National Transportation Safety Board

Office of Research and Engineering

Washington, D.C. 20594

Group Chairman's Factual Report

Electronic Data Group

SS *El Faro*

DCA16MM001

December 13, 2016

Douglas Mansell

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1. ACCIDENT INFORMATION

Vessel:	SS *El Faro*
Accident Number:	DCA16MM001
Date:	October 1, 2015
Time:	0739 eastern daylight time (EDT) 1139 coordinated universal time (UTC)
Location:	North Atlantic Ocean, 40 nautical miles northeast of Acklins and Crooked Islands, Bahamas 23.392522° N, 73.902930° W [1]
Accident type:	Sinking
Complement:	27 crew, 6 supernumeraries

2. ELECTRONIC DATA GROUP

2.1. Parametric Data

A group was not convened for data recovery.

2.2. Voyage Data Recorder

The recovery of data from *El Faro*'s simplified voyage data recorder (S-VDR)[2] capsule was supported by the following technical representatives. A group was convened to transcribe audio recovered from the S-VDR; see the Voyage Data Recorder Audio Transcript Group Chairman's Factual Report for details.

[1] Final position recorded to VDR before sinking.

[2] A simplified voyage data recorder (S-VDR) is commonly called a voyage data recorder (VDR). Functionally, an S-VDR is the same as a VDR, though an S-VDR records fewer parameters.

Group Chairman	Douglas Mansell Vehicle Recorder Division Office of Research and Engineering National Transportation Safety Board Washington, DC
VDR Capsule Manufacturer Representative	Peter Videcrantz Technical Director Danelec Marine Denmark
VDR Capsule Manufacturer Representative	Christian Schaffalitzky de Muckadell Software Manager, Electronics Engineer Danelec Marine Denmark
Marine Accident Investigation Branch, United Kingdom (on behalf of Danish Maritime Accident Investigation Board[3])	Richard North Technical Manager Marine Accident Investigation Branch United Kingdom

3. SUMMARY

On Thursday, October 1, 2015, about 0715 EDT, the US Coast Guard received distress alerts from the 790-foot roll-on/roll-off container ship *El Faro*. The US-flagged ship, owned by TOTE Maritime Puerto Rico (formerly Sea Star Line, LLC) and operated by TOTE Services (TOTE), was 36 nautical miles northeast of Acklins and Crooked Islands, Bahamas, and close to the eye of Hurricane Joaquin. The ship was en route from Jacksonville, Florida, to San Juan, Puerto Rico, with a cargo of containers and vehicles. Just minutes before the distress alerts, the *El Faro* master had called TOTE's designated person ashore (DPA) and reported that a scuttle had popped open on deck two and that there was free communication of water into the No. 3 hold. He said the crew had controlled the ingress of water but that the ship was listing 15° and had lost propulsion. The Coast Guard and TOTE were unable to reestablish communication with the ship. Twenty-eight US crewmembers, including an off-duty engineering officer sailing as a supernumerary, and five Polish workers were on board. The vessel sank in 15,300 feet of water.

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

[3] The recorder was manufactured in Denmark. As the investigation authority in the country of manufacture, the Danish Maritime Accident Investigation Board (DMAIB) was invited to observe the data recovery process. DMAIB requested a representative from the Marine Accident Investigation Branch, United Kingdom, to attend on its behalf.

The National Transportation Safety Board (NTSB) led three voyages in the search for the *El Faro*'s wreckage and to locate and recover its VDR capsule.[4] Data summarized in this report were used to support search and recovery efforts as well as investigative analyses.

4. DETAILS OF INVESTIGATION

The NTSB learned of the accident from the Coast Guard on the afternoon of October 1, 2015. A team of five investigators, a board member, and support staff launched from NTSB headquarters on October 6 and arrived on scene in Jacksonville later the same day. The investigation was led by the NTSB. Parties to the investigation were the Coast Guard, TOTE, the American Bureau of Shipping, and the National Weather Service. The on-scene part of the investigation was completed on October 15. NTSB Research and Engineering staff collected and organized electronic data associated with the accident.

Interviews with Northrop Grumman Sperry Marine personnel were conducted in Harvey, Louisiana, in February 2016. Staff from the National Ocean and Atmospheric Administration (NOAA) Search and Rescue Satellite Aided Tracking (SARSAT) system were interviewed in Suitland, Maryland, in March 2016.[5] The Coast Guard convened Marine Board of Investigation (MBI) hearings in Jacksonville in February and May 2016.[6,7] The NTSB participated in the hearings. Staff from Marlink, operator of Inmarsat land earth station (LES), Eik, in Norway, were interviewed by telephone in November 2016.

5. FACTUAL INFORMATION

This report presents data obtained from a variety of sources. Some sources are compulsory equipment for commercial vessels, some are not. Carriage requirements for VDRs are addressed here. Regulatory carriage requirements for other bridge and emergency communication equipment are discussed in the Nautical Operations and Survival Factors reports.

Vessel tracking data – date, time, and location – from all sources are in general agreement. Investigators relied on data recovered from sources other than the VDR for the first year of the investigation. Initial weather and sea-state studies were conducted using preliminary vessel position data from sources other than the VDR. Once the VDR capsule was recovered, position-tracking data were determined to be consistent with the preliminary data used to analyze weather and sea state.[8]

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[4] Planning and execution details of the search and recovery voyages are not discussed in this report.

[5] Refer to the SARSAT Senior Space Systems Engineer interview transcript, available in the docket.

[6] Refer to the docket for complete transcripts of the Coast Guard MBI hearings. The hearings were open to the public. Coast Guard video of the hearings is available at https://livestream.com/USCGinvestigations. Additional video may be available from other news outlets.

[7] Representatives from Northrop Grumman Sperry Marine testified on the eighth day of the first round of hearings, February 24, 2016.

[8] Refer to the Meteorology Group Chairman's Factual Report for additional information. The basic difference was that VDR data were recorded more frequently than the other sources of position-tracking data.

5.1. Automatic Identification System

The automatic identification system (AIS) is a tracking system used to identify and locate ships by electronically exchanging data on dedicated VHF frequencies with nearby ships, AIS base stations, and satellites. AIS information includes unique identification, position, course, and speed of a ship or station. The Coast Guard records national AIS (NAIS) data from a terrestrial network of AIS base stations along coastlines, in addition to recording AIS data from a satellite network for waters beyond the range of the terrestrial network.[9]

El Faro was equipped with a JHS-182 AIS, serial No. BB44685, manufactured by JRC.[10] Attachment 1 contains AIS data from *El Faro* during the accident voyage, recorded by terrestrial and satellite networks. The last NAIS position was from October 1, 2015, at 0356 EDT.[11]

5.2. WAM Technologies Refrigerated Container Tracking

WAM Technologies, Inc., monitors, controls, and tracks refrigerated containers (reefers) remotely. Using global system for mobile communications (GSM) and global positioning system (GPS) technology, operators can track reefer position and status globally. The service was used for refrigerated containers onboard *El Faro* during the final voyage; data were provided by TOTE. Attachment 2 contains WAM position-tracking data from containers onboard *El Faro* during the accident voyage. The last WAM position was from October 1, 2015, at 0228 EDT.

5.3. Inmarsat FleetBroadband Communications

Inmarsat Globe Wireless supplied *El Faro* with satellite email and voice communications transmitted through an installed Globe i250 FleetBroadband system.[12] The installation consisted of an above-deck and a below-deck unit. The above-deck unit included an antenna, installed on the ship's exterior where there was a clear view of the sky. The below-deck unit included a rack-mounted electronic controller and an uninterruptible power supply (UPS).[13] The below-deck unit was installed on the bridge, and included a voice handset for phone calls; additional phone handsets were installed in the captain's stateroom and the chief engineer's stateroom.[14] 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. Figure 2 diagrams a typical Globe i250 installation.

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[9] Refer to the Coast Guard's NAVCEN website for an AIS overview: http://www.navcen.uscg.gov/?pageName=AISmain.

[10] Equipment identified on *El Faro* ABS Record of Approved Cargo Ship Safety Equipment, p. 29.

[11] AIS data were also recorded on *El Faro*'s S-VDR. Refer to section 5.5.4 of this report for discussion about AIS data recovered from the S-VDR.

[12] Refer to the Globe Wireless website for additional information: http://www.globewireless.com.

[13] A UPS protects electrical equipment from unexpected power disruptions. The UPS stores energy, in batteries or supercapacitors, to allow equipment a short runtime when the normal power supply is interrupted.

[14] Refer to the transcript of the October 7, 2015, interview of *El Yunque* master, p. 38.

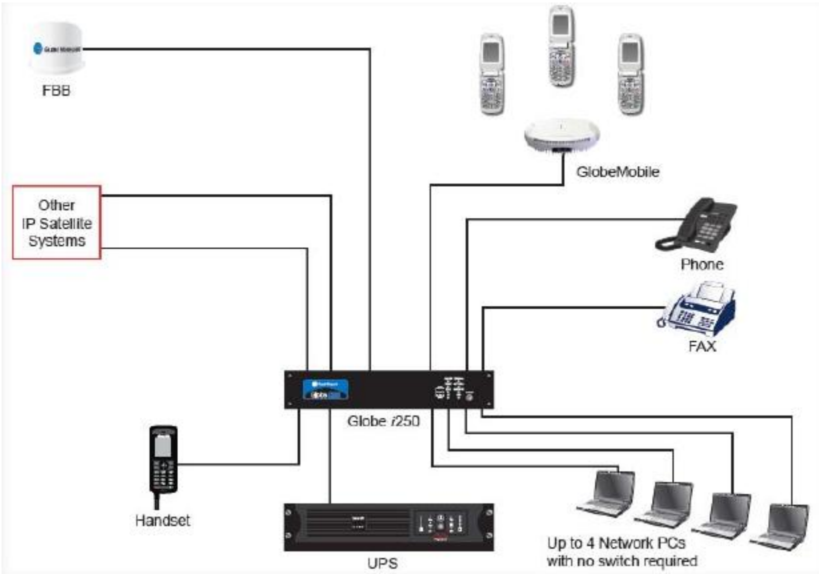

***Figure 2**. Globe i250 system diagram (photo from Globe Wireless installation guide). Optional GlobeMobile module was not installed on El Faro.*

Outgoing email messages awaiting transmission from *El Faro* were queued in an outbox. Outgoing and incoming email messages were transmitted to or from *El Faro* only during an active FleetBroadband data session. FleetBroadband email connections were established using Globe Communications Center (GCC) software installed on a computer in the captain's stateroom. In addition to on-demand connections, the GCC software could be configured to automatically connect and sync emails at scheduled times of the day. TOTE crewmembers told investigators that the system was configured to sync emails periodically, as long as the computer in the captain's stateroom was on and running the GCC software.[15]

TOTE used GlobeArchive to archive all email messages to and from *El Faro's* Globe email accounts. GlobeArchive records include sender, subject, date, time, recipient(s), message text, and attached files. GlobeArchive email records were searched for information to assist investigators, including position reports, weather forecasts, route planning, maintenance history, and other pertinent information.[16] GlobeArchive did not provide email read-receipt records, so there is no indication when, or if, a given email message was actually viewed by the recipient(s).

5.3.1. Email Content: GPS Position Track Logs

The GCC software automatically cached GPS logs of *El Faro's* position.[17] Position logs were automatically transmitted whenever the FleetBroadband email system was synced.

[15] TOTE employees explained in interviews that email transmissions to or from the ship were controlled by the captain's computer. Refer to the transcript of the October 7, 2015, interview of *El Yunque* master (p. 30, line 18), and the October 9, 2015, interview of *El Yunque* chief mate (p. 49, line 24).

[16] This report documents position track logs and the timing of availability to BVS weather forecast products. Other reports may reference additional content recovered from GlobeArchive email records.

[17] Position logs were from the antenna in the Globe i250 above-deck unit.

Attachment 3 contains position-tracking data recovered from *El Faro's* Inmarsat GlobeArchive email records. The last GlobeArchive email position was from October 1, 2015, at 0546 EDT.

5.3.2. Email Content: BVS Weather Forecast Products

The Bon Voyage System (BVS) from Applied Weather Technology, Inc., provided *El Faro* with weather information. Subscribed BVS weather forecast products were routinely emailed to *El Faro*'s captain every 6 hours.[18,19] GlobeArchive email records were used to determine when BVS emails were transmitted to *El Faro*. Table 1 indicates when each of the BVS forecast emails was sent from BVS, when it was available for satellite download to *El Faro*, and when it was actually downloaded to the ship. BVS weather files from the associated emails could not have been viewed on *El Faro* before the download time.

Table 1. BVS email transmissions to *El Faro* during final voyage.

Time BVS Email was Sent from Applied Weather Technologies (EDT)		Time BVS Email was Available for Download from Inmarsat Globe Email System (EDT)		Time BVS Email was Downloaded to *El Faro* (EDT)	
29-Sep-2015	1702	29-Sep-2015	1704	29-Sep-2015	1837
29-Sep-2015	2302	29-Sep-2015	2304	29-Sep-2015	2329
30-Sep-2015	0502	30-Sep-2015	0504	30-Sep-2015	0608
30-Sep-2015	1102	30-Sep-2015	1103	30-Sep-2015	1124
30-Sep-2015	1702	30-Sep-2015	1703	30-Sep-2015	1747
30-Sep-2015	2302	30-Sep-2015	2304	1-Oct-2015	0445
1-Oct-2015	0502	1-Oct-2015	0503	1-Oct-2015	0609

The second-to-last BVS email received by *El Faro* was downloaded to the vessel at 0445 EDT, 5 hours and 41 minutes after it became available. It is not evident which email downloads occurred as a result of deliberate action by the crew and which resulted from scheduled automatic system connections.

5.3.3. Inmarsat Satellite Logs

Inmarsat Maritime provided communication logs that periodically tracked the position of the Globe i250 FleetBroadband antenna installed on *El Faro*. Attachment 4 contains position-tracking data provided by Inmarsat. The last position recorded on the logs was from October 1, 2015, at 0459 EDT.

5.3.4. Inmarsat FleetBroadband Voice Communications

Attachment 5 contains call logs for *El Faro*'s FleetBroadband voice phone line, which had handsets in the captain's stateroom, the chief engineer's stateroom, and on the bridge. This is the only telephone line on *El Faro* that investigators confirmed to have been used for voice communications to or from *El Faro* on the day of sinking.[20]

[18] Refer to the Meteorology Group Chairman's Factual Report for additional information about BVS.

[19] BVS emails were sent to the captain's email address; Interviews of TOTE crew members, conducted December 6, 2015, indicate the BVS emails were commonly forwarded by the captain to the bridge. Interview transcripts are available in the docket.

[20] TOTE's records indicate that other satellite phones were previously associated with *El Faro*. TOTE's Emergency Response Manual, and the EPIRB registration information filed with NOAA, each list a different phone number for *El Faro*.

Two calls originated from *El Faro* the morning of the sinking. At 0659:23 EDT, the captain called *El Faro*'s DPA.[21] The connection lasted 54 seconds, and the captain left a voicemail.[22] The captain then called TOTE's emergency response answering service, at 0700:47 EDT. The call lasted 11 minutes, 46 seconds, split between time on the phone with the answering service and time on the phone with the DPA.[23] On the morning of the sinking, 26 incoming calls to *El Faro's* FleetBroadband voice telephone went unanswered. The first unanswered call was from the DPA, at 0704:07 EDT, while the captain was on the phone with the emergency response answering service. For later incoming calls, Inmarsat call logs indicate "subscriber absent."

5.4. Global Maritime Distress and Safety System

Global Maritime Distress and Safety System (GMDSS) equipment provides automated delivery of marine safety information, including navigational and meteorological forecasts. Marine safety information is commonly transmitted via NAVTEX and Inmarsat-C.[24, 25] For GMDSS transmissions, *El Faro* had a Furuno FELCOM 15 Inmarsat-C mobile earth station (MES), with an internal GPS module.[26]

A distinct audible alert sounded on the bridge whenever an Inmarsat-C SafetyNET message was received. The Voyage Data Recorder Audio Transcript Group Chairman's Factual Report identifies when *El Faro* received Inmarsat-C messages. Table 2 provides a list of incoming Inmarsat-C SafetyNET messages noted in the VDR transcript. The content of received SafetyNET messages is discussed in the Meteorology Group Chairman's Factual Report.

[21] The DPA provides a link between the operating company and the people on a vessel. DPA duties include monitoring safety and pollution prevention on each ship. The DPA has direct access to the highest level of management and provides communication between ship and shore.

[22] The recorded voicemail from the captain to the DPA was publicly released during the DPA's testimony on the fifth day of the first round of Coast Guard MBI hearings, February 20, 2016. A transcript is included in the docket.

[23] During an October 7, 2015, interview of the DPA, investigators listened to the audio recorded between the captain and the emergency response answering service. The recording was publicly released during the DPA's testimony on the fifth day of the first round of Coast Guard MBI hearings, February 20, 2016. A transcript is included in the docket. The recording ended once the captain's call was forwarded to the DPA. Audio recorded to the VDR captured the captain's side of this conversation.

[24] Navigational Telex (NAVTEX) uses narrow band direct printing (NBDP) over medium frequency transmissions. For additional information, refer to the Coast Guard's NAVCEN website, http://www.navcen.uscg.gov/?pageName=NAVTEX, and NOAA's National Weather Service website, http://www.nws.noaa.gov/om/marine/navtex.htm.

[25] Refer to the Meteorology Group Chairman's Factual Report for additional information regarding NAVTEX and Inmarsat-C SafetyNET messages, including the messages transmitted during *El Faro*'s final voyage.

[26] An optional internal GPS module, part 001-017-110, is listed on the Radio Holland (formerly known as Imtech Marine) invoice for the Furuno FELCOM 15 installation on *El Faro*.

Table 2. Inmarsat-C SafetyNET transmission times noted in VDR transcript.

Time audible alert for incoming SafetyNET message begins (EDT)	
29-Sep-2015	0625:08
29-Sep-2015	0638:30
29-Sep-2015	1035:06
29-Sep-2015	1056:51
29-Sep-2015	1223:58
29-Sep-2015	1634:38
29-Sep-2015	1654:19
29-Sep-2015	1824:15
29-Sep-2015	2237:17
29-Sep-2015	2253:24
1-Oct-2015	0026:00
1-Oct-2015	0435:41
1-Oct-2015	0446:55
1-Oct-2015	0623:16

Search-and-rescue crews did not detect any transmissions from either of the search-and-rescue radar transponder (SART) devices on *El Faro*.[27]

Authorities received electronic distress alerts from three GMDSS sources, each discussed further in the following sections: Inmarsat-C distress alert, ship's security alert system (SSAS),[28] and emergency position-indicating radio beacon (EPIRB).

5.4.1. Inmarsat-C Distress Alert

An hour before sinking, the second mate and captain discussed preparing distress alert messages for transmission.[29] The distress alert was addressed from *El Faro's* MES to the Coast Guard Atlantic Area Command Center (LANTWatch) email address. The Eik LES, located in Norway and operated by Marlink,[30] received *El Faro's* Inmarsat-C distress alert at 0713:20 EDT; the original distress alert email was automatically sent to LANTWatch. A copy of Marlink's Inmarsat-C distress alert logs for *El Faro* are provided as Attachment 6. The Inmarsat-C distress alert contained the following information:

[27] *El Faro's* equipment list includes two Jotron SART devices, serial Nos. 595 and 601.

[28] *El Faro's* SSAS was part of the FELCOM 15 installation. SSAS is not required as part GMDSS, but GMDSS equipment can be used to support SSAS.

[29] Refer to the Voyage Data Recorder Audio Transcript Group Chairman's Factual Report.

[30] Marlink was formally known as Astrium Services.

```
-------------- Distress Alert Received --------------
Mobile Terminal No    : 436820812
To CES                : 001
Position              : 23.28'N 73.48'W
Position updated      : 10:30 UTC
Nature of distress    : Flooding
Course                : 235          Speed : 8
Activation            : Distress Alert
Position activated    : Yes
Course/Speed updated  : Yes
-----------------------------------------------------
```

Upon receiving the distress alert at the LES, Marlink sent a separate email to LANTWatch. The supplemental email included contact information for *El Faro*. Marlink did not forward or attach the original distress alert to the supplemental email. LANTWatch confirmed receipt of both emails, and forwarded the supplemental email to the Coast Guard rescue coordination center (RCC) in Miami, Florida.[31] LANTWatch did not forward the original distress alert email to RCC Miami. The RCC in Miami received the following Inmarsat-C distress information for *El Faro*:

```
ALERT DATE: 2015-10-01      ALERT TIME: 11:13:21
TYPE OF ALERT:              INMARSAT
OCEAN REGION:               AORW
ALERT MODE: DISTRESS        POSITION: 23.28N 73.48W
INMARSAT NUMBER:            436820812
ANSWERBACK:                 FARO
VESSEL NAME:                EL FARO
CALL SIGN:                  WFJK
ADDITIONAL INMARSAT NO:     436820811 - TELEX
                            436820812 - TELEX
                            1512137 - TELEX
                            1512137 - TELEX
                            1512140 - TELEX
```

Without a copy of the original Inmarsat-C distress alert, RCC Miami did not know the course, speed, and time associated with the reported position.[32] The format of the Inmarsat-C distress alert position was interpreted as decimal degrees, which resulted in logging an inaccurate primary location in the Coast Guard’s Marine Information for Safety and Law Enforcement (MISLE) system.[33]

5.4.2. Ship Security Alert System

The SSAS is used to transmit a security alert to predetermined recipients when the security of a ship is under threat or has been compromised. The alert is discreet, with no audible or visible alarm generated onboard, and is not broadcast to other ships. Once activated, an SSAS alert

[31] A list of Coast Guard RCCs, and their corresponding areas of responsibility, can be found online at https://www.uscg.mil/hq/cg5/cg534/RCC_numbers.asp.

[32] Coast Guard had other sources of information available, including the SSAS alert and the position *El Faro*’s captain provided the DPA during their phone call, just prior to activating distress alerts.

[33] The MISLE system stores information on the Coast Guard’s marine safety, security, environmental protection, and law enforcement programs.

transmits, at a specified rate until deactivated, time, position, course, speed, and a predetermined message.

El Faro was equipped with a Furuno SSAS, connected to the FELCOM 15 system. The SSAS was activated before the sinking, and two SSAS notifications were received.[34] The first SSAS message, received by the Coast Guard, contained the following information:

```
--- SSAS ALERT MESSAGE ---
Vessel Name: EL FARO
MMSI: 368208000
IMN: 436820812
LAT: 23:25.39N
LON: 073:52.51W
Time: 10/01/2015 11:13:49(UTC)
COURSE: 214 deg
SPEED: 04 kt
Time: 10/01/2015 11:13:49(UTC)
```

The second SSAS message, received by TOTE, contained the following information:

```
--- SSAS ALERT MESSAGE ---
Vessel Name: EL FARO
MMSI: 368208000
IMN: 436820812
LAT: 23:25.22N
LON: 073:52.68W
Time: 10/01/2015 11:15:57(UTC)
COURSE: 227 deg
SPEED: 10 kt
Time: 10/01/2015 11:15:57(UTC)
```

5.4.3. Emergency Position-Indicating Radio Beacon

An EPIRB is used to signal maritime distress. When activated, an EPIRB broadcasts a unique transmission on the 406-MHz distress frequency, once every 50 seconds. EPIRB broadcasts can be detected by a constellation of satellites used for search and rescue. Six satellites in geostationary orbit and five satellites in polar orbit – GEOSAR and LEOSAR, respectively – provide worldwide coverage for the GMDSS. After one or more passes of a LEOSAR satellite, an EPIRB's location can be estimated by interpreting the Doppler frequency shift. Advanced EPIRBs encode a GPS position in the 406-MHz distress transmission, thereby providing an initial EPIRB location to GEOSAR satellites, without having to wait for LEOSAR satellites to pass over the beacon.[35]

[34] Inmarsat satellite data transmission records, provided by Satcom Direct Government, Inc., indicate that *El Faro*'s Inmarsat-C MES terminal sent an additional message to a TOTE employee's cell phone following the two SSAS messages. Investigators have not confirmed the content of that message, or if it was received.

[35] For additional information, refer to NOAA's website, http://www.sarsat.noaa.gov/emerbcns.html, and the Coast Guard's NAVCEN website, http://www.navcen.uscg.gov/?pageName=mtEpirb.

El Faro was equipped with a Jotron 40S MKII EPIRB, serial No. 09170. The device was a float-free[36] Category I (automatically activated) EPIRB, without GPS encoding. The distress signal from *El Faro*'s EPIRB was first detected by the GOES-East geostationary satellite on October 1, 2015, at 0735:05 EDT. The US Mission Control Center notified Coast Guard of the "406 unlocated alert" at 0739 EDT that morning.[37] *El Faro*'s EPIRB was registered with NOAA's SARSAT system, which gave search-and-rescue authorities prompt access to vessel and contact information.[38] The voice telephone number listed on the EPIRB registration was not associated with any phone onboard *El Faro* during the final voyage.[39] The last EPIRB distress signal detected from *El Faro*'s EPIRB was at 0759:15 EDT. No LEOSAR satellites passed overhead within coverage during the 24-minute window of EPIRB transmissions, and a location was not determined.

5.5. Voyage Data Recorder

In January and February 2009, *El Faro* was fitted with a Northrop Grumman Sperry Marine Voyage Master II S-VDR. The data acquisition unit (DAU), serial No. A06032-000937, saved data to the VDR capsule, a Danelec Marine MK3 VDR capsule, serial No. A10631-000480. VDRs enable investigators to download data directly from equipment installed on a ship. As a result of the sinking, normal access to the VDR was unavailable; the only feasible means of recovering VDR data was by recovering the VDR capsule. Figure 3 shows the VDR capsule, as installed on the weather deck above *El Faro's* bridge, soon after installation. The VDR capsule was installed at the base of the antenna mast on the weather deck, directly above the bridge.

[36] Float-free installations enable the automatic release and device activation from a sinking ship.

[37] The US SARSAT Engineering report, appended to the SARSAT Senior Space Systems Engineer interview transcript discusses *El Faro*'s EPIRB distress transmissions; the report also describes an experimental MEOSAR system that, once operational, is expected to be capable of determining the position of non-GPS-encoded EPIRBs from a single distress transmission.

[38] Refer to the EPIRB Registration Form, available in the Survival Factors section of the docket.

[39] TOTE informed investigators that the listed phone number was previously associated with *El Faro*.

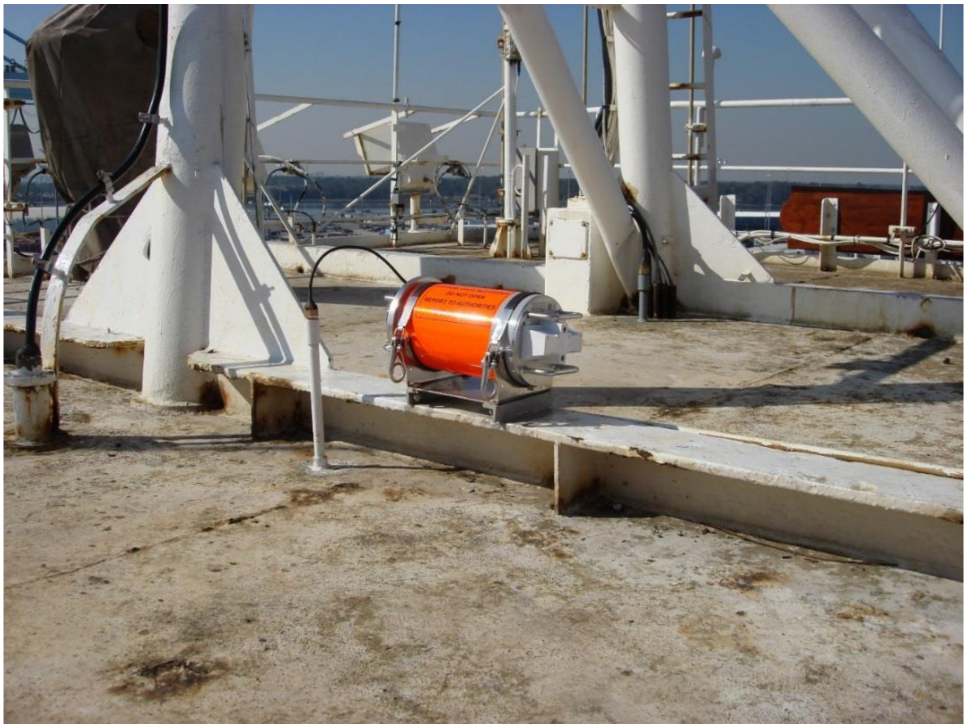

***Figure 3**. VDR capsule installed on* El Faro*’s weather deck, February 2009 (photo from Radio Holland).*

5.5.1. <u>Carriage Requirements</u>

Chapter V of the International Convention for the Safety of Life at Sea (SOLAS), regulation 20, specifies VDR carriage requirements. Cargo ships larger than 3,000 gross tons, and all passenger ships regardless of tonnage, must be equipped with a VDR. The VDR for a cargo ship larger than 3,000 gross tons, constructed before July 2002, may be an S-VDR. El Faro was built in 1975. Table 3 summarizes the requirements for VDRs and S-VDRs. Either system requires a minimum of the most-recent 12 hours to be stored. 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 contained within the main unit of a VDR.[40]

[40] Refer to IMO resolution MSC.214(81) for required download and playback equipment for investigation authorities.

Table 3. Comparison of VDR and S-VDR requirements.

Parameters to be Recorded	VDR after June 2014 [a]	VDR before July 2014 [b]	S-VDR [c]
Date and time	X	X	X
Ship's position	X	X	X
Speed	X	X	X
Heading	X	X	X
Bridge audio	X	X	X
VHF communications audio	X	X	X
Radar	X	X	X [d]
AIS	X		X [d]
ECDIS	if fitted		
Depth (echo sounder)	X	X	X [e]
Main alarms	X	X	X [e]
Rudder order and response	X	X	X [e]
Engine and thruster order and response	X	X	X [e]
Hull openings status	X	X	X [e]
Watertight and fire door status	X	X	X [e]
Accelerations and hull stresses	if fitted	X	X [e]
Wind speed and direction	if fitted	if fitted	X [e]
Rolling motion (inclinometer)	if fitted		
Configuration data	X		
Electronic logbook	if fitted		

[a] Refer to IMO resolution MSC.333(90) for required VDR parameters for installations after June 2014.

[b] Refer to IMO resolution A.861(20) for required VDR parameters for installations before July 2014.

[c] Refer to IMO resolution MSC.163(78) for required S-VDR parameters.

[d] S-VDR installations require radar, unless no commercial off the shelf (COTS) interface is available. If COTS interface for radar is not available, AIS data must be recorded.

[e] Certain parameters are only required for S-VDR installations if an IEC 61162 digital interface is available.

SOLAS Chapter V, regulation 18, requires an annual performance test (APT) for VDRs by an approved testing or servicing facility to verify the accuracy, duration, and recoverability of recorded data. Included in an APT is an inspection of devices fitted to aid location of the recorder.[41] The last two APTs performed on *El Faro*'s S-VDR were on December 2, 2014, and December 3, 2013. Both APTs were conducted by Northrop Grumman Sperry Marine. Copies of the APT checklist and certificate of compliance for 2014 and 2013 are found in Attachments 7 and 8, respectively.

5.5.2. VDR Capsule Recovery

On April 26, 2016, *El Faro*'s VDR capsule was located on the seafloor by an NTSB-led search from the Woods Hole Oceanographic Institution research vessel *Atlantis*. On August 8, 2016, the VDR capsule was recovered from the seafloor, to the United States Naval Ship (USNS) *Apache*. NTSB maintained custody of the VDR capsule once it was recovered. The photo in figure 4 shows the VDR capsule on the seafloor, at the base of the ship's separated antenna mast. Figures 5 and 6 show the VDR capsule as it was being recovered by a remotely operated vehicle (ROV).

[41] Refer to section 5.5.4 of this report for discussion about the acoustic beacon attached to *El Faro*'s VDR capsule.

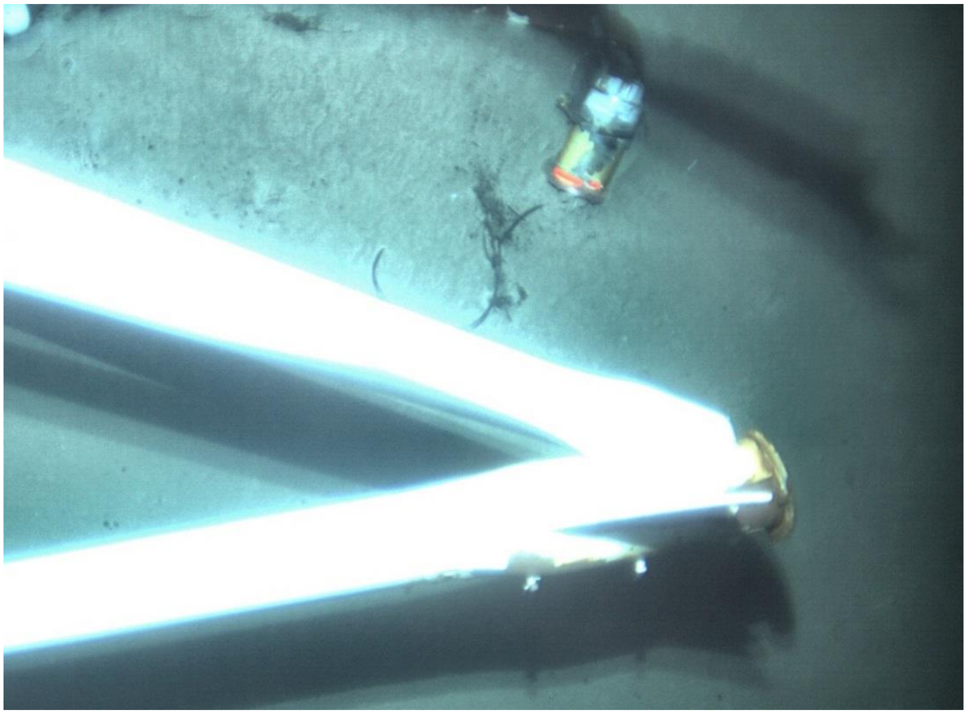

***Figure 4**. VDR capsule on seafloor, about 15,400 feet deep, near base of ship's antenna mast structure (photo from Woods Hole Oceanographic Institution).*

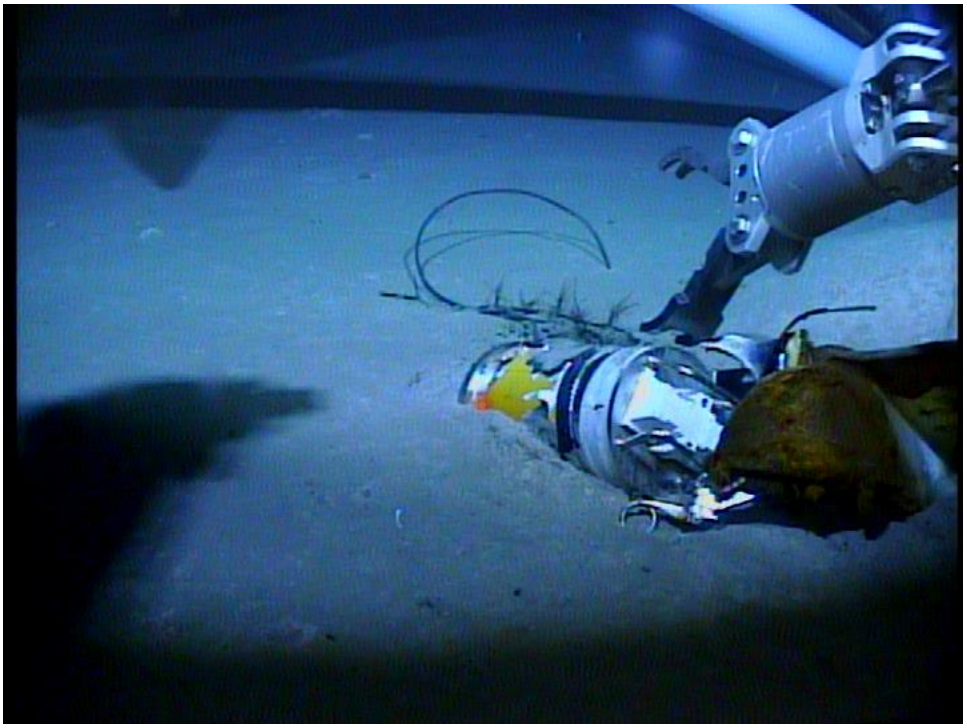

***Figure 5**. VDR capsule being recovered from seafloor (photo from US Navy Supervisor of Salvage).*

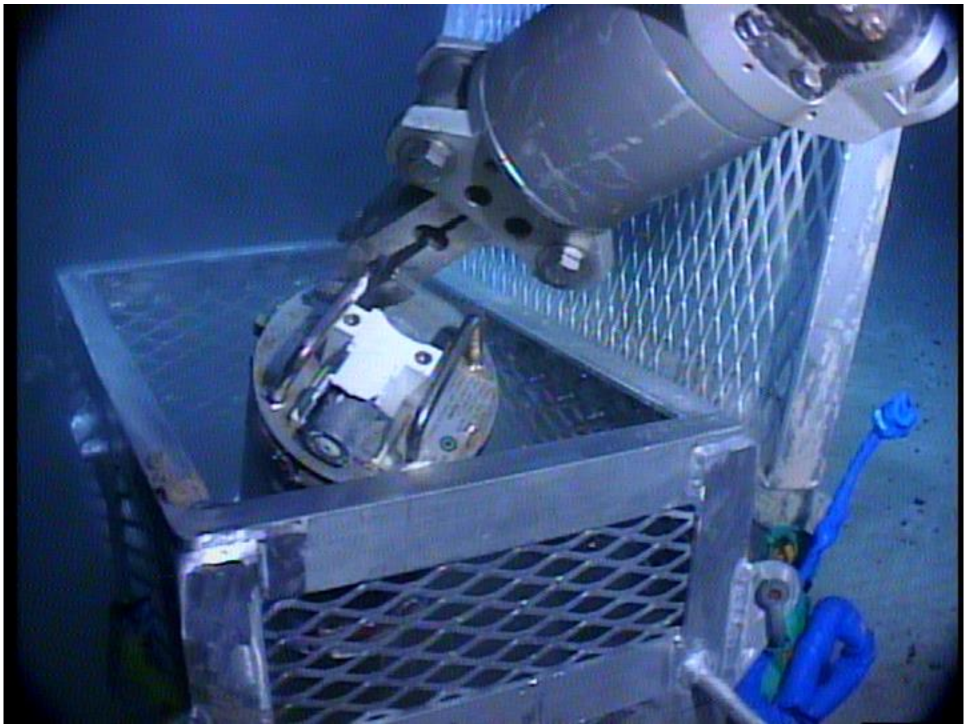

Figure 6. *VDR capsule being recovered from seafloor (photo from US Navy Supervisor of Salvage).*

After the VDR capsule was brought to the surface, it was disassembled and inspected for possible damage to the internal recording medium. Figure 7 shows the VDR capsule before disassembly. Inside the capsule, layers of protective materials housed an inner capsule containing the circuit board assembly that stored the non-volatile memory.[42] The inner capsule assembly is shown in figures 8 and 9. The circuit board assembly was inspected for visible signs of damage or corrosion before being secured for transportation to the NTSB Vehicle Recorder Division laboratory in Washington, DC. Figures 10 and 11 show different sides of the inner capsule circuit board assembly during inspection on USNS *Apache* and at the NTSB laboratory, respectively.

[42] Non-volatile memory is semiconductor memory that does not require external power for data retention.

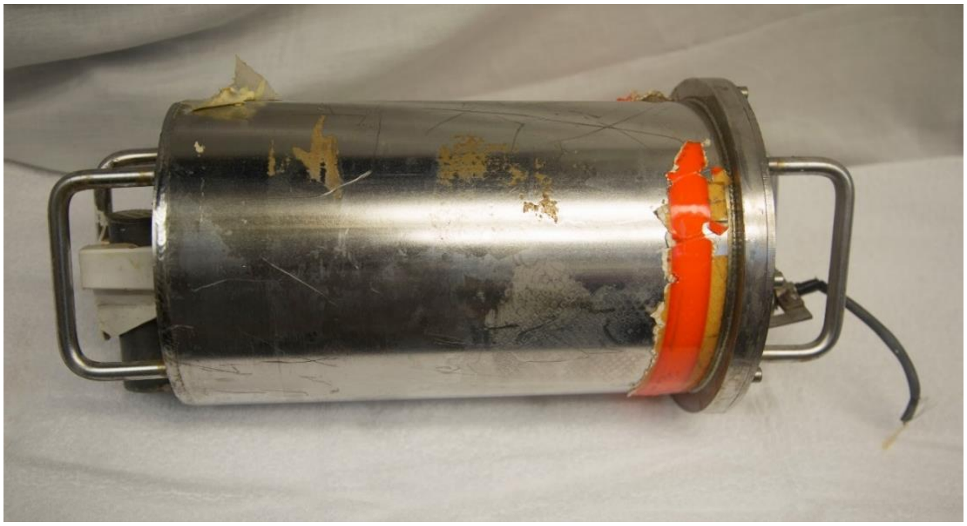

Figure 7*. VDR capsule before disassembly.*

Figure 8*. Inner capsule assembly after removal from VDR capsule.*

***Figure 9**. Inner capsule assembly after removal from VDR capsule.*

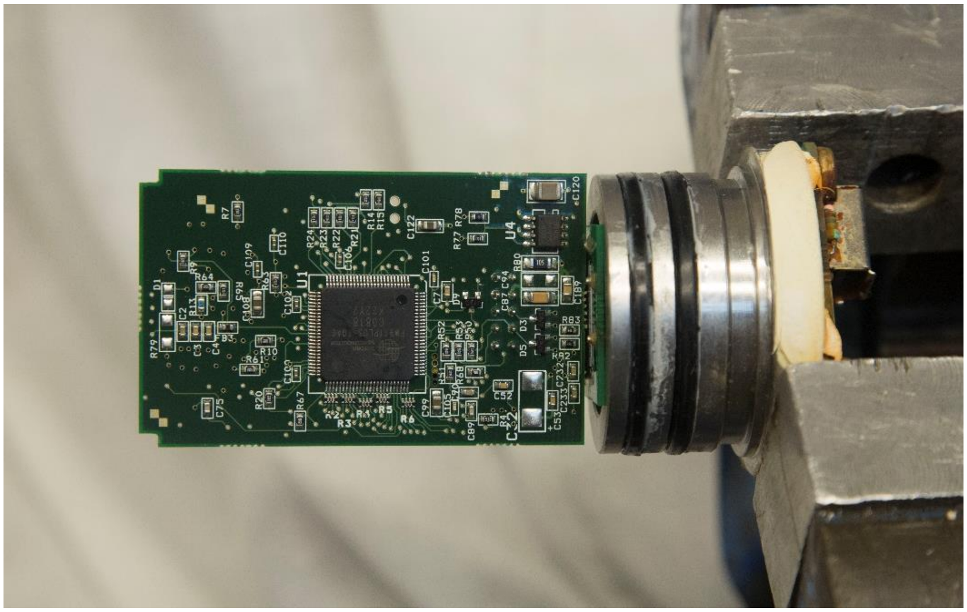

***Figure 10**. Circuit board assembly from inner capsule during visual inspection while onboard USNS* Apache*. This assembly contains the NVM chip that stores the VDR data. The opposite side of the assembly is pictured in Figure 11.*

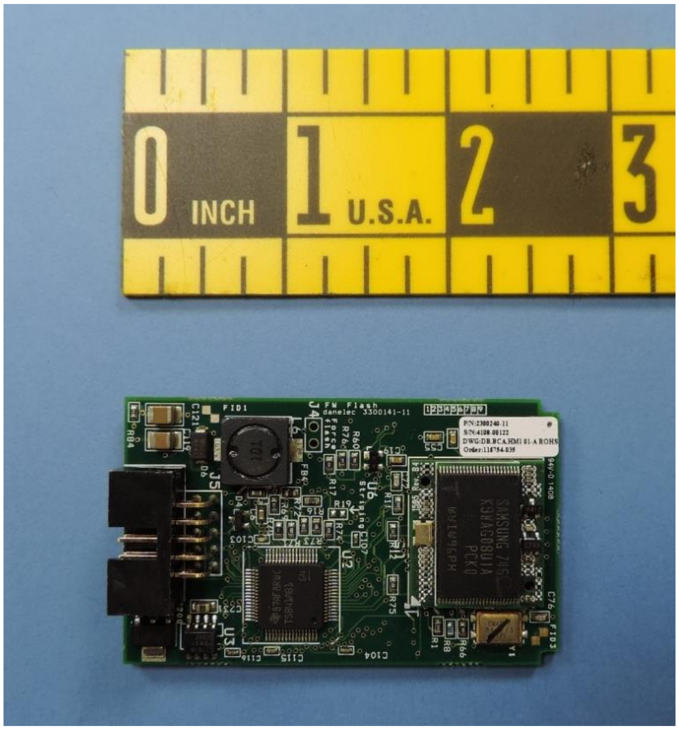

Figure 11*. Circuit board assembly from inner capsule. This assembly contains the NVM chip that stores the VDR data. The opposite side of the assembly is pictured in Figure 10.*

5.5.3. <u>VDR Data Recovery</u>

On August 15, 2016, at the NTSB Vehicle Recorder Division laboratory in Washington, DC, the circuit board assembly from the inner capsule was connected to a functioning surrogate assembly, provided by Danelec. The VDR manufacturer provided technical support and witnessed the VDR data download. A forensic write-blocking bridge was used to copy data from the circuit board assembly.[43] Using manufacturer-provided VDR playback software, the data were exported to a common data file structure for further analysis.[44] A copy of the VDR configuration file is provided as Attachment 9.

Approximately 26 hours of bridge audio, radar images, and parametric data were recovered from the VDR capsule. Audio was saved as multiple WAV audio files for each audio channel.[45] The radar video image was recorded once every 15 seconds; radar images are provided as Attachment 10. Other parameters were recorded as industry-standard text files.[46] Specialized software was used to parse the data files and output the desired data into a tabular format

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

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

[45] For a description of audio quality and the transcription process, refer to the Voyage Data Recorder Audio Transcript Group Chairman's Factual Report.

[46] Parametric data was saved in a format compatible with International Electrotechnical Commission (IEC) standard 61162-1.

(Attachment 11).[47] Table 4 summarizes the parametric data included in Attachment 11. Multiple instances of some parameters (date, time, speed, etc.) are included in the data. In some cases, the data have different units of measure. In other cases, similar data were recorded from a different source.

Table 4. Parametric data recovered from VDR.

Parameter	Source(s)
Date	VDR, GPS
Time	VDR, GPS, AIS
Latitude	GPS
Longitude	GPS
GPS Quality Indicator	GPS
Number of Satellites in Use	GPS
Horizontal Dilution of Precision	GPS
GPS Antenna Altitude	GPS
Geoidal Separation	GPS
Age of Differential GPS Data	GPS
Differential Reference Station ID	GPS
Heading	Gyro
Course Over Ground	Gyro
Speed Over Ground	GPS
Mode Indicator	GPS
Wind Angle	Anemometer
Wind Speed	Anemometer
Data Status	Anemometer
Rate of Turn	Gyro
Data Validity	Gyro
Time of Observation	GPS
Time to Go	GPS
Destination Waypoint ID	GPS
VDR Power AC	VDR
VDR Power Battery	VDR
VDR Power DC	VDR

The VDR parametric data begin on September 30, 2015, at 0536:51 EDT. The last line of VDR parametric data was recorded on October 1, 2015, at 0739:38 EDT.

5.5.4. Discussion of Records and Data

VDR service records

Northrop Grumman Sperry Marine maintained VDR service records for *El Faro*, including recent APT checklists, certificates of compliance, configuration files, and sample data extraction files from recent APTs. Copies of VDR service records were provided to investigators on November 12, 2015.[48]

[47] Tabular data are provided in two formats, CSV and XLSX. The same data are contained in each file. For parameters recorded at more than 10 samples per second, only the first data point per tenth of a second is included.

[48] The first NTSB-led search for *El Faro* departed Little Creek, Virginia, on October 19, 2015. The search was conducted from USNS *Apache*, which arrived in the target search area on October 23, 2015. A towed pinger locator (TPL) was deployed that evening, operated by Phoenix International (http://www.phnx-international.com/phnx/services/underwater-search-and-recovery/), to "listen"

The battery for the acoustic beacon attached to the VDR capsule expired in May 2015, 4 months before *El Faro* was lost.[49] The APT checklist (Attachment 7) indicates that the battery should have been replaced before the VDR certificate of compliance was issued. The APT checklist and certificate of compliance list an incorrect serial number for the DAU. The certificate of compliance lists an incorrect next inspection ("due") date. The previous APT (Attachment 8) was conducted using an out-of-date version of the APT checklist.[50]

Anemometer Wind Data

El Faro was equipped with an anemometer that displayed wind data on the bridge, and wind data was recorded by the VDR.[51] Throughout the VDR recording, over 99% of the anemometer data samples indicate a relative wind direction between 180º and 193º. Transcribed VDR audio from the bridge indicates the crew questioned the accuracy of the indicated wind direction.

AIS

AIS data from the VDR was evaluated to identify AIS message types that *El Faro* sent and received, and to identify marine traffic near *El Faro* along the voyage route. Position reports (message types 1, 3, and 18), static and voyage-related data (message types 5 and 24), base station reports (message type 4), UTC/date response (message type 11), and aids to navigation reports (message type 21) were recorded.[52] Optional safety-related AIS broadcast messages did not exist for the duration of the VDR recording. VDR "own ship" AIS position track was recorded but is not presented in this report.[53]

The last AIS vessel traffic recorded by *El Faro* was more than 11 hours before the sinking, about 190 nautical miles northwest of *El Faro*'s final surface position.

6. TIMING AND CORRELATION OF DATA

Data referenced in this report were primarily recorded in coordinated universal time (UTC), and timing differences between data sources are considered negligible (within a few seconds). Final data are presented in eastern daylight time (EDT), the local time of the accident.

AIS position reports do not contain a full timestamp. The only timing information transmitted with the message is seconds after the minute, based on the GPS time of transmission. The NAIS

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for the expected signal transmission from the acoustic beacon attached to the VDR capsule. After searching for 3 days without detecting the signal, the TPL was secured the evening of October 26. The wreckage was eventually located by other methods.

[49] An acoustic beacon, or pinger, is a water-activated electronic device that transmits a specific signal to aid search crews in the location of the recorder. The acoustic beacon installed on *El Faro* was a Teledyne Benthos ELP 362D, serial No. 47368; designed to transmit for 30 days after activation. The beacon was manufactured in September 2008, and had an expiration date of May 2015. Manufacturers are not required to demonstrate performance on expired acoustic beacons, and empirical data on the performance of expired acoustic beacons is not available.

[50] On the eighth day of the first round of Coast Guard MBI hearings, February 24, 2016, Northrop Grumman Sperry Marine representatives described VDR technician training requirements and APT processes. Changes to the APT process have been implemented since the December 2014 APT conducted on El Faro.

[51] Installation details of the wind sensor installed on *El Faro* at the time of sinking could not be confirmed.

[52] Refer to Coast Guard NAVCEN website for a description of AIS message types, http://www.navcen.uscg.gov/?pageName=AISMessages.

[53] Ship's position data recorded directly to the VDR provided position reports more frequently than AIS.

network adds a GPS timestamp to each AIS transmission as it is recorded. Since this timestamp is applied at the receiving station, irregular time offsets exist in the data. The timestamps for AIS data (Attachment 1) have not been corrected for this offset.[54]

7. OVERLAYS, PLOTS, AND CORRESPONDING TABULAR DATA

The following figures display position data associated with the vessel track, distress alerting, and sinking of *El Faro*. Data is presented in graphical overlays generated using Google Earth. The weather and lighting conditions are not representative of conditions at the time of the accident.

Figure 12 is an overhead view (north up) showing the track history of *El Faro*'s final voyage, using data sources other than the VDR.

Figures 13 through 15 are overhead views (north up) showing the track history of *El Faro*'s final voyage, using data from the VDR. Times corresponding to key events and the final position recorded by the VDR are indicated. Figures 14 and 15 show the same VDR track history as Figure 13, progressively zoomed in near the sinking location.

Tabular data used to generate figures 12 through 15 are included as Attachments 1 through 4, and Attachment 11; these attachments are provided in electronic comma delimited (CSV) format.[55] Attachment 12 contains a compressed Keyhole Markup Language (KMZ) file, providing a subset of *El Faro*'s position track history.[56] KMZ files containing National Hurricane Center best-track data for the path of Hurricane Joaquin, and seamless raster navigational charts, may be downloaded directly from NOAA websites.[57,58]

[54] A review of data in Attachment 1 indicates that the recorded timestamps for AIS position reports are usually within 3 seconds of message transmission. However, on September 30, from 1525 UTC to 1530 UTC, AIS timestamps are offset up to 17 seconds from message transmission.

[55] Attachment 11 is also provided as a Microsoft Excel spreadsheet (*.XLSX) format; data content within each format is the same.

[56] KMZ files may be viewed in Google Earth, ArcGIS, and other mapping applications. Attachment 12 contains all positions from Attachments 1 through 4, and, when available, a subset of positions from Attachment 11 (in 5-minute intervals).

[57] KMZ file containing the best track data for Hurricane Joaquin may be downloaded from NOAA's National Hurricane Center website, http://www.nhc.noaa.gov/gis/archive_besttrack.php.

[58] KMZ file containing seamless raster navigational charts may be downloaded from NOAA's Office of Coast Survey website, http://www.nauticalcharts.noaa.gov/csdl/seamlessraster.html.

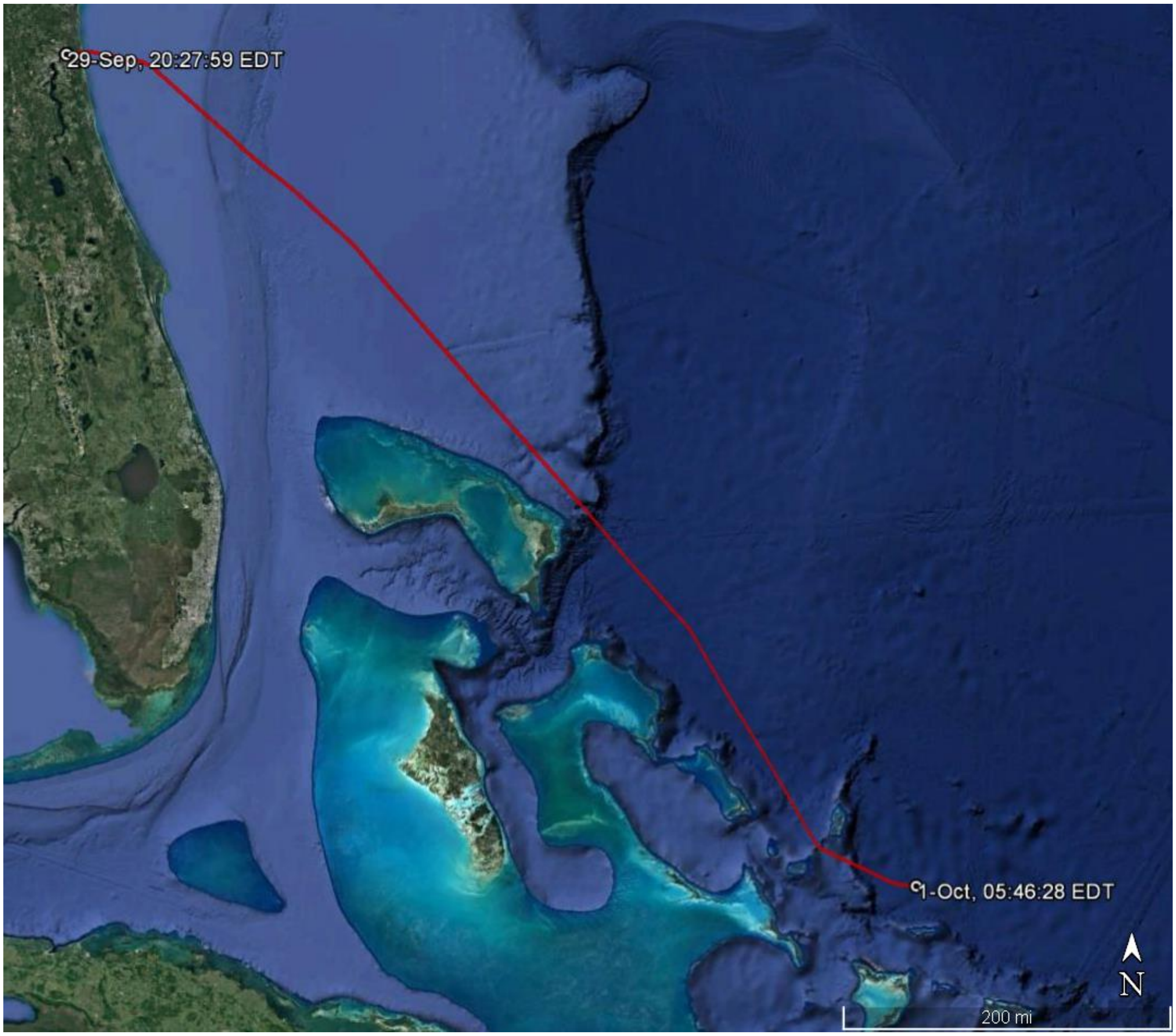

***Figure 12**. El Faro track history, indicated with a red track line.* El Faro *departed Jacksonville on September 29, 2015, about 2030 EDT. The last position recorded from electronic logs (other than the VDR) was from October 1, 2015, 0546 EDT. Authorities began receiving distress alerts shortly after 0700 EDT.*

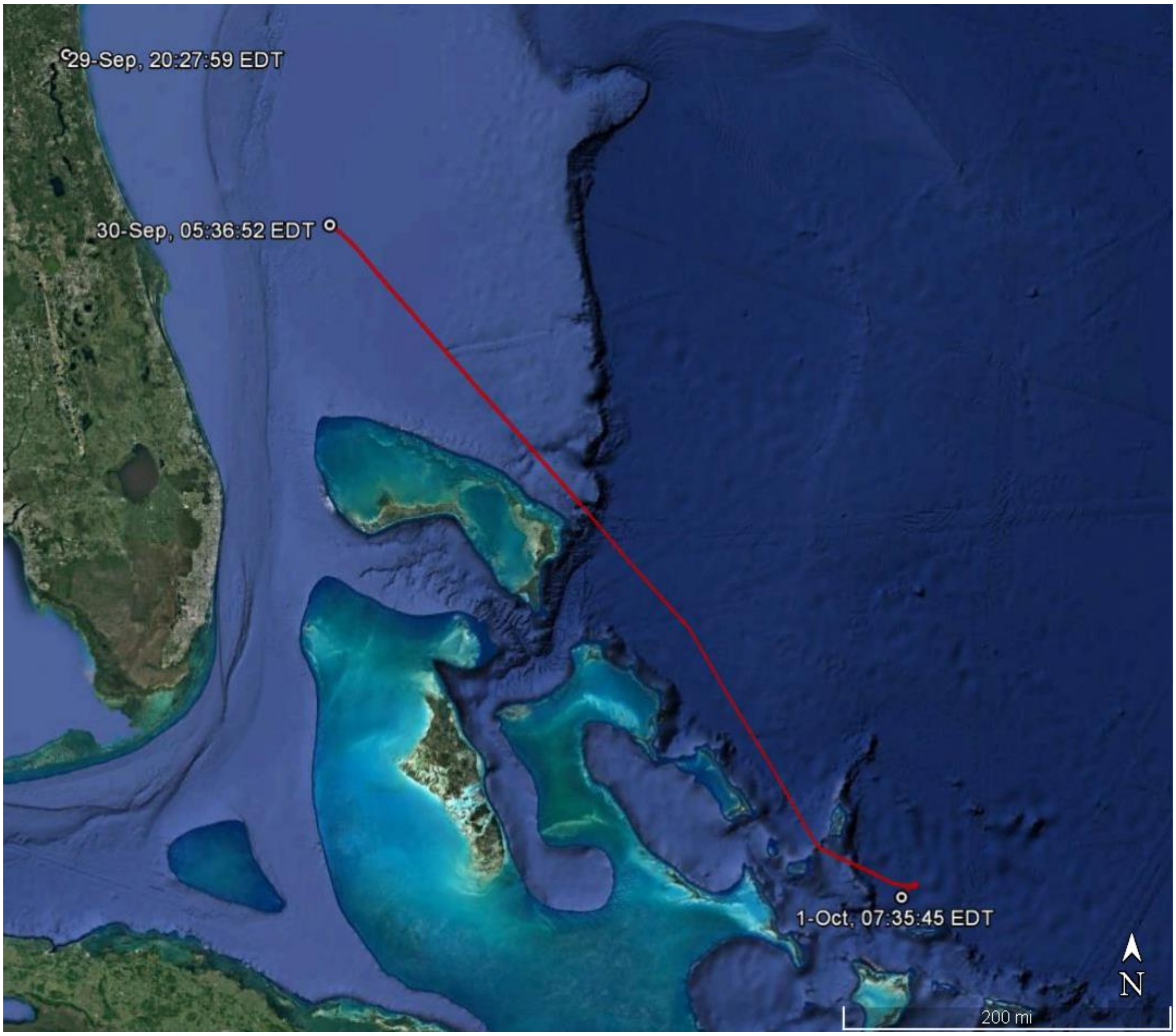

***Figure 13**. El Faro VDR track history, indicated with a red track line.* El Faro *departed Jacksonville on September 29, 2015, about 2030 EDT. Ship's position data recovered from the VDR began September 30, 2015, 0536:52 EDT. The last position recorded to the VDR was from October 1, 2015, 0735:45 EDT.*

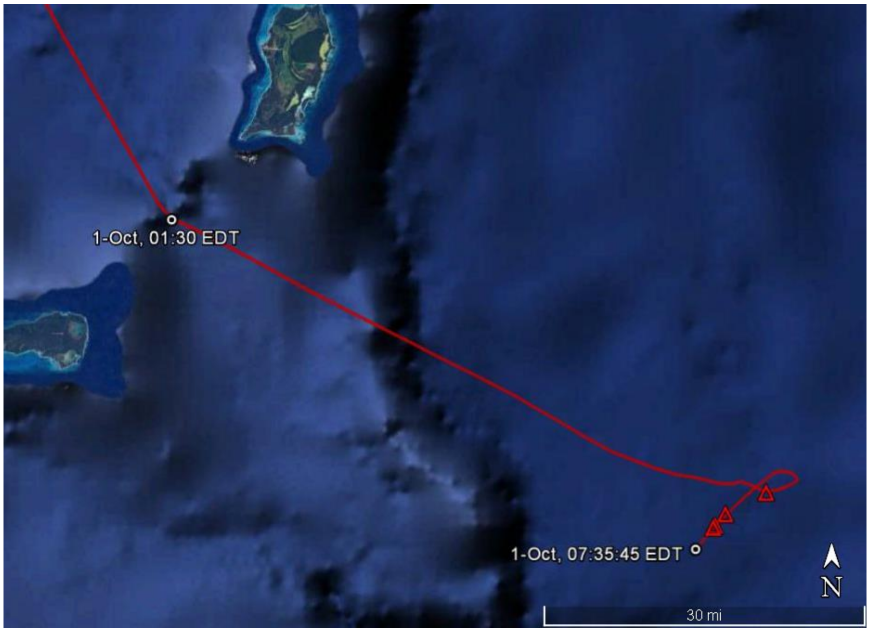

***Figure 14**. El Faro VDR track history, indicated with a red track line. Positions corresponding with distress alerts are indicated as red triangles. The last position recorded to the VDR was from October 1, 2015, 0735:45 EDT.*

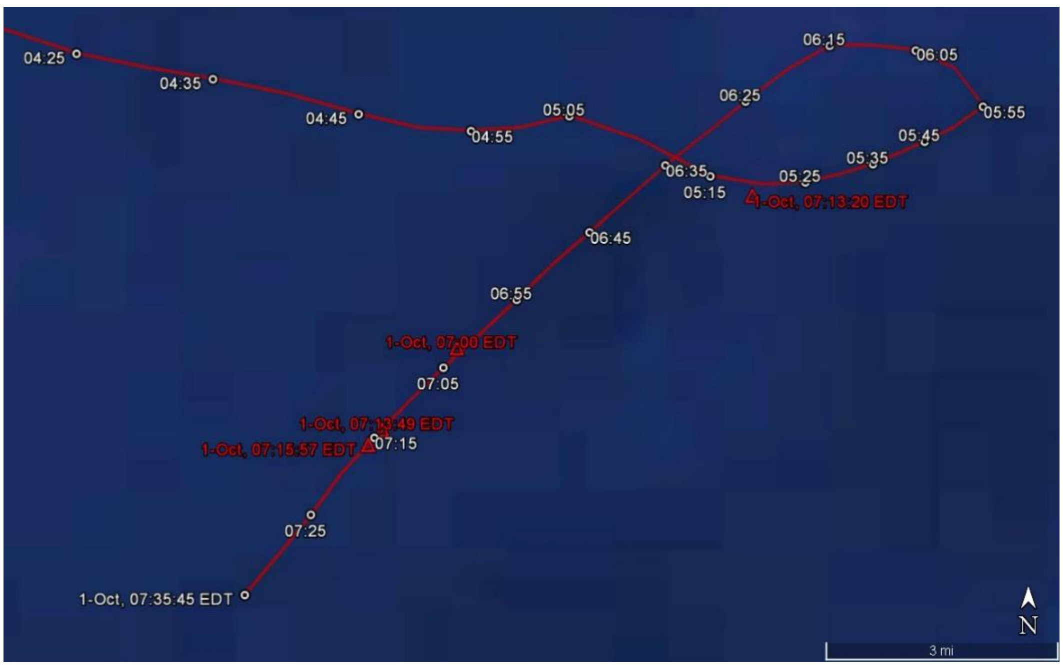

***Figure 15**. El Faro VDR track history, indicated with a red track line. Select VDR position reports (10-minute intervals) are indicated in white. The positions and times corresponding with distress alerts are indicated in red: captain's phone call to DPA (about 0700 EDT), Inmarsat-C distress alert (0713:20 EDT), and two SSAS alerts (0713:49 EDT and 0715:57 EDT). The last position recorded to the VDR was from October 1, 2015, 0735:45 EDT.*