantic Marine, November 24, 1992. (MBI exhibit 422)

[31] See factual report of NTSB Engineering group chairman for information on ACP and *El Faro*'s participation.

[32] *El Faro*, ACP enrollment letter 16711, December 21, 2010 (MBI exhibit 362).

[33] Joint Response to the U.S. Coast Guard Marine Safety Center's Technical Reports Concerning the SS EL FARO Stability and Structures dated January 17, 2017, and March 22, 2017, p. 56 (MBI exhibit 418).

stated that the comment in the Coast Guard's 2010 letter stating a retroactive effective ACP enrollment date of February 27, 2006, should not be taken to mean that ABS was responsible for conducting ACP surveys of the vessel beginning in 2006 (ABS issued all statutory certificates for the *El Faro* beginning in February 2006). ABS stated that the Coast Guard would have been responsible for the structural inspections of *El Faro* from its construction to 2010, when it entered the ACP.

The ACP included an ongoing review of the equivalency between the CFRs, the international conventions and the rules used by classification societies. In 2011, ABS and the Coast Guard produced a revision to the 2003 US supplement to the ABS rules for steel vessels[34] that included items from the class society examination. According to the Coast Guard,[35] *El Faro* should have been subjected to the most recent version of the ABS steel vessel rules supplement at the effective time of enrollment (the 2003 supplement) and the class rules (ABS) applicable when it was enrolled in ACP. The supplement used when enrolled was required to be used for the vessel's entire operational life (except for major modifications and conversions). The 2003 supplement would have been used for either a 2006 or 2010 ACP enrollment date.

7 VESSEL STABILITY INFORMATION

7.1 Loading Condition at Departure on Accident Voyage

The sinking of *El Faro* prevented investigators from obtaining onboard loading and stability information for the time of the accident. Investigators therefore reviewed terminal documentation for the loading of *El Faro* on its final voyage (No. 185 south from Jacksonville to

[34] US Supplement to ABS Rules for Steel Vessels for Vessels Certificated for International Voyages, June 1, 2003, approved June 9, 2003. A revision was issued April 1, 2011, and approved May 3, 2011.

[35] Supplemental responses to testimony provided by Coast Guard CG-ENG, April 2017 (MBI exhibit 415).

San Juan). Shoreside personnel accounted for containers that were loaded on and off the main deck (Lo/Lo cargo) were in a stowage-planning software called Spinnaker, while roll-on/roll-off trailers (Ro/Ro cargo) were separately accounted for in a hand-written stow plan[36]. **Table 4** compares the printouts from the CargoMax stability software used on *El Faro* to the Spinnaker and Ro/Ro stow plans developed shoreside in Jacksonville to load the vessel. The Spinnaker program did not interface with CargoMax, so values from both Spinnaker and the stow plan were manually transcribed to the CargoMax software by TOTE Marine Operations terminal personnel.[37] The CargoMax totals matched the Spinnaker totals for containers, and the stow plan for trailers, autos, and other Ro/Ro cargo and their associated weights (LT).

The 6,862.1 LT of container cargo and 4,183.8 LT of Ro/Ro cargo combined for a total of 11,045.9 LT carried on the accident voyage. The fourth deck, hold D, or hold 4D on *El Faro*'s capacity plan,[38] was the tanktop of the No. 3 hold. *El Faro*'s cargo securing manual[39] showed that hold 4D could carry up to 51 autos alone, or 15 trailers and 4 autos. According to the CargoMax and Spinnaker printouts for the accident voyage, hold 4D contained 50 cars, no trailers, and no other Ro/Ro cargo.

[36] "Spinnaker Planning Management System" is software from Tideworks Technology with graphical interface. The software was first used to plan the loading of TOTE vessels in Jacksonville by shoreside PORTUS terminal/stevedore personnel about 2 weeks before *El Faro*'s last voyage. Previous software used for similar purpose was called a "Terminal Information System." For Ro/Ro cargo, PORTUS used a hand-written stow plan.

[37] Interview transcript, TOTE Jacksonville terminal manager, p. 41, 4 December 2015.

[38] SS *El Faro*, capacity plan, Dwg. SSL-670-100-027 alt. C, HEC, April 27, 2006 (MBI exhibit 133).

[39] SS *El Faro*, cargo securing manual rev. 0, HEC, 12/12/2005, ABS approved January 20, 2006 (MBI exhibit 40).

Table 4. Comparison of printouts from software documenting Lo/Lo and Ro/Ro cargo carried on accident voyage.

Cargo	CargoMax Print[40] 17:56 29Sept. 2015	Stow Plan Print[41] 17:26 29Sept. 2015	Weight (LT) Equal? (Yes/No)
Containers, total	391	391	6862.1, n/a
2nd deck hold A, trailer/auto/other	12/0/0	12/0/0	360.3, Yes
2nd deck hold B, trailer/auto/other	12/7/0	12/7/0	395.3, Yes
2nd deck hold C, trailer/auto/other	15/0/1	15/0/1	455.3, Yes
2nd deck hold D, trailer/auto/other	14/0/0	14/0/0	415.6, Yes
2nd deck hold E, trailer/auto/other	4/6/8	4/6/8	171.0, Yes
2nd deck hold F, trailer/auto/other	9/2/4	9/2/4	245.0, Yes
3rd deck hold A, trailer/auto/other	7/0/2	7/0/2	130.2, Yes
3rd deck hold B, trailer/auto/other	13/12/0	13/12/0	342.1, Yes
3rd deck hold C, trailer/auto/other	13/0/0	13/0/0	335.7, Yes
3rd deck hold D, trailer/auto/other	15/0/0	15/0/0	369.2, Yes
3rd deck hold E, trailer/auto/other	0/0/2	0/0/2	45.5, Yes
3rd deck hold F, trailer/auto/other	0/23/3	0/23/3	71.7, Yes
4th deck hold A, trailer/auto/Other*	2/0/0	-	201.3, n/a
4th deck hold B, trailer/auto/other*	6/7/0	6/7/0	462.8, Yes
4th deck hold C, trailer/auto/other	2/43/0	2/43/0	107.8, Yes
4th deck hold D, trailer/auto/other	0/50/0	0/50/0	75.0, Yes
Ro/Ro, totals, trailer/auto/other**	122/150/20	122/150/20	4183.8, n/a

* Hold A and B had fixed fructose tanks. Not listed in stow plan print and treated as "trailers" in CargoMax.[42]

** "Fixed" fructose tanks, counted as trailers in CargoMax. Stow plan did not track total weight.

[40] CargoMax printout EF185JX, September 29, 2015, 17:56 (MBI exhibit 058). Ro/Ro cargo carried is the same as revised CargoMax printout on October 1, 2015 at 11:48 (MBI exhibit 59).

[41] Stow Plan, including Spinnaker printout, voyage EF 185S, September 29, 2015 (MBI exhibit 069).

[42] In 2014 the *El Faro* had six, 53-foot, 18,000-gallon ISO container tanks installed between frames 64 and 127 on the tanktop (4th Deck). They were accounted for in CargoMax as six trailers of about 100 long tons each in hold 4A and 4B.

The Marine Operations Standard Operating Procedure (SOP) for monitoring stowage, trim and stability, states in part its purpose is to ensure vessels depart all ports within acceptable trim and stability safety standards.[43] The SOP provides the following in Section 3, Responsibilities:

> **3.1** Marine Operations is responsible for the safe load out condition and efficient utilization of cargo space on all SSL vessels.
>
> **3.2** Marine Operations is responsible for coordinating with the Vessel Master/Chief Mate prior to sailing, insuring that the vessel is sailing within acceptable trim, list and stability standards.
>
> **3.3** The Vessel Master is the final authority for approving/resolving any stowage issues. The Marine Operations Department will insure that the appropriate Terminal Operations Department will stow the vessel in accordance with the Vessel Master's decision(s).

Regarding GM margin, list, trim and available deadweight, the SOP states in part, that for loading in Jacksonville:

> **4.1.7** Safe, acceptable sailing conditions for each vessel, at a minimum, are .50 or greater GM margin, positive available deadweight, a list of no more than 2 degrees (preferably no list), and the stern down for trim.

TOTE's Safety Management System (SMS), or Operations Manual-Vessel (OMV), applicable to all TOTE vessels, state in part that the chief mate's duties include standing orders for cargo. The cargo orders must "must include the maximum list and trim that will require the notification of the C/M. This upper limit may vary from one ship type to another but should typically not exceed 2^{o} of uncorrectable list and trim of 2' by the head or 10' by the stern."[44] OMV Section 10.13.7.3 Vessel Safe for Sea (excessive list) provides the same range of list and trims to not be exceeded. It states in part "… where the ship will depart the berth with an excessive uncorrected list or trim

[43] Standard Operating Procedure Monitor Stowage/Trim/Stability, Sea Star, Marine Operations, Doc. No. SSL-MO-SOP-012 Version C, Revised 8/11/2014 (MBI Exhibit 091)

[44] Personnel and Job Descriptions, Chief Mate, Section 5.1.2, Operations Manual – Vessel, TOTE Services, No. OMV – 1 LOC, Revision 21, 08/15 (MBI Exhibit 025).

(> than 2º list, >2'trim by the head or >10' by the stern) the Master must positively determine the source of the list/trim." The OMV also states in section 5.7 that the Master is responsible for the stability of the vessel, and shall ensure that the vessel is at all times maintained within the allowable stability limits.

Interviews of shoreside loading personnel and deck officers with experience on *El Faro* indicated that a 0.5-foot GM margin[45] was added to the statutorily required GM at sailing, which was the effective minimum departing GM.[46] The CargoMax printout from 17:56 hours on September 29 gave a sailing GM of 4.854 feet, corrected for free surface effect to 4.455 feet for departure on the accident voyage.[47] The required sailing GM was 3.655 feet. Therefore, the corrected GM was 0.8 foot above the required GM and 0.3 foot more than the owner-applied 0.5-foot GM margin.[48]

In addition to the 0.5-foot GM margin, the TOTE Maritime Puerto Rico terminal manager who inputted PORTUS Lo/Lo and Ro/Ro loading information into CargoMax for *El Faro* stated that for departure he looked to have that 100 LT of available deadweight remain before sailing and that the ship would have 3 to 4 feet of aft trim.[49] With a seawater specific gravity of 1.025, the departure CargoMax printout had 14,871.6 LT for total deadweight, and a handwritten note "ΔWT=478" or "AWT=478," meaning the available deadweight exceeded the 100 LT requirement. The September 29 printout gave the following departure drafts: aft mark 32 feet, 6.49

[45] GM margin is not a statutory requirement.

[46] Interview transcript, past chief mate *El Faro* and second mate *El Yunque*, December 3, 2015, p. 127.

[47] CargoMax Printouts, EF185JX, printed 29 Sept. 2015 at 17:56 (MBI Exhibit 058)

[48] Interview Transcript, TOTE Jacksonville Terminal Manager, p. 31 & pg. 51, 4 December 2015

[49] Interview Transcript, TOTE Jacksonville Terminal Manager, p. 45, 4 December 2015

inches, midships mark 29 feet, 10.54 inches, forward mark 26 feet, 10.66 inches, with about 5 feet 8 inches of trim between the forward and aft marks.

Immediately before setting sail on the accident voyage, according to the terminal manager loading the vessel, both he and *El Faro* chief mate understood that the fuel quantity had been incorrectly entered into CargoMax for both the double-bottom No. 3 inboard port and the starboard fuel tanks at 346 LT each, whereas they actually contained 246 LT (200 LT total difference). The terminal manager recalled that the chief mate saw there was "more available dead weight and the GM margin would be dropped less than an inch," so the vessel sailed and the terminal manager corrected CargoMax the next day. The morning of the sinking, an updated CargoMax printout[50] included the 200 LT reduction for the fuel oil tanks as well as a 10 LT increase for the lube oil gravity tank. The effect was to reduce GM to 4.685 feet, reduce corrected GM to 4.284 feet, and reduce GM margin to 0.64 foot, while deadweight decreased by 190 LT to 14,681.6 LT. Compared with the September 29 printout, the vessel's departure drafts decreased as follows per the October 1 CargoMax printout:

DRAFTS

A.P.	32 ft-7.06 in	(9.933 m)	Aft Marks	32 ft-4.50 in	(9.868 m)
M.S.	29 ft-8.28 in	(9.050 m)	M S Marks	29 ft-9.12 in	(9.071 m)
F.P.	26 ft-9.50 in	(8.166 m)	Fwd Marks	26 ft-9.88 in	(8.176 m)

The operations manager stated that typically departing with a 0.5-foot GM margin, and with a "normal" fuel burn from Jacksonville to San Juan, the GM margin for arrival in San Juan would be "about 0.27 to 0.3" (feet).[51] A previous operations manager and port captain familiar with both the vessel and the accident route stated that the stability margin at the arrival condition was checked

[50] CargoMax Printouts, EF185JX, printed 1 October 2015 at 11:48 (MBI Exhibit 059).

[51] Interview Transcript, TOTE Marine Operations Manager, p. 109, 2 December 2015.

when reviewing the ship's GM during ISM (International Safety Management system) audits. He stated: "There were times when the GM was close [to minimum GM at arrival], but it was acceptable. That's why you have a margin."[52]

7.2 Typical Vessel Loading Procedure

Incoming Lo/Lo and Ro/Ro cargo in Jacksonville was driven onto a certified scale and weighed at the terminal. PORTUS Spinnaker program operators received a gross weight for that load—truck, chassis, and container with cargo. Based on the equipment numbers for the load, Spinnaker segregated the weights of the individual equipment and accounted for which parts would remain stowed on the ship. For Lo/Lo containers, that was only the container and cargo weight, while for Ro/Ro cargo trailers that would also include the weight of the chassis. The only unaccounted variable was the fuel in each truck, which was universally considered to be a full tank.[53] Spinnaker detailed individual locations and weights for each Lo/Lo container, while a hand-written stow plan was developed for Ro/Ro cargo items; broken into "trailers," "autos," and "other."

Throughout the load out process, PORTUS stevedores created stow plans and gave them to the TOTE Marine Puerto Rico Marine Operations personnel (typically the terminal Marine Operations Manager). Marine Operations reviews the plan and for discrepancies (including hazardous segregation, stack weights, lashing margins, reefer plug availability and wrong container sizes bays) and inputs data into CargoMax throughout the load out process.

[52] Interview Transcript, Interocean Operations Manager/Port Captain, p. 23, 23 March 2017.

[53] Interview Transcript, TOTE Marine Operations Manager, pp. 37-40, 2 December 2015.

For most of the Ro/Ro cargo holds, CargoMax had three input values per hold (port, center and starboard) for trailers, autos, or other cargo. A few holds had only port and starboard input values. The shoreside terminal Marine Operations Manager combined the individual Ro/Ro cargo weights for the port, center and starboard sections of each hold using a separate "space availability" computer spreadsheet (Excel), also called "pink sheets."[54] The port, center and starboard weight totals for trailers, autos, and other were then entered into CargoMax. Table 4 above shows the total Ro/Ro weight of the summed port, center and starboard CargoMax values.

According to the terminal Marine Operations Manager and the Terminal Manager[55], there were typically ongoing discussions with the Master and Chief Mate, after cargo operations began and throughout the day up to the point of the vessel's departure, regarding the loading of the vessel, the GM of the vessel, and the available deadweight (i.e. amount of additional cargo that could be loaded within allowable limits).[56]

According to interviews, the purpose of the ongoing dialogue during vessel load out was to ensure there were no surprises for the Chief Mate and/or Master, when these final stability documents were delivered to the vessel at the conclusion of cargo operations. Prior to departure, the vessel crew recorded the specific gravity of the water (water density, sometimes called "salinity" in interviews) at the dock with a hydrometer and reported the value to the bridge. They also recorded the vessel drafts by reading the marks.

About an hour before departure, the terminal Marine Operations Manager met with the chief mate typically at the dock. He brought the completed CargoMax departure loading condition file

[54] Space Availability Pink Sheet Worksheets, EF185JX_09-29-15 (MBI Exhibit 010).

[55] Terminal Operations Manager, Testimony at MBI 1, pp. 197-198, pp. 176-178, 20 February 2016.

[56] Interview Transcript, TOTE Jacksonville Terminal Manager, p. 45, 4 December 2015.

(case) on a thumb drive and a printed output hardcopy of the load case summary as well as other hard copies of the stow plans, the reefer manifest, dangerous cargo manifest and if livestock was carried, the paperwork for it. The chief mate initially conducted a brief review of the CargoMax departure case summary print out with the terminal Marine Operations Manager present. They compared the immersion table to the actual average draft, incorporating the measured specific gravity of the water.

After, the Chief Mate would typically return to the vessel to review the stability information, including review of the load case using CargoMax onboard the vessel, prior to departure and make a report to the captain.[57] The chief mate compared the CargoMax trim and stability summary against the actual recorded drafts. Final loading and deadweight were determined by consulting the vessel's immersion tables in conjunction with the actual recorded drafts and measured specific gravity.

A former chief mate stated that he recalled times where the center of the Plimsoll mark (load line) was exceeded.[58] When that occurred, the actual midship draft reading was compared with the maximum midship draft from the immersion tables at the measured specific gravity. The same chief mate noted that he recalled comparing the (CargoMax) full-load displacement figure against the maximum allowed displacement (draft marks and immersion table), and recalled no discrepancies.[59] A former port captain and operations manager familiar with the vessel stated that

[57] *El Faro* Former Chief Mate, Testimony at MBI 1, p. 8, 25 February 2016.

[58] Interview transcript, Past Chief Mate *El Faro* and 2nd Mate *El Yunque*, p. 123, 3 December 2015.

[59] Interview transcript, Past Chief Mate *El Faro* and 2nd Mate *El Yunque*, p. 1116, 3 December 2015.

there was a "a good degree of confidence" in the stability book and CargoMax because their outputs were "pretty close" to the fore and aft drafts.[60]

7.2.1 Training of Shoreside Loading Personnel

Neither of the two shoreside loading managers who used CargoMax software to load TOTE vessels, including *El Faro* on the accident voyage, had formal, classroom CargoMax training, direct instruction from the CargoMax software developer, or formal training in ship stability.[61] Rather, they learned the program through peers and on-the-job experience.[62] They had extensive shoreside experience in vessel prestow and loading operations but had no professional sailing experience on vessels. No Coast Guard regulations or ABS rules require onboard crew or shoreside personnel loading a vessel such as *El Faro,* to be certified or formally trained in shipboard stability software programs. TOTE provided a procedural document titled "Cargo Max Program" they stated was used by TPMR personnel as a training aid and informal standard operating procedure.[63] The document contained specific information regarding the "EL" class, including information on CargoMax, loading, checklists, stowage and weights.[64]

7.3 *El Faro's* Stability Documents

An inclining experiment, or stability test, is conducted after vessel construction or modification to determine the vessel's center of gravity and displacement (weight). The obtained values are used to assess the ship's hydrostatics and stability characteristics. The last inclining

[60] Interview transcript, Interocean Operations Manager/Port Captain, p. 21, 23 March 2017.
[61] Interview Transcript, TOTE Terminal Manager, pp. 14 & 42. 4 December 2015.
[62] Interview Transcript, TOTE Marine Operations Manager, p. 109, 2 December 2015.
[63] Email, TPMR CargoMax Document, TOTE to NTSB, 11 August 2017
[64] Cargo Max Program, supplied by TOTE 11 August 2017, undated (circa 2007)

experiment for *El Faro* was performed on February 12, 2006, after its conversion to a Ro/Con, by Herbert Engineering.[65] ABS approved the stability test report on March 22, 2006.

For unrestricted ocean service, US-flagged vessels must meet the applicable stability requirements of 46 CFR Subchapter S, "Subdivision and Stability" (parts 170-174). Subchapter S requires all vessels to carry a T&S booklet (stability booklet), or a simplified stability letter, on board. The stability booklet must contain sufficient information to enable the master to operate the vessel in compliance with applicable intact and damaged criteria. *El Faro*'s most recent T&S booklet was dated February 14, 2007, and was approved by ABS on behalf of the Coast Guard on May 31, 2007.[66]

In addition to its stability booklet, *El Faro* had a CargoMax "stability instrument"[67] on board.[68] CargoMax is a computer-based software program that can calculate loading conditions and evaluate them for compliance with applicable intact and damaged stability criteria. On February 8, 2008, ABS completed a "satisfactory" review on *El Faro* of the "stability aspect only" (not the strength module) of CargoMax version 1.21.162, dated August 31, 2007.[69] At that time, the software was ABS, or class-approved. The CargoMax software installed on *El Faro* was,

[65] SS El Faro Stability Test Report, HEC, 12/2/2016. ABS Approved 22 March 2006 (MBI Exhibit 139).

[66] Trim & Stability Booklet, *SS El Faro* (ex "*Northern Lights*"), Dwg. No. 1252-700-602 Rev E, HEC, 14/02/2007. Stamped by ABS 31 May 2007.

[67] The IMO International Code on Intact Stability, 2008 defines stability instrument as "an instrument installed on board a particular ship by means of which it can be ascertained that stability requirements specified for the ship in the stability booklet are met in any operational loading condition. A stability instrument comprises hardware and software."

[68] CargoMax ™ is Ship Stability and Load Management Software produced by Herbert-ABS Software Solutions, LLC.

[69] S.S. *El Faro* Stability Review on behalf of U.S. Coast Guard – NVIC 3-97, ABS, Task: 314297, 8 February 2008 (MBI Exhibit 016).

however, version 1.21.203, dated June 1, 2010, and was not specifically reviewed and reapproved by ABS.[70] The same version 1.21.203 was used shoreside.

CargoMax's product manager stated that the changes between the [originally approved shipboard] and current shoreside [and shipboard] versions were minor (minor version changes might be as insignificant as a "typo"), and would produce the same calculated values.[71] He also said that at the time of the changes, due to their minor nature, he did not feel they would warrant a re-approval or a resubmittal to ABS in a re-approval process.[72] He also stated that at the time of approval in February 2008, he was "confident" the shoreside version was the same as the version on the *El Faro*.[73] Although the ABS approval letter noted that the stability instrument (CargoMax version 1.21.162) was a Type 3, it was in fact a Type 2.[74] Type 2 instruments calculate intact stability and evaluate damage stability based on limiting curves. Shoreside stability programs are not required to be approved or undergo annual verification by an ABS surveyor.

El Faro's COI permitted ocean routes, and the ship was engaged in trade between Florida and Puerto Rico. The Coast Guard considers US-flagged vessels that travel between the continental United States and US territories such as Puerto Rico to be on international voyages and requires them to have an international load line certificate, issued in accordance with the International Maritime Organization's (IMO) International Convention on Load Lines (ICLL).[75] To obtain a load line certificate, a vessel must "comply with an intact stability standard acceptable to the

[70] ABS Chief Engineer Statutes, Testimony at MBI 2, p. 26, 20 May 2016.

[71] Interview, Herbert-ABS Software Solutions, CargoMax Product Manager, pp.54-57, 8 February 2016.

[72] Herbert-ABS Software Solutions, CargoMax Product Manager, Testimony at MBI 2, p. 145, 23 May 2016.

[73] Interview, Herbert-ABS Software Solutions, CargoMax Product Manager, pg.44-45, 8 February 2016.

[74] Interview, former ABS Load Line & Stability Manager, pg. 71-72, 29 January 2016.

[75] Load Line Policy Notes, Coast Guard Office of Design and Engineering Standards, Naval Architecture Division, pg. 8-1, Rev. 22 September 2008.

Administration." US vessels must meet the applicable stability requirements of 46 CFR Subchapter S (parts 170–174) for unrestricted ocean service, but compliance with the appropriate requirements of the 2008 International Code on Intact Stability[76] is considered equivalent to complying with 46 CFR Subchapter S.[77] *El Faro* was required to meet only the intact stability requirements of 46 CFR Subchapter S (parts 170–174). The COI did not reflect the correct version of the approved T&S booklet, although the Coast Guard was notified and provided updated copies by ABS in 2007.[78]

Probabilistic damaged criteria were applicable to *El Faro* (then the *Northern Lights*) when it was lengthened in 1993 and again when it was modified to a Ro/Con configuration in 2005. ABS performed a damaged stability review against SOLAS damage criteria in 1993 and approved the inclining experiment and stability booklet in May 1993.[79] The information was reviewed by the Coast Guard Marine Safety Center (MSC), which issued a final stability letter for the vessel in October 1993. No additional damaged stability assessment or review was performed for the modification of the vessel to a Ro/Con in 2005.

El Faro's last load line certificate was issued by ABS on January 29, 2011, and was valid until February 26, 2016.[80] The certificate was based on a survey completed on February 27, 2006, and gave a deadweight of 14,734.2 LT. The certificate specified *El Faro* as having a Type B freeboard (see Section 8, Load Line for freeboard description). The freeboards were measured

[76] International Code on Intact Stability, 2008, third edition, IMO, 2009.

[77] Load Line Policy Notes, Coast Guard Office of Design and Engineering Standards, Naval Architecture Division, pg. 11-2, Rev. 22 Sept. 2008.

[78] *El Faro* Trim and Stability Booklet, ABS Approval letter, 31 May 2007 (MBI Exhibit 253).

[79] ABSID 7500285, *El Faro* Stability Timeline, 23 November 2015.

[80] International Load Line Certificate, *El Faro*, Certificate No. 7500285-1926092-002, Issued under the 1996 Load Line convention, as modified by the protocol of 1988, under the authority of the Coast Guard (MBI Exhibit 260).

from the upper edge of the second deck at the side, with a summer load line freeboard of 12 feet, 15/16 inch (12.08 feet).

El Faro's most recent COI was issued by the Coast Guard on February 22, 2011. The vessel was last reinspected on March 6, 2015.[81] The COI was due to expire on February 22, 2016. The COI stated under "Conditions of Operations" that the vessel should "be operated in accordance with the trim & stability booklet bearing ABS Americas approval stamp dated 22 February 2006." The T&S booklet referenced in the COI was not the vessel's most recent booklet (rev. E, dated February 14, 2007). The COI is addressed and issued solely by the Coast Guard, not ABS.

7.4 *El Faro* Stability Book and CargoMax Use

46 CFR 170.110 does not require approval of stability software. Paragraph (f) of 46 CFR 170.110 refers to onboard electronic stability computers and their use as an adjunct to the required booklet. The 2003 ACP supplement states that vessels could satisfy either 46 CFR Subchapter S, or, as an equivalency, the Code on Intact Stability (IS Code), as reflected in IMO Resolution 749 (18). According to the ABS chief engineer for statutes, the International Code on Intact Stability "includes recommendations for intact stability and stability computers. According to the ACP supplement all recommendations in the IS[O] code [intact stability code] are to be considered as requirements. So that's a requirement as well."[82]

The ABS review letter for *El Faro*'s stability instrument [83] advised that although stability software such as CargoMax may be approved according to the ABS steel vessel rules and

[81] USCG Certificate of Inspection, *El Faro*, CG Sector San Juan, amended March 15, 2015 (MBI Exhibit 020).

[82] ABS chief engineer for statutes, Testimony at MBI 2, pp. 12-13, 20 May 2016.

[83] SS *El Faro* Stability Review on behalf of US Coast Guard—NVIC 3-97, ABS, task 314297, 8 February 2008 (MBI exhibit 016).

International Association of Classification Societies (IACS) unified requirement (UR) L5,[84] the software "is not a substitute for the approved stability information, and is used as a supplement to the approved stability information [the vessel's stability booklet] to facilitate stability calculation." That view was confirmed by a principal engineer who was part of the ABS stability and load line group when the stability instrument was approved.

The principal engineer stated that "the stability program allows—gives the Master a lot more flexibility to load the vessel while still complying with the required regulations."[85] *El Faro*'s onboard CargoMax software included an "auto windheel" function that calculated the wind profile of the vessel based on the inputted container loading and calculated the required GM. The vessel's stability booklet did not have this function, and provided limiting GM curves for one, two, three, four and five high tiers of containers, using the full wind profile (maximum container load per tier). Compared to the stability booklet, CargoMax with the auto windheel function would more accurately compute windheel for various container-loading arrangements and their associated wind profiles. For a loading case with less than a full tier container load, the required GM output from CargoMax would be less than the GM calculated according to the stability booklet with a full container load for the same tier. According to ABS, that did not mean the use of CargoMax was "less safe or doesn't meet the criteria."[86] While the CargoMax calculation can be less conservative, it meets the requirements for calculation of minimum required GM specified in 46 CFR 170.170. The CargoMax program is reviewed by ABS against the same stability criteria as a stability booklet.

[84] IACS UR L5, "Onboard Computer/Software for Stability Calculations."

[85] ABS chief engineer for statutes, Testimony at MBI 2, pp.19-20, May 20, 2016.

[86] ABS Chief Engineer Statutes, Testimony at MBI 2, p. 23, 20 May 2016.

Previous deck officers on *El Faro* and its sister (*Ponce*-class) vessels told investigators that CargoMax, not the stability booklet, was the primary tool officers on *El Faro* and its sister vessels used to help meet stability criteria.[87] ABS class rules state that the printed stability booklet is the main approved document and that the stability program (loading instrument, or CargoMax) is a supplement to the printed stability booklet. "It is expected that the programs will allow the Master greater flexibility in loading."[88] Use of CargoMax as the primary means assess vessel stability was "extremely normal" in the maritime industry.[89] CargoMax was installed on over four thousand vessels worldwide, and was used by most U.S. operators of commercial cargo vessels.[90] In addition, parties to the investigation (Herbert Engineering, ABS, and TOTE) agreed that the manner in which CargoMax was approved and used on board *El Faro*, was typical of existing maritime industry practice.[91]

The crew also used CargoMax's strength module to assess the hull girder bending moment and stresses. As a dry cargo ship, *El Faro* was not statutorily required to have a loading manual, and therefore a loading instrument (such as the strength module of CargoMax) was also not required on board the vessel.[92] ABS had not approved the module and there was no requirement to do so. When no loading manual or loading instrument is required for a vessel, it is because loading conditions are considered to be fairly uniform throughout the structure, and therefore ABS does not require or give any operational guidelines to address loading the vessel to stay within the

[87] Interview transcript, Past Chief Mate *El Faro* and 2nd Mate *El Yunque*, p. 97, 3 December 2015.

[88] Interview, former ABS Load Line & Stability Manager, pp. 93-95, 29 January 2016.

[89] Interview, Herbert-ABS Software Solutions, CargoMax Product Manager, p.41, 8 February 2016.

[90] President and Vice President HEC, Testimony at MBI 2, pp. 23-28, May 2016.

[91] Coast Guard Marine Board of Investigation, *El Faro*, PII Submission to the MBI, pg. 24, 4 May 2017.

[92] ABS Manager Structure and Statutes, Testimony at MBI 2, pp. 181-186, 20 May 2016.

vessel's structural limitations. The installation and use of the CargoMax module by the crew was in excess of statutory requirements for *El Faro*.

For *El Faro* and its sister vessels, loading conditions (vessel drafts, trim, stability and longitudinal strength) were assessed by TOTE shoreside terminal operators using CargoMax software (when loading). TOTE's SMS[93] noted that the "Master was responsible" for both approving the "stowage plan of the ship" and the "ship's stability, trim and stress." For the *El Faro*, the shoreside software version was the same as the software used aboard the vessel.

According to Herbert-ABS Software Solutions, LLC, companies were permitted by them to install CargoMax on shoreside computers (in addition to being installed on the vessels); he further stated that there was not an issue or problem with shoreside personnel using the program ashore (and it not being subject to a separate approval/annual survey), so long as it is the same, approved version of the software being used on the vessels (which he was "confident" it was).[94] Investigators found no requirements that the shore side CargoMax program installed on computers ashore had to (1) be separately witnessed by an ABS surveyor (2) be required to receive annual checks similar to class requirements for the onboard program of *El Faro* (3) be separately approved by ABS. The shoreside CargoMax program was never witnessed by an ABS surveyor, never received annual checks similar to class requirements for the onboard program, and was not approved by ABS.[95] ABS noted that it was not within the scope of class to approve or verify the shoreside vessel loading instrument: the classification society reviewed only the onboard program. The class requirements, Coast Guard guidelines, and the International Code on Intact Stability all refer only to the program

[93] TOTE Services, Operations Manual – Vessel (OMV), Rev. 18, Dry Cargo Ships, 13, September 2012.

[94] Interview, Herbert-ABS Software Solutions, CargoMax Product Manager, pp.41-45, 8 February 2016.

[95] Interview, former ABS Load Line & Stability Manager, pp. 88-92, 29 January 2016.

on board a vessel.[96] Both the CargoMax software used on *El Faro* and the software used shoreside were newer than the version noted on the vessel's load line certificate (version 1.2.1.0162) and in the ABS approval letter.[97] The former ABS stability and load line manager stated that it was the responsibility of the vessel owner to advise ABS if it acquired a new version of the program, and then an ABS surveyor would need to check the installation.[98] Although not currently required, he recommended that the installation and annual verification currently required of onboard loading programs should also apply for the same loading programs used shoreside.

For *El Faro*'s accident voyage, according to the terminal manager who loaded the vessel, the loading condition was built in the shoreside CargoMax program. Hard copies (program printouts) and the electronic CargoMax file were hand-delivered to the chief mate "about 30 to 45 minutes" before departure for review.[99]. Per typical loading procedure, after the chief mate reviews the cargo documentation and stability printout with the shoreside terminal manager, the chief mate signs the dangerous cargo manifest. On the accident voyage, the Ro/Ro cargo operations concluded at 1830 and the Lo/Lo operations at 1854. The terminal manager emailed the dangerous cargo manifest at 1915 (which included the chief mate's signature) and *El Faro* departed its berth (last line) at 2007[100]. This timeline places the meeting between the chief mate and terminal manager between 1854 and 1915. The former ABS stability and load line manager stated, that (when assessing the loading of a ship like *El Faro* where less than an hour before sailing the electronic file of the loading condition is supplied from ashore), "it's just a limited time for the mate" to

[96] Interview, ABS Chief Engineer Statutes, pp. 91-92, 29 January 2016.
[97] Interview, ABS Chief Engineer Statutes, pp. 92-93, 29 January 2016.
[98] Interview, ABS Chief Engineer Statutes, pp. 92, 29 January 2016.
[99] TOTE Jacksonville Terminal Manager, Testimony at MBI 1, pp. 127, 20 February 2016.
[100] Emails, Various, Regarding Weather and Operations, p. 93, MBI Exhibit 4.

check the loading condition onboard and "implement any changes that they would see necessary before the vessel sailed".[101]

7.4.1 CargoMax Damaged Stability Module

In addition to approved standard CargoMax features, *El Faro*'s onboard CargoMax program included an optional damaged stability module.[102] The option was not required to be class-approved, nor was it. The CargoMax user's manual[103] contained a section that discussed the calculation steps and theory of damaged stability and remedial action. Investigators entered *El Faro*'s shoreside CargoMax load case file (departure condition with the corrected fuel burn to the accident site) in CargoMax version 1.21.0203 on a laptop computer, and ran the damaged stability module with damage to hold 3 alone.[104] The program's "emergency response calc" immediately provided information including, but not limited to, the vessel's drafts, range of positive stability, and maximum righting arm angle on screen (see **figure 7**). Investigators then ran another case with damage to hold 3 plus hold 2A.

The screen outputs for both case contained a graphic dashed-line for downflooding angle in the legend of the "righting arm" quarter-screen; however, no line was shown on the graph. Investigators printed the results from the CargoMax output screen for both damaged cases (see **appendix B**). Although the printouts included a field for "angle of downflooding" and line for "DF angle" in the legend for the righting arm, no value for downflooding angle or indication for

[101] Interview, ABS Chief Engineer Statutes, p. 90, 29 January 2016.

[102] CargoMax for Windows Version 1.21, Vessel Information for *El Faro*, Rev. 2, Herbert Software Solutions, Inc., p. 5, 13 March 2007 (MBI Exhibit 261).

[103] CargoMax User's Manual, 9th Edition, Herbert-ABS Software Solutions LLC., September 2011 (MBI Exhibit 263).

[104] Assessment did not include verifying that default values or details associated with the program used by investigators matched similar damage module aboard *El Faro*.

downflooding on the graph was generated. The damaged module in CargoMax did not provide information regarding the vessel's downflooding angle to users.

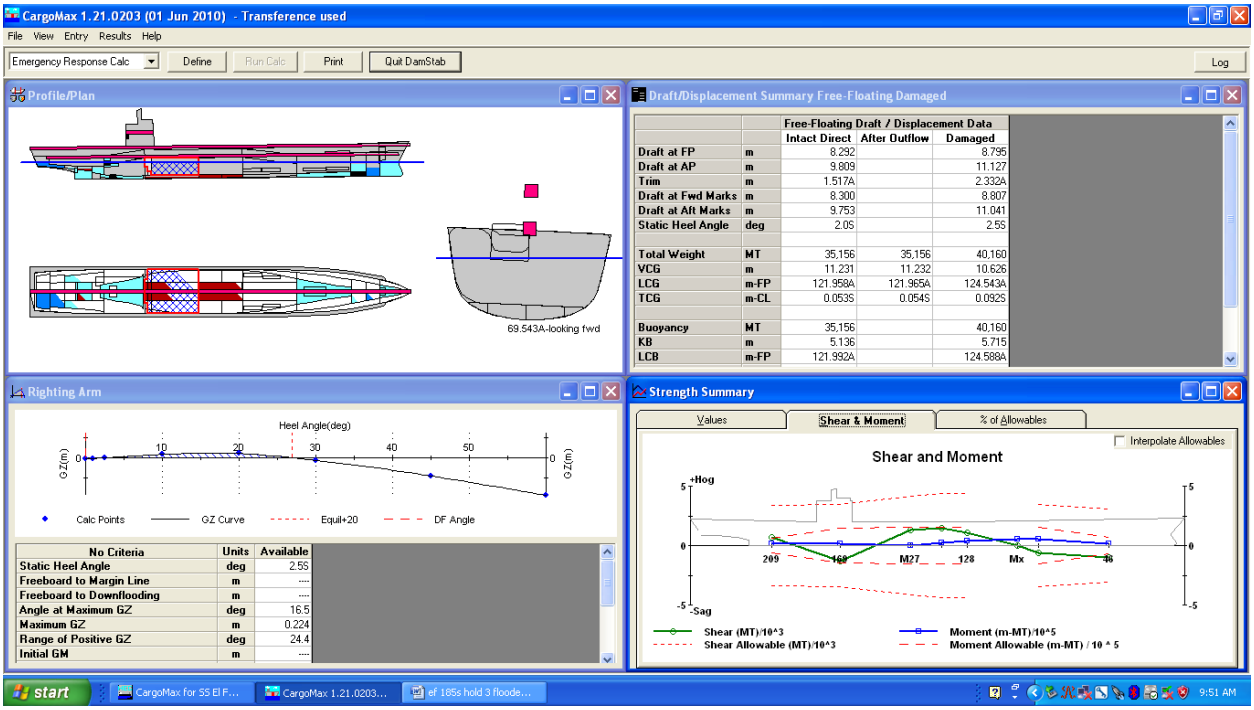


Figure 7. Screen capture of CargoMax damaged stability module, *El Faro* with damage to hold 3.

Investigators asked former *El Faro* senior deck officers if they were aware of or had ever used the damaged stability module of CargoMax. A few stated that they were aware of the module, and all stated that they had not used it.[105,106,107]

7.5 Intact Stability

"Intact stability" is a naval architecture term referring to how an intact, or undamaged, vessel will respond when heeled over in in static sea conditions, assuming no wind and wave action (calm

[105] Former Captain *El Moro*, Testimony at MBI 2, p. 102, 11 May 2016.

[106] Former Chief Mate *El Faro*, Testimony at MBI 1, p. 67, 25 February 2016.

[107] Former Captain *El Faro*, Testimony at MBI 1, pg. 203, 18 February 2016.

conditions). "Damaged stability" is an assessment of the effects of opening various combinations of watertight compartments to the sea. The current IMO intact stability criteria[108] that are applied to determine if a vessel's stability is satisfactory were developed by researchers and regulatory authorities by analyzing the data of vessels that survived or did not survive adverse conditions. As stated in a marine reference document, the "existing stability regulations are codes of practice that provide reasonable safety margins without giving 100% guaranty that the vessel which meets the requirements can survive all challenges."[109]

The Coast Guard stated in an explanatory circular: "The severe wind and rolling criterion (weather criterion) is one of general provisions of the IMO's 2008 International Code on Intact Stability. This criterion was originally developed to guarantee the safety against capsizing for a ship losing all propulsive and steering power in severe wind and waves, which is known as a dead ship."[110] The Coast Guard Naval Architecture Division chief stated that the basic severe wind and wave weather criteria at 46 CFR 170.170 also generally assume that a vessel is without power, in a dead ship condition, with "the attitude of the vessel relative to wind and waves the worst possible for stability or heeling."[111] *El Faro* was not required to meet IMO criteria, but was required only to meet the weather criteria in 46 CFR 170.170.

If built today, *El Faro* would require an international load line certificate, and therefore would be required to meet mandatory part A of the 2008 International Code on Intact Stability. Section 2.3 of part A contains the severe wind and rolling criteria.

[108]International Code on Intact Stability, 2008, third edition, IMO, 2009.

[109] Definition of intact stability criteria from *Wartsilia Encyclopedia of Marine Technology*.

[110] MSC Circular 1281, Explanatory Notes to the International Code on Intact Stability, Chapter 3- Origin of Present Stability Criteria, 2008, IMO.

[111] Coast Guard Chief Naval Architecture Division, Testimony at MBI 3, pp. 266-269, 7 February 2017.

7.5.1 Second-Generation IMO Intact Stability Standards

Investigators asked the Coast Guard whether intact stability standards (other than CFR and IMO standards) exist that would enhance the stability characteristics of future ships. The chief of the Coast Guard's Naval Architecture Division stated that, in his opinion, methods of calculating intact stability in dynamic conditions with other modes of failure, or other vulnerabilities, have greater potential than any existing standards to advance stability standards. These efforts are referred to as IMO second-generation intact stability standards.

At the time of this report, the IMO is working to supersede the existing evaluation criteria for intact stability analysis. The second-generation intact stability criteria are being developed in the Ship Design and Construction (SDC) subcommittee of the Maritime Safety Committee, which will continue its work toward finalizing the criteria at its upcoming session in January 2018. The SDC Working Group on Intact Stability has developed algorithms for several of the proposed dynamic stability criteria, including "dead ship" and "excessive acceleration." According to the VDR transcript, *El Faro* was in dead ship status (had lost propulsion) before it sank. At the time of this report, it is unknown what specific criteria will be used or how soon the second- generation intact stability criteria will be promulgated.

7.6 Stability Review and Oversight

7.6.1 History of ABS Review of Stability Letters

In 1997, Navigation and Inspection Circular (NVIC) 03-97[112] outlined Coast Guard procedures for accepting ABS stability-related reviews and stability letters for US-flagged vessels. The NVIC stated that before 1984, all vessel stability reviews were conducted by Coast Guard

[112] Navigation and Vessel Inspection Circular 03-97, "Stability Related Review Performed by the ABS for U.S. Flag Vessels," March 1997.

technical offices, and that in 1986, the technical offices were replaced by the Coast Guard MSC. ABS began performing stability reviews on some vessels in 1984 under NVIC 3-84 Change 1, and in 1990 began witnessing the stability tests of certain vessels for the Coast Guard. ABS was first authorized through NVIC 03-97 to issue stability letters on behalf of the Coast Guard for vessels on which it conducts a complete stability review.

The *El Faro's* 1993 stability review by ABS was conducted under NVIC 3-84 Change 1. Subsequent reviews were conducted under NVIC 03-97.

7.6.2 Stability Review and Oversight

When *El Faro* was lengthened in 1993, ABS reviewed the vessel's intact and damaged stability under NVIC 03-84 Change 1, independently analyzing the stability calculation package that a naval architecture firm submitted. After its review, ABS forwarded the package to the Coast Guard MSC, recommending that a stability letter be issued. The MSC did its own review and issued a stability letter to the vessel. The process involved three independent analyses of the vessel's stability.[113]

For the 2006 Ro/Con conversion, ABS reviewed *El Faro*'s stability with reference to NVIC 03-97. After reviewing the naval architecture firm's stability calculations to its satisfaction, ABS sent a stability approval letter directly to the vessel. The Coast Guard, through its oversight process, could decide to review the project at any step. ABS would be made aware of a Coast Guard review only if there was a problem. In the case of *El Faro*, the ABS load line and stability manager was not aware of whether the Coast Guard had conducted a review.

[113] Interview, ABS Chief Engineer Statutes, pp. 112-114, 29 January 2016.

The former manager of the ABS Load Line and Stability Group testified that in addition to using NVIC 03-97, ABS conducted stability reviews on behalf of the Coast Guard under an earlier publication, NVIC 02-95, which dealt specifically with the ACP.[114] He stated that when ABS reviews under the terms of NVIC 03-97, it applies Coast Guard regulations and CFRs. However, "under the ACP program we apply the ABS rules, which do include some stability requirements and the international requirements. And then for whatever—there are several issues such as lifting and towing that are not covered under the international rules as of yet that the supplement calls out we apply from the CFR."[115] The ABS manager for stability stated that at the time of the 2006 stability review, *El Faro* "was not considered under the ACP program. . . .Therefore, we had to apply the Code of Federal Regulations requirements", which are applied in accordance with NVIC 03-97. Enclosure 3 of NVIC 02-95 states under "Duties and Responsibilities of the Coast Guard" that the "MSC may conduct plan review oversight for all new construction, modifications (including major conversions), and vessel reflags."

Regarding Coast Guard oversight of stability reviews performed by ABS, NVIC 03-97 states in part: "MSC will perform routine and non-routine oversight of stability review activities conducted by the ABS." Before *El Faro* was lengthened in 1993, the Coast Guard reviewed the vessel's stability. As part of its determination that the lengthening would constitute a major conversion,[116] the Coast Guard approved a request to have ABS conduct plan review and inspection under NVIC 3-84 Change 1, (superseded by NVIC 03-97). The Coast Guard performed an oversight review on both intact and damaged stability for the lengthening. Investigators found no

[114] NVIC 02-95 Change 2, The Alternate Compliance Program (ACP), 5 May 2006.

[115] ABS Chief Engineer Statutes, Testimony MBI 2, 19 May 2016.

[116] Coast Guard Major Marine Conversion Correspondence 1992 File, (MBI Exhibit 422).

evidence that the Coast Guard reviewed the stability (intact or damaged) of *El Faro* after its 1993 review.

7.7 Damaged Stability

Investigators reviewed the general damaged stability requirements for ships as well as the history of damaged stability criteria applicable to *El Faro*.

No damaged stability criteria existed for US or international cargo vessels until 1992. Before then, "deterministic," sometimes referred to as one-compartment or two-compartment damaged stability, was used for large passenger vessels and tankers. Large US-flag cargo vessels built under federal subsidies (MARAD Title IX), were required to meet a "deterministic" MARAD damaged stability criteria promulgated in MARAD design letter No. 3, issued in 1965. As originally launched, *El Faro* met the requirements for single-compartment damaged stability in accordance with the MARAD design letter. See section 7.8 for more information about the MARAD letter.

SOLAS probabilistic damaged criteria (chapter II-1, part B, regulation. 25) came into force for vessels newly built or undergoing a major modification on or after February 1, 1992. When *El Faro* was lengthened in 1992–1993, the MSC determined that the lengthening was a "major conversion/modification" and as such, that the vessel was required to meet the new SOLAS probabilistic damaged requirements. *El Faro* was the first US-flagged cargo vessel to be held to the new standard. ABS performed the stability review in accordance with Coast Guard NVIC 3-84 Change 1 for the SOLAS probabilistic damaged criteria. The Coast Guard MSC reviewed damaged stability (along with the T&S booklet and inclining experiment), and issued a final stability letter in October 1993.

No records indicate that *El Faro* had damaged stability reassessed by a naval architect, or reviewed and approved by ABS or the Coast Guard when it was modified for Ro/Con service in 2005. After 1997, as provided by NVIC 03-97, the Coast Guard allowed ABS to issue stability letters on its behalf.[117] The Coast Guard would oversee the review, at its discretion, after ABS issued a letter.

The naval architects that produced the T&S booklet for *El Faro*'s Ro/Con conversion recalled that they did not reassess the vessel's damaged stability because its deepened load line would be the same as its operating sister vessels *El Morro* and *El Yunque*. In reviewing the T&S booklets of the sister vessels, they stated, the limiting GM criteria were those for intact windheel, not damaged stability.[118] *El Yunque's* T&S booklet from 2001 stated, under notes in the "Windheel Required Metacentric Height" section, that "these requirements exceed dynamic stability and damaged stability requirements."[119] Neither the *El Morro* or the *El Yunque* were subject to any statutory damaged stability criteria.

No documentation from ABS or the Coast Guard was found relating to damaged stability assessments, requirements, or oversight for *El Faro*'s 2005 Ro/Con modifications. The ABS load line and stability manager told investigators that because the vessel's draft increased by about 2 feet, it should have been required to have a damaged stability assessment: "When you increase the maximum draft, you change the parameters in the regulation." He believed that damaged stability was reviewed at the time, but documentation was not found.[120]

[117] ABSID 7500285, *El Faro* Stability Timeline, 23 November 2015.

[118] Interview Transcript, President & Vice President, HEC, pp. 68-79, 28 January 2016.

[119] Interview Transcript, President & Vice President, HEC, p. 172, 1/28/2016.

[120] Interview Transcript, former ABS Load Line-Stability Manager, pp. 26-27, 29 January 2016.

After the accident, ABS and the Coast Guard MSC assessed *El Faro*'s damaged stability with a draft that was more than 2 feet deeper than before the conversion.

7.7.1 Downflooding Points

The only intact stability criteria applicable to *El Faro* were the weather criteria at 46 CFR 170.170. Those criteria do not incorporate downflooding points, although downflooding points are considered in an assesment under the IMO intact stability criteria. [121] The 2008 International Code on Intact Stability limits the GZ (righting lever) curve to an "angle of heel at which openings in the hull, superstructures, or deckhouses cannot be closed weathertight."[122] IMO intact stability criteria did not apply to *El Faro*. If they had, openings that could have been made weathertight would not have been considered downflooding points. In an intact stability assessment under the 2008 IS code, neither the vessel's ventilation intake (supply) openings nor its exhaust openings would have been considered downflooding points because they had watertight (intake/supply) or weathertight (exhaust) closing appliances (manually closable fire dampers).[123]

Under the SOLAS criteria for assessing damaged stability, weathertight openings are considered downflooding points, but openings that can be made watertight are not: "In those cases where the final waterline, taking into account sinkage, heel and trim, immerses: (1) the lower edge of openings through which progressive flooding may take place. . . . Such openings shall include air-pipes, ventilators and openings which are closed by means of weathertight doors or hatch

[121] In naval architecture, downflooding is defined as an ingress of water through external openings to buoyancy volumes. The downflooding angle related to intact stability is defined as the minimum heel angle at which an external opening without a weathertight closing appliance is submerged.

[122] International Code on Intact Stability, Part A, Paragraph 2.3.1, IMO, 2009.

[123] Email, Coast Guard MSC Naval Architect, Re: *El Faro*: Clarification on downflooding points, 25 April 2017.

covers…"[124] Under the SOLAS damaged stability criteria, *El Faro*'s exhaust openings would have been considered downflooding points, but not the supply openings.[125]

Drawings of the cargo hold exhaust ventilators on *El Faro* show a 12-foot-high partition plate (baffle) between the louvered sideshell opening and the weathertight fire damper above the second deck. [126] Such partition plates are typically fitted to create a vertical watertight boundary, and in the case of *El Faro* would have stopped seawater that entered through the sideshell louvers from progressing directly to the fire dampers and down into the cargo holds. For the supply ventilation, the drawings show a pair of openings through a transversely oriented, vertical plate separating the forward and aft sideshell louvered openings from the bellmouth inlet to the supply fan for hold 2A. The lower lip of the plate, scaled from the drawing, measured about 10.5 feet above the second deck.

Two faxes from 1993, during the lengthening of *El Faro*, show that JJH engineers reviewed the positions of the exhaust ventilation openings and took them into account when computing the vessel's probablistic damaged stability.[127] The cover page on the first fax notes that "Supply Vents are not used because they are protected with WT Dampers." The cover page on the second fax says, "Verified that supply trunks in all holds are protected with WT Dampers." The faxes give

[124] SOLAS, Chapter II-1, Part B-1 – Stability, Reg. 7.2, Paragraph 5.2.

[125] Email, Downflooding Points, NTSB Naval Architecture Group Chairman to Coast Guard MSC, 21 April 2017.

[126] Northern Lights Conversion, Ventilation Arrgt Holds NO. 2A & 3, Dwg. No. 1252877-2A, JJH Inc., ABS approved 12 April 1993.

[127] Fax Transmission, JJH Inc., Northern Lights Downflooding Points and Downflooding Points Cont., 10 May 1993 (MBI Exhibit 270).

the height of the exhaust vents above baseline (ABL) for holds 1 through 5. Six exhaust vents in hold 2A and hold 3 each had the lowest ABL (56.14 feet) of all ventilator openings.

ABS confirmed that in 1993, the downflooding points used in calculating *El Faro*'s damaged stability were 56.14 feet ABL (14.0 feet above the second deck) for the ventilation openings in hold 2A and hold 3. The same downflooding points were used for the ABS post-accident damaged stability review in 2016.[128] Similar to the 1993 assessment, the ABS post-accident calculations considered only the exhaust ventitlation openings. The supply ventilation openings were not taken into consideration because they had watertight closures.

The Coast Guard MSC's postaccident damaged stability assessment, completed in 2017, gives 55.2 feet ABL for the supply vent (baffles) in hold 2A and hold 3, and 55.9 feet ABL for all four of the exhaust vents (baffles) in hold 2A and hold 3.[129] Similar to both earlier damaged stability assesments, the MSC analysis (Appendix B, "SOLAS Probabilistic Damage Stability Analysis") considered just the exhaust openings and not the supply openings, in accordance with the relevant SOLAS regulations.[130]

Investigators requested *El Faro*'s ABS "Survey for Loadlines" form (LL11D) to document the height of the cargo hold ventilation openings as noted by class surveyors. The most recent form is found aboard the vessel (not available for *El Faro*). The only available LL11D for *El Faro*, dated November 10, 1974, gave the height of all cargo hold ventilation openings as 8 feet, 0 inches above the second deck (freeboard deck). See section 8, "Load Line," for more information.

[128] Email, ABS Chief Engineer Statutes, *El Faro-El Yunque-El Morro*: LL-11's, 26 April 2017.

[129] Technical Report, SS *El Faro* Stability and Structures, U.S. Coast Guard Marine Safety Center, 22 March 2017.

[130] Email, Downflooding Points, E. Stolzenberg to J. Stettler, Coast Guard MSC, 21 April 2017.

7.7.2 Probabilistic Damaged Stability—Coast Guard NVIC

NVIC 04-93 promulgates IMO resolution A.684 (17), "Explanatory Notes to SOLAS Regulations on Subdivision and Damage Stability of Dry Cargo Ships of Over 100 meters (328 feet) in Length." IMO Resolution MSC.19(58), "Regulations for the Damage Stability Requirements of Dry Cargo Ships," became effective on February 1, 1992, as an amendment to SOLAS, 1974. The Coast Guard published a final rule (58 FR 17316) on April 1, 1993, that adopted the international standard into 46 CFR part 174.

NVIC 04-93 states:

> The probabilistic approach of the regulations takes into account the probability of various extents of damage occurring anywhere along the ship's length and the resulting flooding. At the same time it takes into account the probability that the ship will survive the damage given its stability and draft. This provides a rational means of assessing the safety of ships, where flooding is concerned, no matter what their arrangements might be. For instance, a ship may be designed with less subdivision in part of its length, provided it has additional subdivision in areas shown to have a higher probability of damage. In this respect, it frees designers and operators from unnecessarily arbitrary restrictions on arrangements.

7.7.3 Deterministic vs. Probabilistic Damaged Criteria—Survivability Information to Master

In deterministic damaged stability, if a vessel meets the GM curve and the loading restrictions, the ship will survive the damage (meet the criteria) to the extent (number of compartments) defined in the regulation.[131]

With probabilistic damaged stability, although a vessel may meet the criteria (GM curve and loading restrictions), in certain cases a damaged vessel may not meet the survival criteria. That does not necessarily mean the vessel will sink, but rather that it does not meet the required stability criteria.[132] Probabilistic damaged stability criteria calculations demand multiple likely damaged cases to be run for multiple vessel drafts, and in most cases, the vessel must survive (meet stability criteria). The adding of survivable damaged cases results in an attained subdivision index for the vessel known as "A," and this attained index must meet or exceed the required subdivision index "R". A vessel can comply overall with the probabilistic damaged stability criteria, but there can be specific damaged cases that will not only fail to meet the minimum stability criteria after damage, but potentially result in the vessel sinking.

Investigators asked whether probabilistic damaged stability regulations have increased vessel safety compared with previous deterministic damaged stability. A Herbert Engineering naval architect[133] stated that since deterministic methods allowed for adjusting bulkheads to survive the required number of flooded compartments, they produced varying levels of safety between

[131] Interview Transcript, President, HEC and Vice President, Herbert-ABS Software Solutions, p. 104, 28 January 2016.

[132] Interview Transcript, President, HEC and Vice President, Herbert-ABS Software Solutions, p. 104, 28 January 2016

[133] Interview Transcript, President, HEC and Vice President, Herbert-ABS Software Solutions, p. 105, 28 January 2016

vessels and vessel types. The probabilistic method, whose development began in the late 1970s, attempted to achieve a more consistent level of safety between vessels. Before probabilistic stability was applied to cargo vessels, there were no damaged stability standards applicable for all cargo vessels.

When asked by investigators whether deterministic or probabilistic damaged criteria were more conservative, a former ABS stability manager stated that, in his opinion, "The deterministic criteria is a better criteria."[134] He explained that deterministic means that a vessel would meet all the criteria for all damaged cases, while probabilistic means enough cases survive to meet the criteria. In his opinion, the important thing for the master and crew to know is that given specific damage to the vessel, it could meet the damaged stability criteria and survive. "With the probabilistic damage, there's no guaranty the vessel's going to survive."[135] He stated that a vessel that met probabilistic damaged criteria could still fail "one compartment damage."[136]

Although the probabilistic stability calculations are not required to be kept onboard the vessel, if the master had access to them, there could be hundreds of different damaged cases at each vessel draft, most of which passed the criteria, but some of which did not. The master must first understand what damage has occurred to his vessel and then go through hundreds of cases to figure out "was this covered, did it meet the criteria, and if it did not meet the criteria, did it sink, or did it still remain floating . . ."[137] An assessment of the vessel's survivability would be in addition to the issues a master would be addressing in a damaged situation.

[134] Interview Transcript, former ABS Load Line & Stability Manager, pp. 48, 29 January 2016.
[135] Interview Transcript, former ABS Load Line & Stability Manager, pp. 48, 29 January 2016.
[136] Interview Transcript, former ABS Load Line & Stability Manager, pp. 49, 29 January 2016.
[137] Interview Transcript, former ABS Load Line & Stability Manager, pp. 52-53, 29 January 2016.

The former ABS stability manager stated that in addition to requiring damage control plans on vessels (section 10, "SMS and Damage Control Plan") and providing onboard damaged stability instruments, the marine industry has tried presenting the results of probabilistic damaged calculations to masters in a "damage consequence diagram." He stated that the diagrams have been difficult to develop, because the substantial number of damaged cases means there is "no rapid and simple means for the master to get that information."[138]

The former stability manager said that probabilistic damaged criteria were better than no criteria.

He was aware that onboard software programs can evaluate a vessel's stability after specific damage scenarios input by the user, but said that he had not reviewed them. He stated that if *El Faro*'s stability instrument (CargoMax) had such a capability, it was not presented to ABS to review for that purpose, and ABS did not review it for that purpose.[139]

7.7.4 Probabilistic Damaged Calculations for Damage to Hold 3

Investigators reviewed supporting data for both the Coast Guard MSC[140] and ABS postaccident damaged stability calculations[141] for *El Faro* at its deepest and light-service draft when heeled to port. For one-division damage that encompassed cargo hold 3, two cases were run. The first was for damage of hold 3 and double-bottom 3 outboard port tanks with fixed ballast (denoted in both reports as division 7). The second case damaged the double-bottom 3 inboard

[138] Interview Transcript, former ABS Load Line & Stability Manager, p. 55, 29 January 2016.

[139] Interview Transcript, former ABS Load Line & Stability Manager, p. 56, 29 January 2016.

[140] Technical Report, SS *El Faro* Stability and Structures, U.S. Coast Guard Marine Safety Center, Appendix B: SOLAS Probabilistic Damage Stability Analysis, pp. 141 & 150, 22 March 2017.

[141] SOLAS Probabilistic Damage Stability Analysis- *El Faro*, ABS, 6 May 2016 (MBI Exhibit 166).

port fuel oil tank in addition to the two compartments in the case, for a total of three compartments (denoted in both reports as division 7 +i1).

The MSC results showed that at both deep and light-service draft, both individual cases run for the ship division of hold 3 added to the attained subdivision index A (this would be considered passing for the specific case run). The ABS results showed that at both drafts, division 7 passes, but division 7+i1 does not add to the attained index A and results in a heel angle of about 180° (180° is considered failing in the program for the specific case run).[142] Damage to cargo hold 3 alone, without damaged double-bottom tanks, was not run in either the MSC or the ABS calculations.

The damaged stability calculations also ran two-division cases for damage that encompassed both cargo hold 3 and cargo hold 2A (denoted in both reports as division 6+7 and 6+7i1). In both the MSC and the ABS report, for both drafts and all damaged combinations in the division, the individual cases run did not add to the attained index A and resulted in a heel angle of about 180° (failed). Damage to cargo hold 3 and cargo hold 2A alone, without damaged double-bottom tanks, was not run in either the MSC or the ABS calculations.

7.8 Other Subdivision Standards: MARAD Design Letter No. 3

Historically, MARAD has required all major vessels built under US government subsidy or mortgage guarantee programs to be capable of surviving flooding of any one compartment. The single-compartment standard is an example of "deterministic" damaged stability. Investigators

[142] The Coast Guard MSC comments to this factual report dated 3 August 2017, noted an "important reason for the differences between the ABS and MSC results. MSC has discovered significant errors or bugs with different versions of the GHS software damage stability algorithms which lead to differences in results. MSC is currently working with the software vendor to assess the impacts of this for all ships and will address separately within the Coast Guard and with class societies including ABS."

contacted MARAD for help in determining what, if any, MARAD design standards related to stability might have applied to *El Faro*'s original hull, or to other *Ponce*-class vessels. MARAD replied that that the *El Faro* (hull 670) was built under a mortgage guarantee program[143] and supplied the 1965 version of "Design Letter No. 3, Maritime Administration Subdivision Standards" (for one-compartment damaged stability).[144] MARAD stated that this standard "was in force at the time of the construction of the then-SS PUERTO RICO" and that the vessel as constructed "met Design Letter No. 3 damage criteria."[145]

The 1965 letter states in part that cargo ships should "be capable of surviving the final stage of flooding of any one compartment at any time during any voyage" and that after damage, the ship should exhibit positive GM, not immerse the margin line, and not heel more than 15°. Under the letter's provisions, the assumed extent of vertical damage would be from the top of a ship's double bottom to its margin line. In the case of *El Faro*, the top of the double bottom was the tanktop, so that the vertical damage would have occurred to cargo hold 3 alone. This potential result differs from the probabilistic vertical damage for a hull division calculated by ABS and the MSC for *El Faro*, which included the double-bottom tanks. Another difference is the permeability factor of 60 percent (0.6)[146] assigned in the 1965 letter to cargo spaces, compared with a dry cargo hold permeability of 0.7 prescribed in the applicable 1990 SOLAS damage stability standards that

[143] The mortgage guarantee program was the Federal Ship Financing Program, known as the MARAD Title XI Loan Guarantee Program.

[144] Design Letter No. 3, U.S. Department of Commerce, Maritime Administration, 28 April 1965.

[145] Email, MARAD Ponce Class Stability, 19 April 2016.

[146] In naval architecture, permeability is the percentage of a space that may be occupied by seawater if the space flooded. It varies based on cargo type carried.

both ABS and MSC used in their probabilistic post-accident damaged analyses.[147,148] The 0.7 permeability factor was also used in the 1993 probabilistic damage stability review by ABS.

Design Letter No. 3 was substantially revised in 1983. General cargo space permeability was maintained at 60 percent, but the permeability factor for Ro/Ro holds was increased to 80 percent for containers on deck, 90 percent for containers on wheels, and 85 percent as an average.[149]

Design Letter No. 3 is not a statutory requirement. "It is essentially an owner's requirement," according to the ABS chief engineer for statutes.[150] It was not an alternative to the SOLAS probabilistic damaged criteria that were applicable to *El Faro* at the time of its lengthening in 1992–1993. ABS stated that as Design Letter No. 3 was not a statutory requirement, it was not taken into account in statutory reviews, nor were the results included in the vessel's stability booklets.

Investigators attempted to determine through ABS records the historical stability requirements for *Ponce*-class vessels in general and *El Faro* in particular. ABS determined that since the SS *Ponce*'s keel was laid before July 21, 1968, and ICLL certifications after 1968 show the vessel as an "existing vessel," the load line was assigned under the 1930 Load Line Convention,

[147] Technical Report, SS *El Faro* Stability and Structures, U.S. Coast Guard Marine Safety Center, Appendix B: SOLAS Probabilistic Damage Stability Analysis, p. 140, 22 March 2017.

[148] SOLAS Probabilistic Damage Stability Analysis, ABS Chief Engineer Statures, 6 May 2016, (MBI exhibit 166).

[149] Design Letter No. 3, U.S. Department of Commerce, Maritime Administration, 1 August 1983, reissued 4 January 1991 (editorial changes).

[150] Email, ABS Chief Engineer Statutes, Design Letter No. 3, 5 February 2016.

which did not require Coast Guard–approved stability.[151] Therefore, ABS could not determine what previous intact or damaged stability criteria may have applied to the *Ponce*.

7.9 Guidelines for Conducting Stability Tests

Investigators learned during testimony that the most current NVIC 17-91 guidance for stability testing[152] does not reference the most recent ASTM standard guide for conducting stability tests.[153] NVIC 17-91 states that the ASTM guide was developed by the Coast Guard, in cooperation with an industry task group, to ensure that stability test procedures would accurately determine a vessel's lightship characteristics. NVIC 17-91, which superseded NVIC 15-81, references ASTM Standard Guide F 1321-90, which was adopted in 1990 and has been superseded six times in the ensuing 27 years. The last time was in 2014, with the current ASTM F1321-14.[154]

The former ABS Load Line and Stability Group manager,[155] who had over 22 years' experience in the group, told the MBI that because of conflicts with official Coast Guard requirements and available stability test procedures, he had contacted the Coast Guard Engineering Branch 2 years earlier (2015) to request approval to use the most current ASTM standard. The Coast Guard said that ABS should use the most recent standard in conducting stability test reviews on behalf of the Coast Guard. The former manager stated that the newer ASTM standard allowed for the use of water tubes, inclinometers, and laser readers rather than pendulums. He stated that

[151] Email, ABS Chief Engineer Statutes, LLC applicable to Ponce as originally constructed, 16 April 2016.

[152] Navigation and Inspection Circular No. 17-91, Guidelines for Conducting Stability Tests, 4 November 1991.

[153] ASTM, formerly American Society for Testing and Materials, is an international organization that develops and publishes technical standards on a variety of products, materials, systems, and services.

[154] ASTM International Website, Historical Versions of F1321.

[155] ABS Chief Engineer Statutes, MBI 3 Testimony, 9 February 2017.

in his professional opinion, the updated technology would reduce the amount of uncertainty in stability test results.

7.10 Stability Booklet

7.10.1 Code of Federal Regulations

Title 46 CFR 170.110(a) states that ""Except as provided in paragraph (e) of this section, a stability booklet must be prepared for each vessel." This allows for the issuance of simplified stability letters to certain vessels. At the time of the stability reviews by ABS, 170.110(b) stated: Each stability booklet must be approved by the Coast Guard Marine Safety Center or the ABS. As previously detailed, under NVIC 03-97, ABS may solely review and issue a stability letter. According to Enclosure 2 to NVIC 3-97, "Stability related reviews by the ABS may encompass the following tasks:

> j. Approval of Trim and Stability Booklets or other stability information for operating personnel.

The Nautical Operations group factual report covers 46 CFR requirements, guidance, and considerations for stability books.

7.10.2 NVIC Guidance

NVIC 03-89 is the most current guidance to the marine industry for the presentation of stability information to operating personnel.[156] The purpose of NVIC 03-89 is to provide guidelines for preparing stability information to ensure the safe operation of vessels, as defined by compliance with Coast Guard stability standards. It is applicable to "those required to submit stability

[156] Navigation and Inspection Circular No. 03-89, Guidelines for the Presentation of Stability Information for Operating Personnel, 7 September 1989.

information to the Coast Guard" and to "the Coast Guard during a stability review, or . . . an organization performing stability review on behalf of the Coast Guard."

NVIC 03-89 contains guidance for factoring in the effects of wind under Category 2 information. It states that "wind and/or other heeling lever curves are to be superimposed on the diagram [curve of righting levers (GZ)] as appropriate." ABS stated that as the CFR weather criteria, which was applicable to *El Faro*, is a straight calculation of GM and does not require the evaluation of a GZ curve. Therefore, it is not appropriate to include this information in the stability booklet.[157] NVIC 03-89 also states under "Masters instructions" that specific instructions should be given with regard to the "evaluation of stability parameters if appropriate, in relation to assumed wind and/or wave forces."

Neither *El Faro*'s current stability booklet[158] nor its 1993 booklet[159] contained instructions, guidance, tables, or other information about the effect of wind on vessel stability or heel. The booklets did not contain information about the wind speeds used in stability calculations. ABS commented that "the 1993 stability booklet was reviewed by the Coast Guard without comment, confirming that the wind speed was not required to be included. Therefore, wind speed was not included in any of the following stability booklets."[160]

El Faro's CargoMax program had an "Auto-Windheel Calculation" function, which, when selected, would automatically adjust the required GM for the actual loaded condition of the vessel,

[157] ABS Party Comments to Naval Architecture group factual report, comment p. 50, line 19, 9 August 2017.

[158] Trim & Stability Booklet, Rev E, *SS El Faro*, HEC, 14 February 2007.

[159] Trim & Stability Booklet, DWG No. 1252-700-602 Rev. A1, SS Northern Lights, JJH Inc., 5 June 1993 (MBI Exhibit 251).

[160] ABS Party Comments to Naval Architecture group factual report, comment p. 50, line 19, 9 August 2017.

based on the area of the loaded containers in profile.[161] As actual loaded profiles would differ from the homogeneous wind profiles considered in the stability booklet, the resulting required GM would be different. The required GM was based on the Coast Guard weather criteria found at 46 CFR 170.170. For example, all other factors being equal, the auto-windheel calculation would result in a lower required GM for a voyage if container tiers were not completely full (the actual container area in profile would be less than the full tier profile considered in the stability booklet GM curves). The program would calculate the effect of a beam wind (90° to vessel) on the applicable stability criteria. The CargoMax auto windheel calculation met the necessary requirements for calculation of the minimum required GM in accordance with 46 CFR 170.170. After a post-accident review, including of CargoMax, the Coast Guard Marine Safety Center report stated that "the accuracy of the CargoMax calculations can be considered as good (or better) than the tabular form calculation performed by hand using the T&S booklet.[162]

Wind speed would not vary in CargoMax's auto-windheel option, nor was it required to. Wind speed was based on the 46 CFR 170.170 weather criteria, whose required calculations include a variable for the wind pressure on the projected lateral area of a vessel above the waterline.

For vessels in ocean service, wind pressure variable (P) is calculated according to the formulas in 46 CFR 170.170 as follows:

$$P = 0.005 + (L/14{,}200)^2 \text{ tons/ft}^2$$

where L = length between perpendiculars, feet.

[161] CargoMax for Windows Version 1.21, Vessel Information for *El Faro*, Rev. 2, Herbert Software Solutions, Inc., 13 March 2007 (MBI Exhibit 261).

[162] Technical Report, SS *El Faro* Stability and Structures, U.S. Coast Guard Marine Safety Center, p. 29, 22 March 2017.

For *El Faro*,

$$P = 0.005 + (733.75 \text{ feet}/14{,}200)^2 \text{ tons/ft}^2$$

$$= 0.0077 \text{ tons/ft}^2$$

$$= 17.2 \text{ pounds/ft}^2.$$

HEC used a value of 0.0077 tons/ft^2 in the "pressure" fields for calculating required GM in its windheel report on *El Faro*.[163] At sea level, 17.2 pounds/ft^2 pressure is approximately 69 knots, or 79 mph.

8 LOAD LINE

Load line regulations and policies are found at 46 CFR parts 42-47 and at 46 *United States Code* (USC), chapter 51. The principal Coast Guard office responsible for load line regulations and policy is the Naval Architecture Division (CG-ENG-2).

Load line certificates are issued on behalf of the Coast Guard by ABS or one of several other Coast Guard–approved classification societies. The owner or operator chooses the assigning authority. ABS has been recognized as an authorized assigning authority for load lines on US vessels since 1929.

The Coast Guard Naval Architecture Division has published policy notes to "consolidate into a single document" its current load line polices. [164] The policy notes state that the purpose of a load line is to "ensure the overall seaworthiness of the intact (undamaged) vessel." According to the notes, seaworthiness is accomplished by:

[163] Direct Calculation of Required GM for USCG Windheel Criteria Within the CargoMax Loading Program, Implementation System and Supporting Calculations, SS *El Faro*, HEC, pg. 8, 14 April 2006 (MBI Exhibit 262).

[164] Load Line Policy Notes, Coast Guard Office of Design and Engineering Standards, Naval Architecture Division, Rev. 22 Sept. 2008.

- Ensuring a robust hull that can withstand severe sea conditions
  (i.e., structural design, construction, and maintenance);
- Ensuring weathertight and watertight integrity of hull penetrations and superstructure openings
  (i.e., coamings around exposed openings, and that doors, hatches, vents, hull valves, etc, are fitted with covers or closures that are in good working condition);
- Ensuring that the vessel has reserve buoyancy
  (by a requiring a minimum freeboard above the waterline);
- Ensuring that the vessel is not overloaded
  (by limiting the maximum loaded draft);
- Ensuring that the vessel has adequate stability and strength for all loading and operating conditions
  (by providing approved stability documentation and loading instructions for use by the master);
- Ensuring rapid drainage of water on deck (from boarding seas)
  (by adequate arrangement of scuppers and freeing ports in bulwarks);
- Ensuring safety of crew while working on deck
  (by increased freeboard to reduce boarding seas, and guardrails around deck edges);
- Ensuring that modifications to the vessel do not compromise seaworthiness
  (modifications must be approved by the load line-assigning authority); and
- Periodic inspections (afloat and drydocked) to verify that the above are properly maintained
  (by the load line-assigning authority)

The policy notes define "watertight" and "weathertight" as follows:

q. *"Watertight"* - means capable of preventing the passage of water through the structure in any direction under a head of water for which the surrounding structure is designed. One of the purposes of load line assignment is to ensure the watertight integrity of a vessel below its freeboard deck.

r. *"Weathertight"* - means that in any sea conditions water will not penetrate into the vessel. One of the purposes of load line assignment is to ensure the weathertight integrity of a vessel above its freeboard deck.

El Faro's load line certificate was for a Type B freeboard. Type A freeboards are for vessels that carry liquids in bulk, while Type B freeboards are generally assigned to all other cargo vessels. Compared to Type A vessels, Type B vessels will have increased freeboard. According to the Load Line Technical Manual, Type A vessels have lower freeboard due to 1) the decks have only small access openings with watertight closing arrangements 2) the decks have a higher degree of integrity 3) there is a higher degree of safety against flooding due to a lower cargo permeability.

El Faro, a Type B vessel, did not have a reduced freeboard, although that is allowed for Type B vessels, according to the former load line manager.[165] A damaged analysis, or flooding standard, is required by the ICLL when a vessel has a Type A or Type B reduced freeboard.[166]

8.1 Load Line Treatment of Cargo Hold Ventilation Openings

8.1.1 ABS Definitions

The ABS Load Line Technical Manual, first published in 1990 and annotated in 2008 by the Coast Guard to reflect the 2005 amendments to the 1966 ICLL and 1988 Protocol, gives the following definitions:

> Freeboard Deck: The freeboard deck is normally the uppermost complete deck exposed to weather and sea, which has permanent means of closing all openings in the weather part thereof, and below which all openings in the sides of the vessel are fitted with permanent means of watertight closing. It is the deck from which freeboard is calculated.
>
> Weathertight: Weathertight means that in any sea conditions water will not penetrate into the vessel.
>
> Watertight: Capable of preventing the passage of water through the structure in any direction under a head of water for which the surrounding structure is designed.

8.1.2 Load Line and Cargo Ventilation Openings on *El Faro*

For load line consideration, *El Faro*'s second (freeboard) deck was open for Ro/Ro cargo. The sideshell above the second deck was therefore not considered superstructure or counted as

[165] Interview Transcript, former ABS Load Line-Stability Manager, p. 11, 29 January 2016.
[166] USCG Load Line Technical Manual, Annotated for 2005 Revisions to ICLL.

buoyant volume.[167] Consequently, all openings (including ventilation) on the second deck "would have to meet Position 1 requirements for coaming heights and closing appliances." [168] ICLL regulation 13 defines two positions for hatchways, doorways, and ventilators. [169] Position 1 is closer to the freeboard deck and thus the waterline, so openings in position 1 must meet higher requirements. The cargo hold supply and ventilation trunks on *El Faro* penetrated the second (freeboard) deck and would be subject to meeting position 1 requirements.

The ICLL (regulation 19, "Ventilators") requires that ventilators in position 1 to spaces below freeboard decks be steel or equivalent material and that they "shall have coamings of a height of at least 900 mm (35 1/2 inches) above the deck." Although the exhaust ventilation trunks were fitted with baffles extending several feet above the second deck, baffle heights above 35 1/2 inches were not load line requirements, but "were used as downflooding points for damage stability" assessment. [170]

The ABS load line manager stated that load line regulations and guidance found in the ABS technical manual "require closing devices" on openings, including ventilators.[171] The manual states under "Closing Appliances, General Requirements" that "All ventilator openings are to be provided with a weathertight closing appliance."

[167] Interview Transcript, former ABS Load line-Stability Manager, p. 12, 29 January 2016.

[168] Coaming and Sill Heights are used interchangeably. The Sill height is the distance from the deck to the lowest point of the opening. CG MBI 3, Testimony, ABS Chief Engineer Statutes, p. 646, 9 February 2017.

[169] International Convention on Load lines 1966, and Protocol of 1988, as amended in 2003, Load Lines 2005 Consolidated Edition, IMO Publications, Annex 1, Regulation 19 (4).

[170] CG MBI 3, Testimony, ABS Chief Engineer Statutes, p. 685, 9 February 2017.

[171] CG MBI 3, Testimony, ABS Chief Engineer Statutes, p. 646, 9 February 2017.

Regulation 19 of the ICLL relaxes the requirement for closing appliances for position 1 ventilators if their coamings extend more than 4.5 meters (14.8 feet) above the deck.[172] However, regulation 19 also notes that, generally, "weathertight closures are required on all ventilator openings adjacent to the side shell plating . . . to protect the ventilator opening from 'run up' of water due to waves on the vessel's sides or green water on deck so that water will not penetrate into the vessel under any sea condition." [173]

ICLL regulation 19 notes that where ventilators are required to have closing appliances, they must be steel if built after January 1, 2005. The Coast Guard's load line technical manual states that closing appliances must be "deemed weathertight to the satisfaction of the assigning authority."[174] The assigning authority for *El Faro* was ABS.

According to the former ABS load line and stability manager, the arrangement of *El Faro*'s supply and exhaust ventilation trunks met the ICLL requirements when constructed in 1974, met the requirements in place during its conversions in 1993 and 2006, and would meet the current (2005 ICLL) requirements. "If the same arrangement were proposed today, ABS would accept it, under the current regulations."[175]

8.2 LL11D Forms

The 1988 protocol to the ICLL states that a form showing the "record of conditions of assignment of load lines" should be filled out by attending surveyors and kept aboard a vessel.

[172] International Convention on Load lines 1966, and Protocol of 1988, as amended in 2003, Load Lines 2005 Consolidated Edition, IMO Publications, Annex 1, Regulation 19 (3).

[173] Green water is water not broken into spray as it comes over the deck in foul weather.

[174] USCG Load Line Technical Manual, Annotated for 2005 Revisions to ICLL, Closing Appliances, Types of Closures, p. 147.

[175] Interview, former ABS Load line & Stability Manager, pp. 115-116, 29 January 2016.

ABS internally designated this form the LL11, with an additional letter to denote the revision. The current ABS designation is LL11D.[176] The document lists all openings that could allow water to enter the watertight envelope of a ship, such as doors, hatchways, air pipes, ventilators, and piping, and lists other load line requirements such as guardrails for crew protection.

Investigators requested the LL11D for *El Faro* to determine what the ABS class surveyors listed as watertight and weathertight openings. Because the current version of an LL11D form is kept on board, *El Faro*'s current LL11D was lost with the vessel. ABS in Houston maintains copies of the forms, but copies for *El Faro* after the 1993 lengthening were lost during electronic archiving.[177] The only copy of the LL11D for *El Faro* was the version for the originally constructed vessel (before lengthening), and was actually designated "Form LL 11-C." The former ABS load line and stability manager was certain that an updated version reflecting the 1993 changes was made.[178] If there are changes to the openings or other information on the LL11, it would be updated by the attending surveyor and submitted to the ABS technical office for review.[179]

ABS reviewed surveyor reports associated with *El Faro*'s LL11 for the 1993 and 2006 modifications. ABS concluded that the vessel's LL11 was updated in 1993, but that in 2006 there were "no modifications made which would affect the load lines, so the LL11 was not updated at that time."[180]

8.2.1 Ventilators Listed on LL11 Forms

[176] CG MBI 3, Testimony, ABS Chief Engineer Statutes, p. 647, 9 February 2017
[177] CG MBI 3, Testimony, ABS Chief Engineer Statutes, p. 714, 9 February 2017.
[178] CG MBI 3, Testimony, ABS Chief Engineer Statutes, p. 720, 9 February 2017.
[179] CG MBI 3, Testimony, ABS Chief Engineer Statutes, p. 720, 9 February 2017.
[180] CG MBI 3, Testimony, ABS Assistant Chief Surveyor Americas, p. 921, 10 February 2017.

The original LL11C form for *El Faro*, under "Ventilators in Exposed Positions on Freeboard and Superstructure Decks," lists 22 ventilators on the second (freeboard) deck. They were all 8 feet, 0 inches high (above the deck).[181] The form noted under "Closing Appliances" that there were "8 – 3/8 STEEL WEATHERTIGHT DAMPERS W/DOUBLE LOCKING HANDLES."

Investigators reviewed *El Yunque*'s form LL11, which included an annotation dated and stamped 2013.[182] Under "Reg. 19: Ventilators in Exposed Positions on Freeboard and Superstructure Decks," the form listed 28 ventilators on the second (freeboard) deck. It noted that all were 8 feet, 0 inches high, opening outboard. Investigators reviewed the LL11 for the lengthened *El Morro*.[183] The form listed 28 ventilators on the second (freeboard) deck, all 8 feet, 0 inches above the deck, opening outboard.

8.2.2 Second Deck Scuttles Listed on LL11 Form

The original LL11C for *El Faro*, under "Reg. 14, 15 and 16: Hatchways on Freeboard and Superstructure Decks," noted two steel, transversely hinged, oval "R.M.H. ESCAPES" at frames 122 and 163 on the second deck, with dimensions of 22 3/4 inches by 14 3/4 inches. The form noted that the escapes had rubber gaskets and four evenly spaced dogs. This record, which was made before the vessel was lengthened, would not have included hatchways associated with future hold 2A.

[181] Form LL 11-C, ABS Survey for Load Lines, *Puerto Rico*, Hull 670, ABS Report PA2280 – *El Faro*, 10 November 1974.

[182] Form (Unknown), ABS Survey for Load Lines, Hull 670, ABS Report PA3007 - *El Yunque*, 22 January 1976.

[183] Form LL 11-C, ABS Survey for Load Lines, *El Taino*, Hull 666 Lengthened, ABS Report PA3036 – El Morro, 2 February 1976.

8.2.3 Hull Penetration of Emergency Fire Pump Listed on LL11D Forms

Investigators reviewed the LL11D forms of *El Faro*, *El Yunque*, and *El Morro* for information about the emergency fire pump penetration in cargo hold 3, which was below the freeboard deck. Because of their openings in the interior and exterior of the vessel, traditional seawater fire systems are considered "open." [184] No sea chest penetration or inlet for the emergency fire pump was found on any of the LL11D forms.

Interviews and photographs indicate that the inlet valve to the emergency fire pump was fitted with a reach rod operated from the second deck, which met ICLL regulation 22 for open systems in unmanned machinery spaces.

8.3 Load Line Inspections

The Coast Guard's load line policy notes in Section 6, Enforcement of Load Line Regulations, state that "The enforcement of the load line regulations is the joint responsibility of the Coast Guard district commander and the district director of U.S. Customs." The guidance is not for the issuing authority (ABS for *El Faro*). The Policy Notes state that "on routine inspection duties, marine inspectors and other marine safety personnel will check for load line compliance."[185] In part, they will look for deterioration or modifications (material condition) that might invalidate the conditions of assignment:

> *Material condition:* While the most common reason to detain a vessel is for overloading and submergence of the load line mark, it is equally important to look for deteriorations or

[184] Per Coast Guard Load Line Technical Manual, annotated to 2005: A "closed" system is a system which penetrates the shell, but is essentially a closed loop through which no back-flooding can readily occur, e.g. main and auxiliary circulating systems. An "open" system is "all discharges not considered in a closed system, e.g. sanitary drains, bilge, ballast, and eductors.

[185] Load Line Policy Notes, Coast Guard Office of Design and Engineering Standards, Naval Architecture Division, pp. 6-2, Rev. 22 Sept. 2008.

modifications that might invalidate its conditions of assignment. There are number of items that should be examined at each boarding. These include the condition of hatches, coamings, air pipes, watertight doors, vent closures, and anything that affects the weathertight and watertight integrity of the vessel. Other things to look at include crew protection items, such as lifelines and rails; freeing ports; scuppers; side ports; side scuttles, ventilators, and hatches. Materiel deterioration in these items which would impair their operation or compromise the watertight integrity of the hull envelope are as much grounds for detention as overloading.

9 MARINE SAFETY CENTER TECHNICAL REPORT ON STABILITY AND STRUCTURES

NTSB investigators worked with the Coast Guard to gather factual evidence both through the NTSB investigation and the Coast Guard MBI. NTSB investigators gathered documents and conducted interviews to support input assumptions for both a stability analysis of *El Faro* (intact and damage) and a hydrostatic sinking analysis. In past accidents, such as the sinking of the fishing vessel *Alaska Ranger* in 2008, with simultaneous Coast Guard MBI investigations, the NTSB has used MBI-requested stability and hydrostatic sinking analyses from the MSC. NTSB investigators were aware that as part of the Coast Guards MBI into the sinking of *El Faro,* a similar analysis was to be formally requested by the Coast Guard MBI of the MSC. For *El Faro*, the Coast Guard agreed to share the final MSC report, allowed the NTSB to review the draft scope of the MBI's request, comment on the request,[186] and comment on the draft report. The final "MSC technical

[186] Memorandum, CG-INV to CG MSC, Subj., MSC Technical Review and Analyses of the SS *El Faro*, O.N. 561732, 22 July 2016.

review and analysis of the *El Faro*"[187] included review and analyses for the *El Faro*'s stability, structures, and hydrostatic sinking analyses.

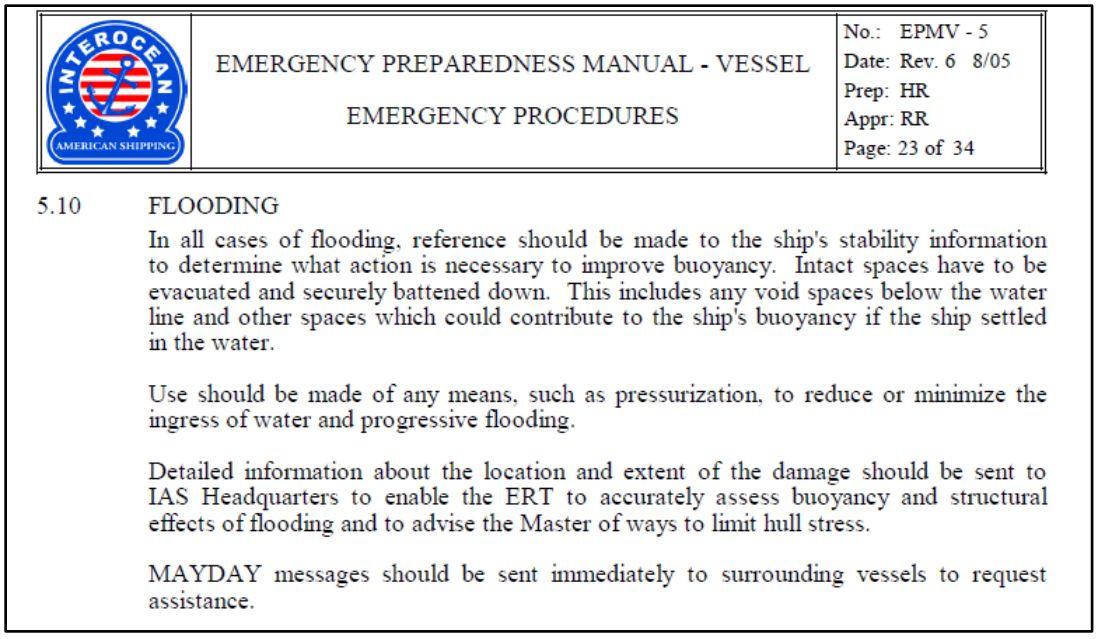
10 SAFETY MANAGEMENT SYSTEM AND DAMAGE CONTROL PLAN FOR FLOODING

10.1.1 Vessel Emergency Procedures and Fire Control and Safety Plan

Investigators reviewed the ship's safety management system (SMS) regarding emergency procedures for flooding. When *El Faro* was operated by Interocean Management, "Emergency Procedures" were found in section 5 of the "Vessel Emergency Preparedness Manual."[188] The emergengy procedures for flooding were found in section 5.10. The table of contents noted "Rev 0 3/96" for section 5.10 Flooding. The instructions for section 5.10 were as follows. The revision date for section 5 noted in the right-hand side of the heading (not for the specific procedure 5.10), is noted as "Rev. 6 8/05."

[187] Technical Report, SS *El Faro* Stability and Structures, U.S. Coast Guard Marine Safety Center, 22 March 2017.

[188] Interocean, Emergency Preparedness Manual, section 5, "Emergency Procedures," No. EPMV-TOC, Rev. 7, August 2006.



EMERGENCY PREPAREDNESS MANUAL - VESSEL

EMERGENCY PROCEDURES

No.: EPMV - 5
Date: Rev. 6 8/05
Prep: HR
Appr: RR
Page: 23 of 34

5.10 FLOODING

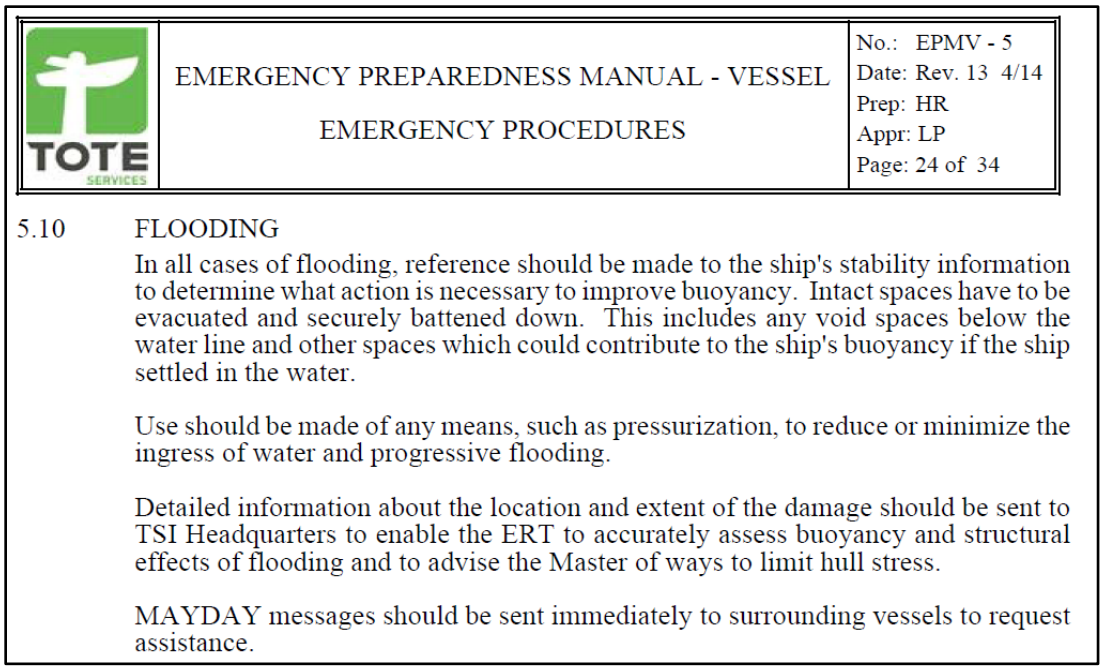
In all cases of flooding, reference should be made to the ship's stability information to determine what action is necessary to improve buoyancy. Intact spaces have to be evacuated and securely battened down. This includes any void spaces below the water line and other spaces which could contribute to the ship's buoyancy if the ship settled in the water.

Use should be made of any means, such as pressurization, to reduce or minimize the ingress of water and progressive flooding.

Detailed information about the location and extent of the damage should be sent to IAS Headquarters to enable the ERT to accurately assess buoyancy and structural effects of flooding and to advise the Master of ways to limit hull stress.

MAYDAY messages should be sent immediately to surrounding vessels to request assistance.

The emergency preparedness manual from TOTE Services[189] current at the time of the sinking was Rev. 13, dated April 2014. The guidance was similar to the Interocean guidance:



EMERGENCY PREPAREDNESS MANUAL - VESSEL

EMERGENCY PROCEDURES

No.: EPMV - 5
Date: Rev. 13 4/14
Prep: HR
Appr: LP
Page: 24 of 34

5.10 FLOODING

In all cases of flooding, reference should be made to the ship's stability information to determine what action is necessary to improve buoyancy. Intact spaces have to be evacuated and securely battened down. This includes any void spaces below the water line and other spaces which could contribute to the ship's buoyancy if the ship settled in the water.

Use should be made of any means, such as pressurization, to reduce or minimize the ingress of water and progressive flooding.

Detailed information about the location and extent of the damage should be sent to TSI Headquarters to enable the ERT to accurately assess buoyancy and structural effects of flooding and to advise the Master of ways to limit hull stress.

MAYDAY messages should be sent immediately to surrounding vessels to request assistance.

[189] TOTE Services, Emergency Preparedness Manual, Section 5 Emergency Procedures, No. EPMV-TOC, Rev. 13, April 2014. (MBI Exhibit 26).

El Faro had onboard a Fire Control & Safety Plan, posted near the bridge, as required of all TOTE managed ships under TOTE's operational and emergency procedures (i.e. TOTE's SMS). The Fire Control & Safety Plan contained information depicting the location and operation of various fittings, systems and equipment on the vessel, including but not limited to: egress routes, scuttles, hatches, cargo hold watertight doors, cargo hold and engine room fire dampers, cargo hold and engine room ventilation closing devices (exhaust & intakes), fire dampers, bilge/ballast pumps, emergency generator, and a variety of remote shutdowns/controls (e.g. for ventilation systems, emergency fire pumps, general alarm, etc.). Investigators reviewed the plan,[190] and noted in part, that it had four cargo space ventilation inlet/outlet closing devices to hold 5 the drawing designated as "HWT doors," (hinged watertight doors). It had a total of 51 cargo hold fire dampers for holds 1, 2, 2A and 3. These were designated as "Fire Damper- Cargo Spaces." The cargo hold supply ventilation closures, or fire dampers, as designated in the plan, were indicated with a "WT" (watertight). The exhaust ventilation closures, were also designated as fire dampers but indicated with a "NT," (non-tight).

10.1.2 Requirements for Damage Control Plans, Booklets, and Information to Master

In 1999, annex guidelines for damage control plans for SOLAS vessels were approved for passenger and cargo ships and published in IMO MSC/Circular 919.[191] In 2009, MSC/Circular 919 was superseded by MSC/Circular1245, which stated that the damage control plan and damage control stability booklet "are intended to provide ships' officers with clear information on the ship's watertight subdivision and equipment related to maintaining the boundaries and effectiveness of the subdivision so that, in the event of damage to the ship causing flooding, proper

[190] Fire Control and Safety Plan, Sea Star Line, LLC, SS *El Faro*, SSL-670-100-050, Rev. A, 18 January 2006 (MBI Exhibit 134).

[191] IMO MSC.1/Circular.919, "Guidelines for Damage Control Plans," October 29, 2007.

precautions can be taken to prevent progressive flooding through openings therein and effective action can be taken quickly to mitigate and, where possible, recover the ship's loss of stability."

After probabilistic damaged stability and damage control plans had been applied to ships for over a decade, in 2005, the IMO's Maritime Safety Committee considered adoption of additional mandatory guidelines for providing damaged stability information to masters.[192] The rationale was that "the probabilistic damage stability concept is rather global and does not really, in a simple and easily understandable way, present the survivability of a ship when subject to the flooding of a particular compartment or group of compartments." Although probabilistic requirements calculate the survivability of a ship for all possible damaged cases studied, "the results of individual damage cases are not necessarily reported to assess the fulfilment of stability requirements." In operational terms, the Maritime Safety Committee recognized that a master experiencing a specific flooding case would not have a means of quickly assessing the vessel's stability in the flooding scenario being experienced. "The aim of the proposed guidelines is to set a minimum level for the presentation of damage stability information for evaluation of a ship's situation when subject to internal flooding. The information shall be very clear and the presentation should be standardized to provide a simple and understandable way to assess the survivability." The guidelines were adopted in MSC/Circular 1245, whose title was expanded from that of Circular 919, "Guidelines for Damage Control Plans," to "Guidelines for Damage Control Plans and Information to the Master." [193]

[192] Maritime Safety Committee, 80th Session, agenda item 3, Consideration and Adoption of Amendments to Mandatory Instruments, draft revised SOLAS chapter II-1, parts A, B, and B-1 – Rule 19.5 – Damage stability information.

[193] IMO MSC.1/Circular.1245, "Guidelines for Damage Control Plans and Information to the Master," 29 October 2007.

Damage control plans and booklets are applicable to all passenger ships built after 1980, dry cargo ships greater than 500 gross tons built between 1992 and 2009 (SOLAS, 1989 amendments, regulation II-1/23-1), and all cargo ships after January 10, 2009 (SOLAS, 2005 amendments, regulation II-1/19). For ships built before January 1, 2009, the plan and booklet have to comply with the requirements of IMO MSC/Circular 919, while for ships built after that date, the material must comply with MSC/Circular 1245.

The SOLAS 1990 regulation on damage control plans for dry cargo ships applied to ships constructed after February 1, 1992.[194]

The 2004 regulation refers to MSC/Circular 919 for guidelines for damage control plans and to MSC/Circular 434 for guidelines for the preparation of information on the effects of flooding to be provided to masters of dry cargo ships. The regulation states in part that "there shall be permanently exhibited or readily available on the navigation bridge, for the guidance of the officer in charge of the ship, a plan showing clearly for each deck and hold the boundaries of the watertight compartments" and booklets with similar information "shall be made available to the officers of the ship." The regulation also requires listing openings and means of closure, arrangements for the correction of flooding, indicators for all watertight and hinged doors in watertight bulkheads, conditions and operational procedures considered by the Administration to be necessary to maintain watertight integrity under normal ship operations, and specific precautions listing elements considered to be vital to the survival of the ship and its crew.

[194] SOLAS 2004, Part B: Subdivision and Stability, chapter II-1: Construction- structure, stability, installations, regulation 23-1, Damage control in dry cargo ships.

A Damage Control plan would have been required for SOLAS dry-cargo ships newly built in 1993, while a plan and booklet would have been required for SOLAS dry-cargo ships newly built in 2005. These were the two years of both substantial modifications to *El Faro*. The Coast Guard did not determine the 2005 modifications to be a major modification and the 2004 SOLAS damage control plan and booklet regulations would not have applied unless specifically required by the Coast Guard. There was no evidence that the Coast Guard required a damage control plan or damage control booklet for *El Faro*, and there was no evidence it had one. The "Information to the Master" would have been required only for ships built after 2009, that is, after *El Faro*'s last conversion.

According to ABS, SOLAS requires the damage control plan to be placed on board a vessel, but it does not require approval, even for vessels built today. For *El Faro,* the Coast Guard officer in charge of marine inspection (OCMI) would have had to require the damage control plan to be placed on the vessel.[195] "Since the modifications were done prior to entry into ACP, that remained the responsibility of OCMI."[196]

10.1.3 References on VDR Transcript to Onboard Stability Instruments

On the VDR audio transcript for October 1, the day of the sinking, there is no discernible evidence that the captain or other officers on the bridge consulted the onboard stability resources for guidance about the ship's heeling angle or the flooding in hold 3.[197] The onboard stability resources were the ship's CargoMax software and its T&S booklet.

[195] ABS chief engineer of statutes, testimony at MBI 2, p. 34, 20 May 20 2016.

[196] ABS chief engineer of statutes, testimony at MBI 3, p. 691, 2 February 2017.

[197] *El Faro*, Voyage Data Recorder Audio Transcript, group chairman's factual report, Office of Research and Engineering, December 12, 2016. The VDR transcript only recorded audible (much was inaudible) bridge discussion and statements. The VDR does not capture conversations which occurred elsewhere on the vessel.

Direct discussion about the vessel's stability or downflooding angles was first captured on the VDR transcript at 07:20:40 on October 1, when the chief mate stated, "my concerns are of course stability (I have/and no) concept of how much water (may be) sittin' down there * * (can't/very) difficult determine *." A couple of minutes later the riding crew supervisor[198] called the bridge, and the captain stated over the electronic telephone, "(uh/on) the down flooding angle? um that I don't have an answer for (ya)." Which was shortly followed by the captain stating, "yup," "what's it called again?" and then "okay we'll check that. (it's/that's) in the chief's office?" Stability was mentioned again at 07:23:47 when the captain said, ". . . we still have reserve buoyancy and stability." The supervisor stated at 05:11:33: "I've never seen it list like this—you gotta be takin' more than a container stack * I've never seen it hang like this."

10.1.4 References on VDR Transcript to Damage-Control Documents

The VDR audio transcript contains evidence that the crew secured the scuttle that was found to be open and allowing green water entrapped on the second deck to enter cargo hold 3 and that the crew was attempting to correct the list and pump flooded cargo holds (dewater). The transcript does not contain evidence that the master or other crewmember consulted a booklet, software, drawings, procedures, plans, or other documents to address the vessel's heel, list, or flooding. There was also no indication or reference on the recorded audio regarding the use of the ABS's Rapid Response Damage Assessment (RRDA) program TOTE was enrolled in.

10.1.5 References on VDR Transcript to Vessel Heel/List

The VDR transcript records bridge crew statements beginning the morning of October 1 indicating that the vessel heeled initially to starboard. The AB (able seamen) stated at 01:28:26:

[198] The riding crew supervisor was an off-duty TOTE chief engineer with experience on *Ponce*-class vessels.

"* * wind heel. Yeaaah." The chief mate stated at 03:48:04: "I assume that we're heelin' to starboard (must be blowin') port to starboard." He said the "heel is not bad" at 04:13:06, and later on the telephone, at 04:37:29, "yea we're heelin' over *." The captain said over the telephone at 04:43:45, "you want us to take the list off a little bit?" and at 04:44:49, "just the list…" The chief mate said at 05:01:02, ". . . I can still see the spray foam to starboard. We're still heelin'." Soon after adjusting course, the vessel heeled to port. A 05:56 the captain said, "alright we got a nice port list . . ." The rest of the transcript (until the sinking) does not contain any statements about the heel returning to starboard.

The VDR first captured the engineering crew's awareness about the vessel's heel, or list, at 0437 during a phone call between the chief mate and the chief engineer. At 04:40:33, the chief mate told the captain over the telephone: "the chief engineer just called . . . something about the list and oil levels."

11 MAJOR CONVERSION

When a vessel undergoes a substantial modification or conversion, the Coast Guard MSC determines if the change meets the definition of a "major conversion" as defined by the US Code:

> Title 46, USC 2101 (14a) a "major conversion" means a conversion of a vessel that:
> a) Substantially changes the dimensions or carrying capacity of the vessel;
> b) Changes the type of the vessel;
> c) Substantially prolongs the life of the vessel; or
> d) Otherwise so changes the vessel that it is essentially a new vessel.

If a vessel is deemed to have undergone a major conversion, it may be subject to several regulatory standards current at the time of conversion, not the standards in place at the time of its original construction. Guidelines for determining the extent to which current Coast Guard

regulations should be applied to inspected cargo vessels that have undergone major conversions are found in NVIC 10-81, change 1.[199] The enclosure to the NVIC states:

> These guidelines are based on the premise that with the passage of time, existing vessels will be retired and only those built to newer standards will continue in service. For this reason, it is costly and impractical to require existing vessels to be modified each time a safety standard is updated. However, when a major conversion or modification of an existing vessel is planned, there is a definite intent to extend the service life of the vessel. When this is the case, it is appropriate to bring the entire vessel into compliance with the latest safety standards where reasonable and practicable. It is also appropriate to review the entire vessel to current standards when bringing existing US or foreign vessels under certification for the first time, or when a vessel has been wrecked or otherwise taken out of service for an extended period of time.

The NVIC states that for a major conversion or modification, "the entire vessel must meet all current standards, as far as is reasonable and practicable, in effect at the contract date of the major conversion."

Regarding stability standards, NVIC 10-81 notes the following for a major modification of a US-flag vessel:[200]

[199] Navigation and Vessel Inspection Circular NO. 10-81, Change 1, Coast Guard Certification and Inspection of Certain Categories or Vessels, 5 October 1981.

[200] Navigation and Vessel Inspection Circular 10-81, Change 1, Coast Guard Certification and Inspection of Certain Categories or Vessels, p. 43.

2. STABILITY STANDARDS
Requirements: If in the opinion of the cognizant mmt office, the alterations: (1) substantially alter the stability characteristics, dimensions, or carrying capacity of the vessel, (2) change the type of vessel, or (3) substantially prolong the vessel's service life, the vessel will have to comply with the stability standards in force at the time of the conversion. Acceptance Criteria: If, in the opinion of the cognizant mmt office, the alterations, modifications or repairs do not result in any of these three criteria being met, the vessel may be permitted to comply with the stability standards to which it had to comply prior to the conversions.

There have been almost 400 major conversion determination requests since the early 1990s, and about 50 percent are determined by the MSC to be so.[201] The current MSC commanding officer noted that congressional intent in the area of a major conversion is broad, and that major conversion/modification determinations must balance two factors at opposite ends of the spectrum. On the one hand, if every change to a vessel is a major conversion/modification determination, then the incentive for vessel owner/operators to effect significant repairs to their vessels is reduced or eliminated. On the other hand, if changes are never determined to be a major conversion/modification, then the opportunity is missed for a vessel to meet newer standards. "So the Marine Safety Center balances that spectrum in accordance with the law."[202]

SOLAS also addresses modifications to vessels and states that ships which undergo "repairs, alterations and modifications of a major character and outfitting related therto shall meet the requirements for ships constructed on or after the date on which any relevant amendments enter into force, in so far as the Administration deems reasonable and practicable."[203]

[201] Interview transcript, Coast Guard Commanding Officer MSC, p. 64, January 2016.

[202] Interview transcript, Coast Guard Commanding Officer MSC, pp. 49-50, January 2016.

[203] SOLAS, Chapter II-1, Construction, Structure, subdivision and stability, machinery and electrical installations- Part A, General, Regulation 1, Application.

11.1 Major Conversion Determination: Potential Effect on *El Faro*

Enclosure 2 of NVIC 02-95[204] states that a major conversion determination (if required) should be made by the Coast Guard's MSC before a vessel is provisionally enrolled in the ACP. The authorized classification society under the ACP is not permitted to make major modification/conversion determinations. The MSC commanding officer stated that the determination is outside the scope of the ACP and that the class society does not formally participate but may supply vessel plans or other information for the MSC's review.[205]

The commanding officer stated that if *El Faro*'s conversion to a Ro/Con in 2004 had been determined to be a major modification, the next question for the OCMI would have been what action was reasonable and practicable for the ship's owners: replace equipment in-kind, or update to new equipment and standards. He stated that the Coast Guard uses "reasonable and practicable as a condition for making that determination on a system-by-system basis."

For a vessel undergoing a conversion determined by the MSC to be a "major conversion/modification," if new stability standards existed, they would typically not be applied to the converted vessel because stability standards influence the design, arrangements, and the structure of the vessel to a significant extent. According to the chief of the Coast Guard's Naval Architecture Division, even if El Faro's 2004 conversion had been determined to be a major conversion, the vessel may have retained its requirement to meet the stability criteria in 46 CFR 170.170 (and therefore not be subject to meeting the criteria in the International Code on Intact Stability that applied to vessels newly built in 2004). However, he stated that the determination of

[204] NVIC 02-95 Change 2, The Alternate Compliance Program (ACP), 5 May 2006.

[205] Interview transcript, Coast Guard Commanding Officer MSC, p. 71, January 2016.

meeting stability standards in place at the time of the major conversion "would still be made by the MSC on a case-by-case basis."[206]

11.2 Marine Safety Center Determinations Regarding *El Faro* Conversions

11.2.1 1993 Determination

The Coast Guard determined the 1993 lengthening and spar deck addition to the *Puerto Rico* (afterward renamed *Northern Lights*) to be a major conversion. Correspondence from the MSC in May 1992 shows that if the vessel had been a "major conversion" initiated after February 1992, it would have been required to meet the new IMO probabilistic damaged stability criteria. Later MSC correspondence confirms that the lengthened vessel was to meet the probabilistic damaged stability requirements at the time of conversion (rather than the owner's initial intent to meet MARAD Design Letter No. 3).[207]

11.2.2 2005 Determination

During the process of converting the Ro/Ro *Northern Lights* to the Ro/Con *El Faro,* TOTE representatives first asked the MSC to determine whether the proposed changes would be considered a "major conversion" in February 2002.[208] The MSC commanding officer replied later the same month that the proposed modifications constituted a major conversion as defined by 46 USC 2101 (14a), and specifically that the additional containers increased the vessel's carrying capacity.

In October 2003, TOTE requested a reconsideration. The company provided clarifying information that the two sister vessels, *El Morro* and *El Yunque*, had been similarly converted in

[206] Coast Guard Chief Naval Architecture Division, Testimony at MBI 3, pp. 277-278, 7 February 2017.
[207] 1992 Major Conversion Correspondence, (MBI Exhibit 422).
[208] 2002 to 2004 Major Conversion Correspondence, (MBI Exhibit 013).

the past without the work being considered a major conversion. In addition, the company stated that the modified vessel would carry less cargo by weight. In a March 2004 reply, the MSC affirmed its previous decision that the proposed modifications would be a major conversion. Shortly afterward, to support its request for reconsideration, TOTE provided alteration histories for all *Ponce*-class vessels and noted that none had been considered a major conversion. The MSC responded that insufficient information had been provided to reverse its position. In August 2004, TOTE provided documentation (drawings) of similar alterations to *El Morro* and *El Yunque* and data that the previous conversions substantially increased the number of cargo units that could be carried. In November 2004, the MSC reversed its February 2002 decision and determined that the Ro/Con modifications would not constitute a major conversion.[209,210]

Regarding the rationale of the MSC's decision-making, the current MSC commander stated, "At the time that this decision was taken, it seemed that the Marine Safety Center heavily valued the importance of the cargo unit as a factor."[211]

12 RAPID RESPONSE DAMAGE ASSESSMENT PROGRAM

12.1 General

According to the program brochure, "Enrollment in the ABS Rapid Response Damage Assessment (RRDA) program provides the shipowner and operator with the essential technical support needed in the critical hours after a vessel is involved in a casualty. Activating the ABS RRDA team of naval architects, marine engineers, master mariners and support staff gives the

[209] 2002 to 2004 Major Conversion Correspondence, (MBI Exhibit 013).

[210] 2002 to 2004 Major Conversion Correspondence, (MBI Exhibit 013).

[211] Interview transcript, Coast Guard Commanding Officer MSC, p. 50, January 2016.

shipowner access to the professional resources needed to conduct the essential structural and stability calculations in the event of an incident that could result in the loss of the vessel, loss of all or part of its cargo or lead to pollution or of the marine environment."[212]

To mitigate the effect of oil spills, tank vessels that carry oil as cargo are required to have an oil spill response plan. As of January 1, 2007, regulations under the International Convention for the Prevention of Pollution from Ships (MARPOL)[213] require all oil tankers of 5,000 deadweight tons and over to have prompt access to computerized, shore-based damaged stability and residual structural strength calculation programs. The Coast Guard Oil Pollution Act of 1990 has required similar shore-based programs for oil tankers in US waters since January 1995. The ABS guide states that the RRDA program is designed to fulfill the requirements of those regulations. [214] The guide further states that the "program provides emergency technical services for owners/operators whose enrolled vessel experiences an incident that may affect the stability or structural strength of the vessel or require the rapid provision of technical analytical services."

Around the time of the accident, ABS had about 2,500 ships enrolled in the RRDA program. About 85 percent of them were ABS-classed. Most were internationally flagged tankers and bulk carriers, but some container ships and other ship types were also enrolled.[215] Nontank vessels are also required to have vessel response plans by 33 CFR subchapter O, part 155, because they carry oil as propulsion fuel.[216] The RRDA manager stated that the only ship types statutorily required by MARPOL to have the ship premodeled for the RRDA and 24-hour RRDA service are tank vessels

[212] ABS RRDO brochure, downloaded September 2016.

[213] MARPOL 73/78 Annex I, in accordance with MEPC.117 (52) regulation 37.4, IMO.

[214] ABS, Guide for Rapid Response Damage Assessment, July 2010, p. ii.

[215] Interview transcript, ABS RRDA manager, pgs. 10-15, 9 March 2017.

[216] Title 33 CFR, chapter I, subchapter O, part 155, subpart J, section 155.5035, "Nontank vessel response plan requirements."

(tankers). Enrollment in RRDA is free for all ship types for the first year. After that, an annual fee is charged as well as hourly billing in the case of an incident.

When a call comes in to RRDA for assistance, the attending engineers mobilize and establish communications. Engineers then access the database to get the computer model of the endangered vessel up-and-running in the RRDA center's HECSALV[217] program. They will then load the departure condition or the current condition (emailed) to the model. At least two engineers will run the model and then validate that their outputs match each other and also match the ship's stability data (primarily vessel drafts), which indicates that the model is working correctly. From there, the engineers develop event trees or input incoming damage information from the vessel.[218]

The RRDA manager told investigators that May 2016 guidance from the International Association of Classification Societies and the ABS RRDA guide state that a service such as RRDA should be able to be "up and running" (inputting details for the conditions of a ship) within 2 hours (1 hour for a passenger ship), and that RRDA is typically up in about an hour when a call comes outside normal working hours. For tank vessels carrying oil, 33 CFR Subchapter O, part 155, requires that an assessment of structural stability begin within 3 hours of the reported casualty and be completed within 12 hours for near-shore and 18 hours for offshore events.[219] There is no time requirement for dry cargo ships such as *El Faro*.

[217] HECSALVE™ is a Herbert-ABS Software Solutions, LLC software product specifically designed for ship salvage. According to the company website, HECSALVE is "salvage and emergency response software used by naval architects, salvage engineers, ship owners, classification societies, and military organizations. Starting with the last known departure condition, HECSALV™ allows for quick data collection and multiple scenario process evaluation for remedial action."

[218] Interview transcript, ABS RRDA Manager, pg. 11, pp. 57-59, 9 March 2017.

[219] 33 CFR Chapter I, Subchapter O, Part 155, Subpart J, Table 155.4030(b) Salvage and marine firefighting services and response timeframes.

Incidents are typically reported to RRDA by a vessel manager, but in the past, it was more frequently the master. The RRDA manager stated that having the vessel manager or designated person contact RRDA allowed for a busy ship master to communicate through a "single point" and was not disadvantageous.[220] However, the manager stated that a "pro" of dealing directly with a master is that RRDA gets information regarding changing conditions more quickly, while a "con" was that in communicating information to the vessel's manager and the RRDA, a master could fail to mention information to one party that he had told the other.[221]

RRDA enrollment allows for one no-cost drill per company (not vessel) a year. Drills typically run 2 to 4 hours. RRDA runs about two drills a month, predominantly on tankers.[222] According to the RRDA manager, feedback about the drills from vessel managers has been positive.

RRDA allows ships to send their departure conditions automatically to the center when they set sail. Only about 50 of the 2,500 vessels do so, predominantly tankers. If RRDA receives a vessel departure condition, engineers do not load it to a ship model immediately but hold it until an incident develops. Although analysis time might be saved if vessels emailed their loading conditions to RRDA at departure, if a designated person or vessel manager emailed RRDA an accurate departure condition with the initial incident call, there would be no advantage in having the departure data ahead of time, according to the RRDA manager.[223]

[220] Interview transcript, ABS RRDA Manager, pp. 26-28, 9 March 2017.
[221] Interview transcript, ABS RRDA Manager, pp. 34, 9 March 2017.
[222] Interview transcript, ABS RRDA Manager, pp. 24,31, 9 March 2017.
[223] Interview transcript, ABS RRDA Manager, pp. 30-31, 9 March 2017.

RRDA can estimate windheel for a vessel. RRDA uses HECSALV for all analyses and can directly import CargoMax data if available, however this is only the case if the CargoMax model was developed using the same computer model as the RRDA HECSALV model. If a vessel does not provide CargoMax output for loading conditions, RRDA engineers typically hand-input the data to the ship model.

The RRDA program responds to about 10 to 12 incidents annually. A case of flooding to a cargo vessel like *El Faro* has been very rare. The RRDA manager stated that the most efficient way for an analysis to be completed was for data to be delivered to RRDA in CargoMax (in a HECSALV-compatible model) and that it would take about 10 minutes. However, the manager stated that for RRDA to tell a ship that it is "going to founder here in the next few minutes. That's a very difficult thing for RRDA to be able to point back and do. And we've never found ourselves exactly in that situation because this is not a dynamic program. We are not analyzing, you know, the dynamic input of wind and wave and weather."[224] Over his 10 years of experience, the RRDA manager did not recall RRDA engineers ever advising, or even discussing the possibility of advising, the crew of any vessel that it might sink or founder due to flooding and that the crew should consider abandoning the vessel.[225]

The RRDA manager stated that in general, correctly loading a large container ship and correctly detailing the amount of damage are two of the longer processes in an RRDA analysis.[226]

[224] Interview transcript, ABS RRDA Manager, pp. 44-45, 9 March 2017.
[225] Interview transcript, ABS RRDA Manager, pp. 46-47, 9 March 2017.
[226] Interview transcript, ABS RRDA Manager, pp. 62-63, 9 March 2017.

He also stated that increasing the master's and crew's "knowledge of what it is RRDA does and can do for those on board would be helpful."[227]

12.2 RRDA for *El Faro*

El Faro enrolled in the RRDA program in July 2015, although as a dry cargo vessel, it was not required to enroll under any international or domestic regulations. The RRDA manager did not recall TOTE running any drills with its vessels or emailing any departure conditions to the RRDA.[228]

On the morning of the *EL Faro* sinking, a port engineer from TOTE made the first call to the RRDA at 1200 EDT (1100 central daylight time).[229] The RRDA team was activated and in place by 1230.[230] The RRDA logged the vessel as being in a severe storm, with cargo hold 3 flooded to the tween deck level and noted the loading condition as "will be sent." By 1243, the Coast Guard MSC's salvage engineering response team (SERT) was working with the RRDA and remained so throughout the event. At 1351, the RRDA team was emailed the departure loading condition and was working on loading the HECSALV model. At 1414, the RRDA requested a clarification from TOTE about the fuel oil in the double-bottom 3 port and starboard tanks. By 1547, TOTE had emailed the corrected fuel tank loads (originally showed 346 LT each, corrected to 246 LT each).

By 2005, the RRDA had emailed three load cases (condition analyses) for the vessel: undamaged loading condition at the time of the reported incident (later found to be near the sinking

[227] Interview transcript, ABS RRDA Manager, pp. 69, 9 March 2017.

[228] Interview transcript, ABS RRDA Manager, pp. 61-62, 9 March 2017.

[229] All RRDA email times and log times are were in Central Daylight Time (CDT), UTC -5. They have been converted to Eastern Daylight Time, the local time for the sinking.

[230] ABS RRDA 000001-000203, ABS RRDA Incident Log, *El Faro*, FOUO

time), the same load condition with hold 3 flooded to 10 percent of its volume, and the same load condition with hold 3 flooded to the point that the vessel reached hydrostatic balance (equilibrium). The RRDA noted in the email that the vessel "tends to heel most with flooding between 10% and 20% volume resulting in 7 degree heel and approx. 4 ft freeboard."[231] Thereafter, the RRDA stood down because there was no further contact with the vessel. The following day, RRDA emailed a fourth case: the same load condition, with hold 3 flooded to 10 percent volume and a 75-knot beam wind. **Table 5** shows output parameters for the four conditions examined by RRDA.

Table 5: RRDA cases developed for *El Faro.*

RRDA Condition	Date/ Time Printed (CDT)	GM (ft)	Draft at AP/ Midship/FP (ft)	Heel (°)	Approximate Maximum GZ (ft) and Angle (°)	Strength Max. Bend/Shear
Initial	Oct. 1/ 18:19	4.28	32.6/29.6/26.7	2.3 stbd	1.40 at 21°	Pass/pass
Hold 3 flooded, 10%*	Oct. 1/ 18:25	2.83	33.2/30.1/27.0	7.3 stbd	0.85 at 21°	Pass/pass
Hold 3 flooded, hydrostatic balance	Oct. 1/ 18:36	3.21	38.0/33.4/28.8	3.1 stbd	0.45 at 13°	Pass/pass
Hold 3 flooded 10%, 75-knot wind effects	Oct. 2/ 15:18	2.83	33.2/30.1/27.0	7.27 stbd, 13.44 stbd with wind	Max. remaining GZ with wind effect ~ 0.4 at 21°	Pass/pass

NOTE: AP = aft perpendicular, FP = forward perpendicular. Stbd = starboard.
* Permeability is 0.85 for all cases.

The RRDA manager said that ideally, having the departure condition for *El Faro* emailed at sailing might have reduced the analysis time by 2 to 4 hours.[232] That is because the RRDA was

[231] ABS RRDA 000001-000203, email RRDA, p. 48, FOUO

[232] Interview transcript, ABS RRDA Manager, p. 65, 9 March 2017.

initially provided with an incomplete load case, required clarification on the fuel load, had to obtain a stowage plan to precisely load cargo data into the program, and needed more information than in the CargoMax output to develop an accurate wind profile.[233]

13 MACHINERY ANGLES OF INCLINATION

13.1 Operation of *El Faro* and Similar Vessels

Investigators interviewed engineers and deck officers who had served aboard *El Faro* or its sister ships, which had similar steam propulsion systems, for evidence of difficulty in maintaining lube oil pressure to the main engine, or other heavy-weather machinery issues that might relate to the casualty[234]. A first engineer[235] on the *Northern Lights* and a chief engineer[236] on the *Westward Venture* had both experienced 35º to 45º rolls while in the Alaska trade, without losing lube oil pressure to the main engine. The first engineer noted that the engine room had a clinometer (also called an inclinometer, an instrument for measuring angles of slope or tilt).

A chief engineer who served on *El Faro* in the Caribbean trade had never experienced heavy weather and therefore had never seen a loss of lube oil pressure as a result of the vessel rolling in heavy weather. He noted that he typically kept 27 inches of oil in the lube oil sump.[237]

Another chief engineer who sailed mostly on the Jacksonville-to-San Juan run said that he experienced heavy weather several times during hurricanes and winter storms. He stated that he did not recall any weather-related engineering casualties, nor had he seen a loss of lube oil pressure

[233] Interview transcript, ABS RRDA manager, March 9, 2017, pp. 67-68.

[234] For details on main engine lube oil sump levels and operations see the Engineering Group Factual report.

[235] NTSB interview summary, previous first assistant engineer *Northern Lights*, 6 December 2016.

[236] NTSB Interview Summary, previous Chief Engineer *Westward Venture*, 7 December 2016.

[237] NTSB Interview Summary, previous Chief Engineer *El Faro*, 9 December 2016.

to the main engines during estimated "15-degree or more rolls."[238] He also stated: "Sometimes there is a hard time maintaining your prime when you start from, say, start from scratch" during startup. He also recalled that after a lube oil pump was sent ashore partly "because it was not picking up prime," that after receiving new mechanical seals it worked. He stated that the normal operating level for the lube oil in the main sump was 28 to 32 inches, and that at 28 inches the crew would add oil.

13.2 History of Design Regulations

Investigators researched Coast Guard regulations and ABS rules regarding the minimum trim and heel angle at which main propulsion and essential auxiliary machinery must be designed to operate. The years selected for review were the original construction of hull 670 in 1974–1975, its lengthening in 1992–1993, its conversion to carry containers in 2005, and finally, for comparison, rules current in 2015, when the vessel sank. As noted above (section 6, "Applicable Rules and Regulations"), the 1973 ABS steel vessel rules and the 1973 or 1974 CFRs would have applied to *El Faro* when it was built. The 1992 ABS steel rules and 1992 CFRs would have applied to the "major modification" lengthening, according to the governing OCMI. Although the Ro/Con conversion was not considered a major modification, investigators reviewed the requirements of the 2005 CFRs and ABS steel rules, as well as the CFRs and ABS rules current in 2015.

13.2.1 Coast Guard Rules

The 2005 edition of 46 CFR 58.01-40 would have applied to newly constructed cargo vessels at the time of *El Faro*'s conversion to carry containers. The 2015 edition contained the same requirement that propulsion machinery, including steam, must be designed to operate at a

[238] NTSB Interview, previous chief engineer *El Faro, El Yunque* & *El Morro*, 27 December 2016.

fixed list of 15º in static conditions, and at lists of up to 22.5º when rolling at trim angles up to 7.5º.

The requirements came into force in 1995. As noted in the *Federal Register* of May 10, 1995 (60 FR 24767), the machinery inclination rules were modified to harmonize with SOLAS 1974, as amended, and to allow the use of current technology:

> 46 CFR 58.01-40 Machinery, angles of inclination.
>
> (a) Propulsion machinery and all auxiliary machinery essential to the propulsion and safety of the vessel must be designed to operate when the vessel is upright, when the vessel is inclined under static conditions at any angle of list up to and including 15°, and when the vessel is inclined under dynamic conditions (rolling) at any angle of list up to and including 22.5° and, simultaneously, at any angle of trim (pitching) up to and including 7.5° by bow or stern.
>
> (b) Deviations from these angles of inclination may be permitted by the Commanding Officer, Marine Safety Center, considering the type, size, and service of the vessel.
>
> [CGD 83-043, 60 FR 24775, May 10, 1995]

The 1992 edition of 46 CFR has no requirement for machinery angles of inclination in section 58.01. The 1973 and 1974 versions of 46 CFR were also reviewed. No requirement was found in section 58.01.

13.2.2 ABS Rules

The 2015 ABS steel vessel rules state in part 4, chapter 1, section 1: "Machinery installations are to be designed such as to ensure proper operations under the conditions shown in 4-1-1/Table 7" (see below):

TABLE 7
Design Angles of Inclination

	Angle of Inclination, degrees [1]			
	Athwartship		*Fore-and-Aft*	
Installations, components	Static	Dynamic	Static	Dynamic
Propulsion and auxiliary machinery	15	22.5	5 [4]	7.5
Safety equipment				
Emergency power installation [3]	22.5	22.5	10	10
Emergency fire pumps and their drives	22.5	22.5	10	10
Switchgear				
Electrical and electronic appliances and control systems	22.5 [2]	22.5 [2]	10	10

Notes

1 Athwartship and fore-and-aft inclinations occur simultaneously.

2 Up to an angle of inclination of 45 degrees, switches and controls are to remain in their last set position.

3 In vessels designed for carriage of liquefied gases and of chemicals, the emergency power installation is to remain operable with the vessel flooded to its permissible athwartship inclination up to a maximum of 30 degrees.

4 *(2004)* Where the length of the vessel exceeds 100 m (328 ft), the fore-and-aft static angle of inclination may be taken as 500/*L* degrees, where *L* is the length of the vessel in meters (1640/*L* degrees, where *L* is the length of the vessel in feet), as defined in 3-1-1/3.1.

The 2005 ABS steel vessel rules, part 1, chapter 1, section 1, give the same angles of inclinations as in the 2015 rules and the same table 7, “Design Angles of Inclination.” The 1992 ABS steel vessel rules, part 1, chapter 1, section 1, table 4/1.1, give the same angles of inclination as in the 2015 rules.

Investigators reviewed the 1973 ABS rules for steel vessels, which would have been applicable to hull 670 and its machinery at the time of construction. The 1973 rules have the equivalent of a requirement for static angle of inclination for lube oil in main propulsion equipment, under “Lubricating Oil Systems.” No rule regarding the dynamic component for angles of inclination of main propulsion equipment could be found. The 1973 rules state the following in section 36, “Pumps and Piping Systems”:

36.65 Lubricating-oil Systems

36.65.1 ***General***

The lubricating systems are to be so arranged that they will function satisfactorily when the vessel is permanently inclined to an angle of 15 degrees athwartship and 5 degrees fore and aft. The lubricating-oil piping is to be entirely separated from other piping systems.

36.65.2 ***Pressure and Gravity Systems***

Vessels using forced lubrication (pressure or gravity) for the main propulsion machinery are to be provided with an independent spare lubricating-oil pump. Where oil coolers are also fitted, two separate means are to be provided for circulating water through the coolers.

36.65.3 ***Turbines***

For turbines see also 33.45.

36.65.4 ***Internal-combustion Engine***

For internal-combustion engines see also 34.33.4 and 34.41.

36.65.5 ***Electrical Machinery***

For electrical machinery see also 35.19.3, 35.29 and 35.45.

Similar to the 1973 rules for the minimum operating angles of main propulsion equipment, the rules define angles for electrical generators in section 35, “Electrical Equipment, Generators,” as follows:

35.29 Lubrication

In general all generators are to be located with their shafts in a fore-and-aft direction on the vessel and they must lubricate and operate satisfactorily when permanently inclined to an angle of 15 degrees athwartship and 5 degrees fore and aft; the bearings are to be so arranged that they will not spill oil under a momentary roll of 22½ degrees. Where it is not practicable to mount the generators with the armature shafts in the fore-and-aft direction, their lubrication will require special consideration. Generators depending on forced lubrication, unless otherwise approved, are to be provided with means to shut down their prime movers automatically on failure of the lubricating system. Provision is to be made to prevent oil or oil vapor from passing into the machine windings.

The 1973 rules further state in section 41, “Shipboard Automatic and Remote Control Systems,” table 41.1 (“Displays, Indications and Alarms for Main Control Stations”), that the main turbine lube oil sump level must have a “low” level alarm, that the lube oil to turbines and reduction

gears must have temperature and pressure displays as well as high and low alarms. There must also be an engine trip function for low lube oil pressure, as shown below:

TABLE 41.1 *(continued)*

Operation	*Display*	*Alarm*	*Remarks*
Boiler-condition Indicators	—	—	See 41.47.4
Feed-pump Discharge	Pressure	Low	—
Feed-water Salinity	Salinity	—	—
Smoke Indicator	Smoke	—	—
MAIN TURBINE			
Stm, Ahead Chest	Pressure	—	—
Astern Chest	Pressure	—	—
Stm, Gland Seal	Pressure	—	—
L. O. to Turbines and Reduction Gears	Temp.	High	—
	Pressure	Low	Engine Trip—See 33.45.1, See also 41.55.3
L. O. Sump Level	—	Low	—
L. O. Gravity Tank	Level	Low	—
Bearings, Turbine, Thrust and Reduction Gear (Individual)	Temp.	High	—

The 1973 rules establish minimum incline angles for control, monitoring, and alarm devices, as follows:

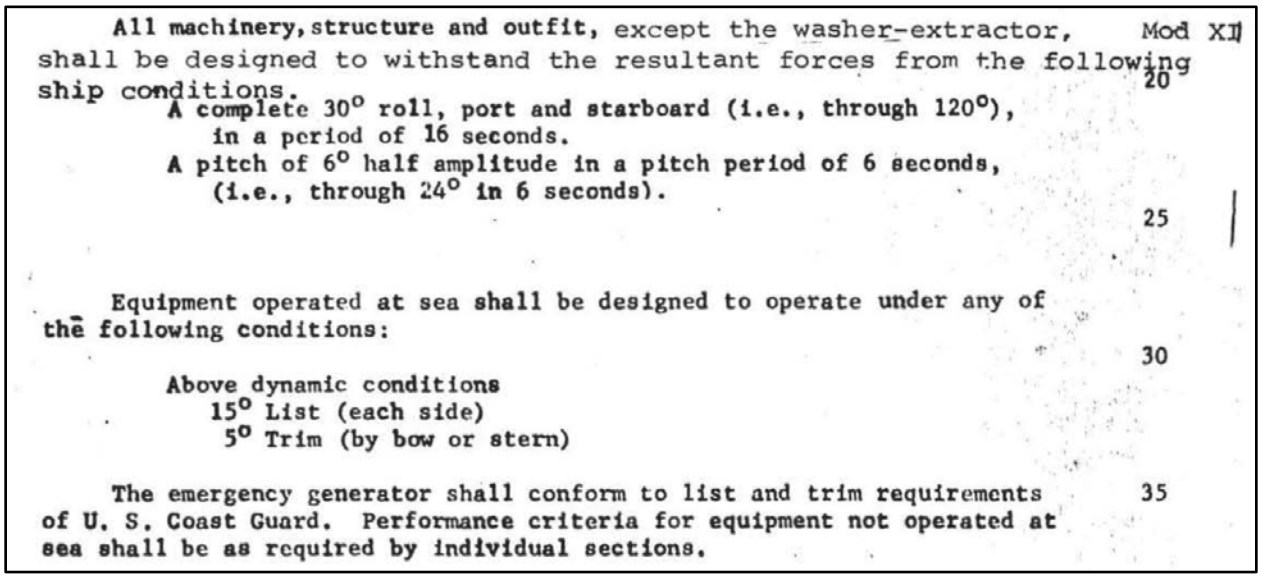
41.37 Ship Motion Effects

All control, actuating, monitoring and alarm devices are to be able to operate successfully when inclined at an angle of 30 degrees in any direction from the vertical and when subjected to vibratory frequencies of 5 to 25 Hz. in conjunction with single amplitudes of 0.7 mm (0.030 in.) for frequencies of 5 to 15 Hz., and 0.5 mm (0.020 in.) for frequencies greater than 15 Hz. Care is to be taken to insure that mounting arrangements for the components will not amplify shipboard vibrations.

13.2.3 MARAD Contract Specifications at Similar Build Date

Investigators asked MARAD whether enrollment in the Title XI building program would have required the originally constructed vessel (hull 670) to be subject to minimum machinery operating angles. MARAD stated that it did not have any machinery angle requirements. MARAD could not locate a contract specification for a *Ponce*-class vessel, but supplied a specification for

a C7 cargo vessels built under Title XI about the same time. The contract contained the following requirements for machinery operating angles:[239]



All machinery, structure and outfit, except the washer-extractor, shall be designed to withstand the resultant forces from the following ship conditions. Mod XII

A complete 30° roll, port and starboard (i.e., through 120°), in a period of 16 seconds.

A pitch of 6° half amplitude in a pitch period of 6 seconds, (i.e., through 24° in 6 seconds).

Equipment operated at sea shall be designed to operate under any of the following conditions:

Above dynamic conditions
15° List (each side)
5° Trim (by bow or stern)

The emergency generator shall conform to list and trim requirements of U. S. Coast Guard. Performance criteria for equipment not operated at sea shall be as required by individual sections.

13.3 Design Operating Angles of *El Faro*'s Main Propulsion Machinery

13.3.1 Boiler

Engineering group investigators contacted *El Faro*'s boiler manufacturer, Babcock & Wilcox, for the boiler's maximum operating angle under the design criteria. A service manager replied that for Babcock & Wilcox marine boilers fabricated around the time of *El Faro*'s boilers, "All components to be supplied for shipboard use must be designed to permit satisfactory operation under the following conditions unless stated otherwise in customer's specifications." The conditions were momentary roll of 30°, permanent list of 15°, and permanent trim of 5°.[240]

[239] Email, General roll for 170 Ro/Ro, MARAD to NTSB, 25 August 2016.

[240] Email, B&W, 6 July 2016.

13.3.2 Turbine

Engineering group investigators contacted General Electric, the manufacturer of *El Faro*'s main propulsion steam turbine plant, to obtain the design criteria for operating trim and heel angles of the main propulsion engine. The investigators learned that General Electric had sold its marine division to private companies, and that the design criteria could not be obtained.

13.3.3 Turbine General

A common shipboard engineering reference, the *Modern Marine Engineer's Manual*, states that lubricating oil pump suction in turbine sump tanks "should be taken from a point about 5 in. from the lowest point in the tank, and so arranged that suction will not be lost when the ship rolls up to 30° or pitches up to 5°."[241]

13.4 Lifeboat Launching Angles for *El Faro*

As stated in the Survival Factors group chairman's factual report,[242] modern Ro/Ro and Ro/Con ships are permitted to have a single freefall lifeboat at the stern of the vessel, or port and starboard davit-launched lifeboats. For newly built ships, both davit-launched and freefall lifeboats are required to launch safely with a vessel list of up to 20° and a trim of up to 10°.[243]

13.5 Recent Low-Lube-Oil-Pressure Accident Investigated by NTSB

On the morning of March 10, 2012, while transiting in the Mediterranean Sea, the US-flagged Ro/Ro vehicle carrier M/V *Alliance Norfolk* encountered rough weather and heavy seas (33- to 50-knot gusts and wave heights of 18 to 32 feet), resulting in damage to its cargo and fire on a cargo

[241] Alan Osbourne (ed.), *Modern Marine Engineer's Manual*, vol. 1, 2nd edition (Centreville, Maryland: Cornell Maritime Press, 1983), p. 68.

[242] Survival Factors Group factual report. For details on *El Faro's* lifeboats and applicable standards see Survival Factors factual report.

[243] Title 46 CFR 199.150(c), SOLAS III/16, and 46 CFR 160.132, all of which incorporate the requirements of the IMO's Life-Saving Appliance Code, chapter IV.

deck. The NTSB determined that the probable cause of the fire was the ignition of flammable material by an undetermined ignition source on deck 5 due to shifting cargo while the vessel was rolling in heavy seas after losing power.

The vessel's chief engineer stated that the loss of propulsion was caused by a large (30° to 35°) roll that tripped the low-lube-oil-pressure alarm and shut down the main engine. He said the engine was restarted and that he bypassed limits on the engine to allow it to come back to full speed faster.[244] The *Alliance Norfolk* was classed by DNV GL (formerly Det Norske Veritas and Germanischer Lloyd) and built in 2007 with a single slow-speed, MAN-B&W (Burmeister & Wain) diesel engine directly driving a propeller.

14 VESSEL OPERATION AND DESIGN RELATED TO SINKING

14.1 Watertight and Weathertight Configuration and Operations

To ascertain configurations and operating procedures regarding weathertight and watertight closures that would apply to *El Faro*, investigators interviewed former engineers and deck officers on the vessel or its *Ponce*-class sister ships, all of which had similar Ro/Con configurations.

El Faro had personnel-sized watertight doors and second deck hatches for crewmember access to compartments below the bulkhead deck (second deck). The General Arrangement drawing abbreviations table notes "RHWT" as "raised hinged watertight." However, the drawing shows an abbreviation of "RWTH" for seven raised watertight hatches on the second deck providing access to the cargo holds below (not RHWT per the abbreviations table).[245] These raised

[244] NTSB Marine Accident Brief, Fire Aboard Vehicle Carrier M/V *Alliance Norfolk*, NTSB Accident ID DCA12LM012.

[245] *El Faro*, General Arrangement, Dwg. No. SSL-670-100-026 Rev. 0, HEC, 4/24/2006 (MBI Exhibit 007).

hinged watertight hatches were commonly called "scuttles" by former crewmembers and by investigators. The general arrangement and *El Faro's* original LL11 Survey for Load Lines form shows eight second deck watertight doors with 6 dogs. The vessel also had nine large hinged-type watertight cargo hold doors distributed on the second deck, third deck, and tanktop. The two cargo doors on the second deck had inset 18-inch by 54-inch watertight doors shown in *El Faro's* original LL11 and the general arrangement drawing.

All the hydraulically operated cargo hold doors required power to activate, were operated locally, and had both a local status (open/close) indicator at the door control, and a remote status indicator panel in the fire control room on the main deck. The personnel-sized watertight doors, watertight raised access hatches (scuttles) and other watertight access doors were not equipped with either a local or remote status indicator.

SOLAS contains regulations regarding openings in watertight bulkheads and watertight doors which applies to cargo ships constructed after 1 February 1992. The regulations state that "access doors and access hatch covers normally closed at sea, intended to ensure the watertight integrity of internal openings, shall be provided with means of indication locally and on the bridge showing whether these doors or hatch covers are open or closed. A notice is to be affixed to each such door or hatch cover to the effect that it is not to be left open. The use of such doors and hatch covers shall be authorized by the officer of the watch."[246]

A previous *El Faro* chief engineer stated that in anticipation of heavy weather, the standing orders on a chalkboard would include a notice such as, "Make sure all entryways to the engine

[246] SOLAS 2004, Part B-1: Subdivision and Stability, chapter II-1: Construction- structure, stability, installations, regulation 25-9-1, Openings in watertight bulkheads and internal decks in cargo ships.

room and engine spaces are dogged down at all times."[247] Regarding the engineering crew, he stated: "If they were taking on real severe weather, we would never allow anybody out on second deck." Access to the second deck was through a watertight door to the steering gear room or through an inset watertight personnel door in the No. 2 cargo door that opened to hold 5 (at frame 169). He recalled that the bridge would not be notified if engineering crew transited through personnel watertight doors or scuttles on the second or other decks, but that the bridge would be notified if crewmembers operated the large, power-activated watertight doors to the cargo holds. He stated that sometimes if it was "flat calm" and they needed to easily transport items between spaces, "there were certain doors that might get left open."

A past chief mate stated that the second deck escape scuttles were closed before getting underway, but that they might be opened at sea.[248] He stated that the bosun or chief mate would check that they were closed at the end of the day, but he did not recall a scuttle ever being left open. No evidence was found, including on the VDR audio transcript, that the power-activated watertight doors to the cargo holds were open during the voyage or were typically left open at sea. The chief engineer serving on the ship before the accident wrote in his turnover notes that a third engineer does an "oil round" each week on the cargo hold watertight doors. He wrote: "Last week when they were washing down the second deck . . . watertight door #2 lower knife edge is hold [holed] and leaking. I have not had a chance to repair but it is on the shipyard list to repair."[249] Watertight door No. 2 is located on the 2nd Deck at the top of the ramp down to cargo hold 5, and isolates hold 5 from green water on 2nd deck.

[247] NTSB Interview, previous Chief Engineer *El Faro, El Yunque* & *El Morro*, 27 December 2016.

[248] Interview transcript, past Chief Mate *El Faro* and 2nd Mate *El Yunque*, p. 62, 3 December 2015.

[249] *El Faro*, Turnover Notes (Master, Chief Engineer, Chief Mate), Chief Engineer, 11 August 2015, p. 11, (MBI Exhibit 130).

14.1.1 Second Deck Scuttles

The VDR transcript indicates that the vertical-access scuttle on the starboard side of the second deck that led to hold 3 was open for a time during the accident. Investigators reviewed drawings and photographs and interviewed previous *El Faro* crewmembers to ascertain the type and dimensions of that scuttle. General arrangement drawings (**figure 8**) show that the second deck had two RWTHs (raised watertight hatches) through the second deck to hold 3, at frame 163 on the starboard side and at frame 138.5 on the port side. Hold 2A also had two such accesses. **Figure 9** is a photo of the second deck forward of the house.

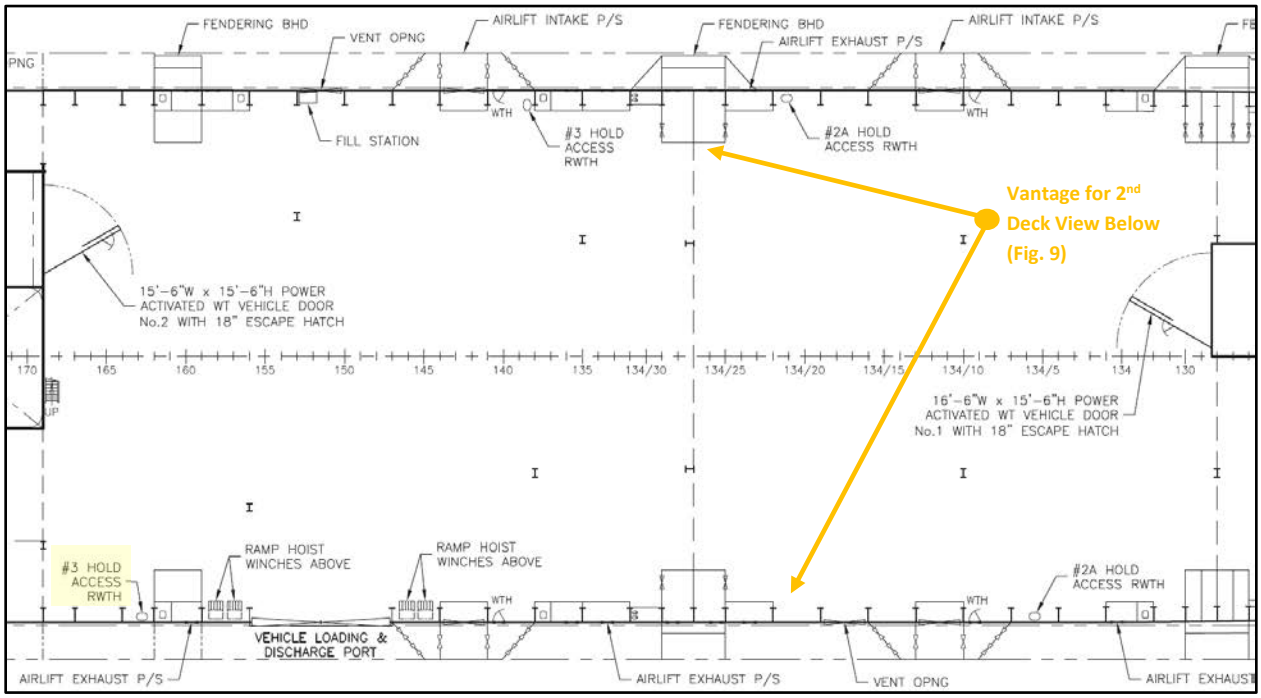


Figure 8. *El Faro*, second deck plan view, showing scuttles (starboard scuttle to hold 3 highlighted and designated "#3 HOLD ACCESS RWTH") and ventilation to holds 3 and 2A below. [250]

[250] *El Faro*, General Arrangement, Dwg. No. SSL-670-100-026 Rev. 0, HEC, 24 April 2006 (MBI exhibit 007).

Figure 9. *El Faro* second deck looking aft from frame 134/8. (Screen capture from video by former *El Faro* second mate, September 2008[251])

A previous chief engineer recalled that the *El Faro* scuttle were "supposed to be" secured for heavy weather, but that securing was the responsibility of the deck department.[252] The only available ABS form LL11[253] for *El Faro* recorded second deck transverse-hinged, R.M.H. (round manhole) oval escapes at frames 122 and 163. The form noted that the escapes had four evenly spaced dogs, with a hatchway dimension of 22.75 inches by 14.75 inches and a coaming height of 12 inches. Images of the scuttles to holds 3 and 2A on the starboard side of *El Faro*'s second deck are shown in **figures 10, 11, and 12**.

On *El Yunque*, investigators measured the oval access scuttle on the ship's second deck, starboard side, as 12 inches off the deck and 24 inches long. The scuttles did not have handwheels to secure them like those on *El Faro*, but rather, four individually operated dogs.

[251] Video, *El Faro* second deck, September 2008 (MBI exhibit 380).

[252] NTSB interview, previous chief engineer *El Faro*, *El Yunque*, and *El Morro*, 27 December 2016.

[253] *Puerto Rico*, form LL-11C, ABS survey for load lines, report PA2289, 10 November 1974.

Figure 10. *El Faro* second deck starboard side, frames 162–170; reach rod handwheel to emergency fire pump and scuttle in left background. (Screen capture from video by former *El Faro* second mate, September 2008[254])

[254] Video, *El Faro* second deck, September 2008 (MBI exhibit 380).

Figure 11. *El Faro* second deck scuttles to hold 3; starboard side at frame 163 (left image), port side at frame 138.5 (right image). (HEC photo, June 2005)

Figure 12. *El Faro* second deck scuttle to hold 2A, port side at frame 134-19.5. Scuttle type similar to hold 3 scuttle in Figure 11. (HEC photo, July 2015)

14.2 Water on Deck During Previous Voyages

Investigators interviewed former engineers and deck personnel on *El Faro* to determine whether green water reached the second deck, and if so, the frequency and depth it reached on deck. A previous *El Faro* chief engineer who sailed on the Jacksonville to Puerto Rico runs for several years told investigators that it "was a very common occurrence in rough weather" [255] for green water to enter the second deck. No crewmembers were allowed on the second deck if "we were taking any real weather . . . rolling enough to take on, say, 2 inches—2 inches or 3 inches" of water. He recalled that the green water would "slosh around some, but it, basically, as soon as it came on, it went off" through the scupper holes and sideshell openings.

Video and photographs of *El Faro* show that the starboard vehicle loading and discharge port was fitted with a semipermanent bulwark centered near the opening **(figure 13).** The bulwark was similar to one fitted on *El Yunque*.

[255] NTSB interview, previous chief engineer *El Faro, El Yunque*, and *El Morro*, p. 40, 27 December 2016.

Figure 13. *El Faro* starboard sideshell opening with installed bulwark. (Screen capture from video by former *El Faro* second mate, September 2008[256])

14.3 Cargo Shifting on Previous Voyages

Investigators interviewed previous *El Faro* engineers and deck personnel to determine the frequency and extent, if any, of shifting or loss of Ro/Ro or container cargo during heavy weather.

A previous *El Faro* chief engineer who sailed the Jacksonville to Puerto Rico runs (never Alaska) for several years on *El Faro*, *El Yunque* and *El Morro* stated: "We've had cargo break loose or get damaged from rough weather." [257] He noted that cargo had been damaged in the bow area of the second deck near the sideshell openings in the past, and that D-rings, buttons, and the lashings themselves had broken. He said that "another big reason why people weren't allowed out on second deck" was "if you tried to go between two containers that were shifting back and forth,

[256] Video, *El Faro* second deck, September 2008 (MBI exhibit 380).

[257] NTSB interview, previous chief engineer *El Faro*, *El Yunque*, and *El Morro*, pp. 6-7, 41, December 2016.

you could get crushed." He also stated that handrails near the bow had been "ripped off from main deck before from weather."

He said that in rough weather, mates on the bridge would watch the Lo/Lo container cargo move on the main deck in front of them. He related that the mates would sometimes note the movement and later discuss lashing changes with the longshoreman in an effort to reduce shifting.

Interviews with ship and shoreside operators did not uncover past evidence of the complete loss of container stacks overboard, or a shifting of containers that caused the vessel to list.

14.4 Recent Ro/Ro Accident with Cargo Shift Resulting in Hull Breach

In January 2015, the outbound pure car and truck carrier (Ro/Ro) *Hoegh Osaka* was rounding a buoy in the Solent (the strait separating the Isle of Wight from mainland England) when it developed a significant list, causing a cargo shift that punctured the vessel's sideshell plate and subsequent flooding.[258] The ship blacked out, grounded on Bramble Bank (a sandbar), and reached a list of 40°. The investigation determined that the vessel departed port with inadequate stability and concluded that cargo most likely shifted due to the ship's excessive list, and was not causal to the accident.

Below deck, several cargo units and items of ship's equipment broke free from their lashings and shifted as the ship heeled. The sideshell on deck 6, which was above the waterline at even keel, was struck by the steel tracks of an excavator, creating a hole measuring about 25 cm by 4

[258] Marine Accident Investigation Branch, *Report on the investigation into the listing, flooding and grounding of* Hoegh Osaka, *Branble Bank, The Solent, UK, on 3 January 2015*, Marine Accident Report 6/2016 (Southampton, United Kingdom: MAIB, March 2016).

cm (10 inches by 1 1/2 inches). A major component of a stone crusher fell onto watertight deck 6 as well, puncturing it and allowing floodwater to enter the decks below.

14.5 Evidence of Car Movement from VDR Audio

The morning before the sinking, while discussing a previous voyage of his in heavy weather (vessel unknown) with the third mate, the *El Faro* captain stated that 13 cars had been damaged. He said they were damaged because they were not secured with "cross straps" on their ends, but ". . . the wheels and the front wheels that on the vehicles that didn't lock they got movin' around those wheels would turn so you got slack a little bit. those wheels would move."[259]

At 0544 the morning of the sinking, a minute after the first indication that there was water in cargo hold 3 and that the second deck scuttle was not secured, the captain stated, "we got cars loose. yeah." Shortly afterward, the captain stated, "it's unsafe to go down in the cargo hold with gear adrift like that (it's just not safe/it's a disaster) * * *."[260]

14.6 National Cargo Bureau Reports

Investigators in the Nautical Operations group asked the National Cargo Bureau (NCB) to review *El Faro*'s cargo securing manual, and also to review the arrangements for cargo stowage and securing at the vessel's departure from Jacksonville. The NCB stated, regarding the Ro/Ro cargo on the second deck, that if the there was an initial lashing failure and the ship had continuing significant movement (primarily rolling), then "progressive lashing failure with potentially catastrophic shift of cargo could be expected." [261] Appendix 3 of the report showed that at a vessel

[259] VDR audio transcript, factual report, *SS El Faro*, 12 December 2016, p. 76.

[260] VDR audio transcript, factual report, 12 December 2016, p. 414.

[261] Report on Review of Cargo Securing Manual and Cargo Stowage and Securing, *S.S. El Faro*, Doc. No. 101CS01704, National Cargo Bureau, Inc. (NCB), 4 August 2016, p. 3.

speed of 24 knots and 60º lashing angles, off-button trailers stowed in the "worst positions" of holds 2A, 2B, and 2C, "will not be effectively secured in this hold." VDR data for *El Faro*'s last 24 hours show a maximum speed over ground of 20.7 knots. TOTE stated that the vessel's service speed was typically 19.5 knots. Regarding their reports and analysis, the NCB testified that (a) they did not review or rely on the VDR transcript; (b) they did not review MBI or NTSB testimony; and (c) in NCB's initial report, dated August 4, 2016, they did not review the EL Class Lashing Guidance (which various witnesses stated was the heavy weather lashing profile for *El Faro* on the accident voyage).[262]

TOTE issued a response on September 16, 2016, to the initial NCB report in which it challenged many of the assumptions and technical findings the report. NCB issued a supplemental report on November 18, 2016. The supplemental report listed the maximum off-button trailer weights in hold 2A that would meet requirements at vessel speeds of between 19 and 24.5 knots and at lashing angles of 45º and 60º, and the angles prescribed in *El Faro*'s heavy-weather lashing requirements (58º, 52º, and 46º).[263] **Table 6** in the next section shows selected results from the supplemental report.

After having reviewed the EL Class Lashing guidance and other aspects of TOTE's response, and issuing its supplemental report, the NCB stated that regarding the possibility of a cargo shift occurring on the *El Faro*: "Depending upon circumstances, cargo shift, if it occurred, may have contributed towards the incident or it may have occurred as a result of the incident. We

[262] NCB Testimony at MBI 3, p. 733, 9 February 2017.

[263] Appendix 2, Supplemental Report on Review of Cargo Securing Manual and Cargo Stowage and Securing, *S.S. El Faro*, Doc. No. 101CS01719, National Cargo Bureau, 18 November 2016.

cannot make that determination."[264]. In addition, NCB stated they found no evidence that any excessive lashing angles or inadequate security points had been used on board the *El Faro*, and that precise breaking or failure points for lashings could not be determined.[265]

14.6.1 Friction of Materials: Effect on Off-Button Lashing Requirements for Ro/Ro Cargo

To increase the friction component of system lashing strength, the current version of IMO's Code of Safe Practice for Cargo Stowage and Securing (CSS Code)[266] notes in annex 4, section 2.4: "Wheel-based cargoes, which are not provided with rubber wheels or tracks with friction-increasing lower surface, should always be stowed on wooden dunnage or other friction-increasing material such as soft boards, rubber mats, etc."

Investigators noted that in appendix 4 of the first NCB report, the coefficient of friction had a large effect on the results of the engineering calculations for the weights of off-button trailers. Appendix 3 of the report, using the "annex 13 advanced calculation method" detailed in the CSS Code, identified off-button trailers that were "not OK" with regard to transverse sliding moments and forces. For an off-button Roloc box, the coefficient of contact between dry steel and steel was 0.1. A wet deck would lower the steel-to-steel friction coefficient to 0.0**.** The friction coefficient for rubber to steel was 0.3.

Investigators asked the NCB to calculate the off-button maximum trailer weights for a hypothetical arrangement in which a rubber mat or other friction-increasing material was placed

[264] NCB Testimony at MBI 3, pp. 580-581, 8 February 2017.

[265] NCB Testimony at MBI 3, pp. 752-753, 9 February 2017.

[266] CSS Code, Code of Safe Practice for Cargo Stowage and Securing1, Resolution A.714(17), Annex 4, Safe Stowage and Securing of Wheel-Based (Rolling) Cargoes, 2 General recommendations Code of Safe Practice for Cargo Stowage and Securing (CSS Code), IMO.

between a Roloc box and the steel deck, keeping other parameters and lashing angles the same. The NCB's calculations[267] showed a much higher allowable maximum trailer weight using the higher friction coefficient for steel to rubber, compared with the results for dry steel to steel and wet steel to steel. **Table 6** compares the NCB's calculations for hypothetical rubber mats placed under the off-button trailers (steel-rubber coefficient) in hold 2A with the maximum values for the (wet and dry) steel-to-steel friction coefficients reported earlier.

Table 6. *El Faro* hold 2A maximum off-button trailer weights, by friction coefficient and lashing arrangement (vessel speed = 19.5 knots).

Maximum Trailer Weight (lb)	Roloc Friction Coefficient	Lashing Angle
74,031	Steel-steel (dry)	45°
60,836	Steel-steel (wet)	45°
122,295	Steel-rubber	45°
59,364	Steel-steel (dry)	60°
47,979	Steel-steel (wet)	60°
101,059	Steel-rubber	60°
67,516	Steel-steel (dry)	Heavy weather
55119	Steel-steel (wet)	Heavy weather
112,950	Steel-rubber	Heavy weather

Source: NCB reports 101CS01719 and 101CS01720.
Note: EL h**eavy-weather** requirements**, lashing** angles of 58°, 52°, and 46°.

14.6.2 NCB Report on *El Yunque* Car Lashings

Nautical Operations group investigators asked the NCB to comment on the lashing arrangement of automobiles photographed on *El Yunque* in December 2015 on the tanktop in hold 3, on the tanktop (**figure 14**). The NCB report stated that photographs showing car lashings secured

[267] Calculations using rubber coefficient of friction for bottom of roloc boxes in the "off button" configuration, S.S. *El Faro*, Doc. No. 101CS01720, 18/11/2016, National Cargo Bureau, Inc.

at various positions along athwartships chains, rather than at designated securing points, such as deck pad-eyes, were not in accordance with the vessel's cargo securing manual. However, the report stated that "as we have no experience of cars being secured in this manner, we are unable to comment on the efficacy of the lashing arrangement or likelihood of failure in adverse conditions."

During MBI testimony, NCB stated they knew of at least one Ro/Ro vessel, the *Matsonia*, where the Cargo Securing Manual allowed automobiles to be stowed without lashings "unless they're on the ramps or they're loaded athwartships."[268,269] They stated that in general, Cargo Securing Manuals were prepared for a worst-case scenario for the North Atlantic, but if a vessel was in less severe routes, lashing requirements might be less. But, those conditions would need to be specified in the Cargo Securing Manual.

No photographs of cars lashed aboard *El Faro* could be found. Investigators visited and photographed similar auto lashings aboard *El Yunque*.

[268] NCB Testimony at MBI 3, pp. 586-588, 8 February 2017.

[269] NCB Testimony at MBI 3, pp. 750, 9 February 2017.

Figure 14. Cars lashed on *El Yunque* during loading in hold 3, tanktop, looking aft and to port. Escape ladder and emergency fire pump reach-rod in left background. (Photo from December 2015)

14.7 Emergency Fire Pump and Fire System Piping in Hold 3

Investigators sought drawings, photographs, videos, and specifications for *El Faro*'s emergency fire pump and sea chest, which were installed at the tanktop level in hold 3 on the starboard side. Very little evidence was found. Investigators therefore interviewed former *El Faro* crewmembers to describe the pump and its associated piping and arrangement, the condition of the system, any protective structures around the piping, and how the emergency system tied into the main fire system. (For additional details, see the Engineering group chairman's factual report.)

14.7.1 Installation and Operation of Emergency Fire Pump

A previous ship's engineer told investigators that the emergency fire pump was fitted with a stop-check discharge valve and a suction valve. He stated that the discharge valve remained open

at sea, whereas the suction valve was closed at sea.[270] Another chief engineer who had served on *El Faro* said that the "emergency fire pump discharge valve was kept open at sea, suction valve was kept closed at sea."[271] He also said that "both the main and emergency fire pump were able to charge the fire main. "Investigators could not locate a detailed piping drawing of the emergency fire pump installation on *El Faro*, but obtained a single photograph (**figure 15**).

Figure 15. *El Faro* emergency fire pump, located at starboard frame 164, viewed from tanktop deck looking aft. (Photo by Maine Maritime Academy cadet, 2015)

General arrangement drawings for *El Faro* show the pump at the tanktop level on the aft bulkhead of the starboard side of hold 3, at frame 163 (**figure 16**). General arrangement drawings of other *Ponce*-class vessels (*Westward Venture* and *El Yunque*) show the same pump in the aft, starboard area of the hold 3 tanktop. Investigators examined sister vessel *El Yunque* to document

[270] NTSB interview summary, previous chief engineer *El Faro*, p. 2, 9 December 2016.

[271] NTSB interview summary, previous chief engineer *Westward Venture*, p. 2, 7 December 2016.

the arrangement and found the vertical access hatch in hold 3 centered at frame 163.5, the sea chest penetration centered at frame 166.5, and the emergency fire pump at frame 168.5 (just forward of the aft bulkhead at frame 169 in hold 3). Investigators noted that the bulkhead configuration of *El Yunque* was not the same as that of *El Faro* in this area. The *El Faro* drawings show a void space from frames 164 to 169, whereas *El Yunque* had a continuation of hold 3.

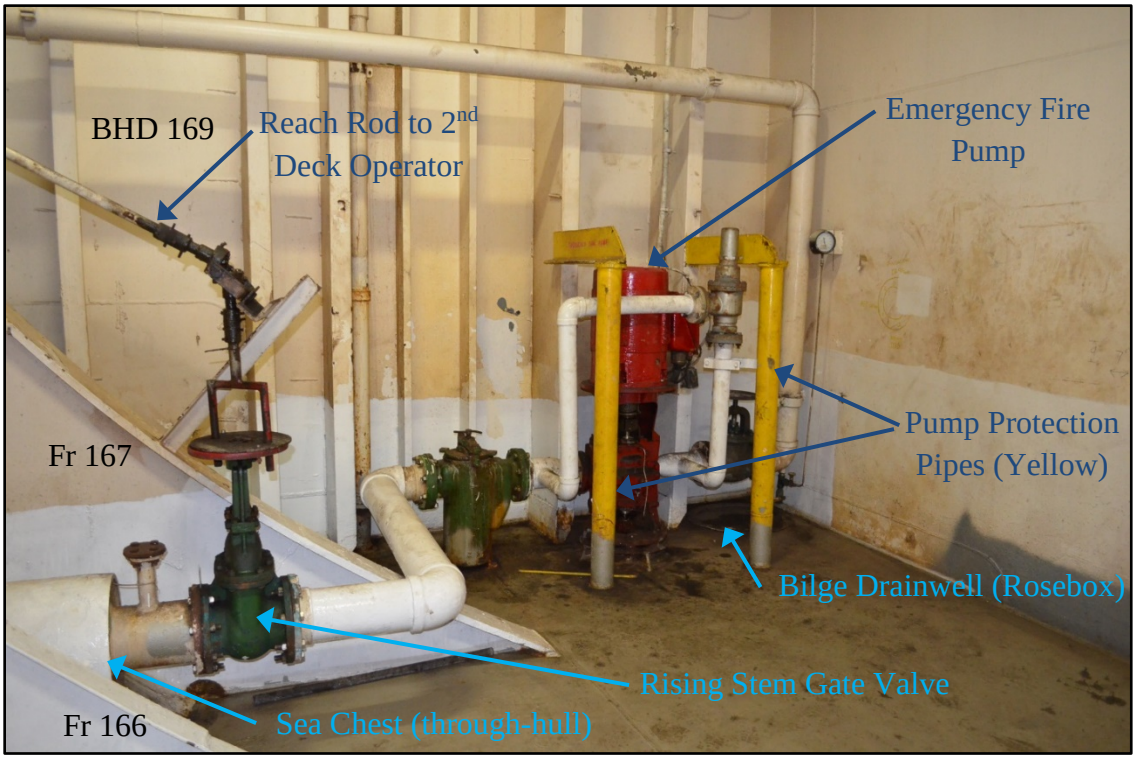


Figure 16. *El Yunque* emergency fire pump (December 2015).

A previous chief engineer told investigators that on *El Faro*, "there was a 4-inch pipe that was welded in place as a guard around that fire pump," but that it did not protect the pump inlet piping. However, he stated that some of the suction piping to the pump was "a little bit higher" on the sideshell slope and therefore "if cargo was shifting, it would have probably stopped . . ." and hit the end of the deck.

No photographs of *El Faro*'s sea chest viewed from inboard could be found. Investigators measured the dimensions of the sea chest on *El Yunque* as follows: 16-inch outer-diameter round pipe with 3/4-inch-thick wall, centered 18 inches off the tanktop with a 6-inch pipe butted to a steel plate inset to the sea chest.

14.7.2 Sea Chest and Shell Plating of Emergency Fire Pump

Ship plans indicate that the sea chest for the emergency fire pump consisted of a 6-inch pipe directly penetrating the hull 9 feet, 0 inches above the baseline at frame 163.5 (**figures 17 and 18**).[272] [273] Shell drawings show plate E11 as the steel plate in way of the penetration as 34.3#, or 0.841 inch (about 27/32 inch). An exterior 30.6#, or 3/4-inch steel doubler-plate with dimensions of 50 inches (vertical) by 48 inches (longitudinal) was centered around the hull penetration.

Investigators reviewed the most recent measurements of plate thickness for *El Faro.*[274] E-strake midbody plates added during the lengthening were designated E6A, B, C, and D. The bottom shell plating for E-strake was not gauged aft of E8. Therefore, the measured thickness of E11, the plate in way of the emergency fire pump sea chest, was not gauged. Both plates E7 and E8 were measured between 0.82 inch and 0.83 inch at forward and aft locations.

ABS performed a Special Periodical Survey in 2011 that included ultrasonic gauging to determine plate thicknesses in accordance with ABS Rules. Repairs/renewals were performed at

[272] Sun Dwg. No. 663-707-3 Alt 10, Shell Plating Fs 87 to 172, Single Screw Roll-on/Roll Off Steam Ship for Transamerican Trailer Transport, Inc., Sun Ship Building and Dry Dock Co. (MBI Exhibit 246, Shell Plating Frs 87 to 172).

[273] The *El Faro* through-hull penetration at frame 163.5 for the sea chest was three frames forward of *El Yunque's* at 166.5.

[274] Report of Ultrasonic Thickness Measurements, *El Faro*, January 2011, D. Voehl Testing Corp. (MBI exhibit 272 Gauging Report M1926092).

bulkhead 169 (ladderway between second and main deck), on the spool piece for the forward fire pump sea chest and sea chests in the engine room on the starboard side.[275] Neither the 2011 survey nor an Intermediate Hull Survey conducted in December 2013[276] noted outstanding issues at frame 164 starboard (the bulkhead where the emergency fire pump was located in hold 3).

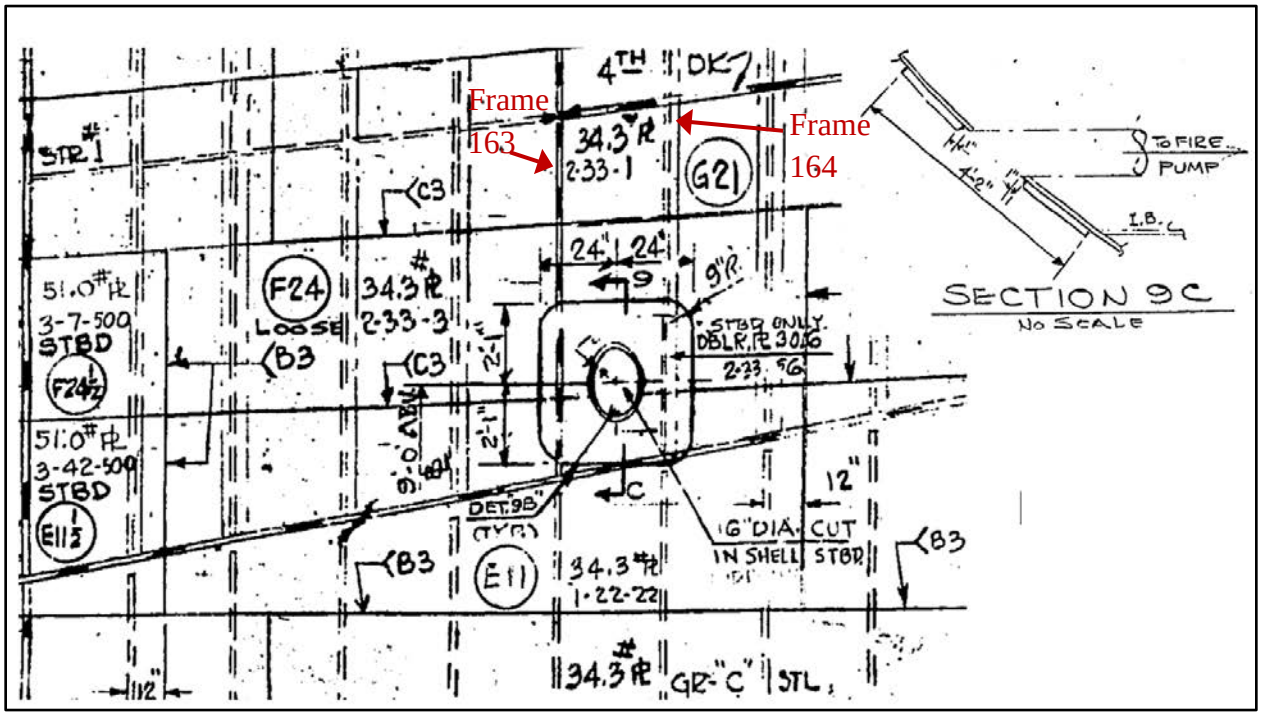


Figure 17. Portion of shell expansion drawing at emergency fire pump sea chest.[277]

[275] ABS Class Survey Report, *El Faro*, Report No. M1926092, January 2011 (MBI Exhibit 404).

[276] ABS Class Survey Report, *El Faro*, Report No. FL2500734, December 2013.

[277] Sun Dwg. No. 663-707-3 Alt 10, Shell Plating Fs 87 to 172, Single Screw Roll-on/Roll Off Steam Ship for Transamerican Trailer Transport, Inc., Sun Ship Building and Dry Dock Co. (MBI Exhibit 246, Shell Plating Frs 87 to 172).

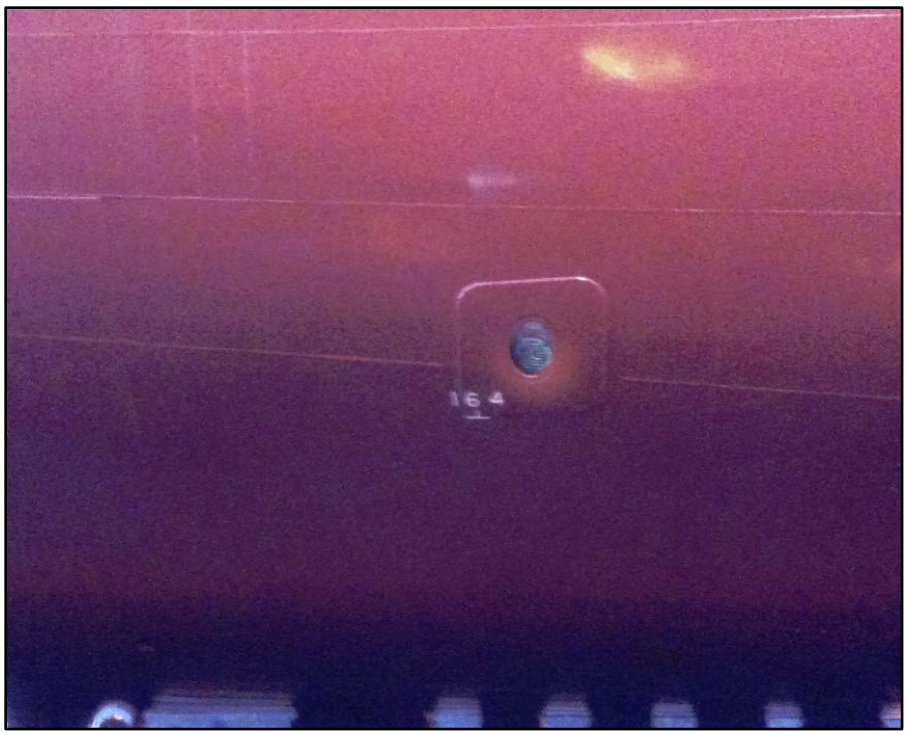


Figure 18. Penetration of sea chest for *El Faro*'s emergency fire pump, viewed from exterior. (TOTE photo from December 2013 drydock)

14.7.3 Emergency Fire Pump: Upcoming Shipyard Specification

The specifications issued in 2015 for the vessel's drydocking and Alaska conversion[278] noted that the emergency fire pump 6-inch suction valve was listed for replacement with a new valve at the next shipyard period. The specification also stated that the sea chest to the pump was to be blasted and painted, and that the shipyard was to "thoroughly examine sea chest for thickness, erosion and corrosion."

Under a section titled "Modifications for Return to Alaskan Service," the specifications called for installing a new Butterworth saltwater heating system (BWS). A 2.5-inch BWS supply line to hold 3 already existed but was blanked off. The specifications called for the installation of a 2.5-inch valve and piping to reconnect the BWS piping to the sea chest. While on *El Yunque*,

[278] *El Faro* Shipyard and Dry Dock Specification RFP 670-01-2015, Sea Star Line, LLC.

investigators noted that a similar BWS pipe was blanked off on the aft starboard bulkhead of lower 3 Hold.

The specifications also listed the motor for the emergency fire pump among items to be determined later for possible reconditioning or replacement, and asked only for the shipyard to estimate the cost of the potential work. The list showed the emergency fire pump suction as having a 6-inch gate valve. No evidence was found in the shipyard specifications that the piping for the emergency fire pump system or the sea chest was known to be corroded or required replacement.

The previous chief engineer's turnover notes stated that there was a "pin hole in the bottom" of the 5-inch crossover valve below the deck (in the engine room) from the fire main to the saltwater service system and that the valve would be replaced in the shipyard.[279]

14.7.4 ABS Machinery Survey of Emergency Fire Pump

A one-day ABS machinery survey performed on July 16, 2015,[280] examined the fire main system, including the emergency fire pump and fire main piping. The fire pump was run and its discharge pressure observed by the attending surveyor, who noted no deficiencies in its operation. The survey report noted their state as "satisfactory" and listed no outstanding deficiencies.

14.8 Cargo Hold Bilge Pumping and Bilge Alarm Systems

Before the vessel lost propulsion on the morning of the sinking, at 0543, the engine room reported to the captain on the bridge (over the phone) that water was detected in cargo hold 3. The

[279] *El Faro*, Turnover Notes (Master, Chief Engineer, Chief Mate), Chief Engineer, 11 August 2015, pg. 13, (MBI Exhibit 130).

[280] ABS Class Survey Report, Special Continuous Survey – Machinery 8, Report JS2920963-A, Jacksonville, FL, 16 June 2015.

VDR transcript shows that the captain stated “we (got) a prrroooblem” and “…go down to three hold- * down there * start the pumping right now * (probably just) water. ***.”[281] Because the VDR recorded only the bridge audio, and the phone channel from the engineers in the engine room was not recorded, it is unclear whether a bilge alarm alerted the engineering watch to the flooding or if it was discovered by other means. With no recording on the engine room phone, the manner and method of the crew’s attempts to pump the cargo holds on *El Faro* is unknown unless the officers on the bridge repeated what the engine room crew said and the repetition was recorded by the bridge microphones.

Investigators reviewed drawings and photographs and interviewed former *El Faro* crewmembers to determine the arrangement and operation of the bilge pumping system and bilge alarm system in the cargo holds. Water in the cargo holds collected in the port and starboard bilge drainwells (bilgewells, roseboxes), located against the aft bulkhead and outboard in each cargo hold on the tanktop (f**igure 19**). Photographs showing details of the drainwells on *El Faro* could not be found.

Investigators visited the sister ship *El Yunque* to ascertain the grating type, bilge well size, and suction pipe location (f**igures 20 and 21**). The floats for the bilge alarm sensors on *El Faro* were like those on *El Yunque*.[282]

[281] VDR Audio Transcript, SS *El Faro*, NTSB, S. Payne, p. 414, 12 December 2016.

[282] Interview Summary, Norcom Services Inc., Owner, 23 September 2016.

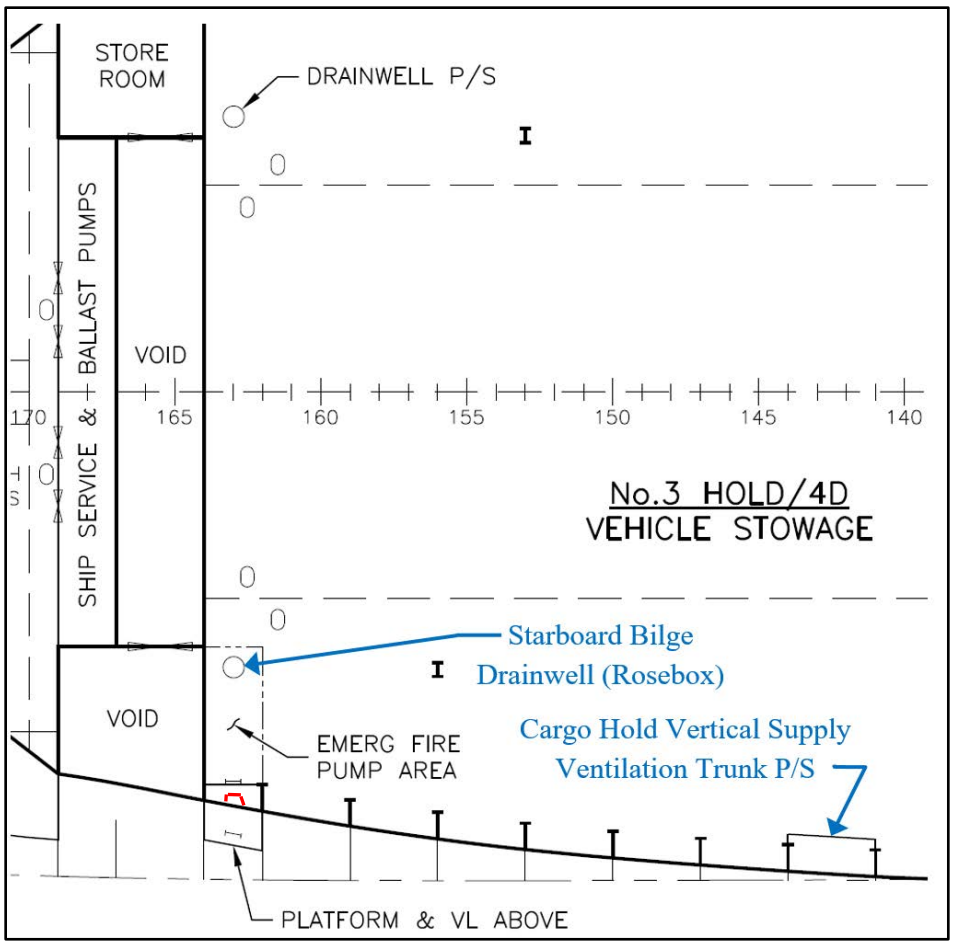


Figure 19. *El Faro* hold 3 at tanktop deck, with starboard bilge rosebox and supply ventilation vertical trunk indicated. The red semi-circle at frame 163.5 indicates approximate location of the seachest to the emergency fire pump inlet piping.[283]

[283] *El Faro*, General Arrangement, Dwg. No. SSL-670-100-026 Rev. -, 24 April 2006 (MBI Exhibit 007).

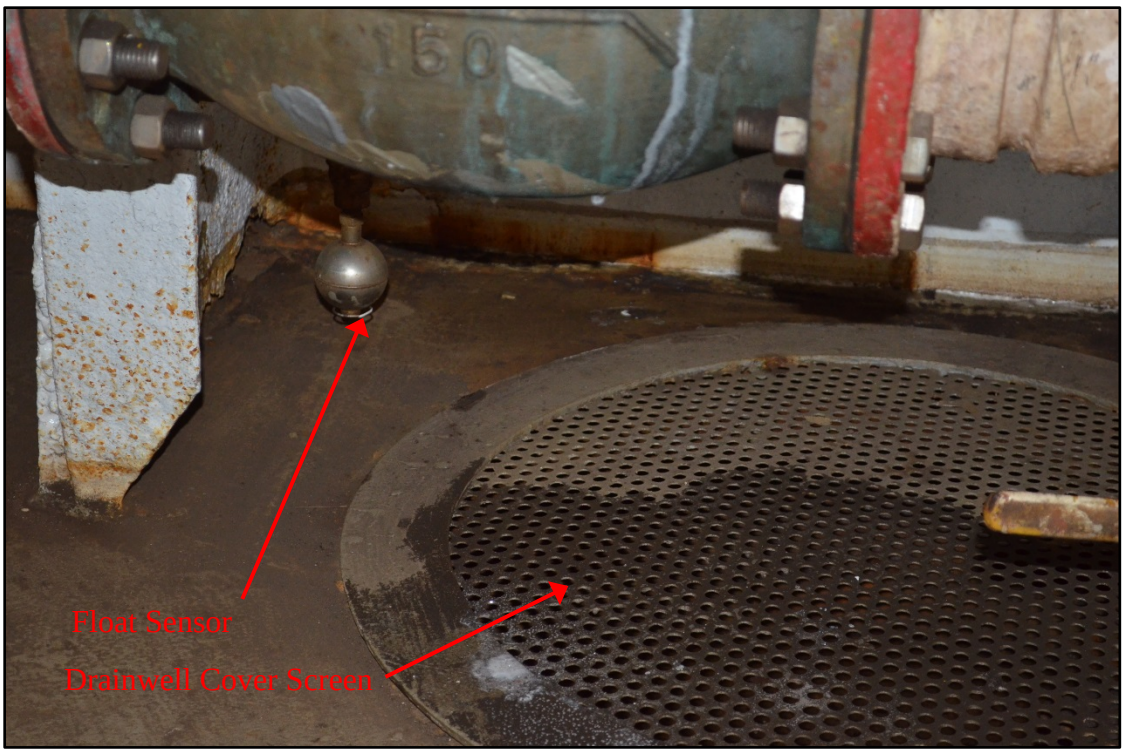


Figure 20. *El Yunque* hold 3 tanktop, starboard-side bilge well alarm float. (Photo from December 2015)

Figure 21. *El Yunque* hold 3 tanktop, portside bilge drainwell (rosebox) with cover screen lifted. (Photo from December 2015)

14.8.1 Operation of Cargo Hold Bilge and Bilge Alarm System

An interview of a previous *El Faro* chief engineer who served on the Florida-to-San Juan run indicated that the bilges in the cargo holds were pumped using the port and starboard bilge/ballast pumps, which "could be used together on the same suction."[284] He further stated:

> The bilge alarm panel was located at the maneuvering level by the throttles. It contained red and green lights and an audible buzzer alarm. The alarm could be silenced. If there was a bilge alarm in cargo holds, the engine department would contact the bridge via phone. If there was a bilge alarm in 3H, engine department personnel could access 3H through water tight doors and look into cargo hold. If there was a bilge alarm in 5H, crew could exit aft of the engine room and investigate alarm. Believed the educator was used for bilge system, but not cargo hold bilges and was tied into the main condenser aft of the fire pump. Bilge pumps were tested for CG/ABS annuals but rarely used since very little water entered cargo hold bilges. Bilge alarms were tested monthly.

A former chief engineer on the *Westward Venture* in the Alaskan trade until 1999, who also served on *El Faro* in the shipyard (but was not underway on *El Faro*), stated that the deck crew used burlap around the bilge suction strainers in the cargo holds to filter debris from the suction piping. He also told investigators that the deck department frequently performed maintenance on the filters.[285]

A past *El Faro* chief engineer with several years sailing from Florida to Puerto Rico said that it was possible to pull water from "whatever side you were listed to" and that in general, ". . . you never wanted to be sucking out of more than one cargo hold at a time—one cargo hold sump at a time. . . ." He stated that hold 3 could be pumped using the port or starboard bilge and ballast pump: ". . . the manifolds could suck from either side. It never was a problem."[286] Both pumps could be operated together, but regarding flow rate, the chief said, "it usually didn't help you"

[284] NTSB Interview Summary, previous Chief Engineer *El Faro*, pg. 2, 9 December 2016.

[285] NTSB Interview Summary, previous Chief Engineer *Westward Venture*, pg. 2, 7 December 2016.

[286] NTSB Interview, previous Chief Engineer *El Faro, El Yunque* & *El Morro*, pg. 49, 27 December 2016.

because of the size of the associated piping. When asked if there were any eductors for bilge suction on *El Faro*, he replied that there were none.

Regarding bilge alarms, the same chief stated that the bilge alarm system was never powered off and was dedicated to bilge wells outside the engine room.[287] Every rosebox (sump) had a high-level bilge alarm with both visual and audible indicators in the engine room. Once silenced, a light continued to indicate the high-level condition until the water level went down and reset the alarm. He stated that if the vessel was rolling, the alarm would sound again and again, and therefore "you'd want to pump it down because you were tired of the nuisance." He stated that the crew could not silence the alarm indefinitely, because it would reset as water went low in the sump (rosebox).[288]

He said that cars and trailers coming in and out of the hold generated "a lot of debris," so when starting to pump out a rosebox, crewmembers "probably have to pull the suction strainer a couple of times. But after that it would just roll and you would not have a problem."[289] He also stated that if a rosebox was "wasted," the pump could suck up rust and clog the suction strainer, but "you'd pull the strainer basket once, maybe twice, and then it would work perfectly fine."[290] The chief recalled that the deck department normally cleaned the roseboxes, and had routines to clean them, but was unsure how often the work was done.

[287] MBI 3 Interview, previous Chief Engineer *El Faro, El Yunque* & *El Morro*, pp. 507 - 509, 8 February 2017.
[288] NTSB Interview, previous Chief Engineer *El Faro, El Yunque* & *El Morro*, pp. 50-51, 27 December 2016.
[289] NTSB Interview, previous Chief Engineer *El Faro, El Yunque* & *El Morro*, pp. 53, 27 December 2016.
[290] MBI 3 Interview, previous Chief Engineer *El Faro, El Yunque* & *El Morro*, pp. 511-512, 8 February 2017.

When asked the general procedure after a cargo hold bilge alarm sounded while under way, the chief[291] said the engineers would typically call the deck personnel and ask them to check out the rosebox for cargo holds 1, 2, and 2A.[292] However, if the weather was rough, the engineering watch might first try to pump the hold "and see if we can clear it without having to send any personnel up." [293] He said that with respect to *El Faro* cargo holds 5 and 3, since there were watertight doors from the engine room to the holds allowing relatively easy access without transiting the second deck, an engine department crewmember (oiler) was usually asked by the watch engineer to check the holds. The crewmember then communicated what was found to the bridge.

He stated that it was understood that in case of a cargo hold alarm they would notify the bridge.[294] The chief said that during the Jacksonville-to-San Juan run, the cargo hold bilge sumps were "almost always dry" and the hold "was dry, clean." He said that was why cars were placed there, to keep them out of the weather. He also stated that "once in a while," the micro switches in the bilge alarm floats would fail closed, resulting in a continual alarm. The crew would then replace the switch.

The same chief engineer indicated the float switch was positioned at the rosebox, and stated the float was "just above the rose box, above the deck.[295] When questioned how much water might be needed to activate the hold 3 bilge alarm in heavy weather, he stated that with the ship having

[291] NTSB Interview, previous Chief Engineer *El Faro, El Yunque* & *El Morro,* pg. 56-57, 27 December 2016.
[292] MBI 3 interview, previous chief engineer *El Faro, El Yunque,* and *El Morro,* February 8, 2017, p. 510.
[293] NTSB interview, previous chief engineer *El Faro, El Yunque,* and *El Morro,* December 27, 2016, p. 56.
[294] MBI 3 interview, previous chief engineer *El Faro, El Yunque,* and *El Morro,* February 8, 2017, p. 511.
[295] MBI 3 interview, previous chief engineer *El Faro, El Yunque,* and *El Morro,* February 8, 2017, p. 508

a starboard list, “it wouldn’t take much water” and estimated that “maybe 50 gallons of water could possibly – all the list to that spot could trigger the alarm.”[296] The contractor who installed the bilge alarm system on *El Faro* (and *El Yunque*) stated that *El Faro* “used stainless steel ball floats to monitor all holds on both their port and starboard side.”[297] He recalled that the floats on *El Faro* were not above the tanktop as on *El Yunque*, but inside their respective roseboxes.

The contractor described the system alarm panel as located near the engine room control flat (area) (**figure 22**), and a previous chief said it was on the starboard side of the main console.[298] He said that if a float was raised for 5 seconds, a high bilge alarm would activate both an engine-room-wide audible alarm (horn) and a flashing indicator (dedicated to each specific rosebox) on the panel. Once the operator pushed a button to acknowledge the alarm, the horn would stop and the light would change from flashing to steady. After the alarm condition was cleared, the light would go off and the system would rearm. He stated that there was no bilge alarm repeater on the bridge, and the power was from the “IC battery system**.”** He did not recall taking a service call on the system and thought it reliable.

[296] MBI 3 interview, previous chief engineer *El Faro*, *El Yunque*, and *El Morro*, p. 532, 8 February 2017.
[297] Interview summary, Norcom Services Inc., owner, 23 September 2016.
[298] MBI 3 interview, previous chief engineer *El Faro*, *El Yunque*, and *El Morro*, p. 507, 8 February 2017.

Figure 22. *El Yunque* bilge alarm panel on engine room control flat. (Photo from September 2016)

14.9 Requirements for Cargo Hold Bilge Alarm Systems

El Faro's bilge alarm system was most likely installed for remote monitoring during a layup in the 1990s. (*El Yunque*'s system was installed in 2016 during a layup.[299]) Although *El Faro*'s system was not installed to meet statutory requirements for underway operation, according to interviews and testimony of former crewmembers, it was functional and operated underway. On the VDR transcript, the chief mate states on the electric telephone at 0716 on October 1 that there is a bilge alarm in hold 2A.[300] The VDR transcript contains no statements regarding a bilge alarm sounding in hold 3.

14.9.1 CFR Requirements for Bilge Alarms

[299] Interview summary, Norcom Services Inc. owner, 23 September 2016

[300] VDR Audio Transcript, SS El Faro, NTSB, S. Payne, p. 484, 12 December 2016.

Investigators reviewed federal requirements relating to bilge systems and bilge level alarms. Requirements for dry cargo ships are found in 46 CFR, Subchapter I ("Cargo and Miscellaneous Vessels"). General marine engineering requirements for dry cargo ships are found in 46 CFR, Subchapter F ("Marine Engineering"), while general electrical engineering requirements are found in Subchapter J ("Electrical Engineering").[301] The bilge and ballast piping regulations at 46 CFR 56.50-50 require the bilge system for a dry cargo ship such as *El Faro* to pump from and drain any watertight compartment, except for ballast, with two independently powered bilge pumps. *El Faro* was equipped in that manner.

No applicable requirement for bilge alarms on a dry cargo vessel was found in 46 CFR Subchapter F or Subchapter J for bilge alarms in cargo holds for a vessel similar to *El Faro* for a vessel constructed in 2016, nor were requirements found for 1973–1974, 1993, or 2005 (i.e., over the life of *El Faro)*. For comparison, new domestic passenger vessels are required to have a bilge level alarm in any space with a through-hull fitting below the waterline, in any space subject to flooding from seawater piping within the space, and in nonwatertight spaces (46 CFR 119.530, "Bilge high level alarms").

14.9.2 International Requirements for Bilge Alarms

The ABS Load Line Technical Manual states that for unmanned machinery spaces equipped with bilge-flooding detection systems, remote operators above the freeboard deck for inlet and discharge valves are not required (as they would be without a detection system).[302] *El*

[301] 46 CFR Subchapter I, Cargo and Miscellaneous Vessels, 2016.

[302] USCG Load Line Technical Manual, Annotated for 2005 Revisions to ICLL, p. 157.

Faro had a cargo hold bilge alarm (flooding detection) system in hold 3 as well as a remote operator for the emergency fire pump through-hull inlet valve.

SOLAS 2004 and current SOLAS bilge system requirements for dry cargo vessels similar to *El Faro* indicate that a bilge system was required (which *El Faro* had). But based on the vessel type, date of build, and arrangement, SOLAS had no requirements for bilge alarms to be fitted in *El Faro*'s cargo holds. Even if built today, only specific types of vessels (single-hold vessels built after 2007, bulk carriers, hatchless container vessels, Ro/Ro passenger vessels with sprinkler systems built after 2010, among others) are required to have bilge alarms in their cargo holds. The requirement does not apply to general cargo vessels.

14.9.3 Bilge System- ABS Class Machinery Survey

A one-day ABS machinery survey on July 16, 2015,[303] examined the bilge system, including the piping and suction valves. The report noted their state as "satisfactory."

14.10 Ramp Tank and Ramp Tank Ballasting System

The VDR transcript contains discussions of the crew pumping ballast water between the vessel's two ramp tanks during the final hours of the voyage. Investigators reviewed drawings and interviewed former *El Faro* crewmembers to determine the arrangement and method of pumping to the ramp tanks.

[303] ABS Class Survey Report, Special Continuous Survey – Machinery 8, Report JS2920963-A, Jacksonville, FL, 16 June 2015.

The ramp tanks were located outboard of shaft alley from frames 200 to 230. They were also called the aft deep tanks, port and starboard. The most recent stability book listed them as freshwater tanks, each with a capacity of 313.5 LT.

The ramp compensating tanks were originally installed to allow for the loading/discharging of cargo on either side of the vessel. Loading ramps stored at the shoreside facility were winched up to reach the portside cargo-loading access cutouts to the second deck or the starboard-side main deck, through which tractors loaded and unloaded trailers. By filling or emptying the tanks to compensate for the weight of the ramp hanging from the vessel, the crew would maintain an even keel during loading and unloading. In its final Ro/Con configuration, *El Faro* loaded Ro/Ro cargo only through the starboard aft access between frames 224 and 233. Containers were loaded or unloaded simultaneously with the Ro/Ro cargo.

According to a previous chief engineer, the ramp tanks "were ballasted using a separate system using fresh water"[304] with a pump located in the shaft alley that was run off the 450-volt electrical bus. A chief who served on the Caribbean run stated that *El Faro* had "a completely separate system"[305] with its own dedicated pumps and piping that were not tied into the primary bilge and ballast system. He said that the tanks were typically used to correct a vessel list, especially in port, and that the engineers communicated with the deck department before pumping. When asked if other tanks could be used to correct a list, he stated that only the ramp tanks could be used, because the fuel tanks were on the bottom of the vessel and on center line and "really didn't affect [a list] too much."

[304] NTSB Interview Summary, previous Chief Engineer *El Faro*, 9 December 2016.

[305] NTSB Interview, previous Chief Engineer *El Faro, El Yunque* & *El Morro*, p. 53, 27 December 2016.

The previous chief engineer (to the accident chief) serving on *El Faro* wrote in his turnover notes that the tank level indicators for both ramp tanks were not functioning due to wasted sensing lines. He also wrote that "the ballast system has been operating without any issues." [306]

15 CARGO HOLD VENTILATION SYSTEM

Investigators attempted to ascertain the arrangement of ventilation for the cargo holds on *El Faro* by reviewing available *El Faro* and other *Ponce*-class plans and photographs, and by examining the sister vessel *El Yunque*. Investigators were unable to obtain photographic evidence of the internal configuration of the cargo hold ventilation trunks on *El Faro*, or their arrangement in the cargo holds.

15.1 Arrangement of Cargo Hold Ventilation

Each cargo hold had two electrically driven supply fans mounted port and starboard (directly opposed) on the semi-enclosed second deck. The supply fans were in "blisters" that bulged out from the hull below the overhung main deck (**figure 23**). The individual supply fans pulled air through four sets of rectangular louvers mounted on the forward and aft sides of the three-sided blister shell plate, then drew it into the fan bell mouth. The fan pushed supply air through a manually activated fire damper (designated watertight in drawings[307]) into a single trunk that passed through the tween holds and into the lower holds at the tanktop. Here the trunk split into horizontal runs mounted longitudinally against the sides of the hold.

[306] *El Faro*, Turnover Notes (Master, Chief Engineer, Chief Mate), Chief Engineer, 11 August 2015, p. 13, (MBI Exhibit 130).

[307] Northern Lights Conversion, Ventilation Arrgt Holds NO. 2A & 3, Dwg. No. 1252877-2A, JJH Inc., ABS approved 12 April 1993.

The ventilation air was distributed into the hold through numerous louvered registers in the horizontal trunk. Positive pressure from the supply fan would exhaust the air back up through the perforations in the tween deck and enter a set of three rectangular screened openings to exhaust trunks mounted on both the port and starboard sides (directly opposed) of the tween hold deck. The air would exhaust up the trunk through the second deck and pass a through a weathertight (not watertight) fire damper into a trunk with baffles on the second deck. The air would push over the baffles and then out through louvered rectangular openings in the vessel's sideshell (**figures 24 and 25**).

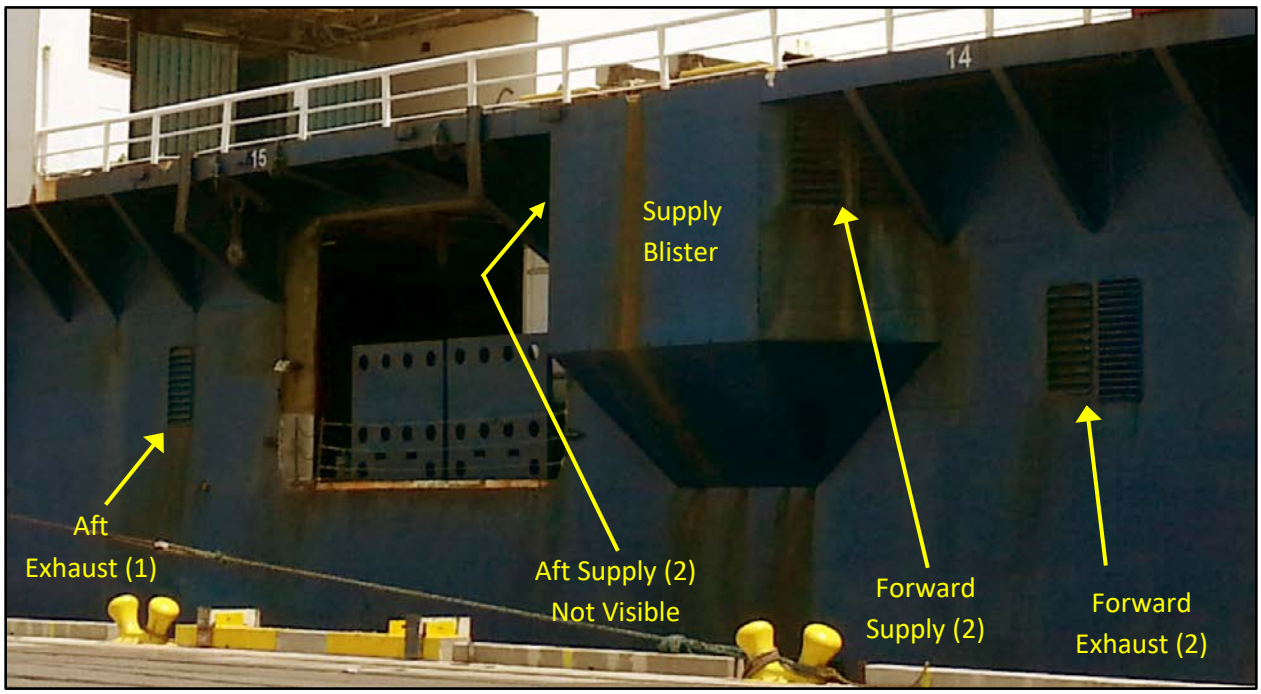


Figure 23. *El Faro* starboard-side supply and exhaust louvered ventilation openings to cargo hold 3. (HEC photo, July 2015)

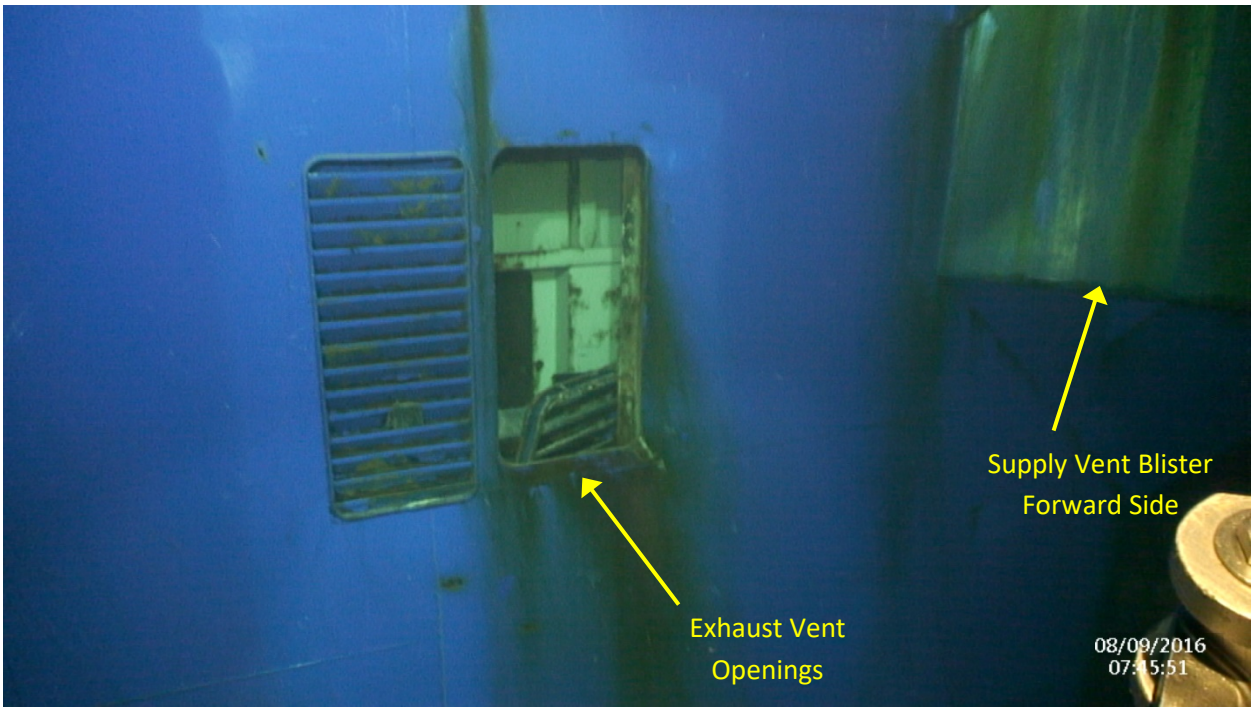


Figure 24. *El Faro* wreckage, port side, hold 3 forward exhaust ventilation openings at frame 134/33. Exhaust louver blades were installed with lower louver lip inboard and upper lip outboard. (Photo from August 2016)

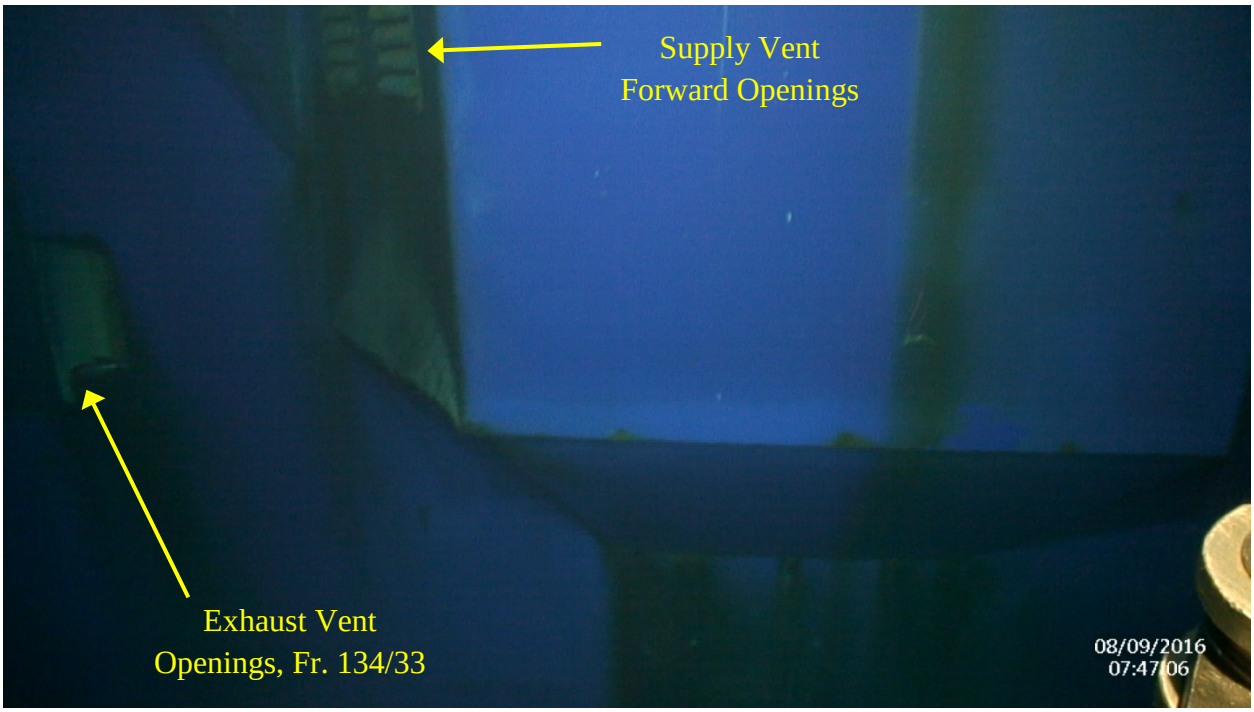


Figure 25. *El Faro* wreckage, port side, hold 3 supply ventilation blister with forward louvered openings at frame 139. (Photo from August 2016)

15.2 Arrangement and Condition of Ventilation Trunks, Baffles, and Dampers

Aside from historical and underwater images of ventilation louvers on the exterior of the *El Faro* wreckage, the ship's internal cargo hold ventilation system could not be examined. Investigators visited the sister vessel *El Yunque* to examine the arrangement and condition of the cargo hold supply and exhaust systems, which were very similar to, though not exactly the same as, *El Faro*'s. Drawings for hull 674 (*El Yunque*) were also reviewed. Because *El Yunque* was not required to meet a damaged stability standard as *El Faro* was, the baffle heights above second deck were not required to be as high. **Figures 26, 27, and 28** illustrate the arrangements on *El Yunque*.

15.2.1 Arrangement

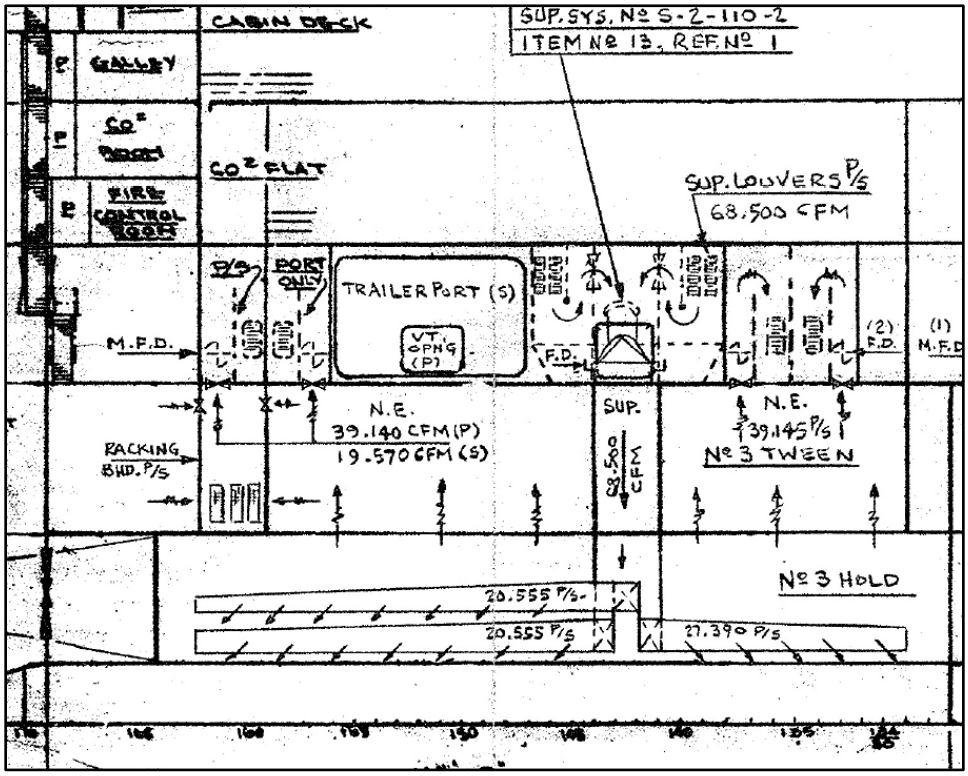


Figure 26. Hold 3 ventilation diagram, profile view, hull 674[308]

[308] Sun Dwg. No. 674-879-04 Alt. 5, Ventilation Diagrammatic Arrangement Main Deck & Below, Roll-on/Roll-off Trailer Carrier, 2 May 1975. Hull 670's Ventilation Diagrammatic was unable to be obtained.

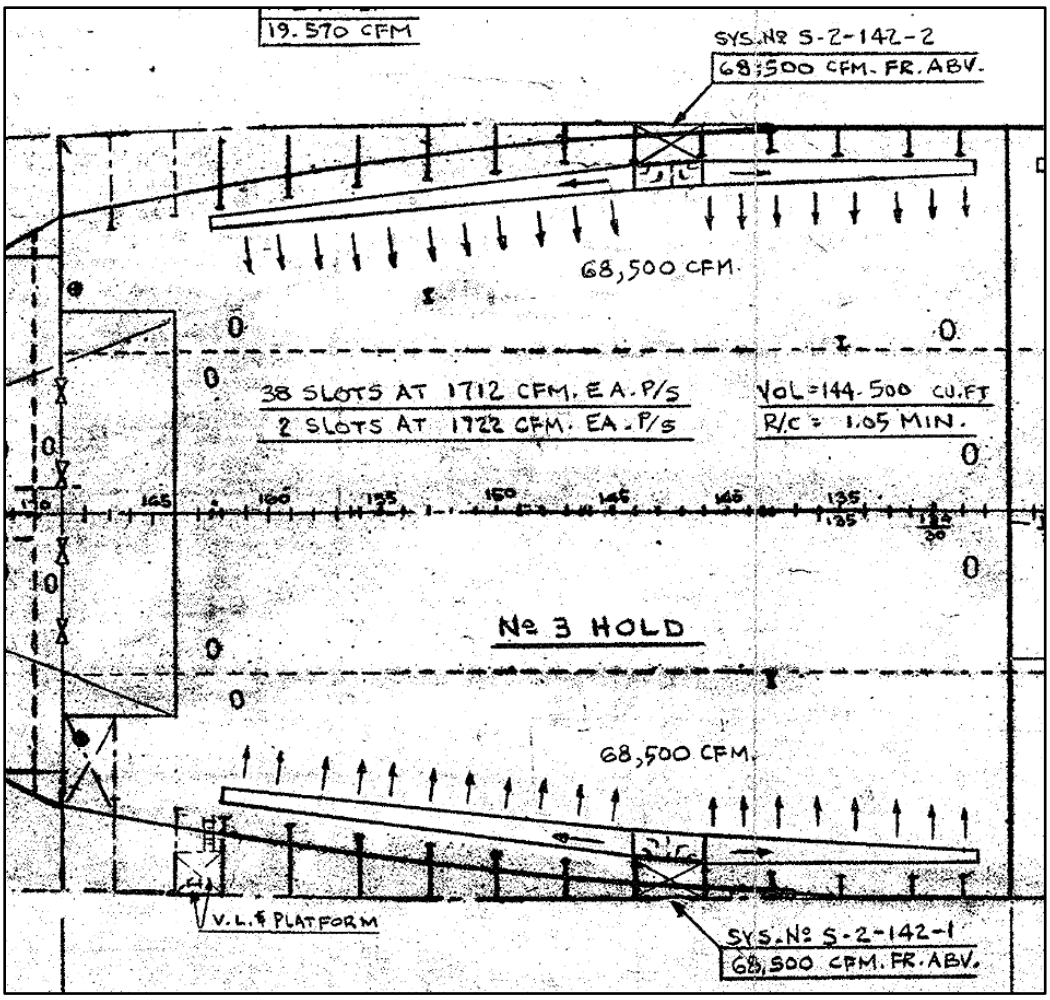


Figure 27. Hold 3 ventilation diagram, plan at tanktop, hull 674[309]

[309] Sun Dwg. No. 674-879-04 Alt. 5, Ventilation Diagrammatic Arrangement Main Deck & Below, Roll-on/Roll-off Trailer Carrier, 2 May 1975.

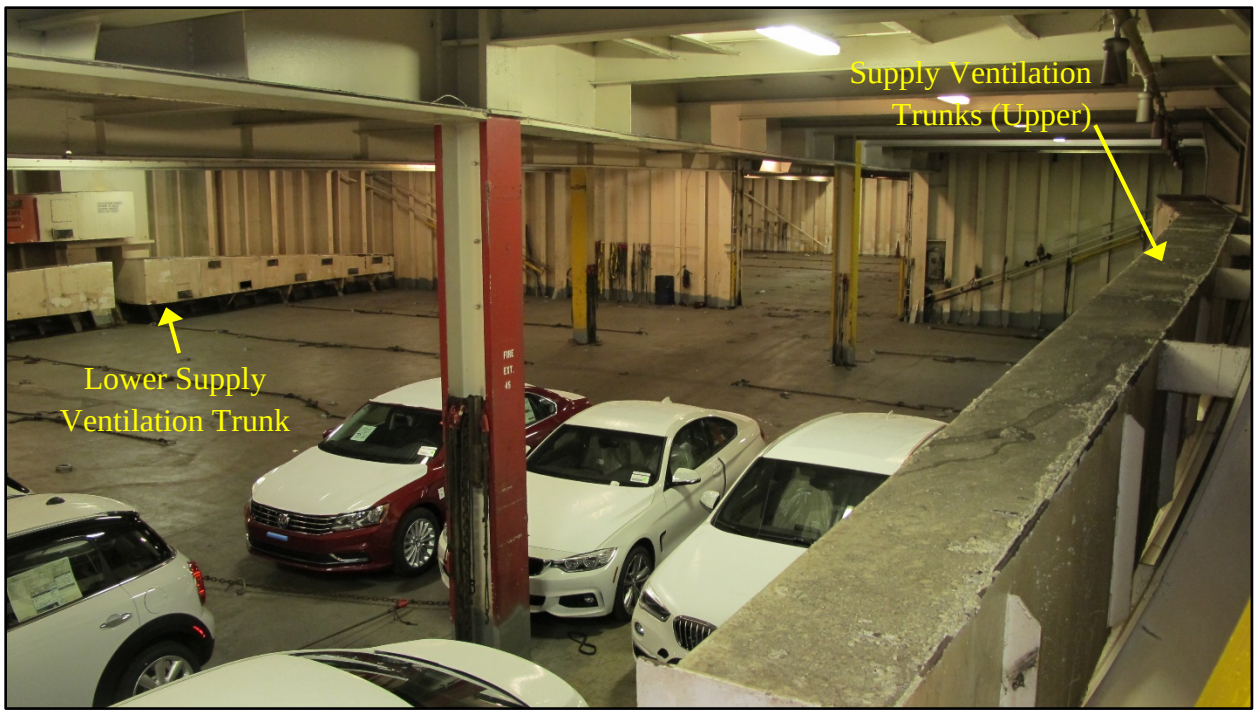


Figure 28. *El Yunque*, view of hold 3 from vertical ladder at frame 163.5, looking forward. (Photo from December 2015)

The lower horizontal supply ventilation trunks in the cargo holds were fitted with downward-facing registers. Investigators measured the distance from the tanktop to the bottom of the horizontal vent trunk at frame 162, near the emergency fire pump sea chest, as 24 inches. The inboard side of the vent trunk was 24 inches off the sideshell at the tanktop. The inboard lip of the 45° downward-facing registers was about 16 inches off the tanktop (see **figure 29**).

Figure 29. *El Yunque*, hold 3 starboard, aft, horizontal supply ventilation trunk end at fame. 162. Trunk bottom 24 inches off tanktop, registers 16 inches off tanktop. (Photo from September 2016)

The closing appliances on the supply trunk were listed as watertight in the *Northern Lights/El Faro* conversion drawings for the ventilation system.[310] The detail of the supply damper shown in **figure 30** stated: "GASKET ALL AROUND AS REQ'D FOR COMPLETE WATER TIGHT CLOSURE." Investigators examined the starboard damper in hold 2A of *El Yunque* (**figure 31**) and found it similar to the supply damper and supply inlet configuration in the *El Faro* drawings.

[310] Northern Lights Conversion, Ventilation Arrgt Holds NO. 2A & 3, Dwg. No. 1252877-2A, JJH Inc., ABS approved 12 April 1993.

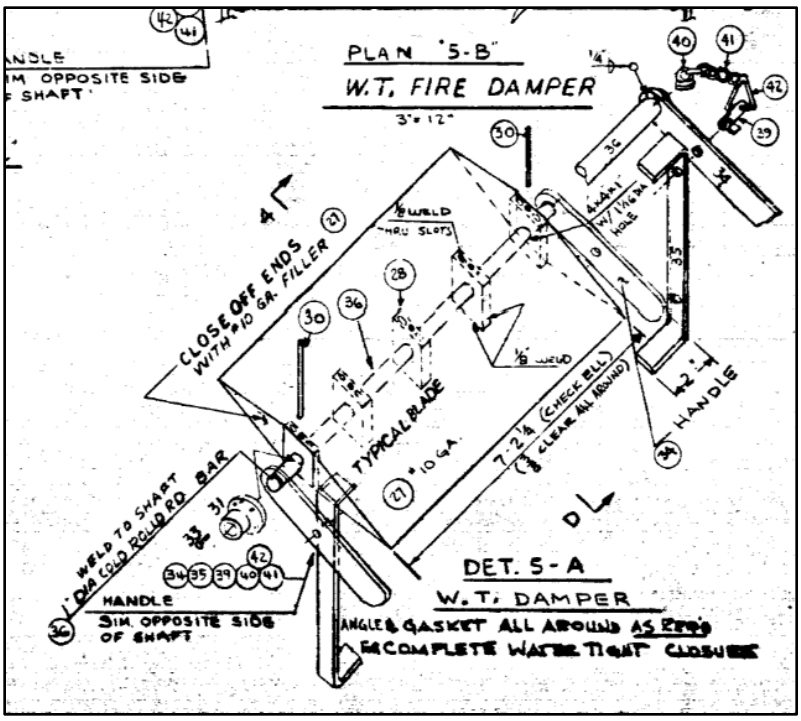


Figure 30. *El Faro* cargo hold ventilation supply, W.T. (watertight) fire damper detail 5-A.[311]

Figure 31. *El Yunque*, hold 2A starboard ventilation supply fan and fire damper housing on second deck (left), internal fire damper/closing appliance (right). Damper's rubber gasket was missing or compressed around most of seal perimeter. (Photo from September 2016)

[311] Northern Lights Conversion, Ventilation Arrgt Holds NO. 2A & 3, Dwg. No. 1252877-2A, JJH Inc., ABS approved 12 April 1993.

The tanktop decks of the cargo holds were naturally exhausted up through the permeable (non-watertight or airtight) tween deck, and then into exhaust ventilation trunk intakes with three screens at the tween deck (**figure 32**).

Figure 32. *El Yunque*, cargo hold 3, natural exhaust ventilation inlets, tween deck frames 158-162. (Photo from December 2015)

The coaming height for the fire damper was measured by investigators in October 2016 as 38 inches above the second deck (**figure 33**). The drawings did not show gaskets for these "weathertight" closures, or fire dampers, and none were found to be installed.

Figure 33. *El Yunque*, cargo hold 3, exhaust trunk fire damper at frame 161.5. Left image is top view of damper, right image is a side view looking outboard. (Photo from September 2016)

15.2.2 Condition of *El Yunque* Cargo Ventilation Trunk

In a May 2016 Coast Guard report[312] on an *El Yunque* inspection, the attending marine inspector noted in the narrative that the gasket material (watertight supply closure drawing detail shown in ventilation arrangement[313]) was missing and that there were holes in unspecified locations of the supply vents for cargo holds 1 to 3 that required them to be added to the worklist for the vessel. The inspector wrote:

> 20MAY2016: Boarded vessel as before. Examined supply vents for the holds 1-3 port and starboard (6 total). Observed gaskets missing; holes in vent ducts; gasket flanges wasted; holes in the sideshell in way of vent inlets. Required all to be added to the work list. /s/ [redacted]

A note added to the report states that on August 14, 2016, the "Company has halted work on returning the vessel to service" and that the Coast Guard had received a request to place the

[312] Coast Guard Activity Summary Report, MISLE Activity ID: 5836311, vessel inspection, April 2016 (MBI exhibit 295), p. 2.

[313] *Northern Lights* Conversion, Ventilation Arrangement Holds NO. 2A & 3, Dwg. No. 1252877-2A, JJH Inc., ABS approved 12 April 1993.

vessel in layup status before scrapping. The general notes section of an April 2016 "Report of Ultrasonic Thickness Measurements, *EL Yunque*"[314] indicated that most of the cargo ventilation plenums on the second deck (exhaust and supply) would need steel work. Comments were similar to those for work item 51, below:

> 51. Shell Frame 134-35 Stbd inside the Exhaust Plenum, crop and renew from 2nd Deck going up 7'-0". 1Pc. 7'-0" length 7" x 4" x 3/8"

15.2.3 September 2016 Review of *El Yunque* Ventilation Trunks

After the vessel had ceased operation, investigators visited *El Yunque* in September 2016 while it was in layup in Tacoma, Washington. Investigators entered most of the cargo hold exhaust ventilation trunks on the starboard side of the vessel. They found a few instances of 1.5-inch-radius drainholes cut through the baffle plates in the trunks. They also found two instances of corrosion and holing of two bulkheads separating pairs of trunks to the same cargo hold. Most sideshell louvers were severely corroded and holed. There was evidence of previous wastage and renewal of baffle plates near the second deck in the trunks, but no holed baffle plates were observed. Photographs of selected trunk interiors are shown in **figures 34, 35, and 36**.

[314] MBI Exhibit 295, "Report of Ultrasonic Thickness Measurements, *EL Yunque*", D. Voehl Testing Corp., pg. 48, April 2016

Figure 34. *El Yunque*, 1.5-inch-radius drainhole inside cargo hold 3 ventilation trunk, second deck at frame 138. (Photo from September 2016)

Figure 35. *El Yunque,* interior bulkhead of exhaust ventilation trunk holed from corrosion at frame 123, viewed looking forward. Bulkhead separates two forward and aft exhaust ventilation trunks for hold 2. The holed plate depicted allows communication only between adjacent trunks to sideshell louver openings. It is not through a baffle plate and does not permit water ingress directly to exhaust ventilation trunks or into the cargo hold below. (Photo from September 2016)

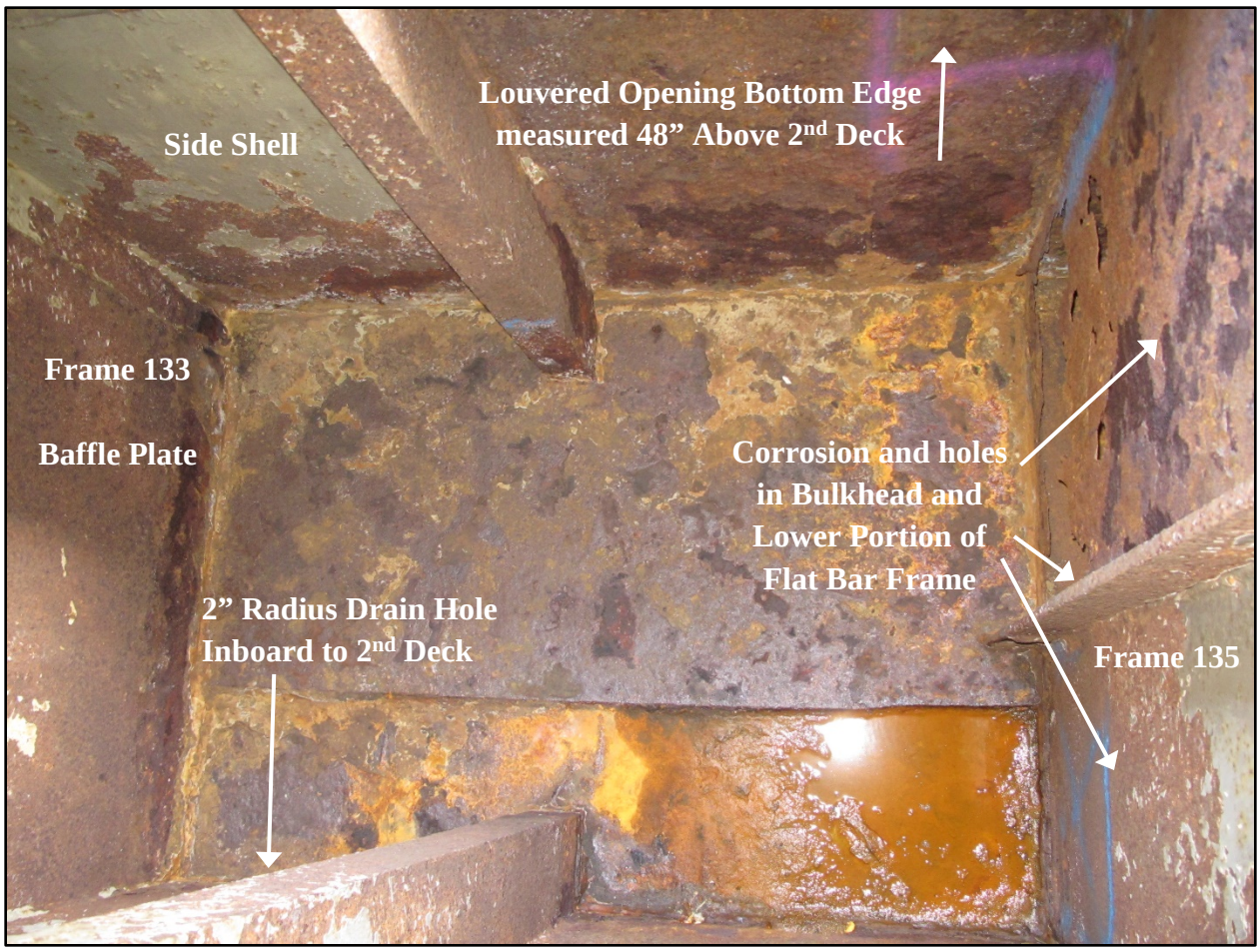


Figure 36. *El Yunque*, starboard side, forward exhaust ventilation trunk interior for hold 2A. Bulkhead at frame 135 separates this forward trunk from aft trunk. Baffle plate height at frame 133 is referenced in load line and damaged stability calculations. View looking down to second deck. Drainholes cut inboard to second deck cargo space. The holed plate at frame 135 allows communication only between adjacent trunks to sideshell louver openings. It is not through the baffle plate at frame 133 and does not permit water ingress directly to exhaust ventilation trunks or into the cargo hold below. (Photo from September 2016)

Several parts of Coast Guard MBI 2 and 3 discussed an opening for a longitudinal angle that penetrated the internal bulkhead (baffle) of the starboard side hold 3 exhaust trunk of *El Yunque* at frame 161.5. The opening was noted by Coast Guard inspectors and subsquently sealed with additional plating. Investigators measured the height of the lowest part of the longitudinal angle flange as 8 feet, 5 inches above the second deck. That is higher than the 8-foot height listed for the same ventilator on the LL11D form obtained for *El Yunque* (see section 8.2.1, above).

Although Coast Guard inspectors elected to close the opening around the longitudinal, damage stability requirements did not apply to *El Yunque* as they did *El Faro*, and the baffle height did not need to match *El Faro's* 12-foot height for damage stability (see Section 7.7.1 Downflooding Point). ABS advised that the 8-foot high baffle arrangement exceeded *El Yunque's* (and similarly *El Faro's*) load line requirement of 35½ inches.

15.2.4 Cargo Ventilation Maintenance and Inspection Schedule

15.2.5 Maintenance of *Ponce*-Class Vessel Cargo Ventilation Trunks

A former port captain stated that corrosion had been found in the past on the ventilation trunks of three *Ponce*-class vessels because they "ingest" salt air.[315] He stated that the trunks were difficult to get at but "were looked at periodically as part of preventative maintenance and they were always on the shipyard list to be opened, cleaned, inspected and repaired as necessary. Always, always a maintenance issue."

15.2.6 ABS and Coast Guard Inspection

Inspection ports for viewing the exhaust fire dampers for the cargo holds were fitted on *El Faro* and *El Yunque*. During annual inspections, ABS surveyors would use the port to view the condition of the fire damper and see it exercised. Surveyors would not typically enter the ventilation trunks during annual inspections. If during an annual inspection a surveyor saw something deficient or suspect inside the trunks, he or she could expand the scope of the survey and access the trunks.[316] A surveyor would be expected to go inside each ventilation trunk at the

[315] Interview Transcript, Interocean Operations Manager/Port Captain, pp. 88-89, 23 March 2017.

[316] CG MBI 3, Testimony, ABS Assistant Chief Surveyor Americas, Vol. 5, pp. 917-919, 946-947, 10 February 2017.

load line renewal survey, which occurred every 5 years. The survey was last carried out on *El Faro* on January 29, 2011.[317]

The Coast Guard oversaw the class society vessel inspections for the ACP program. Oversight was generally not conducted at the same time as the class society inspections.[318] Coast Guard inspectors were "overseeing the authorized class society in its operation, not so much as they're there to do an in-depth hull exam that would be done if the vessel is not enrolled in the Alternate Compliance Program."[319]

Coast Guard MISLE inspection records from year 2005 forward, describe attendances, oversight, and repairs of *El Faro*. Review of the records showed no noted concern or deficiencies regarding the condition of exhaust ventilation trunks. In addition to Coast Guard inspection of *El Yunque* in 2016, a team of Coast Guard inspectors attended *El Yunque* in November 2015 to focus on the area of the mid body extension, all available voids, cofferdams, and ballast tanks (possible to examine) to get a sound assessment of the vessel's condition.[320] After the inspection, the Coast Guard Sector San Juan emailed ABS stating they were satisfied with the current condition of the vessel.[321]

Investigators found no recorded deficiencies for the ventilation trunks from the USCG oversight exams, until a joint ABS Intermediate Survey and USCG expanded oversight exams of

[317] CG MBI 3, Testimony, ABS Assistant Chief Surveyor Americas, p. 947, 10 February 2017.

[318] CG MBI 3, Testimony, Coast Guard Chief of Traveling Inspectors, p. 440, 8 February 2017.

[319] CG MBI 3, Testimony, Coast Guard Chief of Traveling Inspectors, p. 430, 8 February 2017.

[320] Letter, Acting OCMI Sector San Juan to TOTE Maritime Puerto Rico, 28 October 2015 (MBI Exhibit 376).

[321] Joint Response to the U.S. Coast Guard Marine Safety Center's Technical Reports Concerning the SS *El Faro* Stability and Structures. Submitted by Parties in Interest, 17 January 2017, Section F-8, pg. 3 Email dated 13 November 2015 from Coast Guard Sector San Juan to ABS, Subject: Administrative Follow-up from *El Yunque* Structural Exam.

El Yunque were commenced in Seattle, Washington on/about April 5, 2016. The ABS survey was not completed because the owner decided to scrap the vessel for business considerations. ABS closed out its survey(s) for *El Yunque* in October, 2016.

During a shipyard period for *El Yunque* on Grand Bahama in March 2014, according to an ABS class survey report[322], vertical stiffeners inside a ventilation trunk at frame 159 on the port side were found to be wasted. They were cropped out, renewed, and then found satisfactory. Coast Guard marine inspectors oversaw the drydocking and briefly mentioned the work on the ventilation trunk in their report of inspection for the Grand Bahama shipyard. [323]ACP Coast Guard Examination Book

The Coast Guard published an ACP freight vessel examination book that was "intended to be used as a job aid by Coast Guard marine inspectors during annual examinations and reexaminations of US-flagged vessels."[324] The book contained an extensive list of possible examination items, but noted: "It is not, however, the Coast Guard's intention to 'inspect' all items listed." In the "Structural Integrity" section, vents are noted as an annual (square box) item for examination:

☐ Watertight/weathertight openings	
• Watertight doors, gaskets, dogs	ICLL 66 Reg. 12
• Other openings (means of securing)	ICLL 66 Regs. 13 - 18
• Vents, air pipes and closing appliances	ICLL 66 Regs. 19 & 20

[322] *El Yunque*, ABS Survey Report FL253863, last visit date 20 March 2014 (MBI Exhibit 369).

[323] CG MBI 3, Testimony, Coast Guard Chief of Traveling Inspectors, Vol. 3, pp. 431-432, 8 February 2017.

[324] Coast Guard Alternate Compliance Program Freight Vessel Examination Book, CG-840 ACP FV, Rev. 1/99 (MBI Exhibit 226).

15.3 Operational Requirements for Cargo Hold Ventilation in Certificate of Inspection

El Faro's COI noted as a condition of carriage that all cargo spaces are "specially suitable for carriage of vehicles (46 CFR 90.10-38)" and that ventilation was to be maintained in accordance with blueprint 663-879-4 Alt 0: [325] This blueprint was for hull 663, the Ponce class vessel *Fortaleza*.

```
---Liquid/Gas/Solid Cargo Authority/Conditions---
*Conditions of Carriage*
ALL CARGO SPACES ARE "SPECIALLY SUITABLE FOR CARRIAGE OF VEHICLES" (46 CFR 90.10-38),
MAINTAIN VENTILATION IN ACCORDANCE WITH BLUEPRINT 663-879-4 ALT 0 OF BUILDER SUN
SHIPBUILDING AND DRY DOCK COMPANY.
```

As stated in 46 CFR 90.10-38, a space designed for the carrriage of "automobiles or other self-propelled vehicles with batteries connected and fuel tanks containing gaosoline on vessels on ocean or unlimited coastwise vogyages" must meet several other requirements in 46 CFR Subchapter I, "Cargo and Miscellaneous Vessels." *El Faro* regularly carried that type of cargo.

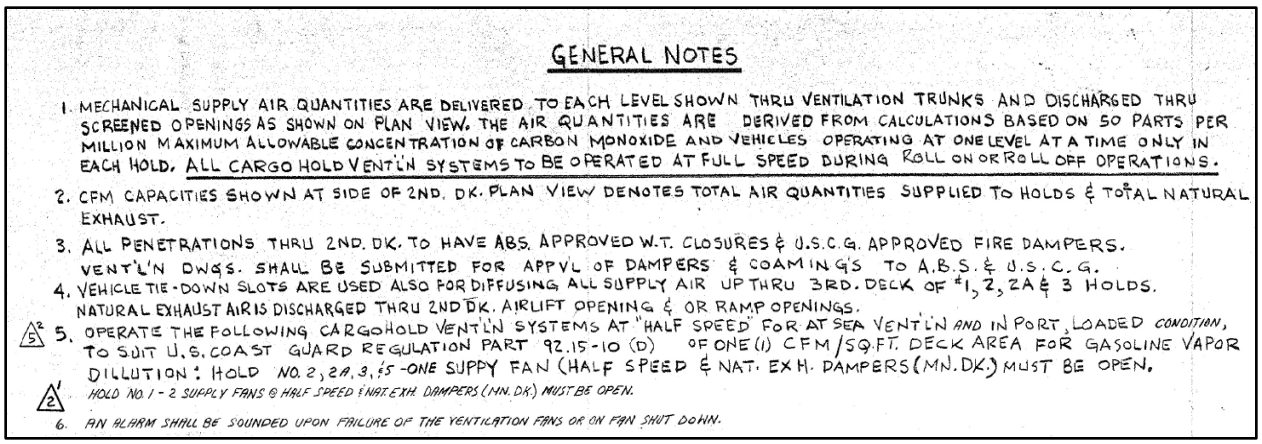
According to ABS, the ICLL Regulations for ventilators did not include requirements similar to 46 CFR 90.10.38. Review of compliance to the CFR cite would have been done by the Coast Guard independent of the ABS review.[326]

Investigators sought Sun drawing 663-879-4 Alt. 0 from ABS, TOTE, and the Coast Guard, but it could not be found. Investigators obtained 674-879-4 Alt. 5 for *El Yunque*,[327] which contained the general notes shown in **figure 37**:

[325] Certificate of inspection, *El Faro*, Coast Guard Sector San Juan, amended March 15, 2015 (MBI exhibit 020).

[326] ABS Technical Review of Naval Architecture Draft Factual Report, 7 August 2017.

[327] Sun Dwg. No. 674-879-04 Alt. 5, Ventilation Diagrammatic Arrangement Main Deck & Below, Roll-on/Roll-off Trailer Carrier, 2 May 1975.



GENERAL NOTES

1. MECHANICAL SUPPLY AIR QUANTITIES ARE DELIVERED TO EACH LEVEL SHOWN THRU VENTILATION TRUNKS AND DISCHARGED THRU SCREENED OPENINGS AS SHOWN ON PLAN VIEW. THE AIR QUANTITIES ARE DERIVED FROM CALCULATIONS BASED ON 50 PARTS PER MILLION MAXIMUM ALLOWABLE CONCENTRATION OF CARBON MONOXIDE AND VEHICLES OPERATING AT ONE LEVEL AT A TIME ONLY IN EACH HOLD. ALL CARGO HOLD VENT'LN SYSTEMS TO BE OPERATED AT FULL SPEED DURING ROLL ON OR ROLL OFF OPERATIONS.
2. CFM CAPACITIES SHOWN AT SIDE OF 2ND. DK. PLAN VIEW DENOTES TOTAL AIR QUANTITIES SUPPLIED TO HOLDS & TOTAL NATURAL EXHAUST.
3. ALL PENETRATIONS THRU 2ND. DK. TO HAVE ABS. APPROVED W.T. CLOSURES & U.S.C.G. APPROVED FIRE DAMPERS. VENT'LN DWGS. SHALL BE SUBMITTED FOR APPVL OF DAMPERS & COAMINGS TO A.B.S. & U.S.C.G.
4. VEHICLE TIE-DOWN SLOTS ARE USED ALSO FOR DIFFUSING ALL SUPPLY AIR UP THRU 3RD. DECK OF #1, 2, 2A & 3 HOLDS. NATURAL EXHAUST AIR IS DISCHARGED THRU 2ND DK. AIRLIFT OPENING & OR RAMP OPENINGS.
5. OPERATE THE FOLLOWING CARGO HOLD VENT'LN SYSTEMS AT "HALF SPEED" FOR AT SEA VENT'LN AND IN PORT, LOADED CONDITION, TO SUIT U.S. COAST GUARD REGULATION PART 92.15-10 (D) OF ONE (1) CFM/SQ.FT. DECK AREA FOR GASOLINE VAPOR DILLUTION: HOLD NO. 2, 2A, 3, & 5 - ONE SUPPY FAN (HALF SPEED & NAT. EXH. DAMPERS (MN. DK.) MUST BE OPEN.
HOLD NO. 1 - 2 SUPPLY FANS @ HALF SPEED & NAT. EXH. DAMPERS (MN. DK.) MUST BE OPEN.
6. AN ALARM SHALL BE SOUNDED UPON FAILURE OF THE VENTILATION FANS OR ON FAN SHUT DOWN.

Figure 37. General notes from ventilation diagrammatic arrangement, hull 674.

Note 5 gives supply fan and exhaust operational requirements to suit Coast Guard regulation 92.15-10 (d) for gasoline vapor mitigation. It states that at sea, one supply fan for each hold (holds 2, 2A, 3, and 5) must be run at half-speed and a natural exhaust damper must be open, while hold 1 requires running two supply fans at half-speed with natural exhaust open. Requirements for continuous positive pressure ventilation of vehicle stowage areas below the weather deck, alarms for loss of ventilation supply, and additional electrical requirements for powered fans are found at 46 CFR 92.15-10 (d), Ventilation for closed spaces.[328] Paragraph (d)(1) states that "areas below the weather deck shall be provided with continuous pressure-positive ventilation at each level on which vehicles are trasnported." Under paragraph (d), cargo hold 3 and other holds in which vehicles were carried were required to be subject to "continuous pressure-positive ventilation" while the vessel was at sea.

Note 3 states that "all penetrations thru 2nd deck to have ABS approved W.T. closures & USCG approved fire dampers." The drawing does not give a key for the abbreviation "W.T.," but

[328] 46 CFR 92.15-10 (e) states that electrical requirements for powered ventilation systems are found at 46 CFR Subchapter J, Electrical Engineering.

the ABS-approved drawing for ventilation arrangements in holds 2A and 3 denotes "W.T." as watertight and "N.W.T." as nonwatertight.[329]

Because the ventilation drawing referenced in the *El Faro* COI could not be obtained, the COI for *El Yunque* was reviewed for similarites. The *El Yunque* COI referenced the same 46 CFR 90.10-38 and a similar ventilation diagram (666-879-A Alt. 0), but for a different hull number. It also referenced Sun drawing C5-647-879 Alt. A. Neither referenced drawing could be obtained from ABS, TOTE, or the Coast Guard.

In summary, the *El Faro* COI required (through reference to a ventilation drawing) that for each cargo hold, at least one cargo hold supply fan be operated and natural exhaust ventilation openings remain open underway at sea when transporting vehicles with fuel tanks. The supply trunks serving the cargo holds were fitted with watertight closing appliances that also served as fire dampers, while the exhaust trunks were fitted with weathertight closing appliances that also served as fire dampers. On the accident voyage, *El Faro* transported vehicles that had fuel tanks (automobiles and some other Ro/Ro vehicles).

15.4 Recent IMO Unified Interpretations of Downflooding via Ventilators

The 96th session of the IMO's Maritime Safety Committee in May 2016 approved several circulars containing unified interpretations, including "Downflooding via Ventilators,"[330]

[329] Northern Lights Conversion, Ventilation Arrgt Holds NO. 2A & 3, Dwg. No. 1252877-2A, JJH Inc., ABS approved 12 April 1993.

[330] IMO, Subcommittee on Ship Design and Construction, 3rd Session, Agenda Item 14, Unified Interpretation to Provisions of IMO Safety, Security, and Environment-Related Conventions, Submitted by IACS, 16 October 2015.

submitted by the IACS.[331] The ABS publication "MSC 96 Brief" describes the interpretation as follows:

> Downflooding via Ventilators – several Circulars issued contain the clarification that machinery space ventilators fitted with weathertight closing appliances, which are required to remain open to supply air to the engine room or emergency generator room (if the same is considered buoyant in the stability calculation or protecting openings leading below) for the effective operation of the ship, are to be considered as a point of down-flooding when evaluating compliance with stability requirements.

This new IACS load line interpretation, titled "LL80, Unprotected Openings", will no longer allow weathertight closures to engine or generator rooms to be excluded as a downflooding points in damaged stability calculations per ICLL Regulation 27(13)(e). LL80 states:

> **ICLL Regulation 27(13)(e)**
> **Subdivision and Damage stability**
> When any part of the deck outside the compartment assumed flooded in a particular case of damage is immersed, or in any case where the margin of stability in the flooded condition may be considered doubtful, the residual stability is to be investigated. It may be regarded as sufficient if the righting lever curve has a minimum range of 20° beyond the position of equilibrium with a maximum righting lever of at least 0.1 m within this range. The area under the righting lever curve within this range shall be not less than 0.0175 m.rad. The Administration shall give consideration to the potential hazard presented by protected or **unprotected openings** which may become temporarily immersed within the range of residual stability.
>
> **Interpretation**
> Unprotected openings include ventilators (complying with ILLC 19(4) that for operational reasons have to remain open to supply air to the engine room or emergency generator room (if the same is considered buoyant in the stability calculation or protecting openings leading below) for the effective operation of the ship.

[331] According to the IACS website, "Unified Interpretations are adopted resolutions on matters arising from implementing the requirements of IMO Conventions or Recommendations. Such adopted resolutions can involve uniform interpretations of Convention Regulations or IMO Resolutions on those matters which in the Convention are left to the satisfaction of the Administrations or vaguely worded. Interpretations are circulated to Administrations concerned or are sent to IMO for information, as appropriate."

The IACS history file noted that the Dutch Safety Board requested the interpretation after its investigation into the capsizing of a tug, in which "one cause of the capsizing was that the weathertight closing appliances to the main engine room were left open in order to supply an adequate air supply to achieve the required bollard pull. These openings had been considered as closed in the intact stability calculations."[332]

The IACS technical background file on unprotected openings noted that IACS recommendation 24, revision 6, already recommended in 2013 that "openings required to be fitted with weathertight closing devices under the ICLL but, for operational reasons, are required to be kept open should be considered as downflooding points in stability calculation."[333] However, a majority in the review panel "concluded that new Unified Interpretations were required to provide consistency in application."[334] The unified interpretation was approved on June 3, 2016 and became applicable on January 1, 2017.

According to the Coast Guard load line policy notes, "[IACS] has issued several Unified Interpretations over the years concerning various ICLL regulations" and the "Coast Guard accepts these interpretations, and therefore they are to be applied as appropriate."

15.5 Cargo Hold Ventilation: Operation Underway

Past crewmembers on *El Faro* and other *Ponce*-class vessels told investigators that both the supply and exhaust cargo hold ventilation trunk closures, or fire dampers, remained open while underway at all times. A previous chief mate stated that they were not closed for heavy weather or

[332] IACS History File + TB, UI LL80 "Unprotected Openings."

[333] IACS Recommendation No. 24, Intact Stability, pg. 2, Rev. 6, 2013 (first published 1988).

[334] IACS History File + TB, UI LL80 "Unprotected Openings," Technical Background, Part B.

any other reason and that the only reason they would "ever" have used the dampers was for a fire.[335] However, he said that in anticipation of heavy weather, he shut the cargo hold 5 ventilation dampers on *El Yunque* during its southbound voyage to Puerto Rico immediately after the loss of *El Faro*. He did this as a precaution, knowing from experience that seawater reached the second deck. He did not secure the ventilation to cargo holds 1 through 4, as his concern was the second deck aft of the house.[336] Several former crewmembers stated that the functionality of the dampers was tested by closing and opening (exercising) them monthly as part of routine testing (drills), and as part of preventative maintenance.

15.6 Engine Room Ventilation: Underway in Rain and Wind

When asked about parts of the VDR transcript in which the crew discussed water coming through the engine room ventilation system, a previous *El Faro* chief engineer stated that he had seen that before, when rain and the wind direction allowed the intakes for the engine room ventilation fans located aft of the house on the main deck to ingest the rain. The water would leak through the ventilation ductwork in the engine room.[337]

16 SURVEY AND INSPECTION

16.1 ISM Audits

Investigators reviewed internal and external ISM audit reports from 2005 until the time of sinking. There was one corrective action request (CAR) related to vessel structure, and no evidence of CARs or nonconformities related to vessel stability. The CAR was issued in May 2014 after

[335] Interview transcript, Past Chief Mate *El Faro* and 2nd Mate *El Yunque*, pp. 60-64, 107, 3 December 2015.
[336] Interview transcript, Past Chief Mate *El Faro* and 2nd Mate *El Yunque*, p. 114, 3 December 2015.
[337] NTSB Interview, previous Chief Engineer *El Faro*, *El Yunque* & *El Morro*, p. 105, 27 December 2016.

both the vent and sounding pipes to the forepeak tank starboard side were found to be wasted.[338] The surveyor cited ISM clause 10.1 and gave a root cause of inadequate implementation of planned maintenance in the deck department and completion of form for submitting repair. The CAR was closed in July 2014 when the attending surveyor noted compliance.

16.2 Survey Reports

Investigators reviewed recent ABS survey history and other reports for entries related to structure, stability, bilge alarms, or the sea chest and piping for the emergency fire pump. The ABS survey history[339] showed that the most recent ABS class surveys (annual hull survey 4 and annual machinery survey 4, as well as statutory survey; annual load line survey 4; annual safety construction survey 4; annual safety equipment survey 4) began in San Juan in January 2015 and were all completed by February 13, 2015.

The annual hull surveys used the same set of checklist items each year. The checklist for annual hull survey 4 included 77 items related to the watertight and weathertight integrity of the hull as well as stability. Included are requirements (sequence No. 22) to confirm "loading guidance, stability data and damage control plans, as applicable," and the working order of installed loading instruments (CargoMax for *El Faro*) to the T&S booklet. The user's instruction manual for the loading instrument was to be confirmed onboard.[340] The "weather decks and hull plating closing appliances together with watertight penetrations [should] be generally examined as far as practicable." Watertight and weathertight doors and cargo doors were on the list. Items were also to confirm that "no alterations have been made to the hull or substructures which would affect

[338] ABS Statutory Survey Report, *El Faro*, Report No. T2655376, 7/5/2014, p.18 (MBI Exhibit 405)

[339] *El Faro* ABS vessel survey history (MBI Exhibit 191).

[340] ABS Annual Hull Survey 4, SJ2834014-B, E*l Faro*, 13 February 2015 (MBI Exhibit 220).

the calculation determining the position of the load lines."[341] From annual hull survey 4, these items were indicated as surveyed. Three items relating to the double-bottom and forepeak tank coatings had an outstanding deficiency that required temporary repairs until the next drydock survey.[342]

Annual load line survey 4 indicated that form LL-11D was onboard *El Faro*.[343] The next annual hull survey was due on February 26, 2016.[344]

17 OTHER SHIP DATA

17.1 Anemometer Location and Data

The position of the *El Faro* anemometers relative to the hull and waterline was estimated from AutoCAD drawings, the vessel's draft during the accident voyage, and photographs. The Nautical Operations group factual report gives details on the type and installation of the anemometers, but installation details could not be confirmed.

A photograph from 2009 of *El Faro*[345] shows two anemometers (Young Wind Monitors, model 05106[346]). The vertical positions of the anemometers were estimated from a shipyard photo (**figure 38**) to be double the rail height on the housetop, or 7 feet. With a departure draft of 29.6 feet amidships, the anemometers would have been about 100.5 feet above the static waterline on the accident voyage.

[341] ABS Annual Hull Survey 4 and Annual Machinery Survey 4, SJ22784122-A and SJ22784122-B, *El Faro*, 9 January 2015 (MBI Exhibit 229)

[342] ABS Annual Hull Survey 4, SJ2816446, E*l Faro*, 23 January 2015 (MBI Exhibit 225)

[343] ABS Annual Load Line Survey 4, SJ22784122-C, E*l Faro*, 9 January 2015 (MBI Exhibit 229)

[344] ABS Survey Manager Survey Status Report, *El Faro*, pg. 12, Printed 1 October 2015 (MBI Exhibit 112)

[345] DSC00908 photograph, TOTE, 2009

[346] R.M. Young Company, meteorological instruments, Instructions, Wind Monitor-MA, Marine Model 05106, PN: 05106-90, Rev: K060915

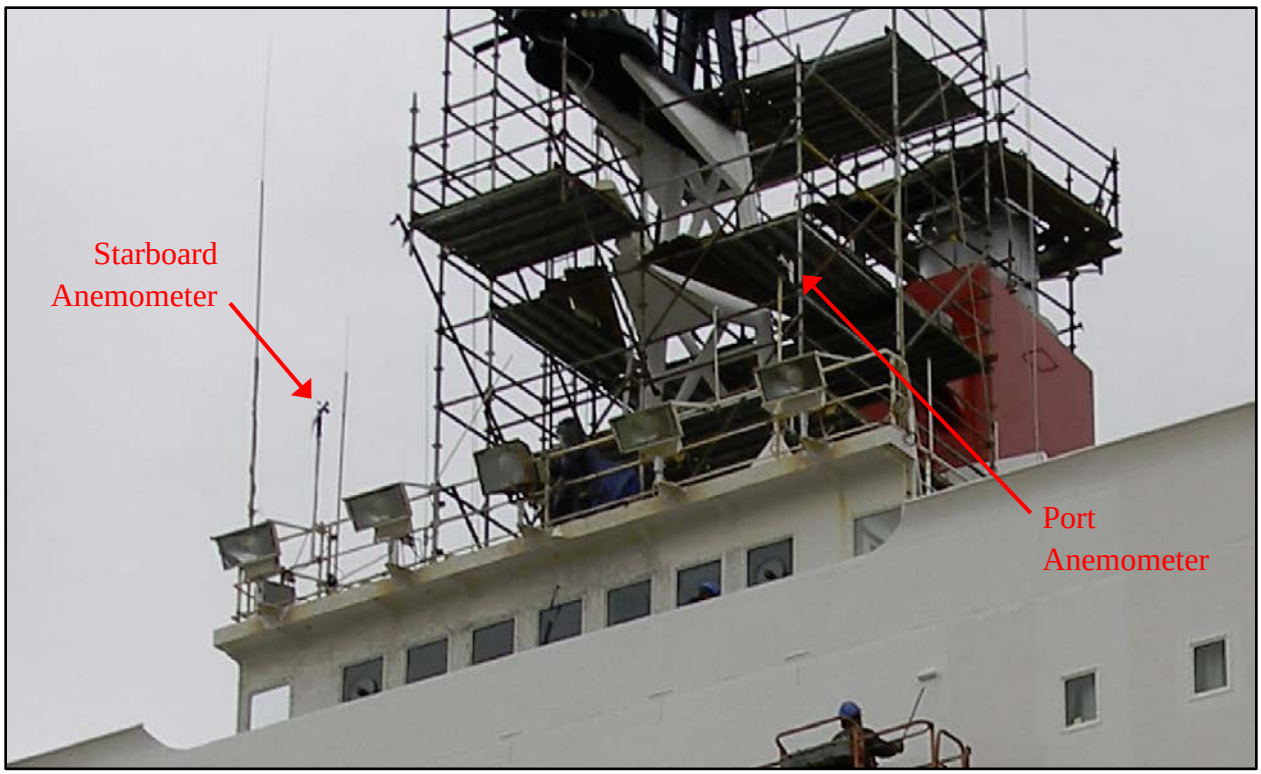


Figure 38. Anemometers on *El Faro* during shipyard period in January 2011. (TOTE photo)

The Young anemometers had individual sensors for both direction and wind speed. Parametric wind data recorded on the vessel's VDR through the last 12 hours show varying wind speed data (**figure 39**). Throughout the entire VDR recording, over 99 percent of the anemometer data samples show a relative wind direction of between 180° and 193°.[347]

[347] Electronic Data group chairman's factual report, December 13, 2017, p. 24.

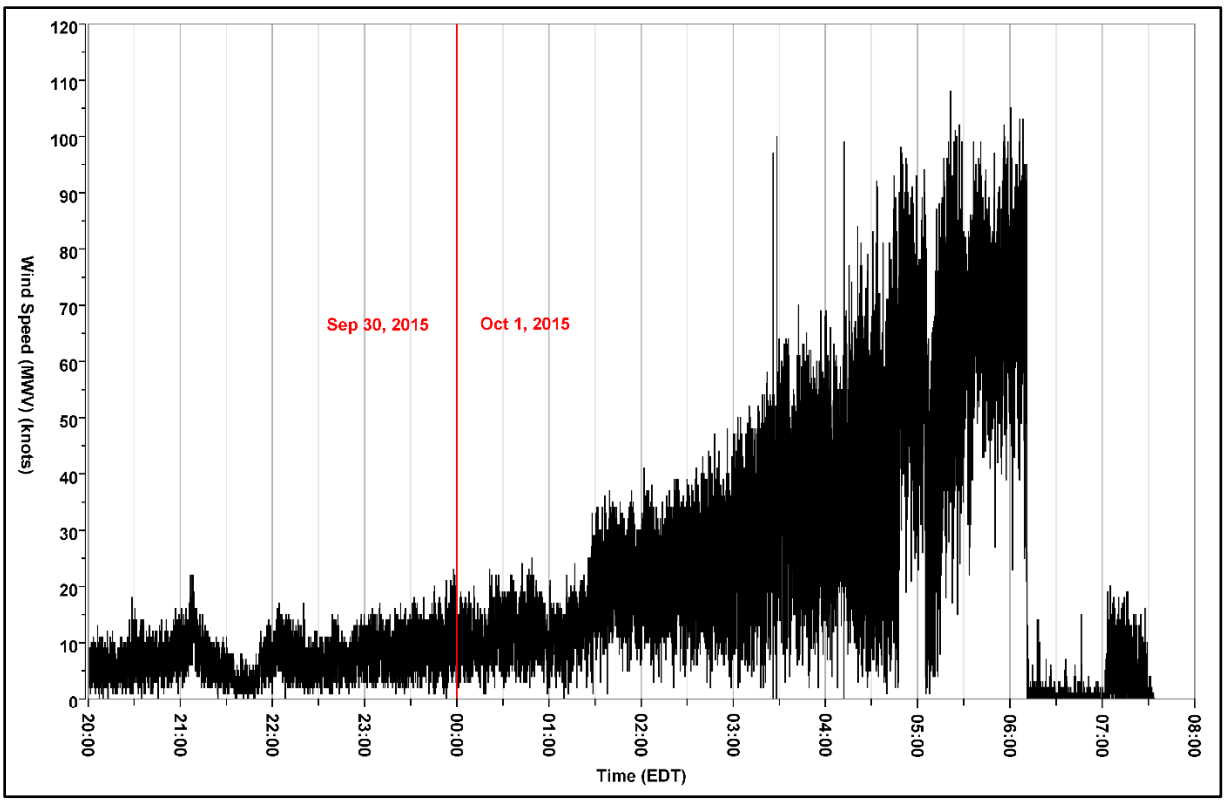


Figure 39. Raw VDR wind speed data, from 2000 on September 30 to data loss on October 1.

17.2 GPS Antenna Location

The *El Faro* GPS antenna position relative to the hull and waterline was determined based on the vessels General Arrangement drawing (in both hard copy and AutoCAD),[348] the vessel's accident draft, and photographs (**figure 40**).

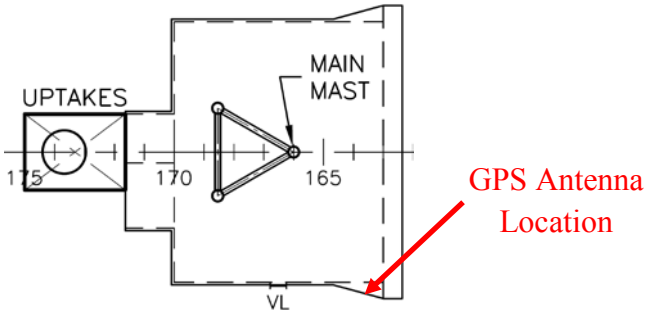


Figure 40. GPS antenna location on housetop deck starboard railing shown on drawing.

[348] *El Faro*, General Arrangement, Dwg. No. SSL-670-100-026 Rev. 0, HEC, 4/24/2006 (MBI Exhibit 007).

Vertical Position

- Distance from baseline to housetop deck = 123′ 3″ (*El Faro*, General Arrangement)
- Rail on housetop 42″ above housetop deck (*El Faro*, General Arrangement)
- Estimate GPS antennae 6″ above rail (*El Faro* and *El Yunque* photographs)
    - Distance from baseline to GPS antenna = 127′ 3″
    - Distance form 29.6-foot waterline at loss to GPS antenna = 97.7′ or 97′ 8″

Transverse Position

- Similar style MX420 mounted starboard side, just forward of housetop deck knuckle (*El Faro* photographs)
- Distance from centerline to starboard rail of housetop deck at frame 164 = 12′ 9″ (*El Faro* General Arrangement, at knuckle)

Longitudinal Position

- GPS Antenna at frame 164 is 514′ 11″ from forward perpendicular (*El Faro* General Arrangement)

The *El Faro* VDR recorded GPS antenna altitude. NTSB studied the altitude parameter for information regarding ship's sinking. See section 19.3, Study of GPS Antenna Height and Position.[349]

18 SEAFLOOR DEBRIS FIELD AND MAIN VESSEL WRECKAGE

18.1 General

The NTSB launched three missions to search for the wreckage and recover *El Faro*'s VDR. Video taken by the CURV-21 remotely operated vehicle (ROV) during the first underwater search (October 19–November 24, 2015) documented that the navigation bridge and the deck below it had separated from the hull and were lying a little more than half a nautical mile north of it. The top of the engine room casing was open to the sea, containers had fallen off the main deck, and the ship's mast and VDR were missing.

[349] Ship Dynamics from VDR Data Study, *El Faro*, DCA16MM001, NTSB Office of Research and Engineering, D. Crider, 29 January 2017.

The second mission (April 18–May 5, 2016), launched to locate the VDR, also included a secondary objective to gather sonar data and images to map and categorize debris in the wreckage field. Individual photos of some parts of the wreckage, taken by the autonomous underwater vehicle (AUV) SENTRY and by the Alvin observation vehicle (AOV), were combined into photomosaics to create complete pictures. The third mission (August 5–12, 2016), in which the VDR capsule was recovered, included additional images taken by the CURV-21 ROV that further documented structural damage to the hull and damaged or missing components.

The main wreckage of *El Faro* lies at a depth of between 15,318 and 15,482 feet (4,719 to 4669 meters) in the Atlantic Ocean, about 20 nautical miles northeast of Samana Cay, Bahamas. The primary debris field, which includes the main hull and ship structure, covers an area of about 0.7 square mile (1.8 square km) between latitude 23.3786 and 23.3936 N and longitude 73.9061 and 73.9172 W. Cargo containers, some ship's equipment and rails, and other cargo items were found outside the primary debris field.[350] Inside the primary field are the remains of *El Faro*'s port lifeboat, some of its cargo (about 40 containers and 7 vehicles), the main hull and the structures that had separated from it, including the mast (with attached VDR), the exhaust stack, the bridge and the deck below it, and a few unidentified items (see **figures 41 and 42**).

[350] See the *El Faro* public docket for additional bathymetric and sidescan sonar maps of larger debris field.

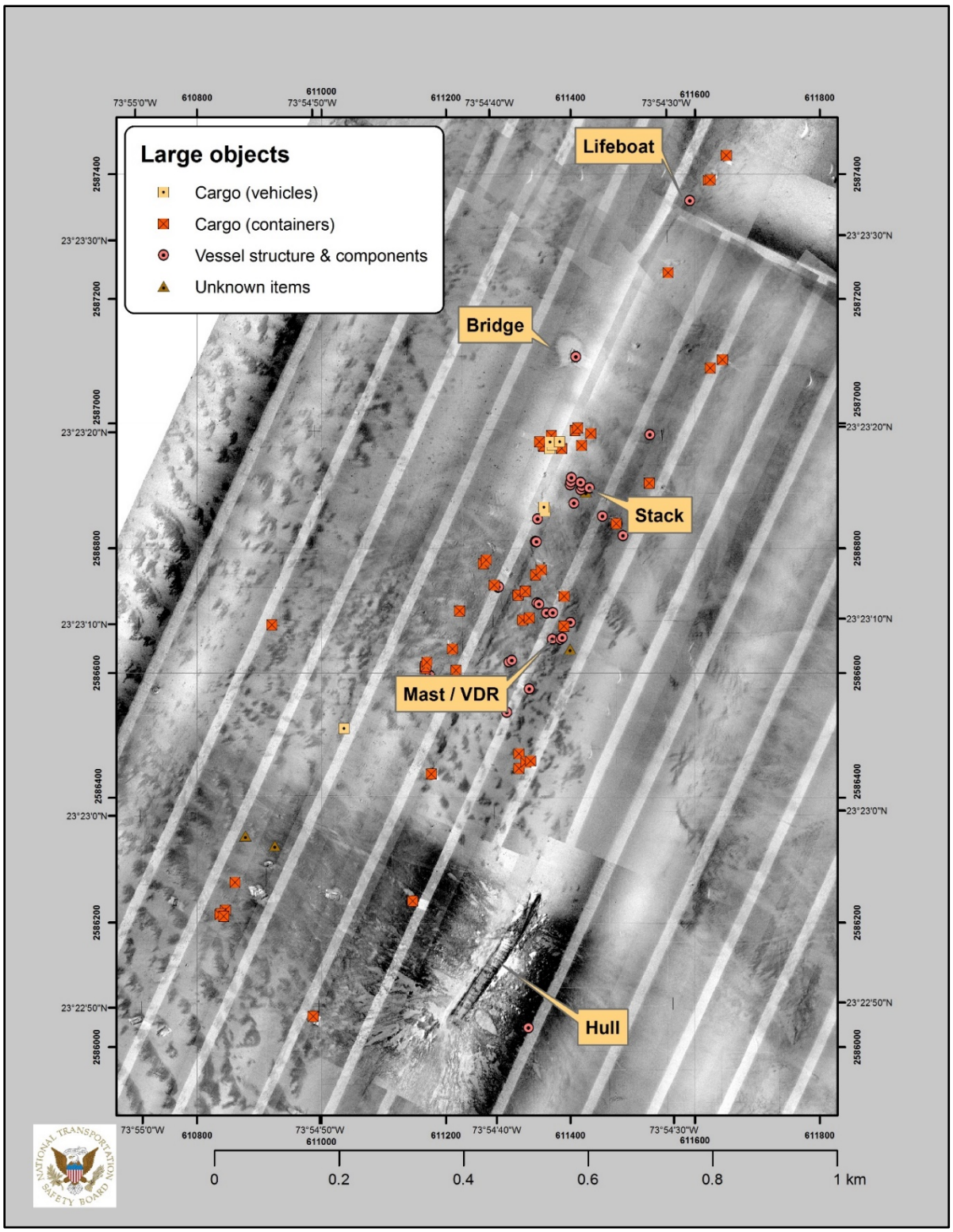


Figure 41. Sidescan sonar map of *El Faro*'s main wreckage field showing large items identified.

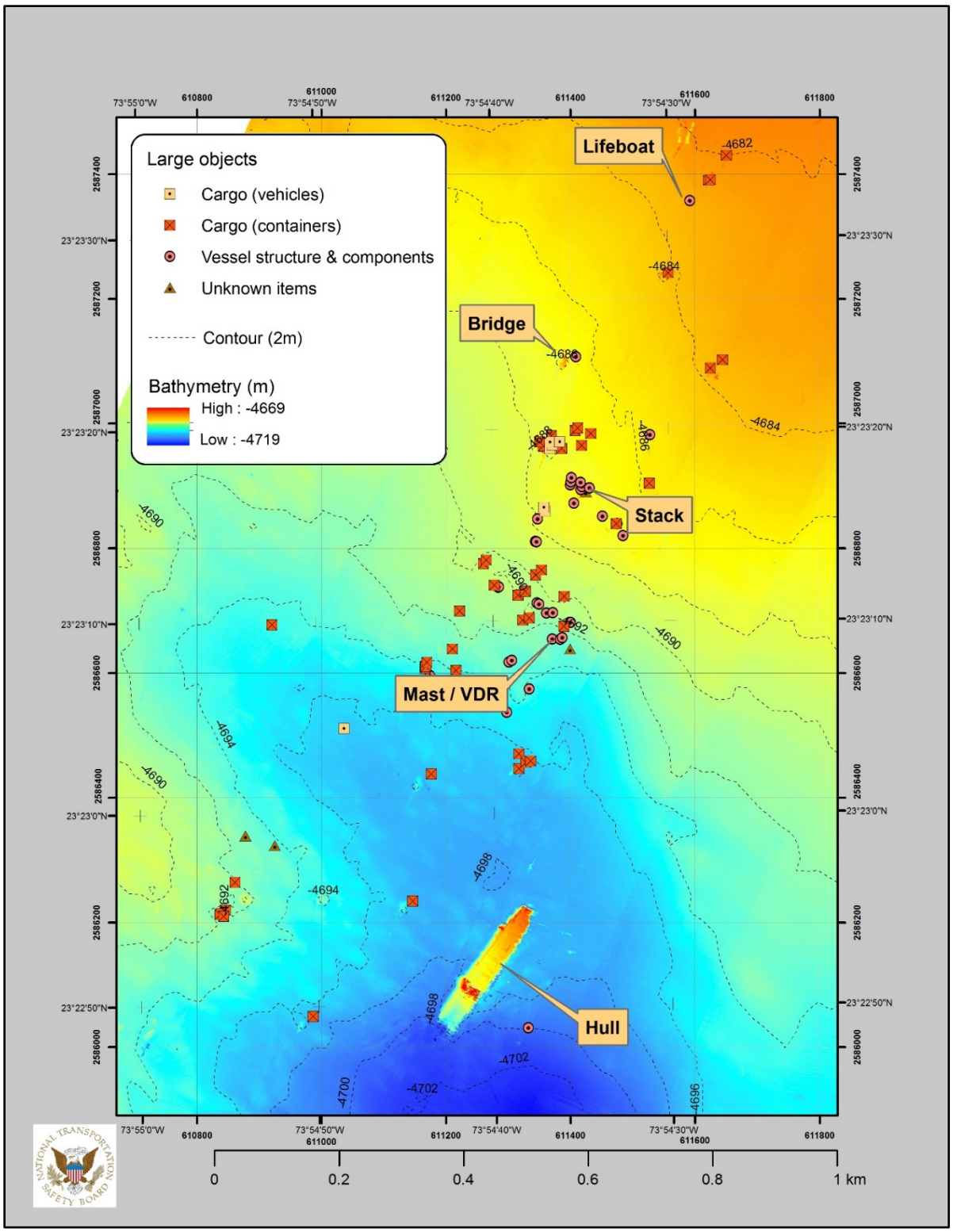


Figure 42. Bathymetric map of *El Faro*'s main wreckage field showing large items identified.

Surface and subsurface positions and times related to *El Faro* and the major debris are summarized as follows:

Description	Time	Position, Lat. (decimal)	Position, Lon. (decimal)	Depth, meters	Depth, feet	Source
Captain Reported Position to DPA	11:08 UTC (07:08 EDT) 2015-10-01	23.4383°	-73.8600°	-	-	NTSB, VDR Audio Transcription
Inmarsat-C Distress Alert	11:13:21 UTC (07:13:21 EDT) 2015-10-01	23.4667°	-73.8000°	-	-	NTSB, RE VDR Factual Report
SSAS Alert Message, received USCG	11:13:49 UTC (07:13:49 EDT) 2015-10-01	23.4232°	-73.8752°	-	-	NTSB, RE VDR Factual Report
SSAS Alert Message, received TOTE	11:15:57 UTC (07:15:57 EDT) 2015-10-01	23.4203°	-73.8780°	-	-	NTSB, RE VDR Factual Report
Last Recorded VDR Position	11:35:45 UTC (07:15:45 EDT) 2015-10-01	23.3925°	-73.9029°			NTSB, RE VDR Factual Report
Last Recoreded VDR Data	11:39:42 UTC (07:39:42 EDT) 2015-10-01	-	-	-	-	NTSB, RE VDR Factual Report
Liferaft (only 1 found)	00:57 UTC (2057 EDT) 2015-10-04	23.4867°	-73.5883°	surface	surface	NTSB, Survival Factual Report
Human Remains - unrecovered	20:47 UTC (1647 EDT) 2015-10-04	23.4267°	-74.1967°	surface	surface	NTSB, Survival Factual Report
Survival Suit 1	22:08 UTC (1808 EDT) 2015-10-06	23.4033°	-73.2350°	surface	surface	NTSB, Survival Factual Report
Survival Suit 2	18:33 UTC (1433 EDT) 2015-10-07	23.9800°	-73.3233°	surface	surface	NTSB, Survival Factual Report
Stbd lifeboat (#1)	19:00 UTC (1500 EDT) 2015-10-04	23.4033°	-73.9083°	surface	surface	NTSB, Survival Factual Report
Port lifeboat (#2)	n/a - 2016-04	23.392181	-73.90797511	4,683	15,364	NTSB-WHOI ARCGIS Wreckage Map
Bridge wreckage	n/a - 2016-04	23.389933	-73.90977787	4,687	15,377	NTSB-WHOI ARCGIS Wreckage Map
Mast &VDR wreckage	n/a - 2016-04	23.385950	-73.91008333	4,693	15,397	NTSB-WHOI ARCGIS Wreckage Map
Vessel Main Hull wreckage	n/a - 2016-04	23.381250	-73.91111667	4,697	15,410	NTSB-WHOI ARCGIS Wreckage Map

Wreckage, Approximate distance between hull (center) to bridge	965 meters, 1055 yards, 0.52 nautical miles	Measured from debris field map
Wreckage, Approximate distance between hull (center) to VDR/mast	525 meters, 575 yards, 0.28 nautical miles	Measured from debris field map
Wreckage, Approximate distance between hull (center) to exhuast stack	800 meters, 875 yards, 0.43 nautical miles	Measured from debris field map
Wreckage, Approximate distance from VDR/mast to bridge	460 meters, 503 yards, 0.25 nautical miles	Measured from debris field map
Wreckage, Approximate distance from main hull to port lifeboat (#2)	1,250 meters, 1,367 yards, 0.68 nautical miles	Measured from debris field map
Wreckage, Approximate distance from bridge to port lifeboat (#2)	230 meters, 252 yards, 0.12 nautical miles	Measured from debris field map

18.2 Examination of Main Wreckage

To establish the condition of and damage to the vessel's hull, bridge, main mast, stack, and lifeboat found on the seafloor, members of the Naval Architecture group (or their designee) met with members of the NTSB's Office of Research and Engineering on January 12–13, 2017, to review video and photographs associated with all three search and underwater recovery missions. The wreckage was investigated solely from photographs and video gathered during the three missions. The ship's hull, bridge, exhaust stack, mast, and lifeboat were examined.

Photos of the vessel's draft marks taken during the third mission showed that the hull was embedded between about 14.5 feet (port) to 12.5 feet (starboard) into the seafloor at the bow, and between and 24 feet (port) and 22.5 feet (starboard) at midships. Both the port and starboard aft draft marks were below the mudline and not visible. The mudline was found to be roughly 3 feet

below the second deck on the starboard stern quarter, which is equivalent to about 47 feet in the mud from the vessel's keel (baseline).

In general, *El Faro*'s main hull and separated bridge deck lie on a flat region of the seafloor in what appears to be soft sand and sediment. The hull is intact, but the house (superstructure) is missing its uppermost two decks (navigation bridge deck and lower navigation bridge deck) and the main mast and stack that were mounted on them. Except for a crushed 20-foot ISO tank container and trailer chassis located outboard on the port side of the main deck at bay 2, and another 45-foot container on the starboard side at about bay 7, no containerized cargo units remain on the main deck.

The main hull has about a 3-foot crack at container bay 16, which extends from the port side mudline, vertically up to the main deck, and across the main deck until terminating at the covered ramp opening aft of the house. The main deck forward of the crack is at an angle of about 2° from the seafloor, while aft of the crack its attitude is about 6°. The transverse attitude of the hull forward of the house is down about 3° to the port side relative to the seafloor. Aft of the house it is about 4° down to the port side. Forward of the crack the hull is minimally damaged, but aft of it the main deck has a large longitudinal seam and extensive deformation of the transom-style stern, particularly on the port side of the transom.

During the second mission, *El Faro*'s port lifeboat was discovered north of the bridge, at a depth of 15,364 feet (see **figure 43)**. The lifeboat was about 754 feet (0.12 nautical mile) north-northeast of the bridge wreckage and about 0.68 nautical mile (4,101 feet) north-northeast of the center of *El Faro*'s hull. The stern of the lifeboat was missing and was not discovered elsewhere.

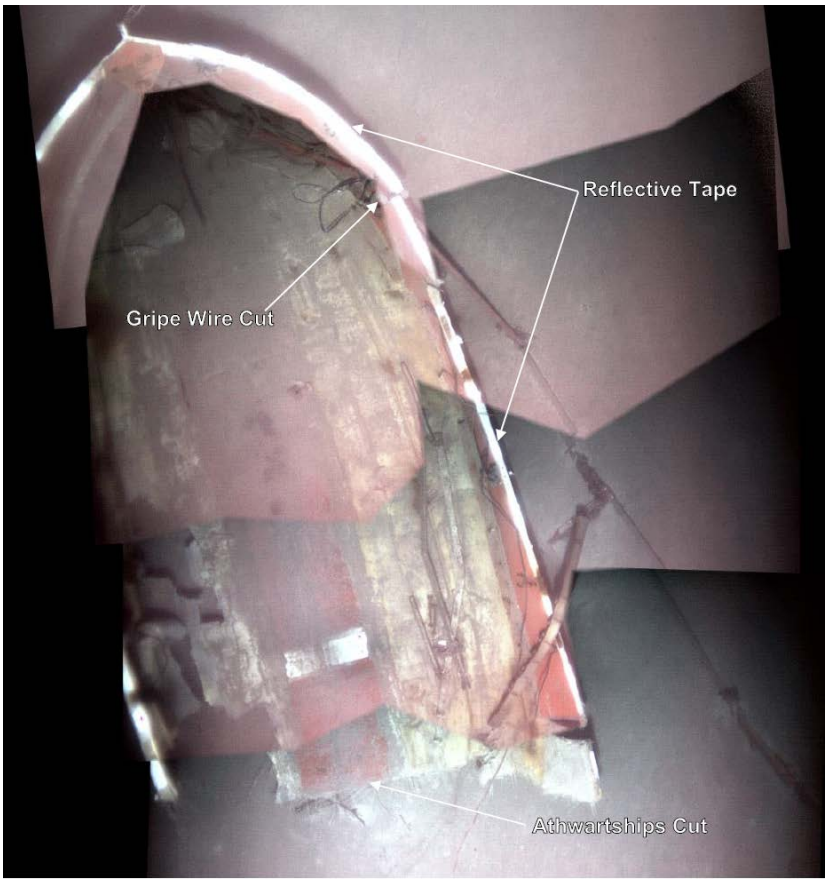


Figure 43. Photomosaic of *El Faro*'s port lifeboat from images taken by AUV during second search mission. Bench seats and other internals are missing. Reflective tape on top of gunwales is illuminated.

El Faro's exhaust stack was discovered during the second mission about 2,625 feet (0.43 nautical miles) north of the main hull (**figure 44**). The forward face was missing its steel plating and the stack was scratched, dented, and deflected inward, but it was largely intact. The boiler uptake funnel was missing from the top.

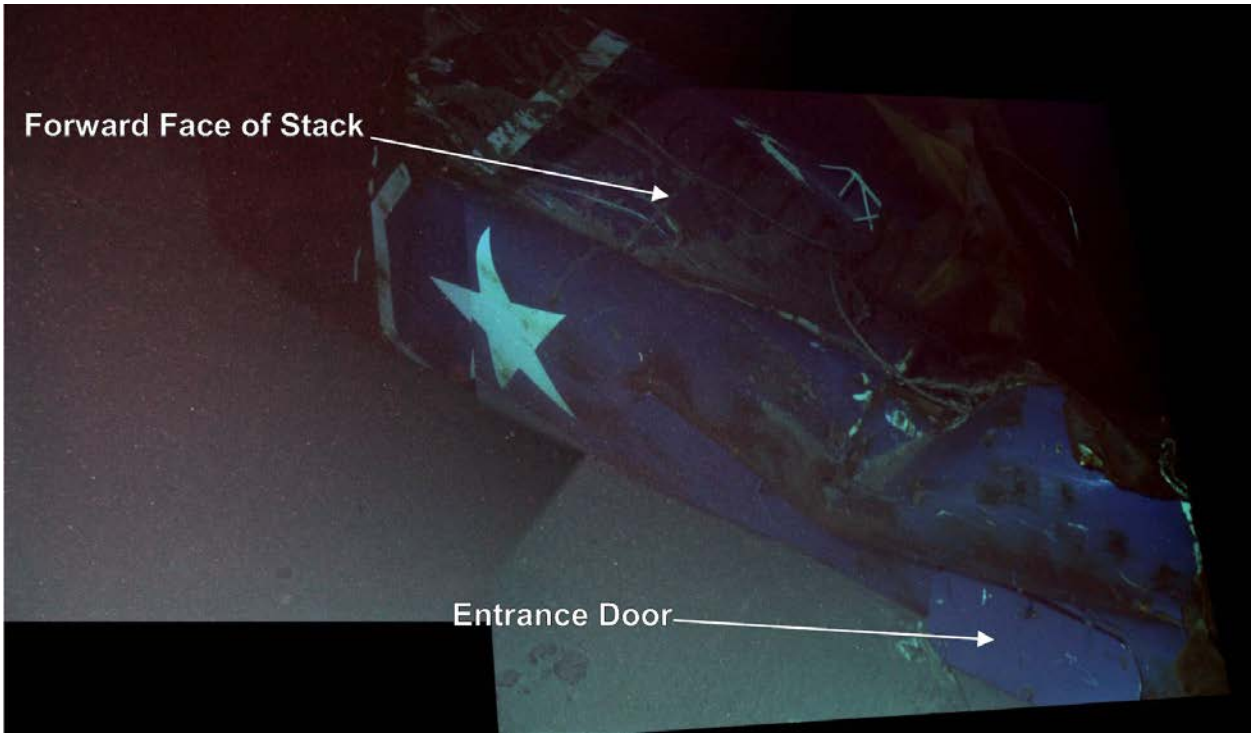


Figure 44. Exhaust stack lying on seafloor, Sea Star (company) symbol clearly visible (photomosaic image from mission 2).

The tripod mast and VDR capsule were discovered on the seafloor about 1,640 feet (0.28 nautical miles) north of the main hull (**figure 45**). The main structural members were intact, though the overall structure was bent aft. The VDR was attached to the port leg and buried in mud.

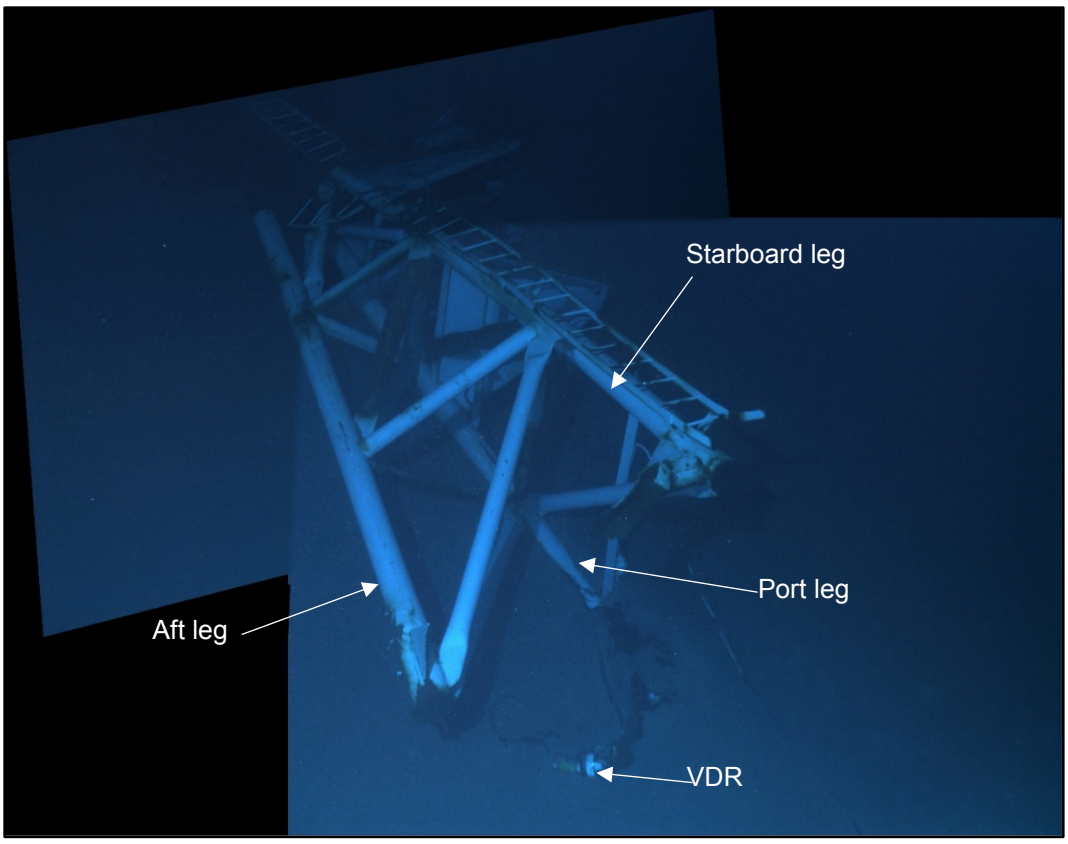


Figure 45. Mast and VDR capsule on seafloor (photomosaic image from mission 2).

The navigation bridge and bridge deck that had been discovered during the first mission were further explored during mission 2. The photomosaic image in **figure 46** shows that the main mast was missing, all windows on the forward side of the bridge were missing, that the windscreen bulwark was bent forward, with mud piled in front of it, and that the top railings were missing, severely bent, or broken. The starboard forward corner of the wreckage was deeper into the seabed than the other corners. A blue bag was noted on top of the bridge.

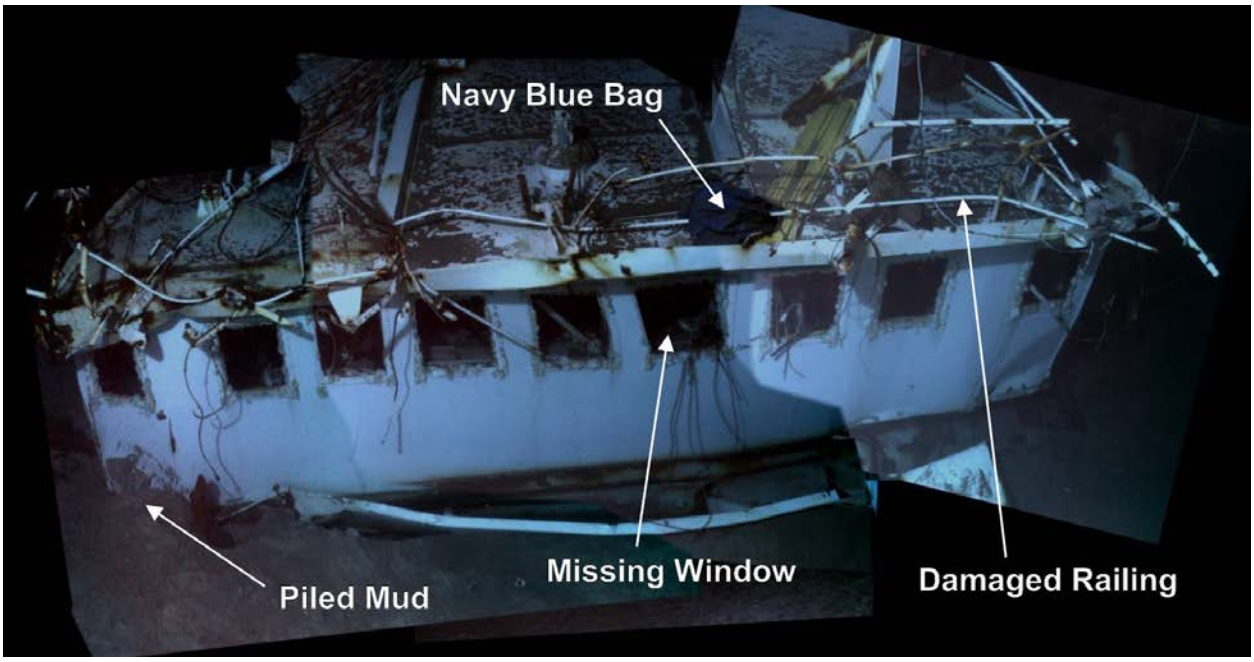


Figure 46. Bridge and bridge deck, looking aft (photomosaic image from mission 2).

As documented during all three missions, the port side of the ship was intact, though dents on the forward side of the supply vent blisters were observed. The starboard side was intact forward of Bay 16. At Bay 16, major hull damage included a large vertical fracture on the starboard side, estimated to be 3 feet wide at the main deck and extending across the deck to the port side ramp opening (**figure 47**). Major damage and fractures were also observed at the stern, including a hull longitudinal fracture extending about 20 feet forward of the transom, which was torn open down to the second deck (**figure 48**). The main deck on the starboard side was severely buckled and inset about 8 feet from the deck edge at frame 234. A gunwale plate on the main deck wing near bay 17 was also deformed.

Figure 47. Hull fracture in starboard side shell and across main deck at container bay 16, just forward of frame 200 (mission 3 image).

Figure 48. Tear in ship's transom (mission 3 image).

In the bow region, the foremast was toppled toward the port side (**figure 49**) and the bow plating was pushed in ("inset"). Hawsers (mooring lines) were observed streaming upward from the debris.

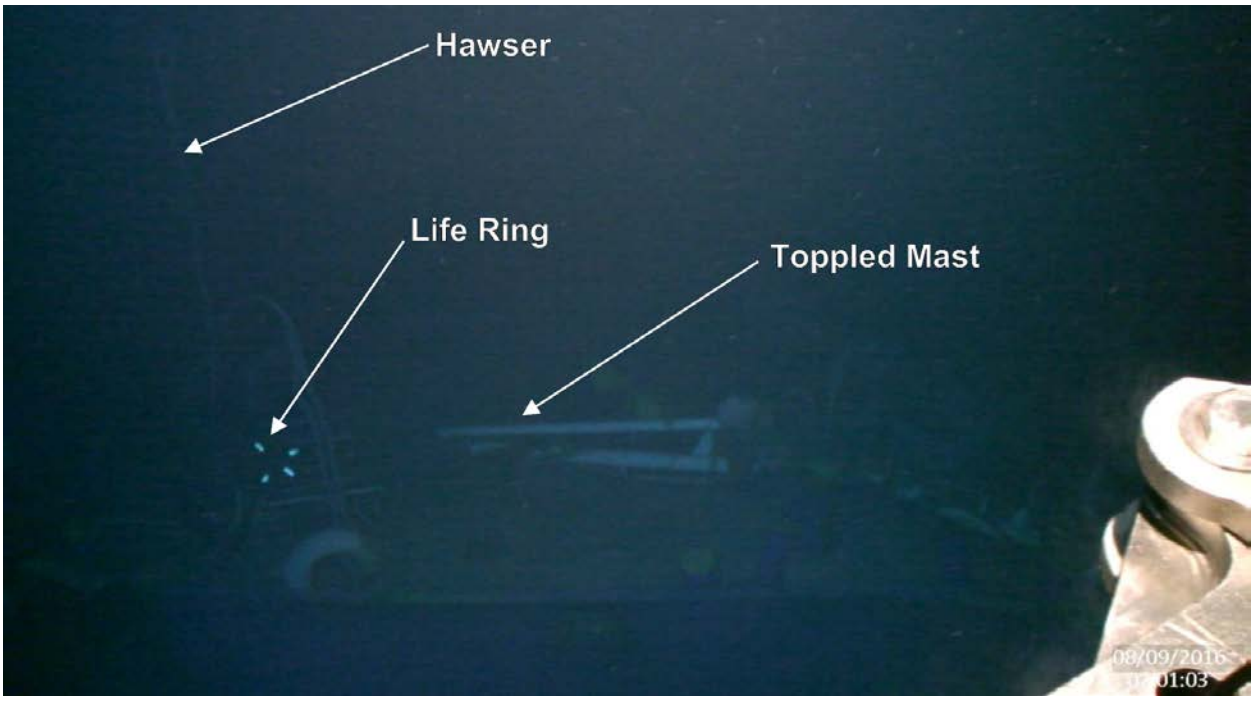


Figure 49. Foremast toppled on port side of bow; reflection is from lifebuoy on railing next to hawser (mission 3 image).

The state of the cargo remaining on the ship was observed. A refrigerated container exhibiting hydrostatic crush damage (damage caused by water pressure) protruded from the vehicle opening near bay 15 on the starboard side (**figure 50**). In bay 2, a 20-foot tank container was crushed but still mounted to its stowage location, with a trailer chassis inboard of it (**figure 51)**. Metal flashing hanging over the deck on the port side was determined to be part of the cargo, while fire hose and broken railing sections were hanging over portions of the starboard side.

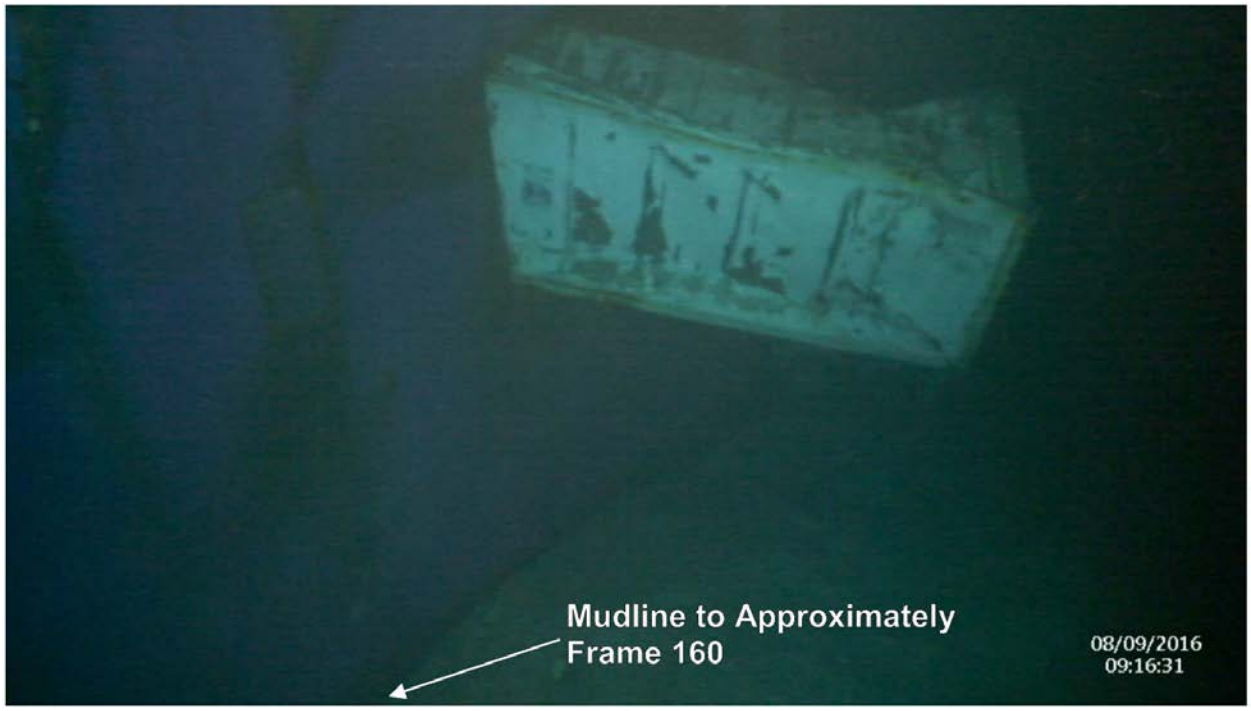


Figure 50. Refrigerated container protruding through vehicle opening at frame 156, starboard side (mission 3 image).

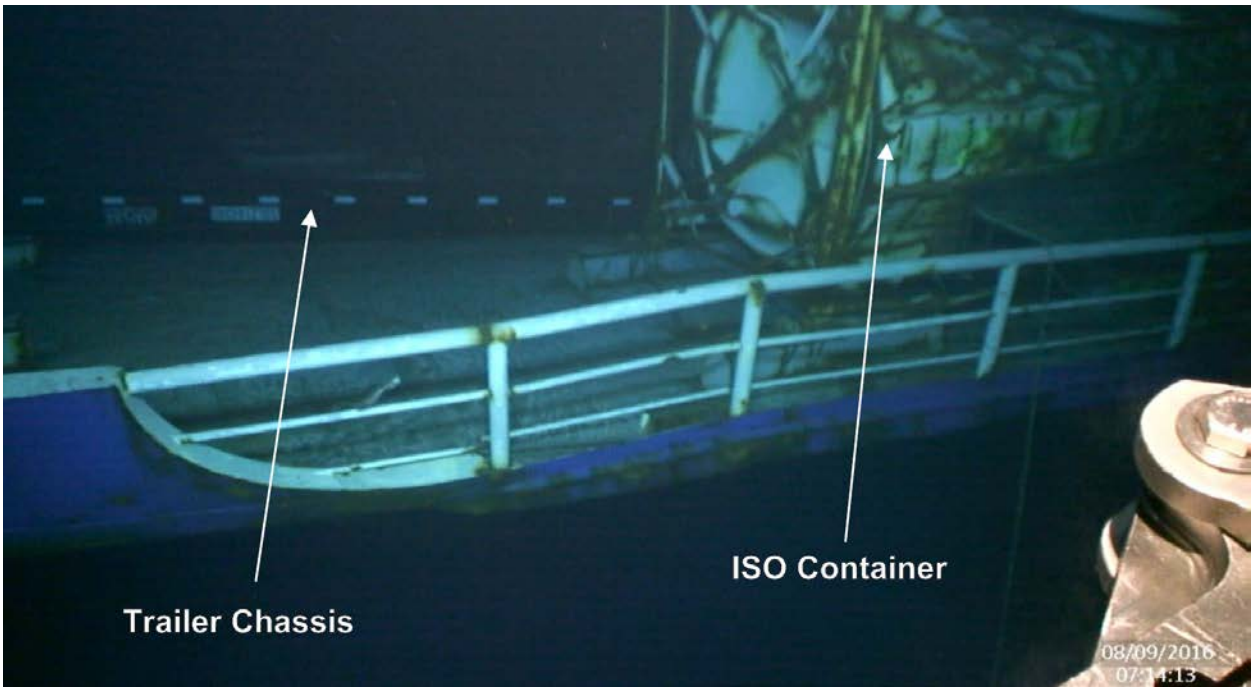


Figure 51. Crushed tank container in bay 2, starboard side (mission 3 image).

The cargo mountings and transfer (support) beams were examined. The fiberglass deck grating was generally missing from the container support beams (**figure 52**). Undamaged container support beams were found forward of the house, however. Both twisted and intact transfer beams were found.

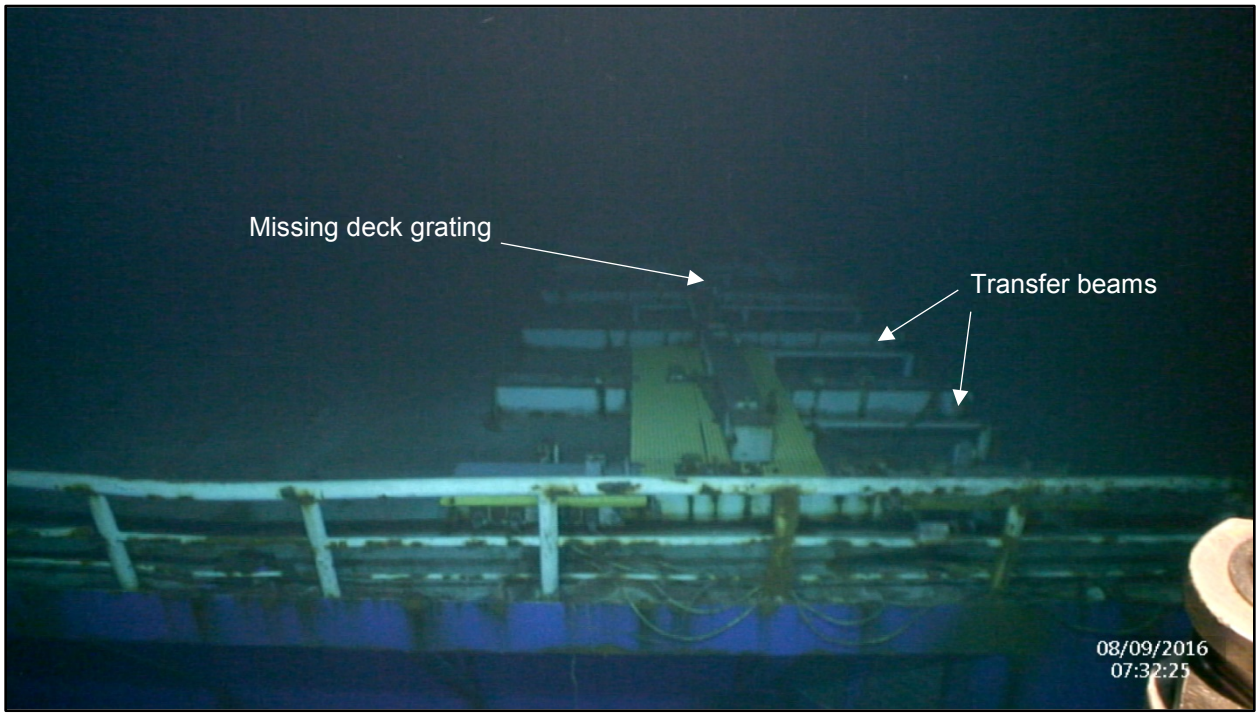


Figure 52. Fiberglass deck grating missing from container support beams, port side at frame 134/10 (mission 3 image).

Missing or bent deck rails were observed all around the ship. Damaged or missing louvers on the air intakes to the cargo holds were also observed. Some fire stations were found intact, others were missing from their mounting locations. Two lifebuoys along the deck rails were observed missing from their remaining mounts, one was found intact at the port bow. A 6-person liferaft and its container were missing from their position at the bow. A personal flotation device (PFD) was observed entangled on the boat deck walkway (**figure 54**).

Figure 53. PFD entangled on boat deck walkway, near ladder down to cabin deck (mission 3 image).

Windows observed in the deckhouse appeared to be intact. The forward side of the deckhouse showed extensive scratches and dents, predominantly on the port side **(figure 55)**.

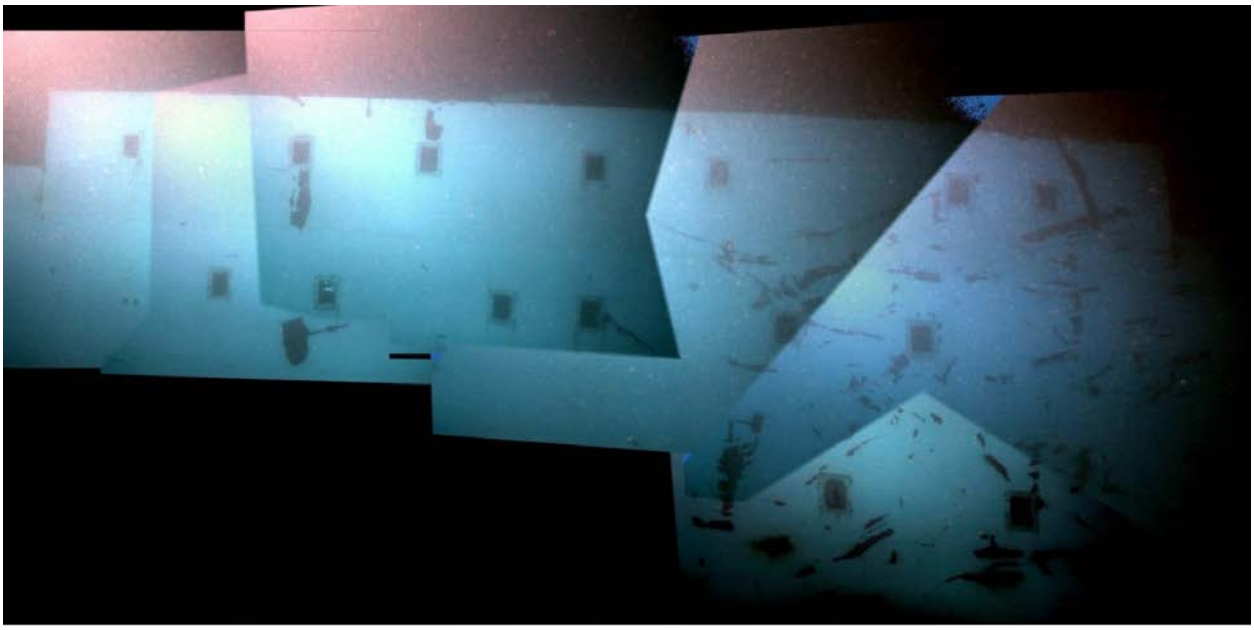


Figure 54. Remaining upper part of forward side of deckhouse showing more scratches and dents on the port side than on the starboard side (mission 2 AOV mosaic image).

The gravity davits for the starboard lifeboat were generally intact (**figure 56**). The arm for the forward davit was displaced and resting on the deck, but the arm's cable was still attached to the track. The gravity davits for the port lifeboat had greater damage, with the aft track and davit broken and the forward davit hanging (**figure 57**).

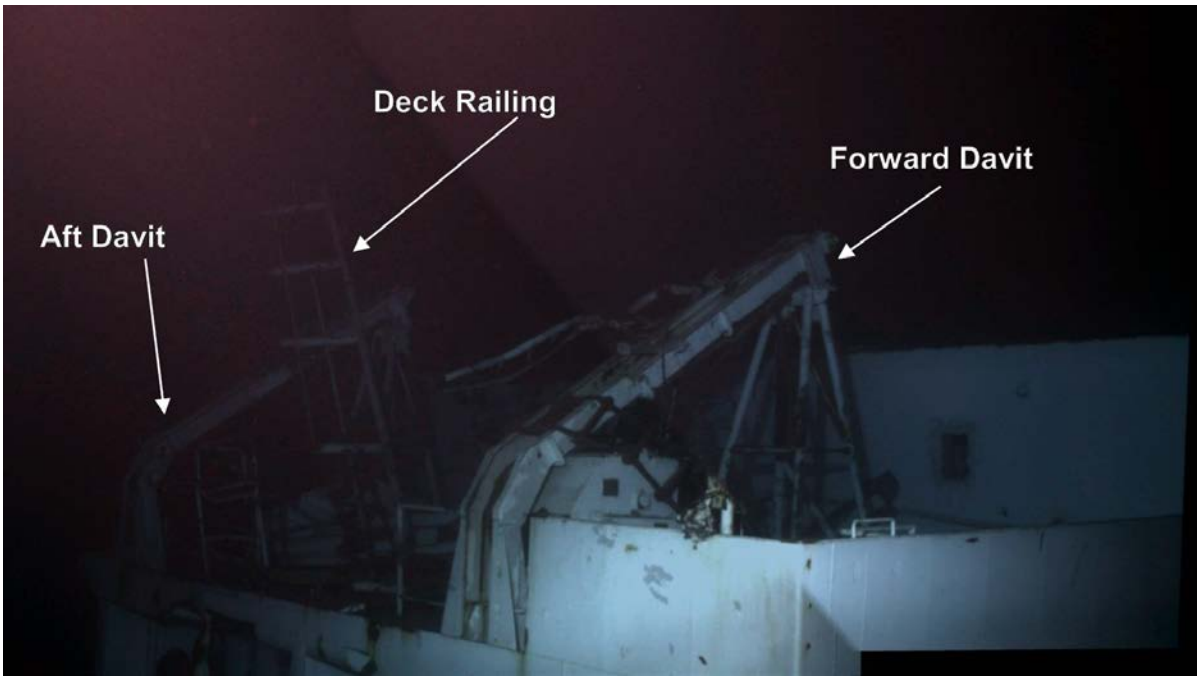


Figure 55. Intact gravity davits for starboard lifeboat, with forward davit in foreground (photomosaic image from mission 2).

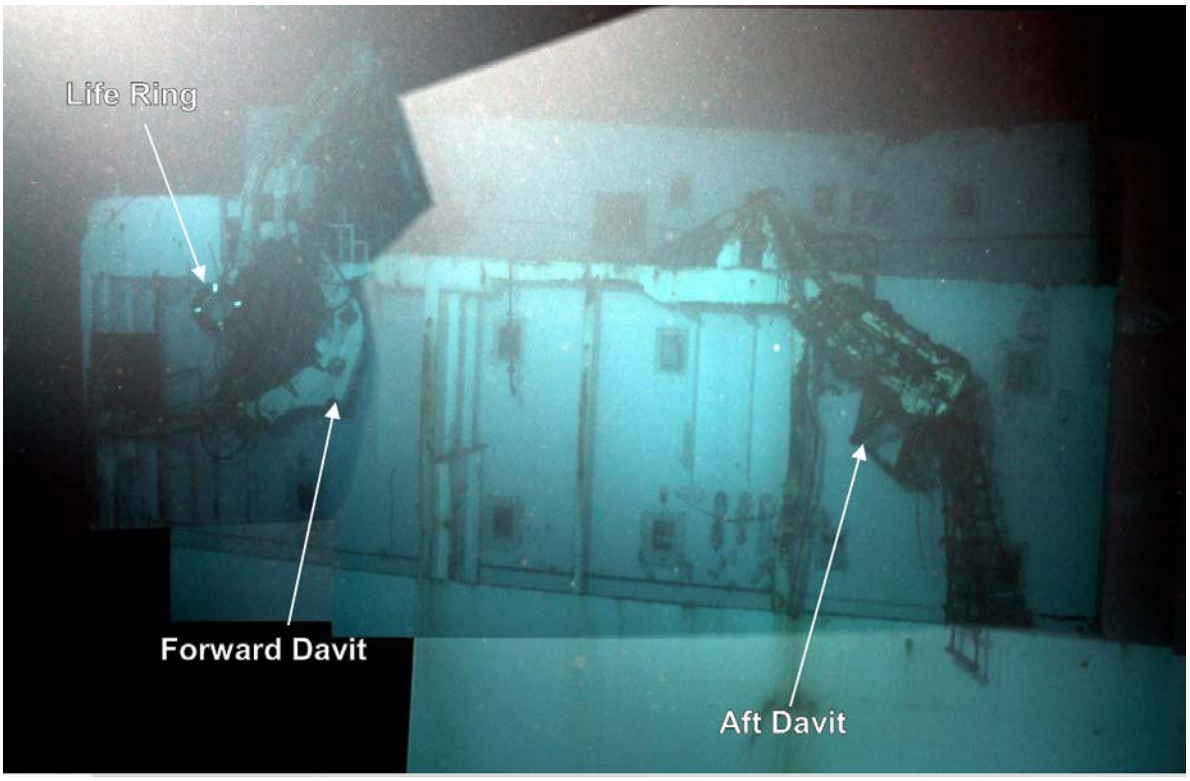


Figure 56. Portside gravity davits showing forward davit track in place but davit damaged. Aft davit track and davit are broken loose and hanging aft (mission 2 AOV mosaic image).

18.3 Hawsers and Ropes Streaming from Wreckage

Entanglement hazards found on the hull and the separated bridge were recorded in a brief summary report.[351] **Figure 58** depicts lines found at the bow of the wreckage. Lines were also found streaming from *El Faro*'s stern, and a mooring hawser was streaming from the detached bridge.

[351] Entanglement Hazards at Wreckage Site, as found with OV (CAMPER) and AUV (SENTRY), RV Atlantis, AT33-04 *El Faro* VDR Search and Debris Field Map, NTSB & USCG, 3 May 2016

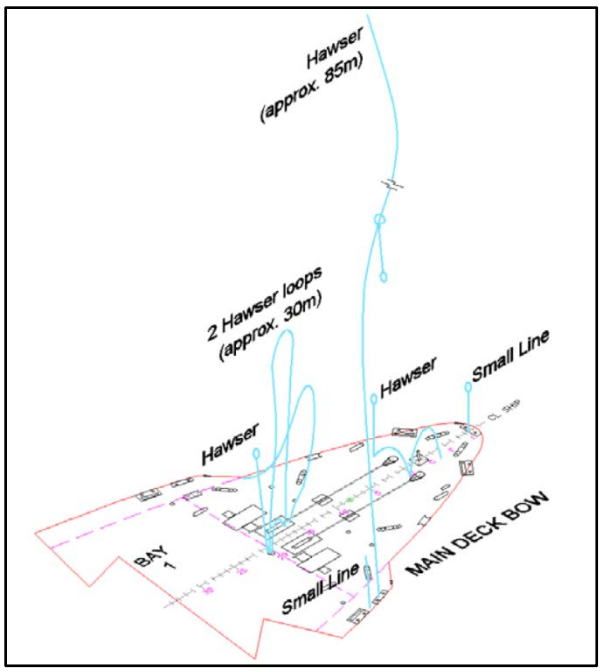


Figure 57. Graphic depiction of lines streaming upwards from bow of *El Faro* wreckage.

18.4 Rendering of Main Hull Wreckage

Poor visibility on the seafloor precluded efforts to create a photomosaic of the entire hull for forensic analysis. In addition, the ropes and hawsers streaming upwards from the wreckage did not permit high-resolution sidescan imaging of the main hull or bridge on the second mission. Therefore, the Naval Architecture group worked with Research and Engineering staff and an in-house graphic artist to render *El Faro* main hull wreckage in three dimensions using (1) a 100-meter altitude "dense" multibeam bathymetric survey performed on search mission 2 and postprocessed by Woods Hole Oceanographic Institution,[352] (2) a simple three-dimensional model of the vessel from the Coast Guard, and (3) video images and photographs of the hull on the seafloor from all three search-and-recovery missions.

At the time of this report, the rendering is not complete.

[352] *El Faro* Post Cruise Data Processing, Woods Hole Oceanographic Institution, September 1, 2016.

19 STUDIES, RESEARCH AND TESTS

19.1 Dynamic and Forensic Sinking Analysis of *El Faro*

19.1.1 Background

Historically, safety regulations with regard to ship capsizing are based primarily on static stability concepts. Although a margin of safety is built into regulations, it is well accepted that the capsizing of a ship is a dynamic phenomenon. This means that some ships that have conventionally accepted stability may be at greater risk than other similarly sized vessels at certain speeds in certain wave and wind conditions. Static stability analysis uses the vessel's stability curve and loading condition, whereas dynamic stability adds the wind and waves, vessel speed, and heading. At this time, there are no federal (CFR) or international standards requiring dynamic modeling and analysis to assess vessel stability.

Simulating ship motion in an irregular seaway, which is closer to the actual conditions a ship may encounter in extreme weather, is an additional method for investigating vessel motions in storm conditions and the vulnerability of the vessel to capsizing. Dynamic analysis (seakeeping) simulates the motion of a ship in both regular and irregular waves. The analyses predict the time rate of change of each of a vessel's six degrees of freedom (roll, pitch, yaw, heave, surge, sway) using the net forces and moments acting on the vessel at each point in time. Such time-domain simulations may be used to predict the probability of a vessel "capsize," which is typically defined by a predetermined roll angle where downflooding occurs, or where the stability curve becomes negative. Although more computationally complex, it is generally accepted that assessing vessel dynamic stability with a dynamic analysis can potentially produce more accurate results.

Vessels such as *El Faro* have cargo securing mechanisms for both above deck containers and lower deck Ro/Ro vehicles and trailers. The mechanisms are intended to hold cargo items to

a predetermined maximum load. The loads are based on the weight of the secured item, the number of fittings, and the acceleration of secured item. Green water building over an area (hydrostatic pressure) and impacts on exposed cargo (wave slap) may impart additional forces on securing mechanisms.

19.1.2 Purpose and Approach

During the first months of the investigation, *El Faro*'s VDR capsule had not been found and future efforts to retrieve it and successfully download its data were not guaranteed. Investigators desired greater understanding into the potential scenarios resulting in the loss of *El Faro*. The NTSB chartered the company CSRA, with the objective of obtaining additional dynamic analyses for the *El Faro* sinking that would yield probabilities of the vessel's range of movement and accelerations, hydrostatic pressure and wave slap at various locations modeled in irregular waves, and storm weather conditions over time. The analyses considered the vessel underway, dead in the water, and dead in water in flooding scenarios. Brief analyses of the sinking, the seabed impact, and the debris field were desired to compare the observed results to surface events that could have led to the sinking.

An iterative, collaborative approach was developed to allow for meetings between involved parties to assess results of scenarios and propose alternate model runs with updated inputs based on new evidence and facts. This included CSRA incorporating government-supplied data from the *El Faro* investigation, and importantly, providing the wind and wave spectra data files (hindcast simulations) NTSB obtained to CSRA for modeling the ship in. The Coast Guard Marine Safety Center (MSC) also assisted in the effort by providing three-dimensional hull models, static analysis data from its own analysis, and the ongoing participation of technical experts.

19.1.3 Results

CSRA developed an approach to modeling the vessel in irregular waves and storm winds and analyzing vessel motions (**figure 59**). The completed analyses will provide time-domain simulations and visualizations of vessel motions in hindcast hurricane-force winds and seas. At the time of this report, the study was not complete.

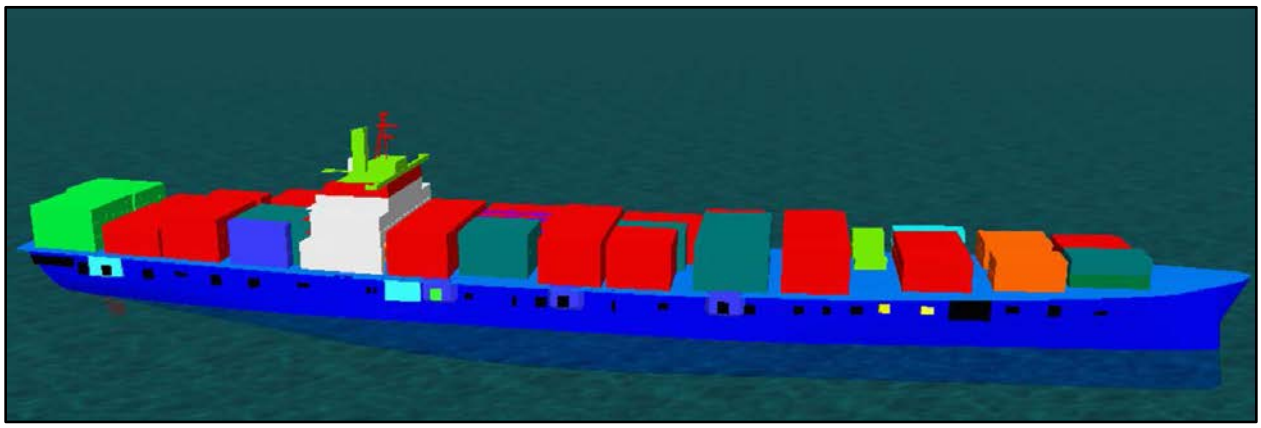


Figure 58. Dynamic analysis model of *El Faro* in loading condition on accident voyage. (CSRA graphic)

19.2 Analysis of Main Propulsion Lube Oil Sump Levels

The VDR audio transcription showed ongoing discussion of the lube oil level in the main propulsion turbine sump as factoring in the vessel's loss of propulsion. Investigators wanted to know how *El Faro*'s reported heel angles may have contributed to difficulty in maintaining lube oil pressure for the main propulsion turbines. Initially, investigators determined the typical operating oil level and then graphically studied the effect of increasing heel angles on the lube oil level at the lube oil pump's suction bellmouth in the sump. This exercise revealed that the starboard offset of the lube oil pump suction bellmouth would likely result in a loss of suction at a smaller angle of heel to port than to starboard. Lube oil sump drawings indicated that *El Faro* had an 8-inch-diameter suction pipe fitted with a concentric bellmouth. The centerline of the bellmouth was

not directly dimensioned on the drawing, but was scaled off the drawing as 21 inches to starboard of the sump (and vessel) centerline. The bellmouth's lower lip terminated 10 inches above the sump bottom.[353] Drawings indicated that the main sump on *El Yunque* was similar to *El Faro*'s. Investigators measured the position and size of the suction bellmouth on *El Yunque* in January 2017 as follows: 12-inch diameter at bellmouth, located about 9 inches above sump bottom, and center of bellmouth about 17 inches to starboard of vessel centerline. The sounding table for *El Faro*'s main lube oil sump was not available, but *El Yunque*'s was obtained. Investigators estimated an oil level of 26 inches, based on engineering logbook entries for the previous 2 years.[354] Twenty-six inches corresponded to 1,346 gallons on *El Yunque*'s sounding table.

Investigators found no evidence of modifications to the lube oil sump in 1993, 2006 or through the life of the vessel.

The Coast Guard MSC modeled and statically analyzed the lube oil levels for the three tanks associated with the main propulsion lube oil system.[355] The MSC report concluded that with a main sump oil volume of 163.8 cubic feet, as shown in the CargoMax printout[356] for the accident voyage,[357] and a 5-foot trim by the stern (0.4°), the bellmouth opening would break the oil surface

[353] Connections on Lube Oil Sump Tank, Sun Drawing 663-904-04, Alt. 9, about 1976 (MBI Exhibit 408).

[354] The Engineering Group Factual report for this accident (NTSB No. DCA16MM001) notes that available engine logs, for the year preceding the accident voyage, show that: (1) lube oil levels predominantly range from about 23 inches to 28 inches (2) About 9 soundings, out of about 1800 recorded entries (soundings), noted the level was 29 inches (3) No record of a soundings more than 29 inches were observed. The last known lube oil tank sounding level, from the engine log for September 1, 2015, was entered as 26 inches.

[355] SS *El Faro* Lube Oil Modeling and Static Analyses Results, Enclosure to MSC Memorandum Serial C3-1700713, 3 April 2017 (MBI Exhibit 412)

[356] Lube oil weight in CargoMax was a relatively insignificant portion of weight in comparison to cargo and fuel. Engine room logs of lube oil level for the main engine are observed and recorded every four hours (per each watch rotation).

[357] CargoMax Printouts, EF185JX, printed 1 October 2015 at 11:48 (MBI Exhibit 059).

at an 18° port list (163.8 cubic feet equates to 1,226 gallons, interpolated for *El Yunque's* sounding table is about 24.68 inches). **Figure 60** shows the graphic results of the MSC analysis.

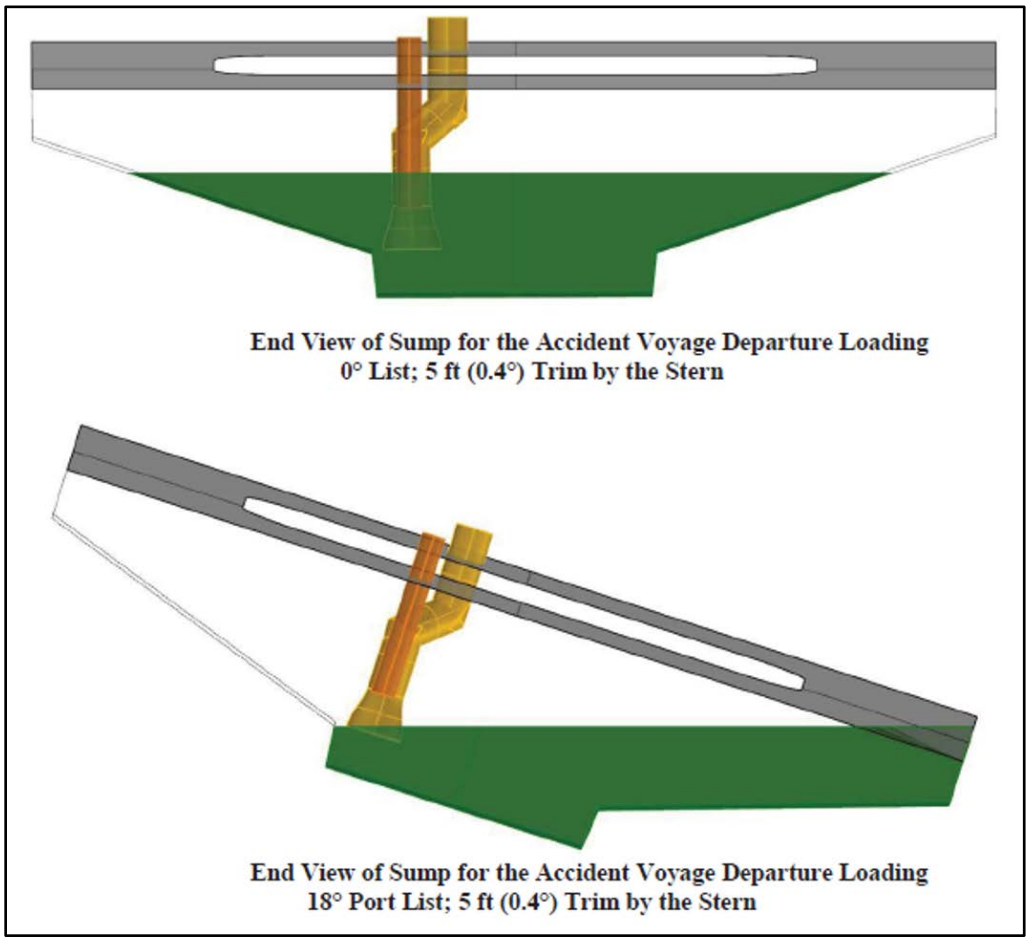


Figure 59. Looking aft at model of main engine sump. Effect of port list on oil level at suction bellmouth, main lube oil sump. (Illustration from Coast Guard MSC lube oil modeling and static analysis)

ABS reviewed the design considerations and approvals for the lube oil system, including the approved drawing and advised the Coast Guard MSC, that: (1) ABS approved the lube oil system based on the 1973 ABS Steel Vessel Rules (SVR); (2) the nominal level for the sump according to the approval for *El Yunque* was 27 inches or 1,426 gallons of innage; (3) that ABS approval of the lube oil system does not guarantee that the vessel can conduct sustained operations in the extreme dynamic environment experienced; (4) *El Faro's* lube oil system's approval was

proper and in accordance with the ABS SVRs.[358] Post-accident, ABS provided its own calculation model to demonstrate that the lube oil system met the criteria set forth by the SVRs, applied to an operating level of 1,426 gallons (ABS stated normal operating level).

19.3 Study of GPS Antenna Height and Position

On downloading the VDR data, investigators noted a recorded parameter for the height of *El Faro*'s GPS antenna. Investigators hypothesized that these data alone, or combined with latitude and longitude data for the same antenna, might provide useful information about the vessel's rate of sinking, roll period, or angle of heel. At the request of the Naval Architecture group, the NTSB Office of Research and Engineering reviewed and analyzed the data channel for antenna height **61**). The office's study stated: "GPS altitude data is not as accurate as GPS position, with significant errors accumulating over long periods of time, but can be expected to be good over short time periods point to point."[359] The study concluded in part that the recorded GPS altitude contained "an approximately 12 second roll period that grew in magnitude as the ship moved closer to the storm ranging to approximately +/- 4.5 meters" and that the oscillation "was at least partially the result of pitch and/or heave motion." The contribution of roll motion could not be ruled out, but was most likely small (see **figure 61**).

[358] Joint Response to the U.S. Coast Guard Marine Safety Center's Technical Reports Concerning the SS EL FARO Stability and Structures. Submitted by Parties in Interest, 17 January 2017, Section E, Design Considerations.

[359] *Ship Dynamics from VDR Data Study*, NTSB Office of Research and Engineering, *El Faro*, DCA16MM001, 29 January 2017.

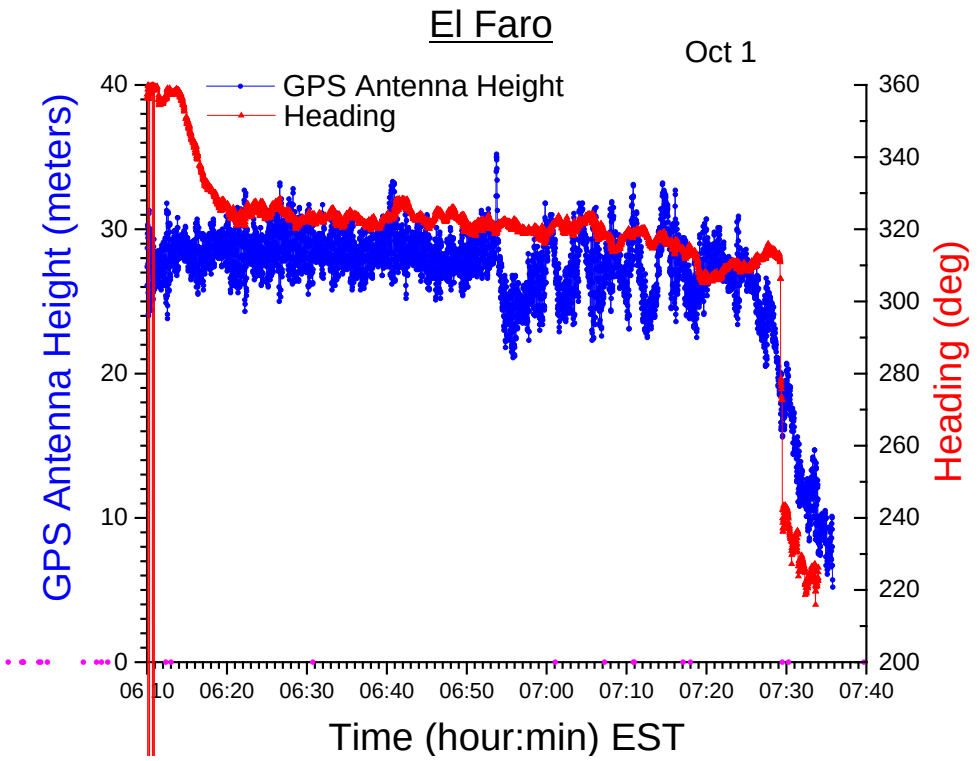


Figure 60. VDR GPS antenna height for the last 1 1/2 hours of voyage. Antenna was about 97.7 feet (29.8 meters) above vessel's static, even-keel waterline prior to sinking.

20 POSTACCIDENT ACTIONS

At the time of this report, Naval Architecture group investigators were aware of the following related postaccident actions:

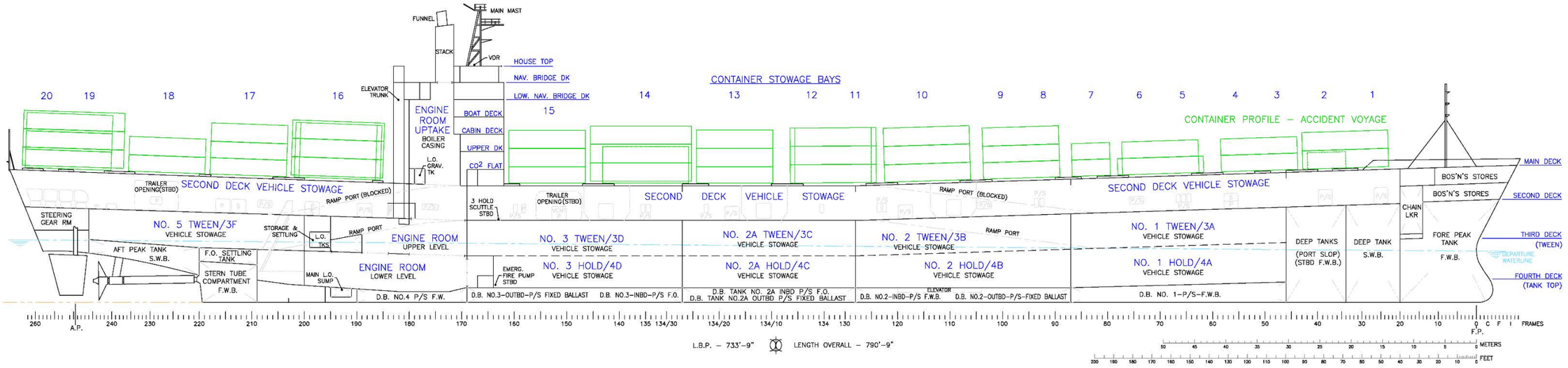
- When operating under way on *El Yunque*, new procedures for transiting through a second deck scuttle require crewmembers to notify the bridge when opening and closing the hatch.[360]

[360] Interview transcript, past chief mate *El Faro* and second mate *El Yunque*, p. 112, 12 December 2015.

- TOTE decommissioned *El Yunque.* Testimony indicated that it was related to business decisions and newly built ships replacing old vessels on the Jacksonville-to-Puerto Rico run.

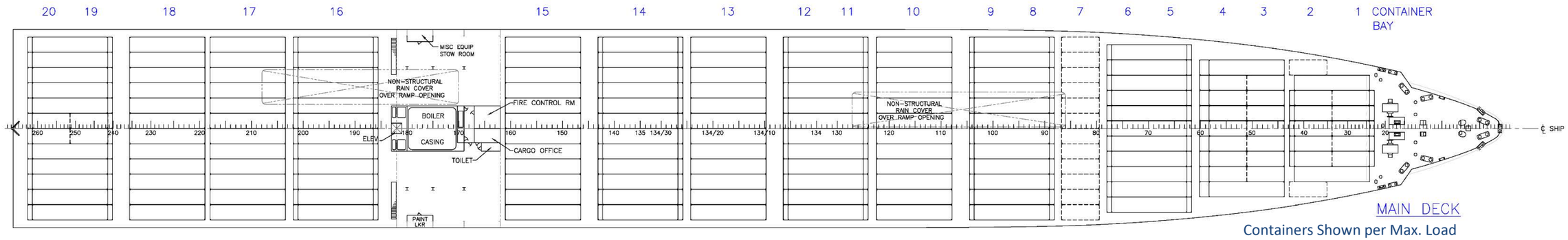
21 APPENDIX A - SIMPLIFIED *EL FARO* PROFILE AND DECK PLANS

Compiled from 2006 general arrangement and capacity plan drawings, and vessel photographs.



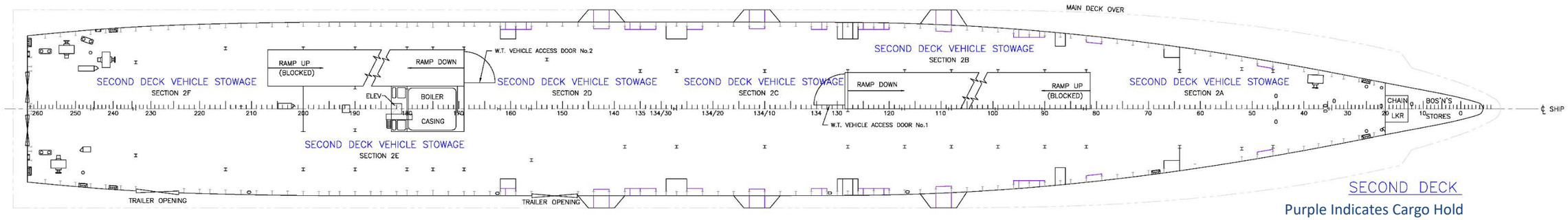
SIMPLIFIED PROFILE

Container Profile and Waterline per Departure Loading on Accident Voyage



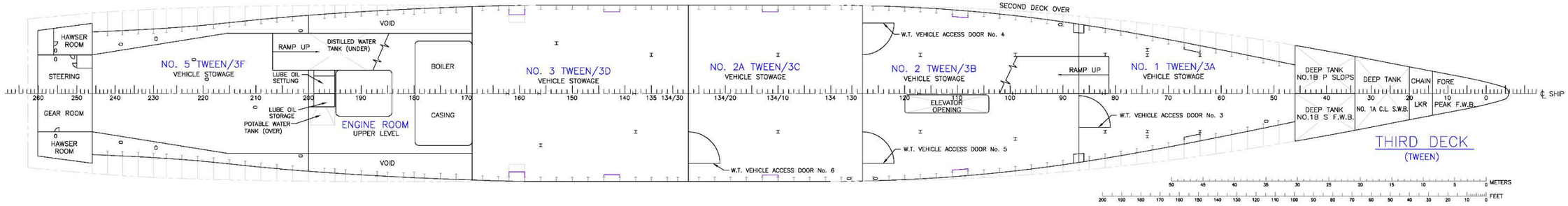
MAIN DECK

Containers Shown per Max. Load
(not accident voyage)

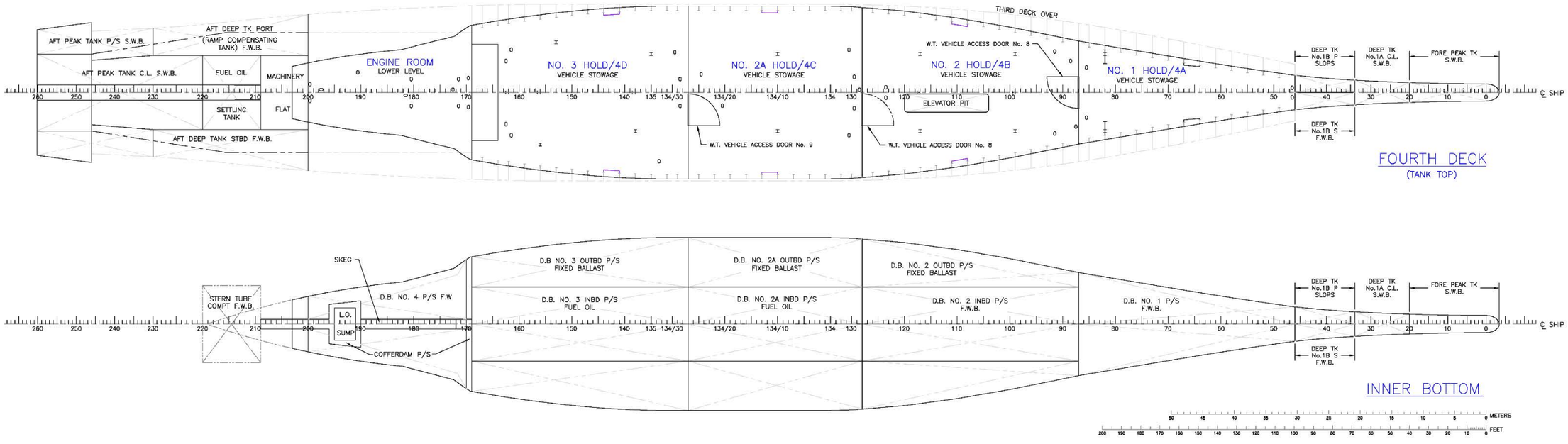


SECOND DECK

Purple Indicates Cargo Hold
Ventilation Trunks (Hold 1, 2, 2A & 3)



THIRD DECK
(TWEEN)


AFT PEAK TANK P/S S.W.B.
AFT DEEP TK. PORT (RAMP COMPENSATING TANK) F.W.B.
AFT PEAK TANK C.L. S.W.B.
FUEL OIL
MACHINERY
SETTLING TANK
FLAT
AFT DEEP TANK STBD F.W.B.
ENGINE ROOM LOWER LEVEL
NO. 3 HOLD/4D VEHICLE STOWAGE
NO. 2A HOLD/4C VEHICLE STOWAGE
NO. 2 HOLD/4B VEHICLE STOWAGE
NO. 1 HOLD/4A VEHICLE STOWAGE
THIRD DECK OVER
W.T. VEHICLE ACCESS DOOR No. 8
ELEVATOR PIT
W.T. VEHICLE ACCESS DOOR No. 9
W.T. VEHICLE ACCESS DOOR No. 8
DEEP TK No.1B P SLOPS
DEEP TK No.1A C.L. S.W.B.
FORE PEAK TK S.W.B.
DEEP TK No.1B S F.W.B.
℄ SHIP
FOURTH DECK
(TANK TOP)
SKEG
STERN TUBE COMPT F.W.B.
L.O. SUMP
D.B. NO. 4 P/S F.W
COFFERDAM P/S
D.B. NO. 3 OUTBD P/S FIXED BALLAST
D.B. NO. 3 INBD P/S FUEL OIL
D.B. NO. 2A OUTBD P/S FIXED BALLAST
D.B. NO. 2A INBD P/S FUEL OIL
D.B. NO. 2 OUTBD P/S FIXED BALLAST
D.B. NO. 2 INBD P/S F.W.B.
D.B. NO. 1 P/S F.W.B.
INNER BOTTOM
METERS
FEET

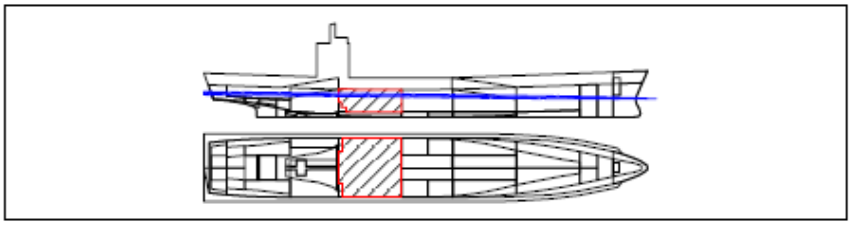
22 APPENDIX B - CARGOMAX DAMAGED STABILITY MODULE OUTPUT

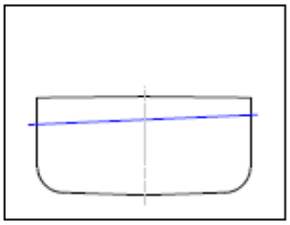
Hold 3 Damage, run on NTSB received version of CargoMax postaccident (1 of 2).

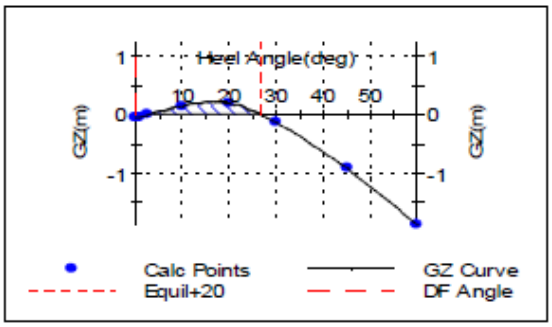
Sea Star Line -- SS El Faro(17 Jun 2010) Printed at 11:54 on 18 May 2017
CargoMax 1.21.0203 (01 Jun 2010)

Free Floating Damaged Condition - Transference used

Sea:1.0250 MT/m3	Disp MT	Draft AP m	Draft FP m	Trim m	Heel deg	KMt m	FSc m	GMt m
Intact from tables	34,936	9.817	8.211	1.606A	2.4S	12.786	0.123	1.262
Intact from offsets	35,156	9.809	8.292	1.517A	2.0S	12.789	0.118	1.440
Damaged	40,160	11.127	8.795	2.332A	2.5S	12.491	0.104	1.124







Damaged CMP	Perm.	Flood MT	% Full (Int)	Dens. MT/m3	Req. Outflow MT
HOLD D	0.700	5,004	0.0	1.0000	0
Total		5,004			0

No Criteria	Units	Available
Static Heel Angle	deg	2.5S
Freeboard to Margin Line	m	—
Freeboard to Downflooding	m	—
Angle at Maximum GZ	deg	16.5
Maximum GZ	m	0.224
Range of Positive GZ	deg	34.4
Initial GM	m	—
Area Under GZ Curve	m-rad	0.0507
Angle Limiting Range	deg	26.9
Angle of Downflooding (Unprotected)	deg	—
Critical DF Comp (Equilibrium)		
DF Point (Equilibrium)		
Critical DF Comp (Range)		
Pass/Fail		Pass

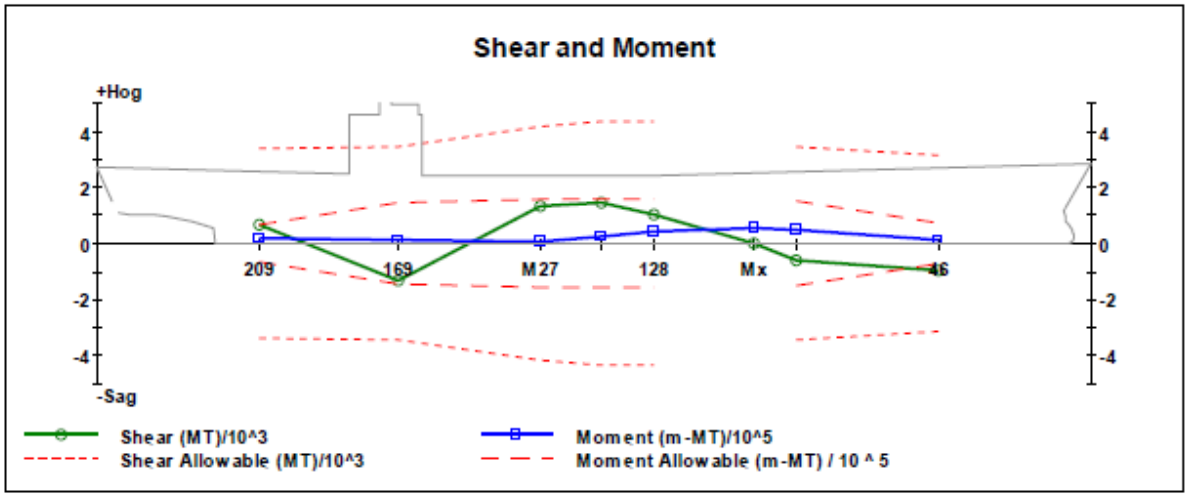
Angle (deg)	GZ m	Draft Aft m	Draft Fwd m	Flooded MT	CDisp MT	CTrim m	Iteration No.
0.0	-0.049	11.138	8.794	5,009	-4.0	0.004A	3
1.0S	-0.030	11.138	8.794	5,009	-5.7	0.004A	1
2.5S	0.000	11.127	8.795	5,004	13.9	0.004A	1
10.0S	0.158	11.068	8.797	4,980	0.4	0.034A	2
20.0S	0.199	11.034	8.925	4,820	-0.6	0.029A	2
30.0S	-0.130	11.599	9.100	4,639	0.3	0.007A	3
45.0S	-0.918	13.477	9.651	4,473	2.6	0.027A	3
60.0S	-1.875	17.401	10.543	4,426	6.3	0.016A	3
	Disp. of	Remaining	Intact Hull	35,156	MT		

Revised Departure - Burnoff for Sinki - (burn240.lc) Created/Modified 10:14 23 Jun 2016 (by: JWS)

Hold 3 Damage, run on NTSB received version of CargoMax postaccident (2 of 2)

Sea Star Line -- SS El Faro(17 Jun 2010) Printed at 11:54 on 18 May 2017
CargoMax 1.21.0203 (01 Jun 2010)

Damaged Shear and Bending Moment
Current



Name	Weight MT	Buoyancy MT	Shear MT	At Sea % Shear Allowable	Wt. Moment m-MT	Buoy. Moment m-MT	Bending Moment m-MT	At Sea % Moment Allowable
209	3,777	3,093	684	20	58,781	42,484	16,297H	25
169	8,889	10,217	-1,328	39	270,414	256,461	13,954H	10
M27	20,990	19,681	1,309	31	770,863	767,523	3,340H	2
MS	25,304	23,843	1,460	33	1,117,210	1,092,987	24,222H	16
128	28,360	27,312	1,048	24	1,458,221	1,417,692	40,529H	26
Mx	33,275	33,268	7	---	2,206,484	2,153,333	53,151H	---
87	34,665	35,262	-597	17	2,552,490	2,502,204	50,286H	34
46	38,232	39,202	-970	31	3,807,263	3,793,904	13,359H	19

Revised Departure - Burnoff for Sinki - (burn240.lc) Created/Modified 10:14 23 Jun 2016 (by: JWS)

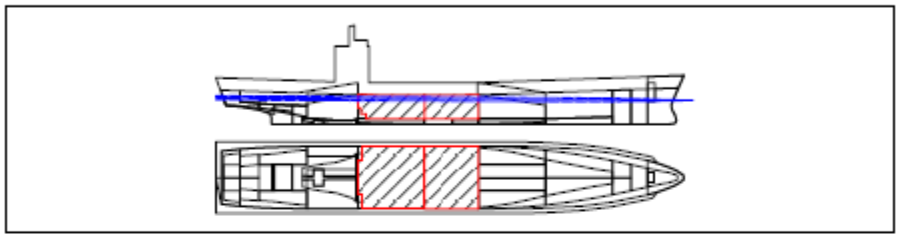
Hold 3 and 2A Damage, run on NTSB received version of CargoMax postaccident (1 of 2)

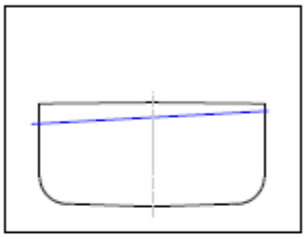
Sea Star Line -- SS El Faro(17 Jun 2010)
CargoMax 1.21.0203 (01 Jun 2010)

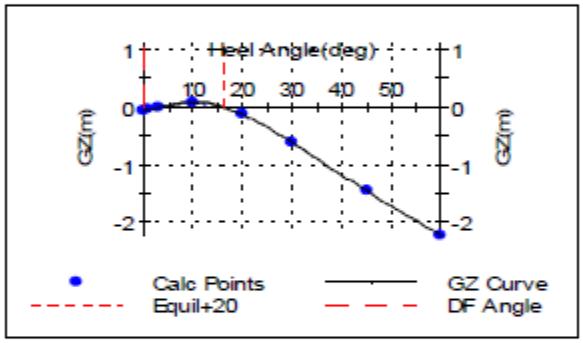
Printed at 11:50 on 18 May 2017

Free Floating Damaged Condition - Transference used

Sea:1.0250 MT/m3	Disp	Draft AP	Draft FP	Trim	Heel	KMt	FSc	GMt
	MT	m	m	m	deg	m	m	m
Intact from tables	34,936	9.817	8.211	1.606A	2.4S	12.786	0.123	1.262
Intact from offsets	35,156	9.809	8.292	1.517A	2.0S	12.789	0.118	1.440
Damaged	45,728	11.678	10.618	1.060A	3.2S	12.222	0.090	0.889







No Criteria	Units	Available
Static Heel Angle	deg	3.2S
Freeboard to Margin Line	m	---
Freeboard to Downflooding	m	---
Angle at Maximum GZ	deg	10.3
Maximum GZ	m	0.089
Range of Positive GZ	deg	13.1
Initial GM	m	---
Area Under GZ Curve	m-rad	0.0128
Angle Limiting Range	deg	16.3
Angle of Downflooding (Unprotected)	deg	---
Critical DF Comp (Equilibrium)		
DF Point (Equilibrium)		
Critical DF Comp (Range)		
Pass/Fail		Pass

Damaged CMP	Perm.	Flood	% Full	Dens.	Req. Outflow
		MT	(Int)	MT/m3	MT
HOLD C	0.700	4,909	0.0	1.0000	0
HOLD D	0.700	5,663	0.0	1.0000	0
Total		10,572			0

Angle	GZ	Draft Aft	Draft Fwd	Flooded	CDisp	CTrim	Iteration
(deg)	m	m	m	MT	MT	m	No.
0.0	-0.050	11.699	10.598	10,576	0.0	0.003A	4
1.0S	-0.034	11.699	10.598	10,576	-1.5	0.005A	1
3.2S	0.000	11.678	10.618	10,572	-0.4	0.030A	1
10.0S	0.089	11.661	10.596	10,477	0.6	0.015A	2
20.0S	-0.126	11.994	10.725	10,092	0.2	0.003A	3
30.0S	-0.609	12.936	10.994	9,721	0.8	0.015A	3
45.0S	-1.448	15.493	11.885	9,239	3.0	0.061A	3
60.0S	-2.217	20.967	13.223	9,019	0.0	0.003A	4
	Disp. of	Remaining	Intact Hull	35,156	MT		

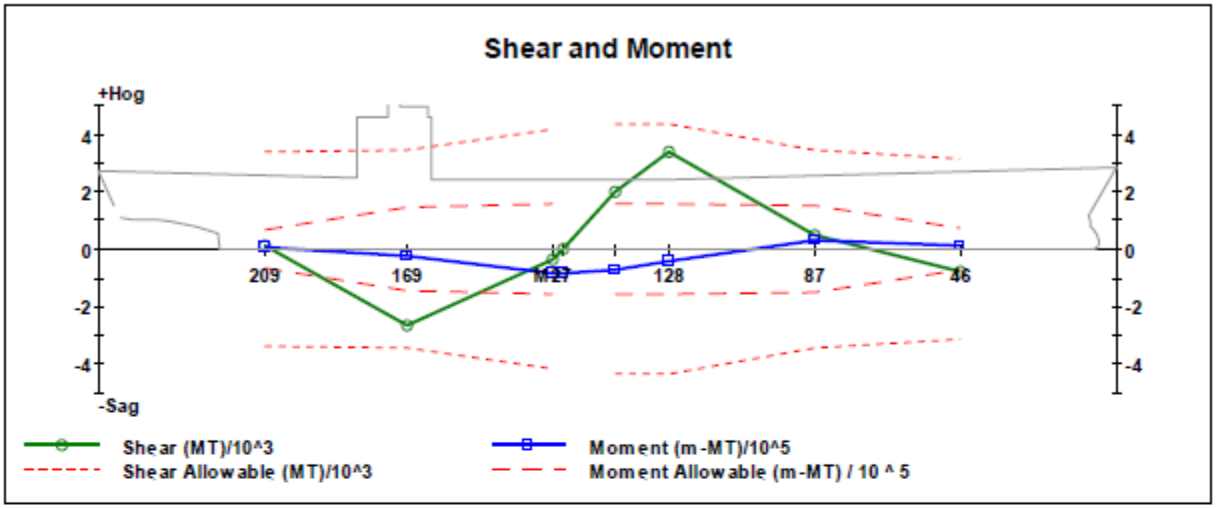
Revised Departure - Burnoff for Sinki - (burn240.lc)

Created/Modified 10:14 23 Jun 2016 (by: JWS)

Hold 3 and 2A Damage, run on NTSB received version of CargoMax postaccident (2 of 2)

Sea Star Line -- SS El Faro(17 Jun 2010) Printed at 11:50 on 18 May 2017
CargoMax 1.21.0203 (01 Jun 2010)

Damaged Shear and Bending Moment
Current



Name	Weight MT	Buoyancy MT	Shear MT	At Sea % Shear Allowable	Wt. Moment m-MT	Buoy. Moment m-MT	Bending Moment m-MT	At Sea % Moment Allowable
209	3,774	3,625	149	4	58,753	50,704	8,049H	12
169	8,889	11,525	-2,636	77	270,353	294,910	24,557S	17
M27	21,649	21,984	-335	8	780,986	867,486	86,500S	56
Mx	22,724	22,726	-3	---	833,721	920,650	86,929S	---
MS	28,621	26,638	1,982	45	1,157,066	1,231,029	73,963S	48
128	33,928	30,554	3,374	77	1,554,556	1,594,018	39,462S	25
87	40,233	39,748	485	14	2,840,166	2,811,522	28,645H	19
46	43,800	44,581	-781	25	4,286,280	4,274,580	11,700H	17

Revised Departure - Burnoff for Sinki - (burn240.lc) Created/Modified 10:14 23 Jun 2016 (by: JWS)

23 APPENDIX C – VDR TRANSCRIPT RELATED TO NAVAL ARCHITECTURE

The following are selected comments from the VDR transcript for the last eight hours of *El Faro's* recorded data, which spans two bridge watches. They were selected, in part, based on relation to wind direction, wind strength, waves and sea state, barometer, water on deck or other indication of spray, flooding, bilge pumping and bilge alarms, propulsion and shaft rpm, damage control, list, trim, and stability.

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
2352	Course is 150 at watch change from 3rd mate to 2nd mate. AB-3 "one-five-zero [spoken to 3M]" 3M "good. Thank you. Good night. [spoken to AB]"	149.0	19.1	152
2359	Mention of course and weather. AB-2 "* * a hundred and (fifteen/fifty) you got a lot of (waves/rain)"	149.3	18.8	151
0043	2nd mate talks to AB about going farther the south and the position of the storm relative to them. 2M "… unless this cour- unless this damn storm goes further south. * Can't win. Every time we come further south the storm keeps trying to follow us."	148.4	20.2	151
0052	Discussion of wind speed and vessel roll. 2M "it doesn't really feel like we're going in- near a hurricane. I mean like you said the wind- when you go outside and there's hardly any wind." AB-2 "right" 2M "relative wind is- you know we're going twenty knots so you wouldn't feel it much. We're not- not rolling."	148.5	20	150
0118	Discussion of sea state and largest roll since watch began. AB-2 "whoa." 2M "oh.okay."	148.7	20.13	151

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
	AB-2 "***.* one roll we took" AB-2 "biggest one since I've been up here." 2M "we're right between the islands– sooo. wondering why we're rolling? [sound of quiet laugh]"			
0120-0123	2nd mate calls master at 0120 and discusses course change and joining Old Bahama Channel. Prior to hanging up, 2M states: 2M "okay. thank you." Mate then says to AB-2: 2M "he said to run it" 2M "hooold on to your ass @AB-2. [spoken very loud and dramatically and then the sound of laughter.]" AB-2 "he wants to change course to one-one-six?"	148.7	20	151
0124	Course change to 116. 2M "alright- let's start easing her over to one-one-six and slow"	148.8	20	150
0124	AB comments on how course change to 116 affects the vessel's ride. AB-2 "things fixin' to change here." AB-2 "here we go." AB-2 "little rougher- little * *."	147.9	20	150
0128-0129	First indication of wind heel on vessel. AB-2 "** wind heel. Yeaaah"	127.3	19.6	138
0129-0130	Indication of course adjustment to 114 and wind increase. 2M "might have to make it one-one-four." AB-2 "one-one-four." 2M "…stay right on the trackline. Startin' to hear the wind now." 2M "can hear it." AB-2 "yes *." 2M "we're also headed into a rain cloud. (a perfect band of rain)– a rain squall– comin' up."	118.0	19.3	131
0131	2nd mate states that a course of 114 is to be maintained remainder of 0000 to 0400 watch. 2M "so this is it. the rest of the watch. this course."	109.9	18.3	117
0131	General comment on weather/seas.	110.2	18.2	116

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
	AB-2 "it ain't too bad right now." 2M "nope."			
0132	Mention of speed reduction and shaft RPM decrease. AB-2 "lost a little speed" 2M "yeah-well-that's alright. With the wind and then the course change you know." 2M "we also lost R-P-M. @3AE isn't paying attention down there."	112.2	18.2	113
0136	Statement regarding boat (vessel) rock. AB-2 "surprised that * * *." AB-2 "yeah. Didn't rock the boat." AB-2 "that's weird. I figured we'd get a little ro- or something."	113.1	18.5	116
0136	2nd mate goes outside on bridge wing and notes wind speed. 2M "yeah * its about right on our (back/bow/head)" AB-2 "* * *." 2M "[sound of laugh]" "not to bad." "I can stand up straight."	112.3	18.6	116
0137	Mention of pitch and sea swell. AB-2 "* * pitchin' a little bit" 2M "* little * *." "one good swell every so often"	114.6	18.7	116
0143	Discussion about flashes observed forward of the house, on main deck near the bow. AB-2 "I just seen another one down here– right there up on the bow." AB-2 "it's like something's flashing." 2M "it's flaaashing?" AB-2 "* * * right there (on/in) the front of the ship– right there it was two flashes of light. " 2M "well– the reefers– are pointing the other way."	113.1	17.8	117
0156	Statement about sea state and that ship is not at maximum RPM. 2M "whoo. That was a good one." AB-2 "* *. * * *." 2M "definitely lost some speed." 2M "although we're not doin' the max RPMs." 2M "damn sure don't want to lose the plant."	114.4	18	118

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
0211-0212	Statement regarding visible green water in the vicinity of the bow. 2M "green water on the bow" AB-2 "there's some clanking going on. * *." AB-2 "picking up" 2M "** steering 114" 2M "*** (get/getting) set."	115.9	17.3	118
0215-0222	Statement that vessel is being set, speed reduction noticed, wind increasing. 2M "we're definitely getting set" AB-2 "down to 16 knots." 2M "that wind is definitely picking up."	110.8	16.4	117
0236-0239	Statement that vessel is pitching, not rolling, in longer swells. AB-2 "we took a little rock- just then." 2M "well- the upside is we're pitching not rolling…" AB-2 "the seas are farther apart", 2M "yeah"	110.8	16.3	116
0242	Statement about spray. 2M "weee.[exclaimed] look at that spray."	110.3	17.2	117
0244	Statement that wind direction is from the north. 2M "and that north wind." "northerly wind."	114.3	16.4	116
0247-0248	Discussion regarding of large waves and unknown swell direction. 2M "#. oh #. that was a bad one." AB-2 "looks like we got knocked off course a little bit but it's coming back." 2M "that surprises me." "that was a doozy. [sound of laughter] that was not a good one." AB-2 "yeah that was a big wave." 2M "(we/she) won't be able to take more of those." 2M "would help if I knew which direction the swell was coming from. I could alter course a little more. Cant see."	110.9	16.6	118
0250	Discussion about movement of items aboard the vessel, possibly internal or personal items. AB-2 "I heard that" "I heard a thump." 2M "huh." AB-2 "boom. [exclaimed] I heard a thump." 2M "oh it must be inside then."	110.8	16.2	117

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
	AB-2 "might be inside" 2M "well it's probably a bunch of # broke loose down there." AB-2 "like my tv."			
0251-0253	Statements about difficulties standing on bridge and vessel heeling over. AB-2 "hit that one right." 2M "(we're really in the #/ * * ship resistance)." AB-2 "both feet are locked in." 2M "[sound of laughter] (watch out) I had to sit down for that one." 2M "she's righting herself"	110.4	15.96	118
0253	First electronic indication vessel is not holding course. M1 [sound of electronic tone consistent with steering stand alarm.] 2M "she off course?" AB-2 "she is." 2M "uhh- oh he has got it set to 3 degrees off course." 2M "now she is coming back."	114.8	16.2	116
0300	Noise attributed to something loose on flying bridge. AB-2 "hell was that?" 2M "something on the flying bridge.	108.5	16.3	117
0305	Mate expresses concern about going outside on bridge wing due to wind. 2M "… you don't wanna get out there in that wind- get caught with a gust now." 2M "I can hear it gusting."	111.3	17.8	117
0317	Statement describing wind direction as northwest. 2M "says the wind's supposed to be west-southwest. Should be comin' on the (forty-five/port side)." 2M "* * * (different from– oops)." 2M "let's see that's- west-northwest." 2M "it's (more/north) northwest at fifty"	108.9	17.1	119
0320-0323	Electronic indication vessel is not holding course. Statement about wind on bow and vessel being set.	114.6	16.6	118

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
	2M "she just got- popped in the ass." AB-2 "yeah it's startin" to get a lil-little bit more active around here." M1 [sound of electronic tone consistent with helm off course alarm.] 2M "yeah- she's goin"- she's goin" left- she's got right rudder." 2M "damn- * got some wind in our face." AB-2 "hear that wind out there?" 2M "yeah." "yup we're getting into it now." 2M "we **. ** pretty good set on us." 2M "we are * *. * * pretty good set on us." "get getting" kinda set."			
0324-0328	Second mate expecting wind shift. AB-2 "just the wind." "man it picked up in the last five minutes." 2M "I think it's shifting. Cause that weather report say tha- uhh- west-southwest wind which we were not getting but I think its starting to shift west and now its coming back around. We're gunna start getting it on the starboard side."	109.9	15.1	121
0329-0330	Statement that wind speed is increasing but the ship is riding well and the swell is not large. 2M "(boy) the wind is blowin" like a bastard- but considering- we're we're riding pretty damn good." AB-2 "that is what I'm thinking." 2M "considering what it could be like." 2M "you know overall we're not bad right now." 2M "this wind is realy starting to pick up." 2M "wondering if– with the storm– I mean it's just sittin' out there *– but the storm itself– the hurricane– it's so new– that I'm wondering if just it hasn't had time to develop a big swell." 2M "the wind is just recently starting to pick up" AB-2 "ye we just. We're doin' good right now." AB-2 "change something up right now– we'll get off.– it don't come real easy.– anyway."	109.8	16.7	120

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
	AB-2 "were lucky. We got lucky."			
0331	Discussion about wind gust. 2M "ohhh #" AB-2 "(chair) flip it upside down." AB-2 "its blowin' out there now girl. Whoa." 2M "(just get through it/it's not bad huh) *." 2M "(hundred knot gust of) wind [sound of laughter, then sound of a sigh]	111.4	17	119
0333	Phone call and mention of vessel RPM. M1 [phone rings] 2M-ET "eighty turns"	109.7	16.1	121
0336	Statement about wind and rain. 2M "kinda like pressure washing the decks." AB-2 "yeah it's blowin" that rain so hard."	109.3	17	119
0340	Statement noting "set" and 2nd mate alters course to 110. 2M "(alright we got one hell of a) set * on us." AB2 "(right behind/rip me out of) that chair over there." AB2 "(I'm holdin') this for you but you (can/can't) for me." 2M "… (starting to shift there.) uh let's come over. what are we doin'? one-one-two." 2M "let's do one-one-zero. (we'll) just do it bit by bit. startin' to roll now so you gotta come over to port."	108	16.4	122
0343	Statement about improved ride on 110 course. 2M "were riding nice on that course for the past two minutes (now)…"	108.4	16.8	121
0344	Chief mate arrives bridge. Statement that either the hurricane or the ship is farther south and visibility is low. CM "(it's/that's) a lot further south." 2M "yeah umm we just (made it/needed) one-one-zero" CM "so you can't see a thing huh?" AB-2 "yeah"	109.1	16.7	121
0346	Statement that engine room watch begins blowing boiler tubes. 2M "alright 2AE blowin' tubes."	107.8	16.2	120
0346	Statement regarding soot blowing. CM "nothing on this (this/list)."	107.1	16.1	120

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
	2M "nothing. so we're one-one-zero. uh about max they can give us with @2AE blowin' soot right now."			
0346	Statement that ship has trouble holding course when it pitches but overall is holding course well. 2M "it's uh– she's been holdin' pretty good. um– when you get uh the good slams and the good pitches she might lose it a little bit but overall she's been holdin' good knock on wood." M1 [sound of electronic tone consistent with steering alarm stand] 2M "that's the (G-F)* alarm." 2M "she'll come back. She did that a couple of times just because uh- we pitched so bad."	103.7	15.7	121
0347	Chief mate switches heading from 110 to 100 before 2nd mate departs watch. CM "okay * come left and steer one-zero-zero." CM "walk it over a little at a time" 2M "have a good watch." CM "thank you." At 0349 AB-2 States "'kay we got one-one-zero…"	103.3	15.5	121
0347	Chief mate has difficulty determining wind direction. CM "It's hard to tell which ways the wind's blowin" huh?"	104.8	15.3	121
0348	Chief mate notes vessel heel may be due to wind. CM "I assume that we're heelin' to starboard (must be blowin') port to starboard."	101.7	15	120
0349-0354	Chief mate alters course from 100 to 095, vessel having difficulty staying on heading with autopilot. AB-2 "…looks like it knocking off * zero once in a while * * * the alarm will go off *** sounds" AB-2 "one-zero-zero mate" CM "alright" CM "I don't like this"	98.5	13.8	116

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
	AB-1 "Hold on" M1 [sound of electronic tone consistent with steering stand alarm.] CM "come left to zero-nine-five" AB-1? "* (let's) put it in (hand/there)? (is) puttin' it at five good?"			
0355	3rd engineer arrives on bridge. Indicates he has been on second deck. Notes reefer cords cut. CM "you can't go up on deck." 3AEX? "yep." 3AEX? "you can come up through the second deck though." 3AEX? "some of those cords go cut (in the) second deck." CM "what cords?" 3AEX? "uh the containers." CM "the reefers?" 3AEX? "yeah" "don't know if we're shortin' out down there * * *" CM "bet they do." 0413 chief mate states to the captain that they were not going to address the reefer cords. CM "the third engineer did report some broken– uh– cords to refer containers we're not doin' anything about it."	88.0	10.6	113
0358	Autopilot alarms and statements about steering difficulties (vessel not holding course). M1 -several in a row [sound of electronic tone consistent with…] AB-1 "* can't come back." "* can't come back * *" AB-1 "naw what I'm sayin' ? (it was) when (when it was raining) * * * heading back to the course (then we just) * *." CM "(gusts) a little little wind (just/let's) head up wind." M1 -several more in a row [sound of electronic tone consistent with…]	86.8	10.8	114
0404	Chief mate states that they are bit south of their intended course and estimates they are steering 30 degrees into wind.	85.9	10	117

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
	AB-1 "are we where we need to be at? Where the (check) to be at?" CM "just a little bit to the right of our track here. See that purple line on the radar there." AB-1 "yeah" CM "we're steerin' up like thirty degrees into the wind."			
0405	Discussion regarding gusts and measurement. AB-1 "what's the gusts out there?" CM "I don't have any idea. (we don't have any) instrument that can measure (it).	84.4	10	117
0409-0411	Captain arrives on bridge, states he slept well and ship is not pounding. CAPT "there's nothing bad about this ride." CM "* (not) sleepin' * *" CAPT "sleepin' like a baby" CAPT "we're not poundin'." CM "that is what I said when I came up." ? "this is just like wind gusts * * *." CAPT "roll. I mean we're not even rollin'. We're not even pitchin' we're not pounding."	87.8	10.2	114
0412	Vessel steering on autopilot, but course alarm has been previously turned off. Vessel is setting. CAPT "* (on the mike right now)? [A reference to the "Iron Mike" which is a slang term for the autopilot system.]" CM "(you on the) mike?" AB-1 "(yeah) Mike" CM "I turned off the course alarm." "It was going off every five seconds…" CM "we're headin' up into the (gusts) and (comin') back down ridin' through lot of ranin * (here)" CAPT "yeah I can see that" "it's not (workin"/worth it * * rollin'." CM "(I mean) we're making good the course I want ya know. I wanna merge with one-one-six." CAPT "ya" CM "(we're settin')." CAPT "steer it up just steer in this direction right now."	84.4	10.5	114

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
0413	First discussion between captain & chief mate about vessel heel and potential cause being wind. First time captain mentions filling the ramp tank to mitigate heel. CM "cap'n yeah we're goin' like this huh I'm guessin' it's on the port bow and …" CAPT "port side yeah." CM "(yeah/wind)." CAPT "the only way to do a counter on this is to fill the port side ramp tank up." CM " *** (starboard to port) *** (no places for any others)." CAPT "yeah." CM "heel is not bad" CAPT "huh?" "no– no– no (not at all) * * *. * * the only thing I can conjure up." CM "no." "the third engineer did report some broken– uh– cords to refer containers we're not doin' anything about it. "	84.7	10.7	112
0413 - 0415	Statements about wind strength and captain's expectation that wind should begin to come around to starboard. CAPT "(oh) it's howling out there." CM "(can't tell the) direction * *." CM "(but) our forecast had it comin' around to starboard." CAPT "the wind?" CM "right." CAPT "it will eventually."	85.45	10.9	108
0415	Captain is aware of vessel speed reducing. Second engineer states they are still blowing tubes. CAPT "startin' to slow down?" CM "uhh I guess * * set (in/to) max." CM "(I'll) have to call @2AE." CAPT-ET "Good morning second- captain here." "how are ya?" "how how ya guys doing (down there/now)?" "yeah-well to be expected." "say uhh everything good as far as R-P-M goes? " "perfect." "yeah. Okay. That	79.2	10.5	109

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
	sound good to me." "thank you very much for the heads up." CAPT "blowin' tubes."			
0421	Statements about limited visibility. CAPT "it's (pourin'/blowin')." CAPT "it's probably better off we can't see anything chief mate. " CM "naw I can see the spray though * *. "	70.9	8.5	109
0424	Statement that barometer is 970 millibars on ship and expected to be 950 at eye. CM "we're at nine-seventy now" CAPT "now?". CM "* * nine-fifty." "think it's gunna go down (before it goes up)." CAPT "that's the eye." "we won't be goin' through the eye."	72.5	8.7	108
0427	RPM is 100 and captain states he would like to increase speed. CAPT "* blowin' tubes?" "* come up." CM "no we're at a hundred now." CAPT "ya." CM "(shoulda/shouldn't) (been/they) be comin' up a little bit faster? " CAPT "don't know tell 'em bring it up." CM "we'll just feel how she can do." CAPT "right now we're poundin' a little bit because we're goin more easterly– (ya know) we're holding (our/that) * right rudder. um gotta let her get up to speed. get a little bit more (more/toward) our course. not * too much. need the R-P-Ms." CM "this might be as high as it's gunna go."	67.9	9.1	103
0433	Captain reminds engineers that weather decks, including second deck, are secure. CAPT-ET "hey listen it– uh– it should go without saying the weather decks are secured but I want to just make sure you wrote it down because– uh– the third came up from the second deck on his way when he got off watch and we don't want anyone else doin' that."	63.7	9.6	98
0434	Captain states he is going to check status of galley.	70.5	9.6	98

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
	CAPT "I think we should see how the galley made out." "gunna take a walk down there."			
0437	First indication of Ro/Ro second deck movement—trailer forward of house leaning over. CM-ET "container where? the second deck? *." "okay I've got on the second deck in front of the house." "trailer." "leaning over." "okay. yeah. we had uh we had * * @3AE2 (and) he was out on the second deck." "* (second's secure)."	70.7	9.8	100
0437	First transcription noting chief engineer is in the engine room. First transcription chief engineer is aware of heel. CM-ET "yeah we're heelin' over *." "I'll pass it on to the captain." "* the galley." A few minute later, the chief mate stated: 0442 CM "that was the chief."	70.8	10.1	100
0440	CM "* (lookin') (fore/four) deck." "can't even see the (level/bubble)."	72.9	10.1	105
0440	First discussion of oil levels. CM-ET "captain– chief mate. the chief engineer just called and (then/they) called back again (yeah) something about the list and oil levels * * *.	69.8	10.2	104
0443	Chief engineer wants to remove the list/heel. Captain returns to bridge and goes from the iron Mike (autopilot) to hand steering, to steer up into wind to take the starboard list off vessel. CAPT-ET "how are you? you want us to take the list off a little bit?" CAPT "gunna steer right up (in to it)." "wants to take the list off. so let's put it in hand steering." CM "go into hand."	70.9	10	106
0443-0444	Chief mate orders vessel head up (into the wind -northward), to 065 degrees. Discussion involves oil sump trouble. CM "looks like we can head up real fast." "keep it right ten."	64.6	9.8	106

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
	CAPT "* * just the list. the sumps are actin' up * . to be expected." CM "yeah the oil sumps I understand."			
0445	Statement barometer is falling. CM "down to nine-sixty millibars."	64.4	9.6	106
0445-0446	Steering 065. Captain takes the conn. AB-1 "zero-six-five." M1 "[sound similar to metal curtain wheels on a metal curtain track moving rapidly as if with the motion of the ship.]" AB-1 "wooo. [dramatically exclaimed, almost similar to a yell]" CM "alright." CAPT "alright." CM "now swingin' right pretty fast." CAPT "alright. Master has the conn."	68.6	9.3	104
0450	Captain comes up further up into wind, orders course 060. CAPT "(wanna/why don't ya) see if you can steer that course right there. zero-six-zero."	59.1	7.3	88
0453	Discussion about possible trailer/container loss. CAPT "did we lose a container or something'? a trailer down on two deck?" CM "he said one was leaning over. one of the trailer's on second deck."	45.8	7.7	96
0456	Barometer at 961 millibars on ship. CM "nine-sixty-one."	49.2	6.8	97
0457	Still in hand steering, captain orders heading of 050, then goes below to check messages. CAPT "zero-five-zero. steer in that general direction." CAPT "gunna check real quick and see if I got any messages then I'll be back up."	50.0	6.6	91
0500	Chief mate states he expects wind shift and vessel still has list/heel. CM "(startin') to look (better)." expecting the wind to come around here to the bow and then to the starboard side. I can still– I can still see the spray foam to the starboard. we're still heelin'."	47.1	6.5	80

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
0503	Statement barometer has moved up to 960 millibars. CAPT "… said the barometer's comin' back up?" CM "yes– *-six-zero * and its (now/still) (nine-six-zero/nine-sixty).	48.2	6.7	72
0510	Riding crew chief (SUP-1) arrives on bridge. Indication that he has looked at second deck. CM "see if any buttons failed." Sup-1 "gunna (look the cable looks) down the on second deck by the bunker station (things are) slappin' around."	85	11	113
0510	Vessel anemometer not providing wind speed indication on bridge. SUP-1 "what's the wind speed? CM "we don't know. we don't have (any) anemometer."	85.7	11	113
0511-0512	Discussion between riding crew chief and captain about low oil pressure alarm to engine (main propulsion turbine), the vessel's list/heel, and container stacks and sail area. CAPT "now (how– how) is this list?" SUP-1 "I've never seen it list like this– you gotta be takin' more than a container stack * I've never seen it hang like this." CAPT "(never?)– we certainly have the sail area." SUP-1 "yeah (happened last night/had the list I didn't) think it was seven." CAPT "how does that affect below your operations as far as lube oil(s) and *." SUP-1 "(you hit) the low pressure alarm on the lube oil * * * (stuck) * * * level of the engine * * *." SUP-1 "never seen it hang like that before." CAPT "yeah * * you got a lot of sail area." SUP-1 "yeah."	81.0	11	114
0512	Discussion of vessel not pounding. CAPT "so we haven't really pounded at all." SUP-1 "no– that's– that's…"	83.0	11	114

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
	CAPT "(we we) a couple– (but todays * though) we're not pounding." SUP-1 "no-no."			
0512	Discussion of speed and RPM. SUP-1 "maintaining speed?" CAPT "eleven." SUP-1 "* * *. " CAPT "no * * little over a hundred. * * whatever they (do)– don't pull that *."	85.1	10.96	114
0513-0515	Chief engineer calls bridge and discusses means to correct list. Captain states he is trying to fix list through steering. M1 "[sound of electric telephone ringing.]" CAPT-ET "I'm tryin' to (get her steadied up)." "ok." "(now) we got a lot a sail area." 0515- SUP-1 "(does/is) @CE have a problem?" 0515- CAPT "uh its @CE– you know he's got a problem like you said a low level."	86.6	10.8	115
0514-0516	Captain orders heading more to the north, into wind. CAPT- "put your rudder left ten– we're gunna steer up into it a little (bit) now." AB-1 "* * rides (pretty/very) well on the (northeast/course east)." CAPT "yup." CAPT "(why don't/want 'chu) you come left– steer zero-six-zero." CAPT "(we're comin' left/put your rudder left) zero-five-zero." AB-1 "roger captain."	89.1	10.9	119
0518	The chief mate mentions the list of the vessel. CM "heading on (angle/eight)." CM "* * yeah * * (eighteen) degree list on * * *."	47.3	6.34	91
0518-0521	Captain expects wind to shift to the north, that they should be on the back side of the storm soon CAPT "only gunna get better from here." CAPT "we're on the back side of it."	47.5	5.8	83.4

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
	CAPT "we agree. waitin' for that wind wind to shift. it's awful * * *." CAPT "right now I'm just (waitin' for wind shift)."			
0522	Barometer 951 millibars. CM "nine fifty (one)."	51.5	5.5	86
0529	Captain engaging in an indiscernible discussion of machinery and the boiler. CAPT "there ya go (got) all the machinery just in front the boiler know what I mean? (cargo shift/cargo ship/probably just) operating * * * (starboard side of the hold)."	51.7	5	75
0530	Statements about loss of bridge wing cloth/canvas canopy. CM "I didn't– I didn't think about takin' that canopy down." CAPT "don't worry about it." CM "it's (blown) away. Supposed to be * * *." CAPT "its still there or?" CM "yup." CAPT "(gone)?" CM "no. hangin' by a thread."	47.9	5.2	80
0530	Statement about change in wind direction and water on stern. CM "change in the relative wind direction the spray is hittin' us instead of goin' cross the beam." "we're takin some (water) on the stern. * * *."	45.7	5.2	80
0540	Captain statement possibly about vessel slowing. CAPT? "** (goin/slowin') down * * *."	49.7	4	73
0543	First indication flooding of hold 3 and first mention of scuttle. M1 "[sound of electric telephone ringing.]" CAPT-ET "we (got) a prrroooblem." "three hold?. Ok." "I'll send the mate down. Yeah." CAPT "watch your step– go down to three hold– go down to three hold. * down there * start the pumping right now * (probably just) water * * *." CM "* * * suspected leak (in) (he said) * *." CAPT "I would tend to concur."	49.4	3.4	60

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
	CM "* * 'specially the scuttle." "* * down * I'll take a look."			
0544	Helm remains in hand steering. CAPT "…we're in hand steering steer right around zero-five-zero * * *.	50.9	3.3	57
0544	Captain sends chief mate to examine hold 3 and scuttle, but tells someone over phone he does not want crew moving about exposed decks. CAPT-ET "yea what I don't want to do is have a lot of people up and running out on deck Im gunna send the mate down. Alright?" "why don't you head on down (uhh)– let me get a radio."	46.5	3.2	59
0544	First indication that cars are adrift in hold 3and it is unsafe in that hold. CAPT "we got cars loose. Yeah." CAPT "I'll go knock on his door. it's unsafe to go down in the cargo hold with gear adrift like that (it's just not safe/ it's a disaster) * * *. (not gunna let them bang themselves up) * * *."	48.7	3	59
0545	Engine room is pumping hold 3 with bilge pumps. Engine room has general idea where water in hold may be coming from. CM-ET "so that's where the water's from?" "Ok. Are we able to pump the bilges?" "okay (that's)." "understand. * ship or (come/roll) over." "that's a lot of water. okay got bilge pumps running right? okay."	47.1	2.6	59
0547	Captain acknowledges report that water is rising in hold 3 even with bilge pumps running. Captain asks and gets agreement that ramp tanks can be used to change list. CAPT-ET "bilge pump running water rising. okay. can we pump from the starboard ramp tanks to port?" "let's do that."	51.1	3.3	66
0547	Chief mate departs bridge with radio to look at flooding in hold 3. Chief mate plans to get third assistant engineer No. 2.	51.0	3.4	67

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
	CAPT "better go down and have a look." CM "get my radio and knock on @3AE2's door."			
0550	Statement that engineers are transferring starboard ramp tank to port. CAPT-UHF "… go down- touch base– see what's goin' on in three hold call me back. If we need to call up more people so be it @CE is transferring internally starboard ramp tank to port." CM-UHF "roger."	49.7	4.9	63
0552	Chief engineer calls bridge and speaks with captain. Captain states that he plans to generate a port list by turning the ship so the crew can have a better look at the hold. Captain attempts to confirm whether scuttle was source of water. CAPT-ET "okay what I'm gunna do– I'm gunna turn the ship and get the wind (on the north side) right there and get (it going) more (in that) direction get everything on the starboard side give us a port list and (um see) if we'll have a better look at it." CAPT-ET "yeah– so it is the scuttle?" 0554 CAPT-UHF "let me uhh– I just got off the house phone with the chief. I want to turn the uhh– ship to port– get the list on the port side there…" 0544 CM-UHF "there's a hold that's flooded on the starboard side * * (we'll have to go into) three hold * * bosun (to wait/awake)."	47.1	5.2	57
0553-0554	Captain begins turn to north in attempt to change vessel list from starboard to port, by getting wind on starboard side of vessel. CAPT-ET "okay real– good real good. I'll umm start the turn now (the) best I can. uh– more R-P-M available?" CAPT-ET "alright (gunna) start the turn to port. alright thank you." CAPT "put your rudder uhhh…" "left twenty"	52.1	5.3	49

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
0555	Chief mate (who is alone) reports flooding in hold 3 on starboard side and through open scuttle on second deck. Indicates that water at the scuttle is knee deep (second deck). CM "there's a hold that's flooded on the starboard side * * (we'll have to go into) three hold * * bosun (to wait/awake)." "(ya got) water against the side just enough to go/throw/pour) over the edge of scuttle about knee deep (in here) water (rolls) right over." CAPT-ET "okay. (now) let me do that (I'm) comin' left right now. (you need) anybody else down there (with ya)?"	46.7	4.9	49
0555-057	Statement about diesel odor on vessel. Chief mate indicates no odors on second deck. 0555 CAPT-UHF "do you smell anything down there? CM-UHF "no. (nothing but spray)." CAPT-UHF thank you" 0557 CAPT-ET "hey chief [CE]– @CAPT here." "(still/smell/spill) a lot of diesel?"	36.5	4.7	52.9
0556	Captain orders heading 350. CAPT "why don't you steer that course right there." "three-five-zero."	351.5	3.8	35.8
0556-0558	0556 is first indication that vessel is now listing to port (no transcript statements or discussion of list changing again). Indication that chief mate and riding crew chief are near starboard scuttle to examine flooding in hold 3 and that port list has removed water from starboard side on second deck. CAPT-UHF "alright mate chief mate we got it listing over to port now can you (see/just) can you see it down there? the water level?" CM-UHF "I got @SUP-1 with me here– we're ready to go (down/below) (on/in) * starboard (scuttle) *" ?-UHF "* * * (on purpose/on for us) * (it's) dry * * * (see it down) the scuttle (we got	347.8	3.7	25.5

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
	water/blown out) * * * (the worst area's already dried out)."			
0556-0557	Captain asks engine room to stop ramp tank transfer to port tank. Captain then asks to transfer from port to starboard. CAPT "…let me go uhh give the engine room a shout * * tell 'em stop transferring." CAPT-ET "alright we got a nice port list can you stop transferring? from starboard to port segregated ballast (from/the) ramp tanks." 0610 CAPT-UHF "alright. that's good. * and transfer over to the starboard ramp tank * * starboard." 0611 CM "* * port to starboard ramp tank."	345.6	3.6	9
0558	Nautical Twilight (under good atmospheric conditions and in the absence of other illumination, general outlines of ground objects may be distinguishable—US Naval Observatory)			
0559	Captain tells 2nd mate that a scuttle popped open, hold 3 is being pumped, and chief mate and riding crew chief are closing the scuttle. CAPT "a scuttle popped open and there's a little bit of water on in three hold. they're pumping it out right now. the mate's down there with @SUP-1he's down (in the/he's closing / * *) the scuttle."	2.4	9.3	312
0600	Captain references ventilation when talking to chief engineer. CAPT-ET "chief." "okay." "(all through) the ventilation?" ?-UHF "* * *."	0.2	7.8	316
0600	Discussion about bringing list back to starboard. Captain states transfer to starboard (through ramp tanks) will start. CAPT-ET "want me to bring it back over to starboard?" "alright." "bring it back roll back over to starboard." CAPT-UHF "say chief mate- @CAPT gunna (start transferring to starboard)."	0.6	7.5	315
0559-0601	Open scuttle on second deck starboard side to hold 3 had water pouring down it. Scuttle is secured by chief mate and riding crew chief from second deck, as water coming down open	1.1	6.8	314

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
	scuttle prevented initial attempt at closure from ladder up from third deck. ?-UHF "('kay cap'/'kay get up here) it's done. it's done. " CAPT-UHF "('kay) you got the scuttle closed?" CM-UHF "(yeah) the scuttle is (closed) we're off the (deck/second/deckie)." CAPT "(yeah) real good." CAPT "@SUP-1 right there with ya?" CM -UHF"(roger)." CAPT "give them a shout down below. one-nine. (let 'em know/tell them) the scuttle has been shut– the scuttle is shut. 2M-ET "yeah the scuttle has been shut." 0605 CM "… I saw the water pouring down through the scuttle from third deck– I couldn't (get/climb) the ladder so I went up to the second deck..."			
0601	Discussion regarding brining radar back up, that had shut down (apparently) at unrecorded time or reason. CAPT "see what's up with this radar right here." CAPT "see if you can get that radar to come back up." 0634 CM "did we secure this radar?" 0634 CAPT "no." 0634 2M "(It it/I think) it went out on it's own."	1.4	6.5	312
0602	Mention of alarms in engine room. 2M-ET "the– the shuttle has been scut– the…" 2M "hear an alarm going off (he/they) couldn't hear me."	3.3	5.6	300
0603	Statement about loss of shaft RPM (loss of propulsion). 2M "did we come down on the R-P-M or did they do that?" CAPT "they did (that/fast)."	359.8	5.3	294

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
0604	Chief mate has returned to bridge and says second deck scuttle was half-open. Chief mate says scuttles were closed and checked earlier in the voyage, but crew may have traversed scuttle later. CAPT "(what was down there?) "what did you find down there?" CM "uhh * * (pump) (sea waters/three quarters) (last night)." CAPT "okay." SUP-1? "how many dogs?" CM "ya know it's– the scuttle('s) half way open. clogged. (the way it's/go ahead) (start those) fire hoses * * pretty clear * the guys closed it." CM "* yeah those scuttles were closed you know they were checked but (something/somebody) (might have went through)."	358.1	5.3	288
0604	Captain asks chief mate if floodwater in cargo hold is going up or down. Captain asks chief mate if he wants anyone else woken up. Indication that chief mate can't do anything except observe water in hold. Chief mate to return to hold 3 to monitor water level. CAPT "see the level goin' * (glasses/lashes) *." CM "yea." "I– I saw it before I went down in the cargo hold. (lights/right?)." CAPT "* (down in) the engine room?" CM-? "so we're good." CM "want me to (run/go) down and monitor the water level?" CAPT "yeah do you need me to wake anyone else up? you want me to get the boatswain up? you want me to get (the/a few) guys up?" CM "I still have * down there umm there's not much I can do except just look down there and see water * * * (um you know) * * *.	0.3	5.5	283

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
	0605 CAPT "yeah get another radio keep it dry we need ears and eyes down there." 0605 CM "alright."			
0605	Captain asks chief mate if he saw cars loose in hold 3. Chief mate could not see them from third deck (tween deck) looking down toward tanktop. CAPT "see any cars that broke free or anything like that?" CM "not that I can see just lookin' from third deck. (okay). I saw the water pouring down through the scuttle from third deck– I couldn't (get/climb) the ladder so I went up to the second deck. If you'd like I'll go back down * *."	3.5	5.7	279
0607-0609	Statement that handrail may have broken loose on bridge top and furniture is loose. CAPT "something broke free up top probably a handrail or something. * don't wanna go out." 2M "its stormy" CAPT "(sounds like * getting worse up here) * right now." 2M "there goes the (lawn) (furniture)." CAPT "let's hope that's all."	3.0	5.4	276
0609	Captain and 2nd mate indicate vessel is not pounding or rocking. CAPT "we're not pounding we're not (rocking)." 2M "nooo."	0.9	5.6	277
0613	Captain expresses concern with vessel heel/list. CAPT "I'm not liking this list."	356.9	6.285	276
0613	Captain statement about loss of propulsion. CAPT "I think we just lost the plant."	358	6.5	276
0616	Captain discusses propulsion loss with engine room on electric telephone. CAPT-ET "so... is there any chance of gettin' it back online?" "any chance of gettin' it back online?" CAPT "(they'll) bring everything back up online."	339.7	6.1	251

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
0617	Discussion about sloshing water or rain entering engine room ventilation system (reference to screens). CAPT-ET "where's the water comin' from?" "do you have all (screens) located?" "(some) water up there?" "okay right there." 2M "did they say uh (they're getting) water (at? / I) when (they/you) told me I was half asleep." CAPT "yeah (they said/there's) water sloshing (and) it's coming in through the ventilation (in) the engine room." 2M "yeah * * (driving rain)."	331.1	6.5	243
0620	Discussion about situation in a hold (unclear if this is hold 3). CAPT-ET "what hold is this?" "alright." "nobody goin' down there." "okay." "alright. thank you. thank you." At 06:24:48 captain states: CAPT-ET "… not only are we transferring ballast but I just talked with @3AE1 * he's back pumping (that/on) hold (too/two)	323.8	6.8	235
0621	Captain on telephone with third engineer. Captain asks if they are still transfering from port to starboard (vessel listing to port)—wants to know if they can tell whether they are actually pumping. CAPT-ET "okay you're transferring from port to starboard?" "yeah and you're– you're still pumpin'?" "still pumping'?" "allright. who is this?" "alright @3AE1." "is there anyway to tell (then) if you (actually) have suction and it is pumping? " 0643 CAPT-ET "yup. I– I just want to know that we're pumping from port to starboard on the ramp tanks."	321.6	6.8	234
0624	Civil twilight (the limit at which twilight illumination is sufficient, under good weather conditions, for terrestrial objects to be clearly distinguished—US Naval Observatory)			

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
0624	Captain asks for update and based on his response, crew is transferring ramp tank ballast water and pumping on a cargo hold. CAPT-ET "yup- can I have an update?" "so you're pumping over segregated ballast (port to) starboard?" "I think that's the plan that's what we're doing right now. and then umm. not only are we transferring ballast but I just talked with @3AE1 * he's back pumping (that/on) hold (too/two)."	325.2	7	232.35
0628-0630	Captain speaking to unknown mate on bridge. Captain wants to know water amounts, and states that vessel is stuck with port list and that an open scuttle on second deck was a source of floodwater. ? "* * * (pouring into the ship) * * * (* hold) somebody somehow (it got opened). * * *. CAPT "* * third mate * I wanna make sure * * * (chief mate) * * * (starboard) * ** (how much) water * * *." ? "It is listing to port * * * (suck/stuck) * * * (there's no way) * * *." CAPT "It was from the scuttle that was open * * * (on three) deck?" ? "second." CAPT "second deck."	322.9	6.8	231
0631-0635	Captain and 2nd mate discuss content of the GMDSS message that 2nd mate is creating. CAPT "flooding. List." 2M "its uhh all I got is flooding or we can do ummm– disabled and adrift * * *multiple." CAPT "I would I would do a bunch of them– no * * don't necessarily go all right now. those are the ones that are preprogrammed." 0635 2M "… * just flooding cargo * time and position umm I saved it."	322	6.7	233
0633-0634	Captain states the (engine room) is getting boiler back up and lube oil pressure up. CAPT–ET "alright that sounds good." "that's fine." "uhh– nope. that's good news. that's– that's good news. thank you very much.	324	6.7	233

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
	CAPT "yeah we'll see– they're gunna get that boiler back up online any (mi-) any second." CAPT "(they're just uh)– they're gettin' that boiler back up. they('re) gettin' lube oil pressure up."			
0634	Chief mate mentions checking water level in hold. CM "(and) I (did/didn't) start to check water * in the hold * * *. "	321.5	6.7	231
0640	Captain wants crew to report water level in hold 3 and acknowledges potential green water on deck. CAPT "(give/get) me some eyes on three hold there." CM "yes sir." CAPT "let me know what's going on down there." "have somebody (observe)." CM "where it is comin' from * *. (seas on the deck)?" CAPT "yeah."	323.5	7	227
0644	Statement that some shaft RPM (propulsion) has returned. CAPT "alright @AB-1 you got some turns right now." CAPT "that's a small victory right there."	322.9	6.6	228
0645	Discussion between captain and 2nd mate about heel and water in hold. 2M "once we uh– start comin' back over * wind... (on) off of our uh starboard side * * * (./?)" CAPT "* * (level it up) and get * over to starboard." 2M "yeah but we know how to fix that one." CAPT "* * (a lot of) water in the cargo hold area." 2M "(well then) suck out the water." CAPT "yup."	320.1	6.4	229
0645	Captain acknowledges that the stern light indicator on bridge is extinguished. 2M "oh the (stern/steering) light went out?" CAPT "yeah."	322.95	6.5	230

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
0645-0650	Statement about loose or damaged railing. M1/M2 "[sound of multiple low frequency thuds in rapid succession.]" CAPT "that's why I don't go out there." "that's a piece of handrail right?" 2M "yup. you're right." "it must be bangin'around in there." "probably loose *."	323.6	6.6	230
0647	Sunrise (the upper edge of the disk of the sun is on the horizon; atmospheric conditions are assumed to be average—US Naval Observatory)			
0648	Statement that there are no shaft RPMs (no propulsion). CAPT "they don't have any R-P-M on it right now so you can just stand by…"	323.15	6.6	229
0654	Statement that there is significant flooding in hold 3, wind on starboard side, and no propulsion. Statement that captain plans to stay with ship, not abandon it, at this time. CAPT-ET "(it's) miserable right now. we got all the uhh– all the wind on the starboard side here. now a scuttle was left open or popped open or whatever so we got some flooding down in three hold– a significant amount. umm everybody's safe right now we're not gunna abandon ship– we're gunna stay with the ship. we are in dire straits right now. okay I'm gunna call the office and tell 'em * *. okay? umm there's no need to ring the general alarm yet– we're not abandoning ship. the engineers are tryin' to get the plant back. so we're workin' on it– okay?"	322.7	6.6	225
0656	Captain attempts to confirm that engineers are still attempting to pump hold 3. CAPT-ET "chief status check." CAPT-ET "yeah the mate's down walkin' about there." are ya still pumpin' three hold?" "alrigh (just)." "yup." "yup." "alright I gotya." "yeah." "yeah." "okay just keep tryin'" "I'm uh– I'm gunna give the office a shout and let 'em know what we got."	319.7	6.7	226
0657	Statement that list is cause of the loss of lube oil pressure.	320.4	6.7	226

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
	2M "they havin' trouble gettin' it back online?" CAPT "yeah because of the list." 2M "* * *." "(with) a list like this (the whole time cargo) *." 0659 CAPT-FBB "… got a pretty good list…"			
0659	Captain leaves message to DPA, describes list and states that crew is safe. CAPT-FBB "captain @DPA– captain @CAPT– Thursday morning zero-seven * * * scuttle * * * got a pretty good list * * * I wanna uh (just touch) contact you verbally (again) everybody's safe * * *."	316.1	6.6	228
0701	Captain begins marine emergency call to a qualified individual. CAPT-FBB "this is a marine emergency. Yes this is a-ah marine emergency and I am tryin' to uh also notify a Q-I."	322.3	6.7	231
0704	Captain asks chief mate about flooding in hold and whether water level is decreasing or increasing. Chief mate can't tell. CAPT-UHF "yea. can you tell what the level is in that hold?" CM-UHF "…we're leanin' over pretty good to port. CAPT-UHF "yea– I'm– I'm sure it is. can you tell if its decreasing or increasing?" CM-UHF "I can't tell (captain) * * seems as if it's goin' down * *." CAPT "okay. all understood." "and uh mate– what else do you see down there? what else do you see?"	322.3	6.7	226
0705	Captain describes heavy list, states that propulsion is lost and cannot be restarted and that scuttle was source of water ingress. CAPT-FBB "… we had a hull breach– a scuttle blew open during a storm– we have water down in three hold– we have a heavy list– we've lost the main propulsion unit– the engineers can not get it goin'…"	322.6	6.6	225
0707	Captain describes scuttle as the source of water ingress, the ship has a port list and no propulsion.	319.1	6.8	227

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
	CAPT-FBB "yea. I'm real good. we have uhh– secured the source of the water coming in to the vessel. uh a scuttle– was blown open uh– by the force of the water perhaps– no one knows. can't tell. uh it's since been closed. however– uh– three hold's got considerable amount of water in it. uh we have a very– very– healthy port list. the engineers cannot get lube oil pressure on the plant therefore we've got no main engine…"			
0708	Statement that pumping effort to dewater hold 3 is not decreasing water level. CAPT-FBB "we are taking every measure to take the list off. by that I mean pump out that pump out that hold the best we can but we are not gaining ground at this time." "uhhh." "right now it's a little hard to tell because all the wind is that on that side too so we got a good wind heel goin'." "but it's not getttin' any better." 0711 same call- CAPT-FBB "that that is correct. the engine room has informed me that they are pumping that hold. there's a significant amount of water in there."	315.7	6.6	226
0708	Captain states that crew is trying to save ship. CAPT-FBB "yup. the– the crew is safe. right now we're tryin' to save the ship (now). but uh all available hands."	313.7	6.6	227
0710-0711	Chief engineer calls bridge regarding inability to "do anything" about the list. Second mate states that all they (bridge) can do is move ballast (ramp tank transfer). Second mate states that high wind speed is a cause of vessel list. 2M-ET "uh we're workin' on it (but) I mean the wind is pushing us over." "there's nothing we can do from up here." "* (overboard) segregated ballast is about all we can do. 'till the wind dies down…" 0714 CAPT "so who's that– that you talked to from the engine room?"	319.0	6.6	225

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
	0714 2M "oh (from) the uh chief. [CE]" "he's just tellin' us the same thing. he can't do anything with this list."			
0709	Statement about severe weather conditions. Captain states it is safest to stay with ship. CAPT-FBB "alright um– priorities. we um– gunna– gunna stay with the ship there na– no one's panicking um everybody's been made aware. um our– our safest bet is to stay with the ship during this particular time– the weather is ferocious out here. and uhh– we're– we're– gunna stay with the ship. now as– go 'head sir."	316.9	6.6	226
0710	Captain states that there is a 10- to 12-foot swell from northeast. CAPT-FBB "(the) swell is out the northeast." "a solid- solid ten to twelve feet (over) spreay high winds very poor visibility that's the best I can give ya right now…"	319.35	6.6	225
0710	Barometric pressure 959 millibars on vessel. 2M "nine-fifty-eight point eight."	318.4	6.6	225
0711	Statement that the vessel list/heel is 10 to 15 degrees. Captain states that wind heel is contributing to vessel list. CAPT-FBB "betcha it's all of fifteen– fifteen degrees." "ten. ten to fifteen degrees but a lot of that's with the wind heel." "(I can't) can't determine that at this time 'cause (three) *."			
0712	SSAS message sent. CAPT "alright now push– push the S-S-A-S button. 2M "roger" 0713 2M "distress button's been activated."	315.5	6.6	225
0714	Statement that pumping is ongoing. Captain is getting information on water level in hold (3) from chief mate over phone, who states water level is rising. Discussion of securing fire main and mention of sea suction and hull. CAPT-ET "yeah chief @CAPT here." "yup." "yeah we're pumpi' your pumpin'." "yeah the	318.8	6.6	223

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
	mate's down there here he is right here." "call ya back." CM "I think that water level's rising captain." CAPT "(okay). do you know where it's comin' from?" CM "* (at) first the chief said something hit the fire main. got it ruptured. Hard." CAPT "um there's no way to secure that?" CM "we don't know if they've (seen/still have) any pressure on the fire main or not. don't know where s'sea– between the sea suction and the hull or what uh but anything I say is a guess." CAPT "alright."			
0715	Chief mate dogged (secured) watertight door to hold which water was nearing. CM "but it was startin' to (go out there) (actually/initially) * (picked 'em up) * (deck) so I came in here and dogged that door tight * * (shook/shake)." CAPT "don't open it again." CAPT "this is the chief he just wants a status update." CM-ET "hello chief. * it's not the list it's the (damage) * * not going down I closed that water tight door on (four) deck I don't think we should open it again."	316.2	6.6	223
0716	First indication that floodwater is in cargo hold 2A (from bilge alarm). CM-ET "yes." "no. nobody's checked two alpha." "roger." "got it." CM-ET "bilge alarm in two alpha. goin' to check (it)." CM? "* (not goin'/goin') on second deck (and opening) the scuttle." "* wanna do that." "uh."	317	6.7	223
0716	Captain and crew discuss pumping all cargo holds (bilges) simultaneously. CM "I mean they can open up all of them (and suck the holds) the same time and one common suction they they can suck just (one/on) two alpha or ya know if three's not goin' down. [during the time the CM was	315.4	6.7	224

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
	speaking, the CAPT stated "(yea)" and "yea."]" CAPT "(don't know)." CM "(I don't know) what else to suggest." CAPT-ET "hey chief [CE] @CAPT here. can you suck on all of all of the uh all of the cargo holds?" Captain recalls what chief engineer stated about attempting to pump all holds and how it could lead to air in the bilge system. 0721 CM "what did he say when he said about pumpin' 'em all." 0721 CAPT "yeah but if you pump and uh you catch air then the whole thing is—" 0721 CM "well yeah two port– two A port * whatever."			
0717	Captain and chief engineer think the vessel list/heel is increasing. CAPT-ET "you think the list is getting worse?" "ya me too."	313.75	6.9	225
0717	Chief mate states he secured (watertight) door. CM "I buttoned that door up as hard as I could and I don't I don't know what else I can do." CAPT "yeah."	312	6.9	225
0717	Statement implying it was not safe for crew to be on second deck. Statement about using portable bilge pump through second deck scuttle to dewater cargo holds. CM "not goin' on deck." CAPT "nuh– nuh– nuh– nuh– no." CM "@SUP-1 was suggesting (uh) like rig a wilden pump...I'm like... where? through the scuttle?"	312.6	6.9	225
0717	No shaft RPMs. Propulsion still lost. ? "* no R-P-M * * we can't do anything."	313.6	6.8	226
0718	Statement implying that floodwater in hold 3 is high enough to float cars. CAPT "the cars that are floating in three hold..." CM "there are."	314.4	6.8	226

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
	CM "they're subs."			
0718	Statement that water level in hold 3 was above the fire system piping. Captain and chief mate discuss whether loose cars in hold 3 could have come in contact with emergency fire main piping. CAPT "um when you went down there before the– the fire main– was there anything near the fire * *? CM (when/I mean) I saw the water level's too high (the) fire main's right below the water dark black water." CM "and I saw cars bobbing around." CAPT "(think) they coulda come through there?" CM? "(do you think anything)." CM "yea there's fire main in the aft end * water could have…" "could have." CAPT "okay." Discussion about isolating engine room fire main piping from hold 3 emergency fire main pump/piping to halt flooding. CAPT "okay." "so what's the only wha– what option do we have to close that valve so we don't a free communication with the sea? * *" CM "[sound similar to a stutter] isolate the fire main." CAPT "ya." CM "in the engine room." CAPT "yup." CM "from that from the uh…" CAPT "engine room they can seg– segregate the fire main cutout." CAPT-ET "hey first." "yea can you... isolate the fire main from down in the uh engine room? the fire pump? isolate it? 'cause that may be the root cause of the water comin' in." CAPT "is there anything else you want me to tell 'em?" CM "I agree with that I just * *." CAPT "that's our last * *."	313.3	6.8	225

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
	CM "* * (cutout) on the engine room side fire main goin' forward." 0719 CAPT-ET "say first. on the on the engine room side the isolation valve suction fire pump (kindly/highly) secure it isolate it on your side so there's no free communication from the sea. alright. thank you." CAPT "'kay what else needs to be (there/done/secured)?" CM "that's it * (as far as we can) * *.			
0720	Captain orders chief mate to secure unknown electrical panels to protect them from rising water. CM "secure this?" "should I just secure these instead of (turnin' them up/burnin' 'em out)? all of 'em?" CAPT "go ahead and secure the (panels) so the water doesn't (get to 'em)."	306.2	6.4	221
0720	Chief mate has concern for vessel stability and does not know how much water (floodwater in cargo holds) is on the vessel. CM "yeah um– my concerns are (of course) stability (I have no/and no) concept of how much water (may be) sittin' down there * * (can't/very) difficult determine *." CAPT "yeah."	305.7	6.4	220
0722	Captain asks riding crew chief what he saw when he looked into hold 3 through scuttle. Riding crew chief asks captain what the downflooding angle is for the vessel and captain does not have immediate answer. CAPT-ET "alright who's this (@SUP-1)?" "alright. what did you see down there when you went and looked through that scuttle?" "okay." "alright." "alright." "it's lookin' pretty nasty." CAPT-ET "(uh/on) the down flooding angle? um that I don't have an answer for (ya)." "yup." "what's it called again?" "okay we'll check that. (it's/that's) in the chief's office?"	309.7	6.6	218

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
	"alright thank you." "um no. I mean we still got reserve buoyancy and stability."			
0723	Captain states he will ring general alarm. CAPT-ET "alright we're gunna ring the general alarm here and (wake/get) everybody up * * *."	309	6.7	213
0724	Captain indicates that the source of flooding is still not definitively determined. CAPT-ET "we're definitely not in good shape right now." "yeah. just tryin' to control that list see where the water's comin' from."	309.2	6.7	213
0724	Captain questions riding crew chief about potential flooding source, and decides to send mate to investigate. CAPT-ET "now the– can you isolate the fire pump from down there on the engine room side?" "okay." "are ya gettin' anything?" "yeah that's... (my god)." "yup. that would be it." "guy on second deck to make a round. yup. got a guy right here." "alright. well. he– he's not gunna open anything up that's already shut." "yeah. okay."	309.1	6.7	213
0725	Statement that water on second deck is/was chest deep. CAPT "* just make a round two deck– see what you can see. this isn't gettin' any better. you alright?" CM "yeah I'm not sure I wanna go on second deck. I'll open a door down there and look out." CAPT "that's fine. " CM "* * chest deep * (water/washin') * *." CAPT "* * * on the deck (right there)." CM "alright." "let me grab someone to come with me."	308.7	6.8	216
0727	Captain tells engine room he will ring general alarm, but will not immediately abandon ship. Emergency signal given (general alarm for 10 seconds).	313.6	7	216

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
	CAPT-ET "alright captain here. just want to let you know I am going to ring the general alarm. I am going to ring the general alarm. (you don't have to/ya know we're not gunna) abandon ship or anything just yet. alright we're gunna stay with it. is the chief there?" M1 "[sound of high frequency bell ringing, the general alarm bell.]"			
0728	Chief mate gives radio command for crew to muster on starboard side. Captain readying to abandon ship. CM-UHF "(everybody) * starboard side" ?-UHF "cap'n you gettin' ready to abandon ship? * *." CAPT-UHF "yeah what I'd like to make sure everybody has is their immersion suits and uh– stand by. get a good head count. good head count." ?-UHF "* * (muster(d) sir)."	313.4	7	217
0729	Statement that containers are in water. 2M "(alright I got containers in the water). [yelled]"	272.7	6.8	221
0729	Captain orders abandon ship. CAPT "alright let's go ahead and ring it– ring the abandon ship. M1 [continuous sounding of a high frequency bell for about eight seconds.]	239.8	6.8	221
0730	Captain states vessel's bow is down (visibly lower). CAPT "bow is down." "bow is down."	237.4	6.7	222
0731	Captain orders rafts thrown overboard and crew to enter them. CAPT-UHF "yeah– yeah– yeah– get into your get into your rafts * * throw all your rafts (in/to) the water. [yelled throughout]" ?-UHF "throw the rafts in the water– roger." CAPT-UHF "everybody– everybody. get off. get off the ship stay together. [yelled throughout]"	231.25	6.7	223

Time (rounded to min.)	Event summary at time in green text Supporting VDR transcript in black "Text"	Heading (deg)	Speed over Ground (kt)	Course over Ground (deg)
0734	Last recorded VDR parameter for a complete set of heading, speed, and course over ground (COG).	222.5	6.7	220
0736-0738	List/heel angle (to port) is increasing to a degree where movement is difficult on bridge. 0736 CAPT "work your way up here." 0737 AB-1 "my feet are (slipping/slippery). [yelled]" 0738 AB-1 "I need a ladder. [yelled]" 0738 AB-1 "(a line.) [spoken loudly]."	-	-	-
0739	Rumbling sound. "[sound of building low frequency rumble until end of recording.]"	-	-	-
0739	End of VDR Audio.	-	-	-