Sinking of US Cargo Vessel SS *El Faro*
Atlantic Ocean, Northeast of Acklins and Crooked Island, Bahamas
October 1, 2015

Accident Report

NTSB/MAR-17/01
PB2018-100342

National
Transportation
Safety Board

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Marine Accident Report

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490 L'Enfant Plaza SW
Washington, DC 20594

National Transportation Safety Board. 2017. ***Sinking of US Cargo Vessel SS* El Faro*, Atlantic Ocean, Northeast of Acklins and Crooked Island, Bahamas, October 1, 2015*. Marine Accident Report NTSB/MAR-17/01. Washington, DC.**

Abstract: On Thursday, October 1, 2015, the SS *El Faro*, a 40-year-old cargo ship owned by TOTE Maritime Puerto Rico and operated by TOTE Services, Inc., was on a regular route from Jacksonville, Florida, to San Juan, Puerto Rico, when it foundered and sank in the Atlantic Ocean about 40 nautical miles northeast of Acklins and Crooked Island, Bahamas. The ship had sailed directly into the path of Hurricane Joaquin, carrying a crew of 33, including 5 Polish contract repair workers. All those aboard perished in the sinking. As part of its accident investigation, the National Transportation Safety Board (NTSB) led a joint effort with the US Navy, Woods Hole Oceanographic Institution, and the National Science Foundation to locate the ship's wreckage and retrieve its voyage data recorder (VDR). The VDR was pulled from 15,250 feet below the ocean surface in August 2016 during the third undersea mission and yielded more than 26 hours of parametric data and audio files. The NTSB's accident investigation identified the following safety issues: captain's actions, use of noncurrent weather information, late decision to muster the crew, ineffective bridge resource management, inadequate company oversight, company's safety management system, flooding in cargo holds, loss of propulsion, downflooding through ventilation closures, need for damage control plan, and lack of appropriate survival craft. The NTSB made safety recommendations to the US Coast Guard; the Federal Communications Commission; the National Oceanic and Atmospheric Administration; the International Association of Classification Societies; the American Bureau of Shipping; Furuno Electric Company, Ltd.; and TOTE Services, Inc.

NOTE: This report was reissued on September 7, 2018, with corrections to pages 6 and 23.

ERRATA SHEET

Page 6, top line: “1,10-nm” was corrected to “1,100-nm”

Page 23, footnote 51: “northwest” was corrected to “northeast”

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Acronyms and Abbreviations

AB	able seaman
ABS	American Bureau of Shipping
ACP	Alternate Compliance Program
ACS	authorized classification society
AIS	automatic identification system
AMO	American Maritime Officers (union)
AMOS	Asset Management Operational System
ASM	application-specific message
AUV	autonomous underwater vehicle
bbl	barrels
BRM	bridge resource management
BVS	Bon Voyage System
CDT	central daylight time
CEO	chief executive officer
CFR	*Code of Federal Regulations*
COI	certificate of inspection
CRM	crew resource management
CSS	(Code of Safe Practice for) Cargo Stowage and Securing
CURV	cable-controlled undersea recovery vehicle
D7CC	Seventh District Command Center (Coast Guard)
DMSP	Defense Meteorological Satellite Program
DP	designated person
DSC	digital selective calling
ECDIS	electronic chart display and information system
EDT	eastern daylight time
EPIRB	emergency position-indicating radio beacon
EPMV	emergency preparedness manual–vessel

FCC	Federal Communications Commission
GAO	Government Accountability Office
GHS	General HydroStatics
GM	metacentric height
GMDSS	Global Maritime Distress and Safety System
gpm	gallons per minute
GPS	global positioning system
GSM	global system for mobile communications
GUDE	general utility deck or engine (crewmember)
HF	high frequency
hp	horsepower
IACS	International Association of Classification Societies
ICLL	International Convention on Load Lines
IEC	International Electrotechnical Commission
IMO	International Maritime Organization
ISM	International Safety Management (code)
ITU	International Telecommunications Union
JSTARS	Joint Surveillance Target Attack Radar System
kHz	kilohertz
LANTAREA	Atlantic Area (Coast Guard)
LNG	liquefied natural gas
LORACS	liaison officer to recognized and authorized classification societies
MARAD	US Maritime Administration
MASECO	Marine Safety Equipment Corporation
MHz	megahertz
MISLE	Marine Information for Safety and Law Enforcement
NASA	National Aeronautics and Space Administration
NAVTEX	navigational telex
NCB	National Cargo Bureau

nm	nautical mile
NOAA	National Oceanic and Atmospheric Administration
NTSB	National Transportation Safety Board
NVIC	navigation and vessel inspection circular
OCMI	Officer in Charge, Marine Inspection
OMV	operations manual–vessel
PFD	personal flotation device
PSDA	probability of survival decision aid
psi	pounds per square inch
psig	pounds per square inch gauge
Ro/Con	roll-on/roll-off container
Ro/Ro	roll-on/roll-off
ROV	remotely operated vehicle
rpm	revolutions per minute
RRDA	Rapid Response Damage Assessment
SAROPS	search-and-rescue optimal planning system
SARSAT	search-and-rescue satellite-aided tracking
SART	search-and-rescue transponder
Sat-C	Inmarsat-C SafetyNet
SFMR	stepped-frequency microwave radiometer
SIU	Seafarers International Union
SLDMB	self-locating datum marker buoy
SMS	safety management system
SOLAS	International Convention for the Safety of Life at Sea
SSAS	ship security alert system
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
SUPSALV	(US Navy) Superintendent of Salvage and Diving
S-VDR	simplified voyage data recorder
TEU	twenty-foot-equivalent unit

UHF	ultrahigh frequency
USC	*United States Code*
UTC	coordinated universal time
VDES	VHF data exchange system
VDR	voyage data recorder
VHF	very high frequency
WAM	wireless asset management

Executive Summary

On October 1, 2015, during Hurricane Joaquin, the US-flagged cargo ship SS *El Faro* sank in the Atlantic Ocean about 40 nautical miles northeast of Acklins and Crooked Island, Bahamas. All 33 people on board perished. *El Faro* was owned by TOTE Maritime Puerto Rico and operated by TOTE Services, Inc. Damages from the sinking were estimated at $36 million. Before the loss of *El Faro*, the last comparable US maritime disaster was the sinking of the US bulk carrier *Marine Electric* off the coast of Virginia in February 1983, in which all but three of the 34 persons aboard lost their lives.

The National Transportation Safety Board (NTSB) determines that the probable cause of the sinking of *El Faro* and the subsequent loss of life was the captain's insufficient action to avoid Hurricane Joaquin, his failure to use the most current weather information, and his late decision to muster the crew. Contributing to the sinking was ineffective bridge resource management on board *El Faro,* which included the captain's failure to adequately consider officers' suggestions. Also contributing to the sinking was the inadequacy of both TOTE's oversight and its safety management system. Further contributing factors to the loss of *El Faro* were flooding in a cargo hold from an undetected open watertight scuttle and damaged seawater piping; loss of propulsion due to low lube oil pressure to the main engine resulting from a sustained list; and subsequent downflooding through unsecured ventilation closures to the cargo holds. Also contributing to the loss of the vessel was the lack of an approved damage control plan that would have assisted the crew in recognizing the severity of the vessel's condition and in responding to the emergency. Contributing to the loss of life was the lack of appropriate survival craft for the conditions.

The NTSB's investigation of the sinking identified the following safety issues:

- Captain's actions
- Use of noncurrent weather information
- Late decision to muster the crew
- Ineffective bridge resource management
- Inadequate company oversight
- Company's safety management system
- Flooding in cargo holds
- Loss of propulsion
- Downflooding through ventilation closures
- Need for damage control plan
- Lack of appropriate survival craft

The report also discusses other issues, such as the automatic identification system, voyage data recorders, and the US Coast Guard's Alternate Compliance Program.

NOTE: The person who occupied the position of master of *El Faro* is referred to as "captain" throughout this report. The NTSB uses the more common title to maintain consistency with other information the agency has produced concerning the accident and to avoid confusion among readers unfamiliar with marine practice.

As a result of its investigation, the NTSB makes recommendations to the Coast Guard; the Federal Communications Commission; the National Oceanic and Atmospheric Administration; the International Association of Classification Societies; the American Bureau of Shipping; Furuno Electric Company, Ltd.; and TOTE Services, Inc.

1 Factual Information

1.1 Introduction

On Thursday, October 1, 2015, the SS *El Faro*, a 40-year-old cargo ship owned by TOTE Maritime Puerto Rico and operated by TOTE Services, Inc., was on a regular route from Jacksonville, Florida, to San Juan, Puerto Rico, when it foundered and sank off the Bahamas (figure 1). The vessel carried a crew of 33, including a "riding gang" of five contract repair workers, all Polish nationals, and their supervisor, an off-duty chief engineer. *El Faro* had sailed directly into the path of Hurricane Joaquin. The hurricane was a Category 3 storm that reached Category 4 strength 20 minutes after the sinking, according to a National Weather Service poststorm analysis (Berg 2016).[1]

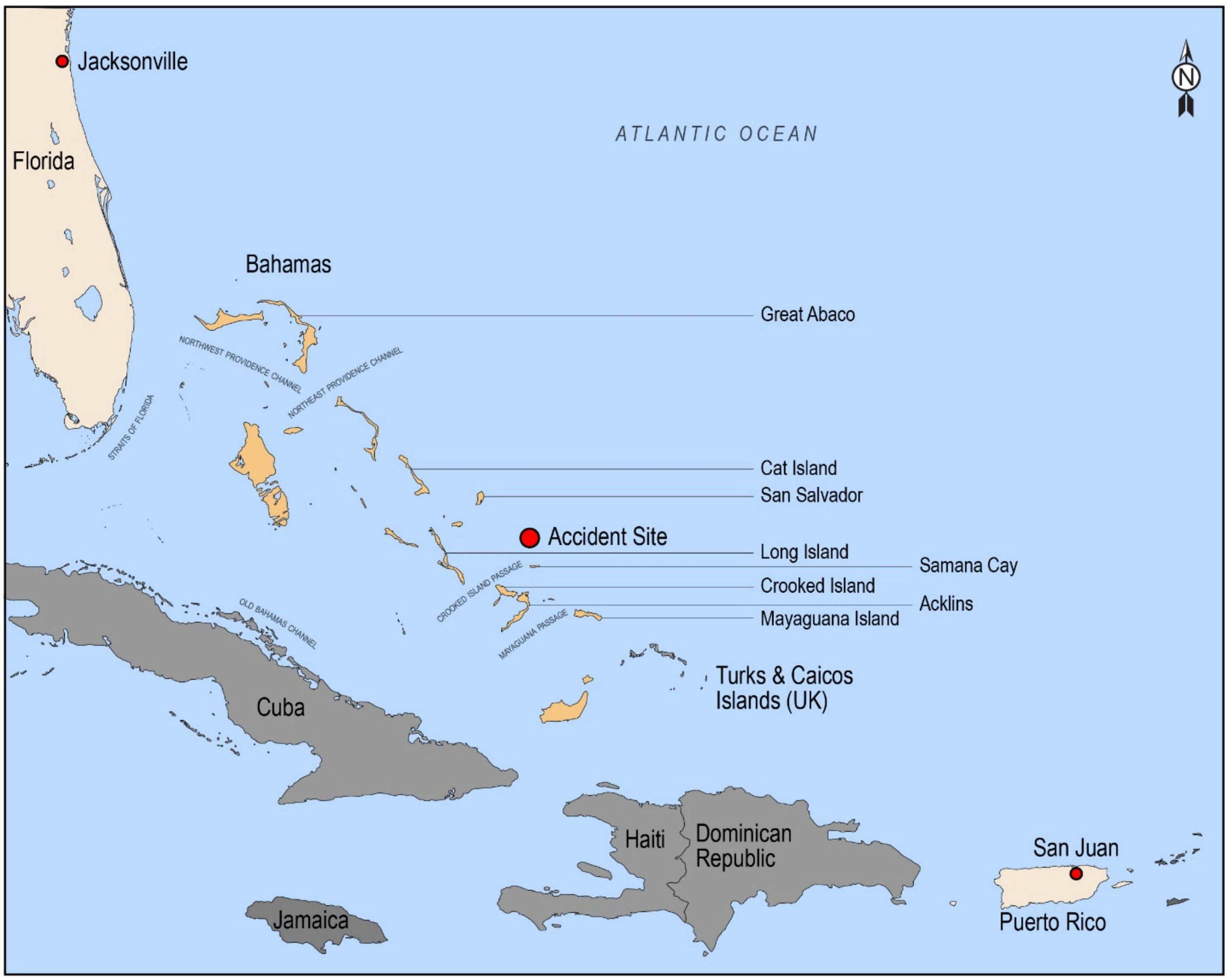

Figure 1. Accident location in Atlantic Ocean near Acklins and Crooked Island, Bahamas.

[1] Category 4 hurricanes carry winds of 130 to 156 mph (113–136 knots). See section 1.10 for detailed information about the storm.

Four days after the sinking, the National Transportation Safety Board (NTSB) contacted the US Navy and began planning an effort to locate the *El Faro* wreckage and retrieve its voyage data recorder (VDR). On October 31, the Navy ship *Apache* located *El Faro*'s hull at a charted depth of 15,410 feet (figure 2), latitude 23.38125N, longitude 073.9111W.[2] A remotely operated vehicle (ROV), CURV-21, confirmed the finding the next day.[3] The search ended on November 15 without locating *El Faro*'s VDR.

Figure 2. Artist's rendering of *El Faro* hull lying on seabed 15,400 feet below surface of Atlantic Ocean.[4]

In April 2016, the National Science Foundation and the Woods Hole Oceanographic Institution jointly sent the research vessel *Atlantis* to the wreckage area to search for *El Faro*'s VDR. An underwater vehicle located the VDR capsule on April 26, but investigators determined that it could not be recovered at that time.

Ten months after the accident, in August 2016, the Navy ship *Apache*, again carrying CURV-21, returned to the accident site on a mission to recover the VDR. On the evening of August 8, CURV-21 retrieved the capsule from a depth of 15,250 feet. After the *Apache* returned to port on August 12, investigators transported the VDR capsule to NTSB headquarters in Washington, DC, where the data were downloaded by recorder specialists in the presence of the

[2] This report gives latitude and longitude as decimal degrees, with degree signs omitted. Geographic positions originally reported in another format (degrees and decimal minutes; or degrees, minutes, and seconds) have been converted, except where necessary to document actual transmissions or describe misinterpretations related to format.

[3] CURV stands for cable-controlled undersea recovery vehicle.

[4] See appendix B for details about the drawing's development.

manufacturer's representatives. Over 26 hours of parametric data and audio files were accessed from the VDR's memory module (see section 1.3.10, "Electronic Equipment").[5] For further details about the three missions to locate the *El Faro* wreckage and recover its VDR, see appendix C.

The sinking of *El Faro* was investigated jointly by the US Coast Guard and the NTSB, with the NTSB as the lead investigative agency. The factual information gathered during the NTSB investigation can be found in the online public docket for the accident.[6] In October 2015, the Commandant of the Coast Guard convened a Marine Board of Investigation into the sinking. The board of investigation held three public hearings, all of which took place in Jacksonville. The first hearing was held in February 2016, the second in May 2016, and the third in February 2017.[7] The NTSB participated fully in the proceedings. Approximately 75 witnesses testified before the marine board, including former and off-duty *El Faro* crewmembers, company officials, and industry experts. Transcripts of the marine board testimony are found in the docket.

Because the sunken *El Faro* could not be physically investigated (although many thousands of images were gathered during the underwater searches), NTSB investigators visited *El Faro*'s sister ship, *El Yunque*, to observe and document its structure and equipment. The visits took place 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, the American Bureau of Shipping (ABS), and TOTE were present at each visit.

El Yunque was also operated by TOTE and traveled on the same run as *El Faro*, on an opposite schedule. *El Yunque*, which was built in 1976, one year after *El Faro*, was considered a sister ship because it was constructed by the same maker to the same hull specifications, though certain arrangements and fittings were not identical on the two vessels. After *El Faro* sank, the Coast Guard reinspected *El Yunque* and discovered many deficiencies, including corrosion in its ventilation system, according to a Coast Guard chief inspector who testified at the marine board hearings in February 2017. *El Yunque* was sold for scrap on December 31, 2016.

In addition to reviewing the testimony of witnesses at the marine boards, NTSB investigators gathered information by interviewing former and off-duty crewmembers, the crew's family members and friends, TOTE officials, industry representatives, Coast Guard officers, and others. Additional first-hand information about *El Faro* came from photographs and written records collected by Maine Maritime Academy cadets who had sailed on the vessel during the summer of 2015, as part of the school's cadet shipping program.

1.2 Accident Narrative

September 28. At 1230 on Monday, September 28, 2015, *El Faro* docked at pier 32 on Blount Island Terminal in Jacksonville and began preparations for its return to San Juan the next

[5] 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.

[6] See http://dms.ntsb.gov/pubdms/search/hitlist.cfm?docketID=58116. The NTSB identification number for the *El Faro* accident is DCA16MM001.

[7] The dates of the marine board hearings were February 16–26, 2016; May 16–27, 2016; and February 6–17, 2017.

evening.[8] *El Faro* made one scheduled round trip a week between Jacksonville and San Juan, leaving Jacksonville on Tuesday, docking in San Juan on Friday, and arriving back in Jacksonville on Monday (figure 3).

Figure 3. *El Faro* at sea loaded with containers, viewed from stern. (Photo taken March 12, 2012, at Port Everglades, Florida, by Captain William Hoey)

At 1300 on September 28, cargo operations began. First, cranes began lifting off the containers that had arrived from San Juan (most of them empty). Then workers began driving the wheeled, roll-on/roll-off (Ro/Ro) cargo (such as automobiles and trailers) off the ship. A new lot of containers began loading at the same time. All the Ro/Ro cargo would be on board before the last containers were stowed.

El Faro's chief mate was on duty to oversee cargo operations, assisted by the second mate or third mate, depending on their schedules. Cargo handling was the work of stevedores (who planned and oversaw cargo discharge, loading, and securing) and longshoremen (who operated cranes, drove trucks and automobiles, and lashed or unlashed cargo). Cargo operations ended for the night at 2100 on September 28. About an hour and a half later (at 2236), the National Hurricane Center, a division of the National Weather Service based in Miami, Florida, advised the public that

[8] Times in the report are eastern daylight time (EDT) according to the 24-hour clock. Occasional references are also made to coordinated universal time (UTC), which is 4 hours ahead of EDT.

a tropical depression about 400 nautical miles (nm) northeast of the central Bahamas had become a tropical storm, named Joaquin.

September 29. Cargo loading and unloading resumed at 0800 the morning of September 29. At 1003, an off-duty *El Faro* second mate texted the captain, "Storm forming north of bahamas." At 1651, about 3 hours before *El Faro* would set sail, the National Hurricane Center announced to the public that Joaquin could become a hurricane the next day. At the time, the storm was centered about 600 nm east-southeast of Jacksonville (at 26.0N, 71.0W). Maximum sustained winds were 55 knots, with gusts to 65 knots.[9] About 25 minutes later, the hurricane center issued the first marine hurricane warning for Joaquin, for a large area (nearly 73,000 square nm) of the Atlantic east of the Bahamas.

The captain and the TOTE port engineer had dinner together the evening of September 29. The port engineer testified at the first marine board that they "discussed the tropical storm that was brewing, but that was all it was, a tropical storm, so there was no concern about major weather."

At 1831, the off-duty second mate sent another text message to the captain: "What's your plan?" The captain replied that he would "steam our normal direct route" to San Juan and that according to the forecasts, Joaquin would "remain north of us." At 1909, the off-duty second mate responded in another text that if necessary, "we have routes" through Mayaguana, Crooked Island, and Northeast Providence Channel, referring to passages through the Bahamas that are described as alternate routes for avoiding storms (see section 1.9, "Waterway Information").[10]

By 1930 the evening of September 29, *El Faro*'s cargo was loaded. At 2007, the ship cast off its last line and was away from the pier, carrying a crew of 33 and 11,046 long tons of cargo.[11] The weather was warm (78°F), humid, and cloudy, with a light wind blowing from the southeast. Rain had fallen during the day, and showers and fog were forecast for the next day. The Coast Guard had put the port of Jacksonville in Hurricane Condition 4, the base state of alert during hurricane season (June to November), and no storm watches were posted.

A harbor pilot was on board to guide *El Faro* down the main ship channel to a sea buoy off the mouth of the St. Johns River, a distance of about 9 nm.[12] The pilot told the second marine board that when he mentioned the storm building in the Atlantic, the captain said, "We're just gonna go out and shoot under it." The pilot said no one on the ship's bridge reacted.

At 2144, the pilot left the vessel near the sea buoy, and *El Faro* embarked on its 1,100-nm voyage to San Juan, intending to follow the usual straight-line track that passed east of the

[9] A *knot* is a unit of speed equal to one nautical mile per hour (about 1.15 statute miles per hour). One nautical mile is 1 minute of arc on any meridian.

[10] The second mate misspelled Mayaguana as "Mauagiez" in his text. Mayagüez is a municipality in Puerto Rico.

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

[12] Jacksonville is situated on the banks of the St. Johns River, which empties into the Atlantic Ocean east of the city. See section 1.9 for a description of the port of Jacksonville.

Bahamas. In the departure report he sent to the TOTE offices, the captain estimated his time of arrival at the San Juan sea buoy as 0500 on October 2.

At 2254, an hour after the pilot left the ship, the National Hurricane Center announced that the Bahamian government had issued a hurricane watch for the central Bahamas.[13] The watch meant that the area could see hurricane conditions in 36 to 48 hours. The storm was moving west-southwest.

September 30. At 0443 on Wednesday morning, the National Hurricane Center announced that the Bahamian government had upgraded its hurricane watch for the central Bahamas to a warning and had now issued a hurricane watch for the northwest Bahamas, excluding Andros Island.[14] A warning means that hurricane conditions are expected within 36 hours. Hurricane hunter aircraft were "on their way to investigate Joaquin," according to the hurricane center's announcement.

Audio data from *El Faro*'s VDR were recovered as far back as 0536 on September 30 (earlier data had been recorded over). The VDR recorded conversations and ambient sounds using six microphones on *El Faro*'s bridge. Figure 4 illustrates the layout of *El Faro*'s bridge deck, showing the location of the helm, navigation and emergency equipment, stairs to the deck below (which included the captain's office), bridge wings, and other items mentioned in the recording. The VDR also captured radar images and parametric data, such as ship's heading, wind speed, and wind direction. Officers on the bridge commented that their anemometer was not working, and the wind direction readings stayed between 180° and 193° (relative to the vessel) for nearly all the recording. Investigators determined that the wind data recorded on the VDR were inaccurate.

At 0601, the captain and chief mate were discussing the storm's route, referring to the ship's onboard weather program, the Bon Voyage System (BVS). BVS files, which contained graphic depictions of weather information, were sent every 6 hours to the captain's email address. At 0608, an emailed BVS weather file was downloaded on the captain's computer.[15] (It had been available at 0504.) The data in the BVS file—storm's current position and forecast track—were consistent with those in the National Hurricane Center advisory (No. 8) issued at 1651 the day before (when the hurricane center also announced that Joaquin could become a hurricane the next day [September 30]).[16] At 0612, the captain emailed the file to the computer on the bridge.[17] Two

[13] The central Bahamas include Cat Island, the Exumas, Long Island, Rum Cay, and San Salvador.

[14] The northwest Bahamas include Grand Bahama, Bimini, Abaco, the Berry Islands, Andros, Eleuthera, and New Providence.

[15] Two previous BVS weather emails had been downloaded on the ship, before the VDR recording began. See section 1.10.3 for more information about BVS.

[16] Because of an updating problem with the BVS system, the weather file received at 0504 duplicated the file emailed to the ship 6 hours earlier.

[17] BVS weather files were sent only to the captain's email address and had to be forwarded from his email account (accessed only in his office) to a bridge email account, where they would be downloaded on the bridge computer.

minutes later, he was recorded as saying: "It's tracking as the written weather has it. . . . It's gone a little south."

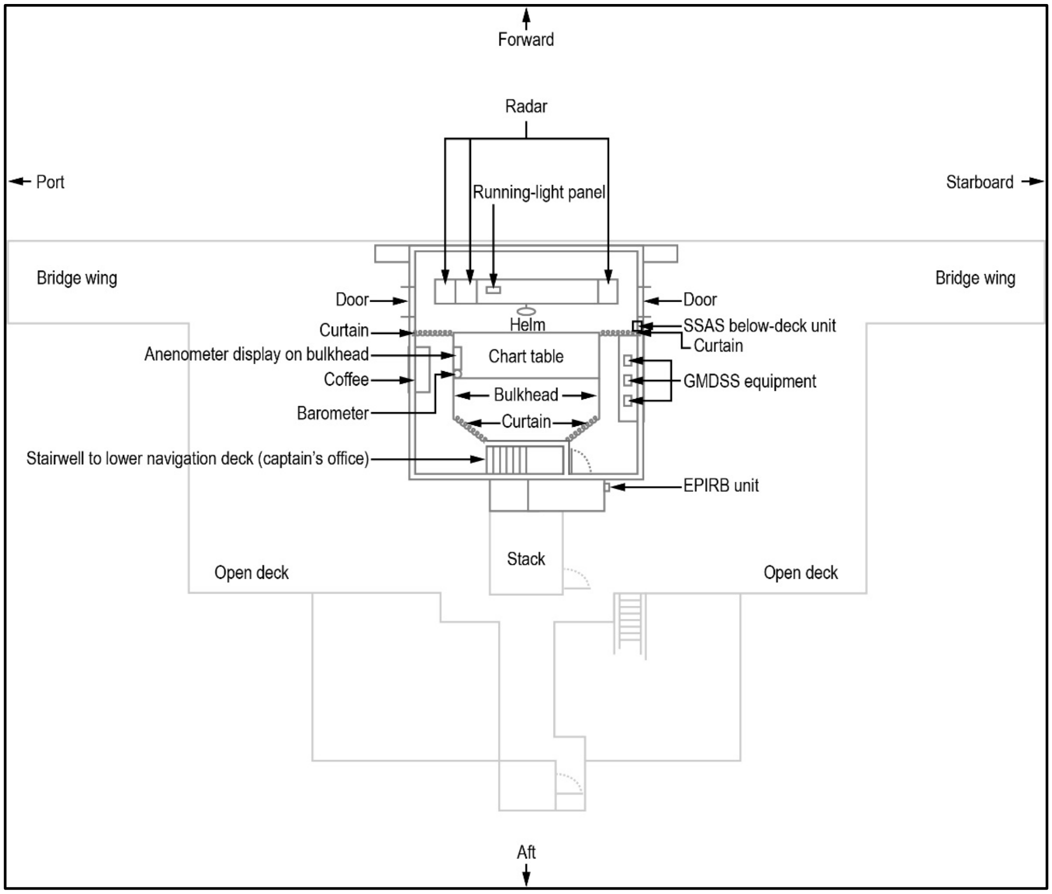

Figure 4. Layout of *El Faro*'s bridge deck. Bridge interior measured about 40 feet (port to starboard) by 32 feet (forward to aft). Investigators attributed some VDR noise to curtains on metal rods being drawn aside to access chart table. Bulkheads are dividing walls. Note location of EPIRB (emergency position-indicating radio beacon) on bridge exterior, starboard aft.

The captain and chief mate then discussed their course, referring to the BVS information, and cleared the chart table of everything except the navigation charts. At 0624, they shifted the vessel's course slightly southward (from 133° to 140°).[18]

At 0625, *El Faro*'s Sat-C terminal received an urgent (pan-pan) high seas forecast predicting that in 24 hours, Joaquin would be near 24.7N, 73.8W, about 50 nm northeast of San Salvador Island.[19] Maximum sustained winds were predicted to be 75 knots, with gusts to

[18] Headings, or bearings, in this report are true. True heading is the direction, relative to true north, in which a ship points. The usual measurement is in degrees and is measured clockwise through 360°. If a vessel heads true north, it heads 000°; east, 090°; south, 180°; west, 270°.

[19] Sat-C is short for Inmarsat-C SafetyNet. Inmarsat (International Maritime Satellite Organization) operates geostationary satellites that transmit safety communications for ships at sea. The National Weather Service delivers weather forecasts and warnings to Inmarsat for satellite broadcast.

90 knots, and seas to 27 feet, in an area that included the accident location. The Ocean Prediction Center, one of the National Centers for Environmental Prediction operated by the National Weather Service, had issued the forecast at 0547.

At 0635, the captain and chief mate were still plotting their course. At 0638, *El Faro*'s Sat-C terminal received National Hurricane Center advisory No. 10 (corrected), which stated that the government of the Bahamas had issued a hurricane watch, rather than a warning, for the northwestern Bahamas excluding Andros Island.[20] The location of the storm center had not changed (east-northeast of the central Bahamas). Maximum sustained winds were 60 knots, with gusts to 75 knots.

The captain and chief mate continued plotting the course and updating their trackline. At 0641, the captain yawned and said, "Oh, look at that red sky over there. Red in the morning, sailors take warning."[21] He and the chief mate continued working on the vessel's route.

At 0655, the captain told the chief mate that he "spoke to the steward about the prevailing weather and the importance of securing the galley for the evening." He then asked the chief mate whether he was comfortable with the recent course change ("a good little diversion"). The chief mate said he was and that the other option was "drastic." The captain said, "Yeah, it doesn't warrant it . . . you can't run every single weather pattern." The chief mate said, "Not for a forty-knot wind," to which the captain replied, "Now that would be the action for some guy that's never been anywhere else . . . we'll just sit on the bank and fish for trout."

At 0711, the captain said, "Needless to say, we'll be watching the weather deteriorate today." A few minutes later he said, "If our anemometer worked." The chief mate said, "Obviously, the direction's not good. Is that number [wind speed] any good?" The captain said, "I wouldn't trust it." The chief mate said, "they're (not gonna) buy a new one for it."[22] The captain told the chief mate that when he addressed the crew that day, he should "let 'em know we got some weather."

At 0719, the captain told the chief mate to "take a hard look at some of that cargo down there" and asked if he had enough lashings. The chief mate replied that he had not looked at any lashing inventory and that the longshoremen in Jacksonville were "doing it [the lashing] wrong." At 0725, the captain left the bridge to "go down and check up on everybody."

At 0732, the chief mate told the second assistant engineer over the electric telephone to secure his personal belongings: "heavy weather tonight."

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[20] The advisory this one was correcting had released the wind information (sustained at 60 knots, gusts to 75 knots) at 0437, about 2 hours earlier. While the VDR did not capture receipt of the earlier advisory, investigators believe the Sat-C terminal received it within minutes.

[21] The captain was quoting an age-old saying used to informally forecast the weather: "Red sky at night, sailor's delight/Red sky in the morning, sailors take warning." The adage has scientific validity in that a rising or setting sun can create a red sky by illuminating clouds on the horizon associated with an approaching or exiting weather system.

[22] On the VDR transcript, uncertain words or phrases are placed inside parentheses.

At 0739, the National Hurricane Center issued an intermediate advisory announcing that Joaquin had officially become a hurricane (winds of at least 64 knots).[23] The storm had intensified and was now centered about 213 nm east-northeast of the central Bahamas (at 24.9N, 72.2W) and about 400 nm southeast of *El Faro*'s position. Maximum sustained winds were 65 knots. *El Faro* did not receive the advisory via Sat-C because intermediate advisories were not scheduled for Sat-C broadcast.[24]

The chief mate and the able seaman (AB) on watch were recorded discussing the ship's speed and estimated time of arrival in San Juan.[25] At 0741, the chief mate said, "We lost some speed . . . we were making twenty knots and now we're not." The ship's speed over ground was 19.4 knots.[26] The AB said, "Might slow it down even more." The chief mate said, "It is what it is. Get there when we get there . . ."

At 0744, the third mate said he had heard on the Weather Channel that the storm was going to be a hurricane the next day or "later today." The chief mate noted that the storm was moving farther south and west than predicted and while discussing the recent diversion (to course 140°) with the third mate, stated, "Now worse comes to worse we can duck in." He went on to say that Northwest Providence Channel "isn't gonna do much because you have to come back out right at the wrong time . . . I mean if you're good (at diverting/I'd rather be) in Old Bahama Channel."[27] In August, *El Faro* had diverted to Old Bahama Channel to avoid Tropical Storm Erika (figure 5).

Around 0815, the chief mate and the AB discussed the weather. The chief mate said, "We're gonna get slammed tonight." The AB said, "Yeah, I was thinkin' that all through August—like it's been too quiet this season" and that "out in the Pacific it's one after the other, a daisy chain of 'em." At 0831, the captain arrived back on the bridge. He said the storm had "morphed its ugly head" between the time they left and when they woke up that morning, then told the AB on watch:

> Tough to plan when you don't know, but we made a little diversion here. We're gonna—we're gonna be further south of the eye.[28] We'll be about sixty miles south of the eye. It should be fine. We are gonna be fine—not should be—we are gonna be fine.

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[23] The poststorm analysis issued by the National Hurricane Center (Berg 2016) states that Joaquin actually reached hurricane strength at 0200 the morning of September 30.

[24] Intermediate advisories could have been obtained from the National Weather Service via FTPmail (see section 1.10.2), but there is no evidence that the crew attempted to do so.

[25] The AB was the helmsman.

[26] *Speed* in this report refers to speed over the ground, not speed through the water. Speed over the ground was measured by the global positioning system (GPS). Investigators determined that *El Faro* did not have a device to measure its speed through the water.

[27] Northeast Providence Channel connects with Northwest Providence Channel west of Great Abaco Island.

[28] The *eye* is the mostly calm region at the center of a hurricane that winds rotate around. The *eyewall* is a ring of cumulonimbus that encircles the eye of a tropical cyclone. It is where the most damaging winds and most intense rainfall occur.

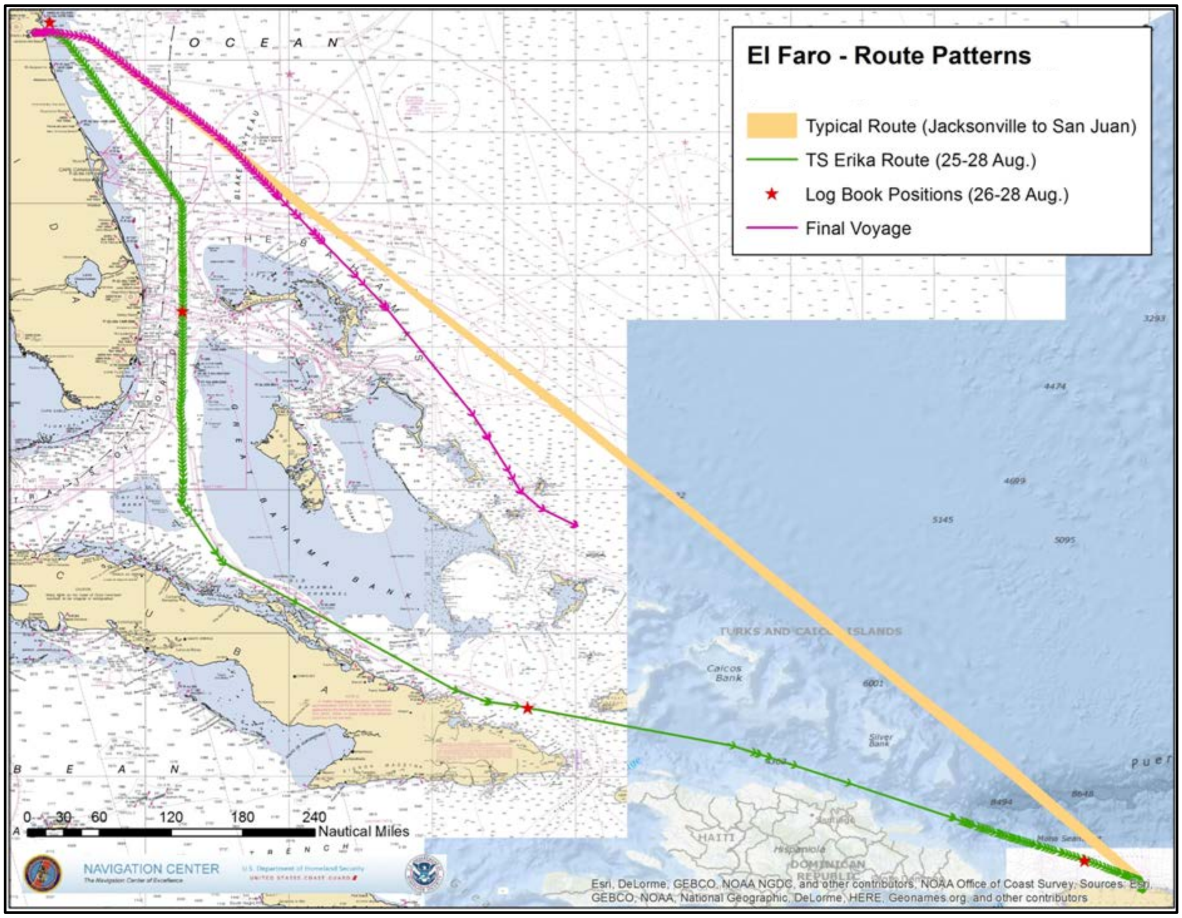

Figure 5. Alternate route via Old Bahama Channel (green) from Jacksonville to San Juan, compared with normal route (orange) and *El Faro*'s route on accident voyage (purple). (Coast Guard diagram)

At 0923, the captain said that Erika was the first real storm he had ever been in with *El Faro* and that the ship was "solid."[29] The third mate agreed: "This ship is solid it's just all . . . the associated bits and pieces . . . the hull itself is fine—the plant no problem." Either he or the captain said, "We're gonna make it, we're gonna make it."

The captain then described crossing the Atlantic in "the roughest storm [he] had ever been in." He said that cars had broken loose, sediment had blocked the fuel strainers, a wind gust had registered 102 knots, and every seventh or eighth wave in a period had been a rogue wave.[30]

[29] It is not clear, but the captain was probably referring to Tropical Storm Erika, which had hit the Caribbean about a month earlier (see section 1.10, "Meteorological Information").

[30] Investigators could not identify which storm the captain was referring to or when it happened. Between 2005 and 2012, he had served on Ro/Ro car and truck carriers crossing the Atlantic (see section 1.8, "Personnel Information"). A rogue wave is an unusually tall wave that appears without warning (see section 1.15.2, "Rogue Wave Analysis").

At 0932, the third mate told the captain about problems receiving messages on the ship's navigational telex (NAVTEX) receiver.[31] He then told the AB on watch that he was worried that the Polish workers ("team Poland") were not prepared for the weather and that they were leaving their equipment unsecured.

At 0952, the captain of *El Yunque*, then about 330 nm southeast of *El Faro*, sent an email to the *El Faro* captain: "Just wondering how you were doing with the Hurricane out there. We sped up yesterday morning to get in front of it. We're to the NW of it now, but it appears to be steadily intensifying and tracking to the SW." The captain received the message at 1002. Fifteen minutes later, the *El Faro* second mate emailed her mother: "We are heading straight into a hurricane."

About 0954, the second mate arrived on the bridge and briefly discussed the hurricane with the third mate. The third mate said, "This is good warm-up for Alaska."[32]

At 1053, National Hurricane Center advisory No. 11 reported that Joaquin was strengthening as it moved southwest. The storm center was about 187 nm east-northeast of the central Bahamas (at 24.7N, 72.6W) and about 330 nm southeast of *El Faro*'s position. Maximum sustained wind speeds were 70 knots, gusting to 85 knots. *El Faro*'s Sat-C terminal received the advisory at 1056. The chief mate told the captain that the latest advisory was "pretty much in line with what BVS is saying as far as direction."

At 1108, the *El Faro* captain emailed the captain of *El Yunque*:

> I have been watching this system for the better part of a week. We did alter our direct route slightly more to the south, which will put Joaquin 65 nm to the north of us at its cpa [closest point of approach]. Fortunately we departed the dock in JAX [Jacksonville] on time last evening and making 20k [knots] doesn't hurt either. All departments have been duly notified and we should be on the back side by 10/01/0800.

At 1112, the captain told the third mate, "I think we're gonna duck underneath it." At 1121, the *El Yunque* captain replied to the *El Faro* captain's email:

> That's good to hear. Hopefully, it will turn to the North soon. As we passed to the west of it, we recorded a 100 knot relative wind gust. Luckily, it was coming from directly ahead.

At 1124, the captain downloaded a BVS weather file that had been available at 1103. At 1147, the second mate said, "He's tellin' everybody down there—ohhh, it's not a bad storm, it's not so bad . . . it's not even that windy out . . . seen worse." A few minutes later, the second mate said, "I think he's just trying to play it down because he realizes we shouldn't have come this way . . . saving face."

At 1153, captain said, "We're getting killed with this speed." At the time, the ship was making 18.9 knots, according to parametric data. The second mate replied, "I think it's not a matter

[31] NAVTEX is an element of the Global Maritime Distress and Safety System (GMDSS). Cargo ships of 300 gross tons or more are required to carry GMDSS equipment when traversing the open ocean.

[32] *El Faro* was being retrofitted to return to the Alaska trade.

of speed. It['s] when we get there, when we get there as long as we arrive in one piece." The captain said, "We'll pick up a little bit . . . gotta get through this storm." At 1209, the second mate told the AB on watch, "Who cares what time we get there as long as we get there."

At 1211, the AB said that the Polish crew was "all excited" about the hurricane: "Ahh if they only knew." At 1219, he said, "Sun's out—blue sky. Don't look like there's many clouds."

At 1222, as required by the company, the captain sent a daily noon report to TOTE.[33] He reported that the ship had traveled 274 nm since departing Jacksonville, that its speed had averaged 19.3 knots, that winds were from the north at force 3 (7 to 10 knots on the Beaufort wind scale), and that 7-foot ocean swells were coming from the east-northeast.[34] The report noted: "Precautions observed regarding Hurricane Joaquin." The report gave no details about the precautions.

At 1224, the second mate announced, "There's our weather." The vessel's Sat-C terminal had just received an urgent high seas forecast from the Ocean Prediction Center, warning that Joaquin was producing maximum seas of up to 25 feet. The forecast reiterated the National Hurricane Center's 1053 advisory that the storm's maximum sustained winds were 70 knots, with gusts to 85 knots, and that its position was near 24.7N, 72.6W, about 300 nm southeast of *El Faro*.

At 1312, the captain emailed the TOTE designated person (DP), copying other onshore company personnel.[35] He listed data for the hurricane from the latest BVS weather file and the National Hurricane Center: "Center of Hurricane Joaquin: 24.7N, 72.6W. Direction and Speed: SouthWesterly at 5 k. barometric Pressure: 971 mb [millibars]." Those figures agree with the National Hurricane Center's advisory No. 11. The captain's email also stated that winds were "50k with gusts up to 70k" and that seas were "12′ – 14′ throughout tonight and into tomorrow morning." Those figures do not agree with any particular National Hurricane Center advisory as far as investigators could determine. The captain's message continued as follows:

> I have monitored Hurricane Joaquin tracking erratically for the better part of a week. Sometime after 9/30/0200 she began her SW'ly track. Early this morning I adjusted our direct normal route in a more SSE'ly direction towards San Juan, Puerto Rico, which will put us 65+/nm south of the eye. Joaquin appears to be tracking now as forecasted and I anticipate us being on the back side of her by 10/01/0800.

The captain's message concluded with a question to the DP about transiting "the Ol' Bahama Channel on our return northbound leg to Jacksonville, FL." He noted that the route would add 160 nm to the trip. He said, "This precaution will take the uncertainty of Joaquin's forecasted track and as you can see, she really develops into formidable weather pattern on 10/03-05/15. I am confident that Joaquin will track in a northerly direction once reaching the gulf stream current."

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[33] The message went into a queue and was not sent from the ship until 1322.

[34] The Beaufort wind scale, developed in 1805, is a method for estimating wind strength without using instruments. The scale ranges from force 0 (winds less than 1 knot) to force 12 (hurricane: winds 64 knots or more). It is still used for its original purpose as well as for tying various components of weather (wind strength, sea state, and observable effects) into a unified picture.

[35] The DP is a designated person or persons ashore with direct access to senior management.

At 1320, the captain told the second mate they might use Old Bahama Channel on the northbound trip from Puerto Rico. He said he was awaiting confirmation from the office.

At 1344, the National Hurricane Center issued an intermediate advisory stating that Joaquin was “continuing to strengthen.” The storm was centered about 165 nm east-northeast of the central Bahamas (at 24.4N, 72.9W) and 275 nm southeast of *El Faro*’s position. The storm was moving southwest, with maximum sustained winds of 74 knots. *El Faro* did not receive the advisory.[36]

At 1402, the captain told the second mate the weather pattern was “crazy erratic” but that “these ships can take it.” The second mate said, “Yeah, they’re built for Alaska.” The captain then talked about taking Old Bahama Channel on the return voyage. He said he informed the company as a “professional courtesy” because it increased the length of the trip.

Beginning at 1414, the VDR recorded a sécurité (meaning important safety information) message broadcast by a Coast Guard aircraft over channel 16 (the maritime distress channel). The message stated that a hurricane warning had been issued for the central Bahamas and listed the islands (it also announced a hurricane watch for the northwestern Bahamas). The message requested that “mariners use extreme caution.” The second mate and captain both said, “Wow.” The second mate said, “So hurricane warnings for—ohhh exactly.”

At 1416, the second mate told the captain that she had sent a weather report, which she had never done before. The captain told her that by 2 o’clock “on your watch—you should be south of this monster.” The second mate asked whether she should steer a course for the “most comfortable” ride or if she should stay on the track. The captain said he would be “up the entire night for the most part” and they might steer a course to get them through the storm: a “weather ride.”

At 1438, the VDR recorded another Coast Guard aircraft sécurité message on channel 16. The message repeated that a hurricane warning had been issued for the central Bahamas and requested “extreme caution” from all mariners. The VDR recorded no conversation related to the message afterward.

Around 1520, the second mate and the AB on watch began discussing *El Yunque*, which was on its way back to Jacksonville. The second mate said, “They’re tryin’ to get away from the storm too.” The AB said, “Nobody in their right mind would be drivin’ into it.” The second mate said, “We are [laughter]. Yaay!” At 1532, the AB told the captain, “We’re gonna go right into it.” The captain said, “Seventy miles south of it.”

During the watch turnover at 1545, the second mate told the chief mate that the ocean swell was about the same: “six to eight feet from the east.” At 1546, the captain received a reply from a TOTE official authorizing him to take Old Bahama Channel northbound on the return trip to Jacksonville. At 1547, the second mate told the chief mate that the boatswain and his crew had tightened the lashings on the second deck.

[36] As noted earlier, the intermediate advisory could have been obtained through FTPmail, but there is no evidence that the crew attempted to do so.

At 1550, as the two vessels came within radio range, the chief mate called the *El Yunque* chief mate on the very-high-frequency (VHF) radio. After a discussion about light bulbs and a tarp, the *El Faro* chief mate asked whether *El Yunque* was "in the clear" and said "we're tryin' to give it an extra thirty to fifty miles from the predicted center as we uh scoot around here." He also said they were "really lovin'" the BVS program.

At 1558, the chief mate told the AB they were diverting south to stay out of the deeper swells. After stepping out the forecast, the chief mate said the winds should be 30 knots on the port quarter at 2000, 40 knots at 0000 (midnight), and 50 knots on the starboard beam at 0200.

At 1608, the captain told the chief mate, "That's a pretty healthy swell buildin' there." The chief mate said the swell was on the port quarter, and the captain said, "As expected." The chief mate said, "We are really comfortable, actually." At 1609, the captain told the chief mate he had sent the company an estimated arrival time of 8 o'clock. He reiterated that he wanted to "come home" via Old Bahama Channel. The chief mate said, "I would expect that anyone in the office would say 'absolutely, you're the only one, you're the one here . . . making the decision.'" The captain said he had been extending "a professional courtesy" by informing the company of his plans for the return trip.

The AB asked the captain if there was a chance they could turn around. The captain said, "No, no, no. We're not gonna turn around . . . the storm is very unpredictable—very unpredictable."

At 1649, the National Hurricane Center issued advisory No. 12, stating that Joaquin, centered near 24.3N, 73.1W, was moving southwest at 7 knots. The eye diameter was estimated at 45 nm. Maximum sustained winds were 75 knots, with gusts to 90 knots. *El Faro*'s Sat-C terminal received the advisory at 1654. The ship was about 212 nm northwest of the center of Joaquin.

At 1658, the second mate observed, "Looks like the hurricane is right over our trackline. Our old trackline right now." She then said, "So two o'clock in the morning. . . . three o'clock. Looks like this storm's coming right for us." Then at 1704, she stated, "We are going to go right through the [expletive] eye." The AB said another company with a "ship like this . . . went through one too and lost a bunch of containers." The second mate said, "The only good thing is it's not gonna last long. By tomorrow afternoon we should be out of it . . . it's just getting through it in the wee hours."

At 1747, the captain downloaded the BVS weather file that had been available at 1703. The current position, forecast track, and intensity for Joaquin were consistent with the National Hurricane Center advisory the ship had received via Sat-C at 1056 that morning.

At 1808, the Ocean Prediction Center issued an urgent high seas forecast, based on advisory No. 12, that identified seas of between 12 and 27 feet within 90 nm of the storm center. The forecast predicted maximum seas of 30 feet for noon on October 1. *El Faro* received the forecast by Sat-C at 1824.

According to the vessel track, *El Faro* passed east of Great Abaco Island in the northern Bahamas during the afternoon of September 30. At 1830, the vessel was about 60 nm from the entrance to Northeast Providence Channel (figure 6). The center of the hurricane was 180 nm southeast of *El Faro*'s position, based on the recent high seas forecast.

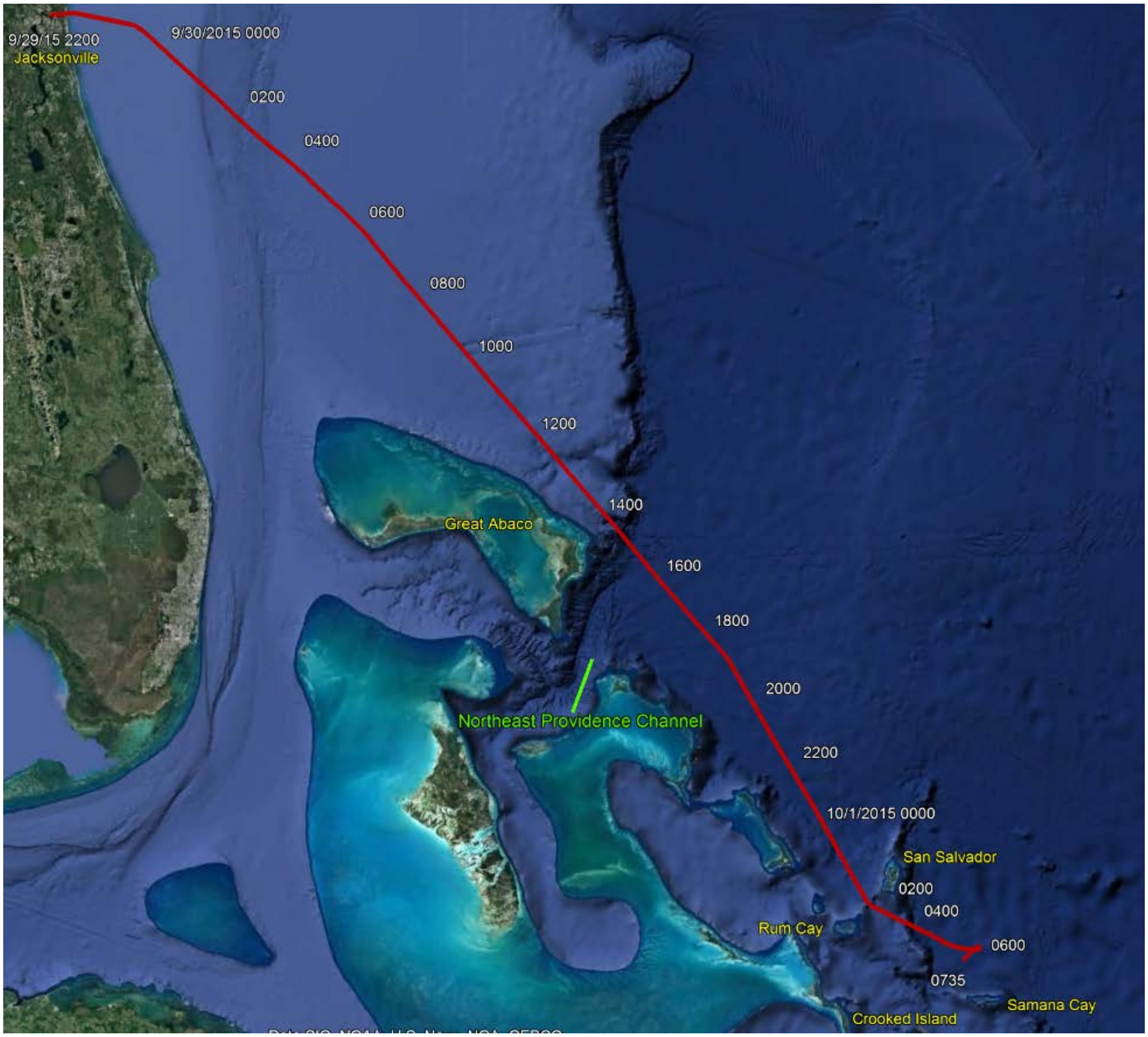

Figure 6. Actual trackline of *El Faro* during accident voyage, from departure to sinking, showing times every 2 hours. (Base map by Google Earth)

At 1847, after discussing the disaster film *The Perfect Storm*, which he remembered as featuring a "container ship rockin' and rollin'," the chief mate said he had to send some crewmembers to the second deck.[37] He stated, "You know those scuttles need to be dogged—not just flipped down . . . they need to be spun and sealed." [38]

At 1858, the sun went down.

[37] *The Perfect Storm* (2000) concerned the commercial fishing vessel *Andrea Gail*, which in 1991 sank with no survivors after encountering three merging weather fronts.

[38] *Scuttles* are man-size hatches. *El Faro* had two scuttles in each cargo hold that provided access between decks. *Dogs* are fasteners. "Dogging a scuttle" means to fasten it securely.

About 1900, the captain adjusted the vessel's trackline again. He and the chief mate decided to change course farther south, from 140° to 150°, which the chief mate said would keep them in "lots and lots of deep water." The chief mate plotted new waypoints past San Salvador Island and northeast of Samana Cay, Bahamas. The captain said, "Puttin' more distance between us and the center of the low." The chief mate said that at 0600 the next morning, they would be "on the upside."

The captain told the chief mate, "You don't necessarily have to go down the Old Bahama Channel. There's lots of places to duck in to." The chief mate said, "Maybe if we had to we (should/could) go to Crooked Island (passage/passed it)." The captain said, "If (this/it) doesn't work out we can use San Salvador as . . . a lee." [39]

At 1943, the third mate arrived on the bridge for the watch change. The chief mate explained that they were navigating using the chart. The captain said, "Safety of the ship comes first." The chief mate said, "Winds are on your port quarter . . . out of the north" and that they were steering 150° "for south of San Salvador." The captain said, "San Salvador's gonna afford a lot of lee." The third mate said, "I just hope it's not worse than what this [BVS] is saying because . . . Weather Underground . . . they're saying' it's more like eighty-five—not fifty wind . . . " [40]

At 1949, the captain said, " . . . we'll be passing clear on the backside of it . . . the faster we're going the better. This will put the wind on the stern a little bit more—it's givin' us a push." At 1950, the third mate said he had put car straps on the liferafts "just in case."[41]

At 1954, the captain told the third mate, "I will definitely be up for the better part of your watch. So if you see anything you don't like . . . give me a shout." Between 1957 and 2020, the captain and chief mate had a brief unintelligible conversation, after which the captain's voice was not detected on the bridge until 0409 the next morning.

At 1957, the National Hurricane Center announced (intermediate advisory No. 12A) that hurricane hunter aircraft had found Joaquin stronger, with maximum sustained winds of 91 knots and higher gusts. The storm was centered at 24.0N, 73.0W, about 80 nm east of San Salvador Island, and was moving southwest at 6 knots. Hurricane-force winds extended up to 30 nm from the center. The storm center was now about 170 nm southeast of *El Faro*'s position. *El Faro* did not receive the advisory.[42]

At 2022, after looking at the storm's trackline as forecast on the BVS program, the third mate said to the AB, "I listened to the Weather Channel and they were talking about it being more powerful than that." The third mate said, "I don't like being so close to something here . . . we

[39] A *lee* is a protecting shelter from the wind and seas. The lee side of an island such as San Salvador is thus the downwind side.

[40] "Weather Underground" probably refers to a television program on the Weather Channel that aired from 1800 to 2000 that evening.

[41] The third mate apparently placed straps (nylon-web lashing and steel binders), ordinarily used to lash automobile cargo to the Ro/Ro decks, around the liferafts to hold them in place during the storm.

[42] As noted, the intermediate advisory could have been obtained through FTPmail, but there is no evidence that the crew attempted to do so.

can’t outrun it.” The AB said, “What if we get close—we get jammed in those islands there and it starts comin’ at us. . . .” The third mate said, “That’s what I’m thinking. Maybe I’m just being a Chicken Little. I don’t know.”

At 2120, the VDR recorded a discussion between the third mate and the AB on watch. The AB said he thought they were going to divert through Old Bahama Channel, as “some captain” would have done, “not takin’ any chances.” The third mate responded that he would not second-guess the captain: “The guy’s been through a lot worse than this . . . he did it up in Alaska.” The third mate and AB discussed the results of traveling through a storm on another ship where the AB said he was thrown from the deck. Later during the watch, the third mate discussed the latest report that he had watched on the Weather Channel regarding the storm, saying that the weather would affect the Bahamas for the next couple of days and that a prediction called for about 20 inches of rain.

At 2249, the National Hurricane Center announced that Joaquin had become a Category 3 hurricane, with maximum sustained winds of 100 knots, and was moving toward the central Bahamas. Hurricane-force winds extended outward as far as 30 nm, and additional strengthening was forecast during the next day or two. Announcements of this sort (National Hurricane Center public advisories) were not scheduled for Sat-C broadcast. As noted below, *El Faro*’s bridge team learned that the hurricane had been upgraded to Category 3 from a radio broadcast 2 1/2 hours later.

The National Hurricane Center also issued an advisory (No. 13) at 2249 saying the storm was centered near 23.8N, 73.1W (about 120 nm southeast of *El Faro*’s position) and was moving southwest (220°) at 5 knots. Maximum sustained winds were 100 knots, with gusts to 120 knots. *El Faro* received the advisory on its Sat-C terminal at 2253.

At 2305, the third mate called the captain from the bridge telephone to suggest that he might want to look at the latest forecast. He told the captain that maximum winds were 100 mph (87 knots) at the storm center and that the hurricane was moving toward 230° at 5 knots: “It’s advancing toward our trackline and . . . puts us real close to it . . . we’re lookin’ [to] meet it at say like four o’clock in the morning.” He said he would call the captain back with better numbers. A BVS weather package was sent to the captain’s email address about this time but was not downloaded.

At 2313, the third mate called the captain again and suggested diverting to the south: “At 0400 we’ll be twenty-two miles from the center. With max one hundred with gusts to one twenty and strengthening . . . from what I can see . . . at 0200 we could head south and that would open it up some. “

At 2326, the third mate told the AB on watch, “He seems to think that we’ll be south of it by then—so the winds won’t be an issue. . . . what he’s saying is ‘well, we’ll be in the southwest quadrant. Wind will be comin’ from the north.’ . . . I trust what he’s saying—it’s just being twenty miles away from hundred knot winds—this doesn’t even sound right.” The AB said he had his survival suit and lifejacket laid out.

The second mate arrived on the bridge for the watch change at 2345. The AB announced the course: "One-five-zero." At 2351, the third mate told the second mate, "(captain's) saying it's better to be on the south side . . . you're not in the dangerous semicircle." At 2357, the third mate said he was concerned that "the information we're getting from other sources is so much different from this." The second mate and third mate discussed the weather and alternate courses, including Old Bahama Channel.

October 1. At 0017 on October 1, the Ocean Prediction Center issued an urgent high seas forecast reproducing the storm particulars issued by the National Hurricane Center an hour and a half earlier. Maximum sustained winds were 100 knots, with gusts to 120 knots. *El Faro*'s Sat-C terminal received the forecast at 0026.

At 0019, the second mate told the AB on watch, ". . . if we go south . . . we can try to connect with the Old Bahama Channel . . . go due south. That's where we get into kinda shallow and there is not wiggle room."

At 0041, the second mate went over the vessel's trackline with the AB after receiving the latest Sat-C weather forecast. She said, "Now we're gonna hit it at four o'clock in the morning." The AB said, "What's he thinking?" The second mate said, "Every time we come further south the storm keeps trying to follow us."

Ten minutes later (0053), the second mate said, "It doesn't really feel like we're going in—near a hurricane . . . when you go outside and there's hardly any wind. . . . we're going twenty knots . . . not rolling." The AB asked, "Sure we gonna change course at two o'clock?" The second mate said, "I don't know, gosh, I might call the captain here shortly if he doesn't come up . . . I don't know how he can sleep knowing all of this." The second mate said she slept well until 9 o'clock, when her ZzzQuil (a sleep aid) wore off, so she put in her earplugs. She said the ZzzQuil "knocks me out" but the rolling or pitching shook her awake.

At 0107, the second mate and AB discussed the storm. The second mate asked if it was a Category 2 and the AB said yes. At 0115, the radio in the background announced that Hurricane Joaquin had become a Category 3 storm. The second mate said, "Oh my God."

At 0118, the AB reacted to a roll: "Biggest one since I've been up here." The second mate wondered why the ship was rolling: "We're right between the islands." According to a VDR radar image, the vessel was west-southwest of the southern tip of San Salvador island and coming out of the lee of the island.

At 0120, the second mate told the AB she was going to "give the captain a call and see if he wants to come up and (look at it)." She called the captain and said, "we'll be meeting the storm" and "it isn't lookin' good right now." She said, "Right now my . . . trackline I have 0200—alter course straight south and then . . . go through all these . . . shallow areas." After the call, the second mate told the AB the captain said to run the course the third mate had plotted (116°), which she said would get them "into the storm at four o'clock in the morning."

At 0124, the second mate directed the AB to change course to 116°, and the ship experienced a windheel.[43] The AB commented, "... wind heel. Yeaaah." The second mate ordered a course adjustment to 114°, then said, "Startin' to hear the wind now." She indicated that the course would stay at 114° the rest of the midnight-to-0400 watch. The vessel's speed was still about 20 knots, which it had maintained throughout the voyage thus far.

Figure 7 plots the ship's speed over ground, which is the ship's motion relative to the earth's surface, as measured by GPS. The VDR recorded this information from the morning of September 30 to the time of the sinking. On October 1, as shown in the figure, the ship's speed over ground slowly decreased after 0100, then dropped precipitously about 0400.

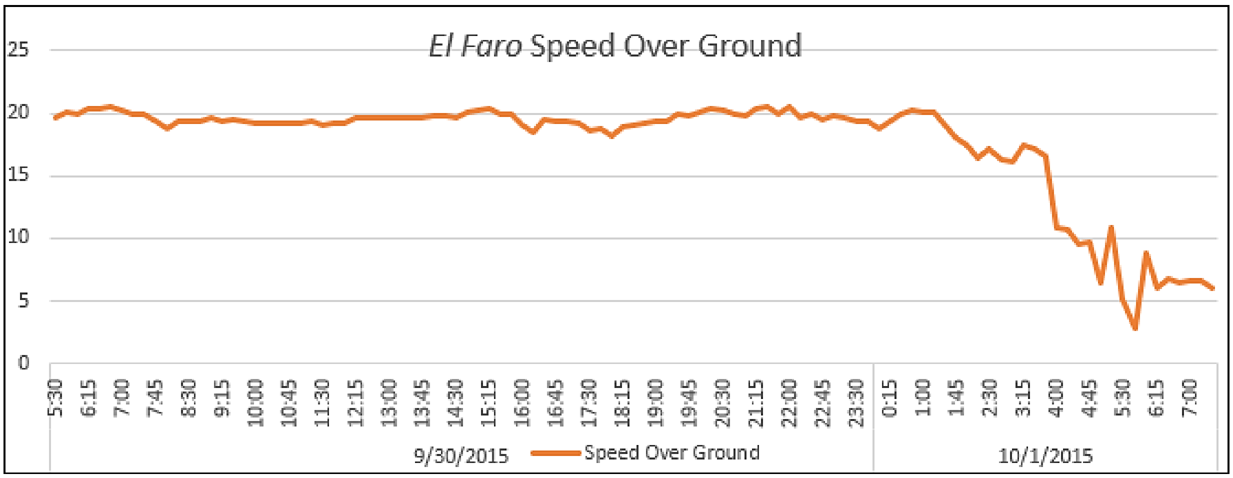

Figure 7. Vessel's speed over ground from 0530 on September 30 until sinking. (Based on VDR parametric data)

At 0131, the National Hurricane Center issued an intermediate advisory that placed the center of Hurricane Joaquin about 30 nm northeast of Samana Cay, with maximum sustained winds of 104 knots. The advisory indicated that Joaquin had moved southwest over the past 3 hours. That was about when *El Faro* completed a course change from 150° to 116°. At 0135, with *El Faro* heading 113°, Joaquin's center position, according to the intermediate public advisory, was 71 nm from *El Faro*, at 7° to port. *El Faro* did not receive this advisory.[44]

At 0132, the AB said, "Lost a little speed." A few minutes later, the second mate went out on one of the bridge wings to test the wind. The second mate said it was "not too bad. I can stand up straight." The AB said, "Pitchin' a little bit," and the second mate noted, "One good swell—every so often." At 0140, the second mate laughed and said,

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[43] *Windheel* is the heeling (leaning to one side) of a vessel caused by the wind acting on the part of the vessel above the waterline. Windheel increases with wind velocity and is greatest when the wind blows directly on the beam (from a direction at a right angle to the side of the ship).

[44] Again, intermediate advisories could have been obtained through FTPmail, but there is no evidence that the crew attempted to do so.

> Usually people don't take the whole . . . survival suit—safety meeting thing very seriously . . . Nobody actually sees to see if their survival suit fits . . . I think today would be a good day [laughter] for . . . the fire and boat drill . . . people are gonna (go/be like) . . . "I really need to see if my survival suit fits—for reaaal" [laughter throughout].

At 0141, the second mate said, referring to her recent phone call to the captain, "Captain was sound asleep. It took a few rings for him to answer." At 0143, the AB reported two flashes on the main deck: ". . . right there up on the bow." He and the second mate discussed possible sources, such as a light bulb blowing out, a crewmember turning lights on in a room, "reefers" (refrigerated containers), or lightning. The AB said it was not lightning.

At 0146, the second mate said to the AB, "We don't have any lifejackets up here on the bridge, do we, like the *El Morro*?"[45] She went on to say, "I was thinking about that safety stuff that was (on) the *El Morro* we don't have over here . . ." At 0156, the second mate said, "Wooo. That was a good one" and that they had "definitely lost some speed." The AB said, "Damn sure don't wanna lose the plant [main engine]." From parametric data, the ship's speed was 17.7 knots.

At 0211, the second mate reported "green water on the bow."[46] The AB said, "There's some clanking going on."[47] The second mate said, "We could hear a lot of clanking." The AB said the vessel's speed was down to 16 knots. The second mate said, "We're definitely getting set" and that the wind was picking up.[48]

At 0246, the AB said, "Well, we ain't got long, 'bout an hour." The second mate said they would be "getting in to the brunt of it at the end of our watch." The AB said, "Figured the captain would be up here." The second mate said, "I thought so too. I'm surprised . . . he said he would probably be up here." The AB said, "He'll play hero tomorrow."

At 0248, the AB and second mate reacted to large waves. The second mate said, "That was a doozy. [laughter] That was not a good one." The AB said, "Yeah, that was a big wave." The second mate said, "(We/she) won't be able to take more of those," and then, "Would help if I knew which direction the swell was coming from. I could alter course a little more. Can't see." A few minutes later, they both heard a "thump" and the second mate said it must be something inside. "Like my TV," said the AB. It became difficult to stand on the bridge. The AB said both his feet were "locked in," and the second mate said, "I had to sit down for that one."

At 0253, the off-course alarm sounded for the first time. (The vessel was operating on autopilot.) The second mate asked, "She off course?" At 0300, the AB and second mate heard something loose on the deck above them, and the second mate said, "You don't wanna get out

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[45] *El Morro* was a TOTE ship, sister vessel to *El Faro*, that was scrapped in 2014. The second mate served on *El Morro* from 2005 to 2014.

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

[47] "Clanking going on" probably refers to the noise created by loose metallic or hard items as they struck the vessel's steel superstructure as a result of the wind or the ship's motion.

[48] A vessel is *set* when the current or wind moves it from its intended course line.

there in that wind . . . I can hear it gusting." The second mate told the AB, ". . . the only comforting thing is that this ship has much better steel than *El Morro*."

At 0320, the off-course alarm sounded again. The second mate said, "She's goin' left—she's got right rudder." She indicated that the wind was increasing on the bow: "Got some wind in our face. . . we're getting into it now." At 0324, the second mate said she thought the wind was shifting west and that they were going to "start getting it on the starboard side." Then she said, "It's just getting bigger. Our path is going right through it."

At 0331, despite the crew's remarks about a broken anemometer, the VDR recorded a wind gust of 58 knots. The second mate said the wind and rain were "kinda like pressure-washing the decks." At 0340, the second mate changed course to 110° to counteract the vessel's set.[49] A few minutes later, she said the ship was "riding nice on that course." The vessel's speed was 16.8 knots.

At 0345, the watch changed. The chief mate arrived on the bridge and said, "So you can't see a thing, huh?" The second mate advised him that the second engineer was blowing tubes (using high-pressure steam to remove soot from the boiler tubes deposited during combustion). The chief mate changed the ship's heading farther east, from 110° to 100°. He had trouble determining the wind direction: "I assume that we're heelin' to starboard." Two minutes later, the off-course alarm sounded again, and the chief mate altered course to 095° (nearly due east). The vessel's speed was 13.8 knots at that point.

At 0352, the second mate emailed a friend: "So we are heading into the hurricane right now full force. Tried to alter our course to avoid it but he's on the war path. Bad seas and really bad winds. Hope to talk to you Friday." At 0353, the second mate emailed her mother: "Not sure if you have been following the weather at all but there is a hurrican[e] out here and we are heading straight into it. Catagory [sic] 3 last we checked. Winds are super bad and seas are not great. Love to everyone."

At 0355, one of the engineers arrived on the bridge and said that some of the electrical power cords to the reefer containers on the second deck had been "cut." The off-course alarm sounded again.

At 0404, the chief mate estimated that they were steering 30° into the wind. The vessel's speed had dropped to 10 knots. At 0405, the AB asked about the wind speed. The chief mate responded, "I don't have any idea. (We don't have any) instrument that can measure (it)."

At 0409, the captain arrived on the bridge. He said he had slept well ("like a baby") and that "this is every day in Alaska . . . a typical winter day in Alaska," He noted that the ship was not pitching.

At 0412, the chief mate said he had turned off the course alarm: "It was going off every five seconds." The vessel was still steering on autopilot. The captain mentioned filling the ramp tanks to correct the heel: "The only way to do a counter on this is to fill the port side ramp tank

[49] To counteract being set, a vessel steers somewhat toward the wind and seas that are pushing it off course.

up."[50] The chief mate said, "Heel is not bad," and that the forecast had the wind coming around to starboard. He said they were not doing anything about the severed power cords to the reefer containers.

At 0415, the captain asked the chief mate whether they were "startin' to slow down" and called the engine room. He asked the second assistant engineer, "Everything good as far as rpm [revolutions per minute] goes?" He then said, "Perfect." He reported that the second assistant engineer had said the engineers were "blowin' tubes."

At 0421, the captain told the chief mate, "It's probably better off we can't see anything." The vessel's speed had dropped to 8.5 knots. At 0427, the captain said he wanted more speed and asked if the ship's speed should be "comin' up a little bit faster." The chief mate reported the engine speed as 100 rpm and said, "This might be as high as it's gonna go." The ship's speed increased slightly, probably after the engineers finished blowing tubes.

At 0434, the captain said he was going to go check the galley. The chief mate called the engine room to remind the crew to secure the weather decks (open decks exposed to the weather). At 0437, the chief mate said a trailer was "leaning over" on the second deck forward of the bridge. The chief mate talked to the caller and said, "Yeah, we're heelin' over." At 0440, the chief mate might have tried to gauge the list with a clinometer ("can't even see the [level/bubble]"). He then told the captain over the electric telephone, "The chief engineer just called . . . something about the list and oil levels."

At 0443, the captain said he was going to steer into the wind because the chief engineer "wants to take the list off" and said to put the vessel into hand steering. The chief mate ordered hand steering and turned the vessel northward to 065°. The captain explained to the chief mate that the "[oil] sumps were actin' up." At 0446, the captain took the conn (control of the helm) and ordered a course change to 060° (farther into the wind). The vessel's speed dropped to 7.5 knots.

At 0445, the BVS weather file was downloaded that had been available at 2304 the night before. (The captain left the bridge at 0434 to check the galley and returned to the bridge at 0442 after the chief mate called him on the phone. A few minutes later, at 0457, he went below again to check his messages. It is likely that the messages were downloaded from the server while the captain was on the bridge.) Joaquin's current position, forecast track, and intensity given in the file were consistent with the data in the National Hurricane Center advisory that had been delivered to the ship via Sat-C at 1654 the previous afternoon (almost 12 hours before).

Just before 0447, *El Faro*'s Sat-C terminal received an advisory the National Hurricane Center had issued a few minutes earlier. The advisory located the storm center at 23.4N, 73.7W (about 17 nm north of Samana Cay), with maximum sustained winds of 105 knots and gusts to

[50] The ramp tanks, also called the aft deep tanks, were located on the aft bottom of the ship, one on the port side and one starboard. They were originally installed to counterbalance the weight of the loading ramps so as to maintain an even keel during loading and unloading.

130 knots. The storm was moving west-southwest at 4 knots. As calculated from the position reported in the advisory, *El Faro* was 11 nm northwest of the storm center.[51]

At 0453, the captain said, "Did we lose a container or something? A trailer down on two deck?" A few minutes later, the captain ordered a heading of 050° and went below to check for messages.

At 0500, the chief mate said things were starting to look better and that he expected the wind to come around, first to the bow and then to starboard. He said, "We're still heelin'."

At 0503, the chief mate said the barometer was rising, and the captain discussed his different sources of weather information. He said he used BVS but that he was getting "conflicting reports as to where the center of the storm is." The captain did not download the BVS weather file that was made available at 0503 until an hour later (0609).

At 0510, the off-duty TOTE engineer assigned to supervise the riding crew arrived on the bridge. He said things were "slappin' around" on the second deck and asked the chief mate what the wind speed was. The chief mate said, "We don't know. We don't have (any) anemometer."

The riding crew supervisor explained the effects of the low-pressure alarm for lube oil in the main engine. He said, "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." The captain said their speed was maintaining at 11 knots and that rpm were over 100.

At 0514, the captain ordered a heading more to the north, into the wind. (The heading seemed to have deviated from the 050° previously ordered.) At 0518, the captain said, "Only gonna get better from here. . . . we're on the back side of it." The chief mate said, "(eighteen) degree list on . . ."[52] The vessel's speed was now 5.8 knots.

At 0521, the VDR recorded a wind speed of 108 knots (the highest wind speed in the parametric data). At 0522, the riding crew supervisor asked how fast the storm was moving. The captain said it had stalled at 5 knots. The chief mate said the last he had seen was 4 knots: "Just sitting there." At 0530, a canopy on the bridge wing blew away. The chief mate said that the relative wind direction had changed ("The spray is hittin' us instead of goin' cross the beam") and that they were taking water on the stern.

At 0535, the National Hurricane Center issued its only tropical cyclone update for Hurricane Joaquin, advising that the government of the Bahamas had issued a hurricane warning for Acklins, Crooked Island, and Mayaguana in the southeastern Bahamas. *El Faro* did not receive tropical cyclone updates via Sat-C, and investigators found no evidence that the ship procured the information from another source.

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[51] The center was more likely about 28 nm northeast of *El Faro*, according to the storm's position about that time from the National Hurricane Center's poststorm analysis (Berg 2016).

[52] In the VDR transcription, (eighteen) degrees was placed in parentheses as a questionable insertion. The VDR transcription group either could not agree on or was uncertain about what had been said.

At 0540, the captain said "(goin'/slowin') down." The vessel's speed had dropped to 4.3 knots.

At 0543, the captain received a call that there was a problem in hold 3 and said that he would send the chief mate down. He told the chief mate to go to the hold and start pumping. The chief mate mentioned a "suspected leak" and "the scuttle." At 0544, the captain said, "We got cars loose."

Beginning at 0545, the chief mate spoke on the electric telephone to a crewmember in the engine room and said, "So that's where the water's from?" and "Are we able to pump the bilges?" The captain took over the call and confirmed that the bilge pump was running and the water was rising. He asked about pumping water from the starboard ramp tank to the port tank and said, "Let's do that." By now the ship was leaning to starboard, possibly about 18°, and its speed had dropped to 2.8 knots.

At 0547, the chief mate left the bridge with a radio to check the flooding in hold 3. The captain talked to the chief mate and told him the chief engineer was transferring ballast water from the starboard ramp tank to the port tank.

At 0552, a crewmember called the bridge and spoke to the captain. The captain said he was going to "turn the ship and get the wind (on the north side)" to generate a port list so that the crew could have a better look at hold 3. The captain said, "So it is the scuttle?" At 0554, the captain began giving orders to turn *El Faro* from 060° to 350°. The chief mate, who was alone in hold 3, reported "a hold that's flooded on the starboard side" and that water was "knee deep" and going over the edge of the scuttle. He said he did not smell anything after he was asked about "a lot of diesel."

At 0556, the captain said to the chief mate, "We got it listing over to port now . . . can you see it down there? The water level?" The chief mate, who had been joined by the riding gang supervisor (they were near the scuttle), may have answered that the worst of the water had dried out on the starboard side, though the recording is not clear. The captain called the engine room and said to stop transferring water from the starboard to the port ramp tanks: "We got a nice port list." The chief mate and riding gang supervisor prepared to close the scuttle. The captain asked, "You got a lifeline on him or anything?"

At 0559, the captain told the second mate, "A scuttle popped open and there's a little bit of water in three hold, they're pumping it out right now." At 0600, the captain talked to the chief engineer and mentioned the ventilation. The captain began orders to bring the list back to starboard by transferring water back to the starboard ramp tanks. The chief mate and the riding crew supervisor reported that they had secured the scuttle on the starboard side of the second deck.

At 0600, the Ocean Prediction Center issued an urgent high seas forecast, warning that Joaquin was near 23.4N, 73.7W, with maximum sustained winds of 105 knots, gusting to 130 knots, and seas reaching 36 feet within 220 nm northeast and 100 nm southwest of the center. *El Faro* received the forecast on its Sat-C terminal at 0623. The forecast reissued the storm's location, movement, and winds published in the National Hurricane Center advisory *El Faro* had received about 0447, with the addition of sea height.

At 0601, the radar stopped functioning, and the captain said, “See if you can get that radar to come back up.”

At 0602, the captain said to “give them a shout down below . . . the scuttle has been shut—the scuttle is shut.” The second mate repeated the information on the electric telephone. The second mate then said she heard alarms going off in the engine room. She then asked, “Did we come down on the rpm or did they [engineers] do that?” The captain said, “They did.” The vessel’s speed was 5.3 knots.

At 0604, the chief mate was back on the bridge. He told the captain that the scuttle on the second deck had been half open but that the scuttles had been closed and checked earlier. He said, “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.” The chief mate returned to hold 3 to monitor the water level.

At 0609, the captain downloaded the BVS weather file that had been available at 0503. The information about the hurricane (current position, forecast track, and intensity) was consistent with the National Hurricane Center advisory the ship had received at 2253 the night before.

At 0610, the chief mate called the bridge on the ultrahigh frequency (UHF) radio. The captain told him to “transfer over to the starboard ramp tank . . . port to starboard ramp tank.” After the call, the captain said, “I’m not liking this list.” At 0613, the captain said, “I think we just lost the plant.” The vessel’s speed was 0.5 knots.

From that point on, the captain stayed in contact with the engine room by electric telephone and with the chief mate by radio. At 0616, after discussing the loss of propulsion with one of the engineers, the captain told the second mate, “(they’ll) bring everything back online.” After another brief discussion with the engine room, the captain told the second mate that water was “sloshing” in the engine room, coming in through the ventilation ducts. When a crewmember from the engine room called again, the captain asked if they were still pumping ballast water from the port to the starboard ramp tanks. The engineers were also pumping out one of the flooded holds (most likely hold 3).

At 0617, nautical twilight began. The general outlines of objects would have been discernible under good atmospheric conditions.

At 0623, the captain told the second mate to go below and wake the third mate.

Beginning at 0628, the captain and one of the mates on the bridge discussed water pouring from the second deck. The mate said the vessel was listing to port. The captain wanted to know the amount of water and whether it was from the open scuttle on the second deck.

At 0631, the captain said he wanted “everybody up.” The third mate arrived on the bridge and asked whether he was relieving the watch. The second mate consulted the captain about the format and addressees of the emergency message he wanted her to send, but not until, as she said, they were “ready to go.” The alerts would report flooding, cargo adrift, time, and vessel position.

At 0633, after speaking to a crewmember in the engine room, the captain said, “They’re gonna get that boiler back up online . . . any second.” At 0634, the chief mate asked whether the radar had been secured, and the captain said no. The second mate said, “It went out on its own.” At 0640, the captain told the chief mate he wanted “eyes on three hold . . . let me know what’s going on down there.”

At 0644, the captain told the AB on watch, “You got some turns right now,” meaning that propulsion seemed to have returned. The radar image in figure 8**,** obtained from the VDR**,** shows that *El Faro*’s bow was headed northwest but that the ship was actually traveling southwest, at a speed (in relation to the ground) of 6.7 knots—that is, it was being pushed sideways by the wind and waves, nearly perpendicular to its original course before losing propulsion.

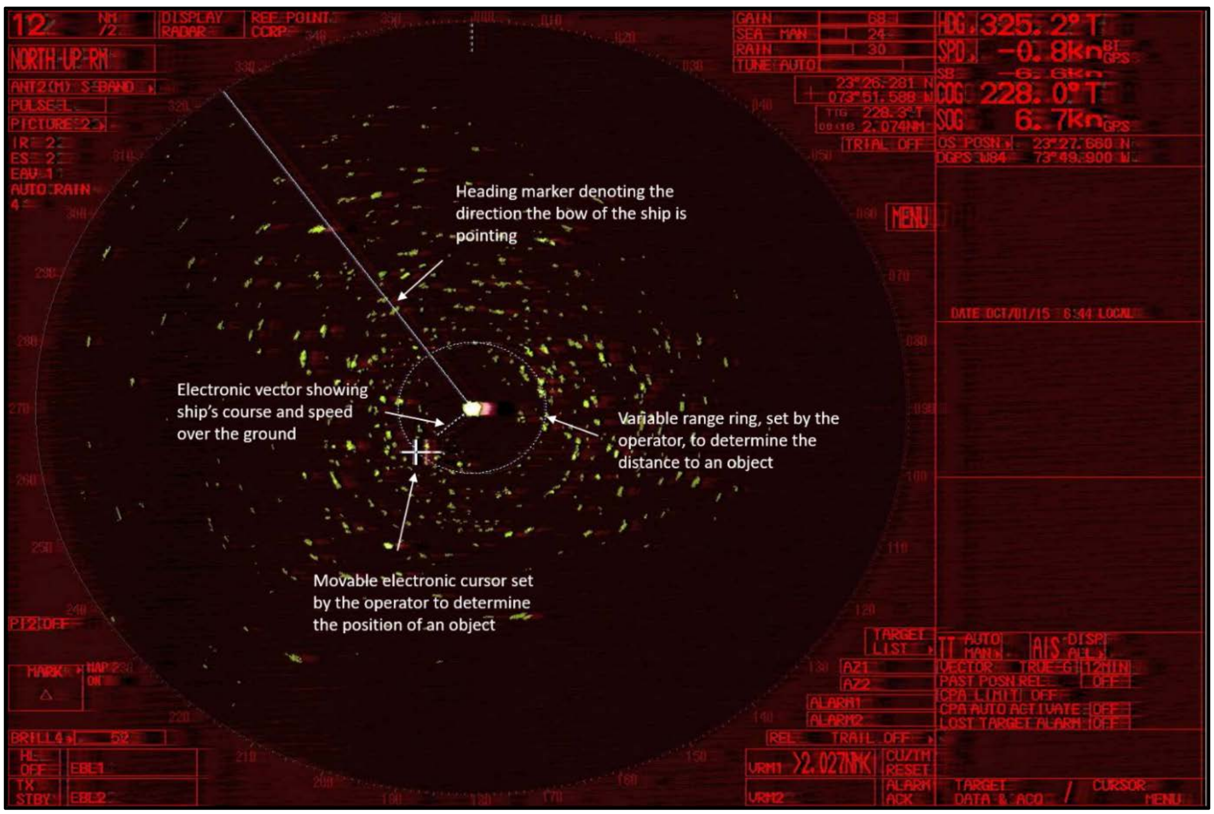

Figure 8. Radar image from 0644 on October 1 showing *El Faro* heading (bow direction) northwest (325.2°) but moving southwest (228°).

At 0645, the indicator light on the bridge for the stern navigation light went out, and a loose handrail was heard banging. At 0647, the sun rose.

At 0648, the second mate asked, “Coffee? Cream and sugar?” The AB said he wanted “Splenda, not the regular sugar.” While that exchange was going on, the captain said they had no rpm (no propulsion).

At 0652, the captain went below to his office. While he was gone, the second mate told the AB that she had been on the same run on *El Morro* during a hurricane and that they “took a thirty-eight degree roll." At 0654, the captain was back on the bridge and said to someone that they had "all the wind on the starboard side," that "a scuttle was left open or popped open or whatever" and there was "significant" flooding in hold 3, but that he did not intend to abandon ship, though they were "in dire straits." He said he was going to call the office and there was "no need to ring the general alarm yet"; the engineers were trying to "get the plant back."

After the call, the AB asked how long they would be in the storm. The captain said, "Should get better all the time. Right now we're on the back side of it." A minute later, low-frequency thuds and crashes were heard, like metal crashing.

At 0657, the captain talked to the engine room again and confirmed that the engineers were still pumping hold 3. The second mate asked, "They havin' trouble gettin' it [the main engine] back online?" The captain said, "Yeah, because of the list." At 0659, the captain called the DP and left a message:

> We have a navigational incident . . . A scuttle popped open on two-deck and we were having some free communication of water go down the three-hold. Had a pretty good list . . . Everybody's safe . . . but I want to talk to you.

At 0701, the captain called TOTE's contracted emergency call center and requested a connection to a qualified individual to notify him/her of a marine emergency. The captain told the operator, "We have a hull breach, a scuttle blew open during a storm, we have water down in three-hold with a heavy list. We've lost the main propulsion unit, the engineers cannot get it going."

At 0706, the captain was connected to the DP and informed him that the ship was listing to port and had lost propulsion because "the engineers cannot get lube oil pressure." He said the crew was safe, that they had secured the source of the water flooding the vessel, and that engineers were pumping out the flooded hold. He said they had a "very, very healthy port list" and that the crew was "taking every measure to get the list off." He told the DP that no one was panicking and that "our safest bet is to stay with the ship . . . the weather is ferocious out here." He reported 10 to 12 feet of spray, high winds, and poor visibility. He said the list was 10° to 15° "but a lot of that's with the wind heel." The call ended at 0712.

While the captain was talking to the DP, the chief engineer called the bridge. The second mate told him, "The wind is pushing us over, there's nothing we can do from up here," and suggested moving ballast.

At 0712, the captain told the second mate to send the distress messages she had prepared earlier. At 0713, the second mate reported that she had pressed the distress buttons (Inmarsat-C and ship security alert system [SSAS]) and that the distress alerts were complete.[53] She then received an alert that one of the messages she had typed failed to send. Nevertheless, at 0715, Inmarsat's land earth station in Eik, Norway, forwarded an Inmarsat-C and an SSAS alert to the

[53] SSAS units are not part of GMDSS but are required for vessels of 500 gross tons or more constructed before July 2004. An SSAS alert is a covert distress signal normally used when a ship is attacked by pirates. It will not alert attackers that the ship has sent an alert. The alert transmits time, position, course, speed, and a predetermined message at a specified rate until deactivated.

Coast Guard's rescue coordination center in Portsmouth, Virginia.[54] At 0717, the Inmarsat station in Norway forwarded a second SSAS alert to TOTE.

After the second mate had sent the alerts, the captain told her, "We're gonna be good. We're gonna make it right here."

At 0714, the chief mate told the captain, "I think the water level's rising." The captain asked whether he knew where it was coming from. The chief mate told him the chief engineer had said "something hit the fire main, got it ruptured, hard." The chief mate said, "I came in here and dogged that door tight," possibly referring to a door on the fourth deck. The captain said, "Don't open it."

At 0716, the bilge alarm for cargo hold 2A (on the fourth deck) sounded, indicating that floodwater had entered the hold. The captain and chief mate talked to the chief engineer on the electric phone. The chief mate said that no one had checked hold 2A.

At 0717, the captain and chief mate agreed that the vessel's list was getting worse. The captain mentioned "cars that are floating in three hold" and a crewmember reported that he "saw cars bobbing around." The chief mate said the fire main in the aft end was "right below the water, dark black water." The captain told the engine room to isolate the fire main ("that may be the root cause of the water comin' in") by securing the valve in the engine room that controlled the suction (seawater intake) for the fire pump.

At 0720, the chief mate said he did not know how much water was in the cargo holds, and the captain voiced a concern for the vessel's stability and for "how much water . . . sitting down there." Between 0722 and 0725, the captain talked on the electric phone to the riding crew supervisor. The supervisor had looked into hold 3 through the scuttle and asked the captain what the vessel's downflooding angle was. The captain said, "I don't have an answer." Then he said, "I mean we still got reserve buoyancy and stability."

The captain told the riding crew supervisor that he was going to ring the general alarm and wake everyone up: "We're definitely not in good shape right now" and "just tryin' to control that list, see where the water's comin' from." After the call ended, the captain sent the chief mate to investigate the situation on the second deck. The mate reported that the water was "chest deep."

At 0724, the DP notified the Coast Guard rescue coordination center of the emergency. At 0731, the DP sent an email to other TOTE officials:

> El Faro emergency 49 miles east San Salvador. Took on water. 15 degree list. Ingress stopped and pumping water. NO main engines. Heavy winds And 15 ft sea. CG [Coast Guard] notified.

At 0726, the captain asked the second mate where the emergency contact numbers were. She said they were "hangin' up on the . . . by the chair." The captain told the chief mate on the

[54] A *land earth station* is a facility on land that routes calls via satellite to and from terrestrial telephone networks.

UHF radio that he was going to ring the general alarm but would not immediately abandon ship. He gave the same message over the electric telephone to the engine room.

At 0727, the general alarm bell rang for 12 seconds.

At 0728, the chief mate gave a radio command for the crew to muster on the starboard side. At 0729, the captain ordered abandon ship. The VDR recorded a bell ringing in seven pulse tones. The second mate yelled, “I got containers in the water.” The captain said loudly, “Tell ‘em we’re goin’ in.” The second mate asked to fetch her vest (life preserver). The captain said to bring his up, too, and to bring one for the AB on watch.

At 0730, the captain said, “Bow is down, bow is down.” At 0731, he ordered the liferafts thrown overboard and the crew to enter them.

At 0737, the captain shouted: “Where are the life preservers . . . here? . . . Where are the life preservers on the bridge?”

At 0738, the AB yelled, “Goin’ down.” The captain said, “You’re not goin’ down. Come on.” The AB said he needed a ladder, then a line. The captain told him they did not have either.

At 0739:07, the AB said loudly, “I’m gone” or “I’m a goner.” The captain yelled, “No you’re not.”

Beginning at 0739:32, a low-frequency rumble was heard that continued until the end of the recording.

At 0739:38, the captain called the AB’s name, then yelled, “It’s time to come this way.”

At 0739:41.8, the audio recording ended.

At 0739, a transmission from *El Faro*’s registered EPIRB, which had been detected at 0735 by a geostationary satellite, was emailed to the Coast Guard.[55] The transmission was forwarded as an “unlocated first alert” because *El Faro*’s EPIRB was not equipped with a GPS beacon. No further *El Faro* communications were received by either the Coast Guard or TOTE.

At 0759, the National Hurricane Center issued an intermediate advisory reporting that the eye of Joaquin was near Samana Cay (at 23.2N, 73.7W). Maximum sustained winds were 104 knots, with hurricane-force winds extending as far as 30 nm from the storm center. A hurricane warning was in effect for the central Bahamas; the northwestern Bahamas (except Andros Island); and Acklins, Crooked Island, and Mayaguana in the southeastern Bahamas.

[55] The last transmission from *El Faro*’s EPIRB was detected at 0759.

El Faro's last known position, according to VDR data, was 20 nm north of Samana Cay, at 23.3925N, 73.9029W. The vessel was about 17 nm from the position of the hurricane's center reported 20 minutes after the sinking.

1.3 Vessel Information

1.3.1 History

El Faro was built in 1975 as the SS *Puerto Rico* (builder's hull No. 670) at Sun Shipbuilding and Drydock Company in Chester, Pennsylvania, a subsidiary of Sun Oil Company. It was one of Sun's *Ponce*-class vessels designed specifically for the Puerto Rican trade. Operated by the Navieras de Puerto Rico Steamship Company, the *Puerto Rico* hauled cargo to and from the US East Coast for 15 years. In 1991, the ship was purchased by Totem Ocean Trailer Express in Seattle and renamed *Northern Lights*. In 1993, the vessel was lengthened by 90 feet at Atlantic Marine, Inc., during a major conversion.[56] It then sailed frequently between Tacoma, Washington, and Anchorage, Alaska. After servicing the Alaska trade, the vessel was chartered by the US government from 2000 to 2003 to carry military cargo for Operation Iraqi Freedom.

In 2005–2006, the ship was converted from a Ro/Ro cargo ship to a roll-on/roll-off container (Ro/Con) vessel and renamed *El Faro*. The Coast Guard did not consider the modification a major conversion. A Ro/Ro vessel is an oceangoing cargo ship that uses ramps to roll on or roll off wheeled cargo such as containers, trailers, trucks, cars, and heavy construction equipment. A Ro/Con vessel is a hybrid that has ramps serving vehicle decks as well as cargo decks accessible to cranes for loading containers.

Until 2 weeks before the accident, the company that owned *El Faro* was named Sea Star Line.[57] From 2006 to 2008, the vessel ran from the US East Coast to the Middle East under charter. Between 2008 and 2011, *El Faro* was laid up except for brief periods of activity, including a run between Philadelphia, Jacksonville, and San Juan. Beginning in 2011, the vessel was laid up in Baltimore and out of service for about 2 years (until December 6, 2013) while waiting for work. In May 2014, *El Faro* was placed into service in the Caribbean trade between Jacksonville and San Juan (see section 1.9, Waterway Information"), replacing the TOTE vessel *El Morro* when it was scrapped. TOTE planned to convert *El Faro* back to Ro/Ro service for the Alaska trade in

[56] According to Title 46 *United States Code* (*USC*) 2101(14a), a "major conversion" means a vessel conversion that (1) substantially changes the dimensions or carrying capacity of the vessel; (2) changes the type of the vessel; (3) substantially prolongs the life of the vessel; or (4) otherwise so changes the vessel that it is essentially a new vessel.

[57] On September 17, 2015, TOTE's parent company announced that Sea Star Line had been renamed TOTE Maritime Puerto Rico.

early 2016. Two new vessels powered by liquefied natural gas (LNG) would take over the Puerto Rico run.[58]

1.3.2 Classification and Inspection

El Faro was registered as a US-flagged ship, with San Juan, Puerto Rico, as its port of registry. The vessel was classed by ABS, one of several nongovernmental classification societies that establish and maintain standards for the construction and operation of ships and offshore structures. For the inspections required by federal regulations (Title 46 *Code of Federal Regulations* [*CFR*] Part 91), *El Faro* was enrolled in the Coast Guard Alternate Compliance Program (ACP), which allows US vessels to obtain a Coast Guard certificate of inspection (COI) if they pass examination by an authorized classification society.[59]

COIs are issued to cargo vessels for 5 years, with requirements for annual and periodic vessel inspections. *El Faro*'s COI was issued on February 22, 2011. The ship had completed an annual examination by an ABS surveyor on February 16, 2015, in Jacksonville. The Coast Guard last endorsed the COI on March 6, 2015, in San Juan, after its annual ACP oversight examination of *El Faro*. In his examination report, the lead Coast Guard inspector described the vessel as "fit for route and service."

1.3.3 Construction and Arrangement

El Faro was constructed entirely of welded steel. As converted, the vessel was 790 feet 9 inches long, with a beam of 105 feet at the main deck. The vessel was equipped with a single fixed-pitch propeller and had a maximum sea speed of 22 knots. See appendix D for further vessel particulars.

Decks and Holds. *El Faro* had an aft deckhouse with six upper decks (navigation or bridge deck, lower bridge deck, boat deck, cabin deck, upper deck, and CO_2 flat—a room where carbon dioxide was stored as a fixed fire-suppression system), a main deck for load-on/load-off container cargo, and three lower decks for Ro/Ro cargo (see profile drawing, figure 9). The navigation bridge, offices, galley, and living quarters were in the deckhouse. The lower decks were the second deck; the third or tween deck; and the fourth deck, or tanktop (ship's lowest deck, above the fuel, water, and ballast tanks).

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[58] Ships fueled by LNG emit almost no sulfur oxide and much less carbon dioxide and nitrous oxide than those powered by traditional fuel oil. The Emission Control Areas that are being established worldwide mandate reduced emissions by ships of sulfur oxide, nitrous oxide, and other pollutants (EPA 2011). In 2011, an Emission Control Area was established within 50 nm of the coasts of Puerto Rico and the US Virgin Islands in the Caribbean. In 2010, a similar area was established within 200 nm of the North American coast. Requirements for Emission Control Areas are laid down in Annex VI to the Marine Pollution Convention (International Convention for the Prevention of Pollution from Ships, 1973, as modified by the protocol of 1978).

[59] See section 1.14 for more information about the ACP.

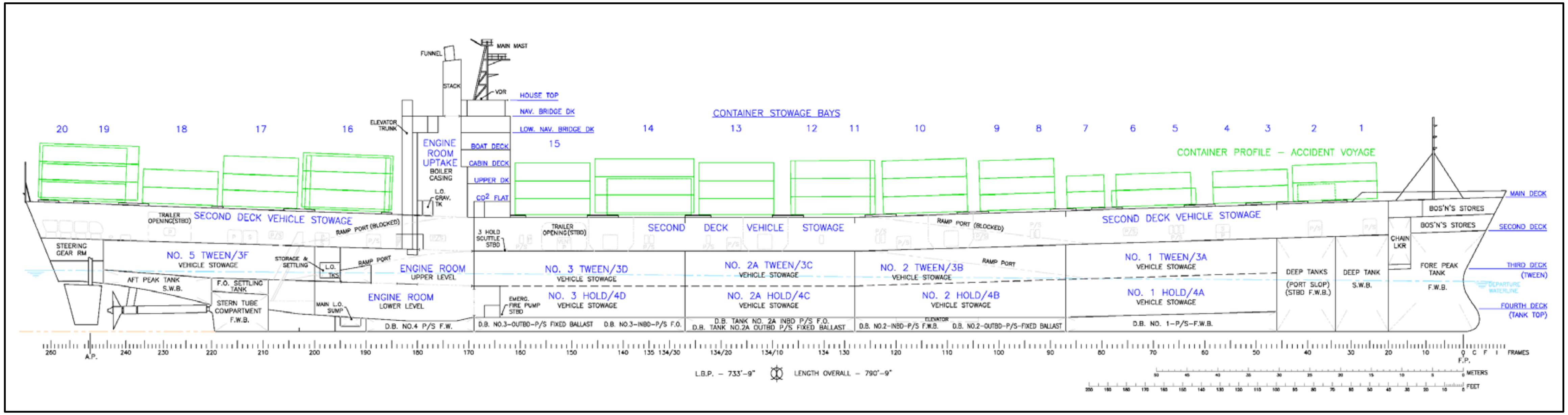

Figure 9. Profile drawing of *El Faro*. Stern left, bow right. Frame numbers shown along bottom, numbers for container bays at top. Deckhouse contained navigation bridge and crew quarters. Lifeboats and 25-person liferafts were stowed on boat deck. Small (6-person) liferaft was stowed at bow.

The second deck was partially enclosed and was the highest watertight deck, or freeboard (bulkhead) deck.[60] The third and fourth decks were divided into compartments, or holds, designated A through F, forward to aft.[61] As shown in the profile drawing, the main and second decks sloped or sheered toward the deckhouse from the bow and stern.

El Faro carried containers on the main deck and trailers and automobiles on the second deck and in holds on the third deck and tanktop. Two working internal ramps and an elevator distributed Ro/Ro cargo throughout the vessel. Two other internal ramps from the second to the main deck were blocked off. The ship loaded Ro/Ro cargo through a trailer access between frames 224 and 233 on the starboard side. Another vehicle access between frames 147 and 155, which was not typically used, was fitted with a removable bulwark that partly covered the opening.

Deck three (the tween deck) was not watertight but was perforated to allow for ventilation between the holds. Six boundaries gave watertight integrity to the vertical hold areas on the third and fourth decks. The boundaries were the port and starboard sides (hull) of the ship, the second deck, the bottom or tanktop, and the forward and aft watertight bulkheads of the hold.

Ramp Tanks. The engine crew pumped ballast water between the vessel's two ramp tanks during the final hours of the voyage. The ramp tanks, which each had a capacity of 313.5 long tons, were located outboard of the enclosure housing the propeller shaft (shaft alley), from frames 200 to 230. Formally known as ramp-compensating tanks, the tanks were originally installed to allow for minor list corrections during the loading/discharging of cargo on either side of the vessel. Loading ramps at the shoreside facility were winched to reach cargo-loading openings through which cars and trailers were loaded and unloaded. By filling or emptying the tanks to compensate for the weight of the ramps hanging from the vessel, the crew could maintain an even keel during loading and unloading.

According to a previous *El Faro* chief engineer, the ramp tanks were ballasted using a separate freshwater system, with a pump located in the shaft alley that ran off the 450-volt electrical bus. A chief engineer who served on the Caribbean run stated that to correct a list, only the ramp tanks could be used because the fuel tanks were on the bottom of the vessel, on the centerline, and "really didn't affect [a list] too much." A chief engineer who departed *El Faro* in August 2015 wrote in his turnover notes that the tank level indicators for both ramp tanks were not functioning because of wasted (deteriorated) sensing lines. He also wrote that the ballast system had been operating "without any issues."

Cargo Hold Ventilation System. Fresh air was drawn into the cargo holds through a system of louvers, fans, and large ventilation shafts, known as trunks. Fresh air entering through louvers in

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[60] The terms *freeboard* and *bulkhead deck* are used interchangeably. The bulkhead deck is the highest deck to which the transverse *watertight* (meaning impenetrable to water except under sufficient pressure to create a structural discontinuity) 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* (meaning that in any sea conditions, water will not penetrate). Below the freeboard deck, all openings in the sides of the ship are fitted with permanent watertight closings.

[61] This report uses an alphanumeric system consistent with that used by shipboard and terminal personnel. For example, the location of cargo loaded on the third deck of A-hold would be 3A.

the hull was blown through supply trunks to the cargo holds on the fourth deck. Air naturally flowed up through perforations in the third (tween) deck. The air was then drawn by natural forces (without the use of fans) into exhaust trunks and finally vented to the outside through another set of louvers. Each supply and exhaust trunk was fitted with fire dampers (designated as watertight closures in drawings) that could be closed to cut off the air supply in case of fire.

All cargo holds had two supply trunks (port and starboard) and at least two exhaust trunks. The supply trunks were fitted with electrically driven fans mounted port and starboard (directly opposed) on the enclosed part of the second deck. The supply fans were in "blisters" that bulged out from the hull below the overhanging main deck (figure 10). The 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 bellmouth. The fans pushed supply air through the fire dampers into a single trunk that passed through the tween holds and into the lower holds at the tanktop. There the trunk split into horizontal runs mounted longitudinally against the sides of the hold. The lower horizontal supply ventilation trunks in the cargo holds were fitted with downward-facing registers, measured as 12 inches above the tanktop.

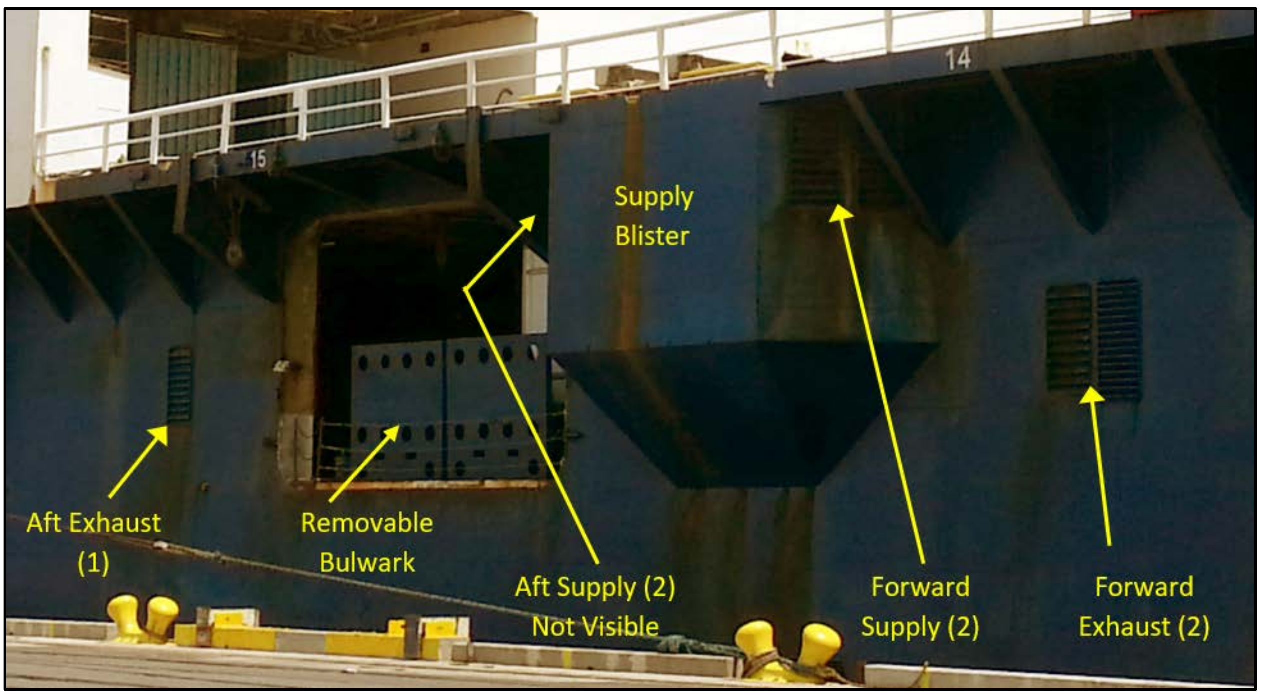

Figure 10. Starboard side of *El Faro* showing supply and exhaust ventilation openings to cargo hold 3. (Photo by Herbert Engineering)

The ventilation air was distributed into the holds through louvered registers in the horizontal trunks. Positive pressure from the supply fan would exhaust the air back up through the perforations in the tween deck, where it would enter a set of three rectangular screened openings to exhaust trunks mounted on both the port and starboard sides (directly opposed) of each hold on the third deck. The air would exhaust up the trunk through the second deck and pass through a manually activated (weathertight, not watertight) closure into a trunk containing baffles on the second deck.[62] The air would pass over the baffles and then out through louvered rectangular openings in the vessel's sideshell.

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 cargo hold supply and exhaust systems, which were very similar to *El Faro*'s, though not exactly the same. Drawings for hull 674 (*El Yunque*) were also reviewed.

As noted earlier, the Coast Guard found extensive corrosion in *El Yunque*'s ventilation system after *El Faro* sank. 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. 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." Investigators visited *El Yunque* in September 2016 and found that most sideshell louvers were severely corroded and holed.

Engine Room Arrangement. The main engine room spaces were below the deckhouse, extending down from the stack. The machinery in the engine room was installed on various decks. The propeller shaft, reduction gear, main condenser, boiler foundations, and most pumps were located on the tanktop. The operating platform, main turbines, turbogenerators, boiler controls, and switchboards were on the third deck. Fans, storage tanks, and heaters were situated above these decks in the engine room uptake (refer to figure 9). Outside the engine room was an emergency fire pump in cargo hold 3 on the starboard side of the tanktop, a steering gear system at the stern, and an emergency generator on the cabin deck. Watertight doors led from the engine room to cargo holds 3 and 5.

1.3.4 Propulsion System

Main Engine. *El Faro* was propelled by a pair of General Electric cross-compound, geared steam turbines that produced a total of 30,000 horsepower (hp). The turbines, one high-pressure (maximum speed 6,700 rpm) and one low-pressure (maximum speed 3,418 rpm), were installed side by side and connected by General Electric (type MD-92-1) reduction gears to a fixed-pitch, five-bladed propeller. The reduction gears lowered the turbine speed to the much slower speed of the propeller (maximum 132 rpm). The turbines were equipped with speed-limiting devices (governor pump and relay) that would restrict steam flow, and thereby engine speed, if maximum rpm were exceeded (overspeed condition).

In remarks recorded on *El Faro*'s VDR at 0613 the morning of the sinking, the captain said, after a call from the engine room, that the main engine had failed. Propulsion was never restored.

[62] *Baffles* are plates installed to check or regulate the flow of air.

Boilers. *El Faro*'s turbines were powered by two Babcock and Wilcox D-type water-tube boilers.[63] The turbines converted the thermal energy of the steam produced by the boilers into mechanical energy that drove the ship's propeller and electrical generators. Steam at lower pressures and temperatures also heated the boiler's fuel oil, produced distilled water, and operated auxiliary machinery.

The boilers had a design steam pressure of 1,070 pounds per square inch (psi), but testimony and logbook evidence indicate that they were operated at about 860 psi at 900˚F in the months before the accident. According to the manufacturer, the boilers were designed so that

> all components to be supplied for shipboard use . . . permit satisfactory operation under the following conditions unless stated in customer's specifications: momentary roll—30˚; permanent list—15˚; permanent trim—5˚.[64]

Data from *El Faro*'s VDR show that while the vessel was sinking, the boilers continued to produce steam pressure, which allowed the turbogenerators to keep generating electrical power (as described below).

Burner management, steam pressure, and water level in the boilers were monitored and controlled by a system designed and installed by a company called Nortech. Off-duty engineering officers told investigators that the crew tested boiler automation annually, in accordance with a periodic safety test procedure. Investigators requested the vessel-specific document from the operating company, but it had been kept aboard *El Faro*. The periodic test procedure from *El Faro*'s sister ship *El Yunque* listed 16 test items.[65] According to interviews with off-duty *El Faro* engineers, a safety test was completed during the off-duty second assistant engineer's last trip, which ended about 9 weeks before the accident.[66]

1.3.5 Electrical Generation and Distribution System

El Faro had two steam turbogenerator sets manufactured by Terry Steam Turbine Company. According to data recorded by *El Faro*'s VDR, the generators continued to produce electrical power until 0734 on October 1, just before the vessel sank.

Each turbogenerator consisted of a steam turbine, powered by 900 psi of superheated steam, that was coupled by a set of reduction gears to a General Electric marine alternating-current generator operating at 1,800 rpm. Each generator had a capacity of 2,000 kilowatts of three-phase power at 450 volts and 60 hertz. The main 450-volt switchboard was energized by the two

[63] *D-type boilers* are so called because the drums and waterwall header appear to form the letter D.

[64] *Trim* is the difference between a ship's forward and aft drafts. The *draft* of a ship is the vertical distance between the waterline and the bottom of the hull.

[65] The 16 test items included a lamp test, manual boiler trip, drum level high/low alarms, low-low drum level alarm and trip, forced draft fan fail alarm and trip, low-air-flow alarm, last-flame-out alarm and trip, boiler control power, burner safety trip control, trial for ignition, purge cycle, boiler in bypass indication, power failure alarms, atomizing steam low-pressure alarm, fuel oil low-pressure alarm, and process controller operation.

[66] He signed off the vessel on August 10, 2015.

turbogenerators. The emergency switchboard, in the emergency generator room, was fed from the main switchboard through an electrical tie.

The vessel was constructed according to the 1973 ABS rules for building and classing steel vessels. The rules required the generators to

> be located with their shafts in a fore-and-aft direction on the vessel and . . . 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 22 1/2 degrees.[67]

A Detroit model 7163-7005-16V71 diesel engine driving an electrical generator served as the vessel's emergency generator. It could automatically start using batteries if power to the main switchboard was lost. According to the 1973 ABS rules for building and classing steel vessels, the emergency generator was required to function when the ship was inclined at 22.5˚ and when the trim of the ship was 10˚. According to entries in the preventive maintenance system, the autostart function of the emergency generator was tested monthly. The monthly tests also included operating the emergency generator under an electrical load for 2 hours. VDR data contained no evidence that the emergency generator was used to supply electrical power or was even started during the accident.

1.3.6 Fuel and Lubricating Oil

Fuel Oil. *El Faro* had a capacity of 11,552 barrels (bbl) of fuel oil. Fuel consumption was approximately 2.0 bbl per nautical mile. The double-bottom storage tanks on *El Faro* were located as follows:[68]

- No. 2A double-bottom inboard port and starboard (approximately 2,202 bbl each).
- No. 3 double-bottom inboard port and starboard (approximately 2,673 bbl each).

At the time of the accident, the vessel burned heavy fuel oil RMK500. Samples of fuel from each bunkering (fueling) operation were kept on board as well as with the supplier for testing if necessary.

The fuel was usually burned at sea from the No. 3 double-bottom inboard storage tanks. Twice a day, a second engineer transferred fuel from the tanks to a single fuel oil settler (capacity 1,800 bbl, or 273 tons).[69] The fuel was heated by steam coils inside the settler to about 130˚F and pumped through two sets of strainers before being heated again by another set of heaters to 230˚F, atomized by 150-psi steam, and burned in the boilers. While it was in liner service between Jacksonville and Puerto Rico, the vessel filled its fuel tanks weekly. It burned about 800 to 900 bbl a day at full sea speed. Postaccident tests on fuel oil from the vessel's last three bunkering

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[67] *Athwartship* means from side to side or across the ship.

[68] The tanks are described as *double-bottom* because they were located on the bottom of the ship, below the tanktop deck. The bottom consisted of two complete layers of watertight hull surface, known as double-bottom construction.

[69] A settler, or settling tank, allows oil to stand while water and other impurities settle out.

operations before the accident found it to be within ASTM specifications (see section 1.15.1, "Fuel Oil Analysis").[70]

Lubricating Oil. According to the 1973 ABS rules for building and classing steel vessels, the lubricating oil system of the main engine was "to be so arranged that it will function satisfactorily when the vessel is permanently inclined to an angle of 15 degrees athwartship and 5 degrees fore and aft." The Coast Guard had no rules for main engine or lube oil operation angles when the vessel was built (or when it was lengthened in 1993). *El Faro*'s lubricating oil system is diagrammed in figure 11. Because the suction for the lubricating oil service pump was located in the starboard, aft section of the sump, a port list with a forward trim would be the worst-case scenario for exposing the suction bellmouth, which could result in a loss of lubricating oil to the main engine.

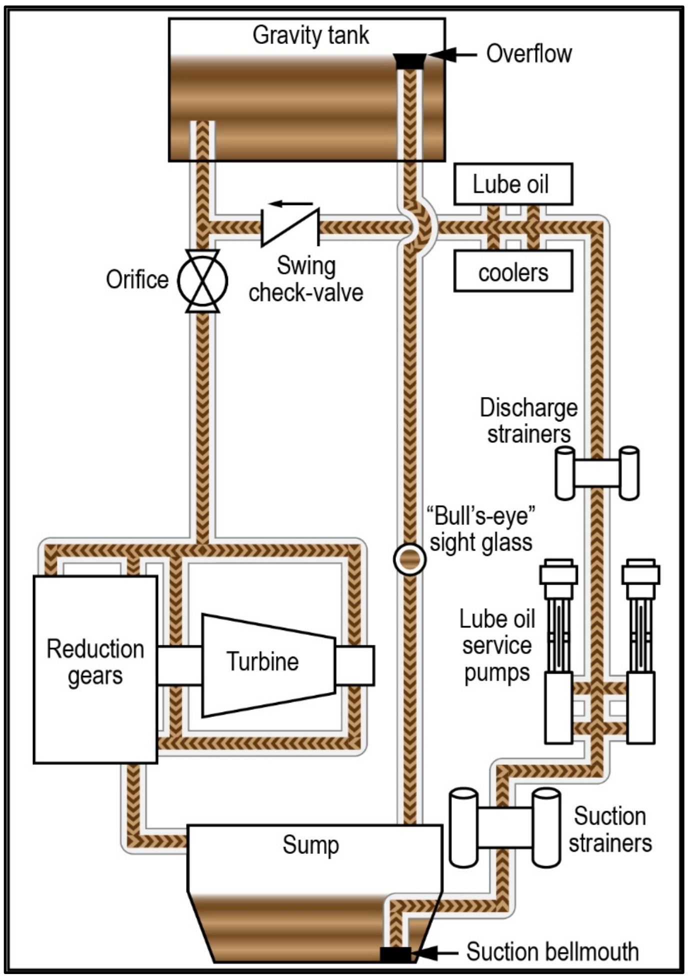

Figure 11. Schematic of *El Faro*'s lubricating oil system, showing component parts and direction of oil flow.

70 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.

The lubricating oil system consisted of two DeLaval-Imo Pump series TKC422BS-337 positive-displacement, vertical rotary screw-type service pumps, rated at 450 gallons per minute (gpm), manufactured by DeLaval Turbine, Inc. (now Imo Industries). The pumps were driven by 40-hp electric motors. According to an original construction diagram, lube oil service pump No. 1 was powered by the main 450-volt switchboard and protected by a 100-amp breaker. Lube oil service pump No. 2 was powered by the emergency 450-volt switchboard and also protected by a 100-amp breaker. The manual for the lube oil pump stated that “running the pump without oil will cause rapid wear of housings, rotors, and other internal parts.” Mechanical seals kept the pressurized fluid inside the pump housings.

The lube oil system normally operated with one service pump running and the second service pump in standby mode. The standby pump would automatically start if a pressure switch sensed a 10-psi pressure drop in the line that supplied lube oil to the bearings. Discharge oil pressure could be low for several reasons, including loss of pump prime, leaks in suction piping, obstructions (such as debris) in suction piping, clogged strainers, air in system, leaking seals, or low oil level.

According to another construction drawing, *El Faro* had communication points to advise watchstanders about lube oil issues. While aboard *El Yunque*, investigators noted the following alarms for the lube oil system on the main control panel: lube oil gravity tank level low, lube oil pump power failure, standby lube oil pump running, lube oil sump level high, lube oil sump level low, lube oil service pump discharge pressure low, lube oil cooler temperature low, and lube oil cooler temperature high.

The pumps discharged lube oil to the main engine bearings through an orifice in the supply line, as well as to a 3,200-gallon gravity tank in the upper engine room. The orifice provided a pressure of 12 pounds per square inch gauge (psig) at the lube oil inlet header to the unit.[71] The oil had a Saybolt viscosity of 520 (Saybolt universal seconds) at a temperature of 100˚F.[72] The 9-foot-high gravity tank was located on the main deck level, about 35 feet above the operating platform (refer to the vessel profile in figure 9). During normal operations, the level in the tank would be maintained above an internal overflow line 10 inches below the top of the tank (refer to figure 11).

From the engine room, overflowing oil, indicating proper operation of the lube oil service pumps, could be monitored through an illuminated port (“bull’s-eye”) in the supply line that returned oil to the sump (figure 12). An engineer who had served aboard TOTE’s *Ponce*-class vessels (last in 2012) told the third marine board that in rough weather, flow in the bull’s-eye might be interrupted by sloshing oil in the gravity tank. In the event of a pressure loss, about 8 minutes

[71] Psig measures pressure relative to ambient atmospheric pressure.

[72] *Viscosity* is a fluid’s internal resistance to flow. Instruments used to measure viscosity are called *viscometers*. Saybolt viscosity is the time in seconds required for 60 cubic centimeters of oil to flow through a standard Saybolt Universal viscometer at a given temperature, depending on the heaviness of the oil. Saybolt refers to George M. Saybolt, an American chemist (Bureau Veritas 2017; Merriam-Webster online).

of reserve oil for the main engine bearings would gravitate directly into the main engine bearings through a 5-inch drop line located 10 inches from the bottom of the gravity tank.

Figure 12. Bull's-eye for monitoring lube oil flow from gravity tank. (Photo from *El Yunque*)

The vessel's two lube oil service pumps drew oil from the main engine reduction gear sump through an 8-inch pipe, a check valve, and duplex magnetic suction strainers. According to the turnover notes of the previous chief engineer from August 2015, both pumps would have required maintenance during the upcoming shipyard repairs (scheduled for November 2015). The forward pump required replacement of the mechanical seal, and the aft pump required rebuilding or replacing because it was "running 3 psi lower than the forward pump." Those items were noted on a worklist for the shipyard.

TOTE's director of safety and services, who had worked as a port engineer and was also authorized to service the main engine, told investigators that he did not believe a pressure drop of 3 psi was significant enough to affect the system. A chief engineer with *Ponce*-class experience testified that he had never experienced a failure of the lube oil pumps because the mechanical seals failed. He explained that a line from the discharge side of the pumps to the suctions would keep the offline pump primed. If oil was lost to the pumps, the head pressure of the storage tank could be used to prime them. If air became trapped in the suction side of a pump, the cooling line for the mechanical seal could be cracked open to bleed out the air.

The lube oil sump was at the bottom of the reduction gear and extended below the tanktop. According to a construction diagram of the lubricating system, the suction pipe was 10 inches above the bottom of the sump, about 22 inches to starboard of centerline and about 24 inches from the aft bulkhead of the sump. Measurements taken aboard *El Yunque* in October 2016 placed the pump suction 73 inches above the tanktop. The suction pipe extended 42 inches into the lube oil sump. The distance from the suction pipe bellmouth to the pump suction inlet was 115 inches.

TOTE's director of safety and services told investigators that if air entered the bellmouth of the suction pipe when the vessel rolled, suction would be lost unless the ship rolled back again and oil was replenished. He said the pumps would not pump if the suction side contained much air. He further stated that if the mechanical seal failed, air entering the pump casing could cause the pump to completely lose its prime. He also stated that having a higher level of lube oil in the sump would have helped the system maintain pressure during the accident. He stated that the lube oil pumps could run for about 30 minutes without lubrication before being destroyed internally.

According to logbook entries from runs in September 2015 before the accident, when *El Faro*'s main engine was operating at about 120 rpm, the normal operating suction pressure of the lube oil was about 8 psig, and the discharge pressure was about 58 psig. The pressure relief valve on the discharge side of the lube oil pumps was set at 85 psig.

The discharge side of the pumps was equipped with a set of duplex magnetic strainers and an orifice installed to maintain 55 psi of pressure to the turbine governor system. Also part of the lube oil system were two coolers—heat exchangers that used seawater to remove heat, generated by the main engine, from the oil. Two Alfa-Laval purifiers were piped into the system to remove water and contaminants from the lubricating oil used in the propulsion turbine/reduction gear and the turbogenerators.

The main engine lube oil sump had a maximum capacity of 2,870 gallons, with a high-level operating capacity of 2,020 gallons, a normal operating level of 1,426 gallons, and a low level of 724 gallons. The alteration section of the construction diagram for the lubricating system of the *Ponce*-class vessels shows that in 1972, before *El Faro*'s keel was laid, the original design specifications for the operating levels of the lube oil sump were changed. The operating capacity was increased from 900 gallons to 1,426 gallons, the low-level capacity was decreased from 750 gallons to 724 gallons, and the sump design capacity was decreased from 4,250 gallons to 2,870 gallons.

According to engine logbooks for the year preceding the accident, the level of lube oil in the main engine sump was ordinarily maintained at between 23 and 28 inches, and at 25 or 26 inches in the months before the accident. The last recorded level of lube oil in the sump was 26 inches, from the engine log of September 1. No levels of more than 29 inches were found in any records during the period investigated. The former *El Faro* chief engineer, who last sailed aboard *El Faro* in 2012, testified that when he sailed on TOTE's *Ponce*-class vessels before 2012, standard operating procedure required the level of oil in the sump to be kept at 28 to 32 inches. He said he would operate with the oil at the "upper level just for safety factor to make sure there was plenty of lube oil in the system." He said that sometimes, depending on the weather and other conditions, the sump level was raised to 30 or 32 inches.

An off-duty chief engineer with recent experience on *El Faro* told the first marine board that the lube oil in the main engine was normally maintained at about 27 inches in the sump. He said it would take about 30 minutes to raise the level in the sump by 1 inch using the purifiers, but that during heavy weather, the purifiers were shut down. With the purifiers shut down, he recalled that the sump could be filled quickly, being gravitated from the tank. He stated that he had never had any issues with the lube oil system during heavy weather, aside from slight variances in pressure due to rolling.

The level of oil in a tank can be manually checked by sounding, that is, measuring the depth from the surface of the oil to the bottom of the tank with a tape or sounding tube. The volume of oil is calculated by comparing the measured depth with a "sounding table" whose values account for the tank's shape. The sounding table for the lube oil in the main engine sump of *El Yunque* indicated that a sounding of 26 inches corresponded to a quantity of 1,346 gallons in the sump. A sump level of 27 inches equated to 1,436 gallons (10 gallons more than the operating level of 1,426 gallons stated in the company's operating manual). *El Yunque*'s sump was equipped with a manual sounding tube as well as a transmitter that displayed the sump level at the operating console.

El Faro had two tanks for storing additional lube oil. A 4,465-gallon storage tank was located on the operating level aft of the main engine, with a 4,608-gallon settling tank next to it. Both tanks had 1-inch pipes connecting the bottoms of the tanks to a 2-inch common line for adding lube oil to the main engine sump. According to a report from the vessel's cargo-loading software, CargoMax, when *El Faro* departed on the accident voyage, the lube oil storage tank contained 10 tons of reserve oil (2,850 gallons) and the settling tank was empty.

TOTE provided investigators with a copy of the machine operating manual from *El Yunque*. The manual stated: "When necessary, add lube oil from the storage/settling tank to the sump via purifier to maintain the normal level at 27 inches. Record the amount added in the logbook." The manual provided information about the levels and capacities of the main engine sump and alarms. The sump design capacity was listed as 2,870 gallons, high-level capacity was 2,020 gallons, operating level capacity was 1,426 gallons, and low-level capacity was 724 gallons. High- and low-level alarms were installed to warn the operator of either a high or a low oil level in the sump. The levels were also identified on the vessel's original drawings. The low-level alarm was set at 18 inches (724 gallons), and the high-level alarm was set at 33 inches (2,020 gallons).

A low-bearing-oil-pressure switch was installed in the oil feed line to the main engine bearings. The switch was electrically connected to a solenoid dump valve (a large emergency valve that allows oil to drain very fast) that was normally deenergized. The pressure switch was designed so that if it sensed a pressure drop at the most remote bearing to a level at which the bearings could be damaged, it would energize and release lube oil pressure from the ahead operating cylinder, thereby closing the ahead steam control valves. If the lubricating system pressure fell below 4 psig at the pressure switch, the throttles would close and stop the flow of steam to the turbines.

The ahead and astern steam control valves could be operated manually if a failure occurred in the throttle control mechanism, including a loss of control oil pressure.[73] Either a long-handled emergency bar or hydraulic hand pumps attached to cables in the overhead could be used to raise the lifting beams and admit steam to the turbines. According to the manufacturer's manual, lube oil could be lost for several reasons: plugged strainer, pump failure, stuck pressure-reducing valve in oil header (distribution pipe), improper valve lineup, defective pressure sensor, low oil level, or broken oil line. If lube oil was lost, the appropriate action was to stop rotation of the shaft and try to restore oil pressure.

The lube oil system also contained overspeed governor pumps, one in each forward bearing bracket of each turbine. If a condition developed that would cause the turbines to overspeed, the output of the governor pumps would increase and actuate an overspeed relay. The relay would

[73] The control oil system provided metered or reduced system pressure to governors, valve actuators, trips, and shutdown devices on the main engine.

cause the steam control valves to move in the closing direction and decrease the speed of the turbines by limiting the amount of steam admitted. The overspeed system was designed to be self-restoring. After an overspeed condition was corrected and normal turbine speed had resumed, the lube oil output pressure would drop and the steam control valves would return to the open position.

1.3.7 Steering System

El Faro's electrohydraulic ram-type steering system, type FR-280, was built by Kawasaki Heavy Industries, Ltd., of Kobe, Japan. Two Kawasaki-Bruninghaus type BV-732 hydraulic pumps were powered by a pair of 60-hp, 1,150-rpm induction motors with an output of 45 kilowatts. One of the electric motors that powered the system was fed by the main 450-volt switchboard and one by the 450-volt emergency switchboard. The system was designed to have a maximum torque (twisting force) of 140 ton-meters and to turn 65° in 28 seconds.

The steering system was located in the steering gear room and remotely controlled from the bridge by a C. Plath Navipilot V marine autopilot system or a C. Plath Navipilot AD II. According to the operating manuals, the control processes of both systems allowed the vessel to be steered manually (hand-steered) or in autopilot mode. In autopilot mode, the vessel received input from one of the vessel's gyrocompasses and steered a gyrocompass heading. Settings to the autopilot could be selected at the master unit on the bridge. The settings allowed navigation personnel to change the response time or sensitivity of rudder movement. Both systems were equipped with visible and audible alarms to warn bridge personnel when the vessel was off course by an operator-defined amount.

1.3.8 Bilge and Fire Systems

Bilge and Ballast. The bilge and ballast piping regulations at 40 *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.[74] *El Faro* was equipped in that manner. The ship's cargo bilge-pumping system was powered by the 450-volt main switchboard. Two vertical centrifugal bilge/ballast pumps, manufactured by Worthington, were on the lower level of the engine room. Each pump was driven by a 20-hp electric motor. The pumps were rated for 850 gpm at 30 psi.

The lower level of the engine room also contained an emergency submersible bilge pump, manufactured by Prosser, that could dewater the machinery space. The pump was powered by the emergency generator and rated at 50 gpm at 30 feet of total dynamic head (discharge pressure). According to the ship's preventive maintenance system, bilge alarms in the engine room and cargo spaces were required to be tested monthly. A bilge alarm panel was located in the engine room. Engine department crewmembers typically notified the bridge when they received a bilge alarm because there was no alarm panel on the bridge.

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[74] Dry cargo ships, which include bulk carriers and container ships, are distinct from ships that carry liquids such as oil or chemicals.

Water collected in bilge drainwells (roseboxes), recessed pockets in the aft corners (one port and one starboard) of the machinery spaces and of each cargo hold on the fourth deck. The bilge pipes for dewatering the holds took suction from the roseboxes, which each held about 10 gallons of water. A stainless-steel float was installed at the top of the roseboxes, below a screen at the tanktop level. There are no requirements for bilge alarm systems in cargo holds. TOTE had installed the alarms to alert shoreside personnel of excess water in the holds while the vessel was in layup.

When the water in a rosebox rose high enough to raise the float for 5 seconds, a signal went to an alarm panel in the engine room and activated audible and visible alarms. An engineer who had sailed aboard *El Faro* estimated that about 50 gallons of water would activate the alarm in hold 3. The sound of the alarm could be turned off, but a red light would remain lit on the alarm panel until the float returned to its normal position. The bilge float was routinely tested by lifting it and verifying that the alarm sounded. No deficiencies had been reported with the bilge system. One of the past chief engineers on *El Faro* told investigators that cars and trailers generated "a lot of debris" that would need to be cleaned out of the roseboxes. Investigators observed debris on the screens over the roseboxes when they visited *El Yunque*.

Fire Main. The fire main system consisted of a combination pump, called a bilge, fire, and general service pump, located on the starboard side of the lower engine room. The pump was a Worthington vertical, centrifugal model rated for 575 gpm at 125 psig. An emergency fire pump, rated for 635 gpm at 125 psig, was located on the starboard side of cargo hold 3, on the tanktop. The pump had its own sea suction (seawater inlet pipe) directly outboard of the pump. As seen in figure 13, the fire pump (shown in the photo) was protected by at least one vertical steel stanchion, and a platform (shown in the drawing) was located above the pump, with a vertical ladder installed nearby.

While on board *El Yunque*, investigators photographed the emergency fire pump in hold 3 on the tanktop, in a similar location to that of *El Faro*'s emergency fire pump (figure 14). The pump aboard *El Yunque* had vertical pipes welded to the deck and framing as protection, but the suction pipe and valve had no surrounding protection. The arrangement of the piping for the emergency fire pump was not identical between *El Faro* and *El Yunque*.

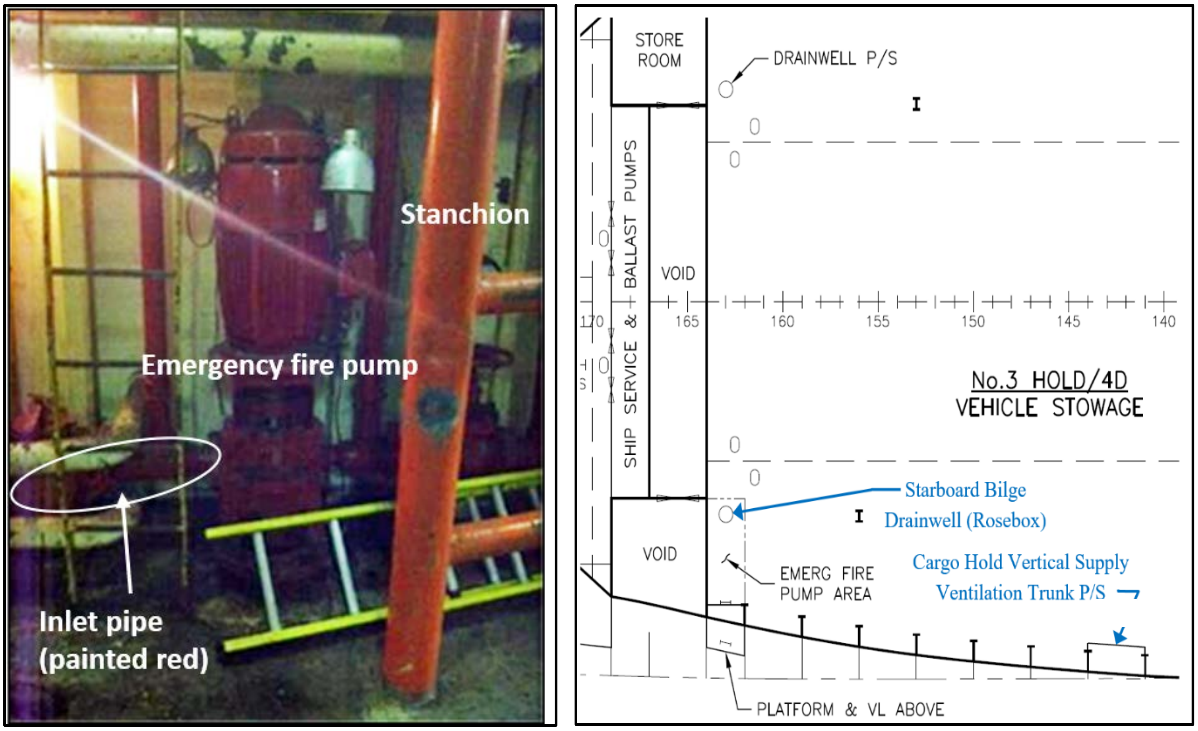

Figure 13. Emergency fire pump. Photo shows emergency fire pump (center rear) in *El Faro*'s hold 3 (photo by Maine Maritime Academy cadet). Diagram, from general arrangement drawing, shows emergency fire pump location in hold 3, fourth deck (VL = vertical ladder).

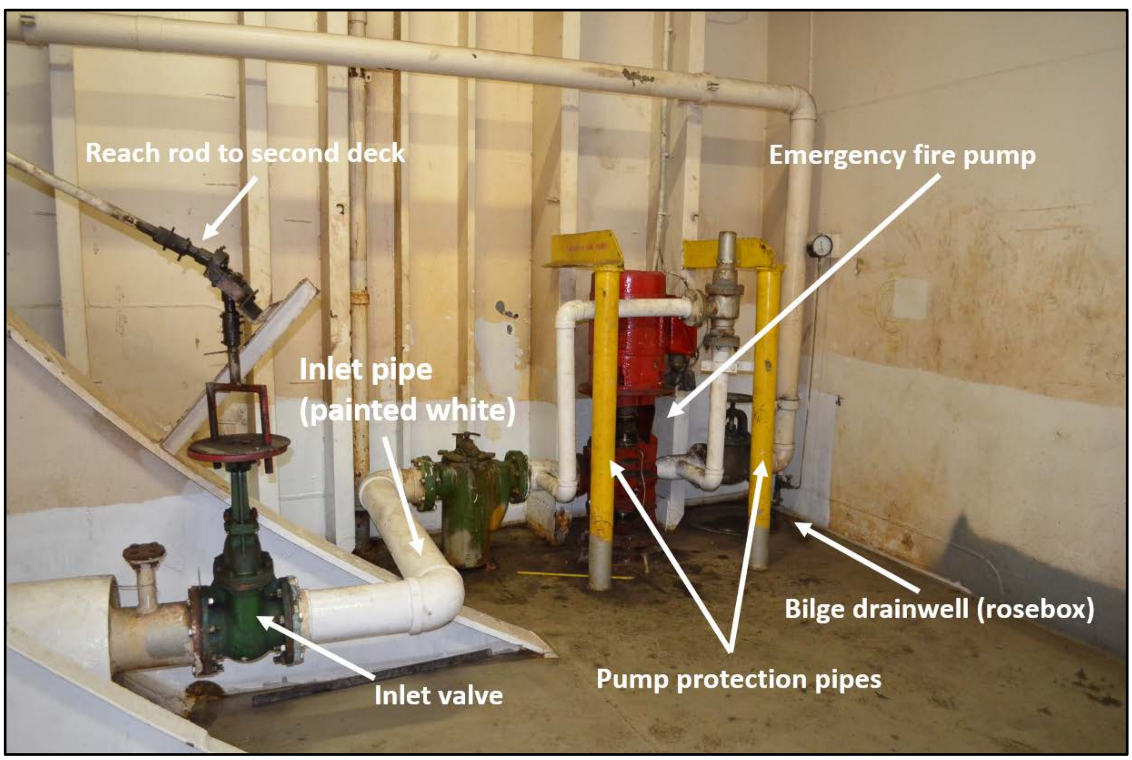

Figure 14. Emergency fire pump and inlet piping in hold 3 of *El Yunque*.

1.3.9 Maintenance

General. The *El Faro* crew used a computerized preventive maintenance, spare parts, and purchase-tracking system called AMOS (Asset Management Operational System). Investigators reviewed maintenance records and purchase orders for the 2 years before the accident, downloaded from the operating company's file server, and conducted interviews. The off-duty chief and first and second assistant engineers reported no overdue or deferred maintenance at the time of the accident. The *El Faro* port engineer stated that he did not check work orders for their completion status and was unaware if there were any outstanding work orders. TOTE's director of ship management–commercial said that he did not monitor the activity in AMOS on a daily, weekly, or monthly schedule but did so when an issue was communicated to him. The director further stated that completion of planned maintenance was verified through internal audits. The chief engineer and first assistant engineer were the only engine department officers with access to AMOS. They would manually enter maintenance histories and order spare parts.

In 2014, *El Faro*'s deck and engine departments entered 308 records for various maintenance tasks. Routine maintenance, such as inspections, oil changes, lubrication, and manufacturer's recommended maintenance, were recorded as part of the planned maintenance program. Equipment tests and surveys were also recorded. In 2015, 435 maintenance records had been entered into the system up to the time of the accident.

Boilers. According to AMOS entries and an email from the chief engineer, the crew inspected and cleaned both boilers in July 2015. (The crew usually performed routine maintenance on the boilers on the northbound voyage, when the ship occasionally ran on only one boiler, compared with two on the southbound leg.) As a result, the chief engineer recommended that Walashek boiler repair company in Jacksonville survey the boilers to determine the scope of work for the November shipyard repairs.

Walashek inspected the fireside (combustion chamber and related parts) of the starboard boiler on September 11, 2015, and recommended renewing the front wall tubes, brickwork, and burner throats on both boilers.[75] The Walashek representative did not recommend a time frame for the repairs. Walashek did not inspect the port boiler, but it was assumed to be in the same condition as the starboard boiler. The last waterside (part of boiler containing water and steam) survey of the *El Faro* propulsion boilers was conducted by ABS in December 2013. The checklist stated that both boilers had been surveyed and that the vessel's maintenance history had been reviewed. The documentation did not include pressures.

Lubricating Oil. The lubricating oil in critical machinery systems was periodically sampled and sent to a Chevron LubeWatch laboratory for analysis. Investigators examined the last 2 years of results. All critical systems had consistently acceptable results, except for the oil in the stern tube and strut bearing systems, which received intermittent warnings.

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[75] Burner throats shape the burner flame, mix fuel and air, and direct stabilizing heat back to the flame.

1.3.10 Electronic Equipment

Automatic Identification System. *El Faro* was equipped with an automatic identification system (AIS) model JHS-182, serial No. BB44685, manufactured by JRC (Japan Radio Company, Ltd.). AIS is a shipboard broadcast system, operating in the VHF maritime band, that sends and receives ship information such as identity, position, course, and speed. The primary purpose of AIS is collision avoidance, but its use has broadened to fishing fleet control, vessel traffic services, and maritime security. AIS transmissions can be received and retransmitted by other vessels and by land-based systems using VHF radio. Satellites can receive the transmissions but do not transmit them.[76] The International Convention for the Safety of Life at Sea (SOLAS), as amended, requires all ships of 300 gross tons or more engaged on international voyages to be equipped with an AIS.[77]

The Coast Guard records national AIS data from a network of AIS base stations along coastlines in the continental United States, Alaska, Hawaii, and Guam, in addition to recording AIS data from a satellite network for waters beyond the range of the terrestrial network. The last national AIS position recorded for *El Faro* was for October 1 at 0356.

Voyage Data Recorder. As required, *El Faro* was equipped with a simplified VDR (S-VDR) that was installed in January and February 2009.[78] The device was a Northrop Grumman Sperry Marine Voyage Master II, manufactured by Danelec Marine (Birkeroed, Denmark). The VDR capsule was attached to a steel channel at the base of the antenna mast on the deck above the bridge (figure 15).

Chapter V, regulation 20, of SOLAS 1974, as amended, specifies VDR carriage requirements for ships engaged on international voyages. Cargo ships larger than 3,000 gross tons constructed after June 2002, and all passenger ships regardless of tonnage or year of construction, must be equipped with a VDR. Cargo ships larger than 3,000 gross tons constructed before July 2002 must be equipped with a VDR or S-VDR. Either system requires storing a minimum of 12 hours of all required information including data, audio, and radar information. In the event of an incident or accident, investigation authorities must be able to download and replay the VDR data without delay. Software, instructions, and special parts necessary for data extraction and replay are required to be in the main unit of a VDR.[79]

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[76] Third-party businesses offer services to customers (at a subscription cost) to monitor AIS signals that are received by satellites but may be out of reach of land- or ship-based antennas. AIS was not anticipated to be detectable from space when it was developed in the 1990s.

[77] SOLAS is an international treaty concerning the safety of merchant ships. The first version of SOLAS was adopted in 1914 after the *Titanic* sank. A new convention was adopted in 1974 and is sometimes referred to as SOLAS, 1974, as amended, because of its numerous updates and amendments.

[78] Standards for S-VDRs are set out in International Maritime Organization (IMO) resolution MSC.163(78), May 2004.

[79] IMO resolution MSC.214(81), annex 1 to resolution A.861(20), establishes performance standards for "download and playback equipment for investigation authorities."

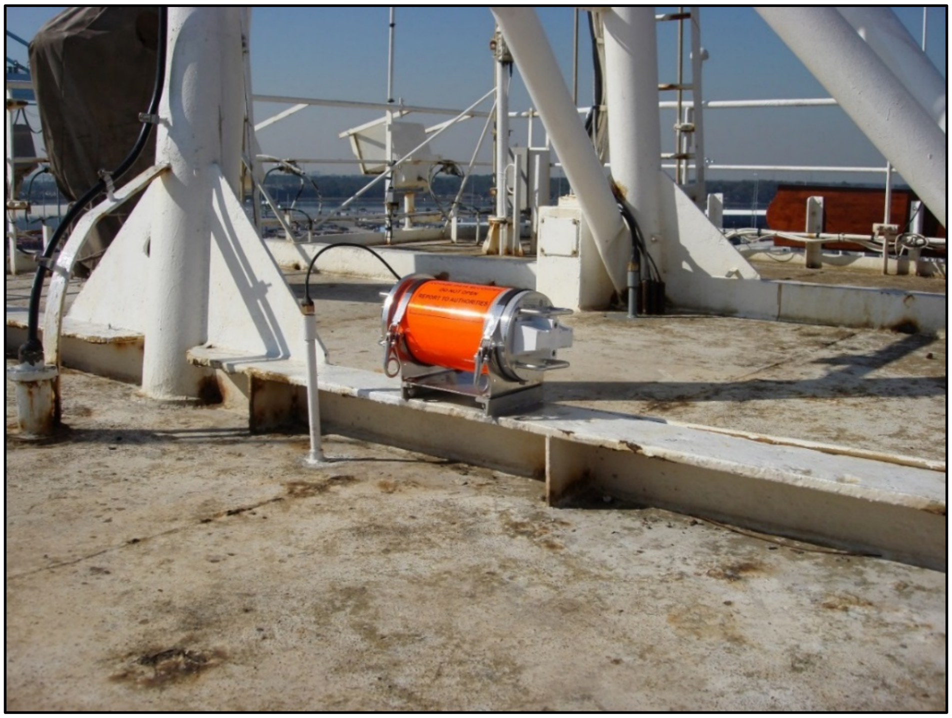

Figure 15. VDR capsule on deck above *El Faro*'s navigation bridge. (Radio Holland photo[80])

Data items required to be recorded on an S-VDR are date and time, ship's position, speed (through water or over ground), heading (from ship's compass), bridge audio, VHF audio communications, radar data, and AIS data, if radar data cannot be obtained. *El Faro*'s S-VDR also recorded wind angle and speed and rate of turn.[81] The recording duration of *El Faro*'s S-VDR depended on the size of the data files and was a function of the quantity of information recorded.

The VDR data were stored on a flash memory chip inside a protective capsule. On August 8, 2016, after the capsule was recovered from *El Faro*'s wreckage, it was submerged in a bath of distilled water aboard the Navy vessel *Apache*, then disassembled and inspected for possible damage to the internal recording medium. Inside the capsule, layers of protective materials housed an inner capsule containing the circuit board assembly that stored the nonvolatile memory (figure 16).[82] The circuit board assembly was inspected for visible signs of damage or corrosion (figure 17) before being transported to the NTSB laboratory in Washington, DC, on August 12.

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[80] Radio Holland, now Imtech Marine, did a safety survey of *El Faro*'s EPIRB on January 27, 2015.

[81] Other parameters (depth, main alarms, rudder order and response, engine and thruster order and response, hull openings status, watertight and fire door status) were not recorded. SOLAS requires them on S-VDRs only if an International Electrotechnical Commission (IEC) 61162 digital interface is available.

[82] *Nonvolatile memory* is semiconductor memory that does not require external power for data retention.

Figure 16. Inner VDR capsule assembly after removal from outer capsule.

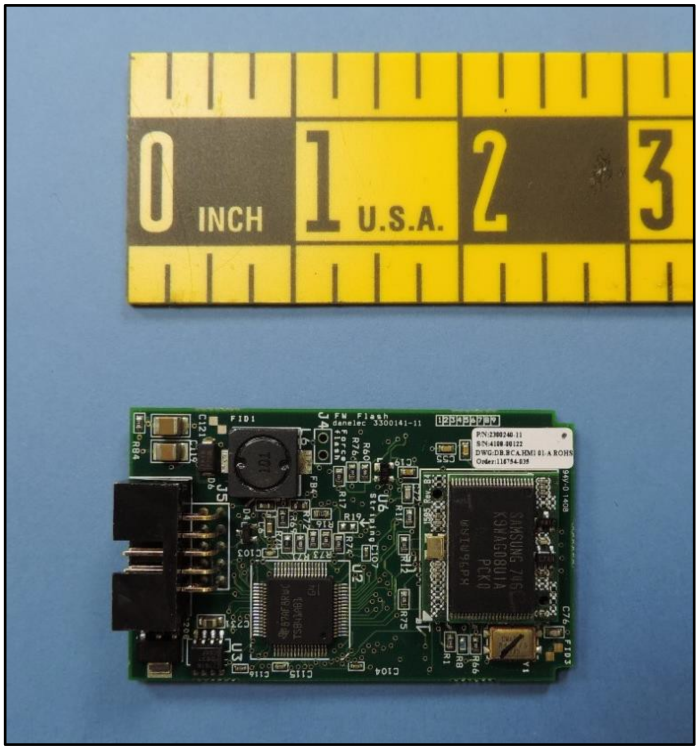

Figure 17. Circuit board assembly from inner VDR capsule.

On August 15, 2016, at the NTSB laboratory, the circuit board assembly from the inner VDR capsule was connected to a functioning surrogate assembly, provided by Danelec. The manufacturer provided technical support and witnessed downloading of the VDR data. A forensic write-blocking bridge was used to copy data from the circuit board assembly.[83] Using manufacturer-provided VDR playback software, the data were exported to a common data file structure for further analysis.[84]

Audio data from the VDR capsule were saved as multiple WAV audio files for each audio channel. The radar video image was recorded once every 15 seconds. Other parameters were recorded as industry-standard text files.[85] Specialized software was used to parse the data files and output the desired data in tabular format.

Audio data were recorded by six microphones on the ship's bridge. Four microphones were installed inside the bridge (center, starboard, port, and chart table) and one on each bridge wing (port and starboard). A separate channel wired to record VHF communications was inactive. Instead, VHF communications were captured by the bridge microphones from an open speaker system. The six microphones in the VDR system were wired into three audio channels, with two microphones on each channel mixed into a single monaural track. Investigators characterized the quality of the audio recording on two channels as "poor" and on the third as "unusable."[86] The unusable data were from the microphones on the bridge wings.

Regulation 18.8 of SOLAS chapter V states: "The voyage data recorder system, including all sensors, shall be subjected to an annual performance test." The last annual performance test for *El Faro*'s VDR was on December 2, 2014. The performance test noted that the battery for the acoustic locater beacon had an expiration date of May 2015 (before the next annual performance test) and should have been replaced. A certificate of compliance was issued without the battery being replaced. No signals from the beacon were detected during the first underwater search. Attempts to locate the VDR switched to sonar after 3 days.

Container-Tracking System. Tracking equipment, consisting of wireless transmitters, was installed on most of the refrigerated containers *El Faro* carried on its final voyage. The tracking equipment was operated by WAM Technologies, Inc., which uses GSM (global system

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[83] A forensic write-blocker allows read-only access to a drive, minimizing the risk of accidentally overwriting the data.

[84] IMO resolution MSC.214(81) requires VDR manufacturers to provide a way to export VDR data to open industry standard formats.

[85] Parametric data were saved in a format compatible with IEC standard 61162-1.

[86] The NTSB's report on the VDR audio data defines "poor" quality as follows: "Extraordinary means had to be used to make some of the crew conversations intelligible. The transcript that was developed may indicate fragmented phrases and conversations and may indicate extensive passages where conversations were missing or unintelligible. This type of recording is usually caused by a combination of a high bridge noise level with a low voice signal (poor signal-to-noise ratio) or by a mechanical or electrical failure of the VDR system that severely distorts or obscures the audio information."

The VDR report defines "unusable" quality as follows: "Crew conversations may be discerned, but neither ordinary nor extraordinary means made it possible to develop a meaningful transcript of the conversations. This type of recording is usually caused by an almost total mechanical or electrical failure of the VDR system or extremely high bridge noise."

for mobile communications) and GPS technology to remotely monitor, control, and track refrigerated containers anywhere in the world.[87] WAM can monitor the location of refrigerated containers and remotely control the temperature inside the containers to keep chilled or frozen goods from spoiling. The last WAM data for *El Faro* were transmitted at 0228 on October 1.

Satellite Communication System. Inmarsat Globe Wireless supplied *El Faro* with satellite email and voice communications transmitted through the Globe i250 FleetBroadband system. The Globe i250 installation had both an above-deck and a below-deck unit. The above-deck unit included the antenna, which was installed on the outside of the ship, where there was a clear exposure to the sky. The below-deck unit contained a rack-mounted electronic controller and an uninterruptible power supply.[88] The below-deck unit was installed on the bridge and included a handset for phone calls. Other handsets were installed in the captain's and chief engineer's staterooms. Email transmissions to or from the vessel were controlled by software installed on a computer in the captain's stateroom, which was connected to the Globe i250 system.

Global Maritime Distress and Safety System. Chapter IV of SOLAS 1974, as amended, and 47 *CFR* Part 80, subpart W, require GMDSS equipment to be carried by cargo ships of 300 gross tons or more when on international voyages or traveling in the open sea. GMDSS is a worldwide network of automated emergency communications for ships at sea that was established by the IMO, a specialized agency of the United Nations. The system uses satellite and terrestrial radio services to rapidly transmit alerts from vessels in distress and support global search and rescue. The Federal Communications Commission (FCC) adopted the GMDSS regulations for US compulsory vessels on January 16, 1992. The international regulations became mandatory for vessels subject to SOLAS on February 1, 1999.

GMDSS has changed distress communication from a ship-to-ship system relying on Morse code and radiotelephones to an automated ship-to-shore system using satellites and digital calling technology. Before GMDSS, ships carried communication equipment based on tonnage. GMDSS requires ships to carry communications equipment based on where they operate. *El Faro*'s COI stated that the vessel was approved for "oceans" as its permitted route. Four sea areas define where GMDSS services are available and the radio equipment GMDSS ships must carry. Sea area A3 (approximately between latitudes 70N and 70S) is the "oceans" waters of the GMDSS.

According to FCC regulations at 47 *CFR* 80.1081, 80.1091, and 80.1095, *El Faro* was required to carry the following GMDSS equipment:

- VHF radios capable of operating by voice and transmitting on digital selective calling (DSC).
- Two search-and-rescue (radar) transponders (SARTs).
- Three GMDSS VHF-FM handheld radios.

[87] WAM stands for wireless asset management.

[88] An uninterruptible power supply protects electrical equipment from unexpected power disruptions. Energy is stored in batteries or supercapacitors so that equipment can run a short time if the normal power supply is interrupted.

- Maritime safety information receiver capable of receiving NAVTEX urgent marine safety information (navigational and meteorological warnings and forecasts, search-and-rescue notices).
- Category 1 406-megahertz (MHz) EPIRB.
- Medium frequency radio installation with 2187.5-kilohertz (kHz) DSC capability.
- Inmarsat ship earth station.

On January 27, 2015, Imtech Marine performed an annual survey and testing of the GMDSS equipment on *El Faro*. A cargo ship safety radio certificate was issued the same day. The certificate affirms that *El Faro* carried the required GMDSS equipment, in accordance with SOLAS, and that it was in working order.

EPIRB. The ship was equipped with a Tron 40S MkII EPIRB, without GPS encoding, manufactured by Jotron and installed on February 16, 2007. The automatically activated, category I device was designed to float free from a bracket equipped with a hydrostatic release.[89] It transmitted on a frequency of 406 MHz by means of a 5-watt omnidirectional antenna and had a minimum operating life of 48 hours, powered by a battery due to expire on February 1, 2019. The EPIRB was registered with the FCC on February 1, 2012; the registration was last updated on December 2, 2013.

Inmarsat Ship Earth Station. The ship carried a FELCOM 15 mobile earth station manufactured by Furuno Electric Company, Ltd. The mobile earth station was equipped with an optional internal GPS module, according to the installation invoice. The SSAS was connected to, and incorporated into, the FELCOM 15 installation. SSAS units are not part of the GMDSS but are required (for vessels of 500 gross tons or more constructed before July 1, 2004) by SOLAS resolution XI-2/6 and incorporated by reference in Coast Guard regulations at 33 *CFR* Part 101 (subchapter H, "Maritime Security"). *El Faro*'s SSAS was tested quarterly, in March, June, and September 2015.

1.3.11 Navigation Equipment

Required navigation equipment for *El Faro* was listed on the ABS Record of Approved Cargo Ship Safety Certificate. According to the certificate, *El Faro* carried the following navigation equipment:

- Two radars (3-centimeter Raytheon radar and 10-centimeter Furuno radar).
- Automatic radar plotting aid.
- Two gyrocompasses.
- Magnetic compass.
- Rudder-angle indicator.
- Rate-of-turn indicator.
- Rpm indicator.

[89](a) Category I is the highest category of EPIRB. The EPIRB automatically activates and is detectable by satellite anywhere in the world. Category II EPIRBs are similar but must be manually activated. (b) A hydrostatic release automatically activates as a result of water pressure when submerged up to 4 meters (13 feet).

- Autopilot for steering system.
- Echo (depth) sounder.

According to a former second mate, the vessel had two GPS receivers aboard, used for navigation and entering waypoints. The receivers could obtain differential GPS signals, which improve location accuracy. *El Faro* used paper charts for navigation to meet SOLAS carriage requirements.

1.3.12 Wind Sensors and Barometers

According to Imtec Marine records, *El Faro* carried two R. M. Young model 05106 (marine model) wind monitors and two Young model 06206 Wind Tracker display units, both installed before 2009. No records for maintenance or replacement of the wind observation equipment were found.

The wind monitors, with individual sensors for both wind speed and direction, were attached to separate steel poles installed on the deck above the bridge about 100 feet above the waterline. The display units were mounted on a bulkhead inside the bridge, beside and above the port side of the chart table (refer to figure 4, section 1.2). According to records, the sensors transmitted wind speed and direction data to the VDR when it was tested in 2014.[90]

The vessel's anemometer displayed wind data on the bridge. Wind speed and direction were recorded by the VDR.[91] Figure 18 shows raw wind speed data captured by the VDR from 2000 on September 30 until the sinking. Throughout the VDR recording, however, over 99 percent of the anemometer data samples indicated a relative wind direction of between 180° and 193°. On the VDR recording, *El Faro*'s captain, chief mate, and second mate questioned the reliability of the wind speed and stated that the wind direction was "not good" and that "we don't have (any) anemometer."

According to National Weather Service records, *El Faro* carried a Belfort aneroid barometer and a DBX1 digital barometer/barograph. The aneroid barometer was installed on April 8, 2011, and was last adjusted on March 24, 2015, to reflect mean sea level pressure. The National Weather Service estimated that it would have been calibrated when it was installed. The digital barometer/barograph was installed and adjusted on October 7, 2014, and, according to internal records, was calibrated on January 1, 2014. The instrument could display up to 5 days of information (tendency, high/low pressure, and 6- and 12-hour pressure change), but the information could not be printed or otherwise recorded.

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[90] Sperry Marine annual performance test, December 2, 2014.

[91] *El Faro* was not required to carry an anemometer under SOLAS 74. However, the company's operations manual required vessel personnel to follow the safety guidelines of the *ICS* [*International Chamber of Shipping*] *Guide to Helicopter/Ship Operations*. Section 3.7.1 to the guide states that "vessels should be fitted with equipment that can measure and record all wind conditions."

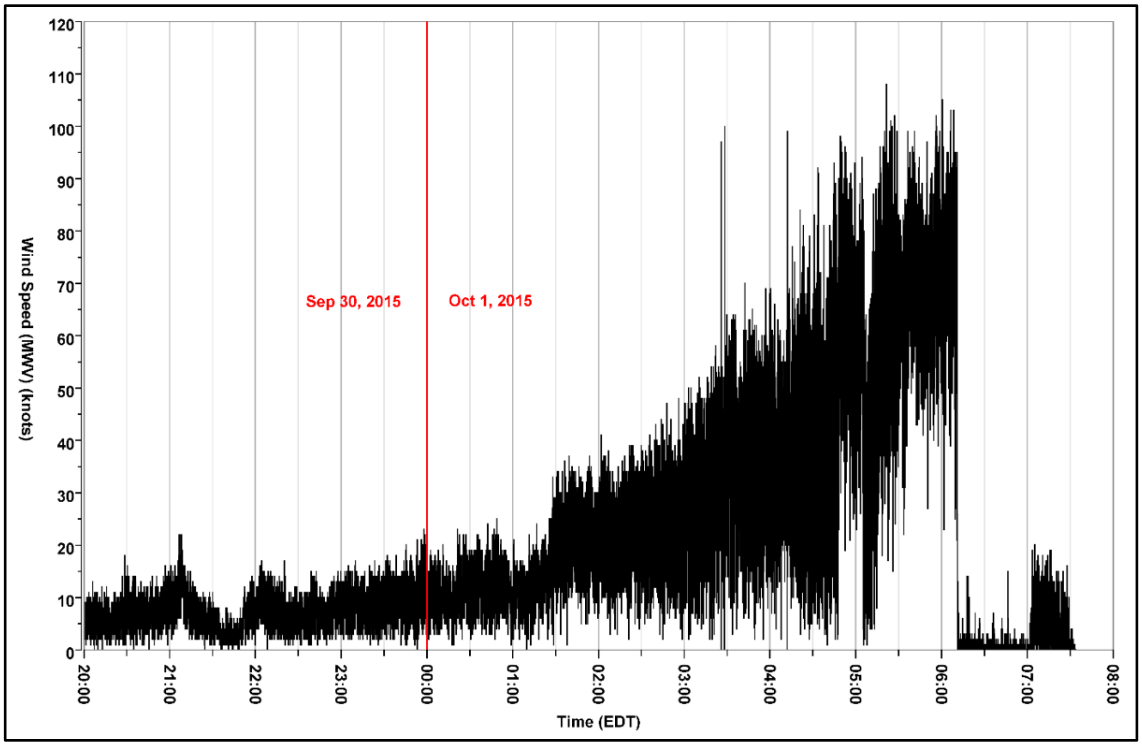

Figure 18. Raw VDR wind speed data, from 2000 September 30 to data loss.

1.3.13 Internal Communication

El Faro had four primary means of internal communication that could carry two-way conversations: dial (electric) telephone, sound-powered telephone, public address or talk-back system, and portable walkie-talkies.[92] None of these devices were connected to the VDR. Electric telephones, also called house phones, were located at fixed locations on the ship, including the bridge and the engine room. The sound-powered telephone was the only system that worked without an external power source or battery. Walkie-talkies were the primary means of communicating with personnel while they moved about the ship. The main control for the vessel's talk-back system was on the bridge. Satellite or remote units were located at the bridge wings, engine room, lifeboat stations, forward and aft mooring stations, crew dining room, crew lounge, officers' lounge, and officers' dining room. The system was similar to an intercom and could be operated hands-free.

As required by SOLAS, the vessel also had a class-approved general alarm system, whistle, and watch call system, used to wake bridge watchstanders. The systems could be used to send one-way signals to the crew during emergencies.

Several computers on the ship had access to the ship's email system. Crewmembers could use the computers to send emails both internally and externally.

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[92] A *sound-powered telephone* is a shipboard telephone system in which the power comes from the sound pressure of the speaker's voice and requires no external power source.

1.4 Cargo Information

El Faro's container capacity was 1,414 twenty-foot-equivalent units (TEUs).[93] Its maximum capacity for automobiles was 733 and for Ro/Ro trailers, 216. As required by SOLAS 1974, as amended, and the Code of Safe Practice for Cargo Stowage and Securing (CSS code), the cargo on *El Faro* was loaded, stowed, and secured in accordance with an approved cargo-securing manual.[94] The international requirements for cargo-securing manuals are incorporated in Coast Guard regulations at 33 *CFR* 97.120. *El Faro*'s manual was developed by Herbert Engineering Corporation and approved by ABS on January 20, 2006.

1.4.1 Loading

Portus Stevedoring was contracted to plan the stowage, loading and unloading, and securing of *El Faro*'s cargo. Portus developed a prestow plan showing where projected cargo would be placed and discussed the plan with TOTE managers, making adjustments as necessary. When the vessel arrived alongside and cargo work began, incoming container (load-on/load-off) and Ro/Ro cargo was driven onto a certified scale and weighed. A computerized cargo-loading and stowage program called Spinnaker accounted for which part of the weighed load would remain stowed on the ship. For containers, that was only the container and cargo weight, while for Ro/Ro cargo trailers, that would also include the weight of the chassis. Spinnaker detailed individual locations and weights for each container, while a Portus superintendent or planner would develop a handwritten stow plan for Ro/Ro cargo items, broken into "trailers," "autos," and "other." The final combined Spinnaker and Ro/Ro stow plans constituted the actual or final stow plan.

As loading of the cargo areas progressed, Portus gave stow plans to the TOTE marine operations manager, or in his absence, the terminal manager (as for the accident voyage). They reviewed the plan for discrepancies (including hazardous segregation, stack weights, lashing margins, the availability of power plugs for the reefers, or mismatched bays and container sizes) and would enter the cargo weights and positions into the CargoMax computer program throughout the loading process. CargoMax is a software application developed by Herbert–ABS Software Solutions, LLC. According to the developer, the program "quickly and precisely calculates ship stability and stress characteristics based on any loading condition specified by the user."

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[93] The 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).

[94] SOLAS 1974, chapter VI, part A, regulation 5.6, and CSS code, section 1.6. The original code was adopted by the IMO in 1991. IMO's Maritime Safety Committee issued subsequent guidelines (termed *circulars*) that amended the CSS code. The 2003 edition of the CSS code incorporated earlier circulars and was in effect when *El Faro*'s cargo-securing manual was submitted for review in 2005. The stated purpose of the CSS code was to "provide an international standard to promote the safe stowage and securing of cargoes by: drawing the attention of shipowners and ship operators to the need to ensure that the ship is suitable for its intended purpose; providing advice to ensure that the ship is equipped with proper cargo securing means; providing general advice concerning the proper stowage and securing of cargoes to minimize the risks to the ship and personnel; providing specific advice on those cargoes which are known to create difficulties and hazards with regard to their stowage and securing; advising on actions which may be taken in heavy sea conditions; and advising on actions which may be taken to remedy the effects of cargo shifting."

CargoMax stability and load management software would calculate the vessel's list, trim, drafts, and stability.[95] The container buildout section of the CargoMax software also determined whether container lashing arrangements and stack weights complied with the cargo-securing manual.[96] The program was not designed to calculate the sufficiency of lashing arrangements for any of the Ro/Ro cargo.

To determine the density of the seawater, the vessel crew would measure the specific gravity of the water at the dock with a hydrometer and report the value to the bridge.[97] They would also read and record the vessel drafts.[98] CargoMax stability calculations would be checked by the chief mate about an hour before sailing when he met with the operations manager, who delivered to him a thumb drive containing the completed CargoMax file on the vessel's departure loading condition. The review would incorporate the measured specific gravity of the water to calculate the vessel's draft. The chief mate would compare the CargoMax trim and stability summary with the recorded drafts. Final loading and deadweight (amount of mass carried, including cargo, fuel, ballast, crew, provisions, and water) would then be determined. Portus longshoremen would work with the vessel's deck officers (mainly the chief mate) to ensure that there were no stowage or securing problems.

Cargo containers were stacked in tiers in 20 bays on the main deck, numbered forward to aft. The vessel carried containers in 20-, 40-, 45-, 48-, and 53-foot lengths, as shown in figure 19. No tier was stacked more than three containers high on southbound trips to San Juan.

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[95] Under SOLAS, the International Code on Intact Stability, ABS, and Coast Guard regulations, CargoMax software and the computer in which it resided were considered a shipboard "stability instrument" or an "onboard electronic stability computer." According to the intact stability code, a stability instrument should have flag approval. The CargoMax software was approved by ABS, for stability portions of the program, on behalf of the Coast Guard. The software version being used on *El Faro* during the accident voyage had not been submitted to ABS for review after minor updates to interface features that did not affect stability calculations. Computations in CargoMax were predicated on calculations used in the vessel's class-approved trim and stability booklet (see section 1.12.4) The CargoMax program used ashore did not require approval by a classification society.

[96] The container buildout section of CargoMax was not required to have class approval.

[97] The density of the water affects the volume of water a ship displaces (displacement). Because seawater is denser than freshwater, a ship rides higher in seawater.

[98] "Reading the drafts" entailed looking at the side of the vessel and observing the water level as measured by markings on the hull.

Figure 19. Cargo stowage arrangement and capacity plan. (Illustration from *El Faro* cargo-securing manual)

1.4.2 Types

Containers were considered standardized cargo. Forty-foot Ro/Ro trailers (whether commercial, over-the-road trailers equipped with wheels or containers secured to wheeled, 40-foot frames called flatracks) and automobiles were considered semistandardized cargo. All other cargo units were considered nonstandarized. The containers and trailers carried goods commonly found in stores, homes, and factories. Some containers and trailers were refrigerated and generally carried food that needed to be chilled or frozen. Most of the refrigerated containers and trailers were monitored by the WAM system, which sent operational information about the containers and trailers to the shippers on shore (by means of cell phone towers and signals).

El Faro's cargo manifest listed all the cargo in the containers and trailers and all other cargoes stowed aboard the vessel such as (but not limited to) automobiles, backhoes, and boats on trailers.[99] Besides containers and Ro/Ro cargo, *El Faro* also carried liquid fructose, kept in six fixed, railroad-car-size storage tanks in the two forward lower holds. Any cargo considered

[99] The *cargo manifest* is a document that lists information about a ship's cargo such as bills of lading, quantities, package units, consignees, consignors, shippers, and weights.

dangerous (as defined by US regulations) was listed on the vessel's dangerous cargo manifest.[100] In his departure report, the captain detailed the cargo as follows: 238 electric reefers, 118 trailers, 149 autos, 15 not-in-container cargo, 391 containers, and 4 fructose tanks. He listed the total tonnage as 11,045.9 long tons. The captain also recorded 345 long tons of (potable) water aboard.

1.4.3 Securing

El Faro had two cargo-securing systems, one for containerized cargo and one for Ro/Ro cargo. Each system had cargo-securing devices that were either fixed or portable. The fixed securing devices were permanently welded to the decks or bulkheads. The portable devices could be shifted from one cargo unit to another and were used for lashing, securing, or supporting the cargo units.

Fixed deck sockets were used to secure the bottom tier of containers to the ship. Portable securing devices (twistlocks) attached the bottom tier to the deck sockets at each corner of a container. The container on the second tier was secured to the top of the bottom container using another set of twistlocks attached to the four corners of the container on the second tier. The third container tier was then secured to the top of the second container tier with another set of four twistlocks installed at the corners of the two containers. Each stack could be further secured using lashing rods and turnbuckles attached to pad eyes, which were welded to the deck or to securing beams on the deck.

Semistandardized Ro/Ro cargo such as 40-foot trailers and autos was secured to the vessel using two types of securing arrangements. The first was a portable securing device called a Roloc box. The kingpin at the front end of a trailer fit into a locking receiver on top of the Roloc box (figure 20). According to the cargo-securing manual, the Roloc box would then be attached to a fixed securing device on the deck of the ship called a Roloc deck socket or button.

The second method of securing a trailer to the deck of the ship was by using portable securing devices (chains and tensioners) leading from a securing point on the trailer to fixed securing devices on the deck. The chain and tensioner unit was called a lashing, and the combined lashing and fixed securing device was called a lashing arrangement. Fixed securing devices on the deck of the ship were either D-rings or cloverleafs cut through the deck.

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[100] Regulations for the carriage of bulk materials that require special handling are found at 46 *CFR* Part 148 and 49 *CFR* subtitle B, chapter I, subchapter C, Part 172, subpart B (which includes a table of hazardous materials).

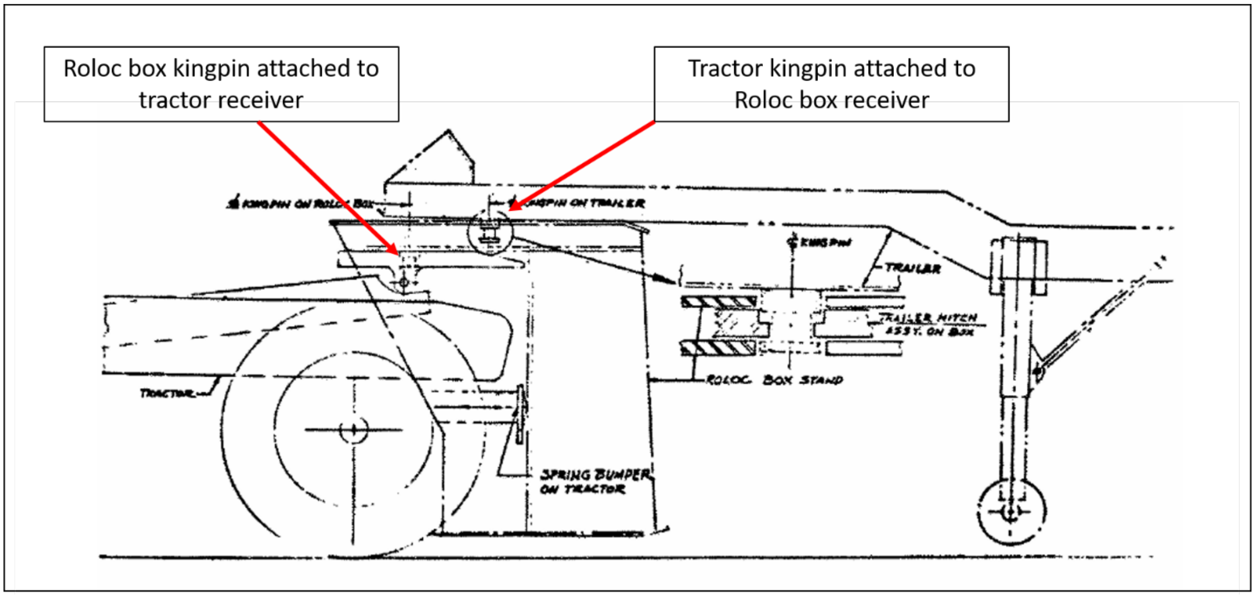

Figure 20. Roloc box diagram showing kingpin of trailer fitted into receiver of Roloc and kingpin of Roloc fitted into receiver of tractor. (Illustration from *El Faro* cargo-securing manual)

Automobiles, considered semistandardized cargo, were to be lashed using portable securing devices consisting of fiber rope or nylon strapping attached to steel tensioners that were fitted with hooks at both ends. Four lashings were to be run, one from each corner of a vehicle, to the fixed D-rings or cloverleafs on the deck (figure 21). A variation of that securing arrangement, not included in the cargo-securing manual, was to run lashings from the four corners of the automobile to a long chain. The long chain ran across the width of the ship and was secured to D-rings at either end. Some of the chains passed through a D-ring before being secured to additional D-rings at each end. A lashing variation observed on *El Yunque* in October 2015 is shown in figure 22**.** One of the longshoremen who had lashed the automobiles on *El Faro* before the accident voyage testified when shown a photo of the lashings on *El Yunque* that they had used that arrangement on *El Faro*.

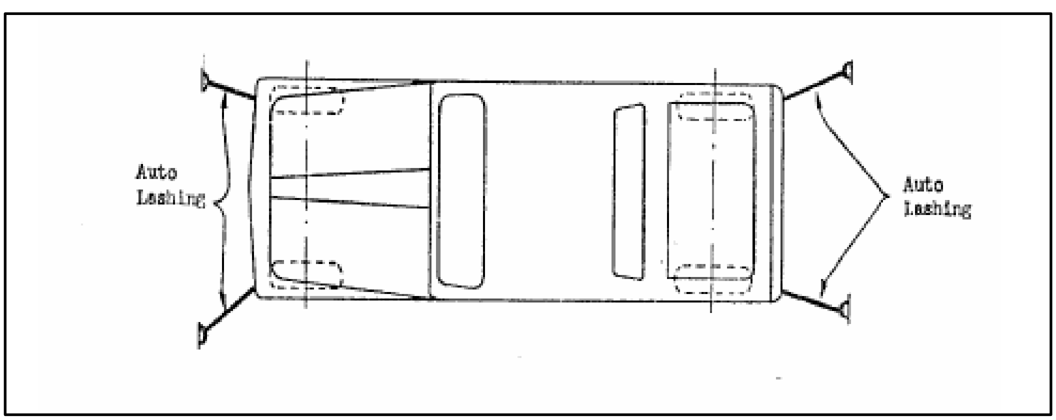

Figure 21. Automobile-lashing arrangement specified for *El Faro.* (Illustration from *El Faro* cargo-securing manual)

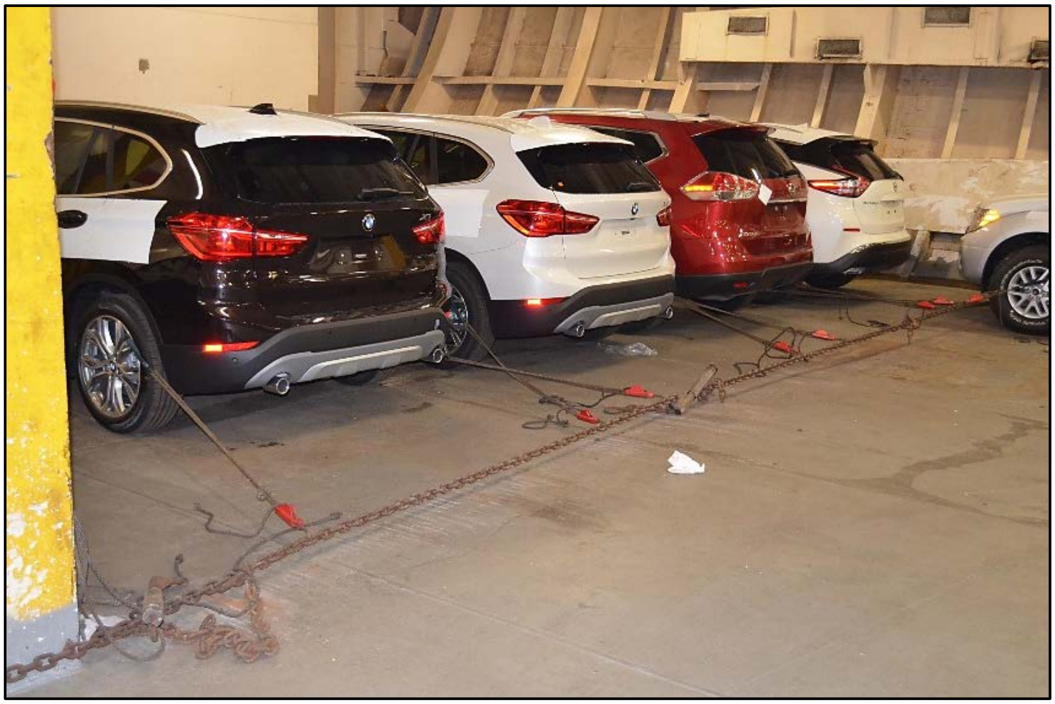

Figure 22. Two automobiles lashed to one length of chain. (Photo from hold 5 of *El Yunque*)

TOTE personnel testified during the first marine board hearing that longshoremen placed extra lashings they referred to as "hurricane" lashings or "bad weather" lashings on *El Faro*'s Ro/Ro cargo during the port call before the accident. The vessel supervisor for that voyage stated that this hurricane-lashing profile was used year-round for *Ponce*-class vessels beginning in 2006. The profile called for (1) Ro/Ro trailers with Roloc boxes not secured on a button to receive six chain lashings instead of the two chains used for an "on-button" stow; (2) the two rows of Ro/Ro cargo along the perimeter, if on Roloc boxes and the boxes on-button, to be lashed with four lashings instead of two; and (3) all Ro/Ro trailers on Roloc boxes, forward of hold B and aft of hold D and regardless of deck, to receive four chains instead of two.

Four past captains on the *Ponce*-class vessels stated that they were unaware of or did not recall whether the vessels were lashed according to a storm or hurricane profile year-round. They said that if ship personnel requested it, longshoremen would add more lashings. The VDR recorded the chief mate saying to the captain that lashings were not done correctly on the Roloc boxes and that "they don't do it [the lashing] the way it oughta be done." The third mate on *El Faro* stated, and the AB on the 0800–1200 watch agreed, that they "didn't ask the longshoremen for storm lashes, which we should have."

Shoreside personnel who normally interfaced with the deck officers on the accident voyage stated that no cargo stowage or lashing concerns were brought to their attention by the crew. The crew (ratings) in the deck department did not ordinarily check to see if cargo lashings were secure at sea. According to a previous *El Faro* boatswain, the second mate would check the lashings and if "we rocked a little more than normal" and lashings were loose, he and the crew would help the mate tighten them.

Appendixes to the vessel's cargo-securing manual listed the quantities of securing devices carried aboard. The manual required the securing devices to be inventoried every 2 months. The last *El Faro* lashing gear inventory provided to investigators was for April 24, 2015.

1.4.4 National Cargo Bureau Review

Investigators noted no VDR conversations alluding to a significant failure of container or Ro/Ro securing arrangements, with the exception of the automobiles in hold 3. After the accident, the NTSB asked the National Cargo Bureau (NCB) to review the sufficiency of *El Faro*'s cargo-securing manual and the sufficiency of cargo securement against the IMO's CSS code for certain cargo carried on the accident voyage. According to the NCB, parts of the manual generally complied with the CSS code. The NCB went on to say that other sections contained errors and omissions or were lacking information but that those issues should not have contributed to the accident. The cargo in question included all containers on the main deck, all high or heavy Ro/Ro cargo, all cargo on the second deck, all cargo stowed athwartship, and all automobiles stowed in the lower hold 3 (cargo area 4D). The NCB issued a report, TOTE responded, and the NCB replied with a supplemental report.[101] The NCB was also asked to compute the failure point for the lashings of the suspect cargo but stated that it could not.

The NCB stated in its first report, regarding the Ro/Ro cargo on the second deck, "In the event of any lashing failure in the presence of continued significant vessel movement, primarily rolling, progressive lashing failure with potentially catastrophic shift of cargo could be expected." Appendix 3 of the report showed that at a vessel speed through the water of 24 knots and 60° lashing angles, off-button trailers stowed in the "worst positions" of holds 2A, 2B, and 2C, "will not be effectively secured in this hold." The NCB's supplemental report listed the maximum off-button trailer weights in hold 2A that would meet requirements at a vessel speed through the water of between 19 and 24.5 knots and at lashing angles of 45° and 60° and the angles prescribed in *El Faro*'s heavy-weather lashing requirements (58°, 52°, and 46°). 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.

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.[102] Appendix 3 of the report identified off-button trailers that were "not OK" with regard to transverse sliding moments and forces. The NCB's supplemental report noted that for an off-button Roloc box, the coefficient of friction between two dry steel surfaces 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.

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[101] The NCB reports and TOTE's response are found in the accident docket.

[102] The *coefficient of friction* is the ratio between the force necessary to move one surface horizontally over another and the pressure between the two surfaces. Loss or reduction of friction generally occurs when decks are wet. Investigators noted that the VDR recorded conversations consistent with the second deck taking on water shortly after 0200 on October 1 and that water was in hold 3 around 0543.

To increase the friction component of system lashing strength, the current version of the CSS code 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 asked the NCB to calculate the off-button maximum trailer weights (for avoiding cargo shift) for a hypothetical arrangement in which a rubber mat or other friction-increasing material was placed between a Roloc box and the steel deck, keeping other parameters and lashing angles the same.

The NCB determined the maximum allowable trailer weight for hold 2A at a vessel speed of 19.5 knots. The calculations 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. The results varied by lashing angle, but the maximum weights were always higher assuming that friction-increasing material was placed between a Roloc box and the steel deck. For a lashing angle of 45°, the maximum off-button trailer weight with a rubber mat placed between the Roloc box and the steel deck was 122,295 pounds, compared with a maximum of 74,031 pounds for a Roloc box placed directly on a dry deck and 60,836 pounds for one placed directly on a wet deck.

1.4.5 Modeling

Later, using finite element modeling, the NTSB examined *El Faro*’s cargo-securing arrangements (and possible failure points) on the accident voyage.[103] The study used as inputs accelerations corresponding to times along the vessel’s route derived from simulated ship motions obtained through a dynamic study carried out by the company CSRA Inc. under NTSB contract (see section 1.12.11). The ship motions at 0345 on October 1, with the vessel moving about a fixed 9° heel, were chosen because they showed the highest peak accelerations before the vessel lost propulsion. Ro/Ro and container cargo that the NCB stated could have exceeded weight limitations of the securing arrangement were studied using finite element models. A Nissan Rogue automobile model was used to evaluate automobile securement because of its relatively high weight and because the ship’s stowage plan showed that a row of five such vehicles was aboard *El Faro*.

The NTSB used a conservative approach in modeling securing arrangements for the Ro/Ro and container cargo. Optimum securing angles were used for the lashings, and minimum breaking strengths of the securing devices were assumed to be as listed in the cargo-securing manual.[104] A conservative approach to the securement of automobiles was also used, assessing a two-car unit rather than the five-car unit investigators observed on *El Yunque.* Under the conditions assumed for the calculations, the finite element modeling study found the following:

[103] *Finite element modeling* is a method of solving engineering problems by dividing a complex structure into an assembly of simplified structural elements. The behavior of the complex structure is then solved by combining in a computer the actions of all the interconnected simpler elements.

[104] Investigators noted that TOTE did not record the results of inspections of fixed securing devices or which ones were inspected. There was no regulatory requirement to test any of the fixed securing devices, and there were no records of what fixed securing devices were actually replaced from new-build or when the vessel was lengthened. Investigators also noted that the buttons were tested for wear before 2014, but that practice was discontinued.

(1) No containerized cargo would have broken free if twistlocks had operated properly.
(2) Ro/Ro trailers on the second deck would have broken free if they were stowed off-button, lashed with six chains, and tire friction was lost.
(3) Automobile lashings in hold 3 would have failed if the coefficient of friction between the automobile tires and the steel deck was between 0.1 and 0.2 (or less than accepted marine values for a tire on a dry steel deck of 0.3).[105] Because of the conservative approach used, the lashings were probably at risk for failing even at higher coefficients of friction between the tires and the deck. The study also found that lashing individual automobiles to fixed securing devices on the deck, such as D-rings, rather than lashing several cars to chains laid athwartships as on the accident voyage, would have substantially lowered their risk of failing.

1.5 Safety Management System

Chapter IX of SOLAS incorporates the International Safety Management Code (ISM code), which went into force in July 1998. Under Coast Guard regulations at 33 *CFR* 96.210, US vessels on international voyages, including cargo ships, are required to operate under a safety management system (SMS). *El Faro* was required to meet the requirements because it was enrolled in the Coast Guard's ACP.

An SMS defines the roles and responsibilities of all personnel, outlines safe practices in ship operation and navigation, and establishes safeguards against certain identified risks. The captain of *El Faro* was responsible for implementing the SMS on board, for motivating the crew in the observation of that policy, and for verifying that applicable procedures and requirements were adhered to. In accordance with the ISM code, the captain was also responsible for periodically reviewing the SMS for areas of improvement and for reporting deficiencies to shore-based management.

A copy of the SMS documents was to be provided in a working language or a language understood by ship's personnel. The primary documents comprising TOTE's SMS, called the safety, quality, and environmental management system, were the operations manual–vessel (OMV) and the emergency preparedness manual–vessel (EPMV). Both documents were kept in electronic form on *El Faro*.

Investigators reviewed TOTE's SMS and found no risk assessments for voyage planning or heavy-weather operations. According to section 1.2.2.2 of the ISM code, a safety management objective of a company should be to assess all identified risks to its ships, personnel, and the environment and establish appropriate safeguards.

The OMV defined the duties of the ship's personnel (see section 1.8, "Personnel Information") and also laid out shipboard policies and procedures. Internal SMS audits were required at least every 12 months, to be completed by the DP. Aboard *El Faro*, external audits

[105] The model considered friction coefficient values ranging from 0.0 to 0.3. The 0.3 value is specified in annex 13 of the CSS code as the friction between steel and rubber (deck and tires) and is used in the code's assessment of lashings against the criteria. The CSS code specifies 0.1 for steel-to-steel on a dry surface and a lower value of 0.0 for steel-to-steel on a wet surface. However, the code does not have a value for steel-to-rubber with a wet surface. The NTSB could not find the value specified for tires on wet steel and estimated the value as between 0.0 and 0.1.

were conducted by ABS. The captain of *El Faro* was required to report to management biannually regarding SMS/ISM compliance. He submitted his latest review on June 30, 2015.

The DP stated that it usually took 5 to 6 hours to complete an internal audit. He completed the most recent *El Faro* audit on March 3, 2015. He stated that the SMS appeared to be well implemented on the ship and that records and logbooks, as well as required manuals, met company inspection criteria. No requests for corrective action or nonconformities were reported.

The company's SMS required regular monthly safety/security meetings to be held on the ship and meeting minutes to be submitted monthly by the captain. His latest submission was dated September 24, 2015.

1.6 Injuries

All 33 persons on board *El Faro* perished in the sinking (table 1). The body of one crewmember, inside a protective immersion suit, was discovered during the search-and-rescue operation after the accident but was not recovered. See section 1.11.1, "Emergency Response," for details.

Table 1. Injuries sustained in *El Faro* accident.

Type of Injury	Crew	Supernumeraries	Total
Fatal	27	6	33
Serious	0	0	0
Minor	0	0	0
None	0	0	0
Total	27	6	33

1.7 Wreckage

The wreckage of *El Faro* lies at a depth of between 15,318 and 15,482 feet (4,719 to 4,669 meters) in the Atlantic Ocean, about 20 nm northeast of Samana Cay. The primary underwater debris field, which includes the main hull and ship structure, covers an area of about 0.7 square mile (1.8 square kilometers) between latitudes 23.3786N and 23.3936N and longitudes 73.9061W and 73.9172W. Cargo containers, other cargo items, and some ship's equipment and rails were found outside the primary debris field. Inside the primary field were 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 separated from it, including the mast (with attached VDR), the exhaust stack, the bridge and the deck below it; and a few unidentified items. Figure 23 is a bathymetric (topographic) map of the seafloor showing the location of the main objects discovered.

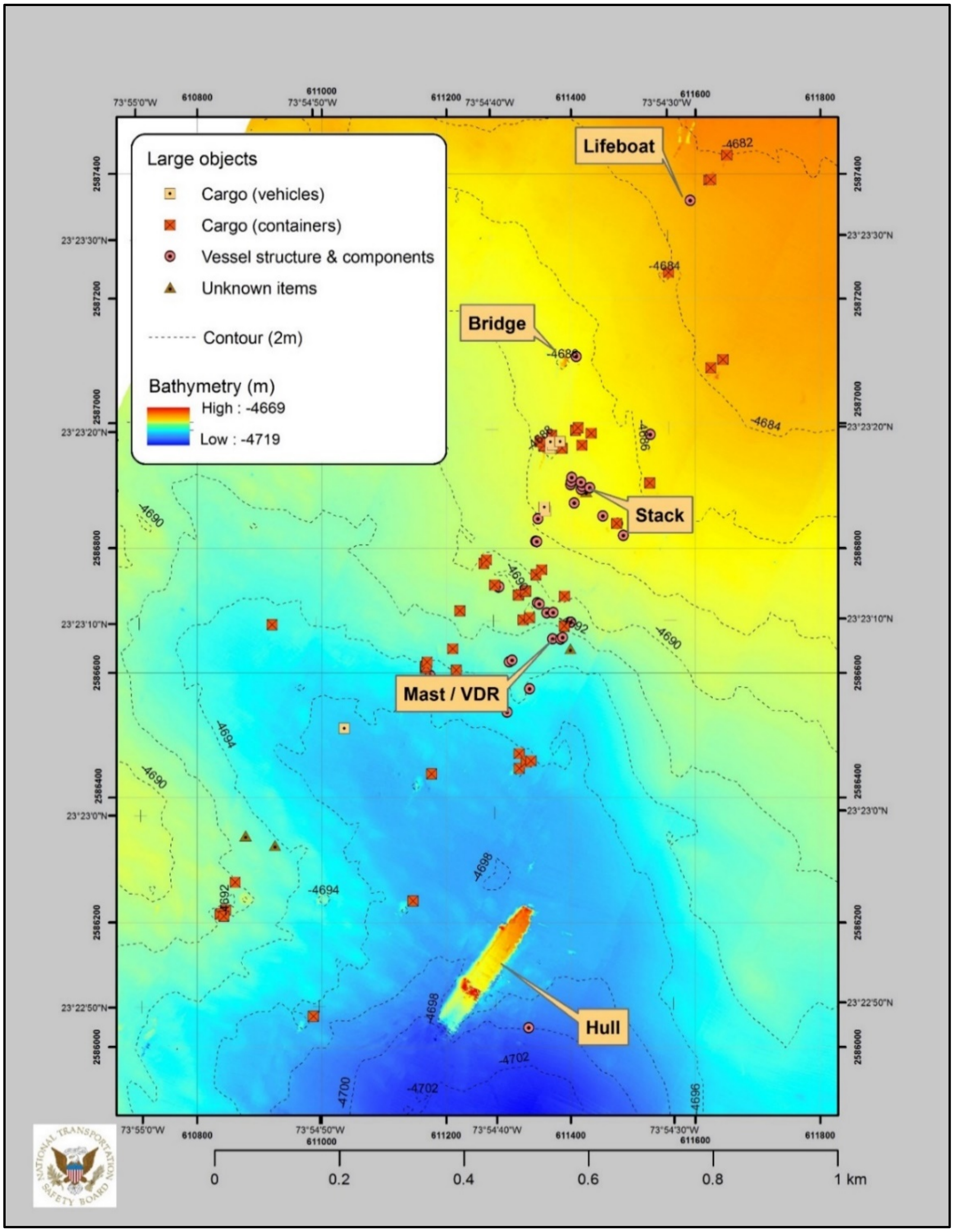

Figure 23. Map of *El Faro* debris field showing large objects. Bathymetry from multibeam-sonar site survey, April 2016.

The wreckage was investigated solely from photographs and video gathered during the three missions that searched for *El Faro* and recovered its VDR. The makeup of the seafloor where the wreckage lay appeared to be generally level and to consist of soft sand and mud. 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 about 14.5 feet (port) to 12.5 feet (starboard) into the seafloor at the bow and between 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 roughly 3 feet below the second deck on the starboard stern quarter, equivalent to about 47 feet in the mud from the vessel's keel (baseline).

Video taken by the CURV-21 ROV during the first underwater search (October 19 to November 24, 2015) documented that the top two decks of the deckhouse, the navigation bridge and the deck below it, had separated from the hull and were lying more than half a mile (3,166 feet) north of it. The top of the engine room casing was open to the sea, all but two containers had fallen off the main deck, and the ship's mast and VDR were missing. Data from the second mission (April 18 to May 5, 2016), launched to locate the VDR, were used to map and categorize debris in the wreckage field. Individual photos of some parts of the wreckage, taken by an underwater vehicle, were combined into photomosaics to create complete pictures. Images taken by CURV-21 during the third mission (August 5 to 12, 2016) documented structural damage to the hull and damaged or missing components.

During the second mission, *El Faro*'s port lifeboat was discovered north of the bridge, at a depth of 15,364 feet (figure 24). The lifeboat was 754 feet (0.12 nm) north-northeast of the bridge wreckage and about 4,101 feet (0.68 nm) north-northeast of the center of *El Faro*'s hull. The stern of the lifeboat was missing and was not discovered elsewhere.

The gravity davits (cranelike devices for lowering boats into the water) for the starboard lifeboat were discovered intact during the second mission (figure 25). 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 showed greater damage, with the aft track and davit broken and hanging (figure 26).

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 27 shows that all windows on the forward side of the bridge were missing; that the windscreen bulwark was bent forward; and that the top railings were missing, severely bent, or broken. The starboard forward corner of the wreckage had settled deeper into the seabed than the other corners.

El Faro's exhaust stack was discovered during the second mission about 2,625 feet (0.43 nm) north of the main hull (figure 28). It was largely intact, though the forward face was missing its steel plating and the stack was scratched, dented, and deflected inward. The boiler uptake funnel was missing from the top of the stack.

The tripod mast and VDR capsule were discovered on the seafloor about 1,640 feet (0.28 nm) north of the main hull (figure 29). The large structural members were intact, but the overall structure was bent aft. The VDR was attached to the port leg and buried in mud.

Figure 24. Photomosaic of *El Faro*'s port lifeboat from images taken during second search mission. Bench seats and other internals are missing. Reflective tape on top of gunwales is illuminated.

Figure 25. Intact gravity davits for starboard lifeboat, with forward davit in foreground. (Photomosaic image from mission 2)

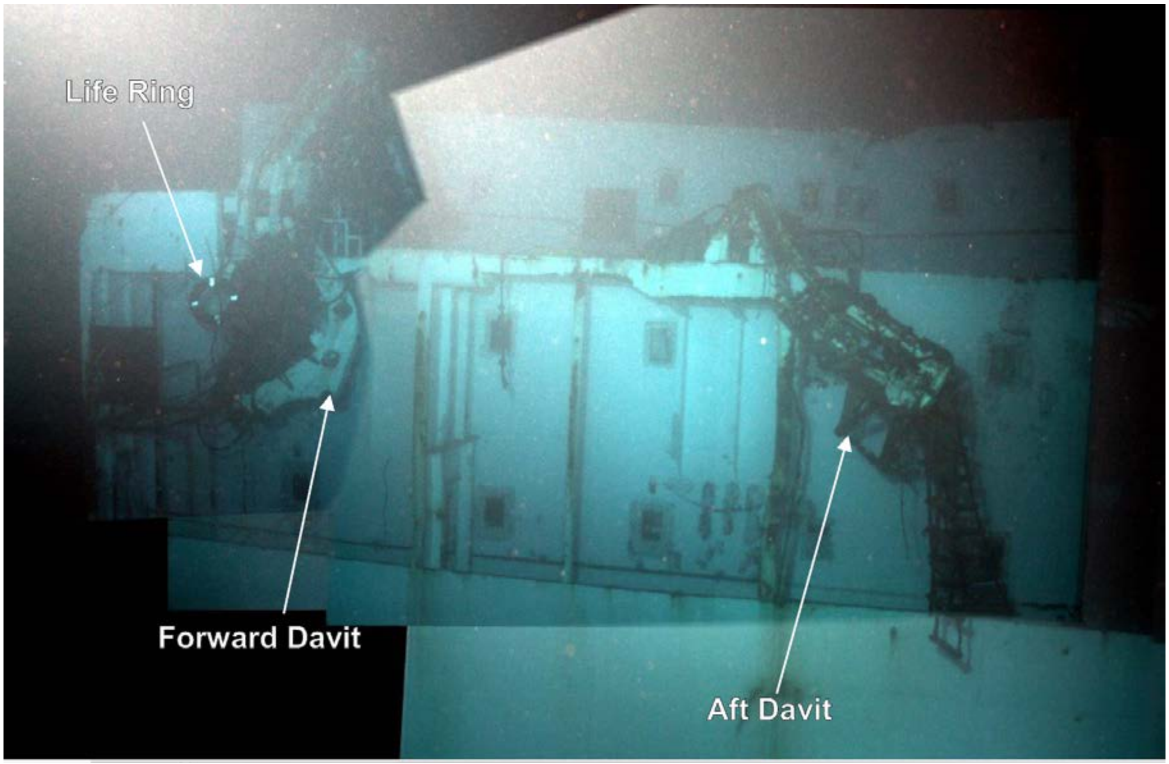

Figure 26. Gravity davits for port lifeboat, showing forward davit in place but damaged and aft davit broken and dangling. (Photomosaic image from mission 2)

Figure 27. Bridge and bridge deck, looking aft. (Photomosaic image from mission 2)

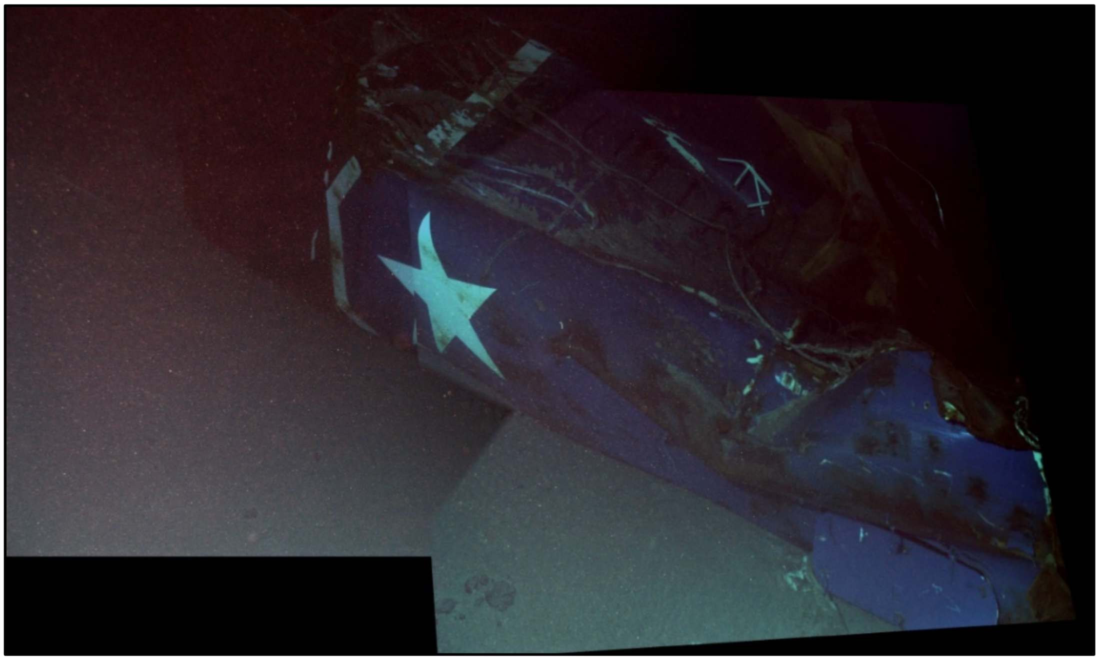

Figure 28. Exhaust stack lying on seafloor, Sea Star (company) symbol clearly visible. (Photomosaic image from mission 2)

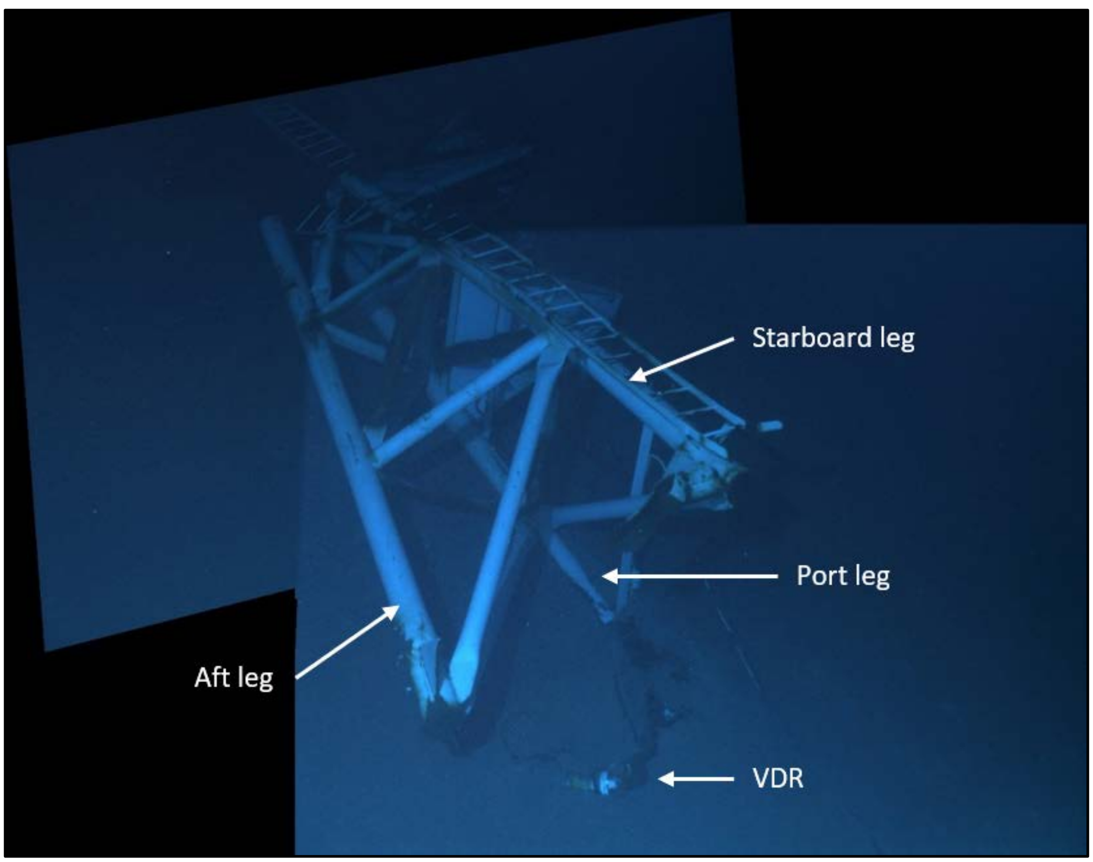

Figure 29. Mast and VDR capsule on seafloor. (Photomosaic image from mission 2)

As documented during mission 3, 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 extending from the mudline up to the main deck, estimated to be 3 feet wide at the main deck and extending across the deck to the ramp opening on the port side (figure 30).

Major damage and fractures were also observed at the stern, extending about 20 feet forward of the transom, which was torn open down to the second deck (figure 31). The main deck on the starboard side was severely buckled and inset (pushed in) 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 30. Hull fracture in starboard sideshell and across main deck at container bay 16, forward of frame 200. (Image from mission 3)

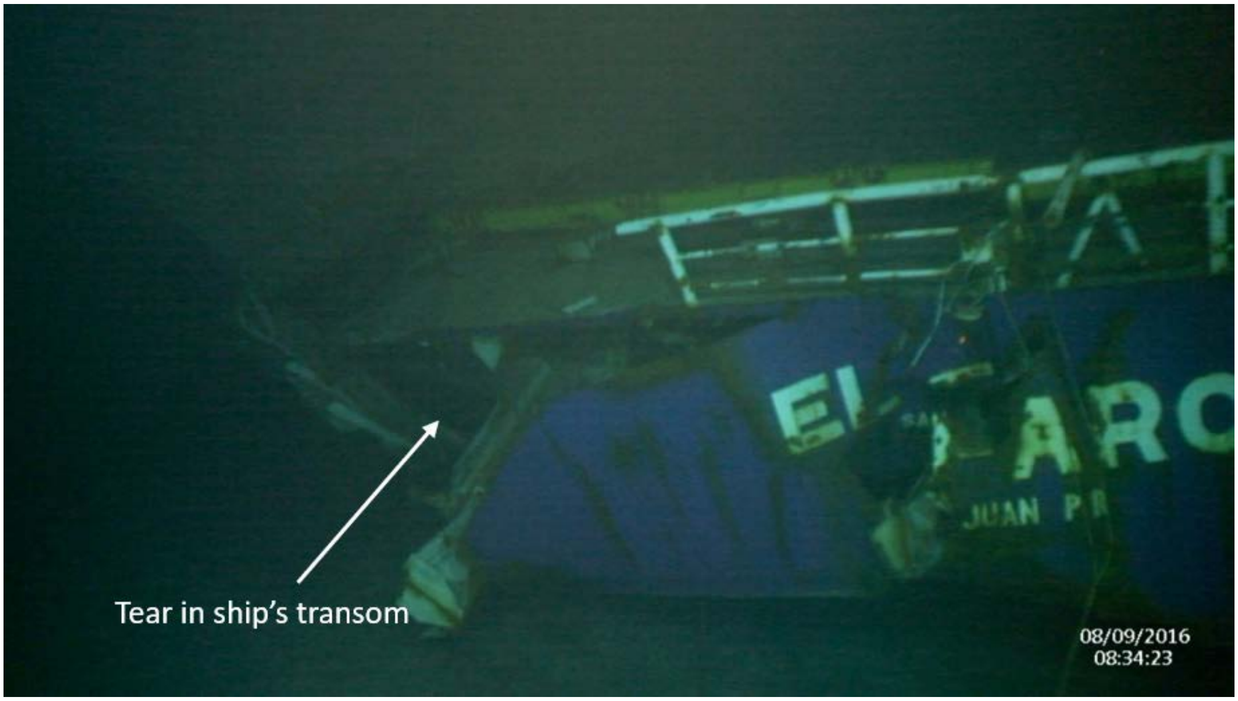

Figure 31. Tear in ship's transom. (Image from mission 3)

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. In the bow region, the foremast was toppled toward the port side (figure 32) and the bow plating inset. Hawsers (mooring lines) were observed streaming upward from the debris.

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 a vehicle opening near bay 15 on the starboard side (figure 33). 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 34). Metal flashing hanging over the deck on the port side (not shown) was determined to be part of the cargo.

The cargo mountings and transfer (support) beams were examined. The fiberglass deck grating was generally missing from the container support beams (figure 35). Undamaged container support beams were found forward of the deckhouse, however. Both twisted and intact transfer beams were found.

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 mounts. Fire hose and broken railings hung over parts of the starboard side. Two lifebuoys along the deck rails were missing from their mounts; one was found intact at the port bow (refer to figure 32). The vessel's 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 36).

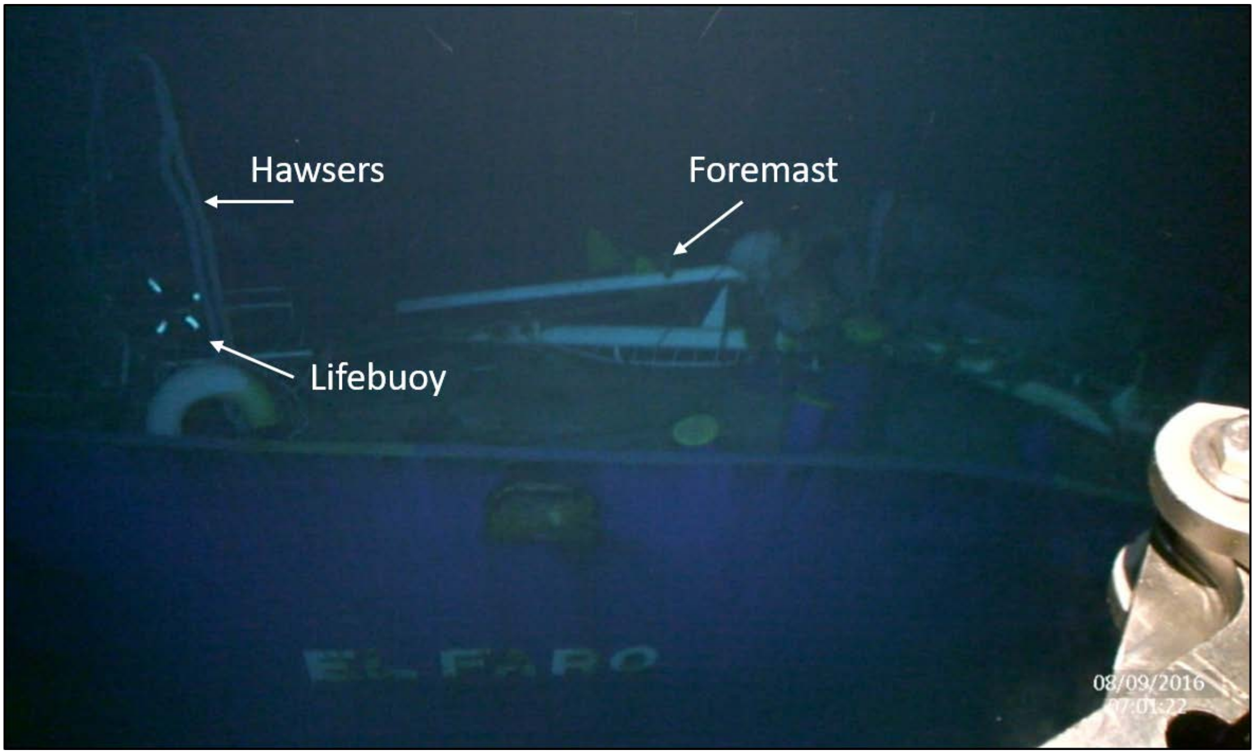

Figure 32. Foremast toppled on port side of bow; reflection is from lifebuoy on railing next to hawsers. (Image from mission 3)

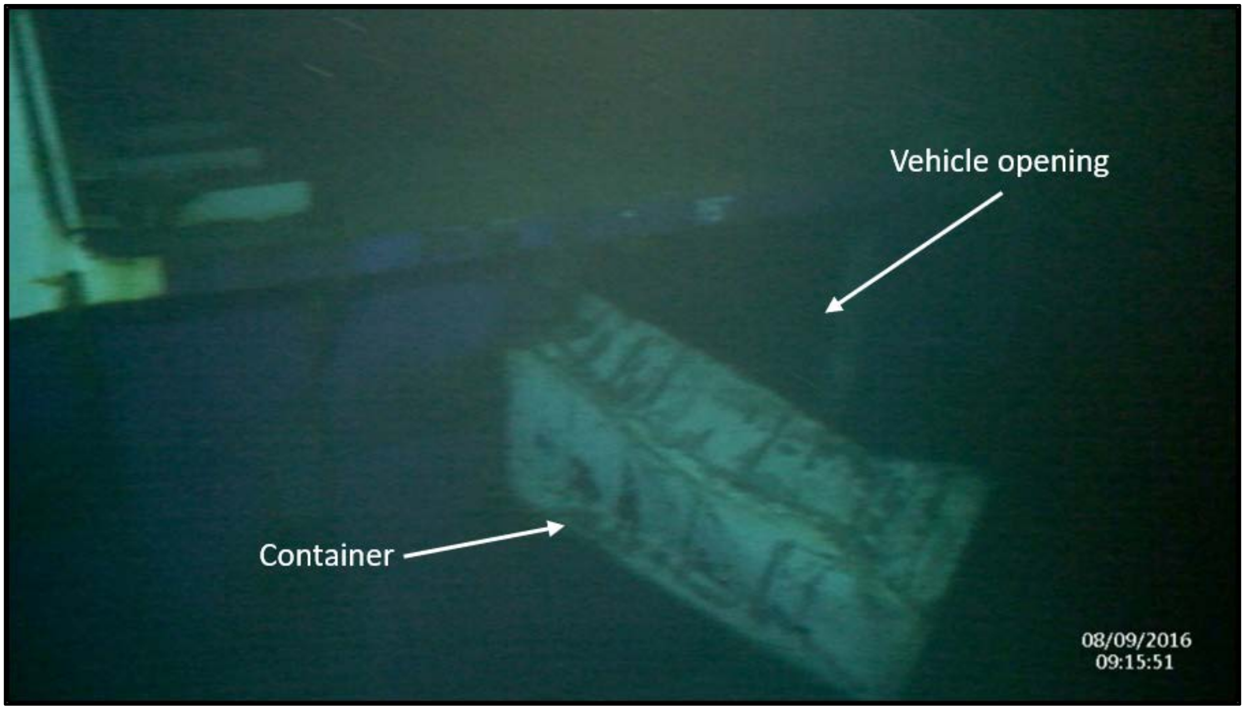

Figure 33. Container protruding through vehicle opening in bay 15, starboard side. (Image from mission 3)

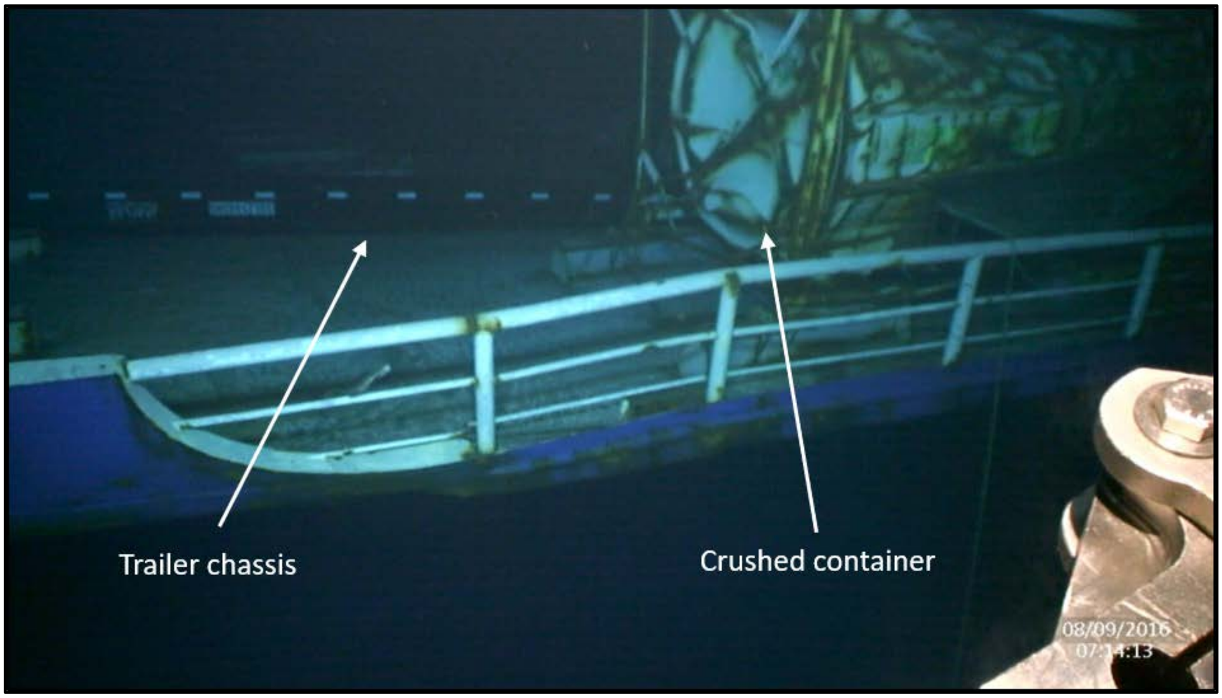

Figure 34. Crushed tank container in bay 2, starboard side. (Image from mission 3)

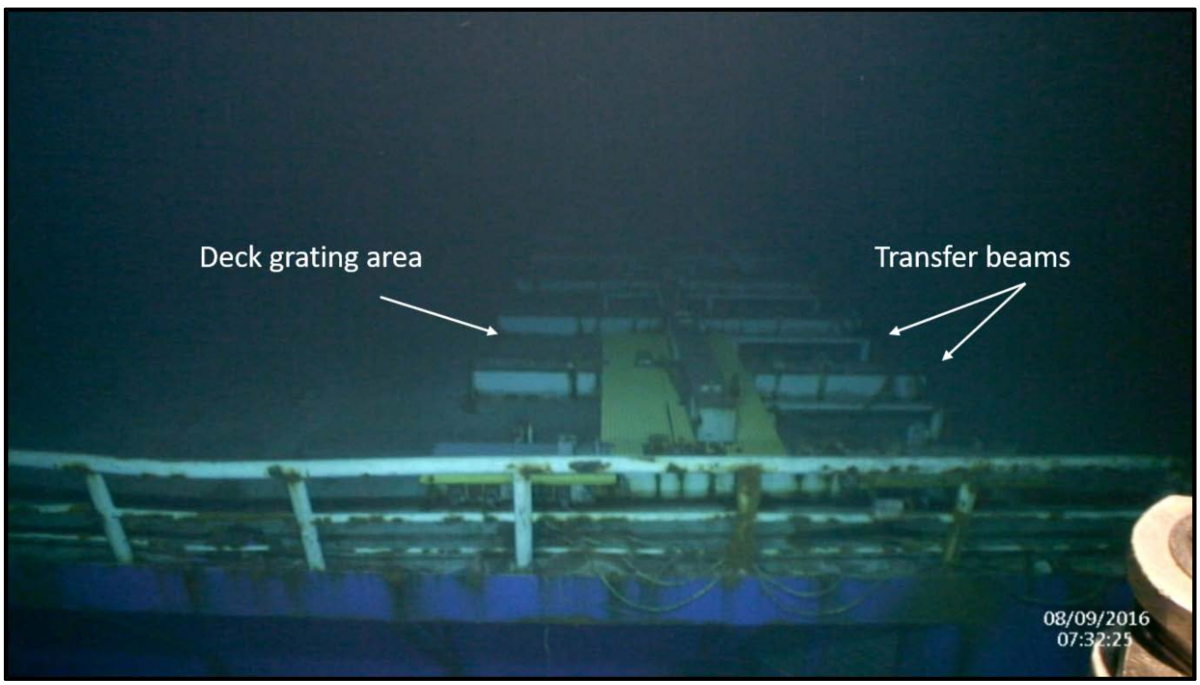

Figure 35. Fiberglass deck grating missing from container support beams, port side, with intact transfer beams. (Image from mission 3)

Figure 36. PFD entangled on boat deck walkway. (Image from mission 3)

1.8 Personnel Information

According to the vessel's COI, *El Faro* was required to be manned by a master, a chief mate, a second mate, a third mate, a chief engineer, a first assistant engineer/second engineer, a second assistant engineer/third engineer, a third assistant engineer, six ABs, and three oilers. An additional requirement was that the crew include five certified lifeboatmen and three GMDSS radio operators. The COI allowed 16 other crewmembers and 9 persons to be on board in addition to the crew, for a total of 42 persons. No passengers were permitted.

Along with the required crew, the following were on board during the accident voyage: two additional third assistant engineers, one boatswain ("bosun"), three general utility deck or engine crewmembers (GUDEs), one qualified member of the engine department, one reefer engineer, one steward/baker, one steward assistant, and one chief cook, in addition to the riding crew and their supervisor.[106]

The credentials of all *El Faro* crewmembers were issued under the provisions of the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978 (STCW Convention), as amended in 1995 and 2010.[107] The ship's officers were members of

[106] The *boatswain*, or *bosun*, is the highest ranking nonofficer in the deck department. He was counted as one of the required ABs on the accident voyage.

[107] Officers and other crewmembers are now issued merchant mariner credentials that take the place of licenses, certificates, and other documents. Mariners formerly referred to as licensed officers carry "officer endorsements" on their credentials. Mariners formerly referred to as unlicensed crewmembers (but who held merchant mariner documents) carry "rating endorsements" on their credentials.

the American Maritime Officers (AMO) union, and the rated crewmembers were members of the Seafarers International Union (SIU).

1.8.1 Deck Officers

Captain. The captain, age 53, graduated from Maine Maritime Academy in 1988. His latest merchant mariner credential was issued by the Coast Guard National Maritime Center on January 28, 2011, and was due to expire on January 28, 2016. The credential stated that under international capacities, the captain was endorsed as master with no limitations. Under national (US) capacities, he was endorsed as master of self-propelled vessels, not including auxiliary sail, of unlimited tonnage upon oceans; as radar observer (unlimited); and as first-class pilot of vessels of unlimited tonnage upon the inland waters of Prince William Sound, Alaska. He was an STCW-certified GMDSS radio operator and vessel security officer and was also endorsed for advanced oil tanker and chemical tanker operation.

Experience. The captain joined TOTE (then known as Interocean American Shipping) in 2005. According to his application letter to TOTE, after graduating from Maine Maritime Academy he worked on the West Coast (Alaska, Washington, and Oregon) for Atlantic Richfield from 1989 to 2000 and then for Polar Tankers until 2003. Among his duties was person-in-charge of oil transfers between ship and shore facilities. During 2004, he served as captain on the research vessel *Atlantic Explorer*, operated by the Bermuda Biological Station for Research (now the Bermuda Institute of Ocean Sciences), and then as chief mate for Sabine Shipping.

At TOTE, the captain served first as second mate, then as chief mate on the Ro/Ro car and truck carrier M/V *Patriot*, sailing between northern Europe and the US East Coast. From 2008 to 2013, he served as captain on the Ro/Ro car and truck carrier M/V *Courage*, operated by Interocean American Shipping until 2010. In 2013, the captain served one tour as third mate on the TOTE vessel SS *Pacific Tracker*, a tracking and telemetry ship, before joining *El Morro* as captain in July 2013. In May 2014, he became captain of *El Faro*. He began his last tour with *El Faro* on August 11, 2015.

Duties. The captain, also known as the ship's master, had overall command of the vessel and was ultimately responsible for its safe operation and navigation.[108] He was the company's shipboard representative, charged with ensuring that the vessel operated in accordance with the company's policies and objectives and with applicable law. All persons on board were under his authority. He was responsible for the oversight of the welfare and safety of the crew and maintained communication between personnel on shore and the vessel. He was responsible for ensuring that a proper voyage plan and deck logbook were kept, for monitoring the weather along the vessel's intended track, for maintaining the ship's stability, for seeing that required maintenance and requisitioning were done, and for making sure crewmembers performed their duties. He also had charge of the vessel's budget and payroll.

[108] As stated in *Minding the Helm*, "By tradition, admiralty law, and legal precedent, the master always remains in command and is ultimately responsible for the safe navigation of the vessel" (NRC 1994).

Performance. The captain's most recent performance evaluation was partially completed ("draft") on October 2, 2014. The port engineer scored the captain's performance as excellent in all categories except one (cooperation with technical manager), which he left blank. He commented that the captain "handles all aspects of the master's position with professionalism" and "handles a diversified and unpredictable crew quite well." The evaluation had not been signed, as required, by the technical manager, or by the captain. The form was not stamped by TOTE's crewing department for formal receipt, nor was it in the captain's personnel file originally provided to investigators. It was provided by TOTE management on request and was said to have been left out of the file inadvertently.

The captain's personnel file contained no documented issues and no evidence indicating that he lacked a set of skills or abilities that would bring his competency as a captain into question. However, the director of ship management and the crewing manager both expressed concern about his performance. In a May 2015 email, the crewing manager expressed "dwindling confidence" in the captain.[109] She told the marine board she felt there were "better candidates available for the Marlins" (the company's new ships, the *Isla Bella* and the *Perla del Caribe*).[110] She added that her dealings with the captain were "regarding crewing, and so I would not have judged his suitability as a master."

The director of ship management, in a July 2015 email to the company's vice president of marine operations, stated, "He's stateroom Captain, I'm not sure he knows what a deck looks like period. Least engaged of all four Captains in the deck operation." The director explained to the marine board that the captain "had a different style than I prefer as a Ship Manager. But he was a very effective captain." No letters of warning or reprimand were found in the captain's personnel file.

The captain had received two letters of warning from a previous employer and had met with management to discuss issues such as a perception of disassociating himself from daily activities and a perception of disharmony between him and senior officers. One warning letter listed two violations regarding an accident report. The letter stated that any further infractions could cause a loss of confidence in the captain and result in disciplinary action, up to and including termination. After a second letter of warning, concerning a failure to report actual or suspected cargo damage, the captain resigned. About 2 months later, in May 2013, the captain was rehired by TOTE.

In early 2015, TOTE assigned captains to the *Isla Bella* and the *Perla del Caribe*. None of the company's current captains was initially selected to crew the vessels. In June, the captain expressed his displeasure at not being placed on one of the new ships in an email to a union (AMO) official. According to the company's director of labor relations, senior management reconsidered and after interviewing the captain on August 4, decided to offer him a position on one of the LNG ships. Before the company could notify the captain, however, management learned of an "alleged" incident in which he had not enforced the company's zero-tolerance alcohol policy. The director of labor relations said the incident "was not documented, it was all verbal second-hand

[109] Investigators reviewed company email records for the 10 months before the accident voyage.

[110] Marlin-class vessels were the world's first container ships powered by LNG.

information." Management delayed notifying the captain about the job. On September 24, the captain emailed a family member that he still did not know if he was going to have a position on one of the new ships:

> It's looking like I won't be home until 03 Dec. They have no one to relieve me and now I am actually on my scheduled rotation, which has me home for Xmas. Again, I feel taken advantage of . . . But, they pay really good. Who knows how long this good fortune will last. I have no idea if I am even going on the Marlin Class vessels yet.

The VDR recorded a conversation between the captain and the chief mate regarding their future employment with the company:

> Chief Mate: When they lay this up they're not gonna (take us back) . . .I hear what you're saying captain. I'm in line for the choppin' block . . . yeah. Same here . . . I'm waitin' to get screwed.
>
> Captain: Same here.
>
> Chief Mate: I don't know what's gonna happen to me.

The director of labor relations told investigators that the company planned to have the captain sail on *El Faro* in the Alaska trade. However, the vice president of marine operations stated, "I do not believe [he would remain] in the master role [aboard *El Faro*], but . . . he could sail on the vessel, say, possibly as chief mate or second mate."

Medical. According to his latest Coast Guard medical examination, completed in March 2015, the captain was not taking any prescription medications and was deemed physically competent to hold a credential.[111]

Chief Mate. The chief mate, age 54, graduated in 1984 from the US Merchant Marine Academy at King's Point, New York. His latest merchant mariner credential was issued on January 8, 2013, and was due to expire on January 8, 2018. The credential stated that under international capacities, the chief mate was endorsed as master, with a limitation that the endorsement was not valid for service on vessels equipped with the electronic chart display and information system (ECDIS) after December 31, 2016. He was credentialed as officer in charge of a navigational watch and GMDSS radio operator. He was also endorsed under domestic capacities as master of steam or motor vessels of any gross tons upon oceans and as radar observer (unlimited).

Experience. The chief mate was employed by Crowley American Transport from 1989 to 1997, when he sailed as both second mate and chief mate. He then spent 2 years sailing for Osprey Ship Management, Inc., again as both second mate and chief mate. From 2001 to 2003, he sailed as chief mate for Sealift, Inc. He began sailing with TOTE (then Interocean American Shipping) in 2004, when he joined the SS *Great Land*, a Ro/Ro vessel in the Alaska trade. He sailed as second mate and then chief mate (beginning in 2005) on the *Great Land* until it was taken out of

[111] The Coast Guard requires completion of form CG-719K, in accordance with NVIC 04-08 (USCG 2008). If the Coast Guard approves the form, it serves as "documentary evidence that regulatory physical requirements have been satisfied and that the applicant is physically competent to hold a credential."

service in 2011. He joined *El Yunque* as third mate in 2011 and was promoted to second mate in 2014. In May 2015, he was assigned to *El Faro* as chief mate. The accident voyage was his second tour on *El Faro.* He joined the ship 2 weeks before the sinking, on September 18.

Duties. The chief mate was head of the deck department and reported directly to the captain. He was responsible for seeing that the cargo was properly loaded, cared for on the vessel, and discharged. One of his duties was to calculate the vessel's stability. As officer in charge of the navigational watch, he was responsible for updating the deck logbook while on watch. Required logbook entries included change of watch, course changes, weather, and inspection of weathertight doors at departure. The chief mate also made entries, outside his normal watch hours, when the large watertight doors were secured for sea and when cargo was secured or checked. He managed deck-related preventive maintenance as well.

Performance. The chief mate's performance evaluations were consistently positive. His evaluation from June 2015 stated that he was "passionate" about his work and "an excellent instructor for the inexperienced."

Medical. According to his Coast Guard records, the chief mate had a condition requiring a medical waiver, but he was no longer taking medication for the condition and no limitations were placed on his credential.

Second Mate. The second mate, age 34, graduated from Maine Maritime Academy in 2004. Her latest merchant mariner credential was issued on March 30, 2015, and was due to expire on March 30, 2020. The credential stated that under international capacities, the second mate was endorsed as officer in charge of a navigational watch, with a limitation that the endorsement was not valid after December 31, 2016. The international endorsements also included GMDSS radio operator and vessel security officer. The second mate held domestic endorsements as second mate of self-propelled vessels, not including auxiliary sail, of unlimited tonnage upon oceans, and as radar observer (unlimited).

Experience. The second mate began working for TOTE (then Interocean American Shipping) in 2005. She sailed as third mate on *El Morro* from 2005 until 2013, when she was promoted to second mate. In July 2014, she transferred to *El Faro* as second mate. She joined the ship for the accident voyage on September 22.

The second mate was the navigation officer. She was responsible for preparing voyage plans, keeping the vessel's charts, and updating the deck logbook while on watch. She was also responsible for bridge navigational equipment. When the ship was in port, the second mate assisted the chief mate in securing the vessel and overseeing cargo operations. The second mate would also take offshore draft readings.

Performance. The second mate received scores of very good or excellent on the most recent performance evaluation in her personnel file, dated November 2011, when she was a third mate. Though she began sailing as second mate in 2013, her file contained no evaluations in that position.

Medical. According to Coast Guard records, the second mate had no medical conditions and was taking no prescription medication. She wore corrective lenses and was required to keep a spare pair on board.

Third Mate. The third mate, age 46, graduated from the Seafarers Harry Lundeberg School of Seamanship (affiliated with the SIU) at Piney Point, Maryland, in 1993. His latest merchant mariner credential was issued on December 5, 2013, and was due to expire on December 5, 2018. The credential stated that under international capacities, the third mate was endorsed as officer in charge of a navigational watch, with a limitation that the endorsement was not valid for service on ECDIS-equipped vessels after December 31, 2016. His international endorsements also included GMDSS radio operator. He was endorsed under domestic capacities as deck officer/third mate of steam or motor vessels of any gross tons upon oceans and as radar observer (unlimited).

Experience. The *El Faro* third mate began sailing with TOTE (then Interocean Ugland Management Corporation) as third mate in 1999. He served as third mate on *El Morro* from 2010 to 2013 and took the third mate position on *El Faro* in May 2014. He began his last tour on the ship on July 28, 2015.

Duties. The third mate stood watches at sea. He generally reported to the chief mate, except when in charge of the navigational watch, when he reported to the captain for navigation and route planning. When in port, the third mate rotated with the second mate in securing the vessel and overseeing cargo operations.

Performance. The most current performance evaluation in the third mate's personnel file was dated February 2014. He received scores of excellent in all deck-related areas.

Medical. According to Coast Guard records, the third mate was not taking any prescription medications and was deemed physically competent to hold a credential.

1.8.2 Engineering Officers

Chief Engineer. The chief engineer, age 34, graduated from the State University of New York Maritime College in 2003. His merchant mariner credential was issued on November 4, 2014, and was due to expire on November 4, 2019. The credential stated that under international capacities, the chief engineer was endorsed as chief engineer, with a limitation that the endorsement was not valid after December 31, 2016. Under domestic capacities, he was endorsed as chief engineer of steam, motor, and gas-turbine vessels with no limitations.

Experience. The chief engineer began his career in 2003, sailing as third and second assistant engineer on a variety of steam-propelled cargo ships. He joined TOTE (then Interocean American Shipping) in 2008 as first assistant engineer on the SS *Petersburg*. He sailed on *El Morro* as first assistant engineer in 2011–2012. In 2013, he served briefly as first assistant engineer on *El Yunque* before rejoining *El Morro* as chief engineer. He joined *El Faro* as chief engineer in 2014, signing on for the ship's last voyage on August 18, 2015.

Performance. The chief engineer had undergone official evaluations throughout his career with TOTE. On July 22, 2013, while aboard *El Yunque* as first assistant engineer, he received ratings of very good or excellent in all categories. He was reported to be "intelligent, hard-working" and had a "good attitude" and no areas that required improvement. An evaluation conducted on January 5, 2012, while he was aboard *El Morro*, stated that he was a "hard working and knowledgeable first working his way to becoming a chief, and that he is able to work through difficult times."

TOTE provided one draft evaluation for the chief engineer, dated October 2, 2014, in which all evaluation criteria were rated exceptional. Another performance evaluation from 2014 was partially completed but was not stamped by the crewing department for formal receipt and was not found in the personnel file provided to investigators.

Medical. According to Coast Guard records, the chief engineer was not taking any prescription medications and was deemed physically competent to hold a credential. He held a Coast Guard medical certificate valid until February 2019 that required him to wear corrective lenses.

First Assistant Engineer. The first assistant engineer, age 33, graduated from Massachusetts Maritime Academy in 2005. He had trained on the academy's steamship *Enterprise*. According to Coast Guard records, his merchant mariner credential was issued on May 8, 2015, due to expire on May 8, 2020. The company's personnel files had not been updated to reflect the new issue date.

The credential stated that under international capacities, the first engineer was endorsed as a chief engineer, with a limitation that the endorsement was not valid on steam vessels or after December 31, 2016. He was also endorsed under international capacities as a second engineering officer, with a limitation that the endorsement was not valid after December 31, 2016. Under domestic capacities, he was endorsed as first assistant engineer of steam, motor, and gas-turbine vessels and as chief engineer (limited) of motor and gas-turbine vessels of less than 1,600 gross register tons upon oceans, near coastal waters, and the Great Lakes.

Experience. The first assistant engineer's first TOTE vessel was *El Morro*, which he joined as third assistant engineer in June 2009. He joined *El Faro* on August 4, 2015.

Performance. The first assistant engineer's first performance evaluation in that capacity contained mostly good ratings, as well as constructive criticism regarding his work performance and leadership in his new position. The same evaluating chief engineer had given him excellent ratings on his previous trip as second engineer.

Medical. According to Coast Guard records, the first assistant engineer was not taking any prescription medications and was deemed physically competent to hold a credential.

Second Assistant Engineer. The second assistant engineer, age 50, began his sailing career in 1990 as an unlicensed mariner, working his way up to third assistant engineer in 1996 and second in 1998. His merchant mariner credential was issued on March 30, 2012, and was due to expire on March 30, 2017. The credential stated that under international capacities, the second assistant engineer was endorsed as officer in charge of an engineering watch (second assistant engineer). Under domestic capacities, he was endorsed as second engineer on steam, motor, or gas-turbine vessels of any horsepower and had served on a variety of steam- and motor-powered tankships and freighters.

Experience. The second assistant engineer joined TOTE (then Interocean Ugland Management Corporation) in 2003 as third assistant engineer on the SS *Westward Adventure*. He served on *El Faro* as third assistant engineer in 2010–2011. He rejoined TOTE in 2013 as second assistant engineer on *El Morro*, then transferred to *El Faro* in 2014. He joined *El Faro* before the accident voyage on August 11, 2015.

Performance. The second engineer received positive evaluations, the most recent (May 2015) stating that he was “one of the most dependable” and “hardest working men” the chief engineer had ever worked with.

Medical. According to Coast Guard records, the second assistant engineer was not taking any prescription medications and was deemed physically competent to hold a credential.

Third Assistant Engineer No. 1. Of the vessel’s three third assistant engineers, the one who had served longest on *El Faro* was 26 years old and graduated from Maine Maritime Academy in 2012. His merchant mariner credential was issued on September 11, 2013, and was due to expire on September 11, 2018. The credential stated that under international capacities, he was endorsed as officer in charge of an engineering watch, with a limitation that the endorsement was not valid for ships in which gas turbines formed part of the propulsion system. Under domestic capacities, he was endorsed as third assistant engineer of steam and motor vessels of any horsepower.

Experience. The third assistant engineer spent 120 days aboard the training ship *State of Maine* (diesel electric) and 72 days aboard the Navy ship *Rappahannock* (diesel) as a cadet before obtaining his third engineer’s credentials.[112] He had made five 70-day trips on *El Faro* before the accident. He joined the ship before the accident voyage on September 22.

Performance. An evaluation in January 2015 stated that he was “a valuable asset to the vessel.”

Medical. According to Coast Guard records, the third assistant engineer was not taking any prescription medications and was deemed physically competent to hold a credential. He wore corrective lenses and was required to keep a spare pair on board.

Third Assistant Engineer No. 2. The 25-year-old third assistant engineer on board at the time of the accident also graduated from Maine Maritime Academy in 2012 and had trained on the diesel-electric *State of Maine*. His merchant mariner credential was issued on July 9, 2012, and was due to expire on July 9, 2017. The credential stated that under international capacities, he was endorsed as officer in charge of an engineering watch (third assistant engineer). Under domestic capacities, he was endorsed as third assistant engineer of steam, motor, or gas-turbine vessels of any horsepower.

[112] In 1997, Maine Maritime Academy replaced its steam training ship *State of Maine* with a diesel electric ship of the same name built in 1990.

Experience. The third assistant engineer had made two trips aboard *El Yunque* before the accident and one on the SS *Bellatrix*, a cargo vessel owned by the US Maritime Administration and operated by TOTE. He began work as a third assistant engineer on *El Faro* in April 2015. He started his last rotation on the ship 2 weeks before the accident, on September 15.

Performance. The third assistant engineer received generally positive evaluations, though his last evaluation, dated November 2014, noted that he needed to pay more attention to detail.

Medical. According to Coast Guard records, the third assistant engineer was not taking any prescription medications and was deemed physically competent to hold a credential. He wore corrective lenses and was required to keep a spare pair on board.

Third Assistant Engineer No. 3. The newest third assistant engineer on board, age 23, graduated from Maine Maritime Academy in 2014. He, too, had trained on the diesel-electric *State of Maine*. His merchant mariner credential was issued on May 3, 2014, and was due to expire on May 3, 2019. The credential stated that under international capacities, he was endorsed as officer in charge of an engineering watch, with a limitation that the endorsement was not valid on gas-turbine vessels. Under domestic capacities, he was endorsed as third assistant engineer of steam, motor, or gas-turbine vessels of any horsepower.

He was endorsed under STCW regulations as officer in charge of an engineering watch and vessel security officer. Under national regulations, he was endorsed as third assistant engineer of steam and motor vessels and as a qualified member of the engine department on vessels of any horsepower.

Experience. The third assistant engineer's first ship was *El Faro*. He signed on in Jacksonville on September 29, the evening *El Faro* departed on the accident voyage.

Performance. Because he was new to the company, no performance evaluations were completed for this third assistant engineer.

Medical. According to Coast Guard records, the third assistant engineer was not taking any prescription medications and was deemed physically competent to hold a credential. He wore corrective lenses and was required to keep a spare pair on board.

1.8.3 Supernumeraries

Riding Gang. Section 312 of the Coast Guard and Maritime Transportation Act of 2006 allows a member of a foreign riding gang to work on board a freight vessel for 60 days at a time.[113]

[113] Public Law 109-241, July 11, 2006.

Each member of a foreign riding gang must possess a US nonimmigrant visa and must receive basic safety training approved by the Coast Guard.[114]

The *El Faro* riding gang was an onboard repair crew contracted through Intec Maritime Offshore Service Corporation, an international company originally established to serve the North Sea oil rigs and now specializing in repair and maintenance of oceangoing vessels. The Intec vice president told investigators that the crew assigned to *El Faro* was hired through the company's office in Gdansk, Poland. The first group of workers joined *El Faro* on August 18. Two electricians in that group left the ship before the accident voyage because, according to the TOTE port engineer, they had run "as much wiring as they could at the time."

Five members of the riding gang, all pipefitters, were on board *El Faro* at the time of the accident. They were 27, 34, 42, 43, and 52 years old. According to the Intec vice president, all the pipefitters had certificates that were renewed every 2 years and stamped "every 6 months that they were approved."

The riding gang was working to restore *El Faro* to its former configuration before the ship returned to the Alaska trade. The work included scraping the deck flush so that trucks could drive over it, removing covers over the deck ramps to allow vehicle access, reinstalling a Butterworth heater (which heats seawater to pump into a ship's deicing system during cold weather) and associated saltwater piping, reinstalling deicing equipment on the ramps, installing a constant-tension winch, verifying that the freshwater cooling system was functional, installing a saltwater recirculation system, and refitting connections for steaming-out (cleaning) the ship's sea chest (an intake reservoir for seawater). Work to install aft, midship, and forward shore ramps was scheduled to be done after the ship reached the West Coast.

Several spouses of the Polish workers stated in written interviews that their husbands were generally happy working on *El Faro* and spoke highly of their supervisor (the off-duty chief engineer).[115] One, for example, reported of her husband: "He was very happy, especially about his relations with the chief who was assigning and supervising the work of the Polish crewmembers." Another said: "My husband liked his work and his relations with his crewmates. He often praised the chief who was supervising his work."

When asked about their husband's safety concerns and working conditions on the ship, one spouse reported: "He didn't go through any training about boat safety, such as an evacuation drill." Another quoted her husband as saying, ". . .you can't even imagine this old rust bucket I have to board." She also reported that in general, her husband was happy with his job. Still another spouse reported: "Early during his contract, my husband told me that the boat was old and rusted throughout." She also said that her husband liked his job.

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[114] A *riding gang member* is defined at 46 *USC* 2101(26a) as an individual who has not been issued a merchant mariner document, who does not perform watchstanding duties or handle cargo, is not part of the crew complement, is not a member of the steward's department, and is not a citizen or resident of a country designated by the United States as a security threat. Laws governing riding gangs are codified at 46 *USC* 8106.

[115] The spouses' interviews were translated from the original Polish.

Riding Gang Supervisor. The riding gang supervisor was an off-duty TOTE chief engineer, age 42, who had graduated from Massachusetts Maritime Academy in 1996. His most recent merchant mariner credential was issued on October 28, 2011, and was due to expire on October 28, 2016. He was endorsed as chief engineer on steam vessels of any horsepower, as first assistant engineer, and as officer in charge of an engineering watch. He started working on the *Ponce*-class ships in December 2003 and spent several years on the *Great Land* before sailing aboard *El Morro*, *El Yunque*, and *El Faro*. He had received positive remarks about his work ethic and safety consciousness. He joined the ship on August 4, 2015.

1.8.4 Port Engineer

TOTE assigned a port engineer to *El Faro* to assist with maintenance, order spare parts and supplies, monitor inspections and surveys, keep track of vessel certificates, arrange repair work with vendors, and provide general shore support. According to TOTE, a backup port engineer was assigned in case the primary port engineer was unavailable. The port engineers were the first point of contact ashore for the captains and the crews of the vessels, although according to TOTE management, they had direct access to the DP or any other company personnel, as required.

TOTE did not employ port captains (who generally oversee port operations and day-to-day ship operations) for its vessels. The *El Faro* port engineer described himself as a combination port engineer and port captain. He said that he did not assess the vessel's voyage plans or review its position reports.

El Faro's port engineer graduated from California Maritime Academy in 1976 and had sailed for 28 years on both steam and diesel ships in several capacities, including that of chief engineer. He started with TOTE as a port engineer in November 2013. He told investigators that he boarded *El Faro* every Monday and Tuesday when the ship was in Jacksonville and occasionally in San Juan.

1.8.5 Work and Rest

According to company records, officers on *El Faro* had the following watch schedules, which were validated by the VDR transcript:

- Captain: dayworker, did not stand a watch
- Chief mate: 0400–0800; 1600–2000 at sea
- Second mate: 0000–0400; 1200–1600 at sea
- Third mate: 0800–1200; 2000–0000 at sea
- Chief engineer: dayworker
- First assistant engineer: dayworker
- Second assistant engineer: 0400–0800; 1600–2000
- Third assistant engineers: could not be determined

The STCW Convention states that for crewmembers on vessels subject to US manning requirements, officers in charge of a navigational watch and any rated person forming part of the watch must receive a minimum of 10 hours of rest in any 24-hour period. The 10-hour rest can be divided into no more than two periods, of which one must be at least 6 hours long (46 *CFR* 15.1111). The captain was required to track the crew's work and rest hours to ensure that they did not violate STCW requirements. According to a relief chief mate, designated department heads (captain, chief engineer, and boatswain [for the ABs]) always reviewed and signed the records. The DP said managers reviewed the timesheets if an issue was reported to them. However, it was unclear who at TOTE (on shore) was in charge of STCW compliance. The DP stated that it was the captain's responsibility to monitor compliance on the vessel and the responsibility of crewmembers to monitor their hours.

At sea, the deck officers stood 4-hour watches. The second and third mates shifted to a 6-hours-on, 6-hours-off watch schedule in port, and the chief mate became a dayworker. Occasionally, a port mate would come on *El Faro* to assist the mates in the loading and unloading operations. The last port mate scheduled to work in Jacksonville was on September 1, 2015. Port mates were used in San Juan for the 1-day port call on September 25. Email evidence shows that the captain, via the chief mate, had requested a port mate before the final cargo-loading operation.

The chief engineer told his wife that he was exhausted from all the maintenance and issues he had in the weeks before the accident. Two friends of the second mate told investigators that she complained about fatigue as a result of her watch schedule, coupled with relieving other officers during mealtimes when she was not on watch and the additional work required at sea under company procedures and the union contract (12-hour days). Evidence of the second mate's use of ZzzQuil (a non-habit-forming sleep aid whose active ingredient is the antihistamine diphenhydramine HCl) was found on the VDR transcript.[116]

The captain, similarly to the other officers, normally worked a 10-week rotation (10 weeks off after 10 weeks on the ship). He started a work rotation on May 5, 2015, and left the ship on July 14. When his relief resigned 3 weeks later, the captain was asked to return early to *El Faro*. Four weeks into his vacation, on August 11, he returned to work on *El Faro*. According to TOTE management, the captain was scheduled to work until December.

1.8.6 Bridge Resource Management

Bridge resource management (BRM), also known as bridge team management, is a process by which bridge crews use all available resources and act efficiently and as a team to safely operate the ship. ABS defines BRM as "a method of performing bridge watchkeeping tasks in which crews behave in an efficient and team oriented manner to maintain overall situation awareness and use all available resources including information, equipment, communication, procedures, and people to achieve safe operation" (ABS 2005). As stated in the company's SMS policy, BRM requires "cooperation and sharing of responsibility . . . between Master, deck watch officers, helmsman and

[116] Several factors influence how long the effects of the medication last if a full recommended dose is taken, according to the manufacturer's website. The manufacturer recommends that ZzzQuil be taken only when the consumer has time to get a full night's sleep (about 8 hours).

lookout." The SMS policy further states, "Teams do not just happen. They have to be formed and trained to work as teams."

As described in a publication for marine navigational officers, when implemented properly, a bridge team has the following characteristics (Nautical Institute 2014):

- Maintains its situation awareness, avoiding becoming preoccupied with minor issues, which might cause them to lose sight of the big picture.
- Continuously monitors the progress of the vessel, making adjustments and corrections as necessary to maintain a safe voyage.
- Acquires relevant information early.
- Appropriately delegates workload and authority.
- Anticipates dangerous situations.
- Undertakes appropriate contingency plans when necessary.

Teamwork is a critical element of BRM. Training in BRM encourages junior officers to put forth their opinions and, when safety is of concern, to challenge their superior officers. Senior officers are, in turn, trained to be open to gathering feedback from the bridge team. Another important element for a properly functioning bridge team is maintaining situation awareness, which can be defined as "comprehension or understanding of a dynamic environment."

During the accident voyage, the mates and ABs discussed their concerns about the weather and the ship's route on the bridge, where they were recorded by the VDR. The conversations were not repeated in the captain's presence. After the captain went to his stateroom about 2000 on September 30, not to reappear on the VDR recording until 0409 the next morning, the third mate called him twice about the forecast and suggested making a course change to the south, which the captain did not agree to. While the second mate was on watch, she plotted a new route, based on weather information from Sat-C. She called the captain about 0120 and in a conversation that was not clear on the VDR recording, suggested a course change to the south that was not accepted by the captain. The day before, the second mate had sent a message to her mother saying that the ship was heading "straight into" the hurricane. Shortly before 0400 on October 1, she sent emails to her mother and a friend with essentially the same message.

At 0503, the captain stated that he had conflicting reports about the location of the center of the storm. The captain was comparing two reports of different types containing forecasts from different times. The first was the 0500 Sat-C report from the National Hurricane Center, which was a text copy of the current forecast. The second was the BVS report issued at 2300 the previous evening. That report was a graphic depiction of the National Hurricane Center forecast from 1700 on September 30 (6 hours earlier). By the time the report was downloaded at 0503, the information was about 12 hours old. The captain repeatedly stated, however, that they were "on the back side" of the storm or would be soon.

All members of the bridge team, except the captain, completed BRM training in 2013. The company was not required to send crewmembers to BRM training, and the Coast Guard does not require any BRM recurrent training. With recurrent training, all officers would have a unified understanding of expectations with regard to effective communication, assertiveness, and working as a well-organized and competent team.

1.9 Waterway Information

The sinking occurred along the sea trade route between Jacksonville, on the Atlantic coast of Florida, and San Juan, capital of the Caribbean island of Puerto Rico. Puerto Rico is an unincorporated US territory. As such, it is subject to laws regulating shipping between the US mainland and its states, territories, or possessions.[117] Section 27 of the Merchant Marine Act of 1920, Public Law 66-261, as amended, commonly referred to as the Jones Act, requires that maritime transport of cargo between points in the United States ("cabotage" or "coastwise shipping") be carried by vessels that are (1) owned by US citizens and registered in the United States, (2) built in the United States, and (3) operated by crews who are predominantly US citizens.[118] The Jones Act was intended to strengthen the US merchant marine and support the nation's shipyards. In addition to regulating the construction and ownership of vessels engaged in coastwise shipping, the Jones Act also codified the rights of injured maritime workers.

Between October 2011 and February 2013, the US Government Accountability Office (GAO) conducted a performance audit of Puerto Rico's maritime trade and the possible effects of modifying the Jones Act. At the time of the audit, most of the maritime trade between the United States and Puerto Rico was shipped in containers by four Jones Act carriers: Crowley Puerto Rico Services, Inc.; Horizon Lines; Sea Star Line (now TOTE Maritime Puerto Rico); and Trailer Bridge, Inc. According to the audit report, in June 2011, Crowley accounted for 31 percent of the US–Puerto Rico market, Horizon for 30 percent, Sea Star Line for 27 percent, and Trailer Bridge for 12 percent (GAO 2013). As of the date of the GAO's report, Sea Star and Horizon operated five self-propelled containerships between them, Crowley operated eight Ro/Ro barges, and Trailer Bridge operated four Ro/Ro barges. The containerships ranged from 38 to 44 years old. Horizon Lines (with its three containerships) ceased operations to Puerto Rico in December 2014.

The port of Jacksonville handles most of the cargo moving between the US mainland and Puerto Rico. According to the Jacksonville port authority's 2015 annual report (JAXPORT 2016), Jacksonville is the nation's eleventh largest container port and is the leading port for vehicle exports. The annual report states that the port of Jacksonville moved 8.2 million tons of cargo during the fiscal year ending September 30, 2015, including over 900,000 TEUs and more than 650,000 Ro/Ro units, primarily passenger cars. A total of 1,826 vessels reportedly called at the port in fiscal 2015, with revenues for the year totaling $55.2 million.

The Jacksonville port authority owns three cargo facilities on the St. Johns River, including the Blount Island marine terminal where *El Faro* docked. The river empties into the Atlantic about

[117] The US Virgin Islands, American Samoa, and parts of the Northern Mariana Islands are not subject to those laws, as stipulated at 46 *USC* 5501(b)(3).

[118] Under the US cabotage laws, only a citizen can serve as master, chief engineer, radio officer, or officer in charge of a deck or engineering watch on a documented vessel, and no more than 25 percent of the unlicensed crew can be noncitizens (46 *USC* 8103). The Jones Act was recodified in 2006 as 46 *USC* 8103, 12103, 12112, 12131, and 55102 (Baatz 2014).

9 nm east of Blount Island. Harbor pilots guide vessels through the main ship channel, which is dredged, to a point near the St. Johns lighted sea buoy, 3 nm from the river entrance.[119]

The usual, rhumb-line sea route between Jacksonville and San Juan stretches about 1,100 nm, heading southeast and bypassing a number of islands, including the Bahamas.[120] An alternate route to San Juan involves traveling south along the Florida coast about 500 nm, then turning southeast into Old Bahama Channel, a deep, narrow passage that runs between the Great Bahama Bank (one of the large underwater platforms in the Bahamas archipelago) and Cuba.

Old Bahama Channel is one of several deepwater passages through and around the Bahamas (see figure 37).[121] Farther north is Northeast Providence Channel, a branch of the Great Bahama Canyon, one of the largest submarine canyons in the world. The eastern entrance to Northeast Providence Channel lies off the south tip of Great Abaco Island, near the “Hole in the Wall” lighthouse. The channel runs through the Bahamas and connects with the Northwest Providence Channel, a wide, deepwater pass between Little Bahama Bank and Great Bahama Bank that leads to the Straits of Florida and the Florida coast.

Farther south is Crooked Island Passage, which lies between Long Island and Crooked Island and provides a route south through the Bahamas toward Cuba. The seaway, which is about 30 nm long and 27 nm wide, ranges from 1,000 to 1,500 fathoms (6,000 to 9,000 feet) deep. Diana Shoal at the southern terminus is at least 42 feet deep, with 18 nm of deep water to either side.

East of the passage lie several low islands that form a triangle enclosing the Bight of Acklins, a shoal-water bay. The northernmost of the group is Crooked Island, covering about 76 square miles and having a population of about 330. Acklins (120 square miles), in the southeast part of the island group, has a population of about 550. The southern continuation of Crooked Island Passage is Mira Por Vos Passage, a deepwater seaway between Castle Island and several low-lying islets and shoals.

South of Crooked Island Passage and east of Acklins lies Mayaguana Passage, a deepwater seaway, about 30 nm long and 15 nm wide, lying between two reef-fringed cays and Mayaguana Island. The seaway ranges from 800 to 1,100 fathoms (4,800 to 6,600 feet) deep and like Crooked Island Passage, leads south toward Cuba. Mayaguana Island covers about 108 square miles and is sparsely populated.

[119] Pilotage is required for US coastwise vessels on the St. Johns River unless a US-licensed pilot is on board (NOAA 2017b).

[120] A *rhumb line* is a straight line on a Mercator projection chart, the type of chart commonly used in marine navigation.

[121] The passages and island groups discussed in this section are described in sailing directions published by the National Geospatial-Intelligence Agency (NGA 2016).

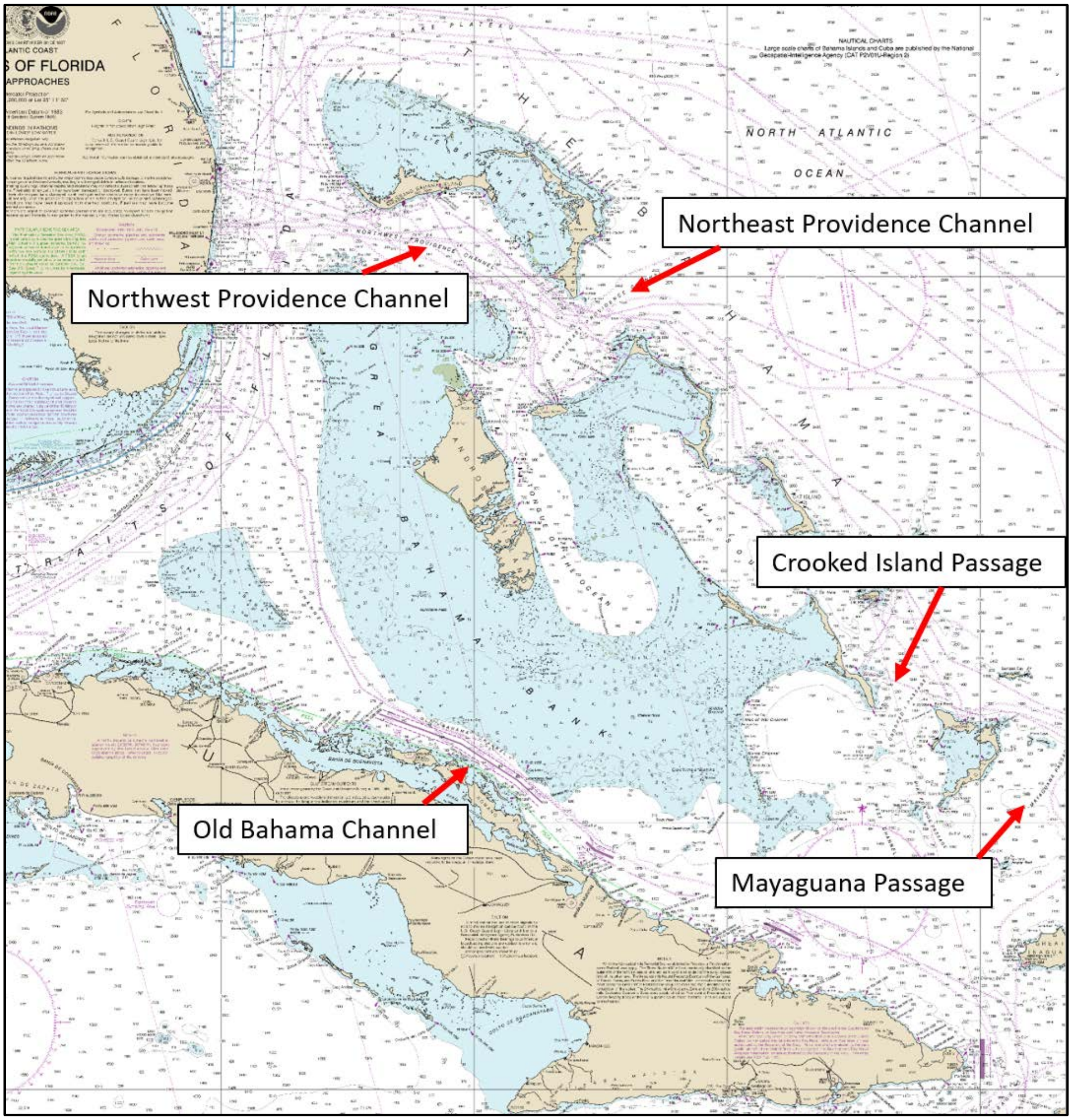

Figure 37. Nautical chart with passages through Bahama Islands and Old Bahama Channel highlighted.

El Faro traveled southeast from Jacksonville in international waters of the North Atlantic Ocean until it entered Bahamas territorial waters on a path between Cat Island and San Salvador Island. The vessel sank about 40 nm northeast of Crooked Island, inside the Bahamas territorial boundary. The ocean in the region is deep, ranging around 2,500 fathoms, or 15,000 feet (NOAA 2012). The average depth of the world's oceans is about 12,100 feet (NOAA 2015a).

The nearest land to the accident site was Samana Cay, a low-lying, uninhabited islet about 20 nm to the southeast.

1.10 Meteorological Information

1.10.1 Atlantic Hurricane Season 2015

Joaquin was the second major hurricane of the 2015 Atlantic hurricane season. In the United States, Joaquin was identified, tracked, and analyzed by the National Hurricane Center in Miami.[122] The hurricane center, which is responsible for monitoring tropical and subtropical storms in both the northeast Pacific and northern Atlantic oceans, issues forecasts in text as well as graphic form. When hurricane-force winds are possible or imminent on land, the hurricane center issues hurricane watches and warnings.

The National Hurricane Center tracked twelve tropical cyclones, including four hurricanes, during the 2015 Atlantic hurricane season (Stewart 2016b). (*Cyclone* is the general term for a wind system, or circulation, that rotates around a center of low atmospheric pressure. Tropical cyclones with sustained wind speeds above 64 knots are known as hurricanes in the North Atlantic and northeastern Pacific and as typhoons in the northwestern Pacific.) The Atlantic hurricane season runs annually from the beginning of June until the end of November. Tropical cyclones form in the Atlantic primarily between latitudes 8N and 20N (Husick 2009). August, September, and October are the months of greatest hurricane frequency in the Atlantic.

Hurricane Danny, which developed in mid-August 2015, was the first major hurricane of the year. It developed off the west coast of Africa on August 14 and by August 21 had reached an intensity of Category 3 on the Saffir-Simpson wind scale (table 2), with maximum sustained winds of nearly 127 mph. By August 24, Hurricane Danny had weakened to a tropical depression (maximum sustained winds of 38 mph or less). The storm brought rain to the Caribbean islands but caused little damage and no casualties (Stewart 2016a).

Table 2. Saffir–Simpson wind scale.

Category	Sustained Winds	Types of Damage Due to Hurricane Winds
1	74-95 mph 64-82 knots 119-153 km/hr	**Very dangerous winds will produce some damage:** Well-constructed frame homes could have damage to roof, shingles, vinyl siding, and gutters. Large branches of trees will snap and shallowly rooted trees may be toppled. Extensive damage to power lines and poles likely will result in power outages that could last a few to several days.
2	96-110 mph 83-95 knots 154-177 km/hr	**Extremely dangerous winds will cause extensive damage:** Well-constructed frame homes could sustain major roof and siding damage. Many shallowly rooted trees will be snapped or uprooted and block numerous roads. Near-total power loss is expected with outages that could last from several days to weeks.

[122] The National Hurricane Center is a division of the National Weather Service, which is part of the National Oceanic and Atmospheric Administration (NOAA), a branch of the US Department of Commerce.

Category	Sustained Winds	Types of Damage Due to Hurricane Winds
3 (major)	111-129 mph 96-112 knots 178-208 km/hr	**Devastating damage will occur:** Well-built framed homes may incur major damage or removal of roof decking and gable ends. Many trees will be snapped or uprooted, blocking numerous roads. Electricity and water will be unavailable for several days to weeks after the storm passes.
4 (major)	130-156 mph 113-136 knots 209-251 km/hr	**Catastrophic damage will occur:** Well-built framed homes can sustain severe damage with loss of most of the roof structure and/or some exterior walls. Most trees will be snapped or uprooted and power poles downed. Fallen trees and power poles will isolate residential areas. Power outages will last weeks to possibly months. Most of the area will be uninhabitable for weeks or months.
5 (major)	157 mph or higher 137 knots or higher 252 km/hr or higher	**Catastrophic damage will occur:** A high percentage of framed homes will be destroyed, with total roof failure and wall collapse. Fallen trees and power poles will isolate residential areas. Power outages will last for weeks to possibly months. Most of the area will be uninhabitable for weeks or months.

As Danny was fading on August 24, another weather system over the Atlantic was developing into a tropical storm, defined as a tropical cyclone in which maximum sustained winds range from 39 to 73 mph (34–63 knots). The tropical storm, named Erika, took a westerly course from the Lesser Antilles across the Caribbean. Torrential rains caused mudslides and major flooding in Dominica and also affected Haiti, Guadeloupe, the US Virgin Islands, and Puerto Rico before the storm moved into the Gulf of Mexico and finally dissipated over Georgia on September 3 (Pasch and Penny 2016).

The weather system that became Hurricane Joaquin originated in a low that developed on September 8 over the eastern Atlantic, west of the Canary Islands, according to a report issued by the National Hurricane Center after the storm (Berg 2016). At 2000 on the evening of September 27, the hurricane center classified the developing system as a tropical depression (No. 11 of the season). The depression was centered about 360 nm northeast of San Salvador Island, Bahamas.

At 2237 on September 27, the National Hurricane Center issued its first public advisory about the storm, identifying it as a tropical depression at 27.5N, 68.7W and stating that a "west-northwestward or northwestward drift is expected during the next couple of days," with maximum sustained winds of 30 knots. From then until 1104 on October 1, the National Hurricane Center and the Ocean Prediction Center issued a total of 137 public advisories, discussions, and forecasts related to Joaquin, including high seas and offshore waters forecasts.[123] The hurricane

[123] The Ocean Prediction Center coordinates with the National Hurricane Center on forecasts for Atlantic tropical cyclones. See attachment 4 to the NTSB's meteorology group factual report, available in the public docket, for a complete collection of all tropical cyclone public advisories, tropical cyclone forecasts/advisories, aviation tropical cyclone advisories, tropical cyclone discussions, tropical cyclone updates, tropical weather discussions, special advisory packages, high seas forecasts, offshore waters forecasts, and marine weather discussions related to Hurricane Joaquin issued by the National Weather Service and Ocean Prediction Center between 2300 on September 27 and 1100 on October 1.

center's tropical cyclone forecast/advisories are numbered; 15 were issued during the period in question.[124]

1.10.2 Publicly Issued Hurricane Information

Once a tropical depression is identified, the National Hurricane Center generally issues information at least every 6 hours. The primary message for conveying forecast position and intensity information is the tropical cyclone forecast/advisory, scheduled for dissemination at 0500, 1100, 1700, and 2300. Actual issuance times can vary from the scheduled ("nominal") time. Linked to the forecast/advisory and issued about the same time are the tropical cyclone public advisory and the tropical cyclone discussion.[125] Intermediate public advisories are issued between regularly scheduled ones when watches or warnings are in effect for land areas. Special forecast/advisories and additional updates can be issued any time.

Also issued every 6 hours by the National Hurricane Center but on a different schedule from that of the tropical cyclone forecast/advisories is the high seas forecast. The high seas forecast can be completed early; it was issued 1 1/2 hours ahead of schedule the night before and the morning of the *El Faro* sinking (at 2255 on September 30 and 0501 on October 1). The Ocean Prediction Center also issues a high seas forecast, which includes the most recent National Hurricane Center's high seas forecast, after it receives the hurricane center's product.

In addition, the hurricane center produces NAVTEX messages, disseminated by the Coast Guard, that automatically print out on a ship's dedicated receiver. Messages sent by NAVTEX, a major element of the GMDSS, summarize major weather systems and forecast tropical cyclone positions and wind and sea states (including swells) out to 120 hours (5 days). NAVTEX messages applicable to *El Faro*'s route, which were transmitted from Miami, repeated Hurricane Joaquin's current position and its forecast track and intensity from the tropical cyclone forecast/advisory issued about 45 minutes earlier. Investigators found no evidence that *El Faro* received weather information by NAVTEX (although NAVTEX is mentioned on the VDR recording).[126]

Radiofax, also known as HF FAX, radiofacsimile, or weatherfax, broadcasts weather charts and other data from the National Weather Service over high frequency (HF) radio. Charts are received by a dedicated radiofax receiver or a single sideband shortwave receiver connected to an external facsimile recorder or to a personal computer equipped with a radiofax interface and application software. *El Faro* had radiofax (weatherfax) on board, but investigators found no evidence that the crew used it to access weather information.

The National Weather Service offers access to its text and graphic products in real time through its FTPmail system. Ideal users are mariners who can send/receive emails (for example, via satellite) but who cannot access the internet for web browsing. The OMV document of the

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[124] The National Hurricane Center issued its last tropical cyclone forecast/advisory (No. 42) for Joaquin at 2300 (nominal time) on Wednesday, October 7. By that time, the storm was moving east at 30 knots from 42N, 37W.

[125] A third text product, the aviation tropical cyclone advisory, is also issued.

[126] NAVTEX text products are found in attachment 7 of the meteorology group factual report in the accident docket.

company's SMS advised that many weather charts that had been previously available through weatherfax were available by email from the FTPmail email address. A review of emails sent to and from *El Faro*, whose crew did not have access to the internet, between September 1 and the accident time did not discover any email traffic between the vessel and FTPmail.

The National Hurricane Center issues tropical cyclone graphics on the same 6-hour schedule as the tropical cyclone forecast/advisory. Tropical cyclone track forecast cone and watches/warnings show a storm's current position, present movement, forecast track and intensity, forecast track uncertainty, and an approximation of coastal areas under watches or warnings. Forecast uncertainty is displayed as a "cone" indicating uncertainty for the 3 or 5 days of the forecast.[127] The position where *El Faro* sank was first shown inside the forecast uncertainty cone issued nominally at 1700 on September 29. From 1100 on September 30, the accident location was always inside Joaquin's forecast uncertainty cone. Figure 38 is the forecast uncertainty cone issued at 2300 on September 29.

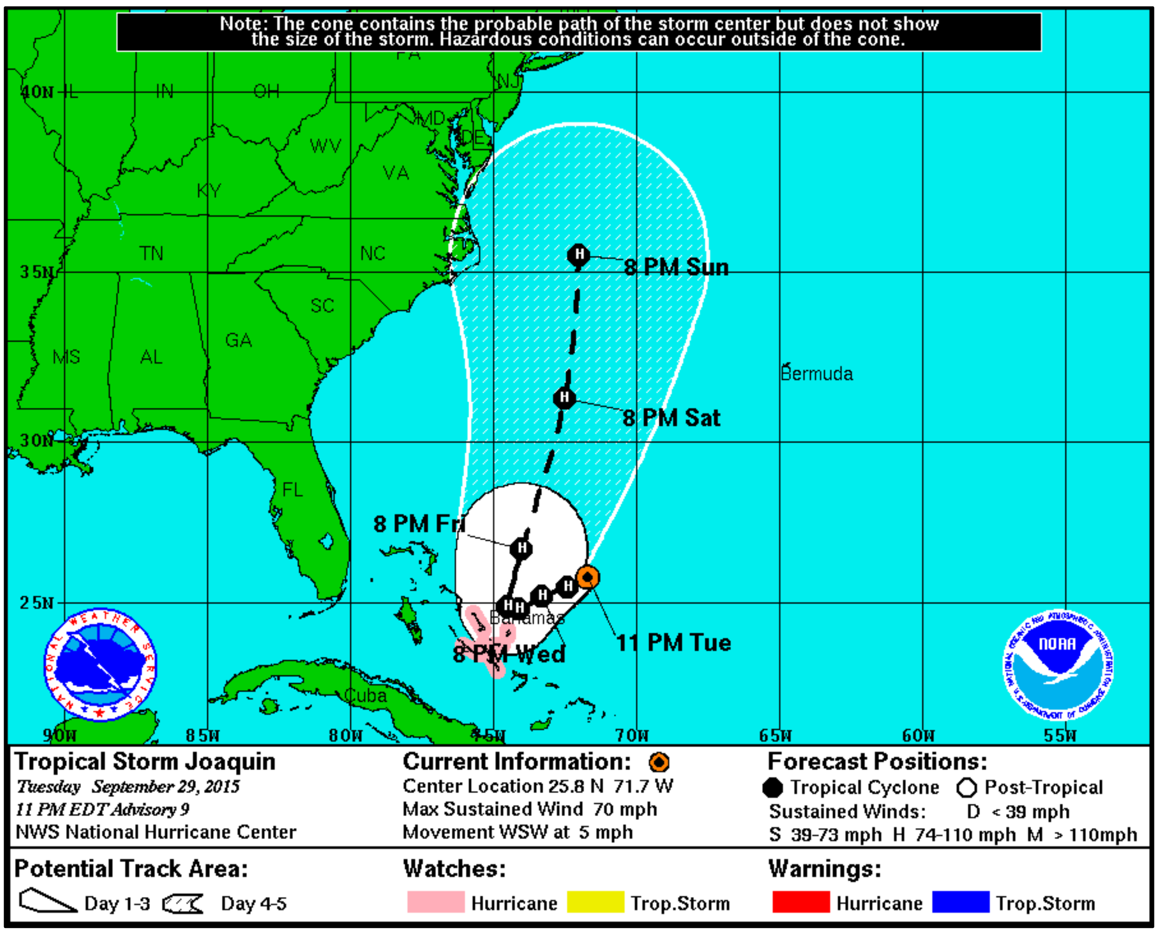

Figure 38. Tropical cyclone track forecast cone and watches/warnings graphic issued for Joaquin at 2300 on September 29. Orange circle shows Joaquin's current position. H inside small black circles indicates forecast intensity of 74-110 mph (64-95 knots).

[127] At the time of the accident, the uncertainty cone was intended to enclose 67 percent of the previous 5 years of official forecast errors.

El Faro is unlikely to have had access to National Hurricane Center tropical cyclone graphics such as the forecast uncertainty cone through any available means.[128] As a result of the *El Faro* accident, the NTSB issued a recommendation that the National Weather Service make such graphics available through FTPmail (see section 1.16.2).

The National Hurricane Center's tropical cyclone danger graphic is intended to help mariners avoid tropical cyclones. The version of the product at the time of the accident depicted avoidance areas based on the mariner's 1-2-3 rule.[129] The shaded "danger" area in the graphic is determined by taking the forecast area of tropical-storm-force winds and extending it outward to reflect the 34-knot wind radii forecast at 24, 48, and 72 hours. The danger area is plotted by adding 100 nm to the maximum radius of the 34-knot winds in the 24-hour forecast, 200 nm to the maximum radius of the 34-knot winds in the 48-hour forecasts, and 300 nm to the maximum radius of the 34-knot winds forecast for 72 hours. A circle is then drawn around each forecast position (moving across the chart with the storm), and a line is drawn connecting the circles. The area enclosed by the line is the danger area or area of avoidance. Figure 39 shows the danger graphic for Joaquin, then a tropical storm, that was valid for the time *El Faro* departed Jacksonville on September 29. There is no evidence that *El Faro* received the danger graphic by email or fax.

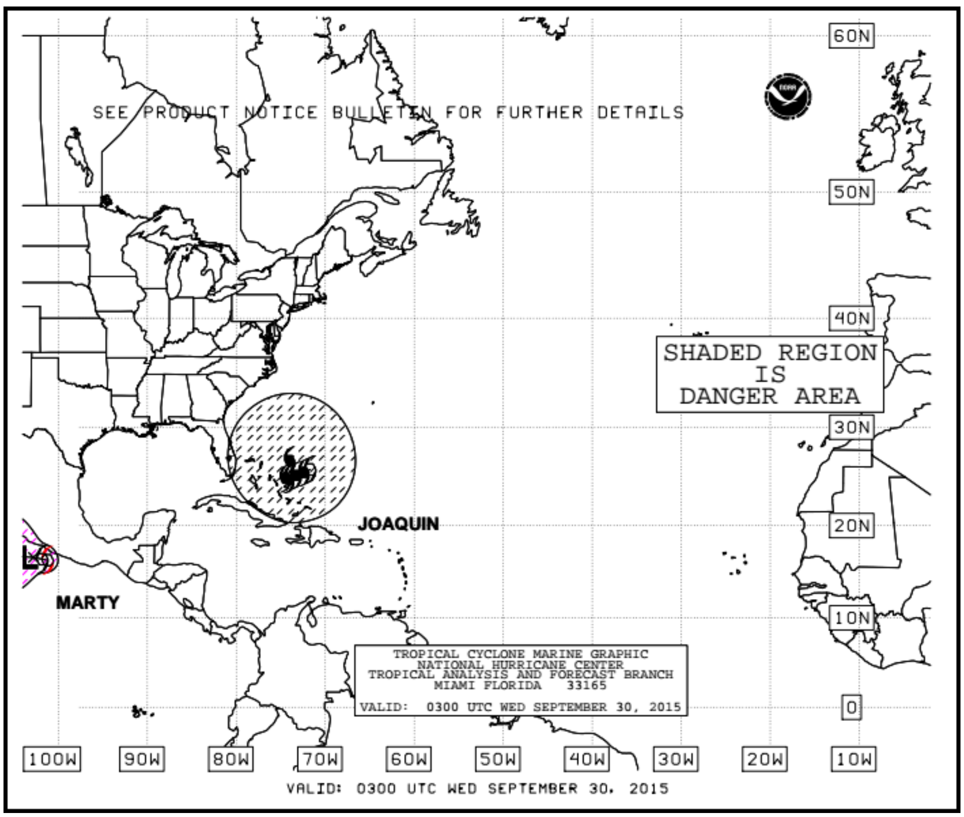

Figure 39. Tropical cyclone danger graphic for Joaquin valid for 2300 on September 29.

[128] It is possible that the crew could have seen the forecast uncertainty cone on the Weather Channel, but no evidence of any such viewing was captured on the VDR bridge recording.

[129] A different methodology, based on wind speed probabilities, replaced the mariner's 1-2-3 rule in 2016.

The National Hurricane Center normally issues a significant wave height analysis ("sea state analysis") every 12 hours (at 0800 and 2000). In its forecasts, the hurricane center defines "significant wave height" as the average height of the highest one-third of the waves. On October 1, the 0800 analysis identified significant wave heights of 36 feet in the area where *El Faro* sank. The hurricane center's offshore waters and high seas forecasts all state, "Individual waves may be more than twice the significant wave height."

1.10.3 Weather Information Accessible to *El Faro*

Radio and Satellite. As a participant in the GMDSS, *El Faro* was required by federal regulations (47 *CFR* 80.1123) to maintain a radio watch on specified channels for maritime safety information (including weather reports) broadcast by the National Weather Service and other government agencies. The ship was also required to maintain a radio watch on safety and distress frequencies. In addition, as a GMDSS vessel that traveled more than 100 nm from shore, *El Faro* was required to be equipped with an onboard Inmarsat ship earth station and to monitor the station for shore-to-ship distress alerts, including weather-related alerts.[130]

Inmarsat is a British company that operates global satellite telephone and data communication services.[131] The company relays weather forecasts and warnings, marine navigational warnings, and other safety-related information to ships and aircraft at no charge through Inmarsat-C SafetyNET, part of the GMDSS. At the time of the *El Faro* accident, the National Weather Service delivered weather information via Inmarsat-C under contract to Airbus DS Satcom Government, Inc., which forwarded the information to Inmarsat via a land earth station in Eik, Norway, for satellite broadcast.

National Weather Service products that applied geographically to the *El Faro* accident voyage and that were received by the vessel via Inmarsat-C SafetyNET were the tropical cyclone forecast/advisories issued by the National Hurricane Center and the high seas forecasts issued by the Ocean Prediction Center. The NTSB determined that a total of about 50 forecasts and advisories (including repeated messages) from the two centers was transmitted to Inmarsat for broadcast between 2000 on September 27 and 1000 on October 1. All high seas forecasts issued by the Ocean Prediction Center from 1803 on September 29 through the accident time carried an urgent priority (pan-pan).

Bon Voyage System. Applied Weather Technology, Inc., a maritime weather-routing software company, made its product BVS available to *El Faro* during the accident voyage. BVS is a desktop application that can be installed on ship or shore computers. Version 7 of BVS, which appears to be the version installed on *El Faro*, is described in the product brochure as

[130] A *ship earth station* is an Inmarsat communication device carried on board a ship.

[131] Inmarsat was originally a nonprofit intergovernmental organization established in 1979 by the IMO but was privatized in 1999.

> a graphical marine voyage optimization system that provides on-board and around-the-clock weather-routing information. . . . Using [an] on-board computer, BVS 7 provides the most recent weather and ocean data to the ship by broadband or email communications in a highly compressed format. . . . This data is then used to generate color-enhanced maps and graphics that allow the ship's captain to easily view and interpret potential problem areas in advance.

BVS is believed to have been installed on at least two computers on *El Faro*, one in the captain's office and one on the vessel's bridge, although the provider was not certain how many installations of BVS were on *El Faro* or where they might have been. Subscribers can receive BVS weather files by email (as did *El Faro*) or by broadband internet. According to Applied Weather Technology, BVS weather files were delivered to only one email address on *El Faro* (the captain's), but single recipients usually distributed the files internally by email.

The computer models that produce forecast data for the BVS weather files start every 6 hours, and the weather files are emailed to users about 9 hours after a model run begins. In the days leading to and including the sinking, BVS files were emailed to *El Faro* 2 minutes after the nominal availability times (0500, 1100, 1700, and 2300). Tropical cyclone information from the National Hurricane Center is included for graphic depiction in the BVS weather files. However, only data available until 20 or 25 minutes before the nominal delivery time of the BVS weather file are included. Thus, if the National Hurricane Center issues tropical cyclone information within 20 to 25 minutes of the BVS delivery time, the information will not be included in the BVS file. As shown in table 3, the National Hurricane Center generally issued its public tropical cyclone forecast/advisories for Joaquin from a few minutes to about a half hour early on the days before the sinking.

Table 3. Nominal and actual issuance times for topical cyclone forecast/advisories.

Date	Issuance Time	
	Nominal	Actual
September 28	1700	1643
September 28	2300	2236
September 29	0500	0432
September 29	1100	1035
September 29	1700	1651
September 29	2300	2253
September 30	0500	0437
September 30	0500*	0634*
September 30	1100	1053
September 30	1700	1649
September 30	2300	2249
October 1	0500	0443

* Corrected version of forecast/advisory.

Separately emailed tropical update files are also available for BVS but only if a user specifically requests them, according to the "Delivery Schedule" section of the BVS user manual.[132] (BVS files delivered on broadband are automatically updated.) Other information in the BVS manual suggests, however, that even without special requests, the most recent data will be delivered by requesting BVS emails at the four times listed on the software's scheduling dialogue box. According to Applied Weather Technology, *El Faro* did not request any separate tropical update files.

Seven BVS files were emailed to *El Faro* during the accident voyage. Each file included six text products from the National Hurricane Center and Ocean Prediction Center that applied to the accident area. Table 4 compares the nominal delivery times of the BVS files with the actual times the text products were publicly disseminated, from the evening of September 29 until the morning of October 1.

Table 4. Delivery times of BVS weather files and dissemination times of text products.

Delivery Time (nominal) of BVS Weather File	Public Dissemination Time (actual) of Included Weather Forecasts and Advisories
1700 September 29	1035 September 29 .... Tropical cyclone forecast/advisory 1250 September 29 .... Tropical cyclone discussion 1403 September 29 .... Tropical weather discussion 1147 September 29 .... Offshore waters forecast 0311 September 29 .... Marine weather discussion 1205 September 29 .... High seas forecast
2300 September 29	1651 September 29 .... Tropical cyclone forecast/advisory 1652 September 29 .... Tropical cyclone discussion 1951 September 29 .... Tropical weather discussion 1718 September 29 .... Offshore waters forecast 1447 September 29 .... Marine weather discussion 1803 September 29 .... High seas forecast
0500 September 30	2253 September 29 .... Tropical cyclone forecast/advisory 2254 September 29 .... Tropical cyclone discussion 0203 September 30 .... Tropical weather discussion 2312 September 29 .... Offshore waters forecast 1447 September 29 .... Marine weather discussion 0002 September 30 .... High seas forecast
1100 September 30	0634 September 30 .... Tropical cyclone forecast/advisory 0449 September 30 .... Tropical cyclone discussion 0812 September 30 .... Tropical weather discussion 0514 September 30 .... Offshore waters forecast 0317 September 30 .... Marine weather discussion 0547 September 30 .... High seas forecast

[132] Tropical update files are sent about 30 minutes after the regular BVS weather files and include any updated National Hurricane Center tropical cyclone information.

Delivery Time (nominal) of BVS Weather File	Public Dissemination Time (actual) of Included Weather Forecasts and Advisories
1700 September 30	1053 September 30 .... Tropical cyclone forecast/advisory 1058 September 30 .... Tropical cyclone discussion 1327 September 30 .... Tropical weather discussion 1155 September 30 .... Offshore waters forecast 1439 September 30 .... Marine weather discussion 1211 September 30 .... High seas forecast
2300 September 30	1649 September 30 .... Tropical cyclone forecast/advisory 1655 September 30 .... Tropical cyclone discussion 1953 September 30 .... Tropical weather discussion 1730 September 30 .... Offshore waters forecast 1501 September 30 .... Marine weather discussion 1808 September 30 .... High seas forecast
0500 October 1	2249 September 30 .... Tropical cyclone forecast/advisory 2250 September 30 .... Tropical cyclone discussion 0154 October 1 .... Tropical weather discussion 2314 September 30 .... Offshore waters forecast 0225 October 1 .... Marine weather discussion 0017 October 1 .... High seas forecast

NOTE: High seas forecasts were issued by the Ocean Prediction Center; others by the National Hurricane Center.

At the times the BVS weather files were emailed to *El Faro*, the storm location and forecast track in the BVS weather files were not current with the information then available from the National Hurricane Center or through Inmarsat-C SafetyNET. Rather, they were consistent with the data issued in the tropical cyclone forecast/advisory about 6 hours earlier (6-hour latency). Information current with the latest tropical cyclone forecast/advisory was, however, available in the tropical update files (which *El Faro* did not elect to receive) that were sent 30 minutes after the BVS weather files. The tropical cyclone forecast/advisories were delivered to *El Faro* via Inmarsat-C SafetyNET and were also available through other onboard options.

Data on Joaquin's current and forecast intensities (maximum sustained wind and wind gust magnitude) in the BVS files also reflected information delivered about 6 hours earlier (through Inmarsat-C SafetyNET). The intensities in the emailed tropical update BVS weather files, if that option had been selected, would have agreed with those in the current tropical cyclone forecast/advisory.

A problem with the BVS system caused the weather file emailed to *El Faro* at 0500 on September 30 to duplicate the file emailed 6 hours earlier (at 2300 on September 29). Intensities in the 0500 file would have been consistent with the tropical cyclone forecast/advisory that was delivered via Inmarsat-C SafetyNet about 12 hours earlier (advisory No. 8). Hence, the information in the file emailed at 0500 on September 30 was at least 12 hours old (12-hour latency). Applied Weather Technology reported that its data update system had "updated 'tropical storm track file' for all products except BVS 7 [the version on *El Faro*] in the specific timeframe."

The VDR transcript captures discussions on *El Faro*'s bridge about images from the BVS weather files. Figure 40 illustrates what the *El Faro* captain and other crewmembers could have seen when using the BVS files. The image is a screenshot from the BVS weather file emailed to *El Faro* about 2300 on September 30 but not downloaded by the captain until 0445 the next morning. The image shows Joaquin's center position and wind fields forecast as valid for 0800 on October 1 (shortly after the sinking). (For reference, the ship's position at 2300 on September 30 is shown by a small blue triangle, which would not have appeared on the actual image.)

The image also shows the sea-level pressure (red contour lines), surface wind (barbs), and significant wave height (colored contours) forecast for the same time. (Users could project forecasts into the future at 3-hour intervals when viewing data from any one BVS weather file. In this case, the storm position for 0800 is shown according to the forecast track that was issued about 1700 the day before.) The storm center is denoted by a solid red symbol composed of an overlapping 6 and 9.

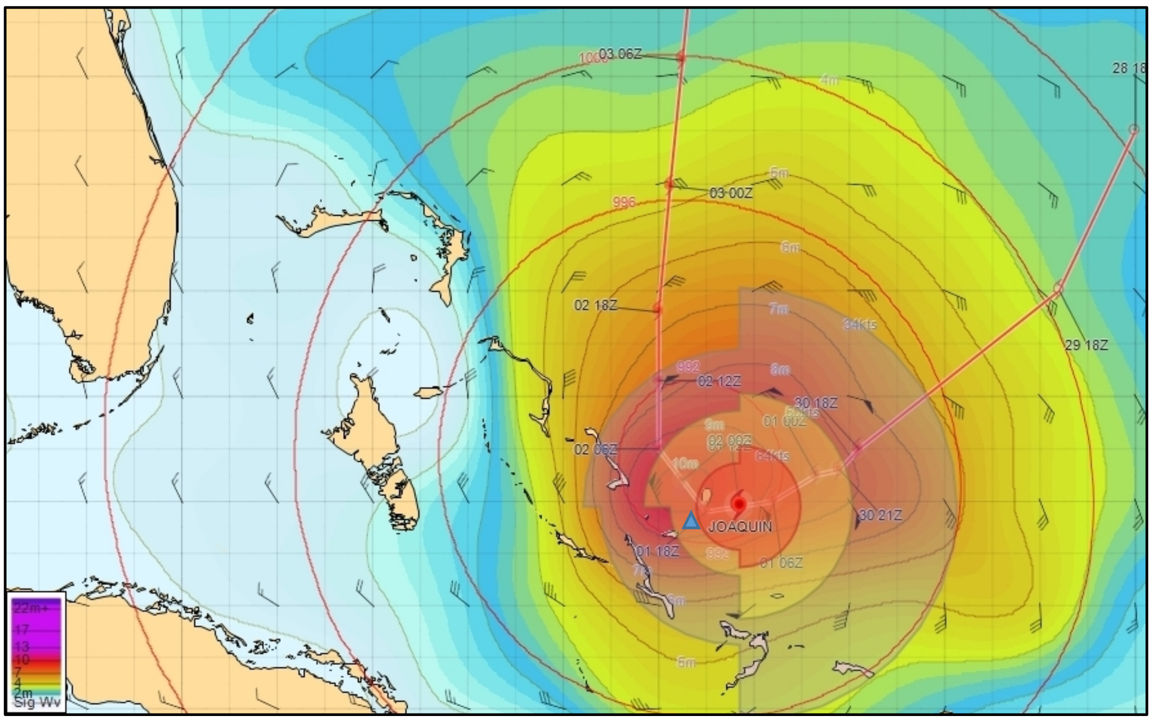

Figure 40. Screenshot of BVS weather file sent to *El Faro* about 2300 on September 30, showing forecast valid for 0800 on October 1. Image was part of BVS file not downloaded until 0445 on October 1. Ship's position at 2300 on September 30 is shown as blue triangle for reference.

Figure 41 is a display developed by NTSB investigators of the wind fields around Joaquin forecast for 0800 on October 1, based on the tropical cyclone forecast/advisory text issued (nominally) at 2300 on September 30 (advisory No. 13). The display shows the maximum extent of the 34-knot (tropical-storm-force), 50-knot, and 64-knot (hurricane-force) wind fields for each quadrant (northwest, northeast, southeast, southwest) around Joaquin's center that were forecast for the same time.

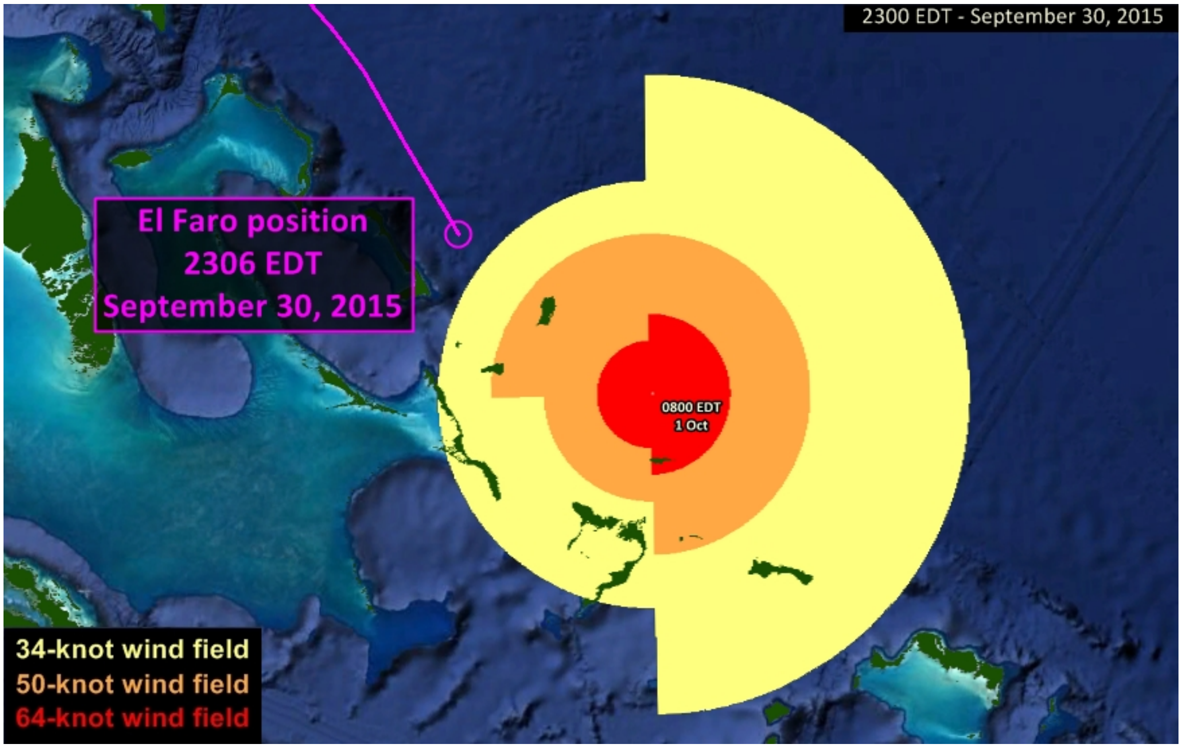

Figure 41. Depiction of wind fields forecast for 0800 on October 1 using data from tropical cyclone forecast/advisory No. 13, issued about 2300 on September 30 and received on *El Faro*'s Sat-C terminal at 2253. Figure also shows ship's position at approximate time forecast was received.

In describing a hurricane, the circle around the eye at the center of the storm is divided into quadrants. The extent of each quadrant is defined by the radius of the maximum wind speed—the distance between the center of the cyclone and its band of strongest winds. Thus, the outlines of each wind field can be different, as in figure 41. Winds are defined as being of tropical storm force beginning at 34 knots.

As explained in a mariner's guide to hurricanes published by the National Weather Service's Tropical Prediction Center (Holweg 2000), 34 knots is a critical value because when winds reach that speed, the sea state begins to severely limit a ship's ability to maneuver away from a storm, putting the vessel and its crew in peril. In the northern hemisphere, conditions are more dangerous on the right side of a tropical cyclone, known as the dangerous semicircle, than on the left side, called the navigable semicircle.[133] The forward motion of the storm increases the speed of the wind in the dangerous semicircle, which creates higher seas. When wind speed doubles, the force it generates increases by about a factor of four. (See appendix E for specific information on hurricane avoidance.)

The BVS weather files went directly to the captain's email address, which he accessed from his office. The computer on the bridge did not receive the BVS emails directly. Rather, the captain would download the data and send them to the bridge email address himself. Once an email was opened, the BVS data could be downloaded and reviewed. According to a chief mate who had

[133] Right and left are relative to the direction in which the storm is traveling.

recently sailed aboard both *El Faro* and *El Yunque*, the process was different on *El Yunque*, where BVS data were sent to the email addresses of both the captain and the bridge.

Investigators used GlobeArchive email records to determine when BVS emails were transmitted to *El Faro* and downloaded (table 5). Records indicate that the captain routinely downloaded the weather package within about 1 hour of receiving it. The BVS email sent at 2302 on September 30, the evening before the sinking, was not, however, downloaded until 0445 on October 1, a gap of 5 hours and 41 minutes. The final BVS weather package downloaded on *El Faro* was the data sent at 0502 on October 1 and downloaded an hour later.

Table 5. Times BVS emails sent to *El Faro* and downloaded during final voyage.

Date	Time Email Sent	Time Email Available for Download	Time Email Downloaded
September 29	1702	1704	1837
September 29	2302	2304	2329
September 30	0502	0504	0608
September 30	1102	1103	1124
September 30	1702	1703	1747
September 30	2302	2304	0445 (October 1)
October 1	0502	0503	0609

Figure 42 plots the information available to the bridge team around 0500 the morning of the accident, after the captain downloaded the previous evening's BVS file that had been available to him at 2304 and just after the new weather information delivered by Sat-C was available on the bridge (at 0446). At that point, the BVS information (blue) was almost 12 hours old (6-hour latency, as described above, plus additional time between receiving the email and downloading the data). The Inmarsat-C information was current as of 0446.

The captain stated on the VDR at 0503, "We're getting conflicting reports as to where the center of the storm is."

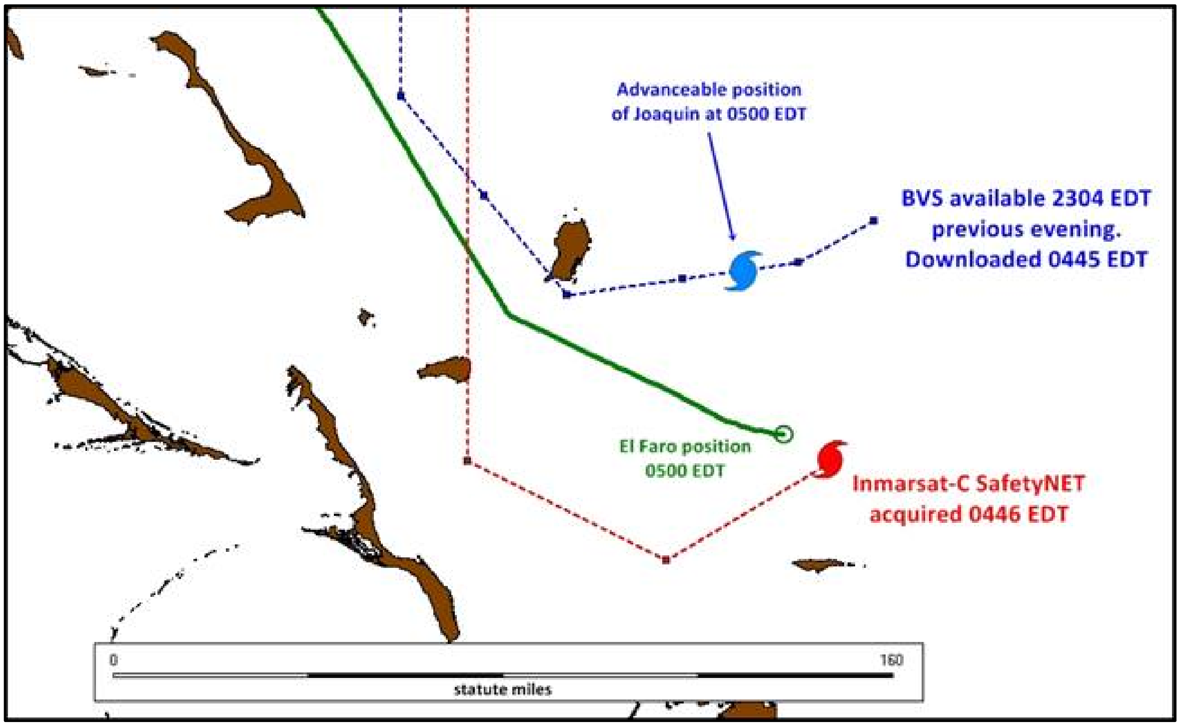

Figure 42. Positions of Joaquin obtained by *El Faro* and available on the bridge around 0500 on October 1. (Plotted by NTSB)

1.10.4 Weather Data from Other Sources

No weather buoys were known to be deployed within 250 nm of the accident site, according to the National Hurricane Center and the National Data Buoy Center website. The National Hurricane Center received four ship reports from vessels that observed winds of 34 knots or greater within 400 nm of the hurricane between 2000 on September 28 and 1400 on October 1. The captain of *El Yunque* emailed the *El Faro* captain on September 30 that he had recorded a wind gust of 100 knots. Investigators could not identify any public ship report that delivered a wind observation of that magnitude.

El Faro sent a public ship report for conditions at 1000 on September 30, the only report the National Weather Service received from *El Faro* during the accident voyage. The report gave wind speed as 3 knots, visibility as 11 to 27 nm, air temperature as 30.6°C (87°F), sea surface temperature as 27.6°C (81.6°F), height of waves as 3 or 4 feet, and period of waves as 4 seconds. The vessel's location was reported as 21N, 77.1W, which would have placed it in Cuba.

Aircraft operated by the US Air Force Reserve 53rd Weather Reconnaissance Squadron and NOAA's Aircraft Observation Center flew missions to collect data on Joaquin. The missions included flight-level observations, retrieval of surface wind magnitude from the stepped-frequency microwave radiometer (SFMR), and dropsonde observations.[134] NOAA's two P3 aircraft were unavailable for missions because both were grounded for maintenance during Joaquin.

Figure 43 illustrates distances from the storm where 34-, 50-, 64-knot, and peak winds might have occurred near the accident time. Distances are based on SFMR surface wind data retrieved during a reconnaissance flight close to the time of the sinking, as well as the National Hurricane Center's poststorm best-track analysis. The best track is a poststorm, smoothed representation of a tropical cyclone's location and intensity over its lifetime (see section 1.10.5). The SFMR data are peak 10-second average observations of surface wind within a 30-second reporting interval. The red and tan areas depict the best-track estimates of the farthest extent that 50- and 64-knot winds occurred in each storm quadrant about 0800 on October 1. In the storm's northwest quadrant, the best-track analysis was that 50-knot winds extended outward as far as 50 nm from the center.

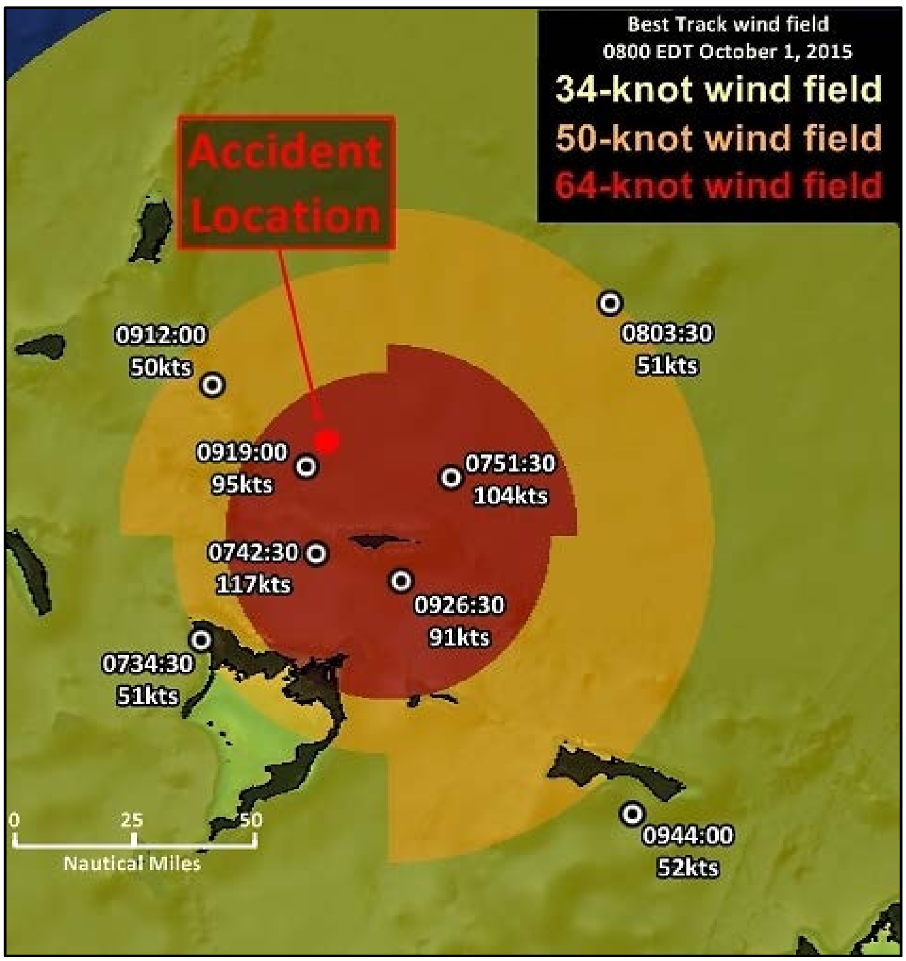

Figure 43. Surface winds from SFMR observations overlaid on best-track wind fields for 0800 on October 1. SFMR observations are labeled with midpoint of each 30-second reporting interval and average wind magnitude.

[134] A *dropsonde* is a miniature radio transmitter dropped by parachute from aloft to obtain pressure, temperature, and moisture measurements of the air below.

Figure 44 is an image from one of the US weather satellites that passed over the accident site around the time *El Faro* sank. The image is from visible (~0.7 micron) data captured about 0800 the morning of October 1 by the Operational Linescan System instrument on the Defense Meteorological Satellite Program (DMSP) F19 polar-orbiting weather satellite. The satellite was operated jointly by NOAA and the Air Force.

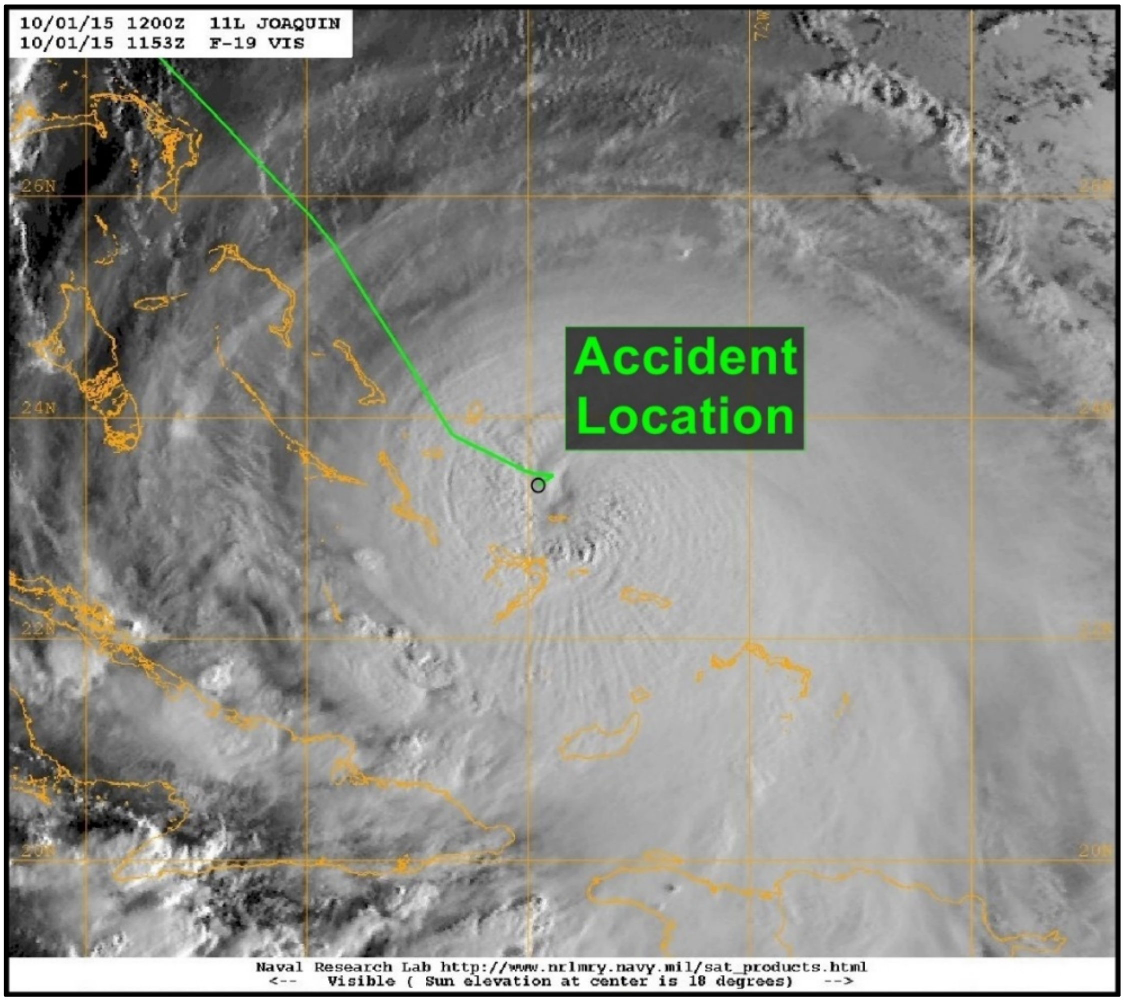

Figure 44. Visible image of Joaquin captured about 0800 on October 1 by DMSP F19 polar-orbiting weather satellite, with *El Faro*'s track superimposed in green.

1.10.5 Tracking Errors

On January 12, 2016, the National Hurricane Center released a poststorm report on Hurricane Joaquin (Berg 2016). According to the report, at the time of the sinking, Joaquin was a Category 3 hurricane with an intensity of 110 knots. The poststorm analysis determined that Joaquin officially became a Category 4 hurricane (intensity of 115 knots) about 20 minutes after the accident. The storm remained near the Bahamas through October 2. On October 3, the hurricane accelerated northeastward away from the Bahamas and reintensified, reaching a peak intensity of around 135 knots, just below Category 5 (winds 137 knots and higher) strength.

The National Hurricane Center told investigators that its best estimate of Joaquin's eye diameter in the hours immediately before and after *El Faro* sank (between 0500 and 0900 on October 1) was 25 to 30 miles. Sea surface temperatures in the accident area were the warmest on record for the period between September 18 and 27, according to the poststorm report. Research has shown a link between warmer oceans and more intense hurricanes (NOAA 2015b).

The report surveyed the meteorological environment before and during the hurricane and plotted its best-track positions, reproduced here as figure 45. The best track plots the cyclone's latitude, longitude, maximum sustained surface winds, and minimum sea-level pressure at 6-hour intervals, ignoring short-term variations in position or intensity that cannot be resolved.

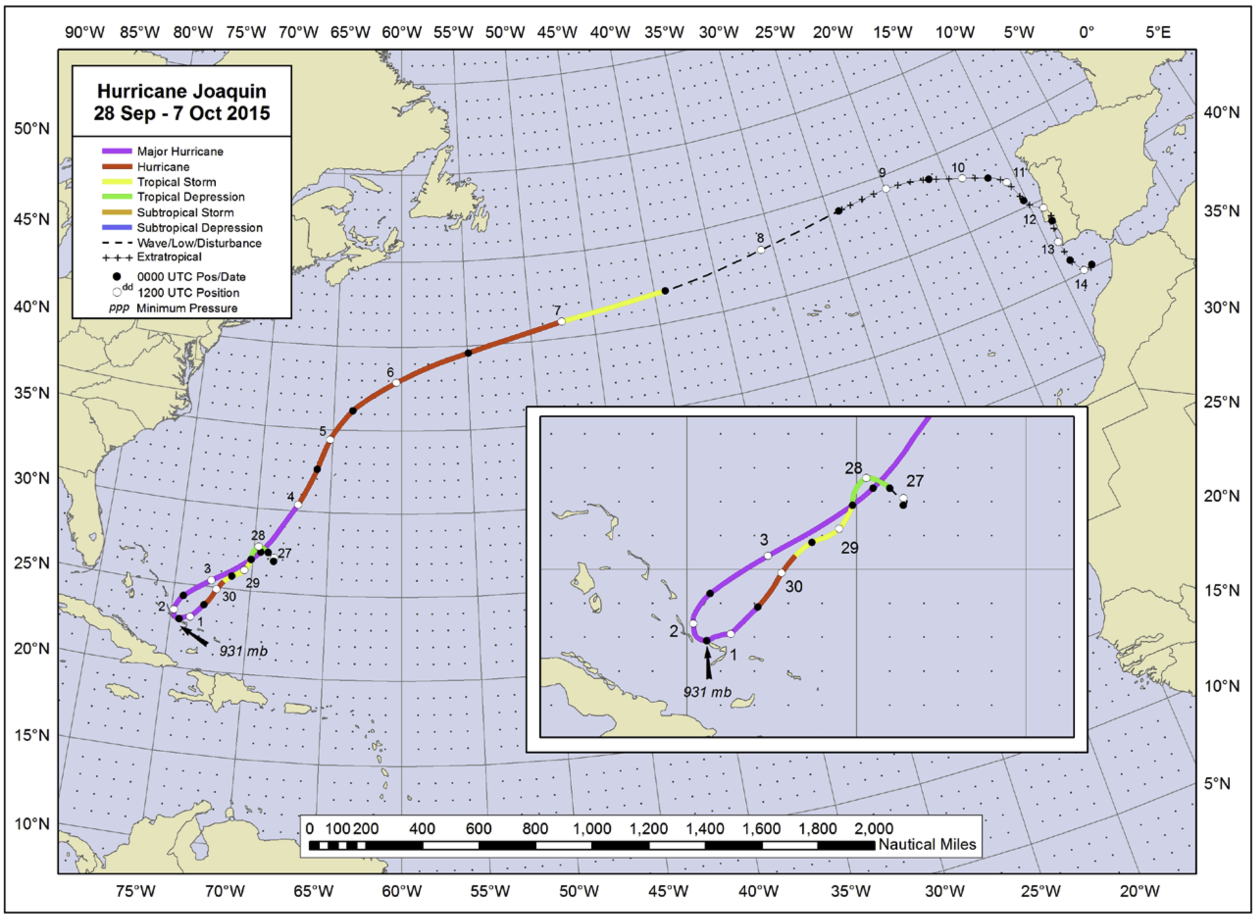

Figure 45. Best-track positions for Hurricane Joaquin. (Image from Berg 2016)

The National Hurricane Center's report critiques its forecasting for Joaquin. Errors in the forecast track "between 72 and 120 h[ours] were double the mean official errors for the previous 5-y[ea]r period." The report attributes the errors largely to "Joaquin's atypical southwestward motion toward the Bahamas" between September 28 and October 1. According to the report, most of the prediction models, as well as the official forecast, indicated that Joaquin would move toward the northwest or west. The model run by the European Centre for Medium-Range Weather Forecasting, however, accurately depicted the hurricane's southwestward motion after the first two model runs, "partly due to the model's deepening of the cyclone more than the other models, with a deeper-layer flow subsequently pushing Joaquin southwestward," according to the report.

Figure 46 illustrates the hurricane center's 5-day forecast tracks and best track for Joaquin through the morning of October 1. With regard to intensity, the National Hurricane Center's report states, "Official forecast intensity errors were greater than the mean official errors for the previous 5-y[ea]r period at all forecast times."

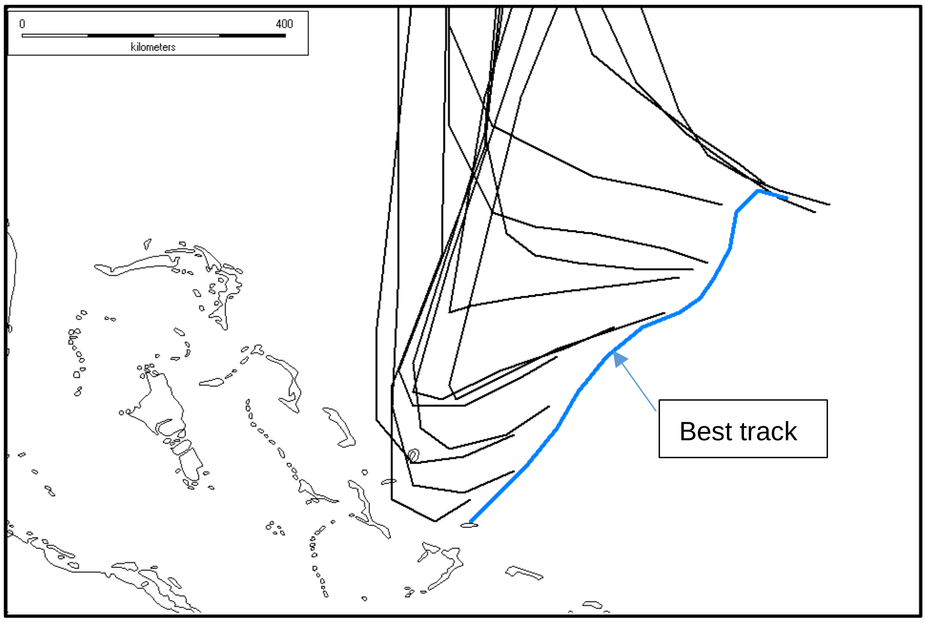

Figure 46. Official 5-day forecast tracks and best track for Hurricane Joaquin through October 1. Joaquin's actual overall movement was south-southwest through October 1, as shown by best track (blue line). Forecast tracks (black lines) show Joaquin moving first northwest, then later west and southwest before beginning to track northward. (Lines track right to left.)

National Hurricane Center employees told investigators that Joaquin was one of its most challenging storms when it came to forecasting the storm track. In particular, the computer models had difficulty defining the cyclone's vertical structure (system depth). According to the hurricane center, early model solutions agreed that Joaquin would remain a relatively weak system because of a strong northerly wind shear and would move northwest.[135] Contrary to the forecasts, Joaquin strengthened, became a deep system, and moved southwest.

Investigators calculated the errors in track and intensity for Joaquin in the tropical cyclone forecast/advisories issued in the 48 hours before the sinking. The calculations compared Joaquin's forecast positions and intensities valid for 0800 on October 1 with the actual, best-track position and intensity on October 1 at 0800 (table 6). Because a forecast is not released (nominally) until 3 hours after the forecast is initiated, the time difference between the product's scheduled

[135] *Wind shear* is a radical shift in wind speed and direction that occurs over a very short distance.

dissemination time and 0800 on October 1 was always 3 hours less than the applicable forecast period.[136]

Table 6. Errors in Joaquin's center position and intensity predicted for 0800 October 1.

Scheduled Forecast/Advisory Dissemination Time	Forecast Center Position and Intensity	Forecast Period	Errors
1100 September 29	26.1N, 073.7W / 55 knots	48 hours	180 nm / 60 knots
2300 September 29	24.8N, 74.1W / 80 knots	36 hours	104 nm / 35 knots
1100 September 30	24.1N, 74.0W / 85 knots	24 hours	62 nm / 30 knots
2300 September 30	23.5N, 73.8W / 110 knots	12 hours	25 nm / 5 knots

NOTE: Errors rounded to nearest whole number.

Mean 5-year errors (between 2010 and 2014) in the National Hurricane Center's forecast track and intensity were 77.1 nm/13.3 knots for the 48-hour forecast period, 60.4 nm/11.5 knots for the 36-hour forecast period, 45.0 nm/9.4 knots for the 24-hour forecast period, and 28.4 nm/6.2 knots for the 12-hour forecast period (Berg 2016).

1.10.6 Simulations

At the NTSB's request, the Environmental Modeling Center at NOAA's National Centers for Environmental Prediction simulated wind and sea-state conditions for Joaquin during the accident time using global atmospheric models, high-resolution hurricane models, and underlying ocean wave and circulation models. The results indicated, in part, that "maximum wind speeds in the area around the time of the accident exceeded 100 knots with waves reaching heights of between 7-10 m[eters] and peak periods of 9-12 s[econds]. Spectral results showed complex crossing sea patterns with swell and multiple wind sea components" (Chawla 2016). Results of the study were used as input values to the NTSB-directed dynamic analysis that simulated motions of *El Faro* during the storm.

1.10.7 Astronomical Data

According to US Naval Observatory data, on the morning of September 30 at 28.65N, 78.66W (*El Faro*'s approximate position at sunrise), nautical twilight began at 0616, civil twilight began at 0643, and sunrise was at 0707. On the evening of September 30 at 25.65N, 75.81W (*El Faro*'s approximate position at sunset), sunset was at 1851, civil twilight ended at 1914, and nautical twilight ended at 1941.[137]

Near the accident site on October 1, nautical twilight began at 0617, civil twilight began at 0624, sunrise was at 0647, sunset was at 1843, civil twilight ended at 1905, and nautical twilight

[136] A forecast initiated at 2000 that is valid for 0800 the next day would have a forecast period of 12 hours.

[137] The moon rose at 2025 on September 29.

ended at 1952. The Naval Observatory website defines nautical twilight as the time when "under good atmospheric conditions and in the absence of other illumination, general outlines of ground objects may be distinguishable." Civil twilight is defined as the time when "illumination is sufficient, under good weather conditions, for terrestrial objects to be clearly distinguished."[138]

1.11 Survival Factors

1.11.1 Emergency Response

Day 1. At 0706 on Thursday, October 1, the *El Faro* captain called the company's DP to inform him that the ship was listing to port and had lost propulsion. At 0724, as required by company procedures, the DP called the Coast Guard Atlantic Area (LANTAREA) command center in Portsmouth, Virginia, which is the Coast Guard Atlantic Area search-and-rescue coordinator, to notify it of the vessel's distress.

The DP set up TOTE's incident command center in Jacksonville and at 0745 put T&T Marine Salvage company of Galveston, Texas, on notice. At 1130 central daylight time (CDT), ABS headquarters in Houston, Texas, assembled a Rapid Response Damage Assessment (RRDA) group. The RRDA group is a team of naval architects, marine engineers, master mariners, and support staff that conducts structural and stability calculations for shipowners. TOTE kept close contact with the Coast Guard's Seventh District Command Center (D7CC) in Miami, holding conference calls in the morning, evening, and during search-and-rescue operations. TOTE provided senior liaison employees to D7CC, and the Coast Guard provided liaison officers from Sector Jacksonville.

At 0713, *El Faro* sent an Inmarsat-C distress alert showing a position about 35 nm northeast of Crooked Island. An Inmarsat-C distress alert can be sent by the crew when a ship is in danger. The GMDSS operator on board, typically a ship's officer, can manually input information, or the GMDSS operator can press and hold down a dedicated distress button for about 5 seconds to transmit an alert. When the button is pressed, a short, preformatted message is transmitted, with priority, from the ship's terminal to a land earth station, which automatically routes it to a maritime rescue coordination center. The distress alert transmits date and time; the ship's position, course, and speed; time of last position update; and nature of distress. If the operator formats a customized message without immediately sending it, the vessel's position is locked in at the time the message was written and is not updated unless the terminal is powered off and restarted.

At 0715, the land earth station in Eik, Norway, automatically forwarded *El Faro*'s alert to the LANTAREA command center. The land earth station also forwarded a supplemental alert that included vessel-specific information. The LANTAREA command duty officer called D7CC and asked it to assume the role of search-and-rescue mission coordinator, work with the Bahamas rescue coordination center to respond, and keep LANTAREA informed. He then forwarded to D7CC the Inmarsat-C alert position as well as the position received from the phone call with the

[138] See http://aa.usno.navy.mil/faq/docs/RST_defs.php.

DP. The Inmarsat-C position was used as *El Faro*'s last known position for the search-and-rescue operation.

Two alerts from *El Faro*'s SSAS were sent at 0713:49 and 0715:57, respectively, and automatically forwarded by the land earth station in Norway on October 1. The first was sent to the Coast Guard at 0715, with position 23:25.39N, 073:52.51W, course 214°, speed 4 knots. The second SSAS alert was sent to TOTE at 0717, with position 23:25.22N, 073:52.68W, course 227°, speed 10 knots. As noted earlier, the SSAS is a covert distress signal intended for use in case a vessel is attacked. It alerts the company's security officer and flag state about an attack but generates no audible or visible alarm onboard the vessel and is not broadcast to other ships. The SSAS is activated by pressing a dedicated button at the ship's emergency communications station, which then transmits the ship's identity, position, course, and speed.

At 0735, a transmission from *El Faro*'s registered EPIRB was detected by geostationary satellite GOES-East. An EPIRB is a float-free, automatically activated device detectable by satellite anywhere in the world. The device emits a 406-MHz distress signal containing a unique identification code that can be used to reference information about the carrying vessel, including its name, type of survival gear, and emergency points of contact ashore. A geostationary satellite, positioned about 22,000 miles above the earth, provides continuous coverage and receives all information transmitted by an EPIRB for a given region. *El Faro*'s EPIRB was identified by a unique hexadecimal beacon identifier that was transmitted to the US Mission Control Center through the local user terminal at the NOAA search-and-rescue satellite-aided tracking (SARSAT) facility in Suitland, Maryland.[139] The beacon identifier corresponds to registration data held by NOAA.[140]

If an EPIRB is not equipped with an embedded GPS receiver, alerts received by geostationary satellites will not contain position information.[141] *El Faro*'s EPIRB model did not have a built-in GPS, so the alert was received and forwarded as a "406 beacon unlocated first alert" message. The message was automatically processed at 0739 and sent as an email to D7CC. The position of a non-GPS-enabled EPIRB can, however, be determined to within about 2 miles by low earth orbit satellites, which travel about 1,200 miles above the earth. According to SARSAT, no low earth orbit satellites were in view of *El Faro*'s position during the 24 minutes the EPIRB was transmitting. The EPIRB stopped transmitting 6 minutes before a low earth orbit satellite passed in view of where the EPIRB had been transmitting.[142] Therefore, no position could be derived from the low earth orbit satellite system (NOAA 2016).

At 1035, D7CC requested that an Air Force hurricane hunter, which was on a weather reconnaissance mission, fly over *El Faro*'s last known position, make radio callouts on VHF

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[139] Distress alerts passed to the US Mission Control Center in Suitland, Maryland, are automatically forwarded by position—in the water to the Coast Guard and on the land to the Air Force.

[140] SARSAT 406-MHz emergency beacons are required to be registered with NOAA. Vessel owners must send their identifying information to NOAA when they purchase a new or used EPIRB.

[141] The position transmitted by a GPS-encoded EPIRB, available since 1998, is accurate to under 100 yards (NOAA 2017a).

[142] The low earth orbit satellites traveled over *El Faro*'s position between 0622 and 0647 and between 0804 and 0824 on the morning of October 1.

channel 16, and conduct a radar search.[143] The aircraft did so, with negative results. The hurricane hunter was unable to descend below 10,000 feet because of the storm, and radar detection was ineffective due to feedback from heavy precipitation.

At 1106, D7CC requested the inter-island freighter *Emerald Express*, the nearest vessel to *El Faro*, to proceed to *El Faro*'s last known position and assist. The captain of the *Emerald Express* declined, stating that he was in the lee of Acklins and Crooked Island attempting to ride out the storm and could not risk exposing his vessel, a modified landing craft, to higher seas. The *Emerald Express* made callouts to *El Faro* on VHF channel 16, heard by the hurricane hunter, with negative results. The *Emerald Express* did not inform D7CC when it stopped making radio callouts to *El Faro*.

Day 2. On Friday, October 2, the day after the accident, an HC-130 aircraft (CG1503) from Coast Guard Air Station Clearwater, Florida, took off at first light to conduct parallel search patterns to locate *El Faro*.[144] The aircraft could not get within 100 nm of the hurricane because of severe winds at 3,000 feet altitude. The aircraft crew reported a visibility of 2 nm, heavy rain and spray, and heavy seas with whitecaps and foam. When the aircraft returned to base, a fuel leak was discovered that was determined to have been caused by the severe weather, so the next sortie was canceled. At 0905, the search-and-rescue mission coordinator canceled all additional sorties that day because of rough weather. The coordinator explained that an MH-60 helicopter flying at 140 knots into 100-knot headwinds would be flying at a speed over the ground of only 40 knots.

Two Coast Guard HC-130s from Air Station Elizabeth City, New Jersey, were temporarily stationed at Coast Guard Air Station Clearwater for the *El Faro* search-and-rescue operations. D7CC also tasked the Coast Guard medium endurance cutter *Northland*, on patrol south of Cuba, to assist. The *Northland* was ordered to proceed to the US Naval Base at Guantanamo Bay, Cuba, for a brief stop for fuel and provisions and then to *El Faro*'s last known position, as weather permitted.

Flying above the hurricane on a storm-surveillance mission, an Air Force hurricane hunter attempted to call *El Faro* on VHF channel 16 and did a radar search, with negative results. The only air sorties on the first 2 days of the search were the high-altitude weather surveillance missions by the hurricane hunters and the single Coast Guard HC-130 sortie that could not get within 100 nm of the storm.

D7CC put into position for the search three Coast Guard MH-60 helicopters that were participating in Operation Bahamas Turks and Caicos.[145] Two helicopters from Air Station Clearwater were deployed on Great Inagua Island, Bahamas, and a third was deployed at the

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[143] The hurricane hunter, a WC-130J Hercules, is a medium-range aircraft flown on weather reconnaissance missions by the Air Force Reserve Command's 53rd Weather Reconnaissance Squadron at Keesler Air Force Base, Mississippi. The aircraft penetrates tropical disturbances to obtain data on a storm's movement, size, and intensity.

[144] *First light* means roughly dawn, twilight to sunrise. When the Coast Guard specifies first light, aircraft are expected to be on scene at dawn to maximize the crew's ability to see objects or people.

[145] Operation Bahamas Turks and Caicos was a combined operation of the US Drug Enforcement Administration, the Coast Guard, and the government of the Bahamas to combat drug smuggling to and from the Bahamas.

Atlantic Undersea Test and Evaluation Center, on the east side of Andros Island, to support search efforts once the storm moved northwest.

Day 3. At 0504 on Saturday, October 3, the same Coast Guard HC-130 that had searched the day before took off from Air Station Clearwater and was on station at 0654 (sunrise was at 0703 in Nassau, Bahamas) to begin searching. The HC-130 completed a 4-hour parallel search pattern assigned by D7CC, with negative results. The aircraft made numerous unsuccessful attempts to break through the wind bands to search the drift area that had been computed based on *El Faro*'s last known position. The aircrew reported challenging search conditions, with visibility as low as 1 nm. Hurricane-force winds caused significant sea spray, white caps, and swells of 20 to 40 feet. The aircraft reported numerous smaller targets on radar but nothing as large as *El Faro*.

Also on October 3, a Coast Guard HC-130 aircraft located a debris field 120 nm northeast of Crooked Island. A Coast Guard MH-60 helicopter relocated the debris field and found three liferings, one of which was stenciled "El Faro." The helicopter located a second debris field 90 nm northeast of Crooked Island, consisting of small unidentified objects believed to be packing material. Three cutters, the *Northland*, the *Resolute*, and the *Charles Sexton*, were en route to the search area as weather and seas permitted.

Day 4. At 0100 on Sunday, October 4, the *Northland* arrived on scene and assumed duty as on-scene commander of search-and-rescue operations. Three HC-130 aircraft (two Coast Guard and one Air Force), a Navy P-8 aircraft, and a Coast Guard MH-60 helicopter completed first-light and morning searches. The Coast Guard HC-130 and MH-60 located the two separate debris fields spotted earlier. Weather conditions in the search area on October 4 were reported as visibility 10 nm, winds 15 to 20 knots, and seas 2 to 3 feet.

Three tugs chartered by TOTE—*Sentinel*, *Sentry*, and *Hawk*—and the cutter *Resolute*, carrying an MH-65 helicopter, arrived on scene about 1130 and began assisting with search-and-rescue and salvage duties. The TOTE vessel *El Yunque* searched as it transited the area while sailing from Jacksonville to San Juan. At 1500, an MH-60 helicopter located *El Faro*'s swamped starboard lifeboat about 7 nm west-southwest of *El Faro*'s position reported in the Inmarsat-C alert. The helicopter's rescue swimmer found the lifeboat heavily damaged, with no one aboard. The tug *Hawk* was directed to investigate and recover the lifeboat.

The Navy P-8 reported two liferafts in separate locations. At 1806, the cutter *Northland* found one of the liferafts at 23.4866N, 073.5883W, about 18 nm northeast of *El Faro*'s last known position. The ship's rescue swimmer searched the partially inflated liferaft for any sign of survivors.[146] Finding no one on board, the *Northland* sank the liferaft, to prevent its rediscovery and an ensuing duplicate search for survivors or remains, and proceeded to the position of the second liferaft. The Coast Guard later determined that the second reported liferaft was actually the starboard lifeboat.

At 1657 on October 4, the Navy P-8 reported an orange immersion suit about 40 nm west-northwest of *El Faro*'s last known position. At 1823, a Coast Guard MH-60 helicopter

[146] The liferaft's size (25-person or 6-person) and markings were not recorded in the Coast Guard's MISLE (Marine Information for Safety and Law Enforcement) database.

located an immersion suit in that area. The helicopter's rescue swimmer found that the immersion suit contained human remains, which he described as being in an advanced stage of decomposition. The body's gender and race could not be determined.

About the same time, the Navy P-8 reported another immersion suit 30 nm away, with a possible person in it waving his or her arms. Given the report of a potential surviving crewmember, the Coast Guard helicopter crew decided not to recover the remains at that time but to move toward the position reported by the Navy aircraft. The helicopter recovered its rescue swimmer and dropped a self-locating datum marker buoy (SLDMB) by the remains. The helicopter could not find the second reported immersion suit and, at sunset, returned to attempt to recover the remains. The crew was unable to relocate them. It was discovered later that the marker buoy had failed to transmit its position.[147] The helicopter aborted the search when darkness fell, and the *Northland* went to the scene to search throughout the night. Coast Guard cutters and salvage tugs continued to search on Sunday evening. The immersion suit with human remains was never recovered. As described below, two empty immersion suits were found later in the search. Figure 47 shows the location of the *El Faro* debris fields and objects discovered during search-and-rescue operations.

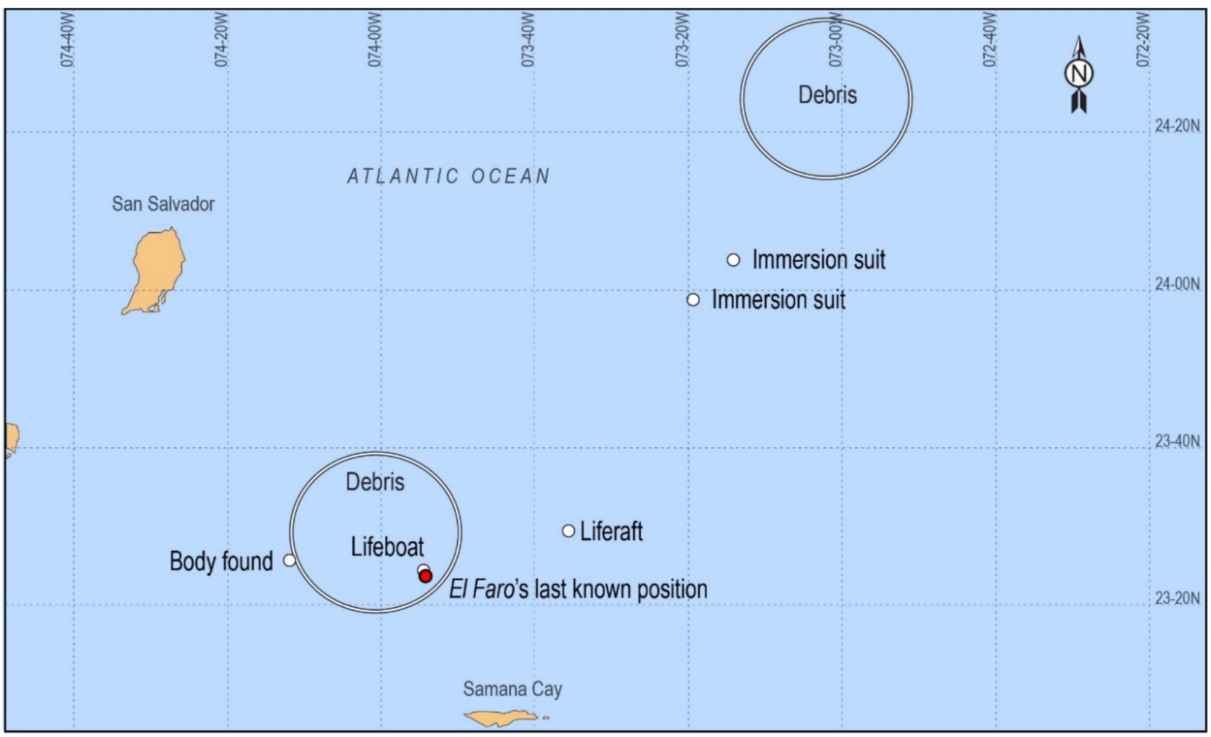

Figure 47. Two debris fields located during search-and-rescue operations and *El Faro*'s last known position from VDR data. Distance between debris fields was about 77 nm. Degrees of latitude are 60 nm apart. Distance between degrees of longitude varies with distance from equator, where it is about 60 nm. (Adapted from Coast Guard graphic)

[147] According to the Coast Guard, an SLDMB transmits real-time GPS position and water temperature to a satellite. The data are updated every 30 minutes for 10 days. The SLDMB used during the search, version 2, had a 62-percent success rate, a 16-percent partial success rate, and a 22-percent failure rate. After the accident, the Coast Guard transitioned to a new Iridium SLDMB.

Day 5. On Monday, October 5, a fixed-wing Navy P-8 and two Coast Guard HC-130s completed first-light and morning searches of the large debris fields and passed information about targets for investigating to the cutters, tugs, and helicopters. The fixed-wing aircraft were relieved in the afternoon by an Air Force and a Coast Guard HC-130. Searchers reported that visibility was unlimited, winds were 14 knots, and seas 2 to 3 feet.

In the early morning, an Air Force Joint Surveillance Target Attack Radar System (JSTARS) reconnaissance aircraft assisted the search effort while transiting the search area. The JSTARS aircraft conducted high-altitude sweeps of 19,305 square miles at a time. It confirmed the debris fields and that there was no large vessel in the search area. The JSTARS information helped establish that *El Faro* had sunk, which led the Coast Guard to change the accident's classification to a major marine casualty.

At 1000 on October 5, the Coast Guard announced at a morning press conference that the search would continue for survivors, but that from the debris that had been found, it was likely that *El Faro* had sunk. A Navy P-8 aircraft continued to support search efforts using a highly sensitive radar. The P-8 was initially used to search for the vessel at a very high altitude, which significantly increased the area searched. As weather conditions improved, the P-8 began to fly at lower altitudes (2,500 feet) to search for smaller objects. Searchers began recovering *El Faro* survival equipment during the day. Three lifebuoys, stenciled "El Faro" or "El Morro," were recovered and secured on board the cutter *Resolute* and the tug *Sentry*.[148] The three cutters continued to search throughout the night of October 5–6, with the three tugs remaining on scene in support.

Day 6. On Tuesday, October 6, a fixed-wing Navy P-8 and a Coast Guard HC-130 completed morning searches, with negative results. An MH-60 helicopter searched for washed-up debris along the Bahamas island chain near Long Island, Great Exuma, and Cat Island. The three cutters continued to follow search patterns, and the three tugs remained on scene in support. Three HC-130 aircraft (one Coast Guard and two Air Force) searched in the afternoon. Searchers reported visibility of 10 nm, winds from 190° at 5 knots, and seas 1 to 2 feet. At 1808, the cutter *Charles Sexton* recovered an empty immersion suit, stenciled "El Faro." The three cutters continued to search throughout the night, and the three tugs remained on scene supporting the search.

Day 7. On Wednesday, October 7, a Navy P-8 and three HC-130 aircraft (two Coast Guard and one Air Force) searched from 0800 to sunset, with no significant sightings. The three Coast Guard cutters (*Northland*, *Resolute*, and *Charles Sexton*) searched throughout the day. At 1433, the *Charles Sexton* located and recovered a second empty *El Faro* immersion suit. The three tugs chartered by TOTE were on scene supporting search efforts. Searchers reported that visibility was 10 nm, winds were from 227° at 3 knots, and seas were 1 foot.

At 1900 (sundown) on October 7, after informing the crew's family members, the commander of Coast Guard D7CC suspended active search for the 33 persons on *El Faro*, pending further developments, and released all Coast Guard, Air Force, and Navy search-and-rescue assets. The survivability time of 120 hours predicted by the probability of survival decision aid (PSDA)

[148] This was the first *El Faro* survival debris to be recovered. The partially inflated liferaft was not recovered.

had been exceeded (154 hours actual time in the water) without any survivors being found.[149] From October 3 to October 7, 15 different Coast Guard, Air Force, and Navy assets conducted 50 air and surface sorties, totaling about 275 hours and covering 195,601 square miles.

1.11.2 Lifesaving Equipment

Coast Guard regulations for lifesaving equipment ("lifesaving appliances and arrangements") are found at 46 *CFR* subchapter W (Part 199). The regulations reflect the requirements of SOLAS chapter III.

El Faro was required to carry specific survival gear by its Coast Guard COI. Table 7 summarizes the type and quantity of survival equipment carried on the vessel, as listed in *El Faro*'s June 2015 monthly safety inspection records and by ABS in its Record of Approved Cargo Ship Safety Equipment dated February 23, 2006 (with updates on February 23, 2007; February 2, 2009; and April 2, 2010). The table indicates whether the equipment was detected or recovered after the accident. The manufacturer, dates of manufacture and approval (if known), and other details of the survival gear carried on *El Faro* are given in appendix F.

Table 7. Lifesaving appliances required by *El Faro*'s COI.

Appliance	Number Required by COI	Persons to Accommodate	Number on Board	Found or Detected After Accident	Recovered
Lifeboat (starboard)	1	43	1	1	1
Lifeboat (port)	1	43	1	1	0
Inflatable rafts (liferafts)	3	46	5[a]	1	0
Life preservers (lifejackets)	45	1 each	65	1	0
Ring buoys (lifebuoys):	14	1 each	31	8	8[b]
With lights	(8)	(c)	15[d]	--	--
With line attached	(2)	(c)	2	--	--
Other	(4)	(c)	14[e]	--	--
Immersion suits	45	1 each	51	3	2

[149] Since June 22, 2010, the Coast Guard has used the PSDA model for all cases involving persons in the water and where people are at risk of hypothermia or dehydration when not immersed. The PSDA model is a physiologically based model of both heat and water loss for survivors immersed in water or in open air. Modeling for *El Faro* used the following input: air temperature 81°F; water temperature 84°F; relative humidity 76 percent; wind speed 13.6 knots; gender–female; height 5 feet 4 inches; weight 154.8 pounds.; fat 34 percent; immersed in water to the neck; turbulent heat loss; and wearing a survival suit.

Appliance	Number Required by COI	Persons to Accommodate	Number on Board	Found or Detected After Accident	Recovered
Portable lifeboat radios	2	n/a	3	0	0
EPIRB	1	n/a	1	0	0

NOTE: n/a = not applicable.

[a] Two extra liferafts were on board. According to TOTE, when two liferafts (25 persons each) were added to *El Yunque* as a precaution after corrosion was found on the lifeboat davits, the same addition was made to *El Faro*.

[b] None of the recovered ring buoys had attachments.

[c] Included in total.

[d] Two were equipped with smoke floats. One smoke float was recovered after the accident, and one was detected on the ocean floor. Smoke floats are floating markers that produce dense orange smoke for at least 15 minutes.

[e] includes 1 spare.

Lifeboats. *El Faro* was equipped with two 43-person open lifeboats, both manufactured by Marine Safety Equipment Corporation (MASECO), which later came under the ownership of Harding Safety.[150] The port lifeboat was powered by a diesel engine. The starboard lifeboat was mechanically propelled by Fleming gear, a means of manually driving a boat forward without using oars. Hand-operated levers on each side of the boat are moved backward and forward, transmitting power by means of rods and gears to the propeller shaft, which gets the boat under way.

Open lifeboats and mechanically propelled lifeboats are allowed only on ships constructed before July 1, 1986.[151] A record search by Harding Safety found that *El Faro*'s survival systems—lifeboats, davits, winches to recover the lifeboats, and hooks to release the lifeboats—were original equipment.

Both lifeboats were designed to be launched from gravity davits, with wire ropes (called fall wires) used to lower them into the water. The davits rolled on tracks. Stopper bars on the tracks kept the boats from traveling too far when being hoisted. The fall wires, which were wound on winches controlled by brakes, traveled across the davits to the boats through grooved pulleys, or sheaves. Wire ropes called gripes held the lifeboats in place in their cradles while the ship was under way.

If a lifeboat was launched, frapping ("tightening") lines would be passed around the fall wires on the bow and stern to keep the boat from excessively swaying. Suspended wires for hauling and lashing, known as tricing pendants, would be used to keep the lifeboat close to the ship during loading. A mechanical apparatus (Rottmer gear) equipped with a releasing handle would be used to disengage the lifeboat from its falls as the final stage in launching. Figure 48 shows a gravity

[150] MASECO was founded in 1945 in Point Pleasant, New Jersey, and merged into Schat-Watercraft, Inc., in 1991. Harding Safety, based in Norway, was formed in 2013 by the merger of Schat Harding and another Norwegian company, Noreq. In June 2016, Harding Safety was acquired by the Palfinger Group. Harding Safety is now Palfinger Marine.

[151] Lifeboat standards and regulations are discussed in section 1.11.4.

davit with a lifeboat such as those carried on *El Faro* in both stowed and launch positions, as well as various parts of the launching apparatus.

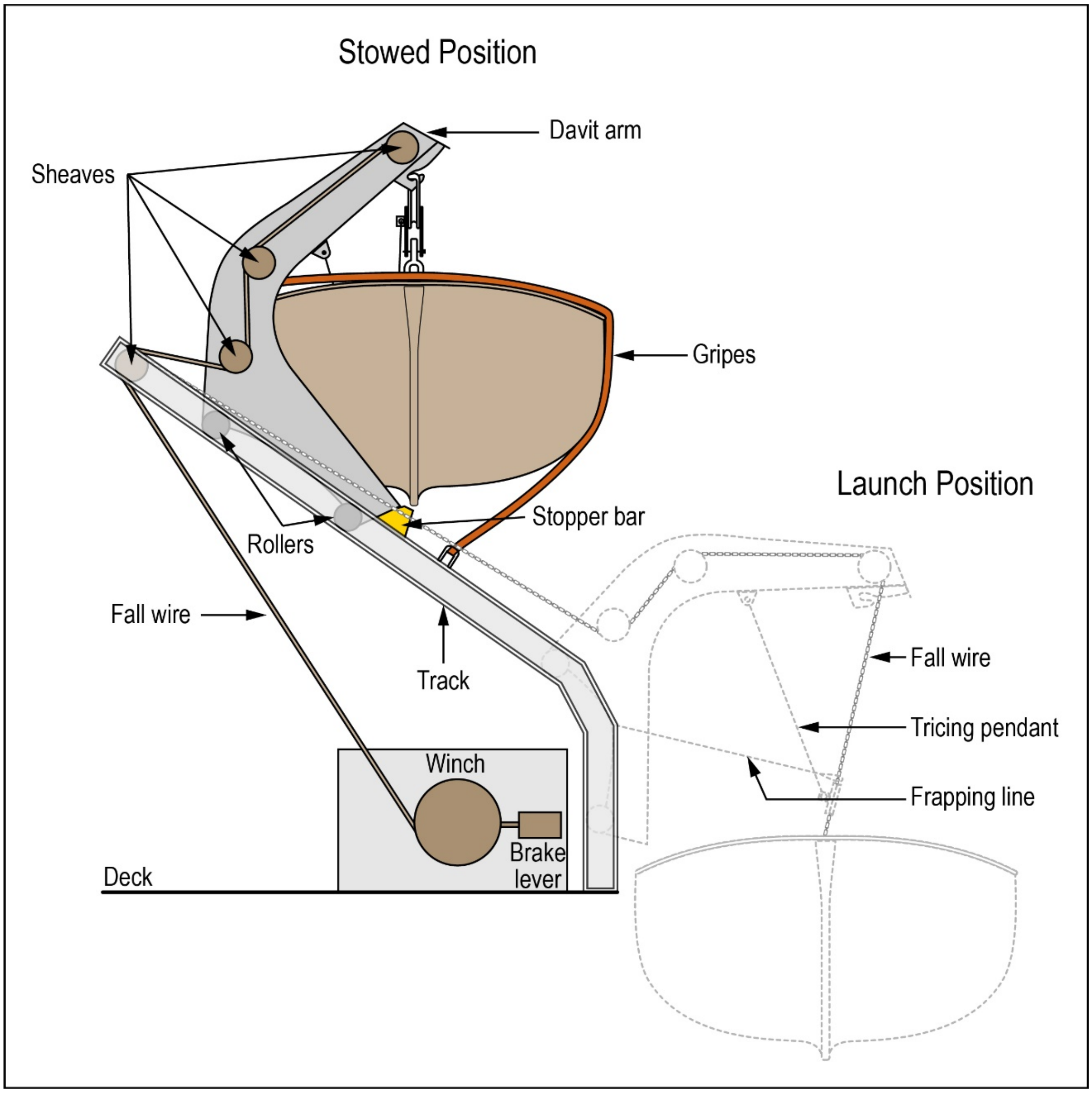

Figure 48. Gravity davit with lifeboat in stowed and launch positions.

The procedure for launching *El Faro*'s lifeboats, based on the builder's instructions, was as follows:

- Remove lifeboat cover and place cap in drain plug.
- Release gripes and stopper bars. Clear them away. Important to swing stopper bars clear of trackways. Be sure they are secured in open position by toggle pins. Otherwise bars are liable to swing back on trackways.
- Raise brake handle. Check speed with hand brake and ease davit over side. Tricing pendant will bring lifeboat to ship's side.

- Hold lifeboat with frapping lines and unhook tricing pendant.
- Load boat.
- Ease off frapping lines.
- Lower to water. Control operation with hand brake.
- As boat reaches water level, allow winch to run out sufficient fall wire to permit easing of Rottmer release hooks. This is accomplished by throwing release handle in boat.

A Harding Safety technician was aboard *El Faro* on August 4, 2015, to conduct the annual inspection of the lifeboats and associated launching appliances. The technician found the davits, winches, lifeboats, and hooks to be in operational condition and observed no major faults. The limit switches on the winch motors were inspected, tested, and found to be working properly.[152] The brakes were opened and inspected, then tested by lowering an empty boat and abruptly applying the brake. The engine and hook release were tested in the water on the port lifeboat. Because the vessel was moored to starboard, the starboard lifeboat could not be lowered to the water for the hook-release test.

The technician noted that the winches and davits showed some scale or corrosion on hardware and foundations and that *El Faro*'s crew was to clean the corrosion before the technician's scheduled follow-up visit on November 4, 2015 (to repair fiberglass damage to the lifeboats caused by their lashings). The technician recommended replacing both freewheel clutches, which were leaking oil, and the starboard winch clutch, which was making a "strange noise."

Another Harding Safety technician was on board the day before and the day of *El Faro*'s departure on the accident voyage (September 28 and 29) to install and test two new freewheel clutches in the lifeboat winches. The technician reported that both lifeboat brakes and winches were in proper working order. A TOTE port engineer testified to the marine board that the company did not notify ABS or the Coast Guard to give them an opportunity to attend the work on the lifeboat winches, as required.

Liferafts. *El Faro* carried five liferafts, although only three were required. Coast Guard requirements for the carriage of liferafts are found at 46 *CFR* 199.261. The aggregate capacity of the liferafts must accommodate 150 percent of the total number of persons on board. Four 25-person liferafts were stowed on the boat deck, two on each side aft of the lifeboats (see figure 49). Two liferafts were manufactured in October 2005 by Viking Life-Saving Equipment and last visually inspected on September 4, 2015. The inspecting technician noted that the necessary additional pressure test (required for liferafts more than 10 years old), gas inflation test, and floor seam test were all within periodicity and that the liferafts were not due for servicing until

[152] A limit switch stops the winch motor before the davit that is being hoisted reaches its stowed position. Failure to stop hoisting could overload the lifeboat fall wires.

September 2016.[153] The other two 25-person liferafts were manufactured by Survitec Group, Inc., in July 2015 and were not due for service for 2 years.

Figure 49. Location of liferaft stowed below *El Faro*'s starboard lifeboat. (Photo by Maine Maritime Academy cadet, summer 2015)

The 25-person liferafts were packed in fiberglass containers for storage on deck (see figure 50). Each container weighed between 380 pounds (Viking model) and 406 pounds (Survitec model) and required two people to launch. The containers were designed to be thrown overboard while attached to a painter (short line) secured on the ship. The other end of the painter was attached inside the container to a cylinder of compressed gas (CO_2). When the painter was pulled, the liferaft inside the container would inflate and the container would pop open. Crewmembers would ordinarily climb down a Jacob's ladder into the liferafts, but the liferafts could also be entered from the water.[154]

[153] The necessary additional pressure test is required at yearly intervals for liferafts older than 10 years by SOLAS resolution A.761(18), "Recommendation on Conditions for the Approval of Servicing Stations for Inflatable Liferafts" (appendix 1, "Necessary additional pressure (NAP) test," and appendix 2, "Frequency of NAP tests"), November 1993.

[154] A *Jacob's ladder* is a rope ladder, usually with wooden rungs, used to board vessels at sea.

Figure 50. Type of containerized 25-person liferaft carried on *El Faro*. (Photo courtesy Survitec)

The procedure for launching the 25-person liferafts was as follows:

- Release manual slip hook.
- Check that painter is made fast.
- Throw liferaft into sea.
- Pull on painter until liferaft inflates, then pull liferaft to ship’s side.
- Vital actions after launching:
  - Right liferaft if it is upturned.
  - Board quickly.
  - Move clear of ship.
  - Stream sea anchor.[155]
  - Close entrances.

The 25-person liferafts had an automatic underwater release in case the ship should sink before the appliances could be launched. A liferaft would be released and float upward, then inflate, break free of the ship, and float to the surface. Figure 51 shows an inflated 25-person liferaft manufactured by Viking.

[155] A *sea anchor* is a parachute-like drag made of canvas or sailcloth that can be thrown overboard to retard drifting.

Figure 51. Inflated 25-person liferaft. (Photo courtesy VIKING Life-Saving Equipment A/S)

As the extra liferaft required by the Coast Guard for vessels over 100 meters (328 feet) long, *El Faro* carried a 155-pound, 6-person liferaft. It was stowed forward on the main deck near the centerline, where it could be picked up by two crewmembers and launched from either side. It was a Viking model manufactured in November 2010. It had been inspected on May 18, 2015, and was due for a 12-month inspection in May 2016.

Lifejackets. All inspected vessels in the United States are required by 46 *CFR* 199.70(b) to carry lifejackets for each person on board. A sufficient number of lifejackets must be carried for watchstanders and for use at remote survival craft stations. Stowed lifejackets must be readily available. The additional lifejackets for persons on watch must be stowed on the bridge, in the engine control room, and at other manned watch stations.

According to ship records, *El Faro* carried 65 adult lifejackets equipped with whistle and light. The Coast Guard approved the lifejackets as "Former—May Use," indicating that the manufacturer no longer made the equipment.[156] The lifejackets were stowed in crew accommodations and work spaces. No lifejackets were recovered after the accident.

The minimum standard lifejacket required on *El Faro* would have been a Coast Guard-approved, inherently buoyant type I PFD. The lifejacket is designed to turn an unconscious adult's head face up and hold it above the water. It is used for all waters, including the open ocean, rough seas, or remote waters where rescue may be slow in coming.

Immersion Suits. Immersion suits, also called survival suits, are designed to protect against the loss of body heat. They are required to be both insulated and buoyant.[157] Approved

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[156] Safegard Corporation, Covington, Kentucky, manufactured or distributed the lifejackets. The company is no longer in business, according to an internet search and a Coast Guard marine safety alert published in July 2016 (safety alert 07-16).

[157] Coast Guard requirements for the construction and performance of immersion suits are found at 46 *CFR* 160.171-9 and 160.171-11. Requirements for carriage of immersion suits by cargo vessels are found at 46 *CFR* 199.273.

immersion suits must provide the wearer with sufficient thermal insulation to ensure that his or her body core temperature does not fall more than 3.6°F after 6 hours of immersion in calm, circulating water of between 32°F and 35.6°F. A person must be able to don an immersion suit in 2 minutes after reading the instructions.

Immersion suits are required to turn an unconscious person face up in the water and be fitted with retroreflective material and a light. They must prevent "undue ingress of water . . . following a period of flotation in calm water of one hour" (46 *CFR* 160.171-11[f]) but are not required to be watertight. They must have a means of preventing water spray from directly entering the wearer's mouth, must not undergo prolonged burning or melting when enveloped in fire for 2 seconds, and must be oil-resistant and usable after a 24-hour exposure to diesel oil.

According to the regulations, an adult-size immersion suit must fit both males and females weighing from 110 to 330 pounds and standing between 59 and 75 inches tall. A small-adult or child-size suit must fit both male and females who weigh from 44 to 110 pounds and measure between 39 and 59 inches in height. An oversize adult suit is intended for a person too large for a standard adult suit.

Survival time for persons in the water is affected by several factors, including proper use of survival equipment, weather conditions, time in water, body type, health, and knowledge of survival techniques. The main danger is hypothermia, which occurs when the body loses heat faster than it can produce it, causing the body's core temperature to drop below 95°F. As core body temperature drops, the organs stop functioning, which can lead to heart failure, respiratory system failure, and death. Water does not have to be extremely cold to cause hypothermia; it need only be cooler than normal body temperature (98.6°F) to bring about heat loss.

Without immersion suits, the expected survival time for a person in the water ranges from 30 to 90 minutes in cold, 32.5°F water to an indefinitely long time in warm water (above 80°F). With immersion suits, the expected survival time in cold water ranges from 2 1/2 to 5 1/2 hours, depending on whether the suit leaks or stays dry, to indefinitely long in water above 50°F. Figure 52 shows expected survival time as a function of water temperature. According to logs kept by the Coast Guard cutter *Northland*, on October 4, the water temperature in the *El Faro* search area was 85°F to 87°F.

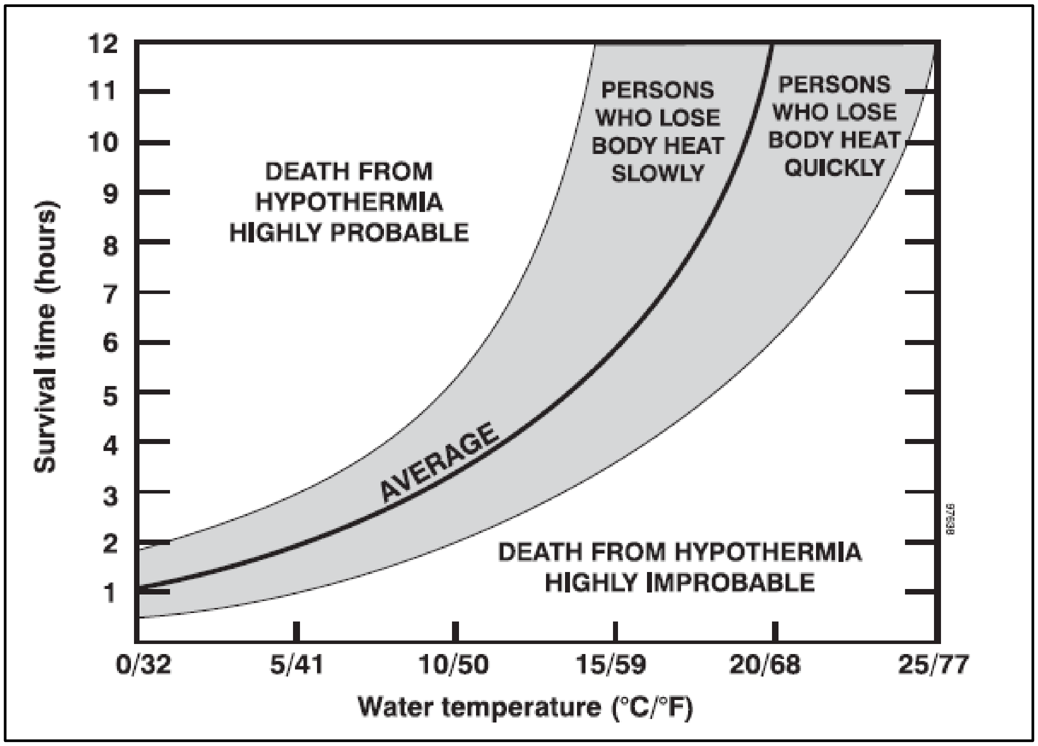

Figure 52. Probability of death from hypothermia as a function of water temperature and time immersed in water. (Graph from IMO/ICAO 2007; reprinted by permission[158])

El Faro was outfitted with 51 immersion suits. The AMOS maintenance system shows a purchase order for required 2-year inspection and pressure-testing of 52 immersion suits on August 6, 2015, by Liferafts Inc., of Puerto Rico. On August 8, *El Faro*'s captain reported to the TOTE port engineer that 52 immersion suits had been inspected and tested (47 satisfactory and 5 condemned). AMOS recorded a purchase order, dated August 19, for 4 oversize adult immersion suits. A former chief mate told investigators that the new immersion suits were received, but he was not sure if they had been stenciled "S.S. El Faro" before the accident. Maintenance records indicate that 11 spare immersion suits were stored in the spares locker on the cabin deck, near fire station 7.

The Coast Guard was asked during the marine board to conduct an experiment on whether immersion suits such as those carried by *El Faro* would remain afloat after an extended time in the water. In June 2016, the Coast Guard Research and Development Center tested two weighted mannequins wearing Coleman-Stearns I590 immersion suits (Lewandowski and Clark 2016). The mannequins floated in waters of the Mobile River in Alabama for 2 weeks, under benign conditions. After recovering the mannequins, researchers concluded that the immersion suits had

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retained their buoyancy. Less than a liter (1 quart) of water had intruded into each suit. However, about 10 pounds of seaweed had grown at the waterlines of the suits.

Lifebuoys. The vessel was equipped with 31 orange lifebuoys, 30 inches in diameter, stowed in various locations. Two with attached lights and smoke floats, which create a distress signal of dense orange smoke that lasts at least 15 minutes, were stored on the bridge wings. The rest were on the weather decks: 13 with attached lights, 2 with throwing line, 13 with no attachments, and 1 spare.

Recovered Lifesaving Equipment. *El Faro*'s starboard lifeboat was discovered during the search-and-rescue operation at 1500 on October 4, swamped and floating bow up. The lifeboat was too big for the tug *Hawk* to recover, so TOTE chartered the offshore support vessel *Megan Beyel* to salvage the boat and deliver it to the Port of Miami. The lifeboat was brought to Coast Guard Air Station Miami and inspected (figure 53).

Figure 53. *El Faro*'s starboard lifeboat on arrival at Coast Guard Air Station Miami. Note fouled propeller, bent propeller blade, and damage to port and starboard sides of hull.

The operations director of Harding Safety told investigators, on being shown a photograph, that the damage to the starboard lifeboat was "indicative of a fall and not [of] a lifeboat actually being released." The damage to the starboard lifeboat is described in appendix F, which gives details of all survival debris from *El Faro* that was discovered during the search-and-rescue operation or in the days or months afterward. The gravity davits of the starboard lifeboat were found intact during the search for the vessel's VDR.

The port lifeboat was not found during the 7 days of search-and-rescue operations. On the first VDR search mission, during which the wreckage of *El Faro* was examined, investigators noted that the lifeboat was not in its davits. The davits were broken and hanging on the hull below the ship's boat deck. On the second VDR search mission, searchers discovered the port lifeboat on the seafloor, at a depth of 15,364 feet. The major damage noted was that the lifeboat's stern was missing (it was not found).

The Harding Safety director told investigators that from the photographs, the port davits appeared to have been damaged by the impact force of wave action, such as heavy seas at the height of the boat deck. He said the port lifeboat looked to have been damaged by heavy seas while it was hanging in the fall wires and that the stern would have been torn off when the boat fell stern first from a significant height. In his opinion, the lifeboat had not been launched.

A partially inflated liferaft of unrecorded size was discovered during the search-and-rescue operation on October 4. The liferaft was searched by a Coast Guard rescue swimmer for survivors or remains. None were found. The liferaft was confirmed to be from *El Faro* and was sunk to prevent its rediscovery by the *Northland* and an ensuing duplicate search for survivors or remains. None of the five *El Faro* liferafts were recovered, and none were observed in a stowed position on the wreckage.

The cutter *Charles Sexton* recovered two of *El Faro*'s immersion suits after the accident. The first suit was recovered on October 6. The back was marked "S.S. El Faro San Juan, P.R." in white but appeared to have been previously marked "El Morro" in black. The second immersion suit (figure 54) was recovered on October 7. It was found with whistle and strobe light (turned off but operational); unzipped, left arm inside out, torn almost in half at right hip seam; and back marked "S.S. El Faro San Juan, P.R." in white but appeared to have been previously marked "El Morro" in black. As noted earlier, an immersion suit containing human remains was located but could not be recovered.

Figure 54. Immersion suit recovered on October 7, 2015.

According to maintenance records for June 2015, the recovered immersion suits were spare immersion suits Nos. 48 and 50. Both were last inspected and pressure-tested in July 2013 by Liferafts Inc., of Puerto Rico, and each had a light with an expiration date of April 2016.

Eight of the vessel's lifebuoys were recovered. One smoke float was found on the ocean floor during the second VDR search. Three new Coast Guard type II PFDs (near-shore buoyant vest for recreational use) were recovered but were determined to be part of *El Faro*'s cargo.

Maintenance of Lifesaving Gear. Maintenance was tracked by a spreadsheet maintained on *El Faro*. According to 2015 AMOS records, *El Faro*'s crew tested the engine in the port lifeboat and the Fleming gear in the starboard lifeboat weekly through September 27. The lifeboats were inspected monthly, through June, though no inspection of the port lifeboat was listed for March. The davit-releasing gear was scheduled to be greased monthly; records show three months missed for the starboard lifeboat and one month missed for the port lifeboat during 2015. The diesel engine on the port lifeboat, which was scheduled for yearly servicing, was last serviced on July 30. Crewmembers had to manually enter the records on the spreadsheet.

During 2015, according to purchase orders, contractors completed numerous surveys, inspections, and maintenance of *El Faro*'s lifesaving equipment. The purchase orders included the annual inspection of the vessel's two 25-person liferafts on September 1, the purchase of 4 oversize immersion suits on August 19, and the purchase of 12 batteries for the water lights on the vessel's lifebuoys on July 27. The last required tests and inspections of *El Faro*'s lifeboats were performed by ABS on January 1, 2011 (5-year renewal of fall wires); on January 29, 2011 (5-year full-weight test of davit and brake); and on January 9, 2015 (light-weight test and annual examination per SOLAS regulation III/20.11.2.2 of lifeboat and Rottmer-type releasing gear).

1.11.3 Emergency Procedures

Emergency Signals. The fire and emergency command station was the bridge. The signal for fire and emergency was one continuous blast of the ship's whistle and continuous ringing of the general alarm bells, both sounded for not less than 10 seconds, coupled with an announcement on the public-address system. The signal to abandon ship was more than six (seven or more) short blasts followed by one long blast of the ship's whistle and the same on the general alarm bells (seven or more short rings, then a long ring).

Muster Stations. The vessel's station bill, also known as the muster list, assigned various duties associated with emergencies to each person on board and also assigned individuals to muster stations and survival craft. Title 46 *CFR* 199.80 states, "The muster list must be posted before the vessel begins its voyage. After the muster list has been prepared, if any change takes place that necessitates an alteration in the muster list, the master must either revise the existing muster list or prepare a new one." Station bills are typically posted in living quarters and work spaces throughout a vessel.

Part of *El Faro*'s station bill consisted of crew assignments in case of emergency or abandon ship (table 8). The captain was in command of all emergency operations and commanded lifeboat 1. The chief mate was in charge at the scene of an emergency and in command of lifeboat 2. The second mate had charge of the muster and was second in command of lifeboat 1, responsible for emergency communication equipment. According to the station bill, *El Faro* had two emergency squads, with the third mate and bosun in charge. Emergency squad 1 would muster at emergency gear locker 1, which was on the upper deck just aft of the crew's mess. Emergency squad 2 would muster at emergency gear locker 2 on the main deck in the vicinity of the fire control room and the cargo office. The extra crew and supernumeraries were to muster in the crew's mess on the upper deck to assist as directed.

Table 8. Duties for emergencies and abandon ship, as specified on station bill.

Billet (Position)	Emergency Duties	Abandon-Ship Station and Duties
Deck Department		
Master (captain)	In command all operations, GMDSS	Lifeboat 1, in command
Chief mate	In charge at the scene	Lifeboat 2, in command
Second mate	In charge of muster, then report to bridge	Lifeboat 1, second in command, lifeboat radio/SART/EPIRB
Third mate	Leader, emergency squad 2	Lifeboat 2, second in command
Bosun	Leader, emergency squad 1	Lifeboat 2, brake/winch operator
AB maint. 1	Emergency squad 2	Lifeboat 1, assist as directed
AB maint. 2	Emergency squad 1	Lifeboat 2, assist as directed
AB, 12–4 watch	Relieve helm	Lifeboat 1, assist as directed
AB, 4–8 watch	Emergency squad 2	Lifeboat 1, assist as directed
AB, 8–12 watch	Emergency squad 1	Lifeboat 2, assist as directed
Deck GUDE	Emergency squad 2	Lifeboat 1, assist as directed
Deck cadet 1	Report to crew mess and assist as directed	Lifeboat 1, assist as directed
Deck cadet 2	Report to crew mess and assist as directed	Lifeboat 2, assist as directed
Engine Department		
Chief engineer	Engine room, in charge	Lifeboat 1, assist as directed
First engineer	Assist as directed in engine room	Lifeboat 2, assist as directed
Second engineer	Assist as directed in engine room	Lifeboat 1, assist as directed
Third engineer, 12–4 watch	Remain on watch or in fire control room	Lifeboat 2, run motor
Third engineer, 8–12 watch	Remain on watch or in fire control room	Lifeboat 2 assist with motor
Electrician	Run emergency diesel generator and/or assist chief mate at scene	Lifeboat 1, brake/winch operator
OMU, 12–4 watch	Remain on watch or report to crew mess and assist	Lifeboat 2, assist as directed
OMU, 4–8 watch	Remain on watch or report to crew mess and assist	Lifeboat 2, assist as directed

Billet (Position)	Emergency Duties	Abandon-Ship Station and Duties
OMU, 8–12 watch	Remain on watch or report to crew mess and assist	Lifeboat 1, assist as directed
Engine GUDE	Emergency squad 1	Lifeboat 1, assist as directed
Engine cadet 1	Report to crew mess and assist as directed	Lifeboat 1, assist as directed
Engine cadet 2	Report to crew mess and assist as directed	Lifeboat 2, assist as directed
Steward Department		
Steward	Assist with muster and report results to bridge via radio	Lifeboat 2, assist as directed
Chief cook	Secure galley, muster, and assist as directed	Lifeboat 1, assist as directed
Steward assistant	Bridge messenger, secure all doors up to bridge	Lifeboat 2, provide lifeboat radio and SART
Supernumeraries		
Rider 1	Report to crew mess and assist as directed	Lifeboat 1, bring lifejacket and warm clothing
Rider 2	Report to crew mess and assist as directed	Lifeboat 2, bring lifejacket and warm clothing
Rider 3	Report to crew mess and assist as directed	Lifeboat 1, bring lifejacket and warm clothing

NOTE: This table is based on an electronic station bill copied from an off-duty chief mate's computer from September 2015. The date of the station bill is unknown, and entries do not represent the exact crew complement carried on the accident voyage. For example, the station bill includes four blank slots for cadets (such as those carried in 2015) and lists only three supernumeraries. OMU = oiler maintenance utility.

The station bill shows that supernumeraries were to report to the crew mess for emergencies and that each was assigned to a lifeboat for abandon ship (about half to lifeboat 1 and half to lifeboat 2). A former supervisor of the riding gang testified that the Polish workers were briefed on liferafts through a translator and could launch a liferaft on their own.

Safety Drills and Meetings. Vessels registered in the United States are required by 46 *CFR* 199.180(c)(2) to conduct monthly fire and boat drills. TOTE required weekly fire/emergency and abandon-ship drills, weather permitting. At the end of each month, the *El Faro* captain would review the deck logs and submit them to TOTE. Deck logs for September 2015 were not submitted. However, according to an unsigned electronic training logsheet that was obtained from a chief mate who had departed the vessel before the accident voyage, fire, emergency, and abandon-ship drills were held on September 10.

According to the September 10 logsheet, the drill involved a fire in the officers' spare room. The crew mustered and fire teams suited up. Both teams fought the fire and conducted fire nozzle training. They then sounded the abandon-ship signal and the crew mustered at lifeboat stations. Both lifeboats were lowered to the embarkation deck, where the crew discussed their duties. After the drill, the crew discussed lessons learned.

Title 46 *CFR* 199.180(d)(4) requires: "Each lifeboat must be launched with its assigned operating crew aboard and maneuvered in the water at least once every 3 months during an abandon-ship drill." The last verifiable date the ship's port lifeboat was lowered into the water during a drill was March 6, in San Juan harbor, as part of a Coast Guard annual examination and fire and abandon-ship drill. The Coast Guard inspector stated that the lifeboat was lowered to the embarkation deck and that the sheaves and brakes were checked. The boat was stopped while being lowered to verify that the brakes held. The inspector stated that the crew was competent in the drills, that they knew their jobs, and that radio communication was good. The inspector checked the manual Fleming gear on the starboard lifeboat, that the liferafts were properly stowed, and that the service tabs matched the Coast Guard's records. The inspector stated that the crew mustered in lifejackets and that he spot-checked their survival suits.

The last verifiable date that *El Faro*'s starboard lifeboat was lowered was June 5, in San Juan. The signed muster sheet shows that nine crewmembers, led by the chief mate, participated. The lifeboat was lowered to the dock and placed in its cradle. The brakes were tested during lowering, the releasing gear and Fleming gear were exercised, and the limit switches were tested. All were found to be in "good order."

El Faro conducted its last monthly safety meeting on September 24, while in San Juan. It lasted 22 minutes. The meeting reviewed the previous safety meeting's minutes, which included using personal protective equipment during docking and cargo operations. The chief mate emphasized wearing a safety harness while deploying the ship's gangway, and the second mate discussed the watchstanding AB's gangway duties and responsibilities. The ship's safety committee noted that the company's SMS manuals were available in the captain's office and on the ship's network computer for crewmembers to review.

Abandon-Ship Requirements. SOLAS section III, regulation 31 ("Survival craft and rescue boats"), paragraph1.5, states,

> all survival craft required to provide for abandonment by the total number of persons on board shall be capable of being launched with their full complement of person and equipment within a period of 10 min from the time the abandon ship signal is given.

1.11.4 Lifeboat Standards and Regulations

International requirements for lifeboats and other lifesaving appliances are codified in SOLAS 1974, as amended. Design differences between old and current lifeboats are separated by the 1983 amendments to SOLAS 1974, which modernized many lifesaving requirements. The amendments came into effect for cargo ships constructed on or after July 1, 1986. Open lifeboats such as those *El Faro* carried were not allowed on newly built vessels, although a relaxation of that prohibition for cargo ships (except oil or gas tankers and gas carriers) was in effect until July 1, 1998. Table 9 summarizes the differences between the design requirements for lifeboats before and after the 1983 amendments came into force.

Table 9. Lifeboat design criteria before and after SOLAS amendments took effect.

Design Criterion	Former (Before July 1,1986) Open Lifeboats	Current (Since July 1, 1986) Fully Enclosed Lifeboats
Maximum wind speed for launching lifeboat	No requirement for maximum wind	No requirement for maximum wind
Maximum sea state for launching lifeboat	No requirement for maximum seas	No requirement for maximum seas
Maximum list	Capable of being safely launched under all conditions of list of up to 15° either way (inboard or outboard)	Capable of being safely launched under all conditions of list of up to 20° either way (inboard or outboard)
Maximum trim	Capable of being safely launched under all conditions of trim of up to 10° either way (forward or aft)	Capable of being safely launched under all conditions of trim of up to 10° either way (forward or aft)

Chapter III of the SOLAS regulations is devoted to lifesaving appliances and arrangements. In addition to the prohibition against open lifeboats, manually propelled lifeboats such as the one carried on *El Faro* that used Fleming gear were no longer allowed under the 1983 amendments to SOLAS: "Every lifeboat shall be powered by a compression ignition engine" (regulation 41, paragraph 6.1). The regulation is now found in the International Lifesaving Appliance Code, section 4.4.6.1.

Both open and enclosed lifeboats are launched by gravity davits, with generally similar launching methods. Lifeboats can be launched with gravity davits as long as the davits meet the latest lifesaving appliance and SOLAS requirements for the installed lifeboat.

Enclosed lifeboats have reserve buoyancy when the doors and ports are closed (watertight), protect the occupants from exposure to the elements, and can be fitted with a water-spray system and air supply.[159] In addition to reserve buoyancy, design requirements for enclosed lifeboats include self-righting, damage testing, and engine propulsion.

El Faro was inspected and surveyed in accordance with the SOLAS regulations applicable to its delivery date of January 1975 (SOLAS 1974 or SOLAS 1974, as amended).[160] A vessel is surveyed under the same regulations as long as it is in service or until it undergoes a major modification. If the vessel undergoes a major modification, it must comply with the SOLAS requirements current at that time as far as is reasonable and practicable, as determined by the local Coast Guard Officer in Charge, Marine Inspection (OCMI).

In 1993, while *El Faro* was named *Northern Lights*, the vessel began what the Coast Guard determined to be a major modification. The OCMI in Mobile, Alabama, advised, "All modifications to the vessel must comply with the most recent SOLAS amendments." However, he stated further, "As a practical matter, all aspects of the vessel not being modified may remain as

[159] The water-spray system is for fire protection. Fire-protected lifeboats are required to have an air supply lasting at least 10 minutes with the engine operating normally.

[160] The convention in effect when *El Faro*'s keel was laid was SOLAS 60.

is, but whenever equipment, such as lifeboats, need replacement they must meet the most recent standards." The lifeboats were not required to be upgraded at that time.

1.11.5 Conventional vs. Freefall Lifeboats

As of October 2, 2017, according to the Coast Guard, 311 inspected vessels in the United States were equipped with lifeboats. Half (152, or 49 percent) of vessels that held valid COIs were equipped with side-launched open lifeboats (grandfathered to pre-1983 amendment standards). A total of 110 vessels (35 percent) were equipped with side-launched fully enclosed lifeboats, and 49 (16 percent) were equipped with stern-launched freefall lifeboats (figure 55).

Figure 55. Stern-launched freefall lifeboat on large container ship. Orange lifeboat is shown in launch position amid stacks of containers. (Photo by Sascha Heuer; used by permission)

Stern-launched freefall lifeboats are stowed in the ready-to-launch position and require fewer steps to launch than side-launched lifeboats (Nelson et al. 1994). Only one stern-launched freefall lifeboat is required, as opposed to two conventional side-launched lifeboats. A freefall lifeboat can be launched in high seas under storm conditions because launching does not depend on the hooks and fall wires used to lower side-launched lifeboats. A freefall lifeboat can be launched by one person in about 3 minutes. Crewmembers enter the lifeboat and strap themselves in before the lifeboat is released and falls into the water. Freefall lifeboats are self-righting and, after being dropped into the sea, can be 330 feet away from a ship or platform in 6 seconds (PBS 2000).

Both davit-launched and freefall lifeboats are required to safely launch under conditions of 20° of list and 10° of trim. In addition, freefall lifeboats must have a secondary means of launch that can safely launch under 5° of list and 2° of trim.[161] Retrofitting vessels for stern-launched freefall lifeboats would require reinforcement to accommodate an above-deck launching structure, new stability calculations, and other measures. The estimated cost to upgrade *El Faro*'s open lifeboats to the modern enclosed design would be about $1 million, according to the representative of a lifeboat manufacturer.

Traditional side-launched lifeboats are estimated to account for 90 percent of lifeboat accidents and incidents that are investigated, as compared with about 10 percent for freefall lifeboats. In an emergency, the probability of successfully launching a stern-launched lifeboat is greater than for a traditional side-launched lifeboat. There is no known successful launching of a lifeboat with survivors under hurricane conditions in winds of 96 to 112 knots, according to the lifeboat manufacturer's representative.

1.11.6 Personal Locator Beacons

A personal locator beacon is a portable unit that operates like an EPIRB. It was originally developed for use in Alaska but was authorized for nationwide use on July 1, 2003. Personal locator beacons are designed to be carried by a person and are registered through the FCC to a person, not a vessel or an aircraft. Investigators could not determine whether any of the *El Faro* crew carried a personal locator beacon.

A personal locator beacon is activated manually and operates on 406 MHz to achieve an accuracy of within 3 miles using the 406-MHz satellite system. It has a low-power homing beacon that transmits on 121.5 MHz. Newer models allow GPS input to the distress signal to achieve an accuracy of about 100 meters (328 feet). Personal locator beacons are not required at sea, but several manufacturers offer models costing between $300 and $400.

1.11.7 Position Format

The various organizations that broadcast or relay maritime emergency alerts use different format styles to render a ship's geographic position (latitude and longitude). The different format styles led to confusion about the last known position of *El Faro*.

In his phone call to the DP at 0706 on October 1, the *El Faro* captain gave his position as a navigator plots positions on a chart: "latitude twenty-three degrees twenty-six point three minutes north, longitude zero-seven-three degrees fifty-one decimal six west" (23°26.3′N, 073°51.6′W). The Coast Guard uses a dash rather than a degree sign (°) to indicate degrees, so when the DP passed *El Faro*'s position to LANTWATCH, it was entered into the Coast Guard's MISLE

[161] See 46 *CFR* 199.150(c), SOLAS III/16, and 46 *CFR* 160.132, which incorporates the requirements of the IMO's Life-Saving Appliance code, chapter IV.

database as 23-26.3N, 73-51.6W. Inmarsat-C uses a decimal instead of a degree sign between degrees and minutes, so the supplemental alert sent to the Coast Guard at 0715 read 23.28N, 73.48W. SSAS uses a colon to separate degrees from minutes, so the SSAS message sent to the Coast Guard, also at 0715, read 23:25.39N, 073:52.51W.

El Faro's position from the Inmarsat-C distress alert was entered into the Coast Guard's search-and-rescue optimal planning system (SAROPS) to determine a search area. The Coast Guard later determined that SAROPS had interpreted the position 23.28N, 73.48W (in degrees and minutes) as decimal degrees (23.28°N, 073.48°W) and converted it to degrees and decimal minutes using the Coast Guard's format (23-16.8N, 073-28.8W). The SAROPS position was off by 23 nm compared with the last known position entered into MISLE. As a result, the Coast Guard launched its search for survivors 23 nm from the accident site.

1.12 Stability Information

1.12.1 Concepts

A vessel that is floating upright in still water will list, or heel over to an angle, when an off-center force, or heeling moment, is applied. A moment is the product of a force tending to produce a rotation about an axis times its distance from the axis. Stability is the tendency of the vessel to return to its original upright position when the force is removed. The properties of stability are usually expressed as the magnitude of a heeling moment necessary to heel the vessel to a certain angle, the angle a vessel may heel to before capsizing, and other parameters that can be calculated.

The principles of ship stability derive from the laws of physics and trigonometry and reflect the relationship between buoyancy (the force pushing on a ship allowing it to float) and gravity (the force pushing the ship into the water). Gravity acts on all parts of the ship's structure, equipment, cargo, and personnel. The force of gravity acts downward through the ship's center of gravity (G), while the buoyant force acts upward through the ship's center of buoyancy. When a vessel is floating at an even keel or upright, the force of gravity and buoyancy are vertically aligned.

A ship's metacenter (M) is the virtual intersection of two successive lines of action of the force of buoyancy when the ship heels through a very small angle. The initial position of the metacenter is used as a reference in stability calculations. The distance from a ship's center of gravity (G) to its metacenter is known as the metacentric height (GM). GM is a measure of the vessel's ability to right itself when experiencing an overturning moment. For the same vessel, a higher GM value indicates a greater initial static stability.

When a disturbing force such as wave action or wind pressure exerts an inclining moment on a ship, the ship's underwater volume shifts in the direction of the heel, which causes the center of buoyancy to shift in the same direction. The shift does not affect the position of the ship's center of gravity, unless cargo, equipment, or water (weights) are free to move. As a result, the lines of action of the forces of buoyancy and gravity separate and exert a moment on the ship that tends to restore the ship to an even keel. That is known as a righting moment.

The *righting moment* is the product of the force of buoyancy times the distance that separates the forces of buoyancy and gravity. That distance is known as the ship's righting arm. The righting arm can be expressed as a curve plotted at successive angles of heel. The length of the righting arm generally increases with the angle of heel to a maximum point, after which it decreases, reaching zero at a very large angle of heel. The area under the righting arm curve represents the energy available to the ship to right itself. A reduction in the size of the righting arm usually means a decrease in stability. The mathematical relationship between the righting arm and the metacentric height makes GM a measure of the initial slope of the righting arm curve and an indication of whether the ship is stable or unstable at small angles of heel.

Intact stability refers to how an intact, or undamaged, vessel will respond when heeled over in calm conditions. *Damage stability* is an assessment of the effects of opening various combinations of watertight compartments to the sea. The method of assessing damage stability for cargo ships is known as probabilistic, meaning that if a vessel "passes" enough individual hypothetical damage scenarios, it meets the damage stability criteria because it probably will not capsize or sink. The specific stability characteristics of a vessel are calculated based on the design drawings of its hull form and an inclining experiment in which precise measurements are taken on board the vessel to determine its displacement and center of gravity. Stability analysis generally requires the services of a naval architect.

Stability criteria, established by regulators, are generally recognized as providing an adequate level of safety for vessels that are operated prudently, which means not overloaded and not operating in dangerous conditions such as violent storms. The IMO intact stability criteria were developed to guarantee safety against capsizing for a ship with no propulsion or steering (dead in the water), in severe wind and waves. The intact *CFR* criteria that applied to *El Faro* also assume dead ship, with the attitude of the vessel relative to wind and waves the worst possible for stability or heeling. A margin of safety is built into the stability criteria that is intended to accommodate events that can happen to a vessel, such as rolling in waves, heeling due to wind, or listing as people or cargo move from side to side. The only way to tell if a vessel meets the stability criteria is through calculations. If something changes about the vessel, such as a structural modification that might affect its stability, new stability calculations should be done.

1.12.2 Changes in Vessel's Configuration

History. *El Faro*'s original general arrangement drawings could not be found. Investigators obtained drawings, however, indicating that the design of hull No. 647, the *Ponce*, was used in constructing the *Puerto Rico* in 1975 and in later modifying it as the *Northern Lights* and then *El Faro*.

The original *Puerto Rico* was 700 feet long, with cargo holds below, a semi-enclosed second deck, and an exposed main deck. Lengthening in 1993 added a new 90-foot-9-inch-long hold (2A) at the midbody and an upper (spar) deck extending from the house forward to hold 2. The added deck area allowed the carriage of a third more trailers and automobiles. The deck and the additional cargo raised the vessel's center of gravity, which required 1,830 long tons of fixed ballast in the No. 2 outboard port and starboard double-bottom tanks.[162] The 1993 full-load draft was nearly the same as the original 1975 draft.

When the *Northern Lights* was converted in 2005–2006 to carry lift-on/lift-off containers in addition to Ro/Ro cargo, the spar deck was removed, both ramps to the main deck were blocked, and the main deck was modified to carry containers rather than Ro/Ro cargo. The alteration added up to 12 containers transversely, stacked as many as five high above the main deck. To support the additional weight of the containers, the main deck was structurally reinforced. Transverse deck beams with container fittings were also added. The altered vessel lost over 40 percent of its Ro/Ro trailer and auto capacity but gained the capacity to carry 1,414 TEUs of container cargo.

The carriage of containers above the main deck again raised the vessel's center of gravity, requiring 4,875 long tons of additional fixed ballast to be fitted in the No. 2A and No. 3 port and starboard outboard double-bottom tanks. The vessel was renamed *El Faro* on January 18, 2006. Table 10 compares selected vessel parameters of *El Faro* with its previous two hull configurations. The ship's main dimensions were unchanged from its configuration after it was lengthened. Its draft increased by 2 feet 1 5/16 inches, however, and its full-load displacement increased from 31,502 to 34,677 long tons, or by just over 10 percent.

Table 10. Comparison of parameters for builder's hull No. 670 in its three historical configurations.

Parameter	Hull 647, *Ponce* (similar to hull 670, *Puerto Rico*)	*Northern Lights*	*El Faro*
Years in service	1975-1992	1993-2005	2006-2015
Draft, full load (extreme)	28'-1 1/8" (8.6 m)	28'-1 1/16" (8.6 m)	30'-2 3/8" (9.2 m)
Freeboard, type B	14'-2 3/4"	14'-2 1/4"	12'-0 15/16"
Displacement, full load (saltwater)	25,350 long tons	31,502 long tons	34,677 long tons
Displacement, lightship	10,721 long tons	15,743 long tons	19,943 long tons
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	--	1,830 long tons	6,705 long tons
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 (TEUs)	--	--	1,414

[162] *Fixed ballast* is solid material placed on a ship to improve stability. On *El Faro*, the fixed ballast consisted of a finely crushed granular iron ore–type material called QCM (density = 190 pounds per square foot).

Major Conversion. When a vessel undergoes a substantial modification or conversion, the Coast Guard Marine Safety Center determines whether the change meets the definition of a "major conversion" as defined by 46 *USC* 2101(14a). 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 Coast Guard navigation and vessel inspection circular (NVIC) 10-81, change 1 (USCG 1981). The enclosure to the NVIC states the following:

> 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-flagged vessel:

> *Requirements*: If in the opinion of the cognizant mmt [merchant marine technical] 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 Marine Safety Center to be so. The current commanding officer noted that congressional intent in the area of a major conversion is broad, and that major conversion or 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 or modification determination, then the incentive for vessel owners or 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 or 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," in the commanding officer's words.

The commanding officer stated that if *El Faro*'s conversion to a Ro/Con in 2005–2006 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."

SOLAS also addresses modifications to vessels and states that ships that undergo "repairs, alterations and modifications of a major character and outfitting related thereto 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."[163]

The Marine Safety Center determined that the lengthening and spar deck addition completed in 1993 was a major conversion. That designation required the vessel and its systems be brought up to the applicable 1992 federal regulations (as opposed to those from 1975). Modifications to the vessel were also required to comply with applicable SOLAS regulations at the time of modification because the vessel was certificated for international voyages. However, even with the major modification designation, new class rules and regulations were applied as reasonable and practicable, by both ABS and the Coast Guard. Correspondence from the Marine Safety Center at the time showed that the determination was the basis for the vessel to meet the new probabilistic damage stability requirements at the time of conversion (rather than the owner's initial intent to meet deterministic damage stability found in a design letter issued by the US Maritime Administration [MARAD] in 1965).[164]

The Coast Guard Marine Safety Center did not designate the 2005–2006 conversion from Ro/Ro to Ro/Con a major conversion. In February 2002, TOTE representatives first asked the Marine Safety Center to determine whether the proposed changes would be considered a "major conversion," and the commanding officer replied they would 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 and provided clarifying information that the two sister vessels, *El Morro* and *El Yunque*, had been similarly converted in the past without being considered a major conversion. TOTE also reasoned that the modified vessel would carry less cargo by weight, but the Marine Safety Center affirmed its previous decision in March 2004.

Shortly afterward, to support its request for reconsideration, TOTE provided alteration histories for all its *Ponce*-class vessels and noted that none had been considered a major conversion. The Coast Guard 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 Marine Safety Center reversed its February 2002 decision and determined that the Ro/Con modifications would not constitute a major conversion.

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[163] See SOLAS, chapter II-1 ("Construction Structure: subdivision and stability, machinery and electrical installations"), part A, regulation 1 ("Application"). The international regulations are similar to those of the Coast Guard.

[164] Large US cargo vessels such as *El Faro* built under federal subsidies or mortgage guarantee programs were required to meet the criteria in MARAD design letter No. 3, issued April 28, 1965. *El Faro* was built under a mortgage guarantee program. MARAD's design letter No. 3 was not a regulatory requirement.

The decision allowed the vessel to continue to meet its existing applicable standards and not be considered against 2006 regulations tied to the contract date of the conversion. Even if the 2005–2006 conversion had been designated a major conversion, Coast Guard policy left the decision to require that modifications to the vessel and its systems meet current standards to the cognizant (local) OCMI, who determined what would have been reasonable and practicable for the ship's owner to update. The same intact stability (46 *CFR* 170.170) and damage stability (1990 SOLAS) standards were applicable in 2006 as in 1993.

1.12.3 Assessment of Vessel's Stability

When *El Faro* was lengthened in 1993, its stability underwent three independent analyses: by a naval architecture firm, which prepared a stability calculation package; by ABS, which reviewed the package and independently reviewed the vessel's stability; and by the Coast Guard Marine Safety Center, which reviewed the stability calculations and issued a stability letter in October 1993. For the vessel's Ro/Con conversion in 2005–2006, ABS reviewed a naval architecture firm's stability calculations on behalf of the Coast Guard (under NVIC 03-97 [USCG 1997]) and issued a stability approval letter to the vessel. The Coast Guard, through its oversight process, could decide to review the stability assessments at any point. No evidence was found that the Coast Guard reviewed the vessel's intact or damage stability for the 2005–2006 conversion.

Damage Stability Standards. No damage stability standards existed for US or international cargo vessels until 1992. As originally launched, *El Faro* met the requirements for single-compartment stability (capable of surviving flooding of any one compartment) in accordance with MARAD design letter No. 3. When *El Faro* was lengthened in 1993, it was required to meet SOLAS probabilistic damage stability requirements that came into force in 1992. *El Faro* was the first US-flagged vessel to be held to the new standard.

No records indicate that *El Faro* had its damage 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 2005–2006. The naval architecture firm that produced the stability booklet for the conversion did not reassess the vessel's damage stability. 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 damage stability assessment.

Intact Stability Standards. The only intact stability standard applicable to *El Faro* was the weather criteria at 46 *CFR* 170.170. The criteria include a formula for calculating a vessel's required GM for particular loading conditions, including angle of heel. The Coast Guard weather criteria do not incorporate downflooding points, though they are considered in an assessment under the criteria of the International Code on Intact Stability. *Downflooding* is an ingress of water through external openings that are normally above the waterline.

1.12.4 Methods of Assessing Stability

Stability Booklet. 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 Ro/Con cargo vessels such as *El Faro* to carry a trim and stability booklet, commonly called a stability booklet. The stability booklet must contain sufficient information for the captain to operate the vessel in compliance with applicable intact and damage criteria. A stability booklet describes a vessel's stability characteristics and contains operating instructions and worksheets for use in calculating the vessel's weight (displacement) and centers of gravity (longitudinal and vertical) under various loading conditions. The booklet is thus a tool for the captain to use in determining a vessel's maximum safe load and in controlling the vessel under different conditions.

The stability booklet carried on *El Faro* at the time of the accident was dated February 14, 2007, and was approved by ABS on behalf of the Coast Guard on May 31, 2007. The booklet was based on a stability test, or inclining experiment, performed on February 12, 2006, after the vessel was converted to a Ro/Con. The stability test was carried out at the Atlantic Marine Shipyard in Mobile, Alabama. ABS approved the test report on March 22, 2006.

US-flagged vessels in unrestricted ocean service are required to have stability booklets or a simplified stability letter. According to Coast Guard NVIC 3-89 (*Guidelines for the Presentation of Stability Information for Operating Personnel* [USCG 1989]),

> The intent of the regulatory requirements is to provide information to the operator of a vessel that will enable the operator to readily ascertain the stability of the vessel under varying loading conditions and to operate the vessel in compliance with applicable stability criteria.

Title 46 *CFR* 170.110 directs that in the development of stability booklets, "consideration must be given to including the following information" (among other things):

- General arrangement plans showing watertight compartments, closures, vents, downflooding angles, and allowable deck loadings.
- General precautions for preventing unintentional flooding.
- Any other necessary guidance for the safe operation of the vessel under normal and emergency conditions.

ABS representatives stated that they reviewed and approved the stability booklet based on guidance in the Coast Guard regulations and NVIC 3-89, but that the items listed in 46 *CFR* 170.110 were considerations only and not required to be included in the booklet.

When *El Faro* was lengthened in 1993, a new stability booklet was prepared. It was updated in December 2005 when the vessel was converted from a Ro/Ro to a Ro/Con configuration. As in the previous booklets, no listing or depiction of downflooding points or angles, areas of unintentional flooding, closures to be made, or windheel information was included. The "Revisions" section of the booklet included information on the addition of deck containers, removal of the spar deck, and increasing the permanent ballast. However, it did not note that the vessel's load line draft had been raised by over 2 feet.

The *El Faro* stability booklet did not identify the cargo hold ventilation trunk openings as potential downflooding points, nor did it indicate that they should be closed to prevent downflooding. None of the former officers or crew of *El Faro* remembered the dampers being closed at sea (even for expected heavy weather), except when they were periodically tested. When asked what a captain should have done if faced with the risk of fire or flooding, an ABS representative stated that the captain would have to "trade off one risk against another risk and maintain certain weathertight integrity while not compromising or not reintroducing some other risk."

The stability booklet also did not mention the wind velocity used to compute the required stability of the vessel according to the Coast Guard weather criteria in 46 *CFR* 170.170. ABS representatives said that the wind velocity had never been included in a booklet the class society had approved. However, investigators found the value for wind velocity used to compute the same weather criteria in an ABS-approved booklet voluntarily provided by another operator. Wind acting on a vessel produces a heel, or a sustained list based on the side profile of the vessel above the waterline, the wind speed, and GM. Investigators also found windheel information in stability booklets provided by other operators.

The Coast Guard has guidance for information in stability books regarding shifting weights or counterflooding during emergency situations (NVIC 4-77 [USCG 1977). The guidance states the following, which was not part of *El Faro*'s stability booklet:

> the stability information for all vessels should contain an appropriate section emphasizing the importance of the Master making every effort to determine the cause of a vessel's list before taking corrective action. In instances where the master can ascertain that off-center flooding has occurred and that a cargo shift has not occurred, counterflooding or shifting weights to bring the vessel to the upright position may be the correct action. In other instances, such measures may be detrimental to the survival of the vessel.

Onboard CargoMax. *El Faro* had a stability instrument, CargoMax, on board, in addition to the CargoMax software used on shore to load the vessel.[165] CargoMax can calculate loading conditions and evaluate them for compliance with applicable intact and damage stability criteria. On February 8, 2008, ABS completed a "satisfactory" review on *El Faro* of the "stability aspect only" of CargoMax version 1.21.164 (August 31, 2007). The CargoMax software installed on *El Faro* was, however, version 1.21.203, dated June 1, 2010, and was not specifically reviewed or reapproved by ABS. CargoMax's product manager stated that the differences between the versions were minor, would produce the same calculated values, and because of their minor nature, would not warrant, he felt, being submitted to ABS for reapproval.

El Faro's onboard CargoMax program included an optional damage stability module. The option was not required to be class-approved, nor was it. A section in the CargoMax user's manual discussed the calculation steps and theory of damage stability and remedial action. Investigators entered *El Faro*'s departure condition from the shoreside CargoMax file into CargoMax version 1.21.203 and ran the damage stability module with damage to hold 3, then for flooding of holds 3 and 2A. For each case, the program's "emergency response calc" immediately provided

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[165] The IMO defines a *stability instrument* as "an instrument on board a particular ship by means of which it can be ascertained that stability requirements for the ship in Stability Booklet are met in any operational loading condition" (MSC.1/Circ. 1229). A stability instrument can be hardware or software.

information including, but not limited to, the vessel's drafts, range of positive stability, and maximum righting arm angle.

For each case the screen outputs showed a 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 for both damage cases. No value for downflooding angle or indication for downflooding was shown on the printed graph, and the CargoMax damage module did not provide general information about a vessel's downflooding angle to users. Investigators asked former *El Faro* senior deck officers if they were aware of or had ever used the damage stability module of CargoMax. A few stated that they were aware of the module, and all stated that they had not used it.

Comparison of Stability Instruments. 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. Paragraph (f) of 46 *CFR* 170.110 refers to onboard electronic stability computers and their use as an adjunct to the required booklet. Previous deck officers told investigators that CargoMax, not the stability booklet, was the primary tool officers on *El Faro* and its sister vessels used to meet stability criteria. Using a stability instrument instead of the written stability book was common practice in the maritime industry according to deck officers, regulators, and naval architects interviewed during the investigation, because of the flexibility and ease of use the instrument offered.

El Faro's onboard CargoMax software included a function that calculated both the wind profile of the vessel, based on container loading, and the required GM. The vessel's stability booklet, which did not have such an "auto windheel" function, calculated limited GM curves for one, two, three, four, or five tiers of containers, using the full wind profile (maximum container load per tier). Compared with 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 loading for the same tier.

While the CargoMax calculation might be less conservative, it would meet the requirements for calculating minimum required GM specified at 46 *CFR* 170.170. ABS reviews the CargoMax program against the same stability criteria as a stability booklet.

Onshore CargoMax. The loading conditions (drafts, trim, stability, and longitudinal strength) of *El Faro* and its sister vessels were assessed by TOTE terminal operators using CargoMax software. The shoreside software used for *El Faro* was the same as that used on board the vessel. The shoreside program was not required to be, and was never, subjected to an ABS survey; was not required to receive and never received annual checks similar to classification society requirements for the onboard program; and was not required to be, and was not, approved by ABS. ABS noted that it was not within a classification society's scope to approve or verify shoreside loading instruments.

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 shortly before the vessel departed. The file was input into the vessel's onboard CargoMax program, as was normally done. The former ABS stability and load line manager told investigators that the installation and annual verification required of onboard loading programs should also apply to the same loading programs used on shore.

Training in CargoMax. 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. Rather, they learned the program through peers and on-the-job experience. They had extensive shoreside experience in vessel prestow and loading operations but had no professional sailing experience on vessels. They also used an informal "CargoMax Program" procedural document as guidance for loading the vessel using CargoMax. TOTE did not provide formal CargoMax training to the deck officers aboard *El Faro*. 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 software programs that calculate shipboard stability.

1.12.5 Loading Condition at Departure

Investigators reviewed terminal documentation for the loading of *El Faro* on its final voyage. Terminal managers used the onshore CargoMax software to load the vessel, as well as stowage-planning software called Spinnaker for containers and a handwritten stow plan for Ro/Ro cargo. 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. A total weight of 6,862.1 long tons of containers and 4,183.8 long tons of Ro/Ro cargo was carried. According to program printouts, the tanktop of hold 3 (hold 4D) contained 50 cars, no trailers, and no other Ro/Ro cargo on the accident voyage.

Shoreside loading personnel and deck officers with experience on *El Faro* told investigators that a 0.5-foot GM margin was added to the vessel's required GM at sailing (3.655 feet).[166] GM margin is not a statutory requirement. The CargoMax printout from September 29 gave a sailing GM of 4.854 feet, corrected for free surface effect to 4.455 feet for departure. (Free surface effect is a reduction in a vessel's stability caused by liquids moving about freely in a tank or hold.) The corrected GM was thus 0.8 foot above the required GM and 0.3 foot more than the owner-applied GM margin of 0.5 foot.

The terminal manager who loaded *El Faro* stated that immediately before sailing, both he and the chief mate understood that the fuel quantity had been incorrectly entered into CargoMax for a pair of double-bottom fuel tanks, resulting in 200 long tons less fuel aboard (originally showed 346 long tons each and corrected to 246 long tons each). After reviewing the effect on GM and deadweight, the vessel sailed and the terminal manager corrected the shoreside CargoMax values the next day. The amended printout showed GM reduced to 4.685 feet, corrected GM to 4.284 feet, and GM margin to 0.64 foot.

[166] Regulations dictate the minimum amount of GM required for a vessel at any time. Adding 0.5 foot of GM margin meant that the vessel had 0.5 foot in excess of what was required when it sailed from Jacksonville.

TOTE Maritime Puerto Rico's terminal manager stated that he typically wanted 100 long tons of available deadweight to remain before sailing and the ship to have 3 to 4 feet of aft trim.[167] The evidence indicates that the vessel sailed with the stipulated available deadweight. With the corrected value for fuel aboard after departure, deadweight was 14,682 long tons.

The CargoMax departure printout gave the following drafts: aft mark 32 feet 6.49 inches; midship mark 29 feet 10.54 inches; and forward mark 26 feet 10.66 inches (with about 5 feet 8 inches of trim between the forward and aft marks). After the CargoMax values were corrected, the vessel's departure drafts decreased at the aft mark to 32 feet 4.5 inches, at the midship mark to 29 feet 9.1 inches, and at the forward mark to 26 feet 9.9 inches. The calculated midship draft was 29 feet 8.3 inches.

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 foot. A previous operations manager and port captain familiar with both the vessel and the accident route 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."

1.12.6 Load Line

Load lines, also known as Plimsoll marks, are marks at the midpoint along each side of a vessel's hull that establish the maximum draft to which the vessel can be lawfully submerged. The purpose of a load line is to ensure the seaworthiness of an intact (undamaged) vessel. As a vessel is loaded, the distance from the hull bottom to the waterline (draft) increases. To prevent overloading or vessel instability, the load line mark should not be allowed to go below the waterline.

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. Load line certificates are issued in accordance with the International Convention on Load Lines (ICLL), administered by the IMO. Load line regulations and policies that apply to US vessels are found at 46 *CFR* Parts 42–47 and at 46 *USC* chapter 51. 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 issuing authority.

A load line certificate, valid for 5 years, is subject under 46 *CFR* 42.09 to annual verification surveys, in which the issuing authority visits the vessel to verify that its watertight integrity is maintained and that the vessel's hull openings, valves, fittings, and freeing ports (openings close to the deck that allow water to drain overboard), as well as the access to crew

[167] *Deadweight* refers to the carrying capacity of a vessel (weight of cargo, fuel, water, food, parts, and other consumables but excluding the weight of the ship itself). Regulations dictate the maximum amount a vessel can carry while at sea. Having an extra 100 long tons of deadweight meant the vessel could load 100 long tons more of cargo, fuel, water, or other consumables.

quarters, are kept in good general condition and that the vessel has not been altered in ways that might affect the position of the load line marks.

El Faro's last load line certificate was issued by ABS on January 29, 2011, and was valid until February 26, 2016. The certificate was based on a survey completed on February 27, 2006. *El Faro*'s freeboard was measured 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).[168]

1.12.7 Watertight Integrity

A vessel's form, construction, and subdivision provide stability and resistance to flooding. The vessel has "watertight integrity" when openings in the hull and bulkheads are sealed or fitted so that they do not allow the passage of water through the structure in any direction under a head (quantity) 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 (in *El Faro*'s case, the second deck).

Doors and Hatches. The deck logbook kept by the ship's officers consistently showed entries stating "W/T [watertight] doors and hatches secured for sea" when *El Faro* departed the dock. (However, the company had no written procedures for monitoring or logging the opening and closing of watertight doors and hatches while the vessel was at sea.) The logbooks also showed that the large watertight doors, which subdivided the cargo areas and that trailers could pass through, were opened in port and secured before departure. The doors provided watertight integrity below the second deck and between cargo holds. Smaller man-size watertight access doors were built into the large watertight cargo doors. Man-size watertight doors also led to the deckhouse, deck lockers, and some engine spaces.

SOLAS chapter II-1, part B-4 ("Stability Management"), regulation 22 ("Prevention and control of water ingress, etc."), permits a watertight door to be "opened during navigation to permit the passage of passengers or crew, or when work in the immediate vicinity of the door necessitates it being opened." The regulation continues, "The door must be immediately closed when transit through the door is complete or when the task which necessitated it being open is finished." SOLAS also requires authorization by the officer of the watch for the "use of access doors and hatch covers intended to ensure the watertight integrity of internal openings."

SOLAS chapter II-1, part B-4, regulation 22, paragraph 13 states the following:

> Hinged doors, portable plates, sidescuttles, gangway, cargo and bunkering ports and other openings, which are required by these regulations to be kept closed during navigation, shall be closed before the ship leaves port.

Each watertight cargo hold in *El Faro* had two man-size watertight hatches called scuttles. The lids to the scuttles were hinged at one side and opened upward onto the second deck.

[168] The ICLL determines the permitted draft/freeboard for a vessel in different climate zones and seasons. The applicable zone for *El Faro* on the accident voyage was the summer zone, and the maximum permitted draft was the summer load line draft.

Immediately below each scuttle opening was a vertical steel ladder that allowed crewmembers to climb into the hold or climb out of (escape from) the hold. According to testimony from past officers and crew, the scuttles were regularly opened at sea so that crewmembers could enter the holds to inspect cargo or make repairs. A review of *El Faro*'s deck logbooks for August 2015 showed no log entries for opening or closing scuttles, hatches, or watertight doors while the vessel was at sea.

To achieve watertight integrity, a scuttle was secured by closing the steel cover (which had a gasket) and turning a wheel. Through a linkage system, the wheel moved four steel pegs (dogs) to seal the scuttle tight and prevent water from entering the hold. A former *El Faro* boatswain testified that a person could not tell by looking at a closed scuttle whether the wheel had been turned to engage the dogs and seal the hatch. A past chief mate and captain of *El Faro* stated, "You would have to grab the handle of it and see if it was locked or unlocked."

The VDR recording indicates that the vertical-access scuttle on the starboard side of the second deck that led to hold 3 was open during the accident. General arrangement drawings (such as figure 56) show that the second deck had two scuttles (called RWTHs [raised watertight hatches] on the drawings), 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. Figures 57 and 58 show the scuttle on the starboard side of the second deck to hold 3 and the scuttle on the port side to hold 2A.

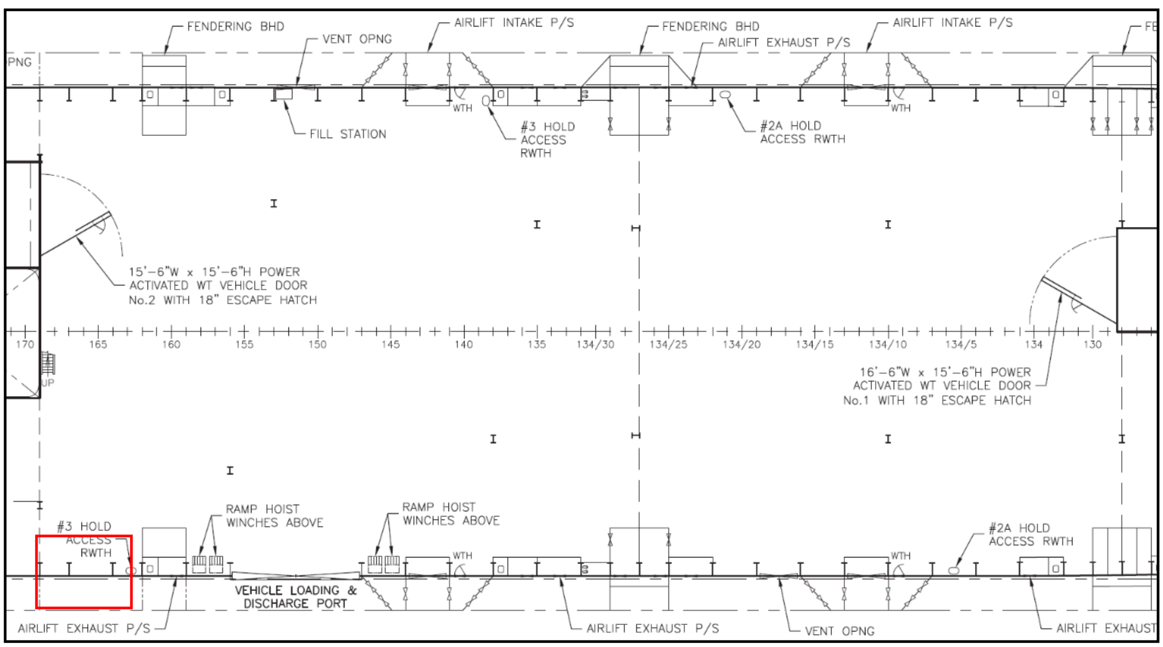

Figure 56. Second deck plan showing scuttles. (Starboard scuttle to hold 3 outlined in red)

Figure 57. Second deck scuttle to hold 3. (Photo by former *El Faro* second mate)

Figure 58. Second deck scuttle to hold 2A, similar to hold 3 scuttle. (Photo by Herbert Engineering)

The steel plates or covers to the scuttles were characterized by crew and officers as being heavy and hard to open. A former *El Faro* chief mate and captain stated that he had “never seen one pop open on its own.” Another former captain of *El Faro*, who had nearly 27 years’ experience as captain or chief mate on that ship and other vessels of the *Ponce* class, stated, “I don’t see a wave getting in there and lifting [a scuttle]. Even if it was not dogged.”

All nine 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, six decks below the navigation bridge. There was no watertight door alarm panel on the bridge or at the engine operation platform. The man-sized watertight doors, watertight raised access hatches (scuttles), and other watertight access doors were not equipped with either a local or a remote status indicator. SOLAS contains regulations regarding openings in watertight bulkheads and watertight doors that apply to cargo ships constructed after February 1, 1992.[169] 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.

Cargo Hold Ventilation Trunks. *El Faro*’s COI required as a condition of carriage that for each cargo hold, at least one air supply fan was to be operated and natural exhaust ventilation openings were to remain open under way at sea when transporting vehicles with fuel tanks (relevant regulations are found at 46 *CFR* chapter I, subchapter I, “Cargo and Miscellaneous Vessels”). Because *El Faro* transported vehicles on the accident voyage that had fuel tanks (automobiles and some other Ro/Ro vehicles), the ventilation ducts were required to remain open.

The ABS technical manual states, “All ventilator openings are to be provided with a weathertight closing appliance.” Regulation 19 of the ICLL 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.” The Coast Guard’s load line technical manual states that closing appliances must be “deemed weathertight to the satisfaction of the assigning authority.”

Outboard-facing louvered ventilation openings in *El Faro*’s sideshell between the main and second decks allowed fresh air into the vessel. The air flowed past baffle plates to supply fans that pushed it through the hull of the second deck down to the fourth deck through supply ventilation trunks on both sides of the vessel (directly opposed). Just above the second deck, the supply trunks were fitted with watertight closing appliances that also served as fire dampers. The exhaust trunks mounted on both sides (directly opposed) of each hold were fitted just above the second deck with weathertight closing appliances that also served as fire dampers.

[169] See 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.”

Past crewmembers on *El Faro* and other *Ponce*-class vessels told investigators that the fire dampers on both the supply and exhaust ventilation trunks always remained open while under way. A previous chief mate stated that they were not closed for heavy weather or for any other reason and that the only reason they would have used the dampers was for a fire. Several former crewmembers stated that the functionality of the dampers was tested by closing and opening (exercising) them monthly as part of drills.

On the VDR recording, the crew is heard discussing water coming through the ventilation system in the engine room. A former *El Faro* chief engineer told investigators he had seen the intakes for the ventilation fans in the engine room ingest rain when the direction of wind and rain allowed it. The water would leak through the ventilation ductwork into the engine room.

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 the ship was constructed in 1974, met the requirements in place during its conversions in 1993 and 2005–2006, and would meet the current (2005 ICLL) requirements. He also stated, "If the same arrangement were proposed today, ABS would accept it, under the current regulations."

The downflooding angle related to intact stability is the minimum heel angle at which an external opening without a weathertight closing appliance is submerged. Under the SOLAS criteria for assessing damage stability, weathertight openings are considered downflooding points, but openings that can be made watertight are not.[170] If fitted with gaskets as shown in the ship's construction drawings, the supply vents would have been watertight, but the exhaust vents were weathertight only. Under the SOLAS damage stability criteria, *El Faro*'s exhaust openings would have been considered downflooding points but not the supply openings, according to correspondence with the Coast Guard Marine Safety Center. Investigators found the gaskets on the sister vessel *El Yunque* to be in poor condition or partially missing.

1.12.8 Damage Control Plan for Flooding

The company's emergency preparedness manual contained the following guidance for 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.

El Faro also had on board a fire control and safety plan, a two-page drawing posted near the bridge, as required of all TOTE-managed ships under TOTE's SMS. The drawing showed, in part, the location of egress routes, scuttles, hatches, cargo hold watertight doors, fire dampers,

[170] See SOLAS, chapter II-1, part B-1, "Stability," regulation 7.2, paragraph 5.2.

ventilation closures, bilge/ballast pumps, emergency generator, remote shutdowns and controls (ventilation systems, emergency fire pumps, general alarm, etc.), and other firefighting equipment. It noted the cargo hold supply ventilation closures for holds 1 through 3 as fire dampers and indicated that they were watertight. It noted the exhaust closures for cargo holds 1 through 3 as fire dampers that were nonwatertight. The plan designated the scuttles to cargo holds as escape trunks and did not indicate that they were watertight. The drawing outlined no procedures.

Under SOLAS, all passenger ships built after 1980 are required to have damage control plans and booklets. Dry cargo ships built after 1993 are required to have a damage control plan, and those built after 2005 are required to also have a damage control booklet. In 2007, the IMO's Maritime Safety Committee published advice on the preparation of damage control plans (MSC.1/Circ. 919). That advice was superseded in 2009 by MSC.1/Circ. 1245, which stated that a damage control plan was

> 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 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.

A SOLAS regulation adopted in 2004 requires a plan to be posted on the bridge showing the boundaries of watertight compartments for each deck and hold, as well as a list of openings and means of closure, arrangements for correcting flooding, indicators of watertight and hinged doors in watertight bulkheads, and other information or procedures necessary to maintain watertight integrity. In 2007, the Maritime Safety Committee adopted mandatory guidelines for providing information about damage stability to masters that was to be included on damage control plans for ships built after January 1, 2009.

El Faro was substantially modified (classified as a major modification by the Coast Guard) in 1993. However, the vessel was not operating internationally and was therefore not required to comply with SOLAS regulations. The vessel was again substantially modified in 2005–2006 (which the Coast Guard did not classify as a major modification). The vessel was enrolled in the ACP program in December 2010, with a retroactive date of entry of February 27, 2006.[171] The ACP included an ongoing review of the equivalency between federal regulations and the SOLAS rules used by classification societies.

There is no evidence that the Coast Guard required a damage control plan or damage control booklet for *El Faro*, and there is no evidence that the vessel had one. The information to the master mandated by SOLAS would have been required only for ships built after 2009, that is, after *El Faro*'s last conversion. According to ABS, SOLAS requires a damage control plan to be placed on board a vessel, but the plan does not require approval, even for vessels built today. It would have been up to the Coast Guard OCMI to require *El Faro* to carry a damage control plan after it was modified, since the modifications were done before *El Faro* joined the ACP.

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[171] The letter from the Coast Guard to Sea Star Line documenting *El Faro*'s enrollment in the ACP did not explain the retroactive enrollment date.

1.12.9 Rapid Response Damage Assessment Program

According to the user manual, ABS's RRDA program provided "rapid response damage assessment support during an emergency incident affecting the enrolled vessel's stability and hull strength." When properly implemented, the intention was to quickly provide information to the captain, particularly in acute emergencies involving stability.

When RRDA receives a call for assistance, the attending engineers mobilize and establish communications. Engineers then access the program's database to get the computer model of the endangered vessel up and running in the RRDA center's HECSALV program.[172] 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.

Although not required to do so by regulation, TOTE subscribed to the RRDA program for *El Faro*. The *El Faro* crew did not use the resource during the accident, however, and an RRDA group was not set up until 4 hours after all contact with the vessel had been lost. ABS's RRDA director said that the team provided one free emergency exercise per year for each fleet of vessels enrolled and that feedback from vessel managers had been positive. He said that increasing the captain's and crew's "knowledge of what RRDA does and can do for those on board would be helpful." No drill had been held for *El Faro* or other TOTE vessels, as the RRDA manager recalled.

A port engineer from TOTE made the first call to the RRDA at 1200 on October 1 (1100 CDT). The RRDA team was activated and in place by 1230. 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 Marine Safety Center's salvage engineering response team was working with the RRDA and remained so throughout the event. At 1351, the RRDA team received *El Faro*'s departure loading condition from TOTE via email 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 (246 long tons each).

By 2005, the RRDA had emailed three load cases (condition analyses) for the vessel: undamaged loading condition at time of sinking, same load condition with hold 3 flooded to 10 percent of its volume, and same load condition with hold 3 flooded to where 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." Thereafter, the RRDA stood down because there was no further contact with the vessel. The following day, RRDA emailed a fourth case: same load condition, with hold 3 flooded to 10-percent volume and 75-knot beam wind (which accounted for windheel).

The RRDA director stated that response times to emergencies varied greatly. He indicated that it was important to have accurate ship models for their program and that the ship's stability

[172] The HECSALV software was developed specifically for emergency response and salvage by Herbert-ABS Software Solutions, LLC.

conditions for the current voyage were critical to shortening response times. He also stated that *El Faro*'s ship model was in the RRDA's stability program but that the vessel did not send its loadout at departure. TOTE sent loadout and fuel information after the accident.

The RRDA director said that dynamic conditions, such as wind and waves, could be built into a ship's model. He stated that they could estimate windheel and that container ships and Ro/Con vessels such as *El Faro* presented difficulties because their deck cargo loads changed, which affected a vessel's wind profile. The director said, however, that the RRDA could build a wind profile of a vessel when it first enrolled in the program, which could then be "tuned" on the day of an incident. RRDA representatives said that while it was important to have actual ship conditions, some assessment and advice could be provided without that information.

1.12.10 Postaccident Analysis of Stability, Structures, and Sinking

After the accident, as requested by the marine board, the Coast Guard Marine Safety Center reviewed and analyzed the stability (intact and damage) and structures of *El Faro* and also conducted a hydrostatic sinking analysis that assessed contributing factors to the sinking (MSC 2017). NTSB investigators worked with the marine board to gather evidence and support the assumptions that went into the technical review and sinking analysis.

Computer Model. The Marine Safety Center developed a three-dimensional computer model of *El Faro* to use in General HydroStatics (GHS), a program that computes a vessel's hydrostatic properties and stability. Analysts compared the GHS outputs with the values in *El Faro*'s most recent stability booklet and in the CargoMax stability software (noting that CargoMax used the same hydrostatic tables as the stability booklet). They found that the "hydrostatic properties compared closely, with approximately 0.1% difference in calculated displacement at the full load draft." The report noted discrepancies in tank volumes, centers, and free surface inertia values for the stability booklet and CargoMax (in excess of 2 percent tolerance in IMO MSC.1/Circ. 1229), which appeared to derive from errors in the original tank geometries and most likely applied to all *Ponce*-class vessels.

Stability Tests and Instruments. Analysts reviewed the last stability test (inclining experiment) for *El Faro* and subjected the test to an uncertainty analysis. The analysis found "95% confidence that the true value of the accident voyage GM was within +/-0.7 feet of the calculated value." Hydrostatic and stability analyses use a ship's lightship weight (displacement) and center of gravity. Regarding the vessel's stability booklet, analysts noted that it was not intended to assess vessel loading and hull strength (bending moments and hull stresses), which would be addressed in a vessel loading manual and that *El Faro* was not required to have a loading manual by virtue of its construction date. Therefore, the vessel's lightship weight distribution did not require approval, nor was it ABS-approved. Analysts found that the transverse center of gravity was incorrectly calculated for the vessel's most recent stability test report.

The loading and securing of cargo is not addressed in a stability booklet but rather in a vessel-specific manual for cargo loading and securing. The report noted that ABS approved *El Faro*'s manual and that the ship's CargoMax software contained features for assessing cargo securing, on which the vessel operators relied for container loading. It also noted that the CargoMax software was neither reviewed nor approved for use in assessing cargo loading and securing.

The Marine Safety Center's report discussed the CargoMax stability software carried on *El Faro* and used by shoreside personnel to load the vessel, which included an application for calculating the ship's longitudinal bending moments and shear forces to the ABS allowable values. Vessel operators relied on those features to assess the hull girder bending moment in load planning. However, since the vessel did not require a loading manual, the calculation application was not required to be, nor was it, approved by ABS for assessing vessel loading and hull strength.

Analysts reviewed the onboard stability software carried by *El Faro*, referred to by ABS as a stability instrument. The stability instrument (CargoMax) was used by vessel officers to determine that the operational loading condition of the ship met the stability requirements specified in the stability booklet. Typically for stability instruments, CargoMax had been reviewed and approved by ABS for use on *El Faro* only as a supplement to facilitate stability calculations, not as a substitute for the approved stability booklet. Therefore, "the vessel operator was obligated to follow all operating instructions delineated in the [stability booklet]."

Analysts found two instructions in the stability booklet that operating personnel had not followed in loading the vessel for the accident voyage using CargoMax. The instructions regarded slack (not completely full) tanks for consumable liquids and saltwater ballast tanks being pressed-up (full). CargoMax had checks and warnings for the load line limit and the intact stability criteria but no warnings for slack tank limitations in the stability booklet. However, analysts noted that CargoMax "does properly include all tank free surface corrections in calculating GM so while this slack loading is not in accordance with the [stability booklet] and it does introduce some additional risk to the vessel, it is not an unassessed risk."

The Marine Safety Center analysis found that the accuracy of the CargoMax calculations could be considered as good (or better) than calculations performed by hand using the stability booklet. Sample load cases from CargoMax compared with the stability booklet were nearly identical, as expected.

The safety center observed that there are no requirements for the use of onboard software for vessel stability, strength, or cargo loading and securing for dry cargo ships such as *El Faro* (although several recent IMO amendments for stability software apply to oil, chemical, and gas carriers). The safety center further observed that "under Coast Guard policy, the master must be provided with the capability to manually calculate stability" but that he or she may use other tools, such as stability software, to assure stability. The safety center stated, however, that "it remains incumbent upon the master to ensure the vessel is compliant with all aspects of the stability booklet."

Intact and Damage Stability. An intact stability assessment was performed by using the Marine Safety Center's computer model of *El Faro* to assess eight benchmark loading conditions against intact stability criteria. The safety center–defined benchmark conditions included the accident voyage departure and the estimated loss of propulsion conditions. The analysis found that all eight benchmark loading conditions met the applicable intact stability requirements of 46 *CFR* 170.170 (the GM weather criteria), which applied to *El Faro*. However, analysts noted that "the vessel was often operated very close to the maximum load line drafts, with minimal stability margin compared to the required GM, and little available freeboard and ballast capacity, leaving little flexibility for improving stability at sea if necessary due to heavy weather or flooding."

The report notes that the minimum GM curves in the stability booklet were generated based on the minimum GM required to meet intact stability criteria in 46 *CFR* 170.170. However, for vessels required to meet both damage and intact stability requirements, such as *El Faro*, the higher of intact or damage stability minimum GM must be reflected in the minimum GM curves. Although the conversion to carry containers in 2005–2006 resulted in an increase of over 2 feet in the vessel's load line draft, no damage stability assessment was done after the 1993 lengthening to verify that *El Faro* would remain limited by intact stability criteria in all loading conditions. Assessing *El Faro* with the draft increase to applicable 1990 SOLAS probabilistic damage criteria in effect at the time of conversion showed that for "load conditions with two or fewer tiers of containers, the limiting stability criteria could be the damage stability instead of the intact stability criteria," and for those load conditions limited by damage stability criteria, this was not reflected on the minimum required GM curves. However, for *El Faro*'s departure condition on the accident voyage, the report concluded that "the limiting stability criteria was the intact stability criteria, which was properly reflected in the [stability booklet] and incorporated in the CargoMax stability software."

Analysts theoretically evaluated *El Faro* against the stability standards that would have applied had the vessel been newly constructed in 2016. *El Faro* would have been required to meet part A of the International Code on Intact Stability (2008). For departure loading conditions on the accident voyage, the vessel would not have entirely met the intact stability criteria because of the limited area under the righting arm curve above 30°. Analysts evaluated *El Faro* against the 2009 SOLAS probabilistic damage stability standards, the 1990 criteria having been superseded after the vessel's conversion in 2005–2006. For the departure loading condition, a minimum GM at full load draft of about 4 1/2 feet was calculated. That was less than the minimum required GM for intact stability. Therefore, as loaded for the accident voyage, *El Faro* would have met both 1990 and 2009 SOLAS damage stability standards.

Regarding stability criteria and their relationship to ship survivability, the report noted:

> . . . since GM is only the initial slope of the righting arm curve (and is only applicable for small angles), the magnitude of GM does not give an indication of the magnitude of the maximum righting arm, the angle at which the maximum occurs, the angle of vanishing stability (range of stability), or the area under the righting arm curve (righting energy). Therefore, the use of GM as a stability indicator may be misleading if used by itself. However, since calculation of GM is relatively simple compared to calculation of righting arms, GM has been used extensively as a basis for evaluating stability of many types of ships, including general cargo vessels.

Later in the report, analysts noted that

> GM is a good indicator of the initial stability for small angles of heel in response to small heeling forces and moments; however, it is in general a poor indicator of overall stability, especially in response to large heeling forces and moments as might be experienced by a vessel in heavy weather where high winds and seas can be expected. The range of stability,

> maximum righting arm and angle, and area under the righting arm curve are the more important stability characteristics for heavy seas, and GM provides little or no insight into these characteristics.

The report found that in comparison with other conventional cargo vessels, the righting arm curves for *El Faro* had a relatively small area (righting energy) and range of stability. The report noted that those characteristics were significant in consideration of both "limited residual righting arms and righting energy with the vessel subjected to heeling forces and moments as might be experienced in heavy weather where high winds and seas are expected" and "of limited residual righting arms and righting energy when subjected to flooding."

Ship Structures. The report concluded that *El Faro*'s "ship structures met all regulatory and class structural requirements for strength." After viewing underwater video of the sunken vessel, analysts noted that although the bottom of the hull was under sediment and not visible, they saw "no visual evidence of structural damage in the amidships region of the hull." The report concluded that because the vessel was loaded in a "hogging" condition (center or keel bent upward), "any significant hull girder structural failure would likely have resulted in compressive buckling of the bottom plating and/or tensile fracture of the upper decks." If the hull had significant bottom plate buckling, there would have been "buckling creasing of the lower side shell above the sediment." The analysis concluded that there was no evidence of buckling creasing or tensile fracture of the upper decks.

Hydrostatic Sinking Analysis. The hydrostatic sinking analysis considered windheel and flooding effects, potential downflooding through multiple paths, and the combined effects of wind, seas, and flooding on hydrostatics. Analytic focus was on righting arms and the effects of windheel and free surface due to floodwater in cargo hold 3 and later in hold 2A.

Results were highly sensitive to the estimated permeability of the cargo hold and to variation in wind speed. *Permeability* is the fraction of a compartment or tank that can be filled with liquid after accounting for piping, machinery, cargo, etc., and is widely variable in holds that carry trailered containers and automobiles.

The vessel was analyzed in a "dead-ship" condition (after loss of propulsion). Loading condition was based on estimates that about 240 long tons of fuel had been burned since departure from Jacksonville and that 110 long tons would have been transferred from the No. 3 double-bottom port and starboard storage tanks, leaving 130 long tons net burn-off from the fuel oil settling tank.

Environmental conditions at the time of loss of propulsion and sinking (between 0600 and 0740) were estimated from hindcasts and numerical simulations. The captain's statement about a 15° list was interpreted to mean that *El Faro* experienced a mean heel angle of about 15° but that wave action also caused the vessel to roll about the heel angle. The wind off the starboard beam was estimated at 70 to 90 knots (sustained). The study found that under those conditions, with the ship dead in the water, a windheel angle of 7° to 11° could be attributed solely to the steady beam wind.

Analysts' review of underwater video and photographs of the hull found no evidence of an exterior or shell plating hull breach that could have contributed to the flooding of hold 3. However, they noted that with even a small opening (1 square foot) just below the waterline, the pumping system on *El Faro*, which had a capacity of less than 1,000 gpm, could not have kept up with the resultant flooding (calculated flow rate = 2,160 gpm).

Holds 1, 2, 2A, and 3 were adjacent and separated by watertight bulkheads. The tween (third) deck of the cargo holds was considered nonwatertight because of small deck plate openings that allowed exhaust-laden ventilation air to circulate from the lower hold up to the exhaust vent trunk openings. As the holds flooded with water up to the tween deck, they would limit the flow of water as the vessel rolled ("pocketing"). Therefore, once flooded above about 20 percent (the approximate percentage needed to reach the tween deck at a 15° heel angle), free surface effects from floodwater would be reduced in the lower cargo holds. In addition, the free communication effect (which reduces stability when a partially flooded, off-centerline compartment has a hull breach allowing free communication with the sea) would not have existed for flooding of the cargo holds because they were symmetric about the ship's centerline.

Flooding of Hold 3. For a condition of no wind, flooding of hold 3 was calculated in 10-percent increments, from intact condition to level of equilibrium (flooded to external waterline), using permeability factors of 0.7 and 0.9.[173] Results showed reduced righting arm and GM (slope of the righting arm curve) for flooding percentages from 10 and 20 percent of hold volume due to an initial free surface effect. The flooding of hold 3 would have resulted in an increase in draft and a corresponding decrease in freeboard. The analysis found that after loss of propulsion, with hold 3 flooded 20 percent and a chosen heel angle of 15° (as may have been possible in the early stages of hold 3 flooding), the cargo hold ventilation openings (tops of baffle plates) would have been close to a still waterline, and intermittently rising water due to waves and vessel roll would have submerged the ventilation openings (see figure 59).

For a condition of wind, heeling arms for 70-, 80-, and 90-knot winds and residual righting arms were calculated for hold 3 flooded 10 percent, 20 percent, and 30 percent (permeability 0.7). Righting arms were also calculated for the same flooding conditions in hold 3, with and without an 80-knot wind. Results were that residual righting energy was reduced significantly even for lower levels of flooding up to 30 percent in combination with an 80-knot beam wind. Further, a combination of windheel and initial flooding of hold 3 could have yielded the 15° heel angle mentioned on the VDR. The report stated, "It is apparent that the vessel would have been in a vulnerable state and susceptible to capsizing even with flooding only of hold 3, when considering the combined effects of partial flooding, wind heel and roll motion."

[173] This type of flooding analysis differs from damage stability analyses performed in accordance with SOLAS requirements, where permeability factors are based on vessel and cargo type.

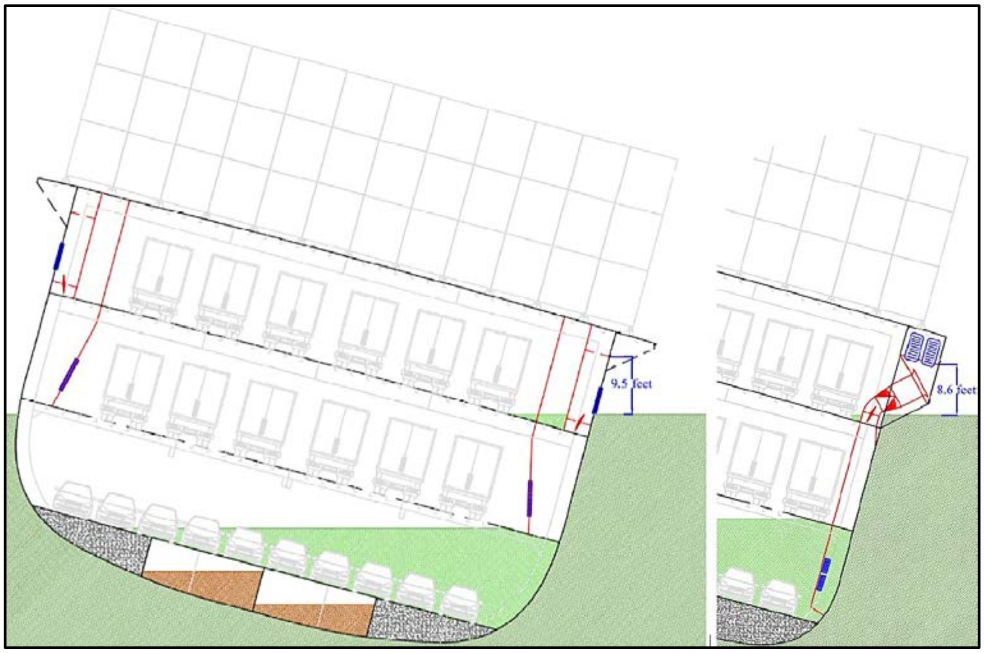

Figure 59. Ventilation supply trunk (right) and aft exhaust trunk (left) in hold 3, with flooding of hold to 20 percent (0.7 permeability) and heel angle of 15°. (Adapted from figure 6-18 in MSC 2017)

Downflooding Through Ventilation Openings. The cargo hold ventilation openings were identified as potential downflooding points (points that would allow seawater to enter the cargo holds as they moved closer to the waterline). Analysts noted that the supply and exhaust ventilation openings in hold 3 were only slightly lower and closer to the waterline than those for holds 2 and 2A due to the sheer of the second deck and the vessel's trim aft. The tops of the baffle plates installed to limit water from entering holds 3 and 2A through the fire dampers, which were about 25 to 26 feet above the accident voyage still waterline, were found after loss of propulsion to submerge at heeling angles of 26° to 29°, with only hold 3 flooded to 20 percent at 0.7 permeability. No damage control plan or emergency plan was found that might recommend securing the fire dampers in extremely high seas to prevent potential downflooding through ventilation openings into cargo holds.

The analysis found that as hold 3 continued to flood, eventually the ventilation openings for hold 2A would have intermittently submerged due to flooding in hold 3 plus windheel, waves, and roll motion. Hold 2A and perhaps hold 2 probably took on water, at least intermittently, as the vessel rolled about a windheel angle of 15° and while hold 3 was flooding. It was noted that progressive flooding into hold 2A could potentially have occurred through leaks in the watertight cargo door seal between hold 3 or in bilge pumping system check-valves. Regardless of the flooding source, the bilge alarm for hold 2A sounded at 0716.

Downflooding angles for 13 downflooding points were calculated and plotted for two conditions—intact condition at loss of propulsion (no flooding) and 20 percent flooding of hold 3 (0.7 permeability). The downflooding angles for the various downflooding points were as follows:

- Hold 3, starboard access scuttle:16.2° (intact condition), 14.9° (hold 3 flooded to 20 percent).
- Hold 2, vent supply baffle: 29.°6 (intact), 28.9° (hold 3 flooded).
- Hold 2, aft and forward exhaust vent baffles: at least 30° in either condition.
- Hold 2A, vent supply baffle: 27.7° (intact), 26.9° (hold 3 flooded).
- Hold 2A, aft vent exhaust baffle: 29.8° (intact), 28.9° (hold 3 flooded).
- Hold 2A, forward vent exhaust baffle: 30.3° (intact), 29.4° (hold 3 flooded).
- Hold 3, vent supply baffle: 27.2° (intact), 26.3° (hold 3 flooded).
- Hold 3, aft vent exhaust baffle: 29.1° (intact), 28.1° (hold 3 flooded).
- Hold 3, forward vent exhaust baffle: 29.5°(intact), 28.6° (hold 3 flooded).
- The other three downflooding points, all in hold 1, required a heel angle of at least 42° to downflood in either condition.

Figure 60 shows the downflooding angles for the downflooding points described above, plus the angle at which the edge of the freeboard deck would have been immersed (about 15°). The downflooding angles are superimposed on two righting arm curves. The upper curve is the righting arm for *El Faro* in the intact condition on the morning of the sinking, before flooding began and with no wind. The lower curve is the righting arm for the vessel with hold 3 flooded to 20 percent and a sustained 80-knot beam wind. The smaller area under the lower righting arm curve, compared with the area under the upper curve, illustrates the severely reduced energy the vessel had available to right itself after hold 3 flooded and the ship lost power, with hurricane winds on its beam (blowing at a 90° angle to its starboard side).

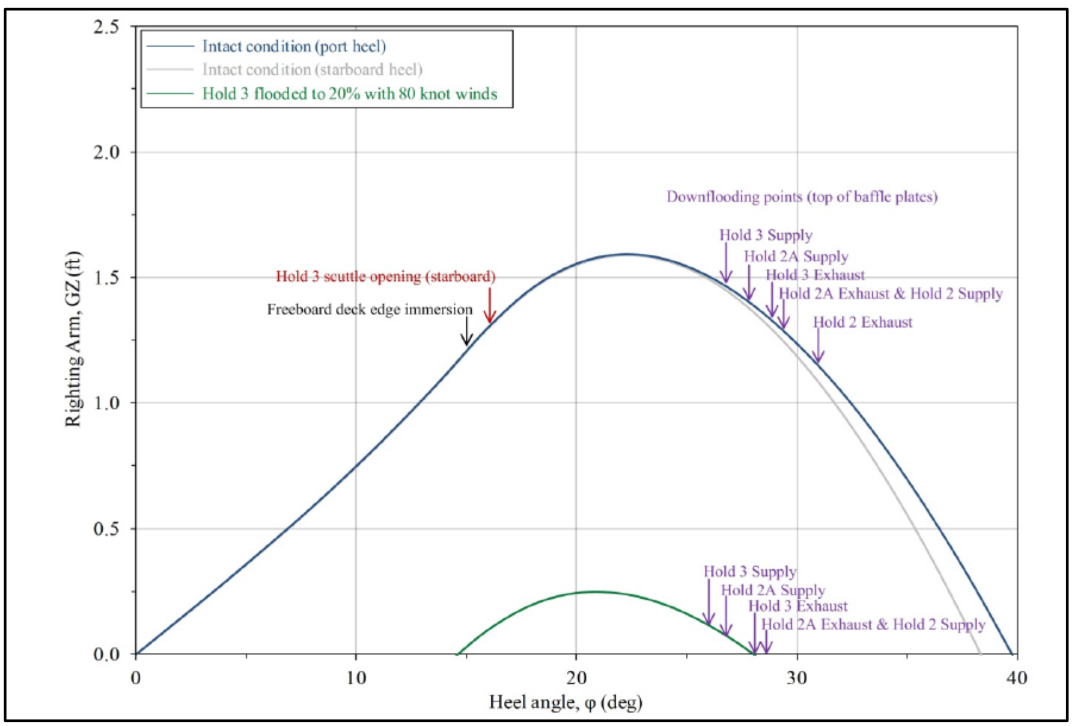

Figure 60. Righting arm curves for *El Faro*, with annotated downflooding angles. Downflooding angles are indicated at various points on curves for convenience; they do not represent values used in righting-arm calculations. (Illustration by Coast Guard Marine Safety Center)

Flooding of Multiple Cargo Holds. The report also considered the effects of flooding in hold 2A after hold 3 flooded. With hold 3 flooded to equilibrium, a significant reduction in GM and righting arms for hold 2A flooded at 10 to 20 percent of hold volume was found. Similar to hold 3 flooded alone, the result was due to an initial free surface effect. At the 10 percent level, negative GM and righting arms indicated “lolling” (vessel would not remain upright but would list to either side) to an angle of about 7° without any wind in calm water. Analysts noted that with hold 3 flooded and hold 2A in the process of flooding, the vessel could have survived in calm water because it theoretically had sufficient residual righting energy. The report concluded, however, that “with almost any significant wind heel and additional wave effects including dynamic rolling, the vessel would likely have capsized.” Analysts investigated the effect of a third cargo hold flooding by running analyses with different compartments flooded. They concluded that it was “evident that any additional free surface effect due to the flooding of a third cargo hold would be sufficient to capsize the vessel, even in calm water.”

Cargo Shifting or Loss. The analysis considered cargo shifting or cargo loss. Cargo shifting was treated as a transverse weight shift. If bays of containers lost structural integrity and leaned to one side without washing overboard, the result would have been similar to a transverse weight shift. The effects of a transverse moment were applied to the intact condition and to the condition of hold 3 flooded 20 percent with 80-knot beam winds. Using an example of 20 containers weighing 25 long tons each shifting an average of 10 feet, the net effect was equivalent to a transverse shift in the ship’s center of gravity, reducing the righting arms and producing a list. Even small transverse shifts in containers would have exacerbated the effects of floodwater and beam winds. However, compared with the effect of floodwater and hurricane-force beam winds, the shift produced relatively “small reductions in righting arms and small induced heel angles.” Cargo loss was modeled by the complete loss of topside containers in a container bay. The loss was found to temporarily improve the vessel’s stability by lowering its center of gravity and increasing the righting arms.

The analysis also considered trapped water on the second deck, which would have allowed water to enter through openings in the sideshell as the vessel rolled. The hydrostatic effects of water on deck 2 were included in the analysis, but dynamic effects could not be incorporated. The reason was that roll motions would have been altered by transverse force components on the sideshell from water trapped to one side and damped by the restriction of flow through the sideshell openings.

Summary of Sinking Analysis. The analysis found it highly *unlikely* that the vessel sank by the bow, even though the captain said, “bow is down,” but highly *likely* that it capsized (but not that it completely inverted because deck containers washing overboard would have temporarily improved stability). The analysis also found it likely that most or all of the deck containers were lost and that most of the internal Ro/Ro cargo broke free and shifted. The 6,700 tons of iron ore fixed ballast in the double-bottom tanks would have turned the vessel upright as it sank. The report concluded the following:

> It is unlikely that the ship could survive uncontrolled flooding into even a single cargo hold with winds in excess of 70 or 80 knots, and it is unlikely that it could survive flooding of more than one cargo hold except in benign conditions with little wind and waves.

In summary, the report stated the following:

> Regardless of the sources of flooding, the free surface associated with the floodwater in multiple cargo holds combined with hurricane force winds and seas would likely have resulted in the capsizing of the vessel. The capsizing may have been slowed or temporarily arrested as containers on deck began to wash overboard, but as the vessel slowly rolled onto her port side, floodwater would have entered through the ventilation openings into all of the cargo holds and the engine room, resulting in the sinking.

1.12.11 Dynamic and Forensic Sinking Analysis

After the sinking, the NTSB contracted with the company CSRA to study and develop dynamic analyses of the *El Faro* sinking that would yield probabilities of the vessel's range of movement and acceleration, hydrostatic pressure and wave slap at various locations modeled in irregular waves, and storm conditions over time. The analyses considered the vessel under way, dead in the water, and dead in the water in flooding (heeled) condition. 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. The analysis yielded time-domain simulations and visualizations of vessel motions in hindcast hurricane-force winds and seas. Hindcast data were produced by numerical models run by NOAA's Environmental Modeling Center at times and locations corresponding to those of *El Faro* on October 1, in 15-minute intervals.

The study's salient conclusions were as follows:

- Traveling at 14 knots at even keel (no heel), seas 45° off the bow at the departure draft with no flooding, seawater would not reach the ship's ventilation louvers in wave heights below about 7.25 meters (23.8 feet).
- After loss of power, with a chosen heel angle of 15° to 18° in storm waves, the vent openings on the lower port side would be submerged a significant part of the time from almost every wave encountered (figure 61).
- Larger heel angles were more likely from cargo hold flooding than a shift of Ro/Ro cargo.
- The severe damage to the stern and the large transverse hull crack just aft of the aft engine room bulkhead (between bays 16 and 17) were both consistent with seafloor impact. Sonar images that appeared to be hydraulic outburst marks to both port and (to a lesser degree) starboard of the crack indicated entrained water jetted outward, moving the bottom sediment.
- The cargo containers most likely floated for some time after they came off the vessel. Dents on the forward side of the deckhouse and the small number of containers found in the mapped part of the underwater debris field support this conclusion.
- After capsizing or foundering (sinking below the surface), the vessel most likely plunged bow-first, with containers tearing away from and floating off the main deck.

Consistent with the last conclusion were the following observations:

- The two separated uppermost house decks (navigation deck and lower navigation deck) probably came off near the surface, as supported by their distance from the main hull wreckage. The mast and stack also probably came off during the plunge near the surface.

- The damage and scraping on the port part of the front of the deckhouse probably resulted from containers floating up or against it.
- The damage to the lifeboat davits probably occurred near the surface as they were hit by containers and other debris.
- The damage to joiner bulkheads inside the remaining upper deckhouse indicated that debris was ejected aft.

Figure 61. *El Faro* rolling about a 15° to 18° static heel with waves or green water reaching ventilation openings after propulsion loss. (Screen shot at extreme position from CSRA video simulation)

1.13 Operational and Management Information

The parent company of TOTE Services and TOTE Maritime Puerto Rico was TOTE, Inc. The TOTE companies were part of a larger organization, Saltchuk Resources, a privately held company headquartered in Seattle.

1.13.1 Company History

According to various company histories, TOTE began in 1975, when Sun Shipbuilding and Drydock Company established Totem Ocean Trailer Express, offering Ro/Ro trailer service (on the SS *Great Land*) from Seattle to Anchorage. In 1976, the company added the Ro/Ro ship SS *Western Adventure* to its Alaska service and moved to the port of Tacoma. The SS *Northern Lights* (later *El Faro*) joined the company's Alaska service in 1993.

Sea Star Line was founded as Sea-Barge line in 1985, with two tugs and barges operating from south Florida. In 1982, Totem Resources Company purchased Totem Ocean Trailer Express from Sun Shipbuilding (Sun Company). In 1998, Sea-Barge became Sea Star Line, LLC, when it was purchased by Totem Resources and other investors. Sea Star Line owned and operated *El Faro*, *El Yunque*, and *El Morro*. On September 19, 2015, just before *El Faro* sank, Sea Star Line and TOTE (Alaska service) were renamed TOTE Maritime Puerto Rico and TOTE Maritime Alaska.

TOTE Services was founded in 1975 as Interocean Management Corporation, which managed crewing for Totem Ocean Trailer Express vessels and a fleet of oil tankers. The company was sold to Totem Resources in 1989 and was known by several names afterward, including Interocean Ugland Management Corporation and Interocean American Shipping. The name of Interocean American Shipping was changed to TOTE Services in 2012.

The owner of the company's new LNG ships, which were under construction at the time of the accident, was listed as TOTE Shipholdings.

1.13.2 Corporate Organization

TOTE Services operated primarily out of Jacksonville, although company officials also worked in the Tacoma office or in other cities, such as San Diego. The president/chief executive officer (CEO) was based in Jacksonville. Reporting directly to the president/CEO were two vice presidents and two directors:

- The *vice president of marine operations–commercial* worked from TOTE's Tacoma office. He was a member of the executive committee and helped formulate long-range goals, objectives, and budgets. He also managed a team of technical personnel who oversaw commercial operations in Jacksonville and Tacoma as well as new construction in San Diego. The vice president was a member of the shoreside emergency response team. He told investigators that he did not know the specific duties of the team and was unsure how the call list was structured.
- The *vice president of marine operations–government* directed the operation of vessels the company managed for the US government.
- The *director of marine safety and services* assisted in the operation of the company's fleet, both active and deactivated, and managed the supervision of 250 or more seagoing personnel on active vessels. He conducted safety inspections and was also responsible for conducting sea trials for newly built or converted vessels. Before being promoted to director in 2014, he served as a TOTE port engineer. He said that beginning in January 2015, his "main focus" (85 percent of his time) had been on the new LNG ships. Although it was not listed in his position description, the director told investigators that he was the alternate designated person when the DP was not available.
- The *director of labor relations and risk management* managed staff in the industrial relations, human resources, and payroll departments. He represented management in collective bargaining matters; assured that crews possessed the required licenses, training, and certificates; oversaw personnel records and appraised performance; and administered the company's Equal Employment Opportunity and Affirmative Action programs.

The following managers, who reported to the vice presidents and directors listed above, had responsibilities directly relevant to the *El Faro* investigation:

- The *director of ship management–commercial operations* reported to the vice president of marine operations–commercial. He was responsible for seeing that the commercial fleet complied with regulatory requirements; for supervising port engineers and the engineering staff of vessels under his responsibility; for interviewing, hiring, and training employees; and for planning, assigning, and directing work, among other duties. He was hired as director in January 2015.

- The *crewing manager*, who reported to the director of labor relations and risk management, was responsible for recruiting vessel personnel and was the primary contact with unions. Among other duties, the manager was responsible for checking medical backgrounds and providing drug-free letters to the Coast Guard and for maintaining employment records and reviewing shipboard evaluations. The crewing manager had been working in that position since 2005.
- The *manager of safety and operations/designated person* reported to the director of marine safety and services. The manager was responsible for enforcing the company's drug and alcohol policy for shipboard personnel; formulating safety policies and procedures; conducting ISM training and internal audits; reviewing permits for "hot work" (including welding, cutting, and heating); submitting accident reports; and seeing that periodic emergency drills were conducted. The manager also performed the role of DP and, as such, was required to report any issues and concerns from the fleet directly to the TOTE president/CEO.[174] Part of his role as DP was to be available 24 hours a day to respond to calls. TOTE had considered hiring an employee to assist the DP with his duties (he managed 14 active and 10 inactive vessels) but reallocated his duties to other staff. The DP had been hired by TOTE in February 2014.

The main offices of TOTE Maritime Puerto Rico were also in Jacksonville. The terminal manager was responsible for managing weather and other significant events and for ensuring that the cargo scales at the terminal were properly calibrated. The manager of marine operations reported to the terminal manager. He oversaw cargo stowage, loading, and discharging; stability calculations; vessel inspections; and weather forecasting and reporting. He was also required to "cover for the port engineer as needed." He had no training in ship stability before *El Faro* sank but received CargoMax training for the new LNG vessels. As Sea Star Line, TOTE Maritime Puerto Rico had both port captains and port engineers to oversee vessel operations. After a reorganization in 2012–2013, which moved personnel such as the DP from New Jersey to Jacksonville, the company filled only port engineer positions.

TOTE management stated in marine board testimony that the reorganization did not impair shoreside support and, in fact, that the relocation of personnel to Jacksonville enhanced shoreside support and oversight. There were, however, conflicting statements on the topic. A former chief engineer who worked on *El Faro* during the reorganization said that the biggest change was that the port engineer "was basically the only guy [we] had contact with in Jacksonville, whereas everybody else would have been West Coast . . ." He said that before the reorganization, "They were all there, right there, so you could deal with multiple guys from Jacksonville." A former captain on *El Faro* testified that the reorganization did not change the availability of someone ashore with whom he could discuss vessel operations. He stated that before the reorganization, he

[174] As noted earlier, the DP was a link between the ship and the highest level of management. Under the ISM code, the DP had the responsibility to monitor "the safety and pollution prevention aspects of the operation of each ship and to ensure that adequate resources and shore based support was applied, as required."

spoke with the former DP in New Jersey, and afterward he spoke with the current DP in Jacksonville. He was asked if he recalled anybody in the Jacksonville area who was involved with marine operations. His response was, “No, sir.”

While cargo was being loaded onto *El Faro* before the accident voyage, the manager of marine operations was on vacation. The terminal manager told the marine board that he performed the vacationing manager’s duties. He said he did not discuss the weather with the *El Faro* captain. He also said that the longshoremen lashed the Ro/Ro cargo for bad weather, that the vessel’s crew did not ask for additional lashings to be placed on the cargo, and that he did not read the vessel’s drafts at departure.

1.13.3 Company Operations

At the time of the accident, the company employed more than 500 seamen and crews and operated a fleet of over 30 vessels, according to the TOTE Services website.

Oversight of Nautical Operations. TOTE regarded captains as the primary nautical experts. According to the director of marine safety and services, “There is no one in the company that formally provides oversight for nautical. We depend on the captains to take on that role.”

Monitoring Ships at Sea. TOTE did not have a policy for monitoring commercial vessels at sea. The vice president of marine operations told the marine board that he did not know if there was anyone in the organization who “may actually know where the ship is . . . through some kind of computer tracking system or some alternate means of communication.” The director of marine services and safety testified that the vessel’s port engineer was responsible for monitoring departure messages, arrival messages, and noon reports. *El Faro*’s port engineer said he believed he saw *El Faro*’s noon position report for September 30, 2015. When asked who reviewed the position reports so that the company could track a vessel’s position at any time, the port engineer said, “I don’t believe anyone does that, sir.”

The manager of safety and operations stated that storms were “not necessarily” plotted against a ship’s position but that “we know the position at times based on their noon position.” (The last noon report of *El Faro* reported its position 18 hours before it lost propulsion.) The manager testified that no one in the company was tasked with monitoring tropical weather**.** He also stated that some of the ships TOTE managed for other companies had an online weather-routing system that tracked both ship and storm positions.

Under the company’s SMS, the captain was responsible for monitoring the weather along the vessel’s intended track and for taking action to prevent excessive damage to the vessel from heavy weather. The captain was also required to advise shoreside management of speed reductions or course changes due to adverse weather.

In August 2015, both Hurricane Danny and Tropical Storm Erika (see section 1.10, “Meteorological Information”) had affected TOTE and its vessels. On August 20, the DP issued a safety alert for Hurricane Danny that included the location of the hurricane and its forecast track. The alert stated that “all our vessels, in all oceans, should review their general and vessel-specific heavy weather procedures and be prepared for the unexpected occurrence." Management also exchanged emails between August 19 and August 23 regarding the storm and related company operations.

TOTE did not issue a safety alert for Tropical Storm Erika. However, managers exchanged a number of emails with each other and with the *El Faro* captain during that storm. In one email, the captain advised the company that he planned to avoid the storm by taking Old Bahama Channel, that the new route would add 160 nm to the voyage but was safer in case Erika's track changed, and that the crew would secure cargo the next day. On August 26, the DP emailed the captain and shoreside personnel: "To ensure we are all on the same page and nothing is missed in the risk assessments and action area, please send me a detailed email with your preparedness/avoidance plans and update daily until all clear." The next day, the captain wrote the DP that he would address cargo securing, the riding gang stopping work and securing its area, and securing all watertight doors in a safety meeting that day.

The company issued no alerts about Hurricane Joaquin before or during the accident voyage. Emails, interviews, and the VDR audio recording yielded no evidence that the company requested a risk assessment during the voyage. The only email communications between the company and the captain were the captain's departure report on September 29, his noon report on September 30, and an email on September 30 in which he summarized the weather information and stated that he "would like" to take Old Bahama Channel on the return to Jacksonville. The director of marine operations authorized the diversion by email. The only telephone contact was initiated by the captain during the last hour of the voyage, when he called the DP to report the emergency.

According to management, the company's concerns during Hurricane Danny and Tropical Storm Erika were its terminals. Hurricane Joaquin was not predicted to affect the terminals. In testimony to the marine board, the director of ship management explained that if a hurricane is bearing down on a port, "You have nowhere to run." In contrast, he said, "Joaquin was—as recently as several days before the incident—a tropical depression heading to the North Atlantic."

Investigators surveyed nine other companies that operated similar vessels, traded on similar routes, or operated in heavy weather. All respondents reported that they provided weather-routing services to their vessel masters. Eight responded that they held weather-related discussions with their masters. All the respondents' SMSs or operations manuals addressed heavy weather. Seven had checklists for securing for sea that specifically referenced heavy weather. Most companies had an assigned person or entity that actively monitored and became involved in their vessels' movements. All company management either contacted vessel masters directly or followed correspondence between shoreside weather routers or nautical personnel and masters.

The stability books of respondents to the survey included situations to avoid (such as certain wave or sea conditions); operations to undertake with caution, such as shifting liquids to correct a list caused by flooding or changing course; and recommendations on ship headings in heavy seas. Some stability booklets contained information relating to windheel. One book contained the wind velocity used to compute weather criteria required by SOLAS. The same books also contained advice or instructions to masters to ensure that closures were made watertight or weathertight.

Weather-Related Training. The Coast Guard did not require deck officers to take any formal heavy-weather training courses, and TOTE did not provide it. TOTE management stated, however, that mariners were given informal heavy-weather safety training on *El Faro* as part of the company's onboard training program. TOTE was not required to ensure that officers obtained additional training outside of what the STCW Convention and Coast Guard regulations required. According to its director of marine services, TOTE did not have a "dedicated trainer" responsible for shipboard training records or ship-specific training. The *El Faro* captain and bridge officers had not attended courses in advanced shiphandling, nor were they required to. Requirements for such training as part of the licensing process did not take effect until 2016.

Investigators found no evidence that users on *El Faro* of the BVS weather forecast and analysis program had any formal training with the system. Testimony from deck officers indicated that there was on-the-job training, and a BVS user's manual and quick reference guide were readily available for use on the vessel. According to crewmembers and TOTE employees, the ship's monthly safety meetings rarely included a discussion of hurricane preparedness.

Safety Training for Riding Gang. Company policy was stated in its SMS as follows: "All members of a riding gang shall be given an indoctrination tour of the vessel before or as soon after sailing as possible." The indoctrination was to be noted on a logsheet and signed by the riders before they started work. Investigators received records of completed indoctrinations up to May 19, 2015. Familiarization and training logs for the Polish workers, who came aboard *El Faro* in August, were retained on the ship, not at company headquarters.

At the third marine board hearing, a Polish worker who had been on *El Faro* in the days and weeks before the sinking (from August 18 through September 29) stated that he and his Polish coworkers went to the captain's office immediately on boarding the ship to fill out forms. He recalled that they were medical. He could not recall having a safety briefing and stated that he was not taken to the lifeboats or liferafts and shown what to do in an emergency. He did state, however, that their supervisor showed them the entire ship when they came aboard. He was aware of where the lifeboats and immersion suits were located, though he never put on a lifejacket or immersion suit while he was on board. When asked if he knew the various emergency signals on *El Faro* (general alarm, fire, and abandon ship), he said he did not.

When queried about emergency drill participation, the Polish worker said they did not participate in the drills "because they did not apply to us." When asked where they would go during safety drills, he said they "were doing their work." An off-duty chief engineer said the riding crew participated in the lifeboat drills. An off-duty third mate stated that the riding gang would muster on the bridge during abandon-ship drills, though he did not personally observe them. The *El Yunque* captain did not recall whether the Polish crew took part in drills or put on lifejackets or immersion suits while he was chief mate on *El Faro*. None of the logsheets that recorded drills contained any of the Polish riding crew's names or signatures.

Emergency Response and Safety Concerns. TOTE had a dedicated emergency phone number that a service manned 24 hours a day. According to company protocol, once the service was contacted, an emergency response team would be notified and would respond as a team. According to emergency response team members, no heavy-weather scenarios were included in their training, nor did the drills include fire at sea or vessel grounding. Team logs for 2015 showed that *El Faro* had emergencies on September 1 and 2 involving diesel oil spilling into the sea. On September 3, a drill was held on contacting the qualified individual in case of emergency.

TOTE provided Tunstall Americas (the contracting company for the call center) with information to help its employees take emergency calls. For example, when a call came in for the emergency response team, operators were instructed to remain on the line until they were sure the call was taken by a TOTE representative. Specific instructions were listed on the operator's computer screen, similar to a checklist.

Crewmembers were directed to contact the DP if they had safety concerns. The DP's phone number was posted throughout the ship, but the only shipboard phone the crew could access was on the bridge, and permission to use the phone was at the captain's discretion. Crewmembers were not prohibited from having their own cell phones or satellite phones. In addition to the DP's phone number, a flyer for an online reporting tool called "Speak Up" was posted on the ship. The flyer listed a link to a company hotline where crewmembers could access "Speak Up."

The vessel's emergency preparedness manual included an emergency procedure in case of flooding. It referred vessel personnel to the "ship's stability information to determine what action is necessary to improve buoyancy." The manual stated: "Intact spaces have to be evacuated and securely battened down. This include[s] 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." The manual also advised the captain to obtain "detailed information about the location and extent of damage" and to send the information to company headquarters so that the shoreside emergency response team (coordinated by the manager of safety and operations) could "assess buoyancy and structural effects of flooding and . . . advise the Master of ways to limit stress."

Delivery Schedule. Delivering cargo on time was one of TOTE's stated goals. The banner on the main page of the company's website in the days following the accident read, "On time, every time."

Four of TOTE's largest customers stated that the company was responsive if there were delays in delivering cargo. TOTE's customer contracts did not include financial penalties for late deliveries. After its competitor Horizon Lines removed two ships from its Puerto Rico service in 2012, then ceased operations in December 2014, TOTE's business increased. The size of TOTE's fleet remained the same, however. To meet the demand, TOTE used barges to supplement cargo deliveries by ship.

TOTE provided investigators with a record of expected versus actual delivery times. If arrivals were within a 2-hour window of the expected arrival time, they were considered "100% on time." If arrivals were over 2 hours late, they were considered "0% on time." Data showed that the *El Faro* captain made his arrival time in San Juan within the 2-hour window 90 percent of the time. His performance evaluations contained no comments related to timeliness of departures or arrivals. Witnesses at the marine boards did not raise any issues with the captain's ability to maintain a schedule.

During the marine board hearings, off-duty crewmembers and shoreside personnel stated that the company did not put pressure on the crew to make arrival times and that the company was not penalized if the vessel arrived late to port. Investigators found ten instances in the VDR transcript of bridge personnel talking about the estimated time of arrival in San Juan. TOTE told investigators that the ship's personnel did not know or were not aware that timeliness was tracked.

1.13.4 Other Information

Departure from Port. Company procedures and guidelines were silent about whether a vessel should remain in port or put out to sea when a storm was approaching. Coast Guard Sector Jacksonville's 2015 Port Heavy Weather Plan contained detailed instructions to follow on the approach of a hurricane. The plan recommended leaving port if a hurricane was approaching but left the decision to the captain whether to remain in Jacksonville or depart. If a captain wanted to keep his vessel in port under heightened hurricane watch/warning conditions, he had to justify that decision and obtain Coast Guard permission to remain.

The plan referenced the Navy's *Hurricane Havens Handbook* (NMOC 2016). The handbook deems the port of Jacksonville (including Blount Island, where *El Faro* docked) a poor hurricane haven, mainly because the low-lying topography provides little shelter from winds and storm surges and the area is on the preferred tropical cyclone track. When sortieing port under a hurricane threat, the handbook recommends that vessels leave in ample time and head eastward, so as to pass north and east of the storm. A second recommended option is for vessels to head south, so as to pass west and south of the storm.

Position Assignments for LNG Vessels. Crewmembers slated for the new LNG vessels were required by the company to sign nondisclosure agreements. According to TOTE, the purpose of the nondisclosure agreements was to ensure confidentiality among current officers and crew who were hired for the new vessels. Some of those being hired into senior positions were working as subordinates for people who had not been selected for the sought-after positions.

A former boatswain and an AB said that crewmembers were upset about not being selected for the LNG ship positions. The boatswain stated that "all the fellows after being on that run for 5 years to 13 years, sure they wanted a shot at the new ship and were upset that they weren't picked, or they hadn't been talked to at least . . ." When asked if the selection of the crew and officers for the new ships caused problems on board, the AB replied, "Oh, it caused a big deal." TOTE managers told investigators that there were no specific criteria by which they selected officers.

Phone Use During Accident Voyage. *El Faro*'s FleetBroadband voice phoneline, which had handsets in the captain's stateroom, in the chief engineer's stateroom, and on the bridge, was the only telephone line used for voice communication to or from the ship on the day of the sinking.[175] The captain used the voice phoneline twice around 0700 on October 1, first to call the DP and then to contact the emergency call center.

[175] FleetBroadband connects ships to satellites. TOTE's records indicate that other satellite phones were previously associated with *El Faro*. TOTE's emergency response manual and the registration information for the vessel's EPIRB filed with NOAA each listed a different phone number for *El Faro*.

Cell phone use by the captain, the chief engineer, and the DP was examined for October 1 from 0300 until 1000 (except for the captain's phone, which was also examined from 0001 until 1000 on September 29). No cell phone calls were made in the hours before the accident. The accident occurred out of cell phone range.

1.14 Coast Guard Alternate Compliance Program

The ACP is a voluntary process for US-registered vessels to obtain a COI by complying with the standards of an authorized classification society (ACS), international conventions, and a US supplement. The ACP is intended to avoid redundancies in the inspection regimes of the Coast Guard under federal regulations and international conventions and by the classification societies under their class rules, while maintaining equivalent levels of safety for US–flagged vessels. At the time of the accident, about 150 deep-draft vessels were enrolled in the program.[176] The ACP is administered under the provisions of 46 *CFR* Part 8 and Coast Guard NVIC 02-95 (USCG 2006). The program began in February 1995.

1.14.1 General Provisions

Under the ACP, the Coast Guard can issue a COI based on reports by an ACS confirming that a vessel complies with the applicable standards. At the time of the accident, the Coast Guard had entered into formal agreements with four classification societies and two pending for ACP participation under the authority of 46 *USC* 3316. The classification society conducts statutory surveys, while the Coast Guard performs safety inspections.

Before being designated as an ACS, a classification society must develop a US supplement that addresses areas where current Coast Guard requirements are not embodied in the class rules or international conventions, or, in the case of international conventions, areas that require interpretation by a flag administration. The supplement, combined with the class rules and international conventions, is equivalent to US regulations.

Class societies complete a gap analysis when creating the supplement. The Coast Guard then performs an analysis to ensure that the gaps are filled by the supplement's provisions. The ISM code is applicable to all vessels enrolled in the ACP, and a recognized organization is responsible for issuing a safety management certificate and for conducting external audits to verify compliance with an enrolled vessel's SMS.[177] *El Faro* was enrolled in the ACP on February 27, 2006, and as such was required to comply with the ABS steel vessel rules, applicable SOLAS conventions, and the US supplement to the ABS rules for steel vessels certificated for international voyages.

The classification society and the Coast Guard share responsibility for updating the supplement to account for changes in the federal regulations and international conventions

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[176] According to the Coast Guard, as of September 2016, the US-inspected fleet contained 228 active diesel-powered cargo vessels and 39 active steam-propulsion cargo vessels.

[177] *Recognized organizations* are classification societies that are recognized by the IMO as authorized to inspect and survey ships on behalf of a flag administration.

(USCG 2006). Investigators found that the Coast Guard was not reviewing supplements in a timely fashion. When the ACP was implemented, there was one ACS. At the time of this report, there were five ACSs, which increased the reviewing requirements. At the time of the accident, the Coast Guard last updated the US supplement for ABS in April 2011. Investigators found that some inspectors and surveyors were unfamiliar with the supplements.

According to NVIC 02-95 and Coast Guard inspectors interviewed after the accident, ACP oversight includes annual vessel examinations by the Coast Guard to verify that the ACSs are enforcing compliance with applicable standards. According to Coast Guard inspectors, the examinations are more limited in scope than Coast Guard inspections that would be required of a vessel not enrolled in the ACP. The scope of the ACP examinations is comparable to that of annual foreign-flagged-vessel port state control examinations. The Coast Guard may also conduct periodic oversight reexaminations to verify compliance.

When conducting oversight examinations of cargo vessels, Coast Guard inspectors are guided by a special ACP examination book for freight vessels (CG-840 ACP FV). The book contains a list of possible examination items but does not require the Coast Guard to inspect each item.[178] According to the Coast Guard, CG-840 ACP FV has not been revised since January 2001, and inspectors used a CG-840 with a 1999 revision date during the March 2015 inspection of *El Faro*. If a non-ACP vessel is found not to conform to the requirements of laws or regulations, the Coast Guard issues a form referred to as CG-835 (“Notice of Merchant Marine Inspection Requirements”) to the vessel’s owner. The form is to be logged into the Coast Guard’s MISLE database and becomes part of the vessel’s history.

If Coast Guard examiners identify deficiencies of an ACP vessel during an examination, the Coast Guard reports to the ACS but does not issue a CG-835 deficiency report. The ACS does not log a report into the Coast Guard’s database because it does not have access to MISLE. The Coast Guard has limited access to the ACS database. An ACS must provide the Coast Guard with unrestricted access to any and all records for vessels in the ACP. Coast Guard inspectors may access the records to review previous results before conducting vessel examinations, but there is no written requirement to do so.

Under NVIC 02-95, the Coast Guard was to establish and maintain a liaison with the ACS. The liaison officer to recognized and authorized classification societies (LORACS) was a centralized point of contact for the ACS and Coast Guard ACP inspectors. The LORACS position was disestablished, however, and the responsibilities reassigned to other people. Many Coast Guard units did not have an assigned ACP officer, and the duties were shared by several people.

1.14.2 Targeted Vessel List

The Coast Guard maintains an “ACP Targeted Vessel” list that is updated annually about October 1. An automated risk matrix is used to determine whether a vessel belongs on the list.

[178] Inspectors use inspection book CG-840 MI for full examinations required of vessels not enrolled in the ACP. The examinations involve greater scrutiny, such as testing of relief valves.

Point values are assigned for issues such as overdue deficiencies, major nonconformities in SMS audits, marine casualties, vessel service, and vessel age. Ten percent of vessels with the highest aggregate score are added to the list. At the time of the accident, *El Faro* had not been added to the 2016 targeted vessel list but was coincidentally slated to be added on the day of the accident.

El Faro had recently reported a medical emergency, which was scored as a "marine casualty" under Coast Guard regulations and added enough points to include the vessel on the 2015 targeted list. Other reportable marine casualties (such as a loss of propulsion because of crew error) would have added points to the vessel's total but were not scored by the automated risk matrix because data could not be entered into the Coast Guard's MISLE system at the time. According to the Coast Guard, no operational controls had been placed on *El Faro* at the time of the accident.

Vessels on the targeted list are subject to additional oversight at the 6-month mark of the examination cycle. The examination scope can increase if inspectors find safety issues on board. The Coast Guard's guidance states that targeted vessels "shall be attended during drydock . . . activities" but that the OCMI could determine whether attendance was necessary.

1.14.3 ABS Surveys

ABS surveyors examined *El Faro* seven times in 2015 before the accident. For planned surveys, vessel owners were required by NVIC 02-95 to give at least 14 days' notice to ACS surveyors. However, that was rarely the case with *El Faro*.

On January 19, an ABS surveyor completed the vessel's annual survey. The emergency generator was tested online. Bilge alarms, steering gear, and lube oil pumps were all tested, and paperwork for the radio equipment was verified. There were no concerns or findings. On January 23, an ABS surveyor attended *El Faro* to conduct the annual hull survey and examined handrails, welding on decks, ventilation ducts, mooring cleats, cargo doors, gangway, and the stability book. A drainage plug in the forward bosun's locker was found to have a small area of wastage, and the coatings on ballast tanks No. 1 port and starboard were rated in "poor condition."

Regarding the procedure for surveying the ventilation ducts on *El Faro*, the ABS assistant chief surveyor for the Americas Division stated that inspection ports were fitted on the ventilation trunks for viewing the fire dampers in the cargo hold exhausts. During annual inspections, ABS surveyors would use a port to view the condition of a fire damper and see it exercised. Surveyors would not typically enter the ventilation trunks during annual inspections. During an annual inspection, if a surveyor saw something deficient or suspect inside the trunks, he or she could expand the scope of the survey and access the trunks. A surveyor would be expected to go inside each ventilation trunk at the load line renewal survey, which occurred every 5 years. The last survey carried out on *El Faro* was on January 29, 2011.

On January 27, an ABS surveyor attended *El Faro* to inspect the coatings on ballast tanks No. 1 port and starboard. The surveyor noted the condition of the coatings as still poor. In addition, while inspecting of the No. 1 port ballast tank, the surveyor found frames 50 and 51 detached at the outboard connection to the tanktop. The fillet welds (triangular welds at, for example, corner joints) were fractured from the tanktop plating between the weld access hole on the frame at the sideshell to 2 feet inboard, terminating at another weld access hole. The surveyor recommended repairing the area, but TOTE was not required to perform temporary repairs. Instead, the welds were to be repaired at the special periodical survey due on February 26, 2016.

On March 10, 2015, an ABS surveyor attended *El Faro* to verify repairs of the steering system to correct a problem, identified during the COI inspection, with a faulty potentiometer that caused an error of 3° to 4° when steering to starboard. The repairs were completed, and the system tested properly. On April 14, an ABS surveyor attended *El Faro* to survey repairs to the overhead of the forepeak space near the hatch in the bosun’s storeroom. The area and related hatch were not watertight spaces, in that they were above both the waterline and the vessel’s watertight deck. The area was repaired to the satisfaction of the surveyor, and no pressure tests were needed to test the sufficiency of the repair to this nonwatertight area.

On June 16, an ABS surveyor attended *El Faro* to conduct a continuous machinery survey, during which various pumps were operated, including the bilge/ballast pumps. The emergency generator was also started and tested. No deficiencies were found. On September 8, an ABS surveyor attended *El Faro* to survey repairs on the port boiler made about 2 weeks earlier, in which Jacksonville Machinery and Repair had installed jumpers to bypass seven leaking economizer tubes. The vessel had made a round trip between Jacksonville and San Juan under normal operating pressure the week before the repairs were made, with no reported problems. The welding repairs to the tubes were inspected and found satisfactory. A hydrostatic test was performed at 800 psi, which the surveyor considered sufficient. Neither the engine logbook nor AMOS contained any entries about the repairs or tests.

1.14.4 Coast Guard Examinations

Investigators found that there was no qualification level required for Coast Guard personnel to conduct ACP oversight examinations. At the time of this report, the Coast Guard did not have a formal training program for the ACP. In an evaluation report on the ACP, the chief of traveling inspectors stated that some Coast Guard marine inspectors lacked significant maritime experience, which limited their ability to accurately assess vessel conditions on the basis of inspections.

For the 2015 *El Faro* inspection, the machinery inspector had not yet received his steam qualifications. Due to the diminishing number of steamships in the US fleet, steam-qualified Coast Guard inspectors were becoming a rarity by the time of the accident, and there were fewer opportunities for Coast Guard inspectors to obtain steam qualifications in their training regime. The Coast Guard Vintage Vessel National Center of Expertise, which was created to be a repository of expertise for steam propulsion, riveted hulls, and other legacy vessels, was discontinued in 2013. Therefore, inspectors did not have a resource to consult for guidance regarding older vessels such as *El Faro*.

After the loss of *El Faro*, the Coast Guard employed traveling inspectors, who were subject-matter experts, to oversee inspections of targeted vessels that were enrolled in the ACP and had successfully completed surveys by an ACS. A number of vessels were found substandard, yet deficiency records for them were lacking. Safety deficiencies were found on each of 15 ACP vessels that were targeted for inspection by the traveling inspection team. Three of the vessels were scrapped and two were issued no-sail deficiencies. The traveling inspectors found that many of the vessels found in substandard condition lacked deficiency records from previous inspections.

One of the inspected vessels was *El Yunque*, the sister ship of *El Faro*. On February 1, 2016, during a SMS audit in Jacksonville, which was attended by Coast Guard traveling inspectors and led by an ABS surveyor, the traveling inspectors examined the ventilation exhaust system in cargo hold 3 and found severe corrosion inside the ventilation trunk. The Coast Guard instructed ABS to oversee the repairs to the ventilation trunks in hold 3 and inspect trunks in the other cargo holds. The following day, temporary repairs were completed and surveyed by an ABS surveyor, who required that permanent repairs be completed to the hold 3 ventilation ducts in 30 days. The ABS surveyor indicated that ventilation trunks in other cargo holds were randomly inspected, and only the starboard exhaust trunk in hold 3 was found to have similar corrosion.

The ship was relocated to Seattle in March 2016 to begin converting the vessel for Alaska service. The Coast Guard traveling inspectors conducted several examinations of *El Yunque* in Seattle and found multiple locations of long-standing and uncorrected wastage in suspect areas and corrosion in the supply trunks of all the cargo holds. In August 2016, TOTE took *El Yunque* out of service to be scrapped.

Coast Guard inspectors and ABS surveyors typically communicated by email or phone regarding vessel inspections and findings, and the ACS surveyors had no access to MISLE to record deficiencies. Although NVIC 2-95 allows the Coast Guard to request ACS attendance during examinations, joint inspections were rare.

1.15 Tests and Research

1.15.1 Fuel Oil Analysis

After the accident, NTSB investigators contacted the fuel oil supplier and obtained samples from *El Faro*’s last three bunkering operations before the accident voyage (September 8, September 14, and September 21, 2015). The samples were sent for testing to an independent facility, Core Laboratories, in Deer Park, Texas. The fuel was tested for flash point, kinematic viscosity, sediment by extraction, and water. The fuel was found to be within ASTM specifications. Table 11 shows results and standards, as reported by Core Laboratories.

Table 11. Analysis of *El Faro* fuel oil samples from bunkering operations before accident.

Sample Date (2015)	Flash Point (°F) Min 140	Kinematic Viscosity (cSt @ 100°C) Min 15, Max 50	Sediment by Extraction (Wt%) Max 0.5	Water (LV%) Max 1	Water (Wt%) Max 2
September 8	196	38.45	0.02	0.05	0.07
September 14	196	38.45	0.01	0.05	0.06
September 21	194	36.57	0.01	0.10	0.11

NOTE: cSt = centistokes; Wt% = weight percent; LV% = liquid volume percent.

1.15.2 Rogue Wave Analysis

At the NTSB's request, researchers from the College of Engineering at the Georgia Institute of Technology and the Italian Ship Model Basin INSEAN Institute in Rome studied the potential that *El Faro* had encountered a rogue wave around the time of the sinking. The team presented its results in October 2016.

The existence of rogue waves—unusually tall surface waves that appear without warning in the open ocean—although previously doubted, has been confirmed over the last decade or so. Instruments on an oil platform off the southern coast of Norway measured an 80-foot wave (known as the Draupner) that struck the rig in January 1995 (crest height—distance from mean sea level to wave top—was about 60 feet); in 2000, a British oceanographic vessel recorded a 95-foot wave off the coast of Scotland; in 2007, a double rogue wave named Andrea (75 feet) was measured in the North Sea (crest height, about 50 feet); and in 2015, an 85-foot rogue wave known as the Killard was observed off the coast of Ireland (crest height, 60 feet). A formal investigation, begun in 2000, into the 1980 sinking of the MV *Derbyshire* during a typhoon south of Japan concluded that the ship had almost certainly encountered waves of at least 92 feet. The possibility therefore existed that *El Faro* might have encountered a rogue wave during Hurricane Joaquin.

The *El Faro* rogue wave analysis focused on the hurricane sea state during a 1-hour interval around the sinking. Researchers combined high-resolution hindcasts and nonlinear numerical simulations of hurricane-generated sea states with probabilistic (stochastic) models to quantify conditions at the accident location and time. The sea states were hindcast using NOAA's Wavewatch III model, balancing wind input, four-wave resonance nonlinearities, and wave breaking. To calculate the maximum wave height that could have been observed during the interval in question, researchers used a stochastic space-time model for the encounter probability of a rogue wave, newly developed to support the *El Faro* investigation.

The probability of a vessel encountering a rogue wave is higher if the ship is drifting than if it is anchored at a fixed location, such as an oil platform.[179] The study found that the probability of *El Faro* encountering a rogue wave with a crest height exceeding 14 meters (46 feet) while drifting at a speed of 2.5 meters per second for 10 minutes was approximately equal to 1/400, accounting for vessel size.[180] Assuming that the vessel drifted for 50 minutes yielded a probability roughly three times larger (≈ 1/130) of encountering a rogue wave of the same size.

Comparing significant wave height, dominant wave period, depth, and other parameters for the simulated *El Faro* sea state with those for the Andrea, Draupner, and Killard rogue waves yielded similar results. That is, the predicted rogue wave for *El Faro* had similar generating mechanisms and characteristics as the Andrea, Draupner, and Killard waves.

[179] This idea is discussed further in an article published in *Scientific Reports*, an online publication of the journal *Nature* (Fedele, Lugni, and Chawla 2017).

[180] Corresponding crest-to-trough (wave) height in this calculation was 23 meters (about 76 feet).

1.15.3 Inmarsat-C Mobile Earth Station Operation

Discrepancies of interpretation of the position reports received by authorities, noted in section 1.11.7, warranted further investigation to understand how distress alerts are initiated and sent. Distress messages, including the Inmarsat-C distress alert and the SSAS messages, received from *El Faro* were transmitted from a Furuno FELCOM 15 mobile earth station installed on the vessel's bridge. On March 9, 2017, investigators from the NTSB and the Coast Guard Marine Board of Investigation traveled to Furuno's support center in Denton, Maryland, for familiarization and hands-on testing of a Furuno FELCOM 15 mobile earth station. Testing revealed that on systems equipped with an internal GPS receiver, manual entries superseded automatic position reports. If a manual entry differed from the actual position, the system did not provide a warning or prompt the user about potential discrepancies. Testing further revealed that after a single manual position entry, automatic position updating for distress alerts was disabled for the remainder of a given power cycle.

1.16 Previous NTSB Recommendations

1.16.1 Broadcasting of Position Data by EPIRBs

In 2009, the uninspected fishing vessel *Lady Mary* sank in the Atlantic Ocean southeast of Cape May, New Jersey (NTSB 2011). Six crewmembers died in the accident, and one crewmember survived. The bodies of two crewmembers wearing immersion suits were recovered after the accident, two bodies were discovered later, and two bodies were never found. The NTSB determined that the probable cause of the sinking was flooding originating in the *Lady Mary*'s lazarette through an access hatch that had been left open during rough weather, contrary to safe shipboard practice.[181] The NTSB also found that the inability of the vessel's EPIRB to transmit position data contributed to a delay in the dispatch of rescue assets.

As required by Coast Guard regulations (46 *CFR* 25.26-20), the *Lady Mary* was equipped with a float-free, automatically activated EPIRB that could emit a 406-MHz distress signal. An EPIRB signal from the *Lady Mary* was detected by a geostationary satellite about the time of the sinking, but the satellite could not determine a position because the vessel's EPIRB was not equipped with an optional GPS receiver. A low earth orbiting satellite, which can establish position information from EPIRBs whether or not their transmissions contain encoded GPS coordinates, had crossed the *Lady Mary*'s location shortly before the sinking but was out of range of the vessel's EPIRB signal by the time of the accident. In addition, the EPIRB had not been correctly registered in the database maintained by NOAA, which meant that the sinking vessel could not be identified for search-and-rescue personnel.

By the time a Coast Guard rescue helicopter arrived on scene, the two victims whose bodies were retrieved had been in the cold water for 3 to 3.5 hours. The probability of their survival, allowing for their immersion suits, was calculated as between 1 and 1.5 hours for functional time (having the ability to move) and between 2.2 and 3.1 hours for survival time

[181] A vessel's *lazarette* is the aftermost compartment below its main deck, typically accessed by a deck hatch.

(staying alive).[182] The NTSB concluded that if a rescue helicopter could have been launched after the first EPIRB signal was received, the two victims found in the water wearing immersion suits might still have been alive when the rescuers arrived. Moreover, it was also possible that the two crewmembers whose bodies were never discovered would have been found alive or that their bodies would not have drifted too far from the scene to be found.

As a result of the *Lady Mary* sinking, the NTSB issued a recommendation on March 11, 2010, in advance of the final accident report, that the FCC take the following action:

> For commercial vessels required to carry 406-MHz emergency position-indicating radio beacons (EPIRBs), mandate that those EPIRBs broadcast vessel position data when activated. (M-10-1)

In a response to the NTSB dated July 1, 2010, the FCC stated that it planned to propose a regulation to implement the NTSB's recommendation. Recommendation M-10-1 was classified "Open—Acceptable Response" on August 19, 2010. On September 1, 2016, the FCC issued a report and order (FCC 16-119) amending 47 *CFR* 80.1061(a) to incorporate Radio Technical Commission for Maritime Services standard 11000.3, which requires EPIRBs to broadcast position data. Safety Recommendation M-10-1 was classified "Closed—Acceptable Action" on October 14, 2016.

1.16.2 Hurricane Forecasting

On June 29, 2017, the NTSB issued ten recommendations addressing tropical cyclone information and its availability to mariners (NTSB 2017b). The recommendations derived from factual information gathered during the *El Faro* investigation and were addressed to NOAA, the National Weather Service, and the Coast Guard.

The factual data revealed that critical tropical cyclone information issued by the National Weather Service was not always available to mariners through well-established broadcast vehicles. The data also suggested that modifying the way the National Weather Service develops certain tropical cyclone forecasts and advisories could help mariners at sea better understand and deal with tropical cyclones. Further, factual data on the official forecasts for Hurricane Joaquin and other recent tropical cyclones suggested that a new emphasis on improving hurricane forecasts was warranted.

As noted earlier, the National Hurricane Center reported that it had difficulty in forecasting Joaquin. A branch chief of the National Hurricane Center testified to the marine board that Joaquin "was particularly resistant to wind shear," which he described as "trying to tear [the cyclone] apart" while "the tropical cyclone is trying to keep the storm vertically coherent." The crew of *El Faro*

[182] The calculations were made using the Cold Exposure Survival Model, developed by Canada's Defence and Civil Institute for Environmental Medicine. The model predicts functional time and survival times for cold air exposure and cold water immersion based on cooling of the body's core and on an individual's physical characteristics, clothing, and weather and sea conditions. The model does not include the effects of dehydration, injuries, medications, drugs, alcohol, sleeplessness, or circadian hormonal cycles.

also failed to receive regular advisories about the storm's changing course and intensity through the ship's satellite system.

In light of this evidence, the NTSB recommended that NOAA take the following actions:

> Develop and implement a plan specifically designed to emphasize improved model performance in forecasting tropical cyclone track and intensity in moderate-shear environments. (M-17-8)
>
> Develop and implement technology that would allow National Weather Service forecasters to quickly sort through large numbers of tropical cyclone forecast model ensembles, identify clusters of solutions among ensemble members, and allow correlation of those clusters against a set of standard parameters. (M-17-9)

The NTSB also recommended that the National Weather Service act as follows:

> Work with international partners to develop and implement a plan to ensure immediate dissemination to mariners, via Inmarsat-C SafetyNET (and appropriate future technology) of the Intermediate Public Advisories and Tropical Cyclone Updates issued by the National Weather Service, in a manner similar to the current process of disseminating the Tropical Cyclone Forecast/Advisory. (M-17-10).
>
> Modify your directives to ensure, for all tropical cyclones of tropical storm strength or greater within your jurisdiction, that your facilities issue, at the 3-hour interval between regularly scheduled Topical Cyclone Forecast/Advisories, an Intermediate Public Advisory, a Tropical Cyclone Update, or another product available (or expected to be available) to mariners via Inmarsat-C SafetyNet (and appropriate future technology), and that the product include the coordinates of the current storm center position, maximum sustained surface winds, current movement, and minimum central pressure. (M-17-11)
>
> Modify your directives to ensure that the "next advisory" time in a Tropical Cyclone Forecast/Advisory clearly indicates when to expect the next update of "current" or forecast information for that particular tropical cyclone. (M-17-12)
>
> Quantitatively define "significant change" in terms of both the track and intensity of a tropical cyclone to guide the issuance of Special Advisory packages. (M-17-13)
>
> Ensure that tropical cyclone graphic products issued by entities such as the National Hurricane Center, the Central Pacific Hurricane Center, the Guam Weather Forecast Office, the Joint Typhoon Warning Center, and Fleet Weather Center–Norfolk are made available in near-real time via the FTPmail service. (M-17-14)
>
> Allow users to schedule recurring, automated receipt of specific National Weather Service products through an enhanced FTPmail service (and appropriate future technology). (M-17-15)
>
> Develop and implement a plan for soliciting feedback from the marine user community, particularly ship masters, about the accuracy, timeliness, and usability of weather services to mariners. (M-17-16)

Finally, the NTSB recommended that the Coast Guard take the following action:

> In collaboration with the National Weather Service, provide timely broadcasts of the Tropical Cyclone Forecast/Advisories, Intermediate Public Advisories, and Tropical Cyclone Updates to mariners in all regions via medium-frequency navigational telex (NAVTEX), high-frequency voice broadcasts (HF VOBRA), and high-frequency simplex teletype over radio (HF SITOR), or appropriate radio alternatives (and appropriate future technology). (M-17-17)

On June 29, 2017, the NTSB classified Safety Recommendations M-17-8 through M-17-17 as "Open—Await Response."

1.17 Other Information

1.17.1 Actions Since Accident

TOTE. TOTE informed the NTSB of several actions the company had taken since the loss of *El Faro*. After the sinking, the company introduced a revised approach to risk assessment involving a more quantitative approach that has been incorporated into the EPMV. At the beginning of the 2017 hurricane season, the company sent a reminder to all vessels to review heavy-weather procedures, which included a provision for convening a company hurricane advisory team during cyclones.

The company has made weather-routing services available since the accident, even for vessels on short runs, including between Jacksonville and Puerto Rico. It has replaced the previous emergency call center with one that also provides vessel tracking and weather monitoring support to the company. It has increased the availability of email and internet services on its Marlin and Orca vessels.[183] The company has formalized its CargoMax training program, instituting regular classes instructed by Herbert Engineering and attended by shoreside personnel and senior deck officers. It has also enhanced its system for tracking crew rest hours and given officers the option to travel the day before they join a ship. It has also upgraded its crew filing and tracking system and is transferring its SMS to an electronic system that will allow access over the internet.

The company has contracted with Radio Holland for regular servicing and inspections of bridge equipment on its Marlin vessels and has added a second EPIRB to each vessel (only one is required). It has installed a camera system for monitoring the terminals in Jacksonville and San Juan and is formalizing and documenting a shoreside procedure for tracking inspection and maintenance records for lashing gear. The company has also produced videos for its Marlin-class ships, including one that illustrates a vessel's general layout and describes the location of safety equipment, escape routes, and emergency equipment.

Coast Guard. On October 1, 2017, the Coast Guard Marine Board of Investigation released its report on the *El Faro* accident. Dated September 24, 2017, the report is titled *Steam Ship* El Faro *(O.N. 561732), Sinking and Loss of the Vessel with 33 Persons Missing and Presumed*

[183] TOTE's Orca-class vessels operate between Tacoma and Anchorage.

Deceased, Northeast of Acklins and Crooked Island, Bahamas, on October 1, 2015. It is publicly available.[184]

1.17.2 Previous NTSB Investigations Aided by VDRs

Information extracted from onboard VDRs has been helpful in several previous NTSB investigations. In certain cases, the VDR information was crucial in revealing the actual course of events, which differed from crewmember or witness accounts.

On November 3, 2007, the tankship *Axel Spirit* allided with Ambrose Light, an aid to navigation, at the entrance to New York Harbor, as the ship was inbound to Perth Amboy, New Jersey (NTSB 2009a). The impact caused $10 million in damage to Ambrose Light and $1.5 million in damage to the ship. The master and the bridge team did not mention the allision to the pilot who boarded the ship shortly thereafter, nor did they notify the Coast Guard or the shipping company about the accident until after the *Axel Spirit* was docked in Perth Amboy and the master had ascertained that the ship had visible damage. He told investigators that he did not realize that the ship had hit Ambrose Light. However, when investigators reviewed the bridge audio recording captured by the ship's VDR, it was clear that the allision was audible, alarms began sounding, and the master reacted verbally to the impact.

On January 24, 2008, the fruit juice carrier *Orange Sun* allided with a moored dredge while outbound in Newark Bay, New Jersey, causing more than $6 million in damage (NTSB 2009b). Initial reports suggested that the *Orange Sun* had experienced rudder failure when it veered off course and struck the dredge. However, when investigators reviewed the extracted wheel input and rudder response information from the juice carrier's VDR, it was clear that the helmsman and the master had made incorrect wheel inputs, which they did not recall making.

On March 5, 2015, tanker *Chembulk Houston* and container ship *Monte Alegre* collided and grounded in the Houston Ship Channel, after the pilots agreed to an overtaking maneuver (NTSB 2016b). The VDR data and audio recovered from both vessels allowed the NTSB to determine that the probable cause of the collision was the pilot's decision to increase speed on the *Monte Alegre* without informing the deputy pilot on the overtaking *Chembulk Houston*.

On March 9, 2015, the inbound bulk carrier *Conti Peridot* collided with the outbound tanker *Carla Maersk* in the Houston Ship Channel near Morgan's Point, Texas (NTSB 2016a). The NTSB determined that the probable cause of the collision was the inability of the pilot on the *Conti Peridot* to respond appropriately to hydrodynamic forces after meeting another vessel during restricted visibility and his lack of communication with other vessels about this handling difficulty. VDR data and audio recovered from the *Conti Peridot* showed that the inbound *Conti Peridot* experienced a near miss with another outbound vessel about an hour before the collision.

[184] See http://www.news.uscg.mil/News-by-Region/Headquarters/El-Faro-Marine-Board-of-Investigation/.

2 Analysis

2.1 General

The analysis first identifies factors for which there was insufficient evidence to support a conclusion or that could be eliminated as causal or contributory to the sinking of *El Faro*. The analysis then discusses the following:

- The sinking
- Weather information
- Captain's decision-making
- Bridge resource management
- Oversight
- Contributions to loss of life
- Other issues

2.2 Inconclusive Factors

2.2.1 Fatigue

The chief engineer told his wife that he was exhausted from all the maintenance and issues he had in the weeks before the accident. Two friends of the second mate told investigators that she complained about fatigue as a result of her watch schedule, coupled with relieving other officers during mealtimes when she was not on watch and the additional work required at sea under company procedures and the union contract (12-hour days for the crew).

The captain, similarly to the other officers, normally worked a 10-week rotation (10 weeks off after 10 weeks on the ship). He started a work rotation on May 5, 2015, and left the ship on July 14. When his relief resigned 3 weeks later, the captain was asked to return early. Four weeks into his vacation, on August 11, he returned to work on board *El Faro*. According to TOTE management, the captain was scheduled to work until December.

When the ship was in port, the crew usually requested port mates to help with loading and unloading cargo in an effort to alleviate the work of the crew and allow the possibility for rest. The captain had requested a port mate to assist the ship with the final cargo-loading in Jacksonville. However, with the exception of September 1, no port mates were available in Jacksonville on any of the ship's September runs, which increased the crew's workload and reduced the time available for rest. The third mate's August–September STCW work/rest logs showed four violations of

Title 46 *CFR* 15.1111, each of which followed a scheduled day in port (one rest period must be at least 6 hours long).[185]

Some of the crew had been working 12-hour days, 7 days a week, for 10 weeks straight. Although detailed work-rest records could not be obtained for the crew on the accident voyage, the VDR audio recording confirmed that the captain and the crew were on the bridge at their scheduled duty times leading up to the sinking. A conversation about a crewmember's use of over-the-counter sleep aids was recorded on the VDR. However, insufficient details (time taken, dosage) prevented investigators from determining whether it could have affected that crewmember's performance. Although the *El Faro* crewmembers were most likely fatigued, the degree to which fatigue affected their performance could not be determined.

2.2.2 Drugs/Alcohol

Regarding potential drug and alcohol use, no toxicological testing could be completed. Evidence was insufficient to determine whether drug or alcohol use played a role in the accident.

2.3 Exclusions

2.3.1 Boilers/Machinery

VDR data did not show that *El Faro* ever lost electrical power during the sinking, which indicates that the ship's boiler system—which supplied steam to drive its electrical generators—was operational. Further, the VDR audio recordings did not indicate any boiler failures. The captain mentioned bringing a boiler back online in the VDR, but that does not suggest with certainty that either boiler was ever actually shut down. In fact, that is the only remark throughout the VDR audio recording about the boilers.

Further, the VDR data identified that the following electrical systems—among other less-critical ones—were operational until the end of the VDR recording: steering system, ramp tank ballast pumps, bilge/ballast pumps, communication equipment, and various ship's lighting systems. There was no mention of the emergency generator needing to supply emergency power. Thus, the NTSB concludes that the mechanical condition or operation of *El Faro*'s boilers, steering, electrical power, and machinery were not factors in the accident.

2.3.2 Riding Gang

The five Polish nationals known as the riding gang were working on installations and modifications to the cargo decks for the vessel's upcoming return to the Alaska trade. The work included reinstalling winches, pulling wiring, and installing piping and was unrelated to the

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[185] STCW regulations require 77 hours off-duty in any 7-day period—the equivalent of a 91-hour-maximum work week. With a 12-hour minimum day, the *El Faro* crew already worked 84 hours per week. STCW regulations also require that if rest periods are broken up within a 24-hour period, at least one of the rest periods must be no less than 6 consecutive hours.

sinking. Thus, the NTSB concludes that the work being performed by the riding gang of foreign nationals did not contribute to the sinking of *El Faro*.

2.3.3 Failure of Container and Ro/Ro Trailer Lashings

Investigators, after reviewing all available data and evidence, determined that some of the Ro/Ro trailers and main deck containers were not loaded and secured in accordance with the guidelines recommended by the vessel's cargo-securing manual. Investigators also determined that the inspection and maintenance of the vessel's cargo-securing gear was not in accordance with CSS code requirements. However, the NTSB concludes that neither improper securement of the trailers and containers nor inadequate maintenance of the vessel's cargo-securing gear contributed to the vessel's initial list.

2.3.4 Cargo Shift

The VDR recorded a crewmember mentioning a trailer leaning and cars loose in hold 3, but there was no specific mention of a large cargo shift or loss of cargo. The Coast Guard's Marine Safety Center analyzed the effect of a shifting of 20 containers by 10 feet (similar to container deformation and leaning to one side without falling overboard) and found that compared with the effect of floodwater and hurricane-force beam winds, such a shift would have produced "small reductions in righting arms and small induced heel angles."

The Marine Safety Center also analyzed a complete loss of topside containers in a bay and found that such a scenario would have temporarily improved the vessel's stability. Dynamic analysis showed that larger heel angles were more likely from cargo-hold flooding than from a shift of Ro/Ro cargo. Investigators estimated that the shifting of cars in hold 3 at the tanktop would also not have caused an appreciable heel angle. Thus, the NTSB concludes that cargo shifting was not a major factor in the vessel's initial list.

2.3.5 Medical Issues

Review of the crewmembers' medical records (on file with the Coast Guard) revealed no medical conditions or use of prescription medications that would have been factors in the sinking. Absent toxicology results, investigators could not verify that crewmembers were not taking medications. The NTSB concludes, however, that the medical fitness of the *El Faro* crew and any prescription medication use by the crew were most likely not factors in the accident.

2.3.6 Captain's Decision to Depart Jacksonville

El Faro's first opportunity to avoid Hurricane Joaquin was before the ship left Jacksonville. Ordinarily, a captain and his navigation team would plan to leave port according to the ship's schedule and after reviewing the passage plan and conducting a risk analysis. Part of a risk analysis should include a review of the weather conditions forecast along the route, giving particular consideration to allowing time to change the ship's speed or route, or both, if necessary.

The ship had more than a day before it expected to encounter bad weather, and options were available for changing its route after departing if the storm became a hurricane. Since the storm was still several hundred miles away, its forecast track also had time to change.

The captain would have weighed the consequences of delaying his arrival in San Juan and most likely considered the risk to be low of departing as scheduled. *El Faro* had sufficient speed and options for avoiding the forecast weather if conditions worsened. Thus, the NTSB concludes that the captain's decision to depart Jacksonville was reasonable considering the availability of options to avoid Tropical Storm/Hurricane Joaquin.

2.3.7 Structural Failure

Significant damage was noted to the vessel's wreckage on the seafloor. Although there was no indication on the VDR recording of a structural failure before the sinking, part of the dynamic sinking analysis was intended to identify the cause of the damage. The severe damage to *El Faro*'s stern and the large transverse hull crack just aft of the aft engine room bulkhead (between bays 16 and 17) were both consistent with seafloor impact.

Sonar images that appear to be hydraulic outburst marks to both port and (to a lesser degree) starboard of the crack indicate that entrained water jetted outward, moving the bottom sediment. In addition, the Marine Safety Center analysis concluded that the ship met all requirements for strength and found no visible evidence of hull failure in video of the wreckage. Thus, the NTSB concludes that there is no evidence that the vessel suffered a hull break or other significant structural failure while on the ocean surface that was a factor in the accident.

2.3.8 Rogue Wave

Although rogue wave formation is still not fully understood, scientists know that certain sea conditions are more conducive to rogue waves than others. Postaccident calculations, conducted at the NTSB's request by scientists from the College of Engineering at the Georgia Institute of Technology and the Italian Ship Model Basin INSEAN Institute in Rome, determined probabilities of about 1/400 and about 1/130 of *El Faro* encountering a rogue wave during the final 10 minutes and final 50 minutes of the accident voyage, respectively. The VDR recorded no discussion on the bridge (and the investigation provided no other evidence) of a rogue wave encounter. Further, the parametric data on ship's motion recorded by the VDR showed no evidence of a response to a rogue wave. Thus, the NTSB concludes that a rogue wave was not a factor in the sinking of *El Faro*.

2.4 The Sinking

El Faro sank an hour and a half after it lost propulsion. From the time it left port the evening of September 29, the ship traveled at near-maximum speed, between 19 and 20 knots, for almost 30 hours. But it began to slow and develop a wind-driven starboard list when it came out of the protective lee of San Salvador Island about 0130 on October 1 and encountered the steadily increasing force of the wind. The ship's speed dropped quickly to 18 knots and fell more or less steadily from then on, as shown in figure 62. (Engine speed, or propeller rpm, was not recorded by the vessel's VDR, but parametric data captured the ship's speed over ground.)

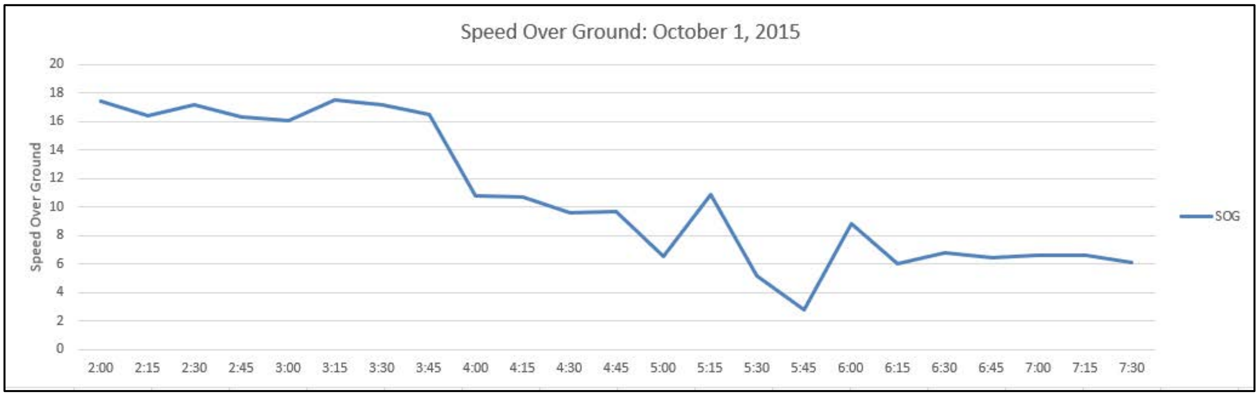


Figure 62. Ship's speed over ground from 0200 to 0730 on October 1.

The wind and seas intensified as *El Faro* continued southward. The vessel started to set, or be pushed from its intended course by the wind and current. Around 0245, it began hitting large waves, and at 0253, the first off-course alarm sounded. (The ship was steering by autopilot.) About a half hour later, the off-course alarm sounded for the second time.

The winds increased, and the off-course alarm began sounding nearly continuously. After the chief mate came on the bridge at 0345 for the 0400 watch change, he turned the alarm off and began slightly changing the heading more into the wind. About the same time, the engineers began blowing tubes in the boilers, which reduced the ship's speed by 2 to 3 knots.

The graph in figure 63 demonstrates the relationship between ship's speed over ground and wind speed and direction, based on poststorm weather analyses. It shows that the increasing winds on the port side between 0400 and 0600 account for the vessel's starboard heel, while the shift of wind to the bow helps explain part of the vessel's slowing after 0400. The NTSB concludes that the initial list was caused by an increasing wind on the vessel's beam generated by Hurricane Joaquin.

About the time the watch changed, the crew began discussing that they were listing, or heeling, to starboard from the force of wind on the port side (windheel). By that point, the vessel's speed had dropped to less than 10 knots. The captain talked about shifting the water in the ballast (ramp) tanks to diminish the list. The vessel continued to make headway, though slowly, despite the sustained starboard list and the deteriorating weather.

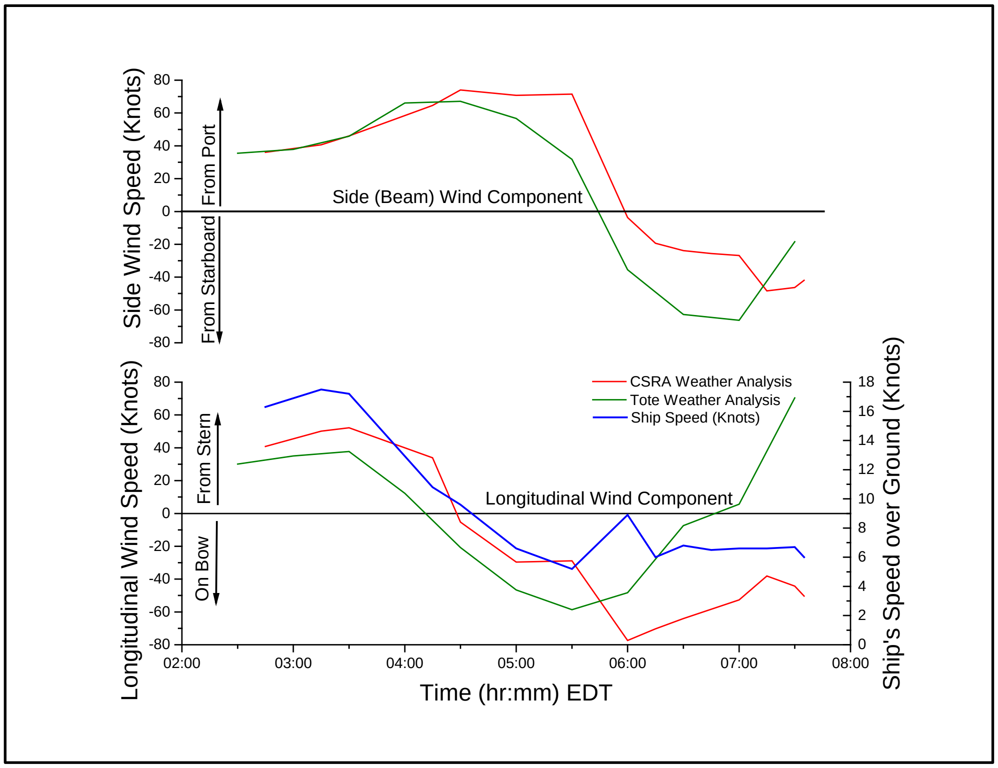


Figure 63. Ship's speed over ground relative to wind direction. Wind directions obtained from NTSB-chartered dynamic analysis (by CSRA Inc.) and TOTE weather analysis submission.

2.4.1 Loss of Propulsion

About 0427, blowing tubes concluded, and the main engine propulsion shaft was running at 100 rpm. At 0440, the engine room notified the bridge that the starboard list was affecting the oil levels in the engine room. (The degree of starboard list on the vessel was not quantified from VDR-recorded audio.) In an effort to correct the list, the captain put the vessel into hand-steering and changed course slightly to port (into the wind to reduce windheel). At 0543, rising water levels in hold 3 were reported to the bridge, along with an open scuttle on the starboard side of the second deck. While talking to the chief engineer a few minutes later, the captain ordered the engineers to transfer ballast water from the starboard ramp tank to the port ramp tank. The tanks, which were on either side of the aft bottom of the ship, could correct a list up to about 3°.

At 0552, the captain told the chief engineer over the phone that he was going to "turn the ship . . . give us a port list." A minute later, the chief mate radioed the bridge and reported that the floodwater was knee deep, pouring over the edge of the scuttle on the starboard side. The captain advised him that he was "comin' left." The captain made a large (about 60°) course change to port, purposely shifting the vessel's heading to put the wind onto the starboard side of the ship to generate a port list that would allow the crew to better investigate the source of the flooding. By 0558, the list had shifted to port. The port list may have been slightly greater than the previous starboard list because of the ballast water that had been transferred to the port ramp tank for a few minutes. The vessel lost propulsion shortly after the list was shifted to port, and the vessel's port list continued until the sinking.

The VDR recorded no conversations from the engine room, so it is unknown what actions the crew took to counter the problem with the lubrication oil levels (which were not captured electronically) or what the problem actually was. The mostly likely scenario, however, is that the vessel's sustained list to port caused the lubrication oil in the main engine sump to fall below the bellmouth of the suction pipe leading to the pumps (refer to figure 11, section 1.3.6).

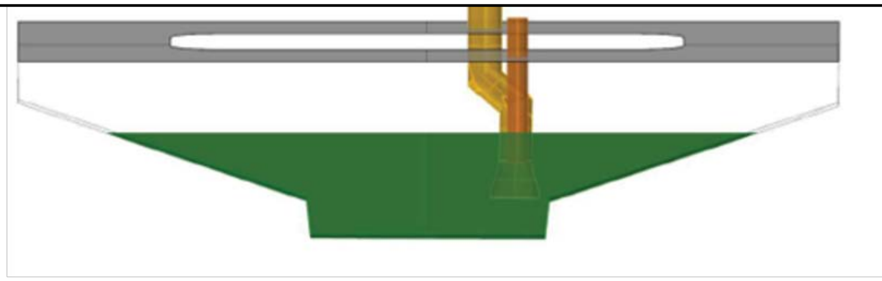
The pumps were about 9 1/2 feet above the suction bellmouth, which was about 10 inches above the bottom of the tank and about 22 inches starboard of the sump's centerline. Because the bellmouth was offset to the starboard side of the sump's centerline, the system was more susceptible to losing suction from a port list. Thus, the NTSB concludes that the port list, coupled with the vessel's motion, most likely caused air to enter the bellmouth of the suction pipe to the lube oil service pump, which resulted in a loss of oil pressure that caused the main engine to shut down. The loss of oil pressure would have triggered a protective device, the low-lube-oil-pressure switch, which would have shut off the flow of steam to the main engine. To reset the switch, lube oil pressure would have had to be restored.

Loss of lube oil pressure would also have caused the reserve oil in the 3,200-gallon gravity tank in the upper engine room to start flowing to the main engine. During normal operations, oil in the gravity tank constantly overflowed back to the main engine sump through an illuminated sight glass ("bull's-eye"). The system was designed so that if lube oil pressure to the pumps was lost, the oil in the gravity tank would automatically flow to the main engine through an orifice and, in about 8 minutes, empty its contents into the sump, giving the engineers time to stop the main engine.

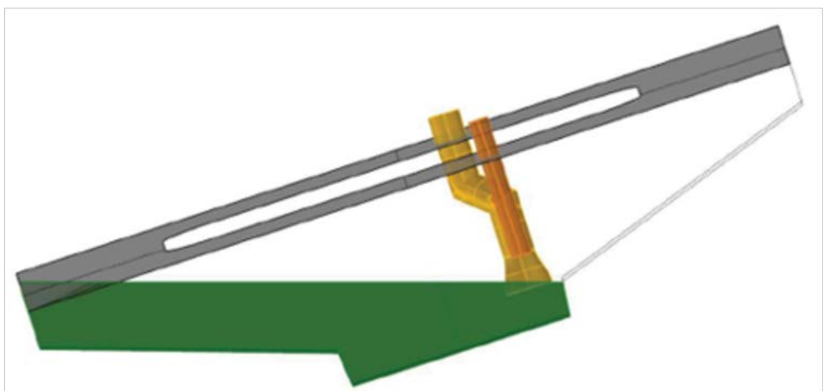
Emptying the gravity tank would raise the oil level in the sump above its 2,870-gallon design capacity. But since the bellmouth would already have risen out of the oil and caused a vapor lock in the lube oil pumps (which were nearly 10 feet above the suction inlet), the pumps would have needed priming before they could draw up lube oil and resume pumping. To establish a prime, the pump casings would have had to be filled with lube oil from another source, such as the storage tank in the upper engine room. Both a former port engineer who was authorized to service the main engine and another engineer who had sailed aboard the *Ponce*-class vessels estimated that the pumps would internally destruct after operating about 30 minutes without lubricating oil.

According to logbook entries, the level of oil in the main engine had been kept at 25 or 26 inches for most of the 2 years before the accident. The sounding table from *El Faro*'s sister ship *El Yunque* indicated that 26 inches corresponded to a quantity of 1,345 gallons. (*El Faro*'s sounding table was not available.) TOTE's operations manual recommended maintaining an operating level of 1,426 gallons. The printout from the CargoMax loading software showed that when *El Faro* left port, it had 163.8 cubic feet of lube oil in the main sump, or 1,226 gallons. On *El Yunque*'s sounding table, that amount corresponded to an oil level of 25 inches. Thus, the NTSB concludes that the level of lube oil in the main engine sump was not maintained in accordance with the vessel's operations manual, which increased the propulsion system's susceptibility to loss of oil pressure.

At 0518, the VDR captured a conversation about a possible 18° list. The captain later reported the list as between 10° and 15°. The 1973 construction standards to which the ship was built required the main engine to operate with a 15° static list (no wind or waves acting on the vessel). The Coast Guard Marine Safety Center modeled and analyzed the lube oil levels in the main engine sump in a static condition. The safety center concluded that with 1,226 gallons of oil in the sump, as was likely on the accident voyage, and a 5-foot trim by the stern (0.4°), the bellmouth opening of the line leading from the sump to the lube oil pumps would break the oil's surface at an 18° port list. At that point, the bellmouth would no longer be submerged in the lube oil and air would enter the pumps, causing a vapor lock. Figure 64 displays the results of the Marine Safety Center's analysis.



View of sump for the accident voyage departure loading condition looking aft to forward with 0° list; 5-foot (0.4°) trim by the stern.



View of sump for the accident voyage departure loading condition looking aft to forward with 18° port list; 5-foot (0.4°) trim by the stern.

Figure 64. Effect of 18° port list on lube oil system with oil level at 26 inches. (Graphic by Coast Guard Marine Safety Center, modified by NTSB)

By 0558, the vessel was listing to port, and about 5 minutes afterward, the ship's speed quickly dropped to 4 knots. At 0606, the speed was zero knots. At 0613, after talking to one of the engineers in the engine room, the captain announced that they had "lost the plant." That is, the main engine had stopped and had not been restarted. From that point, *El Faro* was "dead in the water," with the ship's starboard side nearly perpendicular to the wind (beam to) and at the mercy of the wind and seas. Its speed over ground was now about 6 knots and it was being pushed southwest by the wind, although radar images show that its bow was facing northwest.

Heavy weather poses a risk to critical machinery because it can cause movement of the vessel that places equipment outside normal operating parameters. To mitigate the risk, operators should provide guidance to vessels on what steps can be taken to reduce the effect of heavy weather. In this case, *El Faro* departed Jacksonville with lube oil levels in the main sump below normal operating requirements, and TOTE did not provide guidance to the crew about raising the oil level in critical machinery during heavy weather. Previous *El Faro* engineers testified that the lube oil in the sump had been maintained as high as 32 inches in the past, to keep a safe level.

Additional lube oil could be carried in a 4,465-gallon storage tank on the operating level of the engine room and a 4,608-gallon settling tank next to it. Both tanks had 1-inch pipes connecting the bottoms of the tanks to a 2-inch common line for adding lube oil to the sump. According to CargoMax, the lube oil storage tank had 10 tons of reserve oil (2,850 gallons) when the ship left Jacksonville (the settling tank was empty). Even though only one source of additional oil was available, the crew could have added oil to the sump from the storage tank early in the voyage (before oil pressure was lost) without dangerously depleting the reserve supply.

With an oil level of about 32 inches, as had been maintained in the past, it is unlikely that the lube oil would have fallen below the bellmouth of the suction pipe that supplied oil to the service pumps, even with the vessel listing as much as 18° at about 0600 the morning of the accident. A simulation of the oil level at a maximum operating level of 32 inches is shown in figure 65. With the bellmouth immersed, the oil supply to the pumps would most likely have continued uninterrupted, the pumps would have continued to supply lubrication oil to the main engine, and the engine would have continued to run for longer than in the accident sequence. Thus, the NTSB concludes that if the company had provided guidance to the engineers about the list-induced operational limitations of the engine as well as about raising the level of lube oil in the main engine sump before or during heavy weather, the additional quantity of oil in the sump would have kept the suction pipe submerged at greater angles of inclination and increased the likelihood of maintaining propulsion. Therefore, the NTSB recommends that TOTE establish standard operating procedures for heavy weather that address operational limitations and oil levels in critical machinery to ensure their continued operation.

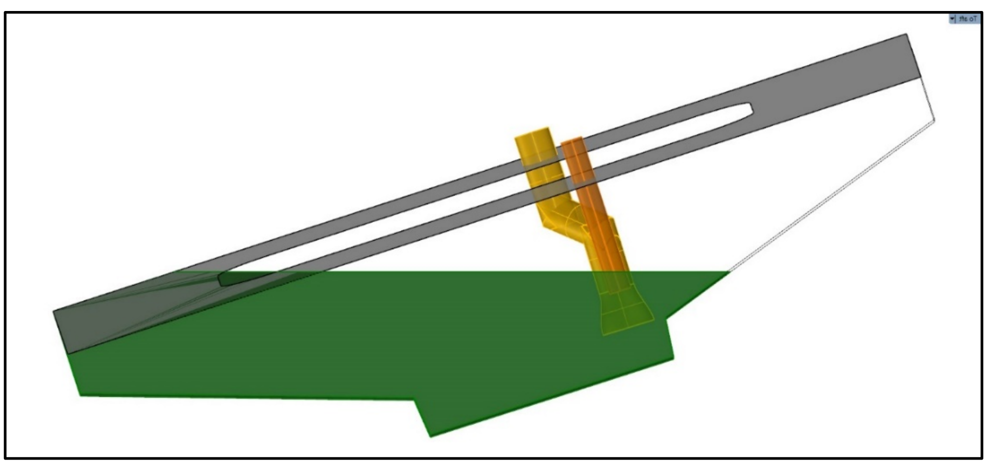


Figure 65. Effect of 18° port list on lube oil system for main engine with 32 inches of lube oil in sump, looking from aft to forward. (Graphic by Coast Guard Marine Safety Center, modified by NTSB)

Design standards known as machinery angle of inclination requirements exist to keep a vessel's critical machinery and electrical systems operating in static and dynamic conditions that a vessel might encounter at sea. *El Faro* sailed meeting the standards in place at the time of its construction, which required all lube oil systems to function satisfactorily when the vessel was permanently inclined to 15° athwartships (list) and 5° fore and aft (trim). Current standards require operation with the same athwartships 15° static list but have a separate 22.5° dynamic component (rolling from wind and waves), while fore and aft angles are 5° static and 7.5° dynamic. Even ships with today's standards can lose propulsion in rough weather and heavy seas. Current standards for lifeboats are that they must be safely launchable at a 20° static list (5° above the machinery standard).

The NTSB recently investigated an accident on a Ro/Ro ship built in 2007 (NTSB 2013b) that encountered rough weather and heavy seas (33- to 50-knot gusts and wave heights of 18 to 32 feet). The vessel lost propulsion when the main diesel engine shut down owing to low lube-oil pressure, placing the vessel beam to the seas and resulting in cargo movement in the holds that started an uncontrolled fire. Thus, the NTSB concludes that increasing the minimum athwartships angle of inclination requirements for both static and dynamic conditions would provide an additional margin of safety for vessels exposed to high winds and large sea states. Therefore, the NTSB recommends that the Coast Guard revise regulations and the International Association of Classification Societies (IACS) recommend to its members to increase the minimum required propulsion and critical athwartships machinery angles of inclination. Concurrently, requirements for lifeboat launching angles should be increased above new machinery angles to provide a margin of safety for abandoning ship after machinery failure.

The initial starboard list and vessel motion most likely resulted in fluctuating liquid levels in various equipment in the engine room, such as the main engine, boilers, and turbogenerators. After phone conversations with the chief engineer, the captain purposely altered course to ease the starboard list to address the issues with the oil levels and allow the crew to investigate the cause of flooding in hold 3 by shifting the floodwater away, which would also allow the crew to secure the scuttle to hold 3. The course change and subsequent port list resulted in an immediate loss of propulsion, most likely because the ship's list and motion exceeded the main engine's maximum design angle of 15°.

Interviews of previous engineers and deck officers aboard *El Faro* and other *Ponce*-class vessels did not discover a historical example of a loss of oil pressure in rolls above 18°. It is therefore unlikely that engineers passed on any experience involving a loss of propulsion due to a vessel list. Investigators determined that it was unlikely that the *El Faro* crew had information readily available that would advise them of the maximum list angles of propulsion or critical machinery. Thus, the NTSB concludes that the crew was most likely unaware of the operational limitations on the main engine from a sustained excessive list.

Machinery manufacturers design equipment to meet an overall maximum angle for satisfactory operation. Postaccident analysis identified the maximum list angle at which the main engine's lube oil system would have continued to operate. Had the captain been aware of the maximum angle, that might have influenced his decision to shift the list to port. More importantly, the increasing list should have been addressed earlier. Thus, the NTSB concludes that if the ship's officers had known the maximum static list angle at which the main propulsion engine would operate, they would most likely have attempted to reduce the initial list sooner and possibly avoided the loss of propulsion. Therefore, the NTSB recommends that IACS recommend to its members to require, and the Coast Guard propose to the IMO, that design maximum operating angles of inclination for main propulsion and other critical machinery be included in damage control documents, stability instruments and booklets, and in the SMSs for all applicable vessels.

2.4.2 Flooding

At 0543 the morning of the sinking, after receiving a phone call, the captain said they had a problem in hold 3. The chief mate mentioned a “suspected leak” and “the scuttle.” On the captain’s orders, the chief mate went to the hold to check for flooding. About 10 minutes later, in another phone call, the captain confirmed that water was coming into hold 3 through an open watertight scuttle. That was probably the first source of floodwater into hold 3 or any watertight part of the vessel. The scuttle was secured about 0600.

Open Scuttle on Second Deck. *El Faro* had scuttles on the second deck. The scuttles were regularly opened and closed at sea so that crewmembers could access the lower cargo holds from the second deck. Such actions were not reported to the bridge or logged in the deck logbook. The evening before the sinking, after a discussion of the film *The Perfect Storm,* the chief mate said he needed to send the crew down to the second deck: “Those scuttles need to be dogged—not just flipped down . . . they need to be spun and sealed.”

Scuttle covers had handwheels that operated steel dogs (fasteners), which drew the gasket on a cover tight to the lip of a scuttle and made it watertight. No remote indicators were installed on the scuttles to indicate whether they were opened or closed (secured). Witnesses at the marine board testified that a person could not tell by looking whether the covers on the scuttles were secured—one had to try to turn the handwheel to determine whether a hatch was closed. Open/close indicator switches could, however, be installed that would indicate that a scuttle was closed only if the gasket on the scuttle’s cover was compressed sufficiently (by the dogs) to ensure the scuttle’s watertight integrity.

International requirements (SOLAS) for cargo ships constructed after February 1, 1992, 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 are open or closed.” The SOLAS requirements do not define “internal opening,” which introduces ambiguity and might allow for a hatch similar to the scuttles on *El Faro*. Thus, the NTSB concludes that if the second deck access hatch (scuttle) had been fitted with a remote open/close indicator at a manned location, such as the bridge, the crew would have known that the watertight hatch to cargo hold 3 was open. Therefore, the NTSB recommends that IACS recommend to its members to require, and the Coast Guard propose to the IMO, that all watertight access doors and access hatch covers normally closed at sea be provided with open/close indicators both on the bridge and locally.

The chief mate said the scuttle on the starboard side of the second deck leading to hold 3 was open when he investigated and closed it about 0600 the morning of the sinking. Because of the starboard list, the starboard side of the ship would have been lower to the waterline, resulting in green seas accumulating on the second deck through the hull openings. The open scuttle would have allowed the water to enter the lower decks of cargo hold 3. Thus, the NTSB concludes that a watertight scuttle to cargo hold 3 on the second deck was open, allowing the unintended ingress of water and violating the ship's watertight envelope. Investigators found no written company procedures for monitoring or logging the opening and closing of watertight doors and hatches at sea. Therefore, the NTSB recommends that TOTE establish procedures for opening, closing, and logging all closures that make up a vessel's watertight envelope while the vessel is at sea.

Water Entering Hold 3, Fourth Deck. The second deck (not the main deck above it) was the freeboard deck on *El Faro*.[186] It was only partially enclosed and could take on green water through several openings on both sides of the ship, including two large openings in the starboard side through which trailers were loaded. Once water began flowing down through the open scuttle on the second deck, openings in the third deck (grated air vents and cloverleaf cutouts that formed part of the cargo-securing arrangements) would have allowed water to reach the fourth deck of hold 3, which held 50 of the 149 cars carried on the vessel. According to the VDR, the bridge was notified of water in hold 3 at 0543 the morning of the sinking, and a minute later, the captain said, "We got cars loose."

From testimony and evidence obtained from *El Faro*'s sister ship *El Yunque*, the automobile-lashing arrangements on *El Faro* did not conform to the recommendations of the vessel's cargo-securing manual. Instead of each automobile being individually secured at each corner to D-rings fixed on the deck, they were secured to a long chain that ran across the width of the ship and was secured to D-rings at either end. Some of the chains passed through a D-ring before being secured to additional D-rings at each end. This arrangement was not as secure as that specified in the cargo-securing manual because it did not allow individual automobiles to be tensioned tightly. Instead of tension at each corner, the cars were attached to chains. Through finite element modeling, the NTSB examined the automobile lashings (and their possible failure points) for the vessel accelerations that were calculated to have been experienced by *El Faro* on the accident voyage. Given the assumptions employed in the models, the automobile lashings in hold 3 would have failed before the loss of propulsion when the deck became wet, reducing the friction between the tires and the deck. Thus, the NTSB concludes that because the automobile-lashing arrangement on *El Faro* did not meet the requirements of the vessel's approved cargo-securing manual, automobiles were more likely to shift from vessel motion in heavy weather.

Flooding in hold 3 would have had three effects on the automobile cargo. First, small amounts of water would have reduced the coefficient of friction between the cars' tires and the ship's steel deck, lowering the list angle and accelerations (caused by vessel motions in the large sea state) needed to allow the cars to slide. If one car slid, it would have tended to pull with it the other cars lashed to the same chain. Second, as water rose in the hold, the cars would have begun to float. Third, even if the automobiles were secured to prevent floating, the mass of sloshing water would have acted against the cars as the vessel rolled, and crew comments recorded by the VDR

[186] 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.

confirm that some had broken free of their lashings. Thus, the NTSB concludes that the introduction of water to cargo hold 3, combined with the vessel's motion, led to failure of some lashings and automobiles becoming unsecured.

Unprotected Inlet Piping to Fire Pump. The vessel's emergency fire pump, sea chest, inlet strainer and valves, and associated piping were located in the starboard aft corner of hold 3 on the fourth deck. At least one vertical steel stanchion and a steel ladder were installed in front of the pump to protect it. There is no evidence, however, that the piping, the strainer, or the inlet valve were similarly protected.

About the time of the initial flooding, the intake pipe (sea suction) for the emergency fire pump was about 22 feet below the waterline, where the head pressure created by seawater would provide ample water supply to the pump. Between the pump and the sea chest was a skin valve that had a manual remote operator, or reach rod, located on the second deck near the scuttle to hold 3. Skin valves with remote operators are fitted aboard a ship to allow the crew to secure the source of unintentional water ingress to a space. The skin valve on *El Faro*'s emergency fire pump was normally closed at sea.

Cars were first reported loose in hold 3 at 0544, at the same time the captain said it was unsafe to enter hold 3 due to "gear adrift" and "a lot of water." The bilge pumps were already running. If cars were loose by that time, one or more of them could have hit the unprotected inlet piping section of the emergency fire pump, rupturing the piping or damaging the skin valve so that it could not stop seawater from entering the hold. At 0714, the VDR recorded the chief mate reporting that the chief engineer had said that something hit the fire main and "got it ruptured, hard." (The entire fire system, including the emergency fire pump and piping, was known as the fire main.)

The captain asked if there was a means to "secure that," and the chief mate replied, "between the sea suction and the hull or what uh but anything I say is a guess." His response indicated that the inlet piping was possibly damaged. No one on the VDR recording mentions that the crew attempted to shut the inlet (skin) valve to stop the flooding, but since it was normally closed, the crew may have already understood that shutting the valve would not stop the flooding. Cars were reported to be floating in hold 3 at 0717, indicating that additional flooding of the hold had reached a level of several feet. Damage to the sea chest or 6-inch sea suction piping would have allowed seawater to rush into hold 3. Thus, the NTSB concludes that it is likely that the seawater piping below the waterline to the vessel's emergency fire pump in cargo hold 3 was inadequately protected from impact and was struck by one or more cars that had broken free of their lashings.

The NTSB estimated that completely severing the 6-inch inlet to the emergency fire piping would have initially allowed about 600 long tons of water per hour into the hold. The Coast Guard Marine Safety Center report (MSC 2017) summarized earlier (in section 1.12.10) shows that partially flooding hold 3 (at 0.7 permeability) to 10 percent would fill it with 693 long tons of seawater. That amount is roughly equivalent to the amount of floodwater that the damaged inlet pipe would produce in the first hour. Considering the reduction in floodwater due to bilge pumping and the 1 1/2 hours from 0543 to 0710, it appears that the piping breach could have filled the hold from 10 to 20 percent. The Marine Safety Center's report further noted that for lower levels of flooding in hold 3 (10 to 30 percent), when considered in combination with an 80-knot beam wind, "the residual righting energy (area under the righting arm curves) is reduced significantly." In addition, the report noted that "the vessel would have been in a vulnerable state and susceptible to capsizing even with flooding only of hold 3, when considering the combined effects of partial flooding, wind heel and roll motion."

In summary, the floodwater in hold 3 would have reduced *El Faro*'s freeboard (increased its draft), placing the ship's cargo hold ventilation openings (tops of baffle plates) closer to the waterline. The floodwater would also have reduced the righting arm and GM, allowing the forces of severe wind and waves to more easily roll *El Faro* about its sustained port windheel. The rolling would have increased the chance of the portside ventilation openings being submerged as well, which were determined by the Marine Safety Center study to then critically downflood and sink the vessel. Thus, the NTSB concludes that impact damage to the seawater piping below the waterline to the emergency fire pump in cargo hold 3 most likely led to flooding in the hold, which significantly compromised the vessel's stability. Therefore, the NTSB recommends that IACS recommend to its members to require, and the Coast Guard propose to the IMO, that on new and existing vessels, seawater supply piping below the waterline in all cargo holds be protected from impact.

Bilge Pump and Alarm System. Water in the cargo holds collected in port and starboard bilgewells, called roseboxes, which were recessed pockets in the aft corners (one port and one starboard) of each cargo hold on the fourth deck. The bilge pumping system for dewatering the holds took suction through 4-inch pipes from the roseboxes, which each held about 10 gallons of water. The bilge system had two electrically driven bilge pumps that were each rated at 850 gpm. Based on the accident draft of the vessel, the initial rate of flow through a completely severed 6-inch sea suction was calculated at roughly 600 long tons per hour (about 2,600 gpm). If impact to piping also damaged the larger-diameter sea chest, the rate could have been higher. Investigators estimated that with operational factors, the bilge system would pump water out of the hold at a somewhat lower rate than the 850-gpm capacity of a single pump, or 600 to 850 gpm (138 to 195 long tons per hour). The crew continuously pumped the hold 3 bilges from the first indication of flooding at 0543. Thus, the NTSB concludes that the rate of flooding in cargo hold 3 exceeded the design capacity of the bilge pumps and therefore did not lower the water level in the hold, despite continued pumping during the accident sequence.

Although *El Faro* was not required to have a bilge high-level alarm system for its cargo holds, TOTE had earlier installed bilge alarms to alert shoreside personnel of excess water in the holds while the vessel was in layup. According to the installer, a stainless-steel float was installed in the upper section of the roseboxes on the tanktop level. When the water in a rosebox rose high enough to raise the float for 5 seconds, a signal went to an alarm panel in the engine room and activated audible and visible alarms. The sound of the alarm could be turned off, but a red light would remain lit on the alarm panel until the float returned to its normal position. The bilge alarm sounded only in the engine room, not on the bridge. The bilge float was tested by lifting it and verifying that the alarm sounded. Both bilge pumps had been operationally tested and found functional at the vessel's last ABS machinery survey on June 16, 2015. A former *El Faro* chief engineer estimated that about 50 gallons might set off the alarm in case of a starboard list.

Engineers and deck department crew who had worked aboard *El Faro* told investigators that a bilge high-level alarm in hold 3 was typically investigated by the engine room watch and reported to the bridge watch. The VDR did not provide direct evidence of how the crew became aware of flooding in hold 3, nor did it record any mention of the bilge alarm going off in hold 3. According to a statement on the VDR by the chief mate, the engine room was running bilge pumps at the same time flooding in hold 3 was reported to the bridge. As the water level continued to rise in hold 3, the captain checked periodically with the engineers to confirm that they were still pumping out hold 3. At 0716, the chief mate reported that a bilge alarm in cargo hold 2A had sounded. The sounding of the alarm in hold 2A indicated that the system was functioning on the accident voyage. Thus, the NTSB concludes that crewmembers in the engine room were most likely alerted to water in cargo hold 3 by the installed bilge alarm system.

Even if built in 2016, dry general cargo vessels like *El Faro* have no Coast Guard or SOLAS requirement for bilge alarms. By comparison, the Coast Guard requires domestic passenger vessels to have a bilge high-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. The sea chest for the emergency fire pump in *El Faro*'s hold 3 was a through-hull fitting below the waterline, and the seawater piping could flood the space. The risk of flooding in such spaces has been identified for passenger vessels, and cargo vessels should be protected against the same risk by alarm systems similar to those on passenger vessels. Cargo vessels with smaller crew complements should have bilge high-level alarms to monitor and identify potential flooding in large or remote spaces where access is difficult. Retrofitting the cargo holds of older vessels with bilge high-level alarms is technically feasible in most cases, as TOTE had done on *El Faro* before a layup period**.**

Thus, the NTSB concludes that new cargo vessels should be equipped with, and existing cargo vessels should be retrofitted with, bilge high-level alarms in all cargo holds that send audible and visible indication to a manned location. The NTSB therefore recommends that IACS recommend to its members, and the Coast Guard propose to the IMO, to require that new cargo vessels be equipped with bilge high-level alarms in all cargo holds that send audible and visible indication to a manned location. The NTSB also recommends that IACS recommend to its members, and the Coast Guard propose to the IMO, to require that existing cargo vessels be retrofitted with bilge high-level alarms in all cargo holds that send audible and visible indication to a manned location.

Downflooding Through Ventilation Openings. *El Faro*'s cargo hold ventilation system was sized to remove exhaust gases from driven vehicles during the loading and unloading of Ro/Ro cargo in port. Because *El Faro* was transporting vehicles that had fuel tanks (automobiles and some other Ro/Ro vehicles) at sea, the vessel's COI required the supply and exhaust air ventilation ducts to the cargo holds to remain open while under way. The supply ventilation fans fed fresh air through openings that penetrated the second deck and traveled down to the fourth deck through ventilation trunks on both sides of the vessel. The hold was naturally exhausted through openings at the tween deck (third deck) and trunks that passed up through the second deck. Manually operated fire dampers located outboard just above the second deck in the ventilation trunks also served as weathertight (in exhaust trunks) and watertight (in supply trunks) closures for stability and load line assessments.

El Faro had a fire control and safety plan showing, in part, the locations and type of fire dampers and other ventilation closures. However, it did not specify that the cargo hold supply and exhaust closures should be secured for flooding or damage control (labeling as "fire damper–cargo spaces" gave the impression that they were to be used only in case of fire). Interviews of former officers on *El Faro* and *Ponce*-class (sister) vessels found that the dampers (closures) were not secured in heavy weather or at any time except during fire drills, inspections, and testing. During the accident voyage, there was no indication that the cargo hold ventilation dampers were closed in preparation for heavy weather or that they were closed after the crew became aware that the vessel was flooding and listing. Once *El Faro* was listing in severe winds, green water accumulating on the low side of the second deck would have made securing the dampers difficult and risky. Thus, the NTSB concludes that all the watertight and weathertight ventilation closures to the cargo holds most likely remained open throughout the sinking sequence.

El Faro's COI required that cargo spaces be ventilated in accordance with a drawing that stated while at sea, for each cargo hold, one supply fan must be run and a natural exhaust damper must be open (to dilute gasoline vapors).[187] The exhaust vents would not be considered downflooding points in the International Code on Intact Stability because they could be made weathertight with installed closures (dampers). (Although applicable to most ships similar to *El Faro* today, the intact stability code was not applicable to *El Faro*, and applicable Coast Guard regulations on intact stability do not consider downflooding points.) The supply vents were not considered downflooding points in either the intact or damage stability calculations because they could be made watertight with installed closures (dampers), according to Coast Guard and international regulations**.**

Although officers might look to secure closures when planning for heavy weather or during casualties, *El Faro* had no documented guidance or instructions that the closures should be secured to meet damage stability assumptions. And the vessel's COI contained clear guidance that the closures must remain open. Operators of *El Faro* were therefore placed between the operational requirements of the vessel's COI and the efforts of designers and regulators to provide a margin of safety through stability requirements. Recently, IACS created a new interpretation that will no longer allow weathertight closures to engine or generator rooms to be excluded as downflooding points in stability calculations. However, there is no explicit guidance for cargo hold ventilation that is operationally required to remain open.

Thus, the NTSB concludes that vessels should not have operational requirements to maintain weathertight or watertight ventilator closures in an open position when the same closures are treated as closed when the vessel's stability and load line are assessed. Therefore, the NTSB recommends that IACS recommend to its members, and the Coast Guard propose to the IMO, that any opening that must normally be kept open for the effective operation of the ship must also be considered a downflooding point, both in intact and damage stability regulations and in load line regulations under the ICLL.

El Faro's applicable intact stability criteria (46 *CFR* 170.170) did not consider downflooding points, as would be the case for vessels subject to the International Code on Intact

[187] In port, the ventilation fans are run and the dampers are open to prevent asphyxiation from carbon monoxide.

Stability, and downflooding points were not mentioned in the vessel's stability booklet. Thus, the NTSB concludes that had the vessel's stability booklet or CargoMax software identified the vessel's downflooding points, the ship's officers might have closed the cargo hold ventilation openings. Therefore, the NTSB recommends that the Coast Guard require that information regarding openings that could lead to downflooding be included in damage control documents, stability instruments and booklets, and SMSs for vessels subject to the intact stability criteria of 46 *CFR* 170.170, regardless of the designation or treatment of such openings in intact stability calculations.

Although the second deck scuttle to hold 3 was secured about 0600 the morning of the sinking, the hold most likely continued to have free communication with the sea from the damaged emergency fire pump piping.[188] The Coast Guard Marine Safety Center's hydrostatic sinking analysis calculated the heel angle for *El Faro* after loss of power in static conditions with hold 3 flooded to 20 percent of its volume (at 0.7 permeability) combined with an 80-knot beam wind acting on the starboard side. Results showed that *El Faro* would have heeled to about 15°, which corresponds to the heeling angle the captain reported at 0711.

The same static conditions in the analysis resulted in the ventilation openings to holds 3, 2A, and 2 submerging when *El Faro* would have reached a heel of 26.3°, 26.9° and 28.9°, respectively, while the exhaust ventilation openings would have submerged at a few degrees higher (29° for hold 3, 30° for hold 2A, and 31° for hold 2). Without propulsion and drifting downwind with a sustained heel angle, the beam-to hurricane winds and wave action would have caused the ship to dynamically roll about the mean windheel to larger angles. Corresponding to the Marine Safety Center's hydrostatic analysis results, the CSRA dynamic modeling and simulation analyses found that with hold 3 similarly flooded and a modeled 15° to 18° heel in storm waves, "the vents on the lower side would be submerged a significant part of the time." Seawater would then have intermittently entered (downflooded) the ventilation trunks and flowed freely down to the lower cargo decks (refer to figure 59, section 1.12.10).

Once seawater flowed down (downflooded) to the fourth deck through the ventilation trunks and their unsecured (open) closures, the vessel would have sunk deeper because of the weight of the added water and rolled more easily as it lost its residual righting arm. At 0716, the bilge alarm sounded for cargo hold 2A (immediately forward of hold 3), indicating that seawater had entered hold 2A. Two cargo holds now had confirmed flooding, and 23 minutes after the bilge alarm sounded in hold 2A, the VDR recording stopped. Presumably, the vessel partially capsized at that point. Thus, the NTSB concludes that about 40 minutes before the sinking, seawater most likely entered the ventilation ducting to several main cargo holds, exacerbating the flooding already under way in cargo hold 3 and accelerating the sinking.

During the final stages of the sinking, the free surface effect from the floodwater in multiple cargo holds and eventually the engine room, combined with hurricane-force winds and seas, would most likely have resulted in the vessel capsizing. That likelihood is supported on the VDR audio by the AB on the bridge talking about having difficulty climbing, suggesting an increasing heel.

[188] Free communication with the sea occurs when one or more of the exterior boundaries of a ship are ruptured so that the sea flows freely into and out of the damaged compartment, with minimal restrictions, as the ship rolls.

As the ship rolled onto its port side, containers most likely broke free and washed overboard, momentarily slowing the capsizing. Impact damage consistent with containers striking the forward port side of the deckhouse indicates that floating containers were in the water while the vessel was still on the surface and listing significantly to port.

Damage Control. Investigators previously determined that the crew did not secure the fire dampers to the cargo holds during the sinking, which accelerated the sinking after hold 3 began to flood. On the morning of the sinking, the officers and crew of *El Faro* were involved with stability and damage control. Before the flooding in hold 3 was detected, the senior officers discussed the vessel's list, and officers mentioned that it was heeling due to wind, or windheel. At 0510, the supervisor of the riding gang, a previous chief engineer with extensive experience aboard the *Ponce*-class vessels, told the captain that he had never seen the vessel list or "hang" like that and said that it had to be "more than a stack" (a cargo shift contributing to the list). The captain replied that they "certainly have the sail area," regarding the effect of windheel, and asked the supervisor how the list was affecting "operations as far as lube oil(s)" in the engine room.

Once flooding began, the captain ordered both a ballast transfer and a course change to switch the vessel list to the opposite side so that the crew could investigate the flooding and secure the open scuttle. The crew was using the bilge system to dewater hold 3. When they eventually determined that the water level was still rising and entering another hold, they discussed means to more effectively dewater the holds. The chief mate was aware of the potential for progressive flooding past hold 3 and shut a watertight door at 0715. The engineers were also addressing the effects of the list on the lubricating oil as part of their effort to regain propulsion.

During the final hours, the VDR recorded no mention of the pumping capacity of the bilge system, and the crew could not quantify how much water was in hold 3. There was no mention of potential downflooding points through which the vessel would begin flooding as its list increased until 20 minutes before the vessel sank. About 0720, the supervisor asked about the downflooding angle, and the captain replied, "I don't have an answer for (ya)." He then appears to have asked the supervisor what document would provide downflooding angles and said he would check the "chief's office" for it. The captain then stated that "… we still got reserve buoyancy and stability," indicating he was at least familiar with those concepts. There is no evidence on the VDR that the captain or crew consulted a plan or procedure for damage control during the heeling, loss of propulsion, and flooding sequence. Investigators later determined that the vessel had no damage control plan or booklet.

Damage control plans and booklets are intended to provide ship's officers with clear information about watertight subdivision and equipment relating to maintaining the boundaries and effectiveness of the subdivision. The information is necessary so that in the event of damage to the ship that causes flooding, officers can take quick action to mitigate the flooding and, where possible, recover the ship's stability. Information such as downflooding points, watertight closures, advice regarding the cause of any list, and the pumping capacities of dewatering devices are typically provided in a damage control plan.

El Faro's SMS included an EPMV that stated in case of flooding, the ship's stability information should be referenced, void spaces below the waterline should be secured, water ingress and progressive flooding should be reduced by any means, and detailed information regarding location and extent of damage should be sent to TOTE so that the emergency response team could assess buoyancy and limit hull stress. However, there was no guidance or procedures specific to *El Faro*. The ship's fire control and safety plan showed egress routes, safety and firefighting equipment locations, and fire dampers and other ventilation closures. However, it did not designate the cargo hold supply and exhaust closures as closures to meet damage stability. A typical damage control plan would have identified those openings to be secured. If the vessel had damage control information, which is typically included in damage control plans and damage control booklets, the crew might have taken action to secure the cargo hold ventilation closures.

Cautionary information regarding list could also have helped the captain decide whether a course change to shift the list would be prudent. Having knowledge of the pumping system, the quantity of water in hold 3, and the potential flooding rate would have alerted vessel personnel to the dangerous condition of the vessel and could have influenced the captain's decision to remain aboard the ship. However, to promptly execute and understand the information available in a damage control plan and booklet in extremis, a crew must undergo drills that incorporate the use of damage control plans and booklets. Thus, the NTSB concludes that if a damage control plan had been available and the crew trained in its use, the crew would have been better able to promptly plan for and address the flooding scenario encountered during the casualty. Therefore, the NTSB recommends that TOTE ensure that damage control plans and booklets are aboard all its load-lined vessels and that officers and crewmembers are trained in their use.

SOLAS requires dry cargo ships built after 1992 to have a damage control plan, those built after 2005 to also have a damage control booklet, and those built after 2009 to have an "information to the master" section. Investigators found no evidence that *El Faro* was ever required to have a damage control plan or booklet. The vessel was not required to comply with SOLAS requirements before or after it was lengthened in 1993 because it was in domestic service. The ship's 2010 entry into the Coast Guard ACP, which was retroactive to 2006, subjected it to the equivalency requirements that are developed by the Coast Guard and classification societies (which inspect ACP vessels) and are intended to assure that vessels satisfy both SOLAS and federal regulations, as appropriate. The Coast Guard OCMI was responsible for applying the rules, and it is not completely clear whether a damage control booklet should have been required in *El Faro*'s case. Confusion about the applicability of the rules would be removed if damage control plans were required for all vessels under SOLAS, regardless of age.

For both new and existing vessels, the development and review of damage control plans and booklets can be accomplished through review of ship's plans and other documents, as well as by consultation and cooperation with classification societies, the Coast Guard, naval architecture firms, owners, and crewmembers. As concluded above, had *El Faro*'s crew had access to and training in a damage control plan, the officers would have had critical information for their decision-making. Thus, the NTSB concludes that existing cargo vessels should have the same damage control plans and booklets as are required for newly built vessels to assist crews in damage and flooding situations. Therefore, the NTSB recommends that IACS recommend to its members that existing cargo vessels be required to have damage control plans and booklets on board that meet current standards. The NTSB further recommends that the Coast Guard propose to the IMO that existing cargo vessels operating under SOLAS be required to have damage control plans and booklets on board that meet current standards.

Although newly built ships require damage control plans and booklets, as of 2017, SOLAS did not require them to be class-approved. It is important that damage control information be accurately based on conditions used in the damage stability calculations. Classification societies possess the technical expertise to provide meaningful review of damage control information aboard vessels because they typically review the same vessel's plans, stability calculations, and load line. Thus, the NTSB concludes that approval by a classification society of damage control plans and booklets would provide an independent check to ensure uniformity and compliance with requirements. Therefore, the NTSB recommends that IACS recommend that its members require, and the Coast Guard propose to the IMO, that damage control plans and booklets required by SOLAS be class-approved.

Investigators found that in reviewing *El Faro*'s probabilistic stability calculations, the most likely damage cases that occurred during the accident—the flooding of a single cargo hold or two cargo holds (cargo hold 3, and then hold 3 with hold 2A)—were not specifically examined. The stability calculations examined two flooding scenarios (cases). In the first case, only cargo hold 3 was flooded and the fixed-ballast, double-bottom tank under it was damaged. The vessel passed that case. In the second case, both cargo holds 3 and 2A were flooded and the fixed-ballast tank under each was damaged. The vessel failed that case.

Probabilistic damage stability regulations have increased vessel safety for dry cargo ships, considering that there was previously no requirement for damage stability. Probabilistic damage stability criteria calculations demand multiple damage cases to be run for multiple vessel drafts, and in most cases, the vessel must survive (meet stability criteria). However, a vessel can comply overall with the probabilistic damage stability criteria, but specific damage cases will not only fail to meet the minimum stability criteria after damage but could potentially result in the vessel sinking. For *El Faro*, the case with two compartments damaged did not meet the criteria. The case of cargo holds damaged without a double bottom in the same division was not run.

Probabilistic stability calculations are not required to be kept on board a vessel. Even if a captain has access to them, there can be hundreds of different damage cases at each vessel draft, most of which pass the criteria, but some of which do not. The captain must first understand what damage has occurred to his vessel and then go through the cases to see whether they passed the criteria. The assessment of the vessel's survivability would be in addition to the issues a captain would be addressing in a damage situation.

The IMO recognized in 2007 (MSC.1/Cir. 1245) that the probabilistic damage stability concept did not present the survivability of a ship in a simple and easily understandable way when the vessel was subject to the flooding of a compartment or group of compartments. In operational terms, the IMO recognized that a captain experiencing a specific flooding case would not have a means of quickly assessing the vessel's stability in the flooding scenario being experienced. Expanded guidance for damage control plans included information to masters for vessels built after January 1, 2009. The aim of the expanded guidelines was to set a minimum level for the presentation of damage stability information for evaluation of a ship's situation when subject to internal flooding and to provide a simple and understandable way of assessing its survivability. Thus, the NTSB concludes that a damage control plan and booklet would have helped the captain of *El Faro* assess the flooding situation. *El Faro* did not have a damage control plan or booklet on board, and even if it had been determined to have undergone a major conversion when modified in 2005–2006 and been required to have a plan and a booklet, those documents would not have included the IMO's 2009 guidelines for "information to the master." The NTSB has recommended above (as a proposal from the Coast Guard to the IMO) that existing cargo vessels operating under SOLAS be required to carry damage control documents meeting current standards (which would include the "information to the master").

El Faro's onboard CargoMax program included an optional damage stability module. The CargoMax user's manual contained a section that discussed the calculation steps and theory of damage stability and remedial action. The damage stability module was capable of assessing compartment-specific damage, such as the flooding of hold 3. The program's "emergency response calc" provided information onscreen including, but not limited to, the vessel's drafts, range of positive stability, and maximum righting arm angle. Previous senior deck officers questioned about the module said they had never used it. The VDR did not record any conversations indicating that *El Faro*'s officers consulted the program during the accident.

Although TOTE subscribed to a shoreside RRDA service, which functioned as intended after the sinking, it took several hours to provide results. Compared with the CargoMax damage module on *El Faro*, the RRDA can run more-complex flooding analyses, including estimating windheel (which was not a function in the damage module) and analyzing conditions with experienced technical experts. Investigators compared the results from RRDA with outputs they ran on a shoreside version of the same damage module found in CargoMax on the vessel. With hold 3 flooded to equilibrium, roughly similar graphics for the reduced area under the righting arm curve resulted (considering that RRDA used a permeability of 0.85 for the hold, while CargoMax used 0.7).

CargoMax showed that the flooded hold would significantly reduce the range of positive stability to less than 27° of list and that the hull's strength (percent of allowable shear and bending moment) was not exceeded. The damage module outputs also contained an indicator for the downflooding angle on the righting arm curve that could alert users to downflooding angles, although for *El Faro* they were not noted. The damage stability module in CargoMax could present information to the captain regarding survivability that would be similar to information provided in damage consequence diagrams but probably would be faster to interpret. Thus, the NTSB concludes that the damage stability module in the CargoMax software on *El Faro* could have provided timely vessel stability information to the officers for the damage conditions the vessel experienced. Therefore, the NTSB recommends that TOTE require senior officers to receive formal training approved by the manufacturer in all functions found in installed stability programs, including damage stability modules.

2.5 Weather Information

In its safety recommendation report *Tropical Cyclone Information for Mariners* (NTSB 2017b), the NTSB noted that moderate-shear cyclones, such as Joaquin, can be challenging for meteorologists to forecast with great precision (more so than with low- or high-shear cyclones). The report also mentioned that, in addition to the National Hurricane Center's tropical cyclone forecast/advisories, which are disseminated to ships through Sat-C every 6 hours when coastal tropical storm or hurricane watches or warnings are in effect, ships should also automatically receive the intermediate public advisories, which the National Hurricane Center issues every 3 hours during watches or warnings but which are not required to be disseminated to ships.[189]

According to bridge audio recordings from September 30 (table 12), both the *El Faro* captain and the chief mate were aware of the "unpredictability" and "erratic" nature of Joaquin. One means by which the *El Faro* crew remained aware of Joaquin's changing position, forecast intensity, and forecast track was the tropical cyclone forecast/advisory. That National Hurricane Center product was delivered as text messages on the ship's Sat-C receiver, with only limited delay.[190] The hurricane center issues the advisory four times a day for active tropical cyclones.[191]

The NTSB identified five instances in the *El Faro* VDR transcript ("sound of Sat-C terminal receiving incoming message") where the Sat-C terminal on the vessel's bridge probably received a tropical cyclone forecast/advisory. The five instances occurred at 0638, 1057, 1654, and 2253 on September 30 and at 0447 on October 1. After reviewing the 2253 Sat-C advisory on September 30, the third mate calculated that *El Faro* would pass 22 miles from the center of the storm and passed that information to the captain. The vessel also received a processed version of the tropical cyclone forecast/advisory through its weather service BVS, which was delayed by 6 hours compared with the Sat-C information.

The VDR audio recording from the bridge made clear that the crew had access to other weather information as well, including the Weather Channel through September 30.[192] The third mate spoke numerous times of watching the Weather Channel during the voyage. Investigators requested but were unable to retrieve footage from the Weather Channel broadcasts between 1000 on September 30 and 0500 on October 1.[193] However, footage between 0500 and 1000 on September 30 indicated that the Weather Channel provided good coverage of Joaquin and prominently displayed the times of the next expected National Hurricane Center advisory. It is likely that the Weather Channel aired updated Joaquin information (including next advisory times) in all its broadcasts during *El Faro*'s final voyage.

In addition, two broadcasts from a Coast Guard aircraft were identified on the VDR recording during the afternoon of September 30. The broadcasts announced areas under hurricane watches and warnings, advised mariners to use "extreme caution," and informed them that the Coast Guard was standing by on channel 16. The first broadcast seems to have received attention

[189] Intermediate advisories may be available through other onboard communication devices, such as open internet browsing, which *El Faro* did not have.

[190] Further discussion of the Inmarsat-C SafetyNET service and the specific products and times of their availability during *El Faro*'s final voyage are found in the meteorology group factual report in the accident docket. Text products received via Sat-C are printed on paper and can also be read on a Sat-C terminal monitor. The Sat-C alert tone and the sound of the printer functioning on *El Faro*'s bridge were documented in the VDR transcript.

[191] The National Hurricane Center nominally issues its tropical cyclone forecast/advisories at 0500, 1100, 1700, and 2300.

[192] At 2359 on September 30, the comment " . . . TV went out" is heard on the VDR recording, which probably meant that the ship had lost its satellite television reception, as would be expected at some point during the transit between Jacksonville and San Juan.

[193] The footage was not archived, or if it was, the archives were not retained until the time investigators requested them.

from both the second mate and the captain. However, the captain stated that the watch/warning areas relayed by the Coast Guard aircraft had already been identified elsewhere. The weather information available on board *El Faro* clearly showed that Hurricane Joaquin would impact the vessel on its planned route. The Sat-C information on its own showed that the vessel would be coming within 22 miles of the strengthening storm and should have been enough to prompt the captain to consider alternate options. Thus, the NTSB concludes that *El Faro* was receiving sufficient weather information for the captain's decision-making regarding the vessel's route.

Table 12. VDR conversation between captain and chief mate about Joaquin.

Captain 14:02:33.8 14:02:43.6	(yeah) we'll just have to watch it. there's not much we can do. (but they) the weather pattern itself is crazy erratic.
Chief Mate 16:16:00.6 16:16:01.4	this storm.
Captain 16:16:01.9 16:16:04.6	oh. no no no. we're not gonna turn around—we're not gonna turn around. [there is a brief unintelligible comment by either the chief mate or AB during the time the captain is speaking.]
Chief Mate 16:16:04.7 16:16:05.7	so that's it then.
Captain 16:16:06.9 16:16:11.1	the—the—the storm is very unpredictable—very unpredictable.
Chief Mate 16:16:07.5 16:16:09.7	the storm could . . . [spoken over by the captain's comment above.]
Chief Mate 16:16:11.3 16:16:14.4	it went high—it went left—it went right—it went back again.
Captain 16:16:14.1 16:16:16.4	this one in particular is very erratic.
Chief Mate 16:16:16.2 16:16:16.7	yeah.
Chief Mate 16:16:17.4 16:16:19.7	it's goin' left—it's goin' right—now it's headin'. . .

At 2249 on September 30, the National Hurricane Center announced that Joaquin had become a Category 3 hurricane, with maximum sustained winds of 100 knots, and was moving toward the central Bahamas. *El Faro* received a tropical cyclone forecast/advisory through Sat-C at 2253 that identified the increased intensity, stating that the hurricane was centered near 23.8N, 73.1W (about 120 nm southeast of *El Faro*'s position) and moving southwest (220°) at 5 knots. Maximum sustained winds were 100 knots, with gusts to 120 knots. The *El Faro* bridge crew also learned of the hurricane's intensification to Category 3 from a satellite radio broadcast 2 1/2 hours later.

At 2305, the third mate called the captain in his stateroom, stating that the hurricane was "advancing toward our trackline and . . . puts us real close to it . . . we're lookin' [to] meet it at say like four o'clock in the morning." Only a few minutes later, at 2313, the third mate was concerned enough, based on the latest weather information, that he again called the captain in his stateroom and suggested diverting to the south: "At 0400 we'll be twenty-two miles from the center. With max one hundred with gusts to one twenty and strengthening . . ." The captain did not agree to the suggested course change. The third mate subsequently told an AB, "He seems to think that we'll be south of it by then—so the winds won't be an issue. . . . I trust what he's saying—it's just being twenty miles away from hundred knot winds—this doesn't even sound right."

The second mate was also increasingly concerned based on the weather information she was receiving. That was evident in her 0352 email to a friend, in which she said that *El Faro* was "heading into the hurricane right now full force. Tried to alter our course to avoid it but he's on the war path. Bad seas and really bad winds . . ." At 0353, in an email to her mother, the second mate again expressed concern about the ship's route, stating that they were "heading straight into" a Category 3 hurricane. She continued, "Winds are super bad and seas are not great . . ."

The captain may have felt confident about the ship's route and proximity to the storm in part because he was relying on weather information that was many hours older than what the bridge crew was reviewing and thus depicted storm positions (and associated wave height and wind fields) that were less threatening. TOTE provided the private weather display system BVS to its ships, and based on VDR bridge audio, BVS was a major source of guidance for *El Faro* during the voyage. In fact, interviews with or testimony from off-duty crewmembers indicated that the captain preferred BVS as a source of weather guidance.

BVS automatically plotted the National Hurricane Center's present and forecast positions of tropical cyclones for visualization on the computer screen, providing graphic depiction of the information in a format that was relatively easy to understand. The BVS-provided information was thus more visually appealing than Sat-C, which delivered the information as text coordinates only (which the crew then had to manually plot). However, the information in the BVS files about Joaquin's position and intensity was usually the same National Hurricane Center information that Sat-C had already delivered about 6 hours earlier. Therefore, leading up to the *El Faro* sinking, the BVS files were not nearly as up-to-date about Hurricane Joaquin as was Sat-C. At 0614 on September 30, the captain stated with regard to Joaquin as reported through BVS, "It's tracking as the written weather has it. It's gone a little south."[194] Later that evening, at 2357 on September 30, the VDR recorded the third mate discussing the difference in weather information from various sources, although it is not clear exactly what was being compared.[195]

In addition, although Applied Weather Technology emailed *El Faro* the new main BVS weather files at regularly scheduled times, for the files to be read, the emails had to be downloaded

[194] This statement also calls into question whether the captain understood that the original source (the National Hurricane Center) of Joaquin's current and forecast positions depicted in BVS was also the source of Joaquin's coordinates in the tropical cyclone forecast/advisories disseminated through Sat-C.

[195] According to the VDR recording, weather information was compared at least three times on *El Faro*'s bridge during the accident voyage.

by a separate action on the part of the captain.[196] On the evening of September 30 and into the morning of October 1, a significant delay occurred in downloading the most recent BVS file. At 2302 on September 30, Applied Weather Technology emailed *El Faro* the new BVS weather file (containing information about Joaquin that was already 6 hours old), but the file was not downloaded until 0445 on the morning of the sinking. Therefore, by the time the captain read that BVS weather file, the information was about 12 hours old. At 0503 the morning of the sinking, the VDR recorded the captain assessing the available information about Joaquin's present and forecast position and intensity and stating the following:

> . . . Here's the thing—you got two GPSs—you got five GPSs—you gonna get five different positions. You got one weather program (and I use/and use) BVS and that's what I (sent) up here * we're gettin' conflicting reports as to where the center of the storm is.

At that point, the captain was comparing the up-to-date information that had just arrived on the bridge via Sat-C with the 12-hour-old BVS information. When the captain identified the discrepancy in the information between BVS and Sat-C, he most likely did not realize that Sat-C was providing more current information than BVS. Thus, the NTSB concludes that although up-to-date weather information was available on the ship, the *El Faro* captain did not use the most current weather information for decision-making.

2.6 Captain's Decision-Making

From the outset of his final journey in command of *El Faro*, the captain kept to his announced intention of following the ship's usual route to San Juan—a direct line passing east of the Bahamas. In an exchange of text messages starting an hour and a half before *El Faro* set sail, the captain told an off-duty second mate that he planned to follow his "normal direct route" to San Juan, and that he expected the storm to remain to their north as forecast. It could not be determined which forecast the captain was referring to in his text message. The second mate reminded him that there were three passages through the Bahamas that could serve as alternate routes if necessary.

The storm that became Hurricane Joaquin was still classified as a tropical storm centered 600 nm away when *El Faro* and its crew of 33 cast off from Blount Island in Jacksonville. The National Hurricane Center had already predicted, however, that Joaquin could become a hurricane the next day. While the harbor pilot was guiding the ship to a buoy outside Jacksonville, the captain told him, with regard to the storm, "We're just gonna go out and shoot under it." An hour after the pilot left the ship, the National Hurricane Center issued a hurricane warning for the central Bahamas, which were directly in *El Faro*'s path.

When *El Faro* left Jacksonville, Joaquin and its tropical storm and hurricane wind fields were forecast to be near the vessel's normal route of travel (between Jacksonville and San Juan) during the voyage. Thus, the NTSB concludes that the original passage plan's straight-line course at departure from Jacksonville would lead directly into the storm's predicted path. Once under way on the accident voyage, the captain had opportunities to avoid the destructive force of Hurricane

[196] Applied Weather Technology emailed the BVS weather files to *El Faro* at set times of 0502, 1102, 1702, and 2302 during the accident voyage.

Joaquin. And when the hurricane was forecast to be in *El Faro*'s direct path, the captain could have decided to divert from the storm.

While the captain could have taken action at any time, there were several significant points along the accident route where the captain was provided with new information that gave him opportunities to adjust course and avoid heading into the storm (see figure 66). At 0624 on September 30, after reviewing the latest weather data from BVS, which showed the storm tracking west-southwest, the captain and chief mate decided to alter the vessel's path slightly southward. The captain described the course change as a "good little diversion" and suggested that Joaquin was not serious enough to warrant what the chief mate described as more "drastic" evasive action.

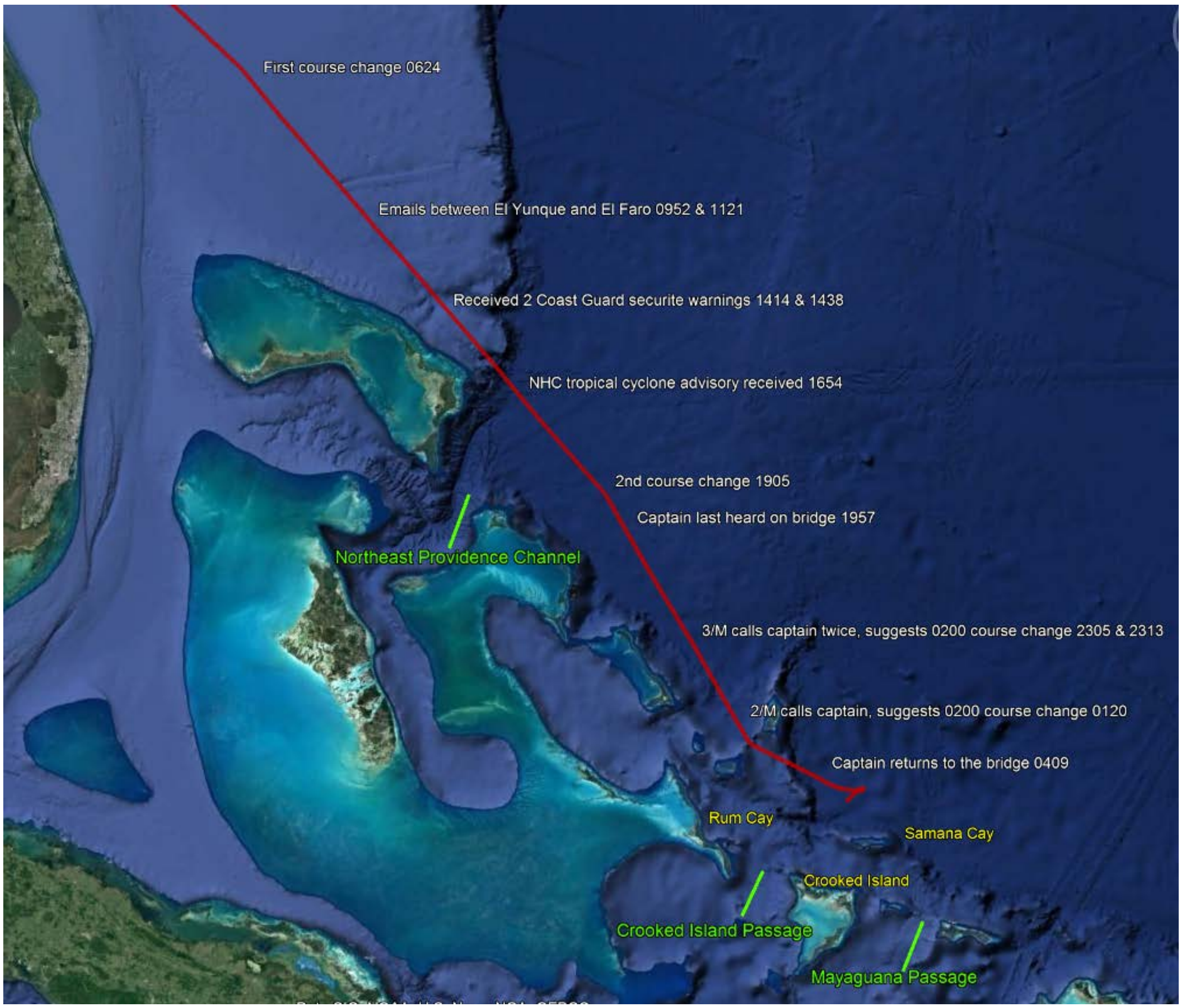


Figure 66. Significant opportunities for decision-making.

The captain was aware that the storm was getting worse. About 0830, he told the AB on watch that they had "a little weather comin' in" and that the storm had "morphed its ugly head" during the night. Even at this early juncture, the captain stated that they would "be about sixty miles south of the eye" but that "it should be fine. We are gonna be fine—not should be—we are gonna be fine."

At 0952 the same morning, the captain received an email from the captain of *El Yunque*, which was northbound from San Juan, saying the storm was intensifying and moving to the southwest. The captain responded about an hour later, saying he had already altered his course and would be 65 nm south of the storm at its closest approach. The *El Yunque* captain replied that his ship had recorded a 100-knot relative wind gust as it passed west of the storm.

At that point, it would have been prudent for the *El Faro* captain to reconsider his planned route. Information that the storm might already be producing such strong winds (which investigators could not, however, verify) should have alerted the captain that the storm could be more dangerous than he originally thought. But he continued on his course.

Nothing seemed to change the captain's mind. He did, however, inform the company (by email about 1300 on September 30) that he would like to take another route back to Jacksonville, once they reached San Juan. That route was Old Bahama Channel, a shipping route that follows the north coast of Cuba and would add time and distance to the trip. A month earlier, the captain had avoided Tropical Storm Erika by sailing down the coast of Florida from Jacksonville to reach Old Bahama Channel and then following it to Puerto Rico.

While *El Faro* was still passing the northern Bahamas, the captain indicated that he was aware that the storm was tracking erratically. About 1400, he described the storm to the chief mate as "crazy erratic." Within the next half hour, the bridge received two sécurité warnings broadcast over the maritime distress channel by a Coast Guard aircraft. Both broadcasts stated that a hurricane warning had been issued for the central Bahamas and said mariners should "use extreme caution." The captain said "Wow" but did not change his course. Around this time, the vessel was north of Great Abaco Island and close to the entrance to the Northeast Providence Channel, one of the suggested passages through the Bahama Islands.

When the AB asked the captain about 1615 whether they might turn around, the captain replied, "No, no, no. We're not gonna turn around, we're not gonna turn around." About 45 minutes later (at 1654), as *El Faro* passed east of Great Abaco Island, the bridge received a National Hurricane Center advisory on its Sat-C terminal, reporting that Joaquin now had sustained winds of 75 knots, gusting to 90 knots.

At 1824, the ship received an urgent high seas forecast that identified seas of between 12 and 27 feet within 90 nm of the storm center and predicted maximum seas of 30 feet for noon on October 1. When *El Faro* received that message, the ship was about 60 nm from the entrance to Northeast Providence Channel and about 180 nm northwest of the hurricane's center. Had the captain chosen to divert at that point, Northeast Providence Channel could have taken his vessel and its crew to safer waters inside the Bahama Islands and then, via Northwest Providence Channel, to the shipping lane along the Florida coast. From there, he could have directed the ship south to Old Bahama Channel, as he had done during Tropical Storm Erika, and then east to Puerto Rico. Instead, the captain and chief mate made another slight course change to the vessel's trackline, plotting a new course past San Salvador Island and northeast of Samana Cay. That course ultimately led the vessel close to the eye of Hurricane Joaquin.

The captain left the bridge around 2000 on September 30. He was not heard on the bridge again until about 0400 the next morning. He was called three times, however, by the mates on watch, who both wanted to change course. The third mate began discussing his concerns about the storm soon after the captain left the bridge, around 2020. He spent about 5 minutes explaining to the AB where they were relative to the storm, stating, “I’ll show you on the program” (presumably on the computer). The third mate described what they were looking at and said that it was “more powerful than we thought.” Then he said the storm was supposed to hook around and go north but added, “what if it doesn’t . . . maybe I’m just being a Chicken Little.”

The third mate called the captain shortly after 2300 to suggest that he come to the bridge to review the weather data. He told the captain the storm had maximum winds of 100 mph (87 knots) and was moving toward *El Faro*’s trackline. He said that at 0400, they would be 22 nm from the hurricane’s center. The captain did not come to the bridge, and he did not order a course change. The third mate reported to the AB on watch that the captain seemed to think they would stay south of the storm.

When the second mate came on watch at midnight, she began plotting another course change through Crooked Island Passage, which would lead the ship south toward Old Bahama Channel. At 0040, she stated that she might “have a solution.” She discussed the route change with the AB on watch, and at 0058, she said, “I might call the captain if he doesn’t come up shortly.” She called the captain at 0120 and told him things were not looking good and, though many of her words were not discernible on the VDR recording, suggested a course change “straight south” about 0200. From what the second mate said to the AB after the call, the captain told her to continue on the course the chief mate had plotted the evening before. The second mate told the AB that their course would intersect with the storm at 0400. At 0247, she told the AB that they were “pretty much committed now.” The captain had chosen not to take advantage of the available escape route through Crooked Island Passage along *El Faro*’s course.

Among the possible explanations for the captain’s decision to continue on his course relates to his understanding of the circumstances, or his mental model. A mental model is a person’s internal representation of events in the real world. Research has shown that people tend to seek confirmation of their mental models. From the beginning, the captain expected the storm to turn north and that they would stay “on the backside” of it, meaning to the south, which would be the safer side for navigation. With that expectation, the captain could have registered only that trend in the weather forecasts and ignored others that predicted different outcomes.

Another possible explanation is that the captain could have been normalizing the risk. When someone has experienced a risky situation and emerged without harm, it is not uncommon for that person to repeat the decision that led to the situation or to take the same risks again. Normalizing the risk could have led the captain to feel overconfident, particularly in predicting how the hurricane would behave. The captain had 24 years of experience, which included operations in heavy weather in Alaska and in the North Atlantic. He had also received training in meteorology and shiphandling at Maine Maritime Academy (he graduated in 1988), although he had not been required to study advanced meteorology or shiphandling since obtaining his original credential.

The captain's training and years of experience do not appear to have prepared him for the conditions presented by Hurricane Joaquin. During the accident voyage, he compared Joaquin to storms in Alaska, implying that the storm conditions *El Faro* was experiencing were not as bad as conditions he had previously encountered. The captain also talked about the worst storm he had ever experienced, which happened while he was crossing the North Atlantic, probably while captaining a car carrier. The storm had been fierce—wind gust of 102 knots and multiple rogue waves—but he and his ship had survived, although cars broke loose. The captain did not mention the differences (in size, shape, and stability) between *El Faro* and the tankers and Ro/Ro vessels in which he had previously experienced severe weather or the fact that he had not served as captain on most of those vessels.

Another factor that may have contributed to the captain's decision-making was maintaining a schedule on weekly liner service. Pressure can come from external or internal sources. The captain was unsure if he was going to be hired to captain one of the new LNG-powered ships. He sent an email to a family member on September 24, suggesting that he still did not know if he was going to get a position on one of the new ships. During the accident voyage, the VDR recorded a conversation between the captain and the chief mate regarding their future employment with the company in which both felt they were "in line for the chopping block."

If the captain thought his performance on this trip would be a deciding factor in getting the job, it might have affected his decision-making. He might have been more risk-tolerant, meaning that he might take additional risks if he thought it would help him get the job. Taking Old Bahama Channel would ultimately cost him more time and fuel and might seem like an unnecessary delay if he thought he understood the storm's path. During Tropical Storm Erika, the captain did not ask permission to divert to Old Bahama Channel. Instead, he sent an email to management, stating that, due to the most recent weather forecast, "*El Faro* will transit the Old Bahama Channel enroute to San Juan Puerto Rico." He then stated that, although the route would add 160 nm to the trip, it was a safer transit. Several managers responded, thanking him for the update. The vice president of the company responded, "Voyage plan noted and concur with your assessment."

This chain of events was unlike those that unfolded during Hurricane Joaquin. On September 30, the captain sent an email requesting permission to take Old Bahama Channel on the return route to Jacksonville as a preemptive strategy to avoid the storm in the coming days. The captain included in the email a caption that read "***QUESTION***," further detailing that he would like to take the alternate route on the return voyage from San Juan to Jacksonville. He said he would await a response before taking that route. In a conversation with the second mate, after this email, as well as in the body of the email itself, the captain specifically stated that he sent the email as a professional courtesy.

With regard to internal pressure, it is unclear what may have prompted the captain to seek permission for that deviation in the voyage. He had applied for one of the company's sought-after positions on the new LNG-powered ships but was uncertain about his status regarding the new position. Whether that played a part in his internal motivation to meet the schedule cannot be determined. However, whether internal or external, there was a built-in pressure to keep to the schedule, particularly on the southbound voyage, where customers expected cargo to arrive on time. The northbound route had a buffer that allowed the crew extra time to return to Jacksonville, and with a lighter cargo load. Knowing that the return route had a buffer built into the schedule may have been what prompted the captain to request a return route that would avoid what would be left of Hurricane Joaquin.

With regard to commercial pressure, it was unlikely to be a matter of the company directly asking the captain to do something unwise and the captain having to either do it or refuse. If the captain was expected to meet the estimated time of arrival, he might have felt pressure regardless of the changing weather forecast. Another element is that when people make decisions under pressure, their judgment suffers, and they tend to accept more risk. A schedule can produce pressure just because it exists—delays are costly, and decisions to change a route must be justified and explained. Sometimes the greatest pressure is one's own internal, self-induced pressure. The captain rarely arrived in port late and may have been highly motivated to meet his schedule, which could have increased his risk tolerance and blocked his full situation awareness of the weather. Thus, the NTSB concludes that although there is no direct evidence that the company applied pressure regarding the vessel's schedule, inherent pressure could have influenced the captain's decision to continue on despite the weather.

A further possible explanation of the captain's actions is what is known as confirmation bias. That is the tendency of a person to search for, interpret, favor, and recall information in a way that confirms his or her beliefs or hypotheses while giving less attention to information that contradicts those beliefs (Plous 1993). Once the captain made his decision to continue on the planned route, he was not swayed by information that contradicted his plan, including his officers' suggestions of route changes to avoid the storm. The captain was also unwilling to change course even though weather forecasts led the officers to believe they would come within 22 nm of the hurricane's eye.

Throughout his conversations with others on the bridge during the accident voyage, the captain regularly minimized the storm (referring to it as a "low") and its possible effect on *El Faro*. The second mate stated that the captain was telling the crew "it's not a bad storm . . . it's not even that windy out . . . seen worse." The captain repeatedly said that things were going to get better, that they would "be fine" or "make it," even after the second mate sent distress messages half an hour before the ship sank.

The captain was aware that he had options to divert away from the hurricane by taking one of three sea passages through the Bahamas. Although the captain altered his course slightly during the voyage, he did not succeed in avoiding the storm. In fact, his last course alteration took *El Faro* close to the eye of the hurricane. Thus, the NTSB concludes that the captain did not take sufficient action to avoid Hurricane Joaquin, thereby putting *El Faro* and its crew in peril.

2.7 Bridge Resource Management

The captain had ultimate responsibility for the vessel's safe operation and navigation. He was also leader of the bridge navigation team and was thus responsible for seeing that the team used all resources, human and technical, to assure the safe completion of their voyage. The formal approach to managing bridge teams is known as BRM.

BRM trains bridge teams to work cooperatively to monitor a vessel's progress, to acquire and exchange information, and to anticipate dangerous situations that could affect the safety of the crew or the vessel. All the deck officers except the captain had received BRM training in 2013. The captain had completed BRM courses in 1995, 1998, and, most recently, 2003. In 2015, he completed a 5-day leadership and management course, which covered topics such as decision-making, effective communications, and obtaining/maintaining situational leadership. BRM was not required as part of the course.

BRM as a management tool in the maritime industry grew out of the concept of crew resource management (CRM) in aviation. CRM, in turn, was a response to a series of fatal aviation accidents in the 1970s, including the deadliest aviation accident in history, the 1977 collision of two Boeing 747s on Tenerife, Canary Islands, that killed 583 people. The accident, which was investigated by Spanish authorities, occurred in part because the copilot and flight engineer failed to challenge the captain's decision to take off before confirming that the runway was clear.[197]

The NTSB has played a key role in advocating for CRM. For example, improving CRM was placed on the NTSB's Most Wanted List in 2006, which led to the Federal Aviation Administration requiring CRM training for all crewmembers, including pilots and flight attendants, on small commuter airlines and on-demand operations such as air ambulances (known as Part 135 operators).[198]

Indeed, the NTSB's investigations into aviation accidents that demonstrated a breakdown of cockpit management and teamwork led directly to the development of CRM. Notable examples include a 1977 accident in Anchorage, Alaska, in which a Japanese cargo plane crashed shortly after takeoff, killing three crewmembers and two cargo handlers (NTSB 1979a). Investigators determined that the captain was intoxicated. The driver who took the crew to the airport informed his dispatcher, who notified the airline's Anchorage office, but no action was taken. The cockpit voice recorder showed that neither flight officer remarked about the captain's intoxication or tried to stop the captain from controlling the airplane. The captain was a US national and two of the junior crewmembers were Japanese. In its probable cause statement, the NTSB determined that "Contributing to the cause of this accident was the failure of the other flight crew members to prevent the captain from attempting the flight."

Another example is the 1978 crash of United Airlines flight 173 into a wooded residential area in Portland, Oregon. The airplane ran out of fuel while the flight crew coped with a malfunction of the landing gear. Ten people died, and 23 were seriously injured. The NTSB determined that the captain had failed to properly monitor the quantity of fuel remaining on the airplane (NTSB 1979b). The NTSB also found that the first and second officers were not assertive enough in trying to communicate with the captain. As stated in the NTSB's determination of probable cause, "Contributing to the accident was the failure of the other two flight crewmembers either to fully comprehend the criticality of the fuel state or to successfully communicate their concern to the captain."

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[197] See https://ntsb.gov/safety/mwl/Pages/was2.aspx.

[198] The Federal Aviation Administration issued its final rule in 2011.

The NTSB has investigated numerous marine accidents in which ineffective BRM played a role. Most involved poor communication between the master and a pilot who had joined the vessel to guide it through a harbor or down a waterway, and none resulted in fatalities. A recent example of a failure in BRM that had fatal consequences was the 2012 grounding of the cruise vessel *Costa Concordia* off the Italian island of Giglio. In its analysis of the accident, the Italian Ministry of Infrastructures and Transports cited the “overly passive attitude of the bridge staff” as a factor (MIT 2013). The accident included the risk normalization element described earlier because the ship had previously sailed close to the island to allow tourists to take photographs. The accident resulted in the deaths of 32 passengers and crewmembers.

In the case of *El Faro*, it is evident from the conversations recorded by the VDR that the environment was not such that feedback from the crew was encouraged or considered by the captain. Though the officers discussed the worsening weather during their watch turnovers, they did not assertively voice their concerns in the captain’s presence. Further, the captain repeatedly ignored the officers’ suggestions to alter course so as to avoid the hurricane.

Before the captain left the bridge on the night of September 30, he told the third mate that he would be “up for the better part” of his watch and that the mate should call if he saw anything he did not like. The captain’s voice was not detected on the bridge again until the next morning. When the third mate called the captain shortly after 2300 to suggest that he come to the bridge to check the weather forecast, the captain did not go to the bridge and did not approve the course change the third mate suggested. The second mate said she did not see how the captain could be sleeping under the weather conditions before she called him about 0120 to suggest another course change. She and the third mate expected that they would encounter the worst effects of the hurricane about 0400, yet the captain did not come to the bridge during the night to check the weather or the status of the vessel. He also failed to download the BVS weather file that had been available at 2304. When the captain arrived on the bridge shortly after 0400, he announced that he had slept “like a baby” and questioned, “Who’s not sleepin’ good?”

According to Crowch (2013), 60 percent of all marine accidents that fault the human operator are related to ineffective communication. As an element of BRM, officers have a duty to speak up if they believe the vessel is at risk. From their statements on the VDR, the *El Faro* mates were clearly concerned about their safety and that of the rest of the crew. They were reviewing incoming weather data and knew the storm was coming closer. The captain, however, did not take any action or make any statements that indicated he was concerned, nor did he come to the bridge to review updated weather information, as suggested by the third mate. Given the responsibility of his position and the risk of the upcoming weather, it is difficult to explain how the captain could have been absent from the bridge while his ship sailed into a hurricane. The second mate remarked how hard it had been to wake him when she called his cabin about 0130.

BRM stresses assertiveness. As this accident shows, however, in practice it can be difficult for officers to challenge a captain’s decisions. There are several possible explanations for the officers’ reluctance to challenge the captain’s decision not to deviate except in minor ways from their route. First, they appeared to have high confidence in the captain’s experience and were reluctant to question his judgment. He had sailed in harsh Alaska conditions and spoke of encountering a severe storm in the North Atlantic before he became captain of *El Faro*. He even stated that the weather they encountered was normal for winter in Alaska. The third mate expressed confidence in the captain's experience, saying on September 30 at 2122, "I don't know. I'm not gonna second guess somebody. The guy's been through a lot worse than this. He's been sailing for a long—long time—he did it up in Alaska." He also said that he trusted the captain, even though he worried about being only 20 nm from 100-knot winds: "This doesn't even sound right."

Second, the officers occupied a subordinate position in relation to the captain. The authority of the captain is traditionally treated as absolute, and mariners are accustomed to deferring to the captain's decisions. The historical view of the marine industry for the unique environment of a crew at sea is that such a hierarchy is necessary to preserve order on board a ship. Although training in bridge (crew) resource management is required for mariners, it has not been as widely accepted or studied as in the aviation realm. The evolution of CRM was a challenge in aviation, and it took time to "overcome the old way" of doing business. Eventually, the pilots (captains) began to recognize the importance of lower-ranking officers being confident enough to speak up about the best way to operate the aircraft. For example, the "go-around" rule was instituted, ensuring that if the first officer asks for a go-around, it will be executed with no questions asked ("no fault" go-around) and no penalties given.

In the marine industry, the gap between the captain and his less-powerful subordinates, known as the power distance, can make it difficult for junior officers to challenge a captain. Power distance refers to the way in which power is distributed and the extent to which the less powerful accept that power is distributed unequally. It is defined as the extent to which a society accepts unequal distribution of power in institutions and organizations (Dorfman and Howell 1988). In a high-power-distance culture, the difference in power is substantial, whereas in a low-power-distance culture, the balance is more team-oriented. For example, in the hierarchical structure of a ship's bridge team, the power distance between the captain and the third officer is greater than the power distance between the second and third officers.

The VDR transcript contains many examples of how the ship's hierarchical structure influenced the flow of communications. Often, the helmsmen and junior officers frankly discussed their opinions of the weather situation and the captain's decision-making. The helmsmen frequently voiced their concerns to the junior officers but never in the presence of the captain. Similarly, when the junior officers discussed navigational issues at critical junctures with the captain, such as their calls to the captain on the night of September 30 and the morning of October 1, they generally spoke in a deferential manner, using hints, preferences, or suggestions.

At 2305, when the third mate called the captain, he said, "Thought you might wanna take a look at it . . . so (yeah) if you have a chance," referring to the latest weather report that showed the eye of the hurricane coming within 22 nm of *El Faro*'s trackline, with observed winds of 100 miles per hour. The third mate phrased his request for the captain to come to the bridge as a suggestion. Such phrasing is indicative of mitigated speech. Mitigated speech is when a person speaks in a deferential way, either to be polite or to show deference to authority. Junior officers would be more likely to make suggestions to the captain or to speak in the form of questions rather than make actionable statements. They would defer to the person in authority to decide instead of proposing an action themselves.

In a study conducted by the National Aeronautics and Space Administration (NASA) of airline crew communications (Fischer and Orasanu 1999), subordinate crewmembers often voiced concerns relating to a hypothetical situation of an airliner penetrating an embedded thunderstorm in the form of hints, preferences, or queries. Hints, preferences, or queries do not specify a corrective action, and in these dialogue exchanges, the senior crewmember was unlikely to change his or her opinion of the situation.

At 0120, after hearing a weather report from the Weather Channel stating that Hurricane Joaquin had been upgraded from a Category 2 to a Category 3 storm and discussing with the helmsman the size of the seas and the ferocity of the wind, the second mate called the captain using the electric telephone. In her call, the second mate stated, "(uh) I just wanted ***. . . we'll be meeting the storm." The second mate continued on the phone call, ". . . alter course straight south then (we'll) * go through all these shallow areas." In that exchange, the second mate discussed a preference, rather than using a command or a crew obligation statement. The NASA study found that more effective ways to influence a senior crewmember would be to either issue a direct command or to use a crew obligation statement—a statement in which the subordinate obligates the senior crewmember as part of the navigational team by using language such as "we should" or "our route."

Although both mates suggested changing the vessel's route to avoid the storm during their respective watches, the captain did not act on their suggestions. They posed their suggestions as hints and preferences, and the captain was not receptive to those suggestions. The concept of mitigated speech is common in a hierarchical system, such as on the bridge of a ship. If a member of the bridge team disagrees with the captain and takes action to defy or challenge his or her authority, that is considered insubordination, which could result in disciplinary action. This creates an environment in which there is hesitancy to challenge a higher authority. There was a degree of uncertainty about the outcome of approaching the hurricane, and the mates would have needed absolute confidence in the outcome to feel comfortable in strongly stating their opinions or taking further action.

Nevertheless, the examples cited earlier show that the failure to challenge a superior officer can have fatal consequences. In the case of *El Faro,* even though the mates clearly had concerns about their route in relation to the storm, they ultimately deferred to the captain's decision to continue on the planned route. Perhaps if the mates had spoken more assertively to the captain, he might have taken their concerns more seriously. Thus, the NTSB concludes that had the deck officers more assertively stated their concerns, in accordance with effective BRM principles, the captain's situation awareness might have been improved.

Regardless, the second and third mates did voice concerns, but the captain chose not to listen. The suggestions of not one but two of his officers should have prompted the captain to at least review the weather information. Whatever the captain's possible other actions, he did not return to the bridge. Moreover, by not coming to the bridge as the mates suggested and by dismissing their suggestions to change course and avoid the storm, the captain missed an opportunity to reassess the situation and alter the voyage plan. Thus, the NTSB concludes that the captain should have returned to the bridge after the second and third mates called him to gain a better awareness of the changing weather situation.

As the person with ultimate responsibility for the vessel and its primary decision-maker, the captain should have gone to the bridge to guide the navigators as the third mate requested when he realized the ship was on a collision course with the storm. The captain's dismissal of the junior officers' suggestions may have made them reluctant to further assert themselves as the weather worsened. Thus, the NTSB concludes that by failing to adequately consider the suggestions of the ship's junior officers to alter the passage plan and failing to alter his decision to proceed, the captain endangered *El Faro* and its crew.

Creating an environment in which all members of the navigation bridge team can freely discuss issues and be comfortable challenging each other's actions, especially in the face of imminent danger, is a core BRM concept. Although the helmsmen and junior officers frequently discussed alternative voyage plans and their awareness of the weather conditions, their information and concerns were not effectively communicated to the captain. He exhibited poor team leadership and did not discuss alternative options with the other officers after he and the chief mate plotted a new route, and there is no evidence that he gathered the crew to discuss the weather or any changes in the voyage plan due to the storm. The disconnect between the captain's and crew's awareness of the proximity of *El Faro* to the hurricane using the available weather information demonstrates inadequate BRM and resulted in the inability of the crew to function as a cohesive team that had a shared mental model of the voyage necessary to maintain a safe distance from the storm.

Thus, the NTSB concludes that the concepts of BRM were not implemented on board *El Faro*. Therefore, the NTSB recommends that the Coast Guard publish policy guidance to approved maritime training schools offering BRM courses to promote a cohesive team environment and improve the decision-making process, and specifically include navigational and storm-avoidance scenarios. The NTSB also recommends that the Coast Guard require recurring BRM training for all deck officers when renewing their credentials.

Actively promoting BRM was the ultimate responsibility of the company. TOTE's SMS stated that the captain was responsible for providing onboard BRM training to the crew every quarter, in accordance with a training addendum to the SMS. However, the most recent version of the training addendum (dated August 2015) did not include a section on BRM, though a version dated February 2013 did. In fact, the section on BRM was marked as deleted on the contents page of the August 2015 addendum. The document control list indicated that *El Faro* had received the newest training addendum. Logs of safety training meetings held during the first two quarters of 2015 contained no reference to BRM as a training topic. TOTE was required by its SMS to ensure that quarterly BRM training was conducted aboard *El Faro* and that BRM principles were addressed in the captain's standing orders. Investigators found no evidence that TOTE management implemented BRM aboard *El Faro*. Thus, the NTSB concludes that the company's failure to ensure the implementation of BRM contributed to the sinking.

2.8 Oversight

2.8.1 Company

Safety Management System. According to the ISM code, it is the responsibility of the company—the owner or any other organization that has assumed responsibility for operation of a ship—to establish an SMS for its vessels. According to section 1.2.2 of the code, the SMS should "assess all identified risks to its ships, personnel and the environment and establish appropriate safeguards." In this manner, the code (section 7) directs that the "company should establish procedures, plans and instructions, including checklists as appropriate, for key shipboard operations concerning the safety of the personnel, ship, and protection of the environment." Furthermore, the code requires that the company "identify potential emergency shipboard situations, and establish procedures to respond to them."

Section 10.8 of the OMV (the operations procedures element of TOTE's SMS) was titled "Adverse Weather." It advised the captain to properly handle the ship and to properly stow and secure all equipment. The section did not address securement of cargo, such as adding additional lashings, or checking watertight doors and hatches. Section 5.12 of the EPMV (the emergency procedures element of the company's SMS) stated that severe weather at sea was to be avoided, if possible, and it directed masters to consult *The American Practical Navigator* for instructions on how to maneuver in extreme weather.[199] Company personnel stated that they believed bad or adverse weather posed a risk to their vessels, yet little other guidance was given for preparing for heavy weather or actions to take if a vessel entered heavy weather. Investigators did not find a heavy-weather checklist in any of the documentation provided by TOTE. The SMS also did not include guidance on the CargoMax software's damage stability module that was capable of assessing compartment-specific damage, such as the flooding of hold 3.

Of the other operating companies surveyed by investigators, seven of the nine stated that their vessels had heavy-weather checklists. Investigators found directives in the manuals and SMS procedures of the companies relating to steps taken before entering heavy weather. They included making closures watertight, increasing GM margin, and using weather routing. Investigators could not find the same level of specificity in TOTE's SMS. The ISM code recognizes that "no two shipping companies or shipowners are the same, and that ships operate under a wide range of different conditions." Hence, "the Code is based on general principles and objectives." But based on these general principals and objectives, it would be expected that a properly functioning SMS would address planning for a safe passage, ensuring vessel watertight integrity, preparing for heavy weather, and crew preparedness for emergencies.

The company identified heavy or severe weather as a risk to its vessels, yet it inadequately mitigated that risk by failing to provide specific guidance, instructions, and checklists to prepare the vessel for heavy or severe weather. Furthermore, company audits did not identify the gaps. As a result, the *El Faro* crew did not adequately prepare for heavy weather, and an open scuttle went unnoticed. Thus, the NTSB concludes that the company's SMS was inadequate and did not provide the officers and crew with the necessary procedures to ensure safe passage, watertight integrity, heavy-weather preparations, and emergency response during heavy-weather conditions. Therefore, the NTSB recommends that TOTE conduct an external audit, independent of its organization or class society, of its entire SMS to ensure compliance with the ISM code and correct noted deficiencies. The NTSB also recommends that TOTE revise its SMS and BRM programs to

[199] See appendix E for more information about *The American Practical Navigator* and its advice to mariners regarding extreme weather.

contain detailed polices, instructions, procedures, and checklists to mitigate the risks of severe weather to its vessels.

Evaluation and Training. To ensure that a vessel's officers effectively carry out their duties and responsibilities, it is essential that a system be implemented to assess and evaluate the officers' performance. Investigators could not to determine how TOTE assessed the capabilities and proficiency of its shipboard officers, though annual evaluations of senior officers were required according to the SMS.

The captain's most recent performance evaluation was drafted a year before the accident, had not been completed, and had not been signed by the technical manager or the captain. The evaluation was not formally received by the TOTE crewing department or placed in the captain's personnel file. The chief engineer's most recent evaluation likewise had been drafted a year before the accident and was not completed. The second mate's most recent personnel evaluation was dated November 2011, when she was sailing as a third mate, and the third mate's most recent evaluation was dated February 2014, over 19 months before the accident.

In the unsigned evaluation from October 2014, the port engineer scored the captain's performance as excellent in all categories except one: "cooperation with the technical manager." The evaluation noted that the captain "handles all aspects of the master's position with professionalism." However, in emails during 2015, the crewing manager expressed "dwindling confidence" in the captain, and the director of ship management stated, "He's stateroom Captain, I'm not sure he knows what a deck looks like period. Least engaged of all four Captains in the deck operation." None of those concerns were formally documented, and no letters of warning or reprimand were found in the captain's TOTE personnel file. (Email records confirmed that a verbal warning was issued to the captain about welding repairs not being carried out, but no record of that was found in his personnel file.) Company officials initially did not want to consider hiring the captain to command one of its new ships, though nothing in his personnel file suggested that he was not qualified.

The captain had been disciplined by a previous employer for causing "disharmony" among officers, as well as failing to follow the chain of command. The company described a loss of confidence in his ability to lead. Before rehiring the captain in 2013, TOTE did not request his personnel records from the previous employer, and according to management, management was not aware that he had two disciplinary letters issued by that company.

A company selection process for hiring or promoting personnel should be described in its policies and procedures. However, when management was asked about hiring practices and policies, no written instruction or documentation was provided, and no notes from interview sessions were kept on file for potential hires or current employees who interviewed for other positions.

Training and officer competency were managed by two different departments in TOTE. While the crewing department supervised evaluations and Coast Guard–mandated training, the safety and operations department handled shipboard training (TOTE did not have a separate training department). The safety and operations department was responsible for ensuring that familiarization training was completed and that quarterly training logs were collected from the vessels. Company management required that the captain conduct crew safety training on board according to its training addendum, although the training topics were general and no additional training materials were provided. The quarterly training logs included a list of topics, and the logs varied as to whether crew signatures were required.

When asked how the safety and operations department determined if an officer needed remedial training, an assistant manager stated, “It’s not part of my job, so I don’t know.” When asked how the department evaluated the quality of the training conducted by the captain aboard the ship, that manager again stated that she did not know. Shipboard training information was not included in the crew personnel files kept by the crewing department.

Crisis management skills are often not tested. But when circumstances arise that challenge the abilities of senior leaders, weaknesses in those skills become apparent. TOTE had a dedicated emergency response team. Training included running scenarios with vessels and any follow-up when scenarios did not go as planned. The SSAS was tested quarterly on all vessels. According to the log of the emergency response team, the tests were conducted on *El Faro* on three separate occasions in 2015.

According to interviews with emergency response team members, no scenarios specific to heavy weather were ever included in training. In addition, none of the drills conducted with the emergency response team included fire at sea, vessel grounding, or flooding of various compartments. Emergency response team logs for 2015 show that *El Faro* had two emergencies in early September, when diesel oil was spilled. After those incidents, a drill on contacting the qualified individual in case of emergency was conducted. The yearly log did not include any drills in which the captain and crew responded to flooding. When asked if those types of drills were conducted, emergency team members and management said they were not.

Evaluations were not completed regularly, and the company did not follow its own general guidelines for evaluations and oversight. There was no evidence of reassessment of officer competency in the hiring process. Furthermore, there was a clear division between the department evaluating crew competency and the department overseeing training, thus limiting the ability of the company to effectively evaluate the skill level and training needs of its officers. Emergency response team drills failed to include scenarios that would assess responses of the crew when faced with emergencies at sea, such as fire, flooding, and grounding. Thus, the NTSB concludes that the company did not have an effective process for evaluating the performance of its officers.

The ISM code (part A, section 6.5) requires companies to “establish and maintain procedures for identifying any training which may be required in support of the SMS and ensure such training is provided for all personnel concerned.” The company SMS required the chief mate to be completely familiar with the vessel’s stability/cargo computation system. The primary method that *El Faro* officers and company shore-based personnel used to calculate ship stability was the CargoMax program. However, TOTE did not provide any formal training to the officers on *El Faro*, and none of the former senior deck officers of *El Faro* who were interviewed said they had any formal training in the use of the software before the accident. A review of the accident voyage captain’s and chief mate’s records indicates that they did not have such training. Officers interviewed stated that their CargoMax training was on the job.

The CargoMax program contained a damage stability module. Although the damage stability module was not approved by the classification society, investigators found it a fairly quick and useful tool for determining the amount of flooding needed for *El Faro* to lose positive stability. Using the program, crewmembers could have simulated different damage conditions (or the effect of various types of damage to the vessel), which would have allowed them to calculate the effects of different stages of flooding and would have provided them with conditions of particular vulnerability. None of the former *El Faro* officers who were interviewed understood how the damage stability module in CargoMax operated.

Training by the CargoMax developers or by instructors certified by the developers would have allowed *El Faro* personnel to be conversant with the full capabilities of the software. They could have experimented in advance with different conditions of damage that would seriously affect the stability of the vessel, quickly determined the status of the vessel during the storm, and recognized the dangerous state *El Faro* was in.

Understanding shipboard stability, particularly in severe conditions, is a critical skill requiring specialized training and experience. That skill allows officers to make competent decisions when faced with complex stability hazards such as list and windheel. The officers on *El Faro* had no training, and the shipboard guidance was not suitable for the circumstances. Thus, the NTSB concludes that the company did not have an effective training program for the use of the CargoMax stability instrument, including its damage stability module.

According to Coast Guard NVIC 10-14 (USCG 2014), an STCW endorsement to master and chief mate credentials on vessels of 3,000 gross tons or more requires, among other obligations, training and assessment in advanced meteorology and advanced shiphandling. Standards for advanced meteorology include "knowledge of characteristics of various weather systems, including tropical revolving storms and avoidance of storm centers and the dangerous quadrants." Standards for advanced shiphandling include the "management and handling of ships in heavy weather"; the "means of keeping an unmanageable ship out of trough of the sea"; and suggestions of methods, such as weather routing, to prevent vessel damage.

About 0500 on the morning of the accident, the *El Faro* bridge team was looking at two different weather data reports that gave differing positions for the center of Hurricane Joaquin. The BVS report, which was downloaded at 0445 but was almost 12 hours old, forecast the advanceable position of the storm's center to the northwest of the vessel's position, placing *El Faro* in the navigable semicircle and proceeding away from the storm. The Inmarsat-C report, which was current as of 0446, reported the storm's center directly east of the vessel's position, placing *El Faro* in the dangerous semicircle and proceeding toward the storm (see figure 42**,** section 1.10.3). At 0503, the VDR recorded the captain saying, "We're getting conflicting reports as to where the center of the storm is," but it appears that there was no recognition that the perceived conflict was due to the difference in valid times for the weather sources' center positions for Joaquin.

Investigators' review of the BVS program indicated that the user interface is not difficult to use. However, setting up the system to deliver optimal information can be complex, particularly if no additional training is provided. Operators need to consult the manual, which is not easy to understand and, at times, was confusing to investigators. Because the purpose of using the software is safe navigation of the vessel, a full understanding of how the system works and the data used to populate the program is critical. Decision-makers on board any vessel, as well as any shoreside support personnel, should be thoroughly familiar with weather information that is readily available to them, including the latency, or time delay, of the data. Mariners and shoreside personnel should also understand the information that is not available to them through routine channels, determine whether the information is critical, and identify when and how to acquire it.

TOTE did not require or provide formal training for its officers on the shipboard weather services and information sources. BVS was one of the *El Faro* crew's primary sources of weather information—VDR audio indicates that BVS was, in fact, the preferred source—yet the officers did not have formal training in using the system. Officers did not have adequate knowledge of the capabilities and limitations of BVS. Therefore, they did not recognize the time delay in the BVS tropical cyclone information and thus the source of conflict between it and the more-current Sat-C information. Tropical storm updates were available through Applied Weather Technology, the BVS system developer, but because the crew did not have that function set up in their system, they did not obtain those data. The crew's lack of understanding was illustrated by the actions they took or failed to take throughout the entire voyage. Thus, the NTSB concludes that the company did not have an effective officer training program for the use of the ship's BVS weather information software.

There is no formal requirement for vessels to have a weather-routing or information service, such as BVS, or other bridge software. However, bridge officers should have adequate training in the use of such a system, including all functionalities, if it is on board a vessel. For example, BVS data could be customized to receive updated storm information more frequently, yet the *El Faro* crew was either not aware of that function or was not familiar enough with the program to use it. Knowledge of the system (via training and functional user manuals) would have provided them with the information they needed to acquire the additional weather information. Applied Weather Technology provides training to companies that request it, though the training varies according to company needs. Crewmembers should also be fully knowledgeable about all sources of weather information at their disposal and understand the time delays in the information provided. Therefore, the NTSB recommends that TOTE provide formal and recurrent training to its deck officers on the public and commercial weather information systems provided on board each vessel to ensure that the officers are fully knowledgeable about all weather information sources at their disposal and understand the time delays in the information provided.

Shipboard Instruments. An accurate determination of wind speed, wind direction, and barometric pressure on board *El Faro* would have allowed the crew to resolve the conflicting weather reports.[200] Although *El Faro* had a functioning aneroid barometer and a digital barograph, it did not have a properly functioning anemometer. As the *American Practical Navigator* (Bowditch 2002) notes,

[200] It is unlikely that the crew would have been able to use Buys Ballot's Law to determine the direction of the storm center without an anemometer (the law states that an observer whose back is to the wind has the low pressure on his or her left in the Northern Hemisphere; see appendix E for further information about Buys Ballot). The ship's motion, combined with worsening conditions and squalls, would have made it extremely difficult to determine the direction of the wind from the bridge wings or weather decks.

> the winds are probably the best guide to the direction of the center of a tropical cyclone. . . . Within the cyclonic circulation, a wind shifting to the right in the northern hemisphere . . . indicates the vessel is probably in the dangerous semicircle. A steady wind shift opposite to this indicates the vessel is probably in the less dangerous semicircle.

A former *El Faro* second mate, who left the vessel less than 2 weeks before the accident, stated that *El Faro* had one anemometer and that it had not been working for 2 to 3 months. In a conversation recorded on the VDR between the captain and chief mate, investigators confirmed that the anemometer did not work properly. The captain said, “obviously the direction is not good,” and the chief mate, when asked about a number on the readout, stated he would not trust it. The captain also said, “they’re not (gonna buy) a new one for it.” At the first marine board hearing, the vessel’s port engineer said that he knew the anemometer was not operating properly, that it was not captured in the planned maintenance system for the vessel, and that no one told him to fix it.

A properly working anemometer would have allowed the ship’s crew to compute the true wind direction and speed. With that information, the captain would have had additional information to determine the vessel’s position in relation to Hurricane Joaquin. Thus, the NTSB concludes that the company did not ensure that *El Faro* had a properly functioning anemometer, which deprived the captain of a vital tool for understanding his ship’s position relative to the storm. The NTSB therefore recommends that TOTE require its vessels to be equipped with properly operating meteorological instruments, including functioning barometers, barographs, and anemometers. To ensure that vessels are equipped with properly functioning weather equipment, the NTSB also recommends that the Coast Guard require that vessels in ocean service (500 gross tons or over) be equipped with properly operating meteorological instruments, including functioning barometers, barographs, and anemometers.

RRDA Program. When *El Faro* experienced a large heel angle hours before sinking, the crew did not consider using the RRDA service from ABS, which could have helped the captain evaluate the situation and determine courses of action. Although not required to do so by regulation, TOTE subscribed to the RRDA program for *El Faro*. Based on VDR audio, *El Faro* personnel did not know the effects of windheel on their vessel or, initially, the source of the list. Shortly after 0722 on the accident morning, the riding gang supervisor asked the captain about the ship’s downflooding angles, and the captain did not know the answer. That was the type of information that RRDA could have provided. With windheel and stability information in hand, the captain could have taken early proactive steps to determine the source of the list and might have decided to muster the crew sooner. Support would have been even more effective had the RRDA team been supplied with vessel loadout data for the voyage.

According to statements by company representatives and a former *El Faro* master, the company did not actively use or require the crew to be familiar with the RRDA system, and no drills were conducted in its use. No information about the vessel’s loadout was provided to ABS before the accident voyage. Nominal departure conditions for Jacksonville and San Juan using various container stack heights would have been helpful. Conceivably, windheels for full deck loads of two-high or four-high container stacks could have been modeled for loadouts of lesser or greater heights, and RRDA should have been able to provide the *El Faro* captain with a worst-case windheel. However, based on VDR audio, RRDA was neither discussed nor considered by the crew. Enrollment in RRDA allows for drills, but the company had not participated in any. The

RRDA manager stated that the program would be more effective if the captain and crew knew what RRDA could do. Thus, the NTSB concludes that the company subscribed to the RRDA service, although not required, but did not train the crew in its use. Therefore, the NTSB recommends that TOTE provide shoreside management and vessel senior personnel with training in the RRDA program and standard operating procedures, to include requirements to conduct annual drills and submit departure stability conditions for each vessel on each voyage.

Shoreside Support. The ISM code states that the "Company should ensure that the master is given the necessary support so that the master's duties can be safely performed." When investigators asked TOTE personnel if they monitored the movements of their vessels, especially when they were in or set to enter an area of heavy weather, they stated that no one was assigned that duty and that they were not required to do so. Although the port engineer said he believed he looked at the September 30 noon message from *El Faro*, he told investigators that he did not believe anyone tracked the vessel's position at any time. For weather tracking, two TOTE terminal personnel received BVS weather reports, but none of the management personnel obtained BVS or other contracted weather service information.

The company did not provide the captain with competent sources of nautical experience for the purpose of consultation. According to TOTE representatives, the captain was the primary nautical expert. There were other captains in the TOTE organization, such as the DP, but he was overwhelmed with other duties. The captains at sea themselves were the company's nautical experts. According to the director of marine safety and services, "There is no one in the company that formally provides oversight for nautical. We depend on the captains to take on that role."

In the past, TOTE had both port captains and port engineers to oversee vessel operations. After the company reorganized, port captains were no longer in the organizational structure for the commercial fleet, though port engineer positions remained. TOTE management stated during marine board testimony that the company's reorganization in 2012–2013 did not negatively impact shoreside support and that the relocation of personnel from New Jersey to Jacksonville had enhanced shoreside support and oversight. Investigators, however, found very little shoreside oversight or support for the accident voyage.

When *El Faro* left Jacksonville, then-Tropical Storm Joaquin's wind fields were forecast to be near the vessel's normal route of travel to San Juan. TOTE shoreside personnel did not monitor the vessel, even as the storm was upgraded to a hurricane. There is no indication that anyone from TOTE management contacted the vessel once it departed Jacksonville, aside from responding to the captain's email regarding the return transit from San Juan.

The lack of engagement from TOTE management differed from company practices earlier in the 2015 hurricane season. Hurricane Danny prompted the DP to issue a safety alert to all vessels, with guidance to review heavy-weather procedures and "be prepared for the unexpected occurrence." For Tropical Storm Erika, TOTE management contacted *El Faro*'s captain and asked for his preparedness/avoidance plans, action area, and risk assessment "to ensure we are all on same page and nothing is missed." *El Faro*'s captain responded with a message outlining the route he was taking (Old Bahama Channel), why he was taking the route, and the steps taken to mitigate damage. The vessel successfully weathered the storm.

During the accident voyage, the captain wrote in the notes section of the September 30 noon report, “Precautions observed regarding hurricane Joaquin.” After receiving the report, the company did not question the captain’s plans or monitor the ship’s progress. In fact, the company seemed unaware that a potential hurricane was affecting the vessel’s route. The company’s lack of engagement during Hurricane Joaquin indicates that management had become complacent.

Investigators learned that shoreside managers of the company that managed the Sea Star Line vessels (which were subsequently managed by TOTE) had a process by which they would contact the vessel to determine the captain’s plans for any weather systems that might affect the vessel. Also, eight of nine companies that were voluntarily surveyed stated that they contacted their captains directly or monitored routing and weather-related correspondence between their ships’ captains and contracted with weather or nautical services. Thus, the NTSB concludes that the company did not monitor the position of *El Faro* relative to the storm and did not provide the captain with support for storm avoidance and heavy-weather preparations during the accident voyage. The NTSB further concludes that the company failed to assess the risk posed by Hurricane Joaquin to *El Faro.* The NTSB therefore recommends that TOTE institute a formal company process to provide independent weather routing, passage-planning assistance, and vessel position monitoring.

Summary. Merely having an SMS is not sufficient to prevent catastrophes. It is necessary to have dedicated personnel assigned to provide captains with effective guidance and procedures. Robust training and auditing ensure that guidance and procedures are being followed. DPs should be actively involved in the maintenance of the SMS and should monitor their assigned vessels throughout each voyage.

The NTSB has concluded that the company had an inadequate SMS and an ineffective process for assessing officer performance; that it did not provide effective training for onboard equipment and programs; that it did not ensure that *El Faro* had a functioning anemometer; that it failed to ensure that the risk posed by Hurricane Joaquin was adequately addressed; and that it failed to track the vessel’s position relative to the storm and support the captain during the accident voyage. Had the company addressed some of the safety issues identified in this report, the casualty might not have occurred. Thus, the NTSB concludes that the company’s lack of oversight in critical aspects of safety management, including gaps in training for shipboard operations in severe weather, denoted a weak safety culture in the company and contributed to the sinking of *El Faro*.

2.8.2 Regulatory

Training for Heavy Weather. The *El Faro* captain obtained his master’s credential in 2001. The requirements for assessing competency in heavy-weather operations went into effect in 2002, with Coast Guard National Maritime Center Policy Letter 04-02 (USCG 2002) for new applicants only. The policy did not address masters and chief mates who had received their licenses before 1998 and thus were not subject to the requirements. NVIC 10-14, issued in 2014 (and which superseded the policy letter), extended the requirements to all mariners. However, masters and chief mates credentialed before 2014 were grandfathered under the former policy until December 31, 2016.

As of the date of this report, the Coast Guard has no plans to address this gap in training. Therefore, because of the grandfathering clause, mariners who had obtained their initial credential before 1998 were not, and are still not, required to take an advanced meteorology course approved by the Coast Guard. Thus, the captain was not required to have completed the advanced meteorology and advanced shiphandling courses. As of January 1, 2017, those courses are now a requirement for new applicants. Those who already hold credentials are required to take the courses only if upgrading to a higher license. The same was true for the chief mate on *El Faro*. According to their most recent certificates, none of the bridge officers had attended the advanced meteorology or advanced shiphandling courses.

If the captain had had training in advanced meteorology and advanced shiphandling, he may have made different decisions with respect to storm avoidance. Current Coast Guard training requirements include a grandfathering clause that exempted the captain (and any other mariner credentialed before 1998) from taking a Coast Guard–approved advanced meteorology course. Thus, the NTSB concludes that training in heavy-weather operations, including advanced meteorology and advanced shiphandling, from which the captain was exempt, might have provided him with additional information to consider while evaluating options and might have resulted in a different course of action. The NTSB therefore recommends that the Coast Guard require that all deck officers, at both operational and management levels, take a Coast Guard–approved advanced meteorology course to close the gap for mariners initially credentialed before 1998.

In addition, the NTSB recommends that the Coast Guard publish policy guidance to approved maritime training schools offering management-level training in advanced meteorology, or in an appropriate course, to ensure that the curriculum includes the following topics: characteristics of weather systems including tropical revolving storms; advanced meteorological concepts; importance of sending weather observations; ship maneuvering using advanced simulators in heavy weather; heavy-weather preparations; use of technology to transmit and receive weather forecasts (such as NAVTEX or weather-routing providers); ship-routing services (capabilities and limitations); and launching of lifeboats and liferafts in heavy weather.

The NTSB further recommends that the Coast Guard provide policy guidance to approved maritime training schools offering operational-level training in meteorology to ensure that the curriculum includes the following topics: characteristics of weather systems, weather charting and reporting, importance of sending weather observations, sources of weather information, and interpreting weather forecast products.

Stability Guidance. Stability booklets are required on most ships and are used by the crews to operate vessels in compliance with applicable criteria. It is important that the vessel's stability booklet bring vessel vulnerabilities related to stability to the attention of the ship's officers. When the ship encounters forces that cause unusual angles of heel, such as wind and unintentional flooding, the stability booklet must clearly indicate safe limits and identify hazards to aid officers in decision-making during normal operations and crisis management situations. Discussions between the captain and deck officers on *El Faro*, as captured by VDR audio in the hours before the sinking, indicate that the crew did not have sufficient information about the vessel's downflooding angles—openings that might result in unintentional flooding, and the effect of windheel.[201]

Raising the vessel's load line meant that it sat lower in the water by more than 2 feet, increasing the risk of unintentional flooding through all openings above the waterline, including ventilation ducts and scuttles to the cargo holds. (The ducts and scuttles had not been modified from the vessel's previous configurations.) *El Faro*'s stability booklet did not contain any information on the downflooding angles (heel angle at which an opening reaches the waterline) for the openings or for closures that needed to be made to prevent downflooding through the openings. The importance of the openings as potential downflooding points would have been obscure to the crew for several reasons. First, the stability booklet did not contain guidance about closing the cargo hold ventilation ducts. Second, the vessel's COI required the closures to remain open while under way. Third, the ventilation closures doubled as fire dampers and were tested and operated as such. Fourth, the ventilation closures were labeled on vessel plans and on the closures themselves as fire dampers, not closures.

Investigators believe that wind velocity and windheel information would have helped the *El Faro* captain determine what was causing his vessel to list because he would have an estimate of the wind-driven heel at given wind velocities. His awareness of the extent to which hurricane winds would have heeled his vessel might have influenced his decision to seek an alternate route or a greater closest-point-of-approach to the hurricane. Thus, the NTSB concludes that *El Faro*'s stability booklet should have included downflooding angles and windheel criteria to increase the officers' awareness of the ship's vulnerabilities in heavy weather, such as unintentional flooding and listing.

The guidance and instructions in *El Faro*'s stability booklet complied with current regulations and were little changed from when the vessel originally traded as a Ro/Ro. The Coast Guard NVIC outlining stability information to be included in a stability booklet (NVIC 3-89) provides only guidelines. Coast Guard regulations (46 *CFR* 170.110) contain broad requirements for stability information and other provisions described as "consideration must be given," not as required. Several of the provisions would have provided the *El Faro* officers with critical information during the accident voyage, such as plans showing watertight compartments, closures, vents, downflooding angles, precautions to prevent unintentional flooding, and other necessary guidance for the safe operation of the vessel under normal and emergency conditions. That information was not in *El Faro*'s stability booklet. The stability booklet was developed for TOTE by a naval architecture firm. The classification society reviewed the booklet and the Coast Guard could have as part of its oversight role (though it did not). Thus, the NTSB concludes that neither the Coast Guard nor the classification society adequately assessed the vessel's stability booklet to ensure that it contained critical information detailed in Coast Guard regulations and guidance.

In summary, a more comprehensive stability booklet might have changed the course of events. If the vessel's stability booklet had contained specific information (downflooding angles, ventilation damper closure, the effects of wind [windheel], the wind speed used in calculating required stability, and actions to avoid and consider when flooding and cargo shifting occur), the

[201] Deck officers, such as captains and mates, are the shipboard officers who calculate ship stability.

captain might not have taken the route that brought him close to strong winds or taken the actions that placed the vessel in danger. The Coast Guard provides general guidance in NVIC 3-89 and 46 *CFR* 170.110, but the information listed above is not specified or required. Therefore, the NTSB recommends that the Coast Guard revise 46 *CFR* 170.110 (stability booklet) to require (1) stability instructions, guidance, or data on wind velocity used to calculate weather criteria; (2) list of closures that must be made to prevent unintentional flooding; (3) list of closures that must be made for an opening not to be considered a downflooding point; and (4) righting arm curve (GM) table to note the angle at which initial downflooding occurs; also, add a windheel table for vessel full load displacement or the condition of greatest vulnerability to windheel.

El Faro had flooding in a cargo hold with cars adrift (Ro/Ro cargo) and a sustained starboard windheel. The captain made a course change to put the wind onto the opposite side, intending to switch the list to port. At the same time, he was attempting to correct the list by shifting water between the ramp tanks. Those actions resulted in a rapid shift to a port list.

Coast Guard NVIC 4-77 (*Shifting Weights or Counter Flooding During Emergency Situations*) was developed in response to an accident related to bulk cargo stability. The NVIC encourages captains (masters) to make every effort to determine the cause of a vessel's list before taking corrective action. It also gives specific guidance (regarding shifting weights and counter-ballasting) for vessels carrying bulk cargo.

The *El Faro* accident shows that the guidance in NVIC 4-77 is applicable to Ro/Con cargo ships. Attempts by ship personnel to correct a list (course changes, counter-ballasting) can produce dangerous results if cargo is already adrift. In addition, if wet decks have reduced the friction between Ro/Ro cargo and decks, the risk of lashing failure and subsequent cargo shift increases. NVIC 4-77 would benefit from specific guidance tailored to Ro/Ro or Ro/Con vessels.

Thus, the NTSB concludes that Coast Guard NVIC 4-77 should be revised to include specific guidance regarding the dangers of taking corrective action if Ro/Ro cargo is adrift or the decks are wet. The NTSB therefore recommends that the Coast Guard update the guidance in NVIC 4-77, based on the circumstances of the *El Faro* accident, to include a warning that actions by ship personnel intended to correct a list can produce dangerous results if Ro/Ro cargo is already adrift and water has reduced the coefficients of friction for lashed cargo.

Alternate Compliance Program. Investigators examined the inspection history of *El Faro*, interviewed Coast Guard and ABS staff regarding the vessel's enrollment in the ACP, and reviewed the Coast Guard chief traveling inspector's report on the program. The investigation revealed a number of significant failures in the implementation of the program:

- The Coast Guard lacked resources to complete the reviews of US supplements for ACSs, and Coast Guard marine inspectors and surveyors were either not familiar with the supplements or were using unapproved versions. Thus, gaps between ACS rules, international conventions, and Coast Guard safety regulations could not be identified.
- TOTE (as well as other owners and operators surveyed by Coast Guard traveling inspectors) provided inadequate notice to ABS for planned surveys, and therefore Coast Guard inspectors had little to no notice of those surveys. Joint examinations were rarely conducted.

- Communications between the Coast Guard and ACSs was lacking. The LORACS position required by NVIC 2-95 had been discontinued and duties distributed among several individuals. OCMI offices did not have dedicated ACP officers to coordinate with ACSs for surveys and inspections.
- Shipboard discrepancies and nonconformities found by ACS surveyors were not reported to OCMIs and thus not recorded in Coast Guard databases. Thus, the Coast Guard did not have a record of high-risk vessels enrolled in the ACP program.
- Coast Guard marine inspectors lacked experience and training that would have allowed them to discover discrepancies with enrolled vessels. Vessels that had successfully completed ACS surveys and were later inspected by Coast Guard traveling inspectors were found to have serious safety deficiencies, some resulting in scrapping or no-sail orders. The deficiencies had gone unnoticed during oversight examinations due to the inexperience and inadequate training of field inspectors.
- Coast Guard marine inspectors lacked extensive experience to make proper decisions regarding questionable ACP vessel inspections.
- The Coast Guard has no procedures or authority to assess the performance of the ACS surveyors that are performing inspections on its behalf.
- During Coast Guard annual quality audits of ACSs, Coast Guard personnel attend as observers and are limited in their ability to assess an ACS's performance for compliance to ACP for US-flagged vessels.
- During audits of the documents of compliance and safety management certificates performed by the ACS, the Coast Guard attends only as an observer and has no authority to make findings or nonconformities.
- A lack of guidance, experience, and qualification requirements has degraded the inspection knowledge and experience of Coast Guard marine inspectors.

In 1983, the Coast Guard conducted a Marine Board of Investigation for the capsizing and sinking of the bulk carrier *Marine Electric* (the NTSB also investigated the accident [NTSB 1984]). Although the ACP was not in effect at the time, the Coast Guard had delegated to ABS the authority to survey and assign load line certificates to US-flagged vessels. In its 1984 report, the marine board found that ABS failed to properly conduct surveys on the *Marine Electric*, allowing the vessel to continue in service with significant wastage and insufficient repairs to hatch covers and decks (USCG 1985). It was determined that failures in the hatch covers and decks allowed water to enter the forward holds and eventually sink the ship. Coast Guard inspectors with oversight responsibilities had also failed to detect the problems with the hatch covers and decks.

The marine board concluded that ABS surveys and visits were "oriented toward protecting the best interest of marine insurance writers, and not for the enforcement of Federal safety statutes and regulations." Furthermore, the board concluded that Coast Guard examinations of the vessel before the accident

> were performed by Coast Guard personnel who lacked the experience to conduct safety examinations of a vessel the size, service, and configuration of the MARINE ELECTRIC. The incompleteness of these inspections as to the dictates of regulations and policy was attributed to the lack of training and experience on the part of the Coast Guard inspectors.

Based on its findings in the *Marine Electric* investigation, the marine board recommended that examinations of US commercial vessels should "be conducted and determined by knowledgeable members of a U.S. Government agency. The responsibilities for these functions should not be delegated or entrusted to the private sector." The marine board also called for a commission to conduct an in-depth review of the Coast Guard's commercial vessel safety program, with emphasis on the experience and training of program administrators, program and project managers, OCMIs, and field inspectors.

In response to the marine board's report on the *Marine Electric* accident, the then-Commandant of the Coast Guard rejected the recommendations to cease delegation of responsibilities to third-party organizations and to review the commercial vessel safety program. The commandant stated that "the MARINE ELECTRIC surveys in question were poorly conducted, but the fact does not condemn the entire system of third party delegation which has been authorized and encouraged by Congress." Delegation of authorities did not end. In fact, with the advent of the ACP program in 1995, the practice increased. A review of the commercial vessel safety program was also not conducted because, according to the commandant, "efforts commenced before and after this tragic casualty are already addressing the mentioned issues."

Thirty-two years after the *Marine Electric* accident, Coast Guard and NTSB investigators found similar issues with *El Faro* and other vessels enrolled in the ACP, which revealed that the Coast Guard is not performing sufficient oversight of the ACSs to adhere to federal safety standards and that Coast Guard field inspectors do not have the resources, experience, training, and authority required to perform effective oversight. Thus, based on the evidence, the NTSB concludes that the Coast Guard's ACP is not effective in ensuring that vessels meet the safety standards required by regulations and that many vessels enrolled in the program are likely to be operating in substandard condition.

Accordingly, the NTSB recommends that the Coast Guard conduct a complete review of the ACP program to assess the adequacy and effectiveness of the program. The NTSB further recommends that the Coast Guard review and implement training of Coast Guard inspectors and ACS surveyors to ensure that they are properly qualified and supported to perform effective, accurate, and transparent vessel inspections, meeting all statutory and regulatory requirements. The NTSB further recommends that ABS enhance training of its surveyors to ensure that they are properly qualified and supported to perform effective, accurate, and transparent vessel surveys, meeting all statutory and regulatory requirements.

Major Conversions. The Coast Guard's final determination not to designate the conversion of *El Faro* to a Ro/Con as a major modification appears to have been based on past determinations. However, the conversion resulted in a significant increase in load line draft and new load-on/load-off container capacity. The converted ship lost over 40 percent of its Ro/Ro cargo but gained 1,414 more TEUs of container cargo. The relatively higher position and added weight of the containers raised the vessel's center of gravity, requiring nearly 5,000 long tons of additional fixed ballast that increased the ship's maximum allowable draft by over 2 feet, thereby lowering the unmodified hull openings the same amount.

Load line draft is typically considered a principal dimension of a vessel in naval architecture and marine engineering and can be found under the same title on vessel plans, vessel particulars, and in naval architecture textbooks. Under 46 *USC* 2101(14a), which defines major conversion, the draft increase could have been considered a substantial change in the vessel's dimension. The conversion to carry load-on/load-off containers could be argued to be a change in the type of the vessel, and the carriage of containers could be assumed to prolong the life of the vessel by allowing it to competitively trade in a new service. Thus, the NTSB concludes that the 2005–2006 conversion of *El Faro* to carry load-on/load-off containers and the associated increase in draft should have been designated a major conversion by the Coast Guard. The NTSB therefore recommends that the Coast Guard review and revise the policy for major conversion determinations to consider load line (maximum) draft as a principal vessel dimension.

Lifesaving Appliances. Designating the 2005–2006 conversion as a major conversion would not have affected the stability standards the vessel had to meet (because the applicable standards were the same as in 1993). The OCMI could still have reviewed other systems and possibly required the vessel to meet newer safety standards, such as lifesaving. In 1993, the OCMI did not require *El Faro*'s lifeboats to be updated to closed-type standards because the lifeboats themselves were not modified in the conversion. Rather, the OCMI stated that if the lifeboats were replaced in the future, they would have to meet the standards applicable at the time of replacement.

The same situation prevails today. That is, the OCMI uses the guidance of "reasonable and practicable" when considering whether vessel systems and equipment must comply with the standards current at the time of modification. Therefore, there is no objective guidance for lifesaving appliances to comply with current standards on the date vessels undergo a Coast Guard–designated "major modification." In addition, existing vessels that have not undergone a major modification might be in service for decades without their safety and lifesaving appliances ever being reviewed—even to the "reasonable and practicable" standard.

Advances in lifesaving appliances increase the safety and survivability of crewmembers. Those advancements are incorporated in newer standards, such as those for enclosed lifeboats. All vessel crews should be afforded modern lifesaving equipment on board their vessels. The NTSB believes that vessel owners and operators who choose to repower, modify, convert, or make significant repairs to their vessels should not be placed at a competitive disadvantage (compared with owner/operators who do not modify their vessels) by being required to replace existing lifesaving appliances during designated major conversions. Thus, the NTSB concludes that for inspected vessels in coastal, Great Lakes, or ocean service, having their lifesaving appliances regularly reviewed for compliance with current standards would improve crew survivability.

The average life of international merchant ships varies by ship type but is roughly 20 to 30 years. *El Faro* was 40 years old. Open lifeboats were superseded by closed lifeboats about 30 years before the sinking. SOLAS currently requires vessels to be drydocked twice in a 5-year period. A multiple of 5 years, or another interval coinciding with significant regulatory or class examinations, could be a practicable method of reviewing and upgrading lifesaving appliances to new standards. Considering the average service life of vessels, a maximum 20-year interval for upgrading lifesaving appliances is reasonable. Therefore, the NTSB recommends that the Coast Guard, at regular intervals, not to exceed 20 years, review all lifesaving appliances on inspected vessels that are required by 46 *CFR* Part 199, and require compliance with current standards.

2.9 Contributing to Loss of Life

Hours before *El Faro* sank, it developed a starboard list (heel) from the wind and weather. At 0545, the engineer supervising the riding gang and the chief mate reported that *El Faro* was in danger, with uncontrolled flooding and cargo (cars) adrift in hold 3. The reports should have prompted the captain to take immediate action, including sounding the general alarm and notifying the DP ashore of the vessel's condition. Sounding the general alarm would have woken and mustered the crew, providing additional resources to assist the chief mate in investigating and potentially locating and controlling the sources of flooding.

At 0554 the morning of the accident, the captain turned the vessel to port, after discussing with the chief engineer problems with the oil levels in the engine room machinery, and put the wind on their starboard side to shift the list to port. It appears that the captain believed that shifting the list to port would allow them to identify the source of the flooding on the starboard side. The shift of the list to port eventually resulted in a loss of lubrication oil pressure and a main engine shutdown (loss of propulsion) at 0613 near the Category 3 hurricane's center. The lubrication system that caused the engine shutdown was designed to operate with up to 15° of list and 5° of trim, suggesting that *El Faro*'s port list had exceeded 15°.

El Faro's main propulsion could not be regained because of the list. The loss of propulsion, placing the vessel at the mercy of increasing hurricane-force winds and seas, should have been a clear indicator to the captain to sound the general alarm, yet he did not. Not until 12 minutes before the sinking did the captain sound the general alarm to muster the crew, despite obvious signs that the ship was in extremis. He did not order abandon ship until 10 minutes before the ship sank.

The captain had sufficient information regarding the ship's perilous condition, and sounding the general alarm much earlier, when flooding intensified in hold 3, would have been prudent. Failing that, the loss of propulsion should have spurred him to muster the crew. The captain clearly held to the conventional wisdom that the vessel provided the best shelter from the elements and should only have been abandoned when it became apparent that it was no longer seaworthy. However, by the time the captain finally recognized that the vessel was no longer seaworthy, it was too late for the crew to successfully abandon ship. Thus, the NTSB concludes that the captain's decision to muster the crew and abandon ship was late and may have reduced the crew's chances of survival.

El Faro's open lifeboats were in compliance with the lifeboat standards in force when the vessel was delivered in 1975. Specifically, the vessel carried two open lifeboats, one motor-propelled and the other manually propelled, that were capable of being launched with a list of up to 15° and a trim of up to 10°.

Marine regulators recognized in the early 1980s that open lifeboats did not provide adequate protection to the occupants and needed to be phased out. Standards were updated accordingly. Open lifeboats and manually propelled lifeboats were not allowed on oceangoing vessels delivered after 1986. However, vessels delivered before that time could still carry lifeboats that adhered to the previous standards as long as they were maintained in adequate condition.

Current US and SOLAS regulations require enclosed lifeboats to be powered by a compression ignition engine. Modern enclosed lifeboats can be launched with a list of up to 20°; can be boarded and launched directly from the stowed position; have added reserve buoyancy when watertight doors, hatches, and ports are closed; and protect the occupants from exposure.

Half of all US-inspected oceangoing vessels currently in service (152, or 49 percent) were delivered before 1986 and have onboard side-launched open lifeboats. The remaining vessels were delivered after 1986 and have enclosed lifeboats in either side-launched (110, or 35 percent) or freefall-launched (49, or 16 percent) configurations. Thus, roughly half of US-inspected oceangoing vessels are equipped with lifesaving appliances that have been considered insufficient for over 30 years. Stern-launched freefall lifeboats provide additional safety benefits above even side-launched enclosed lifeboats in that they can be launched by one person, that once launched they separate themselves from the vessel, and that they are free from the limitations of fall wires for launching. Thus, the NTSB concludes that survivability would be increased if new cargo vessels were equipped with stern-launched freefall lifeboats, where practical.

When an existing vessel undergoes a major modification, it provides the Coast Guard with the opportunity to bring that vessel's systems and equipment into line with the latest safety standards, if determined reasonable and practicable. When *El Faro* was lengthened in 1993, the Coast Guard determined that it was a major modification, but the owner was not required to upgrade its lifeboats.

When the captain ordered abandon ship at 0729 the morning of the accident, the ship was most likely listing more than 15°, based on VDR audio statements and the fact that lube oil pressure had been lost. Thus, the vessel's list exceeded the capabilities of the lifeboat-launching equipment, and a successful launch was unlikely. The hurricane-force winds and seas would have made a successful launch even less likely. Further, because the captain instructed the crew to prepare liferafts when the order to abandon ship was given, it appears that he realized launching the lifeboats was impractical (either because they were outside launching parameters or because they would not provide adequate protection).

During the investigation, the lifeboat manufacturer's representative testified that there has been no known successful launching of a lifeboat or liferaft with survivors under hurricane conditions with winds of over 96 knots. Photo evidence of *El Faro*'s port and starboard lifeboats and their associated davits suggests that neither was successfully launched. Even if successfully launched, the lifeboats would have provided little protection from the hurricane-force winds and seas. Thus, based on the evidence, the NTSB concludes that the severe weather, combined with *El Faro*'s list, made it unlikely that the lifeboats could be boarded or launched. The NTSB further concludes that the vessel's open lifeboats would not have provided adequate protection even if they had been launched.

Modern enclosed lifeboats enhance survivability compared with the open lifeboats carried by *El Faro*. It is possible that some of the crew of *El Faro* would have survived if the vessel had been outfitted with modern enclosed lifeboats. Thus, the NTSB concludes that survivability would be increased if open lifeboats on all vessels remaining in service were replaced with enclosed lifeboats that adhered to the latest safety standards. Therefore, the NTSB recommends that the Coast Guard require that open lifeboats on all US-inspected vessels be replaced with enclosed lifeboats that meet current regulatory standards and freefall lifeboats, where practicable.

El Faro had four 25-person liferafts stowed in pairs just aft of each lifeboat and a 6-person liferaft stowed forward. The liferafts were designed to be manually launched. To do so, crewmembers would have had to traverse the weather decks of the listing *El Faro* in hurricane-force winds, tie off the liferaft painters to the ship, lift each encapsulated liferaft (weighing 380 or 406 pounds) from its stowage cradle and throw it overboard, then inflate the liferafts by pulling on the painter, jump into the water, and finally board the liferaft. If the crew could not manually launch the liferafts, the rafts were designed to automatically inflate when the vessel sank.

No matter how the liferafts were launched, any crewmembers who survived the sinking would have had to swim to the liferafts and board them under the prevailing conditions. An hour and a half before the order came to abandon ship, the Ocean Prediction Center had reported winds in the area of 105 knots sustained, with gusts up to 130 knots and seas reaching 36 feet. Also, postaccident examination of *El Faro*'s superstructure showed multiple deep cuts and battered metal, most likely from floating containers that hit the superstructure before the vessel sank. Any crewmembers in the water would have had to swim to an inflated liferaft through the wind-swept, floating containers, mountainous seas, and unbreathable wind-driven sea foam before boarding a liferaft. Thus, the NTSB concludes that the severe weather, combined with *El Faro*'s list, made it unlikely that the liferafts could be launched manually or boarded by crewmembers once in the water.

According to the National Hurricane Center's poststorm report, at the time of the sinking on October 1, Joaquin was a Category 3 hurricane (a major hurricane) with 110-knot winds. Twenty minutes after the sinking, Joaquin was upgraded to a Category 4 hurricane with 115-knot winds. The storm remained near the Bahamas through October 2. On October 3, the hurricane accelerated northeastward away from the Bahamas and reintensified, reaching a peak intensity of around 135 knots, just below Category 5 strength (winds 137 knots and higher).

At the request of Coast Guard D7CC, an Air Force hurricane hunter aircraft flew over *El Faro*'s last known position less than 3 hours after the sinking, made radio callouts on VHF channel 16, and conducted a radar search. However, the aircraft was unable to descend below 10,000 feet because of the storm, and radar detection was ineffective due to excessive feedback from heavy precipitation. The nearest vessel to *El Faro*, the inter-island freighter *Emerald Express*, was unable to assist in the search for *El Faro* because it was sheltering from the storm in the lee of Acklins and Crooked Island. On October 2, a Coast Guard HC-130 aircraft tasked with searching for *El Faro* could not get within 100 miles of the hurricane because of severe winds at 3,000 feet altitude. The flight crew reported visibility of 2 miles, heavy rain and spray, and heavy seas with whitecaps and foam. The aircraft was damaged by the severe weather, prompting cancellation of the second sortie of the day.

During the first 2 days, D7CC positioned surface and air assets behind the storm, but search-and-rescue efforts did not fully begin until Hurricane Joaquin moved away from the area on October 3. Beginning at sunrise on October 3 and ending at sunset on October 7, altogether 50 air and surface sorties were conducted, with over 274 hours of active searching for *El Faro* and survivors. Fifteen different Coast Guard, Air Force, and Navy search-and-rescue assets searched 195,601 square miles. Thus, the NTSB concludes that search-and-rescue efforts were carried out as effectively as possible given the extreme weather conditions in the days following the accident.

An accurate position of a vessel in distress is critical to ensuring that search-and-rescue assets can reach the vessel in time to rescue people or prevent environmental damage. The distress message that was sent from *El Faro* via Inmarsat-C and relayed to the Coast Guard's rescue coordination center in Norfolk, Virginia, gave the vessel's position as 23.28N, 73.48W. (As written in traditional format, the position was 23°28′N, 73°48′W.) Inmarsat-C formatting, however, uses a period (full stop) to separate the degrees and minutes in a vessel's latitude and longitude.

When the Inmarsat-C position (23.28N, 73.48W) was entered into the Coast Guard's SAROPS program, the period was misinterpreted as a decimal point, with the numbers after the point being read as tenths and hundredths of a degree. SAROPS then erroneously converted the position to degrees and decimal minutes—23-16.800N, 073-28.800W. (The Coast Guard format for latitude/longitude uses a hyphen to separate degrees from minutes.) The SAROPS position had an error of 23 nm compared with the last known position of *El Faro*, and as a result D7CC launched its search for *El Faro* and survivors at a distance from the accident site. Thus, the NTSB concludes that because of differences in latitude and longitude formatting between Inmarsat-C and the Coast Guard's SAROPS, the last known position of *El Faro* according to SAROPS was 23 nm from the actual position.

In addition to the differences between Coast Guard and Inmarsat-C formatting, the SSAS used yet another format, separating degrees and minutes of latitude and longitude with a colon and expressing minutes as a decimal. The SSAS position for *El Faro* sent to the Coast Guard was thus 23:25.39N, 073:52.51W. The different formats that can be used to express the same latitude and longitude are shown in the hypothetical example below (seconds are used in the traditional format to further illustrate the differences, and the decimal format used throughout this report is added for comparison):

Traditional (deg, min, sec)	23°28′15″N, 73°48′30″W
Inmarsat-C	23.28N, 73.48W
SSAS	23:28.25N, 73:48.5W
Coast Guard	23-28.25N, 73-48.5W
Decimal degrees	23.47N, 73.80W

The differences between location formats can create confusion. Although the error in the last known position did not ultimately affect the outcome of the *El Faro* search-and-rescue efforts, it highlights the potential that similar errors could hinder future time-critical search-and-rescue operations. Thus, the NTSB concludes that although position errors did not affect the outcome of search-and-rescue efforts after *El Faro* sank, position information should adhere to a standardized format to eliminate similar errors in future accidents. Therefore, to prevent future errors in converting position data such as occurred in the *El Faro* accident, the NTSB recommends that the Coast Guard work with manufacturers of GMDSS equipment, communication providers, and land earth stations to remove ambiguity from the Inmarsat-C distress alert position reports.

EPIRBs are designed to save lives by automatically alerting rescue authorities and indicating the location of a vessel in distress. A category I 406-MHz EPIRB is float-free, automatically activated, and detectable by satellite anywhere in the world. The EPIRB's digital code indicates the identity of the vessel to search-and-rescue authorities, who can refer to a registration database to find vessel information, vessel contact information, and the 24-hour emergency contact's information.

El Faro was equipped with a non-GPS-enabled EPIRB. The EPIRB was detected at 0736 on October 1 by a geostationary satellite, and a "406 beacon unlocated first alert" was sent to the Coast Guard D7CC at 0739. The position of a non-GPS-enabled EPIRB can, however, be determined to within about 2 miles by low earth orbit satellites, which travel about 1,200 miles above the earth. According to SARSAT, no low earth orbit satellites were in view of *El Faro*'s position during the 24 minutes the EPIRB was transmitting. The EPIRB stopped transmitting 6 minutes before a low earth orbit satellite passed in view of where the EPIRB had been transmitting. Therefore, no position could be derived from the low earth orbit satellite system. The ship's EPIRB was designed to transmit a signal for 48 hours. Why its transmissions stopped after only 24 minutes is unknown.

The position transmitted by a GPS-encoded EPIRB, available since 1998, is accurate to under 100 yards on the first transmission. Had *El Faro* been carrying that type of EPIRB, it is likely that a position would have been transmitted on activation. A previous accident investigated by the NTSB, the sinking of the commercial fishing vessel *Lady Mary* on March 24, 2009, which resulted in six fatalities, also involved a non-GPS-enabled EPIRB. The NTSB determined that the inability of the EPIRB to transmit position data following activation contributed to a delay in the dispatch of rescue assets. Accordingly, the NTSB recommended that the FCC mandate that, for commercial vessels required to carry 406-MHz EPIRBs, those EPIRBs broadcast vessel position data when activated (Safety Recommendation M-10-1).

In September 2016, the FCC amended 47 *CFR* 80.1061(a) to require that EPIRBs meet Radio Technical Commission for Maritime Services standard 11000, which includes the capability of EPIRBs to provide position data on activation. This change implements the NTSB recommendation, but the new requirement does not come into effect for new EPIRBs until January 2018, and EPIRBs currently in service that do not meet the standard will be allowed to remain in service until January 2023. Thus, given the impact to the search-and-rescue efforts in the *El Faro* and *Lady Mary* accidents and the potential to affect future search-and-rescue operations, the NTSB concludes that the use of older EPIRBs such as the one on *El Faro* that do not transmit GPS positions reduces positional accuracy in search-and-rescue operations. Therefore, the NTSB recommends that the FCC require that all US vessels required to carry 406-MHz EPIRBs immediately discontinue the use of EPIRBs that are not GPS enabled.

The probability of survival after a sinking depends on weather and sea conditions and the availability of lifesaving gear such as immersion suits and liferafts. However, the probability of survival decreases exponentially over time as the threat of hypothermia and drowning increases. Further, as time progresses, the search for and rescue of survivors becomes more difficult as those adrift in the seas may become separated because of winds and currents. The major debris fields for *El Faro* were separated by 77 nm, with immersion suits and a liferaft found between the two fields.

In another accident the NTSB investigated, the abandonment of the weather-damaged liftboat *Trinity II* in 2011, all 10 crewmembers successfully escaped the vessel and clung to a lifefloat, but they were not found until 3 days later (NTSB 2013a). The survivors were found about 150 miles northeast of the accident site, and four of the crewmembers died from the effects of exhaustion and hypothermia. This case demonstrates that early detection and rescue are critical to the chances of survival.

The 406-MHz personal locator beacon is a portable unit that operates like an EPIRB. The device is designed to be carried by a person and is registered through NOAA to a person (not a vessel or aircraft). The personal locator beacon is activated manually and operates on 406 MHz to get an accuracy of within 3 miles using the 406-MHz satellite system. The device also has a low-power homing beacon that transmits on 121.5-MHz frequency. Newer models allow GPS input to the distress signal to achieve an accuracy of about 300 feet. Personal locator beacons are not required at sea, but several manufacturers offer marine models costing between $300 and $400.

A personal locator beacon can be assigned to crewmembers by billet number while aboard a vessel in the same manner as other safety gear such as lifejackets and immersion suits. Three days after the sinking, on October 4, searchers spotted the remains of one *El Faro* crewmember in an immersion suit. It is not clear when the crewmember perished, or whether any other crewmembers were able to abandon ship. But had that crewmember, or any others who were able to evacuate, been equipped with a personal locator beacon, the device would have provided essential information to focus rescue efforts. Given the wide availability and relatively low cost of personal locator beacons, the NTSB concludes that providing all persons employed on board vessels in coastal, Great Lakes, and ocean service with personal locator beacons would enhance their chances of survival. Therefore, the NTSB recommends that the Coast Guard require that all personnel employed on vessels in coastal, Great Lakes, and ocean service be provided with a personal locator beacon to enhance their chances of survival.

2.10 Other Issues

2.10.1 VDRs

The sound quality of *El Faro*'s VDR bridge audio recording was poor. Of the approximately 61,300 words in the VDR transcription, the audio transcription group detected 1,792 individual words that were unintelligible and unable to be transcribed, and the group could not unanimously agree on 827 other phrases or words. Table 13 shows that the recorded audio quality of all channels on board the bridge varied from poor to unusable.

The transcript was prepared primarily from channels M1 and M2, because the other channels were either of unusable quality or inactive. Each channel of audio (M1, M2, and M3) recorded two microphone inputs. The two inputs were mixed into each channel in the VDR electronics cabinet on the bridge. The cabinet mixed the two microphones on each channel into a single mono track. Using a monaural channel to record two independent inputs does not allow for isolation of individual microphones during audio postprocessing. Because individual microphones cannot be isolated, poor performance or a “noisy” recording from a single microphone can cause irreparable damage to a recorded monaural audio channel. In this manner, a poorly performing microphone or loud noises next to an individual microphone will cause the overall audio quality to be degraded across a monaural audio channel. If an introduced noise is present near one bridge-mounted unit, the audio from a different area of the ship's bridge can become degraded or unusable.

Table 13. Audio quality and channel description.

Source Microphone	Location	Channel	Quality
BMU 1A; BMU 1B	Bridge center; bridge starboard	M1	Poor
BMU 2A; BMU 2B	Chart table; bridge port	M2	Poor
BMU 3A; BMU 3B	Port bridge wing; starboard bridge wing	M3	Unusable
VHF 1	Unknown VHF source	V4	Inactive
AUD 4	N/A - Unused	M5	Crossover

For example, the placement of the bridge-mounted microphones in relation to other hardware on *El Faro*'s bridge affected the quality of the audio recording. Specifically, microphone BMU 2A, mounted near the chart table, repeatedly captured noise pollution from a metal curtain rail that hung in the area. The continual sound of metal chafing of the curtain rod hangers on the metal curtain track affected the audio transcription group's ability to discern what was being said near that microphone during critical moments of the voyage.

The chafing sound was initially correlated with crewmembers entering the chart table area and manipulating the curtain to gain access to the table. The chafing sound also correlated with the crew's comments about *El Faro* rolling in rough seas during the voyage. As the weather deteriorated further, the nature of the metal chafing sound increased in frequency, duration, and intensity. During the final transcribed portion, the chafing sound persisted, and many crew conversations were drowned out by the sound of the metal curtain track. Thus, the NTSB concludes that the poor audio quality and poor placement of the VDR microphones aboard *El Faro* inadequately recorded conversations on the navigation bridge, which impeded investigators' ability to accurately transcribe the recording.

Microphone installations that record audio of poor or unusable quality restrict the ability of investigative authorities to review audible activity on the bridge. Performance testing of the bridge audio and downloads of related VDR data typically occur while a ship is pierside, not while it is under way using its main propulsion. Performing such a test pierside does not simulate realistic conditions on the ship's bridge while under way.

The current standard applicable to VDRs on new ships (since July 2014) states that a performance test of VDR microphones be such that "a normal speaking voice should provide adequate intelligibility while the ship is performing its normal operations." According to IMO resolution MSC.333(90), 5.5.5:

> Microphones should be positioned on the bridge covering all work stations as described in MSC/Circ. 982 so that conversation is recorded. The recording should be such that, on playback, a normal speaking voice should provide adequate intelligibility while the ship is performing its normal operations. This performance should be maintained at all work stations while there is a single audio alarm anywhere on the bridge or any noise, including noise from faulty equipment or mounting, or wind. This should be achieved through the use of at least two channels of audio recording. Microphones positioned outside on bridge wings should be recorded on at least one additional separate channel.

Although IMO resolution MSC.333(90), 5.5.5, clearly identifies potential sources of noise pollution that could interfere with a VDR's audio recording, the resolution does not define how performance testing should be conducted other than that it should be done during "normal operations." The IMO does not define "normal operations." However, it would be reasonable to expect that it would mean when a ship is under way using its main propulsion unit. Thus, the NTSB concludes that the most effective performance testing of VDR audio quality would take place while the ship is under way using its main source of propulsion.

In addition, during the accident voyage, critical voice exchanges took place over the telephone between the officers on *El Faro*'s bridge and crewmembers in other locations on the ship. However, the IMO does not require a VDR to capture both sides of internal phone calls, and as designed, the VDR recorded only the bridge officers' side of the conversations. As a result, investigators could not hear what personnel in the engine room were communicating to the bridge. Once *El Faro* encountered rough seas and began flooding and listing, the frequency of calls from other areas of the ship to the bridge increased, and the calls continued until the sinking. However, because only the bridge side of the phone conversations was recorded, the VDR missed potentially critical information concerning safety and the ship's status that was exchanged between the bridge officers and the engineering crew. In phone calls to the bridge, the captain commonly responded "yeah" or "okay," which left investigators with few details regarding the conversations. Thus, the NTSB concludes that *El Faro*'s VDR system was not configured or required to capture both sides of internal phone calls, which prevented investigators from hearing the engineering officers' communications with the bridge.

In addition, channel V4 for the VDR's hardwired VHF was inactive. During the voyage, the ship's VHF radio was used by the *El Faro* bridge crew; however, inactive VDR channel V4 did not record those VHF communications. Instead, investigators had to transcribe the VHF communications through ambient noise from an open speaker system recorded to VDR channels M1 and M2.

Investigators found that VDR channel V4's signal trace was a flat signal with minimal interference. The presence of the flat signal suggests that VDR channel 4 recorded an unpowered VHF radio signal. It is possible that the bridge crew used another VHF radio than the one being recorded by the VDR. Thus, the NTSB concludes that to ensure optimum sound quality for accident investigation, it is vital that all VHF radios used for ship operations be recorded by individual inputs on the ship's VDR.

During *El Faro*'s most recent VDR annual performance test (in December 2014), the battery on the acoustic locator beacon was still current. However, although the form the VDR technician completed during the performance test indicated that the battery would expire that next spring (May 2015), the technician did not replace the battery. Moreover, no actions were taken to ensure that the battery was replaced later (before or by the expiration date).

When investigators arrived at the site of the *El Faro* sinking on October 23, 2015, and began listening for the sound of the VDR locator beacon, they did not know that the battery had expired nearly 4 months earlier. Investigators had requested VDR service records from the manufacturer, Northrop Grumman Sperry Marine, which included the battery's expiration date, but they did not receive the service records until November 12, 2015. After a few days on site with no sound detected from the locator beacon, it became clear that the wreck of *El Faro* would not be found by listening for the locator beacon. Instead, investigators deployed sidescan sonar to try to locate the wreck.

VDR manufacturers are not required to demonstrate performance on expired locator beacons, and empirical data on the performance of such beacons are not available. Thus, the NTSB concludes that the annual performance test for *El Faro*'s VDR was inadequate because the technician did not replace the locator beacon's battery even though it would expire before the next performance test. The NTSB further concludes that the postaccident recovery of *El Faro*'s VDR was greatly hampered because the battery had expired about 4 months before the sinking and the beacon was silent during the search.

Therefore, the NTSB recommends that the Coast Guard modify guidance and training for marine inspectors to ensure that VDR annual performance tests include the replacement of locator beacons prior to expiration and that audio used to evaluate quality is recorded while a ship is under way using its main propulsion unit. The NTSB further recommends that the Coast Guard propose to the IMO to amend resolution MSC.333(90) to specify that "normal operations" are defined as when a ship is under way using its main propulsion unit and to assess VDR problems, including not capturing both sides of internal phone calls on the bridge electric telephone and unrecorded VHF communications, and identify steps to remedy them.

2.10.2 GMDSS Position Safety Alert—FELCOM

The Furuno FELCOM 15 terminal that the *El Faro* bridge crew used to transmit the Inmarsat-C distress alert had an interface that did not automatically update the ship's position report once crewmembers had manually entered a position at any time during the power cycle. About an hour before the sinking, in preparation to send a distress alert, the second mate entered the ship's present GPS position. (Note that she entered the position incorrectly.) However, she did not send the distress alert until about 0713, when the captain approved her doing so. The software was not designed to ask a user whether the position entered earlier should be updated before sending a distress alert (the ship would have moved since the position was originally entered). Moreover, the software was not designed to detect and correct the second mate's error in entering the ship's position by sending the ship's actual position. Thus, the NTSB concludes that the design of the GMDSS equipment used on *El Faro* allows erroneous ship positions to be sent in emergency alerts. The NTSB therefore recommends that Furuno Electric Company, Ltd., update its GMDSS software to detect and correct user errors when entering ship positions using GPS.

Moreover, Inmarsat-C records GPS positions in an ambiguous format allowing for misinterpretation of degrees and minutes as decimal degrees. In fact, recent investigations showed that because of such ambiguous formats, the Coast Guard misinterpreted the ship positions of both *El Faro* and the fish-processing vessel *Alaska Juris* (which sank in the Bering Sea in July 2016) in Inmarsat-C distress alerts (NTSB 2017a). Although the Coast Guard's misinterpretation of the GPS positions for the *El Faro* distress alert did not play a role in the search-and-rescue effort, the NTSB is concerned that the originally reported ship position (even though it contained a GPS error entered by the second mate) was 23 nm away from the location where the Coast Guard subsequently interpreted the ship to be.

2.10.3 Ship Reporting of Weather Information Using AIS

In situ collection and near real-time dissemination of meteorological and oceanographic data is vital to support global meteorological authorities who aim to produce the best possible weather forecasts and advisories to keep mariners safe. However, although surface-based data collection networks on land are geographically extensive and, in many cases, provide good temporal coverage, no such network exists over the world's oceans, despite their covering 71 percent of the earth's surface. Satellites retrieve valuable data from the ocean surface; however, there are limitations. For example, there are large areas of the world's oceans from which meteorologists receive limited or no satellite weather data. Moreover, according to the National Weather Service's Voluntary Observing Ship program—which recruits vessels to take, record, and disseminate weather observations at sea—satellite information is best when used together with other data sources.

In addition, forecasting can be challenging and awareness of current conditions limited even when extensive technologies, such as satellite data, are available. Weather observations by ships could provide crucial, in situ weather information to mitigate such challenges. The Ocean Prediction Center (a division of the National Weather Service) gave a recent example of the upgrading of an existing gale warning to a hurricane warning based on one weather report from a ship that encountered 70-knot winds southeast of Newfoundland. Although that particular storm structure had initially looked impressive in satellite imagery, Ocean Prediction Center forecasters had not expected hurricane-force winds at that time of year. The in situ report from the one ship provided critical evidence to the contrary.

Another recent example involved a ship that was traveling off the US East Coast when it encountered winds of more than 100 knots despite the weather forecast having predicted only 65-knot winds. Had the incident not occurred and the vessel's VDR information not been retrieved, meteorologists might never have known that such severe weather conditions actually occurred that day. During the event, the bridge crew did not send manual, conventional weather reports because they were busy responding to the developing situation, and the ship's AIS was not calibrated to automatically send weather reports. Nevertheless, other vessels in the region—especially those headed toward the storm—could have greatly benefited from such a real-time, in situ warning.

According to the Joint World Meteorological Organization/Intergovernmental Oceanographic Commission Technical Commission for Oceanography and Marine Meteorology, only a fraction of the number of ships that could provide regular weather reports actually do so.

Globally, about 2,000 to 2,500 ships are considered active participants in weather reporting, and the reports may be as infrequent as every 6 months. Most of the ships provide manual, conventional reporting, which requires crewmembers to compile and report the data. The remainder use automated weather systems to provide weather reports; globally, only about 13 to 16 percent of ships use automated weather systems for weather reporting.[202]

Meteorologically, ships can provide critical ground truth for buoys and satellite data. In addition, weather observations from vessels can be assimilated into global weather models, which provide key guidance to all weather forecasters. According to the National Weather Service's Environmental Modeling Center, the most important parameters that vessels can provide for weather modeling are barometric pressure and sea-surface temperature.[203] Pressure is important in part because it yields information about the entire column of the atmosphere, and knowledge of sea-surface temperature is critical because the models must try to resolve the complex air–sea interaction that occurs over water. In addition, both air temperature and wave height information can be useful, particularly in regions with limited or biased satellite coverage (such as coastal areas and high latitudes). Vessels whose drafts are 10 meters (33 feet) or greater and that can be outfitted with water-temperature sensors down the submerged portion of their hull could also provide important water-temperature data below the sea surface.

Also, according to the Environmental Modeling Center, observations from vessels are an important input for weather models because they provide data from locations that satellites might not cover for extended periods. Such a situation can occur, for example, when prolonged cloud coverage exists over a region, prohibiting satellite retrieval of sea-surface temperature. A 2003 paper in the *Bulletin of the American Meteorological Society* highlighted model performance issues with the forecasting of cyclones off the East Coast of the United States (Thiébaux et al. 2003). The paper identified that, during their development, cyclones are sensitive to sea-surface temperature and that persistent regional cloudiness can hamper satellite-only retrieval of sea-surface temperature. Further, ship reports of meteorological data can be beneficial in regions that can pose problems for space-based remote sensing (as within several kilometers of coastlines).

Ships providing a continuous stream of real-time marine data would enhance both awareness of current conditions and forecasting or early-warning tools, benefiting not only the marine industry but also other public and private entities across the globe. In October 1998, the 282-foot-long schooner *Fantome* sank in the waters north of Honduras while encountering Hurricane Mitch. All 31 people on board were lost. At the time, Mitch was the strongest hurricane on record for the month of October and one of the deadliest Atlantic tropical cyclones in history.

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[202] The term *automated weather systems* in this report refers to onboard vessel systems that collect and automatically disseminate (without human involvement) weather information to external users. Automated weather systems allow more frequent observations (compared with manual observations); also, because the instrumentation is usually calibrated and more aptly quality-controlled at the source, data quality is overall good. Another positive aspect of automated weather systems is that most countries that implement the systems use standardized instrumentation or algorithms and are moving toward standard best practices on instrument standards globally. According to the National Weather Service, Europe is implementing autonomous (or stand-alone) automated weather systems, whereas the United States has not done so. In the United States, only vessels with integrated automated systems, or ships that have on-site, self-developed automated systems, contribute hourly reports.

[203] This report defines *sea surface* as the top 20 centimeters of the ocean.

The National Hurricane Center's poststorm report cited that even the most reliable weather models had a "persistent northwest bias" with regard to the storm's forecast track (Guiney and Lawrence 1999). But instead, the storm moved westward and southward, and the predicted turn toward the northwest did not happen until after the hurricane moved across Honduras and Nicaragua. Limited local weather observations (such as lack of information about barometric pressure and humidity levels—data that ships could provide) contributed to the difficulty in forecasting for Mitch.

The NTSB believes that the already widespread and mandatory use of AIS by vessels around the globe and the fact that AIS is already engineered to support the transfer of meteorological data via predefined messages (discussed further below) establishes AIS as a suitable means to report weather observations, in near real time, from ships at sea to global meteorological authorities and other vessels. AIS-equipped fleetwide dissemination of automated (and also manually obtained) meteorological and oceanographic data could ensure that global meteorological authorities have much-enhanced access to near real-time weather data at a high temporal resolution from an extensive global network of ships. As a National Hurricane Center branch chief stated during the *El Faro* marine board hearings, "No meteorologist would ever turn down more observations." Thus, the NTSB concludes that increased reporting and improved transmission of meteorological and oceanographic data from vessels at sea would significantly improve the availability of vital information to enhance weather awareness, forecasting, and advisory services aimed at improving mariner safety.

To make sure that the most significant benefits are realized, automated weather service on board AIS-equipped vessels must be able to communicate its data to the AIS system in a format that can be translated into a predefined AIS message. Currently, a commercially available off-the-shelf solution with a standard interface between weather equipment and existing AIS equipment is unavailable, primarily due to lack of a single preferred application-specific message (ASM) format for meteorological and oceanographic data. Further, consideration must be given to the quality of data currently provided by automated instrumentation on board vessels, for example, the proper placement and calibration of equipment to measure wind speeds and sea-surface temperatures. Whenever a ship is outfitted with such equipment, standards established by the International Organization for Standardization should be used.

In addition, manual observations must be able to be entered into the system that can translate the information to AIS for dissemination via the proper predefined message. Because certain weather parameters that are useful to global meteorological authorities can be observed only by humans despite onboard instrumentation, the ability to manually report via AIS must be recognized; it is also important that mariners are able to augment automated reporting.[204]

From its inception, AIS was designed to adapt to future needs by establishing a robust framework to facilitate effective communications of short messages in standardized formats. Formats for ASM have been established to transmit, for example, virtual navigation aids, lock

[204] The parameters observable only by humans include sea state (period and height), visibility, ice accretion, and cloud cover. The NTSB recognizes that human augmentation of high-frequency automated weather reporting would not be feasible; however, the *ability* to correct or supplement automated observations in AIS transmissions to alert recipients to suspect weather information (biases, instrument issues, etc.) is important.

orders, meteorological and oceanographic data, and more.[205] IMO SN.1/Circ. 289 defines standard data formats for selected AIS ASM, recommended for broad international use. Included in SN.1/Circ. 289 are messages for "weather observation report from ship" and "WMO [World Meteorological Organization] weather observation report from ship," which contain all parameters typically reported by voluntary observing ships.

Benefits of using AIS ASM to automatically disseminate meteorological and oceanographic ship reports include reduced crew workload, reduced potential for error resulting from approximated times of observation and inaccurate position determination, and minimized operator costs.[206] In fact, when the second mate on board *El Faro* prepared and sent a weather report the day before the sinking, she entered an incorrect vessel position.[207] Automated weather reporting through AIS would eliminate such errors.[208]

Any proposed solution for improved weather reporting from vessels at sea by ASM should ensure timely inclusion of data from as many vessels as is practicable into the Global Telecommunication System and should consider adaptive scaling of weather report transmissions in areas of heavy AIS traffic (where fewer AIS slots may be available) to prevent system overload. Additionally, a single ASM format should be defined to ensure standardization for disseminating meteorological and oceanographic data from ships.

Although AIS appears to be the most suitable technology for significantly improving the quantity of weather observations from vessels at sea, the NTSB is unaware of any trials that have been conducted with AIS to specifically establish the viability of transferring weather information via AIS predefined messages from vessels at sea, by way of land stations and space-borne satellites, to meteorological authorities in real time (or near real time). Such a trial could also establish what environmental parameters, formats, and metadata available from vessels are the most critical and could ensure that processing of such data by meteorological authorities after AIS relay is feasible. Thus, the NTSB concludes that because of the significant benefit that AIS could provide in improving the quantity of weather reports from ships globally, a "proof-of-concept" project is warranted to establish its viability. The NTSB therefore recommends that NOAA coordinate with the National Weather Service, vessel operators, AIS service providers, and required onboard technology vendors to perform a "proof-of-concept" project to establish whether AIS, or another suitable alternative, can practically deliver, in a single message (1) meteorological

[205] The International Association of Marine Aids to Navigation and Lighthouse Authorities maintains a list of all existing ASM. See www.iala-aism.org/asm.

[206] Once installed, a functioning AIS requires no additional expense to transmit or receive AIS communications. As it currently exists in the Voluntary Observing Ship program, the primary financial burden for introducing weather observations from vessels at sea to the Global Telecommunication System would be the responsibility of the meteorological authorities that seek to include more data. The Global Telecommunication System is part of the World Weather Watch, which collects and distributes meteorological information worldwide.

[207] The second mate appeared aware of the importance of weather reporting from ships. At 1355 the day before the accident, she stated, ". . . (when we're) going through this storm (they'd) probably like to have weather reports . . . don't know if they'll have any other ships reporting (although) I don't know if any other ships are going right into it like we are."

[208] The incorrect vessel position rendered the weather report from *El Faro* essentially unusable. However, a recipient of the report (for example, a National Weather Service forecaster) could identify the specific vessel by the report and then locate its position in real time using the AIS broadcast.

and oceanographic data obtained directly from automated instrumentation and manual observation on board vessels at sea, (2) vessel position and time of observation, and (3) other important metadata, by satellite and land-based receivers, to global meteorological authorities via the Global Telecommunication System with acceptable time delay.

The NTSB understands that the IMO may be reluctant to establish new mandates on ship reporting of weather that could cause vessel operators additional burden and workload. However, vessels at sea provide such an important platform for retrieving data that effort should be made to increase global participation in weather reporting. Thus, the NTSB concludes that if the "proof-of-concept" project recommended above establishes that AIS can deliver, in a single message, (1) meteorological and oceanographic data obtained directly from both automated instrumentation and humans on board vessels at sea, (2) vessel position and time of observation, and (3) other important metadata, via satellite and land-based receivers, to global meteorological authorities via the Global Telecommunications System with acceptable time delay, AIS must be used immediately to improve the quantity of ship weather reports across the globe.

Therefore, the NTSB recommends that, if the actions recommended to NOAA in Safety Recommendation M-17-52 establish that AIS is a viable means by which to relay (with acceptable time delay) meteorological and oceanographic data and metadata from vessels at sea for use by global meteorological authorities, the Coast Guard propose to the IMO that vessels required to use AIS also be equipped with meteorological and oceanographic sensors—including, at a minimum, sensors for barometric pressure and sea-surface temperature—that will automatically disseminate the data at high-temporal resolution via AIS. The NTSB also recommends that the Coast Guard propose to the IMO that vessels under SOLAS regulations that are not already automatically disseminating meteorological and oceanographic data by other means be required to manually disseminate such data while at sea via AIS or the Voluntary Observing Ship program at the times of 0000 UTC, 0600 UTC, 1200 UTC, and 1800 UTC.

Since implementation of AIS, usage has expanded significantly.[209] With a limited number of slots available per minute and certain messages occupying multiple slots, system overload is a concern. Increased usage of AIS, including ASM, will eventually affect standard AIS ship-to-ship communications. The International Telecommunications Union (ITU), in coordination with the International Association of Marine Aids to Navigation and Lighthouse Authorities, the IMO, and providers of AIS equipment and service, has already acted to mitigate the problem by assigning two separate frequencies in the VHF maritime mobile band for the transmission of AIS ASM. Moving ASM transmissions to dedicated ASM channels will improve the efficiency of ASM transmissions and protect the original functions of AIS, including collision avoidance, and is included as part of international standards commonly referred to as the VHF data exchange system (VDES). One challenge to these efforts is global acceptance of the allocation of frequencies for VDES transmissions. Although some countries have adopted the new standard, the United States has yet to reserve the specific radio frequencies for this purpose. In the United States, the specific VDES ASM frequencies are within a band that is currently commercially licensed for other use by the FCC. The license expires in 2018.

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[209] In addition to mandatory AIS installations, commercial and recreational ships may install AIS transponders.

Thus, the NTSB concludes that expanding AIS message transmission capabilities to provide mariners with timely access to a variety of navigational, weather, and marine safety information by establishing new channels for VDES is a prudent international effort. Therefore, the NTSB recommends that the FCC reserve the designated ASM frequencies for VDES use in US territories, as identified in ITU recommendation ITU-R M.2092-0, and consistent with international efforts.

3 Conclusions

3.1 Findings

1. The mechanical condition or operation of *El Faro*'s boilers, steering, electrical power, and machinery were not factors in the accident.
2. The work being performed by the riding gang of foreign nationals did not contribute to the sinking of *El Faro*.
3. Neither improper securement of the trailers and containers nor inadequate maintenance of the vessel's cargo-securing gear contributed to the vessel's initial list.
4. Cargo shifting was not a major factor in the vessel's initial list.
5. The medical fitness of the *El Faro* crew and any prescription medication use by the crew were most likely not factors in the accident.
6. The captain's decision to depart Jacksonville was reasonable considering the availability of options to avoid Tropical Storm/Hurricane Joaquin.
7. There is no evidence that the vessel suffered a hull break or other significant structural failure while on the ocean surface that was a factor in the accident.
8. A rogue wave was not a factor in the sinking of *El Faro*.
9. The initial list was caused by an increasing wind on the vessel's beam generated by Hurricane Joaquin.
10. The port list, coupled with the vessel's motion, most likely caused air to enter the bellmouth of the suction pipe to the lube oil service pump, which resulted in a loss of oil pressure that caused the main engine to shut down.
11. The level of lube oil in the main engine sump was not maintained in accordance with the vessel's operations manual, which increased the propulsion system's susceptibility to loss of oil pressure.
12. If the company had provided guidance to the engineers about the list-induced operational limitations of the engine as well as about raising the level of lube oil in the main engine sump before or during heavy weather, the additional quantity of oil in the sump would have kept the suction pipe submerged at greater angles of inclination and increased the likelihood of maintaining propulsion.
13. Increasing the minimum athwartships angle of inclination requirements for both static and dynamic conditions would provide an additional margin of safety for vessels exposed to high winds and large sea states.
14. The crew was most likely unaware of the operational limitations on the main engine from a sustained excessive list.

15. If the ship's officers had known the maximum static list angle at which the main propulsion engine would operate, they would most likely have attempted to reduce the initial list sooner and possibly avoided the loss of propulsion.
16. A watertight scuttle to cargo hold 3 on the second deck was open, allowing the unintended ingress of water and violating the ship's watertight envelope.
17. If the second deck access hatch (scuttle) had been fitted with a remote open/close indicator at a manned location, such as the bridge, the crew would have known that the watertight hatch to cargo hold 3 was open.
18. Because the automobile-lashing arrangement on *El Faro* did not meet the requirements of the vessel's approved cargo-securing manual, automobiles were more likely to shift from vessel motion in heavy weather.
19. The introduction of water to cargo hold 3, combined with the vessel's motion, led to failure of some lashings and automobiles becoming unsecured.
20. It is likely that the seawater piping below the waterline to the vessel's emergency fire pump in cargo hold 3 was inadequately protected from impact and was struck by one or more cars that had broken free of their lashings.
21. Impact damage to the seawater piping below the waterline to the emergency fire pump in cargo hold 3 most likely led to flooding in the hold, which significantly compromised the vessel's stability.
22. The rate of flooding in cargo hold 3 exceeded the design capacity of the bilge pumps and therefore did not lower the water level in the hold, despite continued pumping during the accident sequence.
23. Crewmembers in the engine room were most likely alerted to water in cargo hold 3 by the installed bilge alarm system.
24. New cargo vessels should be equipped with, and existing cargo vessels should be retrofitted with, bilge high-level alarms in all cargo holds that send audible and visible indication to a manned location.
25. All the watertight and weathertight ventilation closures to the cargo holds most likely remained open throughout the sinking sequence.
26. Vessels should not have operational requirements to maintain weathertight or watertight ventilator closures in an open position when the same closures are treated as closed when the vessel's stability and load line are assessed.
27. Had the vessel's stability booklet or CargoMax software identified the vessel's downflooding points, the ship's officers might have closed the cargo hold ventilation openings.
28. About 40 minutes before the sinking, seawater most likely entered the ventilation ducting to several main cargo holds, exacerbating the flooding already under way in cargo hold 3 and accelerating the sinking.

29. If a damage control plan had been available and the crew trained in its use, the crew would have been better able to promptly plan for and address the flooding scenario encountered during the casualty.

30. Existing cargo vessels should have the same damage control plans and booklets as are required for newly built vessels to assist crews in damage and flooding situations.

31. Approval by a classification society of damage control plans and booklets would provide an independent check to ensure uniformity and compliance with requirements.

32. A damage control plan and booklet would have helped the captain of *El Faro* assess the flooding situation.

33. The damage stability module in the CargoMax software on *El Faro* could have provided timely vessel stability information to the officers for the damage conditions the vessel experienced.

34. The original passage plan's straight-line course at departure from Jacksonville would lead directly into the storm's predicted path.

35. Although there is no direct evidence that the company applied pressure regarding the vessel's schedule, inherent pressure could have influenced the captain's decision to continue on despite the weather.

36. *El Faro* was receiving sufficient weather information for the captain's decision-making regarding the vessel's route.

37. Although up-to-date weather information was available on the ship, the *El Faro* captain did not use the most current weather information for decision-making.

38. Had the deck officers more assertively stated their concerns, in accordance with effective bridge resource management principles, the captain's situation awareness might have been improved.

39. The captain should have returned to the bridge after the second and third mates called him to gain a better awareness of the changing weather situation.

40. The captain did not take sufficient action to avoid Hurricane Joaquin, thereby putting *El Faro* and its crew in peril.

41. By failing to adequately consider the suggestions of the ship's junior officers to alter the passage plan and failing to alter his decision to proceed, the captain endangered *El Faro* and its crew.

42. The concepts of bridge resource management were not implemented on board *El Faro*.

43. The company's failure to ensure the implementation of bridge resource management contributed to the sinking.

44. The company's safety management system was inadequate and did not provide the officers and crew with the necessary procedures to ensure safe passage, watertight integrity, heavy-weather preparations, and emergency response during heavy-weather conditions.

45. The company did not have an effective process for evaluating the performance of its officers.

46. The company did not have an effective training program for the use of the CargoMax stability instrument, including its damage stability module.

47. Training in heavy-weather operations, including advanced meteorology and advanced shiphandling, from which the captain was exempt, might have provided him with additional information to consider while evaluating options and might have resulted in a different course of action.

48. The company did not have an effective officer training program for the use of the ship's Bon Voyage System weather information software.

49. The company did not ensure that *El Faro* had a properly functioning anemometer, which deprived the captain of a vital tool for understanding his ship's position relative to the storm.

50. The company subscribed to the Rapid Response Damage Assessment service, although not required, but did not train the crew in its use.

51. The company did not monitor the position of *El Faro* relative to the storm and did not provide the captain with support for storm avoidance and heavy-weather preparations during the accident voyage.

52. The company failed to assess the risk posed by Hurricane Joaquin to *El Faro*.

53. The company's lack of oversight in critical aspects of safety management, including gaps in training for shipboard operations in severe weather, denoted a weak safety culture in the company and contributed to the sinking of *El Faro*.

54. *El Faro*'s stability booklet should have included downflooding angles and windheel criteria to increase the officers' awareness of the ship's vulnerabilities in heavy weather, such as unintentional flooding and listing.

55. Neither the Coast Guard nor the classification society adequately assessed the vessel's stability booklet to ensure that it contained critical information detailed in Coast Guard regulations and guidance.

56. Coast Guard Navigation and Inspection Circular 4-77 (*Shifting Weights or Counter Flooding During Emergency Situations*) should be revised to include specific guidance regarding the dangers of taking corrective action if roll-on/roll-off cargo is adrift or the decks are wet.

57. The Coast Guard's Alternate Compliance Program is not effective in ensuring that vessels meet the safety standards required by regulations, and many vessels enrolled in the program are likely to be operating in substandard condition.

58. The 2005–2006 conversion of *El Faro* to carry load-on/load-off containers and the associated increase in draft should have been designated a major conversion by the Coast Guard.

59. For inspected vessels in coastal, Great Lakes, or ocean service, having their lifesaving appliances regularly reviewed for compliance with current standards would improve crew survivability.

60. The captain's decision to muster the crew and abandon ship was late and may have reduced the crew's chances of survival.

61. The severe weather, combined with *El Faro*'s list, made it unlikely that the lifeboats could be boarded or launched.

62. The vessel's open lifeboats would not have provided adequate protection even if they had been launched.

63. Survivability would be increased if open lifeboats on all vessels remaining in service were replaced with enclosed lifeboats that adhered to the latest safety standards.

64. Survivability would be increased if new cargo vessels were equipped with stern-launched freefall lifeboats, where practical.

65. The severe weather, combined with *El Faro*'s list, made it unlikely that the liferafts could be launched manually or boarded by crewmembers once in the water.

66. Search-and-rescue efforts were carried out as effectively as possible given the extreme weather conditions in the days following the accident.

67. Because of differences in latitude and longitude formatting between Inmarsat-C and the Coast Guard's search-and-rescue optimal planning system (SAROPS), the last known position of *El Faro* according to SAROPS was 23 nautical miles from the actual position.

68. Although position errors did not affect the outcome of search-and-rescue efforts after *El Faro* sank, position information should adhere to a standardized format to eliminate similar errors in future accidents.

69. The use of older emergency position-indicating radio beacons such as the one on *El Faro* that do not transmit global positioning system positions reduces positional accuracy in search-and-rescue operations.

70. Providing all persons employed on board vessels in coastal, Great Lakes, and ocean service with personal locator beacons would enhance their chances of survival.

71. The poor audio quality and poor placement of the voyage data recorder microphones aboard *El Faro* inadequately recorded conversations on the navigation bridge, which impeded investigators' ability to accurately transcribe the recording.

72. The most effective performance testing of voyage data recorder audio quality would take place while the ship is under way using its main source of propulsion.

73. *El Faro*'s voyage data recorder system was not configured or required to capture both sides of internal phone calls, which prevented investigators from hearing the engineering officers' communications with the bridge.

74. To ensure optimum sound quality for accident investigation, it is vital that all very-high-frequency radios used for ship operations be recorded by individual inputs on the ship's voyage data recorder.

75. The annual performance test for *El Faro*'s voyage data recorder was inadequate because the technician did not replace the locator beacon's battery even though it would expire before the next performance test.

76. The postaccident recovery of *El Faro*'s voyage data recorder was greatly hampered because the battery had expired about 4 months before the sinking and the beacon was silent during the search.

77. The design of the Global Maritime Distress and Safety System equipment used on *El Faro* allows erroneous ship positions to be sent in emergency alerts.

78. Increased reporting and improved transmission of meteorological and oceanographic data from vessels at sea would significantly improve the availability of vital information to enhance weather awareness, forecasting, and advisory services aimed at improving mariner safety.

79. Because of the significant benefit that the automatic identification system could provide in improving the quantity of weather reports from ships globally, a "proof-of-concept" project is warranted to establish its viability.

80. If the "proof-of-concept" project recommended in this report establishes that the automatic identification system (AIS) can deliver, in a single message, (1) meteorological and oceanographic data obtained directly from both automated instrumentation and humans on board vessels at sea, (2) vessel position and time of observation, and (3) other important metadata, via satellite and land-based receivers, to global meteorological authorities via the Global Telecommunications System with acceptable time delay, AIS must be used immediately to improve the quantity of ship weather reports across the globe.

81. Expanding automatic identification system message transmission capabilities to provide mariners with timely access to a variety of navigational, weather, and marine safety information by establishing new channels for the very-high-frequency data exchange system is a prudent international effort.

3.2 Probable Cause

The National Transportation Safety Board determines that the probable cause of the sinking of *El Faro* and the subsequent loss of life was the captain's insufficient action to avoid Hurricane Joaquin, his failure to use the most current weather information, and his late decision to muster the crew. Contributing to the sinking was ineffective bridge resource management on board *El Faro,* which included the captain's failure to adequately consider officers' suggestions. Also contributing to the sinking was the inadequacy of both TOTE's oversight and its safety management system. Further contributing factors to the loss of *El Faro* were flooding in a cargo hold from an undetected open watertight scuttle and damaged seawater piping; loss of propulsion due to low lube oil pressure to the main engine resulting from a sustained list; and subsequent downflooding through unsecured ventilation closures to the cargo holds. Also contributing to the loss of the vessel was the lack of an approved damage control plan that would have assisted the crew in recognizing the severity of the vessel's condition and in responding to the emergency. Contributing to the loss of life was the lack of appropriate survival craft for the conditions.

4 Recommendations

As a result of its investigation of this accident, the National Transportation Safety Board makes the following safety recommendations.

To the US Coast Guard:

> Revise regulations to increase the minimum required propulsion and critical athwartships machinery angles of inclination. Concurrently, requirements for lifeboat launching angles should be increased above new machinery angles to provide a margin of safety for abandoning ship after machinery failure. (M-17-21)

> Propose to the International Maritime Organization that design maximum operating angles of inclination for main propulsion and other critical machinery be included in damage control documents, stability instruments and booklets, and in the safety management systems for all applicable vessels. (M-17-22)

> Propose to the International Maritime Organization that all watertight access doors and access hatch covers normally closed at sea be provided with open/close indicators both on the bridge and locally. (M-17-23)

> Propose to the International Maritime Organization that on new and existing vessels, seawater supply piping below the waterline in all cargo holds be protected from impact. (M-17-24)

> Propose to the International Maritime Organization to require that new cargo vessels be equipped with bilge high-level alarms in all cargo holds that send audible and visible indication to a manned location. (M-17-25)

> Propose to the International Maritime Organization to require that existing cargo vessels be retrofitted with bilge high-level alarms in all cargo holds that send audible and visible indication to a manned location. (M-17-26)

> Propose to the International Maritime Organization that any opening that must normally be kept open for the effective operation of the ship must also be considered a downflooding point, both in intact and damage stability regulations and in load line regulations under the International Convention on Load Lines. (M-17-27)

Require that information regarding openings that could lead to downflooding be included in damage control documents, stability instruments and booklets, and safety management systems for vessels subject to the intact stability criteria of Title 46 *Code of Federal Regulations* 170.170, regardless of the designation or treatment of such openings in intact stability calculations. (M-17-28)

Propose to the International Maritime Organization that existing cargo vessels operating under the International Convention for the Safety of Life at Sea be required to have damage control plans and booklets on board that meet current standards. (M-17-29)

Propose to the International Maritime Organization that damage control plans and booklets required by the International Convention for the Safety of Life at Sea be class-approved. (M-17-30)

Publish policy guidance to approved maritime training schools offering bridge resource management courses to promote a cohesive team environment and improve the decision-making process, and specifically include navigational and storm-avoidance scenarios. (M-17-31)

Require recurring bridge resource management training for all deck officers when renewing their credentials. (M-17-32)

Require that all deck officers, at both operational and management levels, take a Coast Guard–approved advanced meteorology course to close the gap for mariners initially credentialed before 1998. (M-17-33)

Publish policy guidance to approved maritime training schools offering management-level training in advanced meteorology, or in an appropriate course, to ensure that the curriculum includes the following topics: characteristics of weather systems including tropical revolving storms; advanced meteorological concepts; importance of sending weather observations; ship maneuvering using advanced simulators in heavy weather; heavy-weather preparations; use of technology to transmit and receive weather forecasts (such as navigational telex or weather-routing providers); ship-routing services (capabilities and limitations); and launching of lifeboats and liferafts in heavy weather. (M-17-34)

Provide policy guidance to approved maritime training schools offering operational-level training in meteorology to ensure that the curriculum includes the following topics: characteristics of weather systems, weather charting and reporting, importance of sending weather observations, sources of weather information, and interpreting weather forecast products. (M-17-35)

Require that vessels in ocean service (500 gross tons or over) be equipped with properly operating meteorological instruments, including functioning barometers, barographs, and anemometers. (M-17-36)

Revise Title 46 *Code of Federal Regulations* 170.110 (stability booklet) to require (1) stability instructions, guidance, or data on wind velocity used to calculate weather criteria; (2) list of closures that must be made to prevent unintentional flooding; (3) list of closures that must be made for an opening not to be considered a downflooding point; and (4) righting arm curve (metacentric height) table to note the angle at which initial downflooding occurs; also, add a windheel table for vessel full load displacement or the condition of greatest vulnerability to windheel. (M-17-37)

Update the guidance in Navigation and Inspection Circular 4-77 (*Shifting Weights or Counter Flooding During Emergency Situations*), based on the circumstances of the *El Faro* accident, to include a warning that actions by ship personnel intended to correct a list can produce dangerous results if roll-on/roll-off cargo is already adrift and water has reduced the coefficients of friction for lashed cargo. (M-17-38)

Conduct a complete review of the Alternate Compliance Program to assess the adequacy and effectiveness of the program. (M-17-39)

Review and implement training of Coast Guard inspectors and accredited classification society surveyors to ensure that they are properly qualified and supported to perform effective, accurate, and transparent vessel inspections, meeting all statutory and regulatory requirements. (M-17-40)

Review and revise the policy for major conversion determinations to consider load line (maximum) draft as a principal vessel dimension. (M-17-41)

At regular intervals, not to exceed 20 years, review all lifesaving appliances on inspected vessels that are required by Title 46 *Code of Federal Regulations* Part 199, and require compliance with current standards. (M-17-42)

Require that open lifeboats on all US-inspected vessels be replaced with enclosed lifeboats that meet current regulatory standards and freefall lifeboats, where practicable. (M-17-43)

To prevent future errors in converting position data such as occurred in the *El Faro* accident, work with manufacturers of Global Maritime Distress and Safety System equipment, communication providers, and land earth stations to remove ambiguity from the Inmarsat-C distress alert position reports. (M-17-44)

Require that all personnel employed on vessels in coastal, Great Lakes, and ocean service be provided with a personal locator beacon to enhance their chances of survival. (M-17-45)

Modify guidance and training for marine inspectors to ensure that voyage data recorder annual performance tests include the replacement of locator beacons prior to expiration and that audio used to evaluate quality is recorded while a ship is under way using its main propulsion unit. (M-17-46)

Propose to the International Maritime Organization to amend resolution MSC.333(90) to specify that "normal operations" are defined as when a ship is under way using its main propulsion unit and to assess voyage data recorder problems, including not capturing both sides of internal phone calls on the bridge electric telephone and unrecorded very-high-frequency communications, and identify steps to remedy them. (M-17-47)

If the actions recommended to the National Oceanic and Atmospheric Administration in Safety Recommendation M-17-52 establish that the automatic identification system (AIS) is a viable means by which to relay (with acceptable time delay) meteorological and oceanographic data and metadata from vessels at sea for use by global meteorological authorities, propose to the International Maritime Organization that vessels required to use AIS also be equipped with meteorological and oceanographic sensors—including, at a minimum, sensors for barometric pressure and sea-surface temperature—that will automatically disseminate the data at high-temporal resolution via AIS. (M-17-48)

Propose to the International Maritime Organization that vessels under regulations of the International Convention for the Safety of Life at Sea that are not already automatically disseminating meteorological and oceanographic data by other means be required to manually disseminate such data while at sea via the automatic identification system or the Voluntary Observing Ship program at the times of 0000 coordinated universal time (UTC), 0600 UTC, 1200 UTC, and 1800 UTC. (M-17-49)

To the Federal Communications Commission:

Require that all US vessels required to carry 406-megahertz emergency position-indicating radio beacons (EPIRBs) immediately discontinue the use of EPIRBs that are not global positioning system enabled. (M-17-50)

Reserve the designated application-specific message frequencies for very-high-frequency data exchange system use in US territories, as identified in International Telecommunications Union (ITU) recommendation ITU-R M.2092-0, and consistent with international efforts. (M-17-51)

To the National Oceanic and Atmospheric Administration:

Coordinate with the National Weather Service, vessel operators, automatic identification system (AIS) service providers, and required onboard technology vendors to perform a "proof-of-concept" project to establish whether AIS, or another suitable alternative, can practically deliver, in a single message, (1) meteorological and oceanographic data obtained directly from automated instrumentation and manual observation on board vessels at sea, (2) vessel position and time of observation, and (3) other important metadata, by satellite and land-based receivers, to global meteorological authorities via the Global Telecommunication System with acceptable time delay. (M-17-52)

To the International Association of Classification Societies:

Recommend to your members to increase the minimum required propulsion and critical athwartships machinery angles of inclination. Concurrently, requirements for lifeboat launching angles should be increased above new machinery angles to provide a margin of safety for abandoning ship after machinery failure. (M-17-53)

Recommend to your members to require that design maximum operating angles of inclination for main propulsion and other critical machinery be included in damage control documents, stability instruments and booklets, and in the safety management systems for all applicable vessels. (M-17-54)

Recommend to your members to require that all watertight access doors and access hatch covers normally closed at sea be provided with open/close indicators both on the bridge and locally. (M-17-55)

Recommend to your members to require that on new and existing vessels, seawater supply piping below the waterline in all cargo holds be protected from impact. (M-17-56)

Recommend to your members to require that new cargo vessels be equipped with bilge high-level alarms in all cargo holds that send audible and visible indication to a manned location. (M-17-57)

Recommend to your members to require that existing cargo vessels be retrofitted with bilge high-level alarms in all cargo holds that send audible and visible indication to a manned location. (M-17-58)

Recommend to your members that any opening that must normally be kept open for the effective operation of the ship must also be considered a downflooding point, both in intact and damage stability regulations and in load line regulations under the International Convention on Load Lines. (M-17-59)

Recommend to your members that existing cargo vessels be required to have damage control plans and booklets on board that meet current standards. (M-17-60)

Recommend that your members require that damage control plans and booklets required by the International Convention for the Safety of Life at Sea be class-approved. (M-17-61)

To the American Bureau of Shipping:

Enhance training of your surveyors to ensure that they are properly qualified and supported to perform effective, accurate, and transparent vessel surveys, meeting all statutory and regulatory requirements. (M-17-62)

To Furuno Electric Company, Ltd.:

Update your Global Maritime Distress and Safety System software to detect and correct user errors when entering ship positions using the global positioning system. (M-17-63)

To TOTE Services, Inc.:

Establish standard operating procedures for heavy weather that address operational limitations and oil levels in critical machinery to ensure their continued operation. (M-17-64)

Establish procedures for opening, closing, and logging all closures that make up a vessel's watertight envelope while the vessel is at sea. (M-17-65)

Ensure that damage control plans and booklets are aboard all your load-lined vessels and that officers and crewmembers are trained in their use. (M-17-66)

Require senior officers to receive formal training approved by the manufacturer in all functions found in installed stability programs, including damage stability modules. (M-17-67)

Revise your safety management system and bridge resource management programs to contain detailed polices, instructions, procedures, and checklists to mitigate the risks of severe weather to your vessels. (M-17-68)

Conduct an external audit, independent of your organization or class society, of your entire safety management system to ensure compliance with the International Safety Management code and correct noted deficiencies. (M-17-69)

Require your vessels to be equipped with properly operating meteorological instruments, including functioning barometers, barographs, and anemometers. (M-17-70)

Institute a formal company process to provide independent weather routing, passage-planning assistance, and vessel position monitoring. (M-17-71)

Provide formal and recurrent training to your deck officers on the public and commercial weather information systems provided on board each vessel to ensure that the officers are fully knowledgeable about all weather information sources at their disposal and understand the time delays in the information provided. (M-17-72)

Provide shoreside management and vessel senior personnel with training in the Rapid Response Damage Assessment program and standard operating procedures, to include requirements to conduct annual drills and submit departure stability conditions for each vessel on each voyage. (M-17-73)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

ROBERT L. SUMWALT, III
Chairman

EARL F. WEENER
Member

CHRISTOPHER A. HART
Member

T. BELLA DINH-ZARR
Member

Adopted: December 12, 2017

Board Member Statements

Chairman Robert L. Sumwalt, III, filed the following concurring statement on December 19, 2017.

The Spanish words *El Faro* mean “the lighthouse” in English. I am confident that the safety recommendations that stemmed from the investigation of the SS *El Faro* sinking can serve as a beacon to guide present and future generations of mariners.

The Board unanimously adopted a probable cause statement that stated, in part, “contributing to the sinking was ineffective bridge resource management on board *El Faro*, which included the captain’s failure to adequately consider the officer’s suggestions.” This statement shines light on an area I feel can help ensure voyage safety by increasing the effectiveness of bridge resource management (BRM).

BRM grew from aviation’s crew resource management (CRM), which came about from a series of aviation disasters in which crewmembers didn’t adequately relay their concerns to the captain. Through effective CRM courses, aviation employees of all ranks—including first officers, flight attendants, maintenance technicians, and dispatchers—now feel empowered to clearly state concerns to the captain to ensure the captain has information he/she needs to ensure safety of flight.

Likewise, an objective of BRM is to ensure those in command have accurate, unfiltered information that could affect safety. In that light, as stated in the *El Faro* report, “As an element of BRM, officers have a duty to speak up if they believe the vessel is at risk. From their statements on the VDR, the mates were clearly concerned about their safety and that of the rest of the crew.” The report also states, “BRM stresses assertiveness.” Despite the crewmembers’ concerns, and despite BRM stressing assertiveness, the crewmembers’ speech lacked assertiveness when they called the captain (on a total of three occasions) to notify him that their planned route would pass extremely close to the hurricane’s projected path.

There is no doubt that the final responsibility for the operation of the vessel falls squarely upon the captain. However, in order for the captain to make informed decisions, he/she must have an accurate perception of the current and future state of his/her vessel. In this case, the captain seemingly had no situational awareness regarding the storm’s location relative to the ship’s planned course. Absent his coming to this realization himself, the only way to increase his awareness of the perilous situation facing his ship would be for crewmembers to clearly, and in unambiguous terms, state their concerns and then agree upon an acceptable plan to ensure safety. Therefore, in a 3 to 1 vote, the Board adopted a finding that stated: “Had the deck officers more assertively stated their concerns, in accordance with effective bridge resource management principles, the captain’s situation awareness might have been improved.”

Communication is a two-way street; if someone isn’t getting the message, the person attempting to communicate must alter his/her communication style to ensure the message is truly understood and addressed.

This report will be studied by mariners, young and old, for many, many years. It is critical that we point out how important it is for all crewmembers to voice concerns and achieve agreement on a suitable solution. It would be easy to take from this tragedy that the captain just didn't listen to his crew. While that may be a true statement, the message should be that "although the captain didn't take action upon the crewmembers' concerns, the mates were not assertive enough to make their concerns clearly known to effect a safer course of action."

CRM has taught, and BRM is intended to teach, when someone is not comfortable, they have an obligation to speak up. The purpose of BRM is not, nor is it the intention of this concurring statement or this accident report, to encourage "command by committee." Rather, a guiding light of BRM is that senior officers should establish an environment where all crewmembers feel comfortable voicing concerns, and where senior officers encourage and welcome such input. But an equally important facet of BRM is to ensure that crewmembers know how to be assertive enough to convey their concerns to senior officers, and then achieve agreement on a suitable solution.

Member Earl F. Weener joined in this statement.

Member T. Bella Dinh-Zarr filed the following concurring and dissenting statement on December 18, 2017.

As I stated on scene and during the board meeting, I extend my deepest condolences to the families and friends of the crew of *El Faro*. I assure you that from that first day I had the privilege of meeting many of you in Jacksonville, our NTSB investigative team has worked tirelessly to provide answers and to craft this report in hope that no other maritime families will have to endure what you have endured.

I applaud and thank the NTSB staff for completing a thoughtful, evidence-based report. I wholeheartedly concur with the work of the NTSB staff on this report. However, I do not agree with the amendment about adding the mates' lack of assertiveness as a finding to the report. Therefore, I dissent to the addition of Finding 38 regarding the actions of the mates and the potential effect those actions might have had on the master/captain (an amendment made during the board meeting).

Seafaring has existed for thousands of years. The term and position of a professional master has existed for centuries. In the maritime profession, much like in the military profession, a power differential exists that is necessary to maintaining good order and discipline. This power differential has existed for hundreds, if not thousands of years—so in that respect, the power differential is not comparable to that of a pilot and copilot in aviation—an industry which is just over 100 years old.

As a master, you oversee a floating city. The ship has its business, its bridge, its engine, its living quarters, its mess hall, and, yes, its brig. The master must balance maintaining discipline and command of the ship with creating an environment where his/her crew will speak up during times of concern. In this respect too, it is far more comparable to the military than to the other modes of transportation we see here at the NTSB. We must be cognizant of those key differences when we talk about bridge communications.

We cannot take a one-size-fits-all approach to the modes. While crew resource management (CRM) has helped improve aviation safety and bridge resource management (BRM) has important lessons to learn from CRM, there must be adjustments to accommodate the differences that exist in different modes to be truly effective. BRM in maritime is important—it is important for the crew to communicate and work as a team. However, in this case, the mates "challenging" the master during a storm is more akin to the lieutenant challenging the general's orders on the battlefield—there is a proper way to do it given the necessary power differential.

While I understand, in BRM, there are certain phrases that crew can be trained to say to better or more clearly communicate the urgency of a message. I would note, in the maritime world, a single call to the captain's quarters in the middle of the night is the equivalent of these phrases. In response to my question in the board meeting as to whether it was unusual that the captain did not return to the bridge prior to 0400, an NTSB investigator and former master of *El Faro* (when it was named the *Northern Lights*) stated, "Pretty much industry standard would be if a junior officer, a third mate or second mate, calls and expresses concern, the master would be up on the bridge to address that concern."

I am not, in any way, implying that training in BRM is not necessary, but I think we also cannot ignore hundreds of years of seafaring history or minimize the importance and courage of the *El Faro* mates in making these middle-of-the-night calls to the captain.

Therefore, I dissent on adding the mates' (or deck officers', as the term "mate" was changed to "deck officer" in this finding) assertiveness as a finding in this report. At sea, it is an unusual circumstance for a mate to call the captain during the evening in his stateroom once, let alone on three different occasions. All the mates aboard *El Faro* were more than competent and qualified to perform their duties. The third mate and his helmsman had a specific conversation discussing challenges to authority. The third mate stated he did not have a problem speaking up to authority. During his call to the captain, he told the captain that they would be 22 nautical miles from the center of the hurricane. He personally called the captain twice. As third mate, he was the junior bridge officer and stood the 2000–2400 watch, so the captain would be available to assist him, if needed. On the voyage data recorder (VDR), the second mate sounds confident. She called the captain and woke him up just after 1 a.m. We'll never know why the captain did not return to the bridge sooner the evening before the sinking or the morning of the sinking, but I do not think it was due to lack of trying on the part of the crew.

I would ask my fellow Board Members, whose experience in CRM and aviation I respect, to reflect on this hypothetical situation: If you were captain on a long-distance flight and the pilots flying called back to you during your rest period, not once, not twice, but three times, would it matter what words or tone they used with you? Most captains would be up in the cockpit to check and see what was going on. The same was true on *El Faro*.

Finally, to the families of those mariners lost on *El Faro*, I ask you not to let the inclusion of one finding in this report take away from the memory of your loved ones. The men and women of *El Faro* fought, as a crew, to save their ship. What I heard in that last hour on the VDR reflected the courage and teamwork of the crew, including the master who refused to leave a crewmember alone. It was, as the maritime community would say, "all hands on deck." They fought, as they lived, together. My hope is that our report and its recommendations will prevent other families from suffering as I know you all have suffered—that your loss will lead to real, meaningful change. Treasure the memories of your loved ones. They will not be forgotten.

Appendix A
Investigation

The NTSB learned of the accident from the Coast Guard on the afternoon of October 1, 2015. A team of five investigators, Board Member T. Bella Dinh-Zarr, and support staff launched from NTSB headquarters on October 6 and arrived on scene in Jacksonville, Florida, later the same day. The investigative team consisted of specialists in engineering, operations, naval architecture, survival factors, human performance, meteorology, and electronic data.

The on-scene part of the investigation, led by the NTSB, was completed on October 15, 2015. On October 31, the US Navy ship *Apache*, fitted with underwater detection equipment, located the wreckage of *El Faro* at a depth of about 15,000 feet. In April 2016, the oceanographic research vessel *Atlantis* located *El Faro*'s VDR but did not retrieve it. In August 2016, the *Apache* returned to the wreckage and retrieved the VDR. In February 2016, May 2016, and February 2017, the Coast Guard convened Marine Board of Investigation hearings in Jacksonville. The NTSB participated fully in the hearings.

The NTSB investigated the accident under the authority of the Independent Safety Board Act of 1974, according to NTSB rules. Parties to the investigation were the Coast Guard, TOTE Services, Inc., the American Bureau of Shipping, the National Weather Service, Harding Safety USA (Palfinger), and Herbert Engineering.

Appendix B
Note on the Drawing

What looks like an artist's hand-drawn sketch of the wreckage of *El Faro* resting on the ocean floor (figure 2 in the report) is actually the computer-generated result of a sophisticated series of modeling exercises involving various people, organizations, and software. The drawing is based on four types of data. First, archival photographs and architectural drawings of *El Faro* and its sister vessel *El Yunque*. Second, photos and video of the *El Faro* wreckage taken during the three underwater searches for the vessel and its VDR on the bottom of the Atlantic Ocean. Third, bathymetric (undersea topographic) sonar data obtained during the second underwater search. Fourth, a three-dimensional model of *El Faro* developed by the Coast Guard's Marine Safety Center using the Rhinoceros® (Rhino) computer graphics software.

A naval architect in the NTSB Office of Marine Safety gathered and reviewed the vessel photographs and structural drawings. Scientists at Woods Hole Oceanographic Institution supplied bathymetric sonar data from the second underwater search mission and produced a "point cloud" model of the hull and surrounding seafloor. Point clouds consist of a set of data points located in a three-dimensional coordinate system that when put together, give the impression of the surface of an object.

Next, staff in the NTSB Office of Research and Engineering verified that the Coast Guard's three-dimensional model was compatible with the Woods Hole point cloud model. Staff added a break to the Coast Guard model to match a crack in the vessel shown in the sonar data. Accurate hull dimensions were retained. The top two navigation decks were removed from both models because they had separated from the hull when *El Faro* sank and were lost or lying at a distance from the other wreckage.

A graphic artist in the Digital Services Division of the NTSB Office of Safety Recommendations and Communications then imported the Rhino model into the Autodesk Maya® three-dimensional software and added details such as windows, ladders, draft marks, and lifeboat davits—even a dangling cargo trailer. In collaboration with the NTSB naval architect, the artist scrutinized the architectural drawings and images captured during the underwater searches to make the details as accurate as possible. Adobe Illustrator® software was used to render the three-dimensional image in the style of a hand-drawn sketch. Over several weeks, the artist fine-tuned the digital image with further details and the use of Adobe Photoshop® to produce the final drawing.

Appendix C
Search for *El Faro* Wreckage and Voyage Data Recorder

At the beginning of the accident investigation, the NTSB contacted the Navy's Superintendent of Salvage and Diving (SUPSALV) for help in locating the *El Faro* wreckage. (The NTSB and the Navy have a memorandum of understanding to support accident investigations.) The Navy ship *Apache* was made available, with support personnel from SUPSALV and a contractor, Phoenix International, along with three underwater assets. The assets consisted of a towed ping locator, a towed side-scan sonar (ORION), and the ROV CURV-21.

Apache departed Little Creek, Virginia, on October 19 and arrived at the site of the sinking on October 23. Using the ping locator, investigators listened for the VDR acoustic beacon but heard nothing. On October 27, the team deployed ORION. Four days later, on October 31, ORION located a large target of interest. The next day, November 1, the team deployed CURV-21. The ROV's portable transponder, which was mounted on a lowered mast, did not function, necessitating manual (dead-reckoning) navigation through the debris field while looking at a live video feed from the vehicle. Communication from *Apache* to NTSB headquarters was limited to email and voice.

During the ROV's second dive, investigators spotted the wreck of *El Faro* at a depth of more than 15,000 feet, near the vessel's last known position off Crooked Island, Bahamas. The team surveyed the hull and found that the top two decks of the superstructure—including the navigation bridge, mast, and VDR—were missing. On November 11, CURV-21 located the missing decks but did not find the mast or VDR (the VDR was attached to the mast during normal operations). On November 15, after the team had further surveyed and documented the wreckage, *Apache* departed the scene, returning to Little Creek on November 24.

NTSB investigators analyzed CURV-21's video footage of the hull and debris field and calculated the trajectory of several objects to identify where the mast and VDR might have come to rest, given their weight and dimensions. Three fields of high probability emerged. In addition, objects seemed to rest on a firm ocean floor where visibility was fair, making both sonar and visual detection possible. The NTSB determined that it would be feasible to launch a second search, focused on locating *El Faro*'s mast and VDR.

In consultation with SUPSALV and the Woods Hole Oceanographic Institution, the NTSB developed a new mission outline. If the VDR could not be located near the mast, the search area would have to be widened, and assets would need upgrading to maximize their search capacity. A vessel with dynamic positioning would be preferable, with a mix of sonar and image capabilities fitted to an autonomous underwater vehicle (AUV) to recover the VDR if found.[1] The team would need the ability to send large quantities of data from the vessel to investigators on shore, who could help with processing and prioritization.

[1] An AUV is a programmable, robotic device that differs from an ROV in that it that can move through the ocean without control by human operators, whereas an ROV is attached to an operator by cables.

The NTSB and the Woods Hole National Deep Submergence Facility entered an interagency agreement for a second mission. To locate a dynamic-positioning vessel (dynamic positioning allows a vessel hosting underwater search vehicles to remain on station even during bad weather), the NTSB contacted the National Science Foundation's National Oceanographic Laboratory System and learned that the oceanographic research vessel *Atlantis* was available in April 2016. Also available during the same time was the AUV *Sentry*, which could be programmed to search wide areas with different sonar frequencies, take photographs, and operate independently while the team on *Atlantis* did other work.[2] *Atlantis* had on board an observation vehicle that was suspended from a winch cable and had limited means to maneuver.

The observation vehicle was expected to generate a great deal of sonar and video material. The University of Rhode Island's Inner Space Center, which had provided NOAA with a real-time "telepresence" that allowed scientists ashore to view data and video from the seafloor, was contracted to support the second search mission. The University of Rhode Island, the NTSB, and Verizon prepared a data stream from *Atlantis* to NTSB headquarters.

The second voyage to the accident site began when *Atlantis* departed Charleston, South Carolina, on April 18, 2016. The ship arrived at the site on April 21. Investigators used the ship's hull-mounted multibeam sonar to create a bathymetric base map for use in planning a search grid. The team first deployed *Sentry* (figure C-1) with 120-kHz sidescan and 400-kHz multibeam sonar on preprogrammed searches of high-probability debris corridors. The AUV detected more than 200 targets of interest.

The National Deep Submergence Facility used the same navigation method to operate its underwater vehicles as SUPSALV. Video from the first mission had shown mooring lines from *El Faro* floating above areas of the wreck, which posed entanglement hazards, and the 15,000-foot depth at the site still posed a challenge. The observation vehicle obtained high-definition video and photos of *El Faro*'s hull and interrogated the various targets the AUV had previously detected. One of them turned out to be the *El Faro* mast, with the VDR attached. It was located in the search area the NTSB determined from its wreckage trajectory studies. The telepresence transmitted the imagery in real time to NTSB headquarters. The VDR appeared to investigators to be in fair condition but entangled and possibly attached to the mast with obstructions, which would preclude a simple recovery. Therefore, the NTSB decided to leave the VDR in place and arrange with SUPSALV to return to the site later, using CURV-21 and the first available support vessel.

A third mission, aimed at recovering *El Faro*'s VDR, was launched in August 2016, the first available date for the Navy ship *Apache*, which could support CURV-21. In preparation for the trip, CURV-21 was equipped with high-definition cameras. *Apache* departed Little Creek on August 5 and arrived at the accident site on August 8. At 1950 that evening, CURV-21 freed the VDR capsule from the mast, which was partly buried in the seafloor, and brought the capsule to the surface (figures C-2, C-3, and C-4). The investigative team spent several additional days surveying the *El Faro* hull before returning to port on August 12.

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[2] *Sentry* can explore the ocean down to 6,000 meters (19,685 feet), according to the Woods Hole website (https://www.whoi.edu/main/sentry).

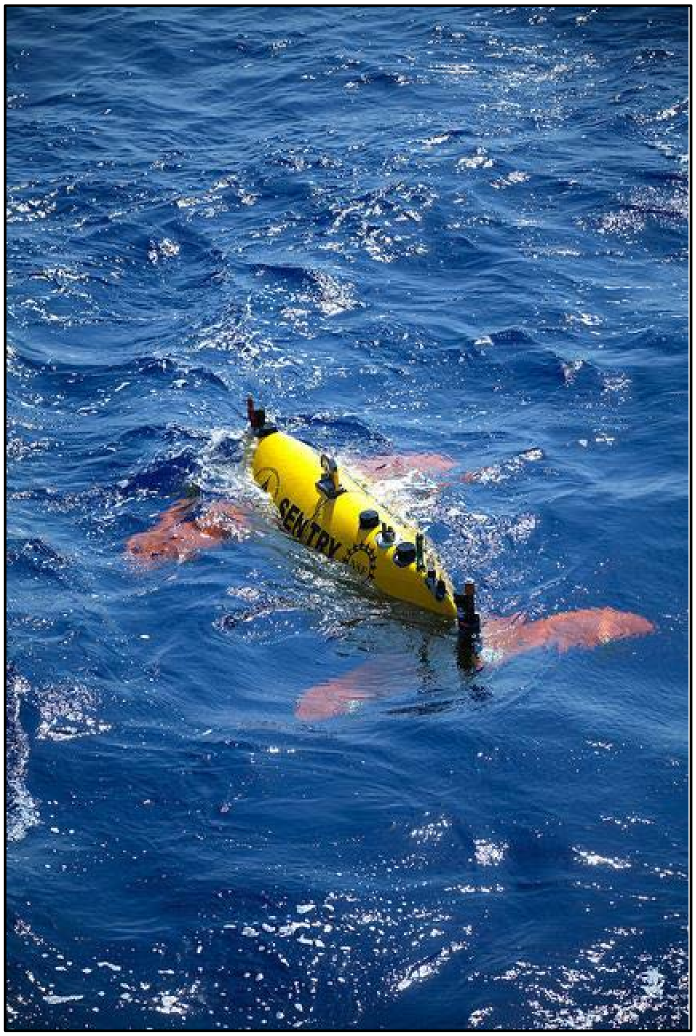

Figure C-1. *Sentry* deployed on second search mission.

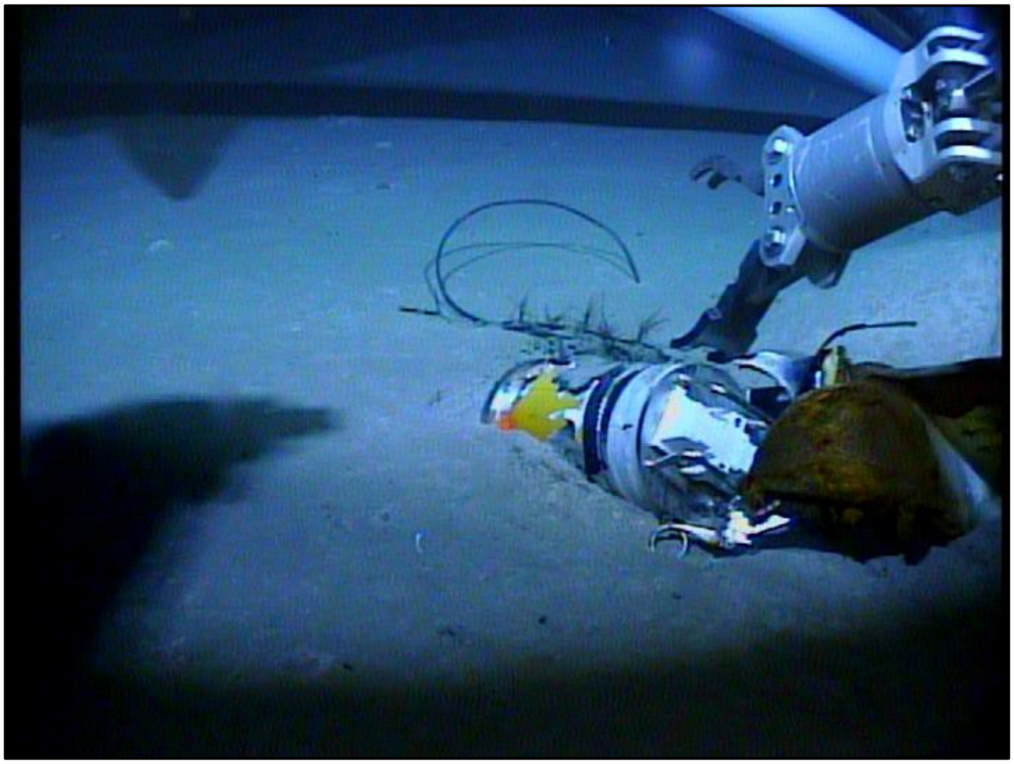

Figure C-2. CURV-21 freeing VDR capsule from seafloor. (US Navy photo)

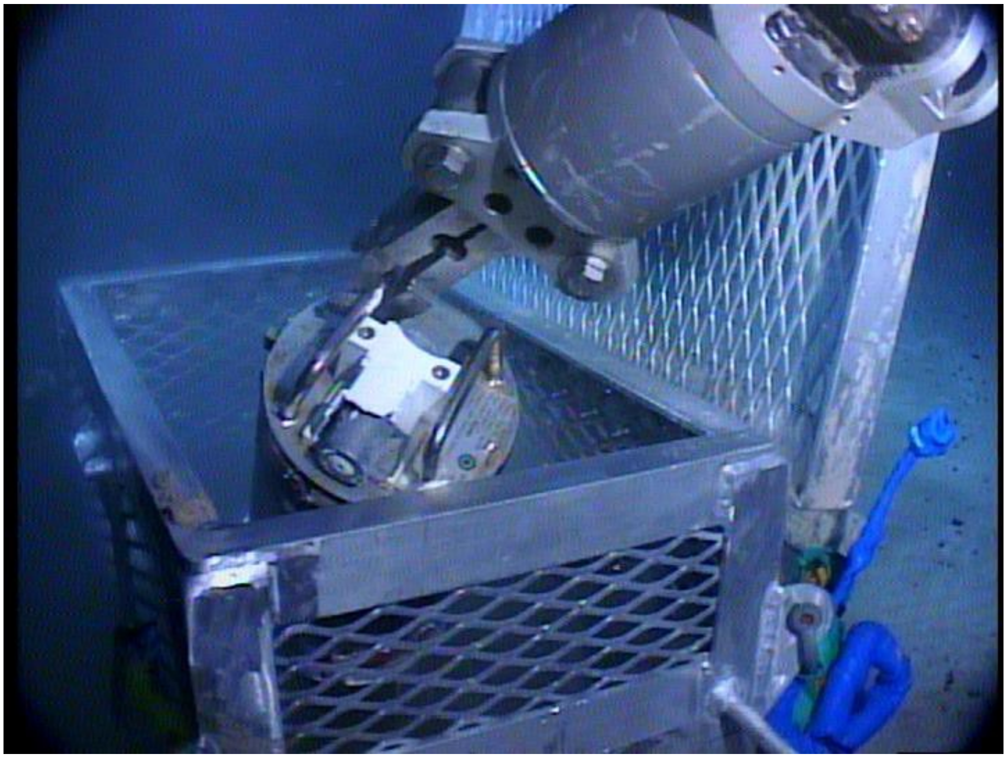

Figure C-3. CURV-21 placing VDR capsule in basket for transport to surface. (US Navy photo)

Figure C-4. CURV-21 landing on *Apache* deck after retrieving VDR.

Appendix D
Vessel Particulars

Vessel Name	SS *El Faro*
Owner/operator	TOTE Maritime Puerto Rico/TOTE Services
Port of registry	San Juan, Puerto Rico
Flag	United States
Type	Cargo—Ro/Ro container
Built	1975, Chester, Pennsylvania
Official number	561732
IMO number	7395351
Classification society	American Bureau of Shipping
Construction	Steel, reduced scantlings
Draft, full load (extreme)	30 feet 2 3/8 inches (9.2 meters)
Displacement, full load	34,677 long tons
Draft (departure)	29 feet 8 5/16 inches (9.05 meters)
Length	790 feet 9 inches (241.0 meters)
Beam	105 feet 0 inches (32.0 meters)
Depth, main deck to keel	60 feet 1 5/8 inches (18.3 meters)
Gross/net tonnage (international)	31,515/21,473
Engine power and type	Steam turbine, 30,000 shaft horsepower (22,370 kilowatts), single screw
Service speed	20 knots
Cargo	Containers and rolling cargo (automobiles and trailers)
Container Capacity	1,414 TEUs
Autos/40-ft trailers/20-ft trailers capacity	74/24/290
Fuel capacity	11,757 barrels
Freshwater capacity	410 long tons
Ballast water capacity	4,623 long tons
Complement, total	42 (33 crew and 9 others)
Persons on board	33
Fatalities	33
Damage cost	Estimated $36 million

Appendix E
Hurricane Avoidance

The best-known encyclopedia of navigation in the United States, *The American Practical Navigator* (commonly known as *Bowditch*), states, “The safest procedure with respect to tropical cyclones is to avoid them” (Bowditch 2002).[1] The ideal action, according to *Bowditch*, is to set a course “that will take the vessel well to one side of the probable track of the storm, and then continu[e] to plot the positions of the storm center as given in the weather bulletins, revising the course as needed.” For a vessel inside the storm area, the correct action for avoiding danger depends on where the ship is in relation to the storm center and the direction in which it is traveling. *Bowditch* offers a vivid description of the onset of a tropical cyclone:

> An early indication of the approach of a tropical cyclone is the presence of a long swell. In the absence of a tropical cyclone, the crests of swell in the deep waters of the Atlantic pass at the rate of perhaps eight per minute. Swell generated by a hurricane is about twice as long, the crests passing at the rate of perhaps four per minute. Swell may be observed several days before arrival of the storm.
>
> When the storm center is 500 to 1,000 miles away, the barometer usually rises a little, and the skies are relatively clear. Cumulus clouds, if present at all, are few in number and their vertical development appears suppressed. The barometer usually appears restless, pumping up and down a few hundredths of an inch.
>
> As the tropical cyclone comes nearer, a cloud sequence begins which resembles that associated with the approach of a warm front in middle latitudes. Snow-white, fibrous “mare’s tails” (cirrus) appear when the storm is about 300 to 600 miles away. Usually these seem to converge, more or less, in the direction from which the storm is approaching. This convergence is particularly apparent at about the time of sunrise and sunset.
>
> Shortly after the cirrus appears, but sometimes before, the barometer starts a long, slow fall. At first the fall is so gradual that it only appears to alter somewhat the normal daily cycle (two maxima and two minima in the Tropics). As the rate of fall increases, the daily pattern is completely lost in the more or less steady fall.
>
> The cirrus becomes more confused and tangled, and then gradually gives way to a continuous veil of cirrostratus. Below this veil, altostratus forms, and then stratocumulus. These clouds gradually become more dense, and as they do so, the weather becomes unsettled. A fine, mist-like rain begins to fall, interrupted from time to time by rain showers. The barometer has fallen perhaps a tenth of an inch.
>
> As the fall becomes more rapid, the wind increases in gustiness, and its speed becomes greater, reaching perhaps 22 to 40 knots (Beaufort 6–8). On the horizon appears a dark wall of heavy cumulonimbus, called the *bar* of the storm. This is the heavy bank of clouds comprising the main mass of the cyclone. Portions of this heavy cloud become detached from time to time, and drift across the sky, accompanied by rain squalls and wind of

[1] *The American Practical Navigator* is called *Bowditch* after its first author, Nathaniel Bowditch. The work has been published for over 200 years. The US government bought the copyright in 1867. The document is accessible online through Wikisource. Hurricane avoidance is treated in chapter 35 of the document (https://en.wikisource.org/w/index.php?title=The_American_Practical_Navigator/Chapter_35&oldid=4344173).

> increasing speed. Between squalls, the cirrostratus can be seen through breaks in the stratocumulus.
>
> As the bar approaches, the barometer falls more rapidly and wind speed increases. The seas, which have been gradually mounting, become tempestuous. Squall lines, one after the other, sweep past in ever increasing number and intensity.
>
> With the arrival of the bar, the day becomes very dark, squalls become virtually continuous, and the barometer falls precipitously, with a rapid increase in wind speed. The center may still be 100 to 200 miles away in a fully developed tropical cyclone. As the center of the storm comes closer, the ever-stronger wind shrieks through the rigging, and about the superstructure of the vessel. As the center approaches, rain falls in torrents. The wind fury increases. The seas become mountainous. The tops of huge waves are blown off to mingle with the rain and fill the air with water. Visibility is virtually zero in blinding rain and spray. Even the largest and most seaworthy vessels become virtually unmanageable, and may sustain heavy damage. Less sturdy vessels may not survive. Navigation virtually stops as safety of the vessel becomes the only consideration. The awesome fury of this condition can only be experienced. Words are inadequate to describe it.
>
> If the eye of the storm passes over the vessel, the winds suddenly drop to a breeze as the wall of the eye passes. The rain stops, and the skies clear sufficiently to permit the sun or stars to shine through holes in the comparatively thin cloud cover. Visibility improves. Mountainous seas approach from all sides in complete confusion. The barometer reaches its lowest point, which may be 1 1/2 or 2 inches below normal in fully developed tropical cyclones. As the wall on the opposite side of the eye arrives, the full fury of the wind strikes as suddenly as it ceased, but from the opposite direction. The sequence of conditions that occurred during approach of the storm is reversed, and passes more quickly, as the various parts of the storm are not as wide in the rear of a storm as on its forward side.

Hurricanes can be viewed as "atmospheric heat engines," in which heat energy from warm ocean waters is transferred to the atmosphere and transformed into mechanical energy, i.e., wind. As spiraling warm air moves up, then outward, it loses heat in the cold upper atmosphere, then sinks back down into the lower atmosphere, where it warms again. As long as the warm air rises faster than the cooler are spirals inward, the pressure at the center of the storm will fall.

Bowditch points out that relying on weather bulletins to determine the storm center and the semicircle in which a vessel is located is problematic "because of the lag between the observations upon which the bulletin is based and the time of reception of the bulletin, with the ever-present possibility of a change in the direction of the storm." Although radar can eliminate the lag, "the return may not be a true indication of the center." *Bowditch* concludes:

> Perhaps the most reliable guide is the wind. Within the cyclonic circulation, a wind shifting to the right in the northern hemisphere indicates the vessel is probably in the dangerous semicircle. A steady wind shift opposite to this indicates the vessel is probably in the less dangerous semicircle. . . . If in doubt, the safest action is usually to stop long enough to define the proper semicircle. The loss in time may be more than offset by the minimizing of the possibility of taking the wrong action, increasing the danger to the vessel. If the wind direction remains steady (for a vessel which is stopped), with increasing speed and falling barometer, the vessel is in or near the path of the storm. If it remains steady with decreasing speed and rising barometer, the vessel is near the storm track, behind the center.

Bowditch presents specific guidelines for avoiding hurricane-force winds:

> As a general rule, for a vessel in the Northern Hemisphere, safety lies in placing the wind on the starboard bow in the dangerous semicircle and on the starboard quarter in the less dangerous semicircle. . . . If it becomes necessary for a vessel to heave to [stop], the characteristics of the vessel should be considered. A power vessel is concerned primarily with damage by direct action of the sea. A good general rule is to heave to with head to the sea in the dangerous semicircle, or stern to the sea in the less dangerous semicircle. This will result in greatest amount of headway away from the storm center, and least amount of leeway toward it. If a vessel handles better with the sea astern or on the quarter, it may be placed in this position in the less dangerous semicircle or in the rear half of the dangerous semicircle, but never in the forward half of the dangerous semicircle. It has been reported that when the wind reaches hurricane speed and the seas become confused, some ships ride out the storm best if the engines are stopped, and the vessel is left to seek its own position, or lie ahull. In this way, it is said, the ship rides with the storm instead of fighting against it.

These rules are summarized as follows:

> **Right or dangerous semicircle:** Bring the wind on the starboard bow (045° relative), hold course and make as much way as possible. If necessary, heave to with head to the sea.
>
> **Left or less dangerous semicircle:** Bring the wind on the starboard quarter (135° relative), hold course and make as much way as possible. If necessary, heave to with stern to the sea.
>
> **On storm track, ahead of center:** Bring the wind 2 points on the starboard quarter (about 160° relative), hold course and make as much way as possible. When well within the less dangerous semicircle, maneuver as indicated above.
>
> **On storm track, behind center:** Avoid the center by the best practicable course, keeping in mind the tendency of tropical cyclones to curve northward and eastward.

In 1857, a Dutch meteorologist, C.H.D. Buys Ballot, published a law outlining general rules for steering vessels away from the worst part of any rotating storm system. Buys Ballot’s technique relies on cloud formations, wind speed, and barometric pressure. The underlying principles of Buys Ballot’s law state that for anyone ashore in the northern hemisphere and in the path of a hurricane, the most dangerous place to be is in the right front quadrant of the storm. There, the observed wind speed of the storm is the sum of the speed of wind in the storm circulation plus the velocity of the storm’s forward movement. Buys Ballot’s Law calls this the “dangerous quadrant.” Likewise, in the left front quadrant of the storm, the observed wind is the *difference* between the storm’s wind velocity and its forward speed. This is called the “safe quadrant” due to the lower observed wind speeds. If a person stands with his or her back to the wind, the atmospheric pressure is low to the left, high to the right, because wind travels counterclockwise around low-pressure zones in the northern hemisphere. The left side is thus the direction in which the storm is moving.

According to the *Mariner’s Guide for Hurricane Awareness in the North Atlantic Basin*, published by the National Weather Service (Holweg 2000), typical hurricanes possess tropical storm force wind fields of about 300 nm in diameter. The guide therefore advises mariners:

> do not focus on the location and track of the center, because the hurricane's destructive winds and seas cover a broad path. Hurricane force winds can extend outward about 25 nautical miles from the storm center of a small hurricane to more than 150 nautical miles for a large one. The range over which tropical storm force winds occur is even greater, possibly extending as far as 300 nautical miles from the eye of a large hurricane.

The mariner's guide contains rules for hurricane avoidance as well as information about the nature of tropical cyclones and where to obtain storm forecasts. The guide recommends doing a risk analysis four times a day when an active tropical cyclone is approaching or near the region where the vessel is operating. (Four times a day coincides with the issuance of the National Hurricane Center's tropical cyclone forecast/advisory.) The risk analysis should include obtaining the latest forecasts and charts, including surface, upper level, and sea state; plotting current and forecast positions of active tropical cyclone activity; and comparing forecast tracks to evaluate whether to increase the buffer zone around the tropical cyclone. According to the guide's risk-analysis checklist, plotting should ensure that the vessel meets the requirements of the 34-knot rule and the 1-2-3 rule.

The 34-Knot Rule. For vessels at sea, the maximum wind speed of a storm and its position and forecast track are less important than the size and shape of the wind field—in particular, where sustained wind speeds are at least tropical storm force (34 knots) or could become that strong. Hence, avoiding the 34-knot wind field of a tropical cyclone is critical for mariners. As stated in the mariner's guide, "All vessels in the vicinity of a tropical cyclone should, at a minimum, remain outside of this danger area."

The 1-2-3 Rule. One method of avoiding the dangerous area of a tropical storm or hurricane is by following the "mariner's 1-2-3 rule." The danger area is plotted by adding 100 nm to the maximum radius of the 34-knot winds in the 24-hour forecast, 200 nm to the maximum radius of the 34-knot winds in the 48-hour forecasts, and 300 nm to the maximum radius of the 34-knot winds forecast for 72 hours. A circle is then drawn around each forecast position (moving across the chart with the storm), and a line is drawn connecting the circles. The area enclosed by the line is the danger area. The 1-2-3 rule is illustrated in figure E.

The National Hurricane Center's tropical cyclone danger graphic is based on the mariner's 1-2-3 rule (the rule was replaced in 2016 with a method based on wind speed probabilities), shading a map to show the danger area of a tropical cyclone. The danger graphic for Hurricane Joaquin valid for the time *El Faro* departed Jacksonville on September 29 is included as figure 39 in the report.

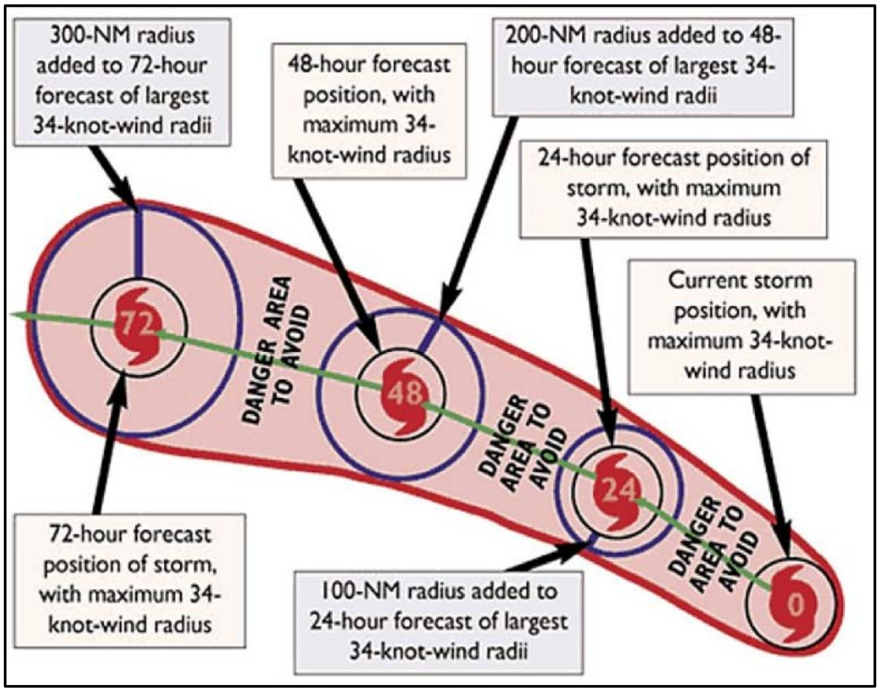

Figure E. Diagram of 1-2-3 rule. Green line represents center of storm track. (Adapted from figure 29 in Holweg 2000)

Appendix F
Detailed Information about Vessel's Lifesaving Equipment

The manufacturer, dates of manufacture and approval, if known, and other details of the survival gear carried on *El Faro* are listed in table F-1. The Coast Guard certificates of approval for items marked "Former—May Use" were in effect indefinitely but had been transferred to the National Archives in Washington, DC, for storage. Coast Guard approval numbers were provided by Harding Safety, the company that serviced *El Faro*'s lifeboats, then searched on a Coast Guard database. Table F-2 lists details of the debris from *El Faro*'s survival gear that was discovered or recovered after the sinking.

Table F-1. Details of survival equipment carried by *El Faro*.

Equipment	Manufacturer	Manufacture Date	Approval	Characteristics
Lifeboat 1 (starboard)	MASECO	9/5/1974 (boat 2413)	Coast Guard No. 160.35/461/0 Issued: 4/11/1980 Exp: 9/6/1986 Status: "Former—may use lifeboat for merchant vessels"	Dimensions: 26.5 ft x 9 ft x 3.83 ft Capacity: 43 persons Construction: open Propulsion: mechanical (hand-propelled Fleming gear) Material: fiberglass-reinforced plastic with internal buoyancy foam Launch: gravity davit Recovery: winch
Lifeboat 2 (port)	MASECO	unknown (boat 2412)	Coast Guard No. 160.035/460/0 Issued: 5/9/1975 Exp: 6/2/1980 Status: "Former—may use lifeboat for merchant vessels"	Vessel's rescue boat Dimensions: 26.5 ft x 9 ft x 3.83 ft Capacity: 48 persons Wt. (full load): 12,782.4 lb Construction: open Propulsion: motor (diesel engine) Material: fiberglass-reinforced plastic with internal buoyancy foam Launch: gravity davit Recovery: winch
Davits (same on both lifeboats)	MASECO	unknown	Coast Guard No. 160.032/173/0 Issued: 3/16/1982 Exp: 3/16/1987 Status: "Former—may use"	Type: gravity Serial No.: 26-15 Maximum working load: 15,000 lb per set (7,500 lb per arm) using 2-part fall wires
Winch (same on both lifeboats)	MASECO	unknown	Coast Guard No. 160/015/93/2 Issued: 11/12/1988 Exp: 11/12/1993 Status: "Former—may use lifeboat winch for merchant vessels"	Type: 35G-MK II Model: 256 Serial No.: 1070-1 Load: 3,750 lb per fall

Equipment	Manufacturer	Manufacture Date	Approval	Characteristics
Release hook (same on both lifeboats)	MASECO	unknown	(a)	Type: Rottmer SWL 7000
Liferaft 1	Viking Life-Saving Equipment	10/2005	Coast Guard no. 160.151/117/0 Issued: 6/24/2015 Exp: 6/24/2020 Status: Approved	Type: inflatable Serial No.: Viking 25DK+10245946 Emergency pack: SOLAS A Capacity: 25 persons Packed weight: 380 lb Location: boat deck, starboard side Inspected: 9/4/2015 Next Insp: 9/2016
Liferaft 2	Viking Life-Saving Equipment	10/2005	Coast Guard no. 160.151/117/0 Issued: 6/24/2015 Exp: 6/24/2020 Status: Approved	Type: inflatable Serial No.: Viking 25DK+10245947 Emergency pack: SOLAS A Capacity: 25 persons Packed weight: 380 lb Location: boat deck, port side Inspected: 9/4/2015 Next Insp: 9/2016
Liferaft 3	Viking Life-Saving Equipment	11/2010	Coast Guard No. 160.151/108/0 Issued: 6/24/2015 Exp: 6/24/2020 Status: Approved	Type: inflatable Serial No.: Viking 06DK+11355928 Emergency pack: SOLAS A Capacity: 6 persons Packed weight: 155 lb Location: port side, forward on main deck Required on vessels over 100 m long Inspected: 5/18/2015 Next Insp: 5/2016
Liferaft 4	Survitec Group, Ltd.	7/2015	Coast Guard No. 160.151/130/3 Updated: 6/24/2014 Issued: 8/22/2016 Exp: 6/24/2019 Status: Approved	Type: inflatable Model: Elliot SOLAS style MkIV TO Serial No.: 5086300200735, lot 2451 Emergency pack: SOLAS A Capacity: 25 persons Packed weight: 406 lb Manufactured: 7/2015 Next Insp: 7/7/2017
Liferaft 5	Survitec Group, Ltd.	7/2015	Coast Guard No. 160.151/130/3 Updated: 6/24/2014 Issued: 8/22/2016 Exp: 6/24/2019 Status: Approved	Type: inflatable Model: Elliot SOLAS style MkIV TO Serial No.: 5086300200613, lot 2463 Emergency pack: SOLAS A Capacity: 25 persons Packed weight: 406 lb Manufactured: 7/2015 Next Insp: 7/27/2017

Equipment	Manufacturer	Manufacture Date	Approval	Characteristics
Lifejackets	Safegard Corporation	unknown	Coast Guard No. 160.002/70/0 Issued: 12/6/2004 Exp: 12/6/2009 Status: “Former— may use”	Type: with whistle and light Model: 3, 190, or 190RT kapok most recent type 1 on CG EQList database Location: crew quarters (41); bridge (3); engine room control station (3); bow (2); port lifeboat (2); starboard lifeboat (2); gear locker spares (12)
Lifebuoys	Datrex, Inc.	For 2 recovered: 12/2004, 11/2008	Coast Guard No. 160.050/127/0 Update: 1/29/2009 Issued: 1/29/2014 Exp: 1/29/2019 Status: Approved	Size: diameter = 30 in. Type: with self-igniting ACR lights (13); quick-release with light and smoke floats (2); with buoyant line (2); without attachments (13); spare (1) Location: weather decks, except 2 quick-release on port and starboard bridge wings
Immersion suits	Various: Imperial, Stearns, Baileys, Fitzwright, Revere; Kent for 4 new XL suits	For 1 recovered: 6/1985 (Imperial Manufacturing Co.)	Coast Guard No. 160.071/1/2 Issued: 9/1/1987 Exp: 9/1/1992 Status: “Former— may use”	Type: Adult universal Model: 1409 Serial Nos.: 94797, lot 348; and 95015, lot 351/6 Size: total includes 4 oversize, newly purchased Location: crew quarters
EPIRB	Jotron	unknown	FCC: Type- accepted Coast Guard No. 161.011/91/0 Issued: 3/26/2008 Exp: 3/26/2018 Status: Approved	Model: Jotron Tron 40S MkII Frequency: 406.037 MHz Serial Nos.: 09170 (on 1/27/2015 safety survey by Imtech Marine/Radio Holland); ADCDO 28F4A 40C01 (ID FCC registration); 49989 (on ABS certificate) Antenna: omnidirectional, 5 watts GPS: none Operating life: minimum 48 hr Battery exp: 2/1/2019 Release: manual or hydrostatic Bracket: Type FB-6; Serial 03101 Hydrostatic release exp: 2/1/2016 Date Registered: 2/1/2012 Last Update: 12/3/2013 Decal exp: 12/3/2015 In service: 2/16/2007, Jacksonville FL
Lifeboat radios (3)	ACR Electronics	unknown	FCC: B668L2ACR-SR-102 Issued: 2/8/2000 Exp: none	Serial Nos. (battery exp): 952061 (1/1/2019); 14609 (1/1/2019); 95703 (12/12/2018) Model: SR-102R, 2-channel VHF GMDSS survival radio

Equipment	Manufacturer	Manufacture Date	Approval	Characteristics
SART 2	Jotron	unknown	FCC: VRVTRONSART20 Issued: 5/16/2008 Exp: none	Model: Tron, SART, 9 gigahertz Serial Nos.: 10595, 10601 Both units' batteries exp: 2/1/2018 Operation life: 96 hr standby, 8 hr continuous Trigger: X-band radar on search-and-rescue vessel
Long-range identification and tracking	Thrane &Thrane	unknown	Coast Guard No.165.207/1/0 Issued: 3/16/2009 Exp: 3/16/2004 Status: Expired FCC cert. required	Model: TT-3000LRIT ID: 4TT088FF662A Freq: Rx and Tx GPS: 1575.42 MHz GPS module: 12-ch; 1 sec updates Serial No.: 436820881 TT-3026M Mini-C transceiver In service: 4/2/2010, Baltimore MD Last ABS survey: 4/15/2010

NOTE: "Former" approval status indicates "product is no longer approved for production but previously produced items may continue to be used as long as in good and serviceable condition" (Coast Guard Maritime Information Exchange, Approved Equipment List).

[a] No information available. Certificate of approval for release hook had been removed from Coast Guard files but was not found in Coast Guard records deposited at National Archives.

Table F-2. *El Faro* survival debris discovered or recovered.

Survival Debris	Evidence ID	Description
Starboard lifeboat	None	Lifeboat 1 sighted by air ~1500 on October 4, at 23.4033N, 073.9083W. Tug *Hawk* arrived at 1537 and found lifeboat heavily damaged, floating vertically with 2-3 ft of bow above water. At 1552, Coast Guard helicopter lowered rescue swimmer onto tug *Hawk*. Rescue swimmer was in water from 1600 until 1616, inspecting lifeboat. Helicopter retrieved rescue swimmer at 1620. Lifeboat damage: -Port bow missing section of gunwale 61 in. long and 32 in. toward keel. -Port quarter missing gunwale section 42 in. long and 33 in. down. -Starboard quarter missing 150-in. section of gunwale extending down to keel. -Many sections of hull cracked. -Propeller fouled with lines, blade bent. -Bow and stern manual hook release handles bent and inoperable. -Rudder tiller missing. -Sea anchor tangled with sea painter.
Port lifeboat	Dive S381 Contact 0153	Lifeboat 2 found on ocean floor by AUV *Sentry* at position 23.3916N, 073.9083W. One end was cut off.
Liferaft	N/A	Discovered 2057 UTC on October 4 at 23.4866N, 073.5883W by cutter *Northland*. Searched and found empty, then sunk. Second liferaft, reported at 1657 on October 4 by Navy P-8 at 23.4116N, 073.915W, could not be relocated. Coast Guard determined that it was vessel's starboard lifeboat.

Survival Debris	Evidence ID	Description
Lifejacket	Mission III, ROV CURV-21, date/time 8/9/2016 09:10:06	Lifejacket with reflective material found by AUV under debris on aft starboard side of *El Faro*'s boat deck, near ladder down to cabin deck.
Immersion suit—1 of 3; with human remains	N/A	Found 2047 UTC on October 4 at 23.4266N, 074.1966W. Investigated, but after helicopter was called away, could not be reacquired.
Immersion suit—2 of 3	176809	Recovered 2306 UTC on October 6 at 24.0644N, 073.235W by cutter *Charles Sexton*. Label: "Imperial Manufacturing Co., Bremerton, WA 98310; Adult Universal (more than 110 lbs); Model No. 1409; Serial No. 94797; Lot No. 348; manufacture date 6-85."
Immersion suit—3 of 3	176812	Recovered 1603 UTC October 7 at 23.9816N, 073.325W by cutter *Charles Sexton*. Label: "Imperial Manufacturing Co., Bremerton, WA 98310; Adult Universal (more than 110 lbs.); Model No. 1409; Serial No. 95015; Lot No. 351/6; manufacture date 6-85."
Lifebuoy—1 of 8	None	Recovered by *El Yunque* and passed to cutter *Northland* for transfer to Coast Guard Sector Jacksonville.
Lifebuoy —2 of 8	None	Stenciled "El Faro"; damaged DATREX label; missing circular plastic plug for inserting flotation material.
Lifebuoy—3 of 8	176808	Recovered 1810 UTC on October 6 at 24.0983N, 073.4266W by cutter *Charles Sexton*. DATREX buoy broken in half; stenciled "El Morro San Juan, PR."
Lifebuoy—4 of 8	197131	Recovered October 5 at 24.6266N, 073.055W by cutter *Resolute*.Stenciled "El Faro." DATREX Inc. Kinder LA commercial ring buoy type IV PFD; Model DX03250; deck buoy; issue no. e-843; lot no. 822; insp. 12-08; mfg date 11-08.
Lifebuoy—5 of 8	197132	Recovered October 5 at 24.62N, 073.0616W by cutter *Resolute*.Stenciled "El Morro." Torn, missing circular plastic plug for inserting flotation material. Embossed DATREX Buoy.
Lifebuoy—6 of 8	197134	Recovered October 5 at 24.6383N, 073.03W by cutter *Resolute*. Stenciled "El Faro." Damaged label reads "No. E-122" and "2002"; same label format as DATREX deck buoy.
Lifebuoy—7 of 8	197135	Recovered October 5 at 24.64N, 073.02W by cutter *Resolute*. Stenciled "El Far." DATREX Inc. Kinder LA USA; issue No. E-843; lot No. 711; mfg date 12-04; insp. 12-04.
Lifebuoy—8 of 8	None	Recovered around November 11 on Man-O-War Cay, Abaco Island, Bahamas, at about 26.5983N, 077.0033W, by beachcomber. Stenciled "El Faro." DATREX Inc. Kinder LA USA.
Smoke float—1 of 2	None	Recovered by cutter *Charles Sexton*.
Smoke float—2 of 2	Dive S385	Found on ocean floor by AUV *Sentry* at 23.3866N, 073.91W.

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