NATIONAL TRANSPORTATION SAFETY BOARD
Office of Research and Engineering
Washington, DC

Sinking Wreckage Trajectory Study

El Faro

DCA16MM001

March 20, 2016

Crider Dennis

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1. ACCIDENT INFORMATION

Vessel:	*El Faro*
Accident Number:	DCA16MM001
Date:	10/1/2015
Time:	14:35 Eastern standard time
Location:	North Atlantic Ocean, 40 nautical miles northeast of Acklins and Crooked Islands 23.3925˚ N, 73.9029˚ W
Accident type:	Sinking
Complement:	28 crew, 5 supernumeraries

2. GROUP

No group was formed for this activity.

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 (Ro/Con) ship El Faro. The US-flagged ship, owned by TOTE Maritime Puerto Rico (formerly Sea Star Line, LLC) and operated by TOTE Services, Inc. (TOTE), was 40 nautical miles northeast of Acklins and Crooked 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 were received, the El Faro master had called TOTE's designated person ashore 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 15,400 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 event a major marine casualty. The Coast Guard suspended the unsuccessful search for survivors at sundown on Wednesday, October 7.

4. DETAILS OF INVESTIGATION

4.1. Purpose of Study.

The first search for the El Faro wreckage was conducted by SUPSALV and found the ship's hull and a debris field. However, the initial search was unsuccessful in finding the voyage data recorder (VDR), a primary objective of the El Faro recovery effort. Accordingly, a second search was launched with Woods Hole Oceanographic Institute which found the recorder.

It was desired to estimate the sea floor location of the VDR to aid in its recovery. The ship's bridge was located in the first SUPSALV effort but neither the voyage data recorder (VDR) nor the mast and connected adjacent structure it was attached to were in their normal position above the bridge. Thus, it was not known if the VDR remained attached to the mast or sunk separately. Accordingly, both the case where the VDR sunk independently and where it remained attached to the mast were considered.

4.2. SUPSALV search

The first search located the bridge and found that the VDR and mast was not with the main wreckage. A trajectory effort was undertaken to determine the most likely area to search for the VDR. Requests were made for underwater ocean current and other data needed for a trajectory analysis, but producing such data takes time so this was not available in the time frame needed to aid the first search. Accordingly, a simplified two-dimensional analysis was attempted in which underwater current and sinking location for the VDR trajectory would be derived based on recovery location of ballistic wreckage[1] and calculated sinking characteristics of this wreckage. Much of the wreckage was from the cargo containers. Cargo containers may have floated a while before flooding and spilling their cargo. Hence, wreckage from cargo containers could not be used in the analysis. This left only four items that were considered to have been from the ship that could not have flooded. Unfortunately, this small number of items proved insufficient for uncertainties in calculated falling characteristics (ballistic coefficients) to balance out to produce a useful result. Further the failure in navigation equipment during the first search produced greater errors in the wreckage locations than anticipated at the time. For example, the second search found the wheelhouse/bridge structure 1079 ft from the location reported in the first search (see figure 8) indicating that the location accuracy was well below that needed for the two dimensional method.

4.3. Woods Hole Oceanographic Institute Search

4.3.1. The Woods Hole Oceanographic Institute search occurred April 18, 2016 to May 1st, 2016. For this second study wind data was available from NOAA simulations. At the time and position of the Ship Security Alert Message (SSAS) message[2] the winds were estimated at 34.36 kts from 347.5 deg. At the time and position of the sinking the winds were estimated to be 85 kts

[1] Ocean wreckage is ballistic if only drag and buoyancy forces act on it and it floods at a known rate or not at all.

[2] The SSAS message is a distress signal containing the ship's position, speed and heading. The message was sent at 7:15, about 15 minutes before the sinking.

from 22 deg +/-10 degrees. The Navy provided ocean current (figure 1) and density profiles (figure 2) for the accident time and position.

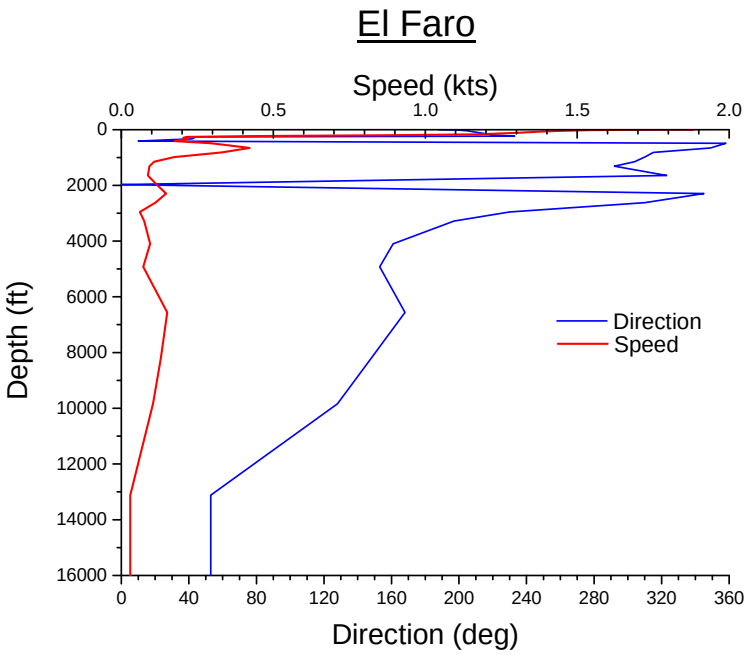

Figure 1 Underwater current speed and direction at the time of El Faro's sinking.

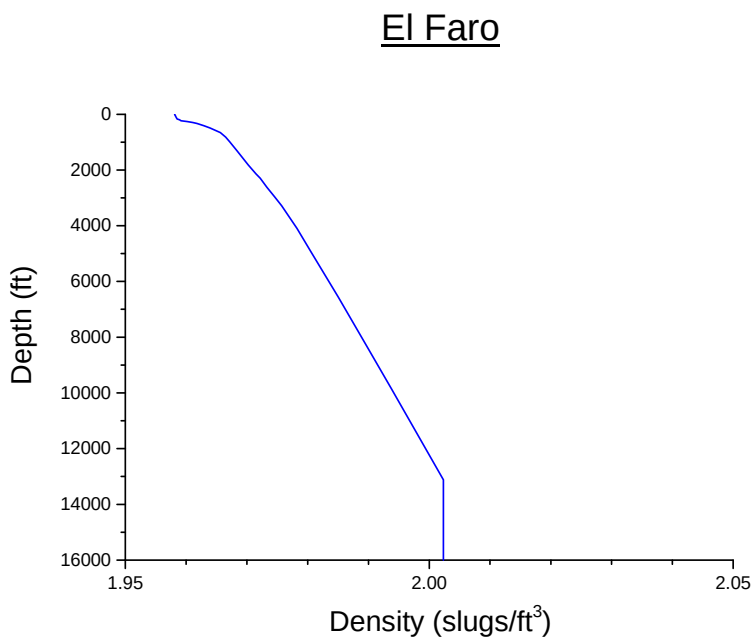

Figure 2 Ocean density

4.3.2. Drift Speed

The drift speed of the ship at sinking can be estimated from 10 kt drift speed of the ship at the SSAS message and the winds at the SSAS message and at the sinking.

$$\tfrac{1}{2}\,\rho_{air}\,V_{air}^2\,C_{Dair}\,S_{air} = \tfrac{1}{2}\,\rho_{water}\,V_{water}^2\,C_{D\,water}\,S_{water}$$

$$V_{water}^2 = (\rho_{air}/\rho_{water})V_{air}^2\,(C_{Dair}\,S_{air}/C_{D\,water}\,S_{water})$$

The characteristic $(C_{Dair}\,S_{air}/C_{D\,water}\,S_{water})$ is calculated from the SSAS ship speed and 82 knot from 34 deg estimated winds at the SSAS message as follows.

$$\tfrac{1}{2}\,\rho_{air}\,V_{air}^2\,C_{Dair}\,S_{air} = \tfrac{1}{2}\,\rho_{water}\,V_{water}^2\,C_{D\,water}\,S_{water}$$

$$\tfrac{1}{2}\,0.002378 * (1.688*82)^2\,C_{Dair}\,S_{air} = \tfrac{1}{2}\,2.0\,(1.688*10)^2\,C_{D\,water}\,S_{water}$$

$$(C_{Dair}\,S_{air}/C_{D\,water}\,S_{water}) = 2.0\,(1.688*10)^2/\,(0.002378 * (1.688*82)^2)$$

$(C_{Dair}\ S_{air}/C_{D\ water}\ S_{water}) = 12.5$

So the drift speed through the water for the El Faro is:

$V_{water}^2 = (\rho_{air}/\rho_{water})\ (C_{Dair}\ S_{air}/C_{D\ water}\ S_{water})\ V_{air}^2$

$V_{water}^2 = (0.002378/2.0)\ 12.5\ V_{air}^2$

$V_{water}^2 = 0.0149\ V_{air}^2$

At the time and position of the sinking winds were estimated as 85 kts from 22 deg true.

$V_{water}^2 = 0.0149\ V_{air}^2$

$V_{water}^2 = 0.0149\ 85^2$

$V_{water} = 10$ kts

4.3.3. Sinking location

The sinking location was estimated as the intersection of a line derived from Navy data and the ship's drift direction from the wind. The estimated wind was from 22 degrees with an uncertainty of plus or minus 10 degrees. To account for the uncertainty in the wind, a sinking location was determined for the nominal 22 degree wind direction as well as 12 degree and 32 degree wind directions. To cover the possibility that the mast and VDR separated from the ship before the main sinking event, trajectories were also run assuming that the VDR or VDR/mast separated ½ nautical mile before the main sinking event for each wind case.

4.3.4. Results

Underwater trajectories were run using the Board's underwater trajectory program. Unlike the two dimensional method the program accounts for 3 dimensional accelerations as density and current vary as parts move towards the ocean floor. An object moving through a fluid that can be treated as only experiencing drag and buoyancy forces can be treated as ballistic. The program was run covering a range of ballistic object characteristics to create an ocean floor locus. The fast falling (low drag/high density) end of the locus will approach alignment with the initial course while the slow falling (high drag/low density) end of the locus will approach alignment with the current. Any object falling ballistically (and that would not flood) from those initial conditions and through the current density field will be on that locus. For this accident most objects located

were from the cargo containers or otherwise missed the ballistic object no flooding time transient criteria. Figure 3 shows the drift lines with the nominal and +/-10 degree winds, the predicted sinking position for each drift line and the cases where the VDR may have separated before the main sinking and the predicted ocean floor positions (loci) from the six sinking positions evaluated.

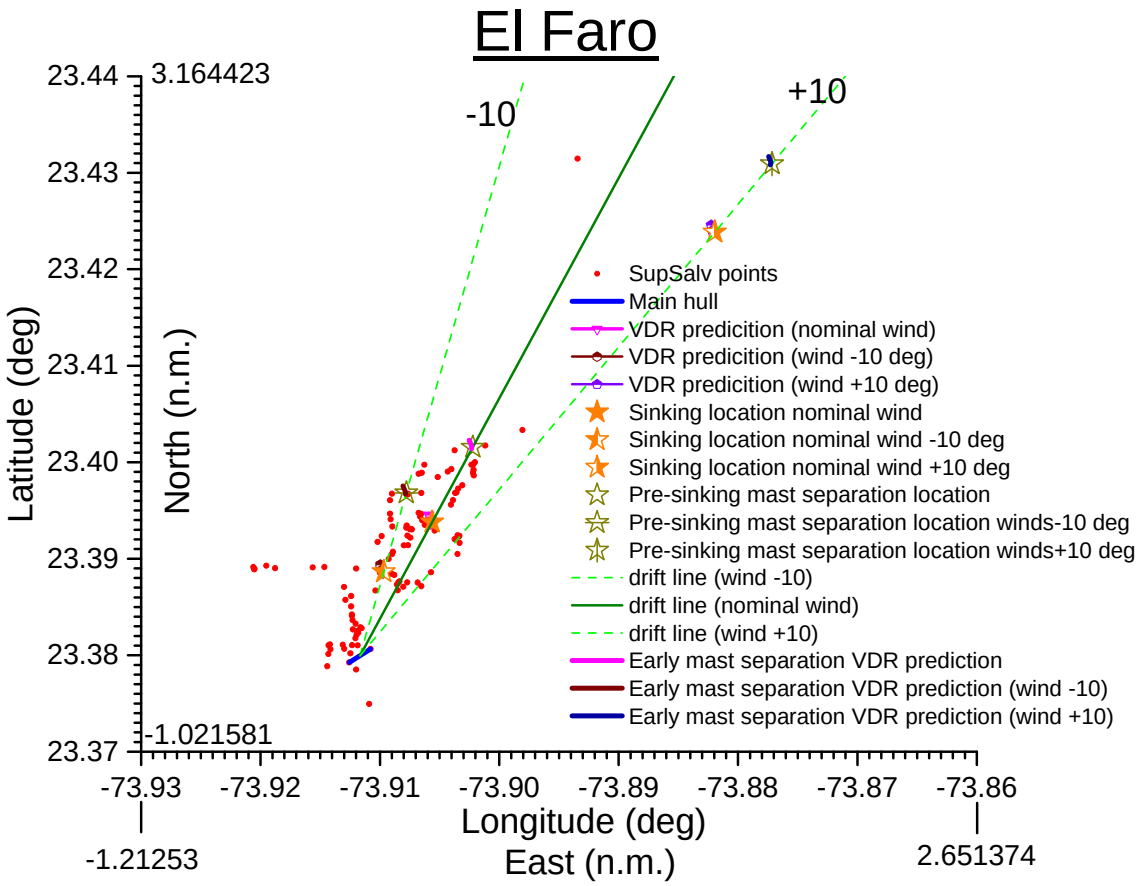

Figure 3 Trajectory results

The sinking locations on the wind direction +10 line are too far from the bridge and hull to be likely. Accordingly, figure 4 shows the more viable western portion of the trajectories on a smaller scale.

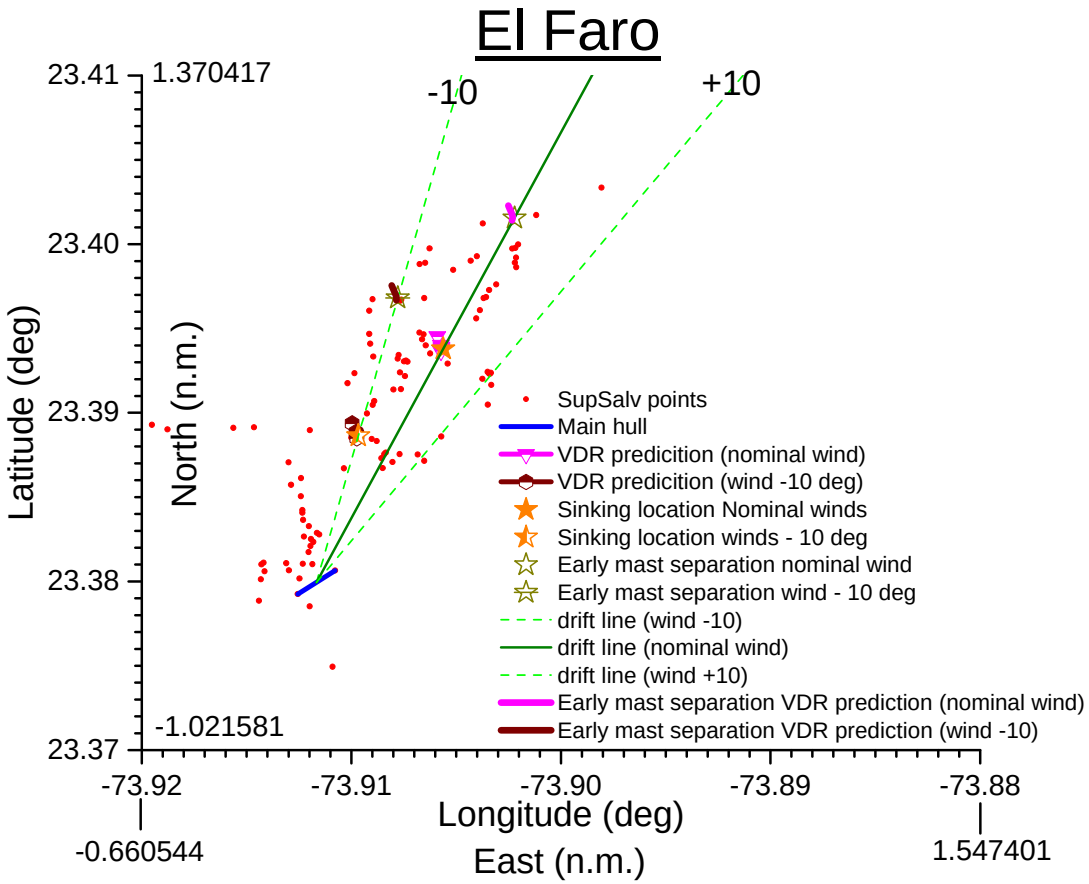

Figure 4 Trajectory Results zoomed in

Figure 5 removes the SupSalv located wreckage points from figure 4 to emphasize the predicted VDR locations and their associated sinking positions. Both with and without the mast attached the VDR should behave ballistically. Figure 5 also suggests a prime search area (search box 1) covering a mast separation at sinking and the possibility of an early VDR separation. The ocean floor wreckage loci, which cover a wide range of wreckage, are about 0.06 nautical miles long.

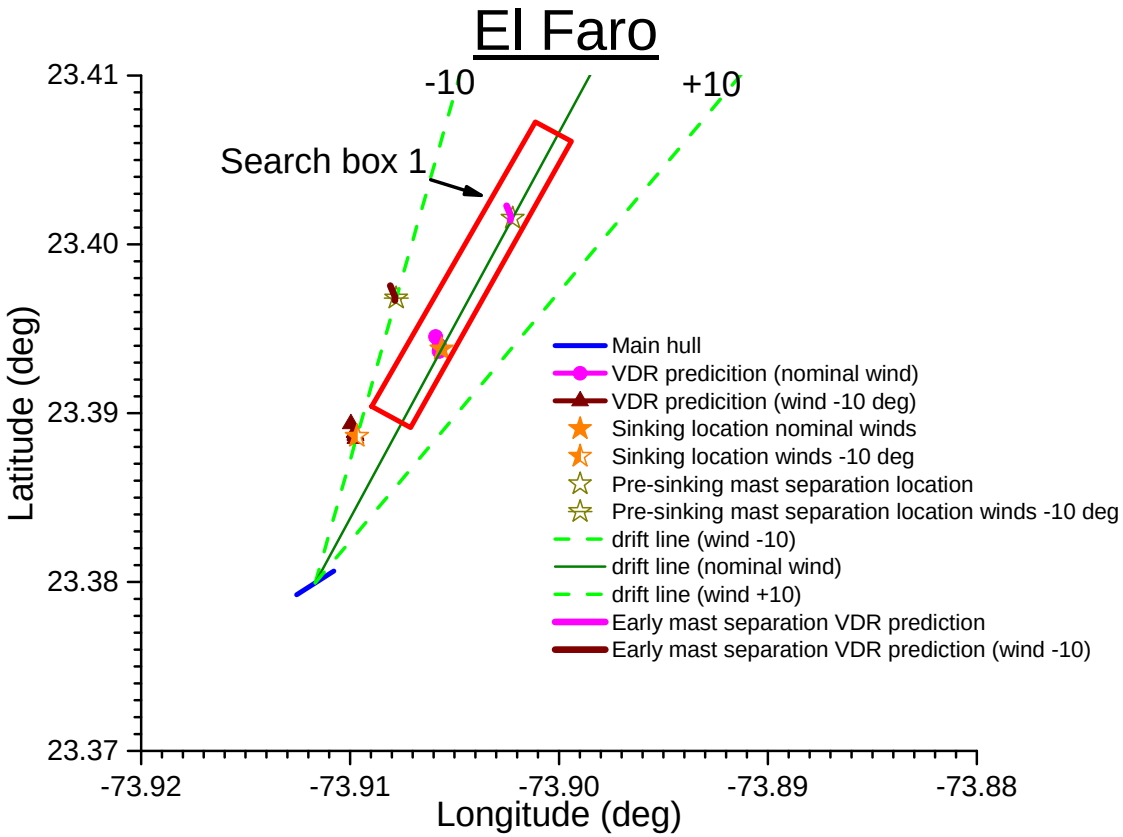

Figure 5 Predicted VDR positions, Search box 1

A larger search box, search box 2, is shown in figure 6 to account for uncertainty in the winds, earlier pre-sinking mast separation and mast separation as the main hull gained speed on the way to the bottom. A third search box, search box 3 shown in figure 7, was added as a third priority area to account for the possibility that the mast was separated from the main ship after the SSAS message but before the sinking perhaps by wave impact.

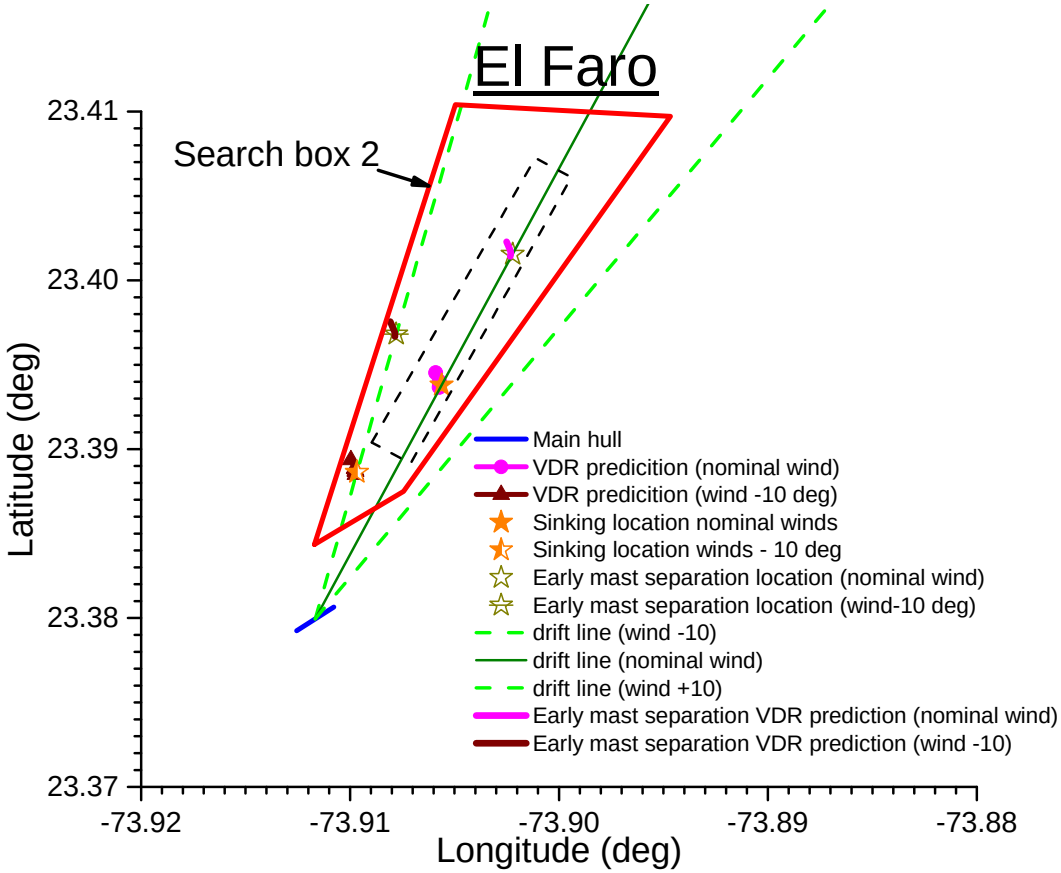

Figure 6 Search box 2

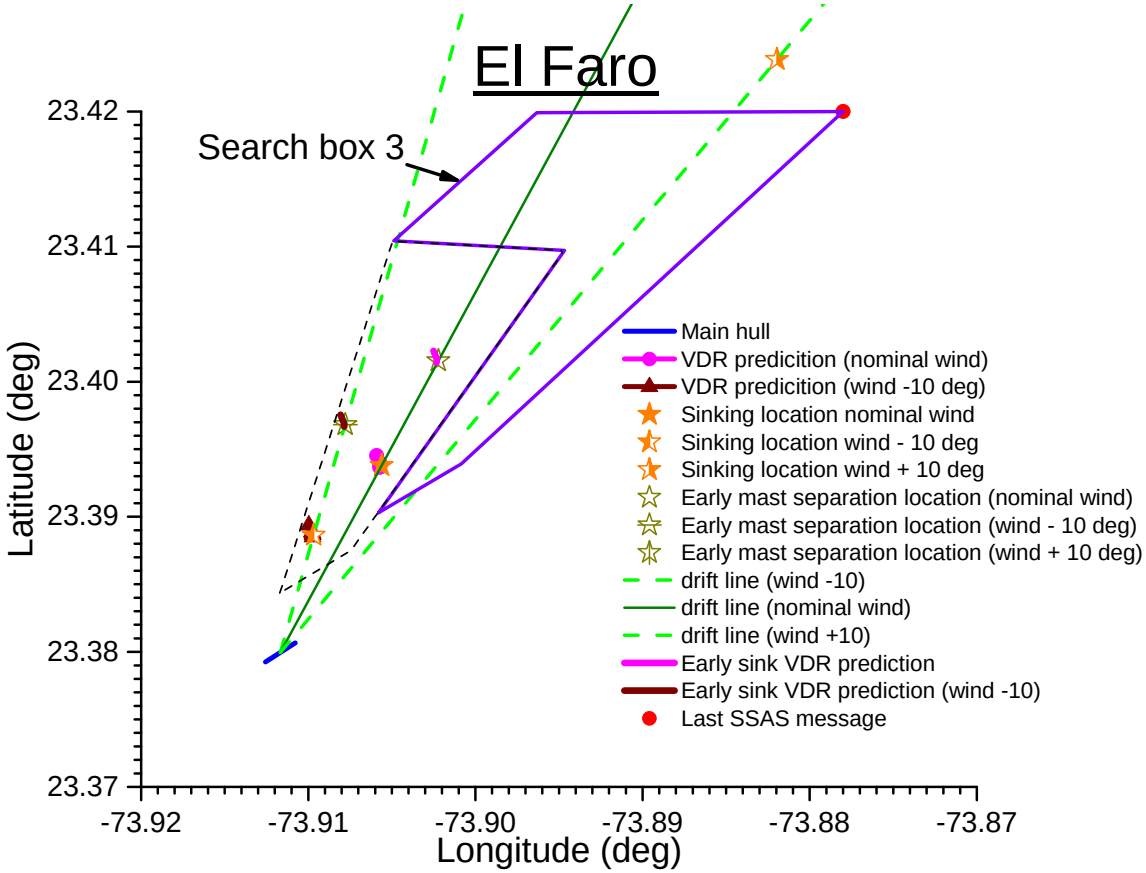

Figure 7 Search box 3

The mast and VDR were found in the southern portion of search box 2 as shown in figure 8. Figure 8 also compares the bridge/wheel house location as determined by the first search in November with the bridge/wheel house location from the second search in April.

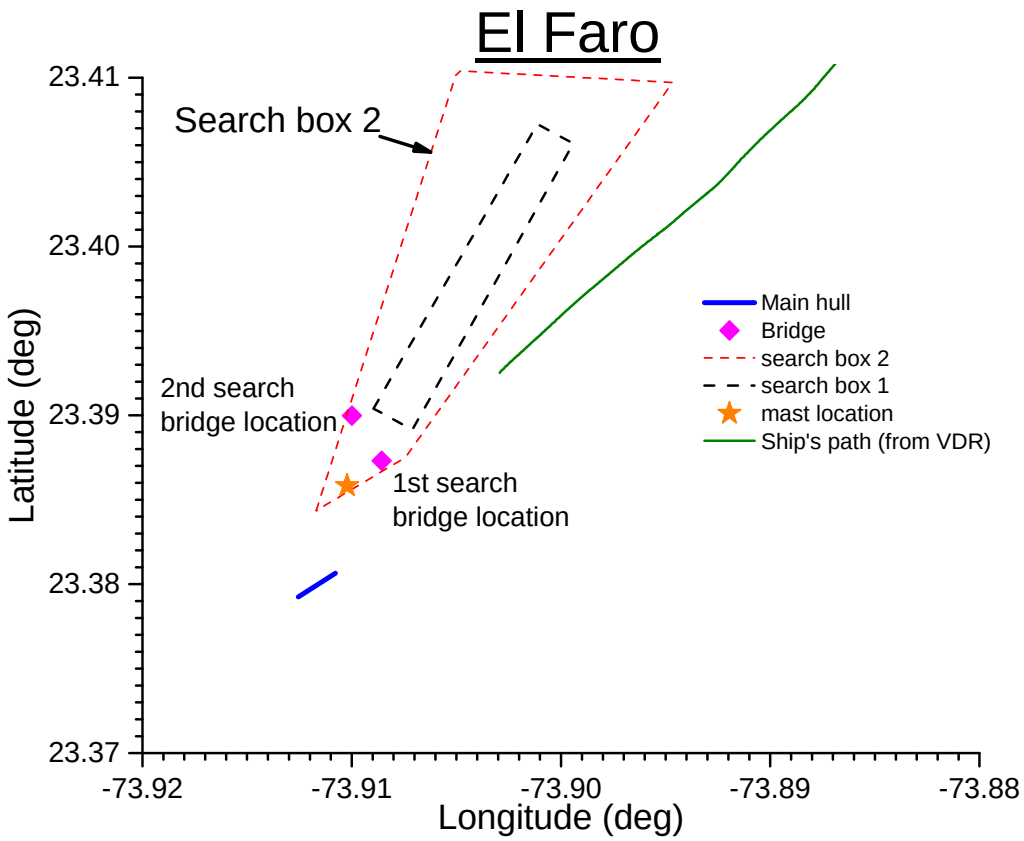

Figure 8 location mast and VDR found

The position of the mast south of the sink line indicates that it did not depart the ship ballistically at the time of sinking. Two possibilities are:

1. The mast separated from the rest of the ship as it gained speed on the way to the bottom.
2. The mast was subject to a hydrodynamic force not directly opposing the direction of motion.

The first possibility requires either that the bridge/wheel house be subject to a hydrodynamic force not directly opposing the direction of motion and move north after the mast separated and it separated from the main hull or that the mast somehow remain connected to the main hull for a time after the bridge/wheel house departed. Marks on the ocean floor indicated that the bridge/wheel house did arrive at its resting location with some speed from the south.

4.3.4.1. Contingencies

A contingency search box four was created in case the mast was not located in the first three search boxes. At the last SSAS message the recorded velocity was 10 kts at 227 degrees. This, together with the location of the last voice message established search box four shown in figure 9.

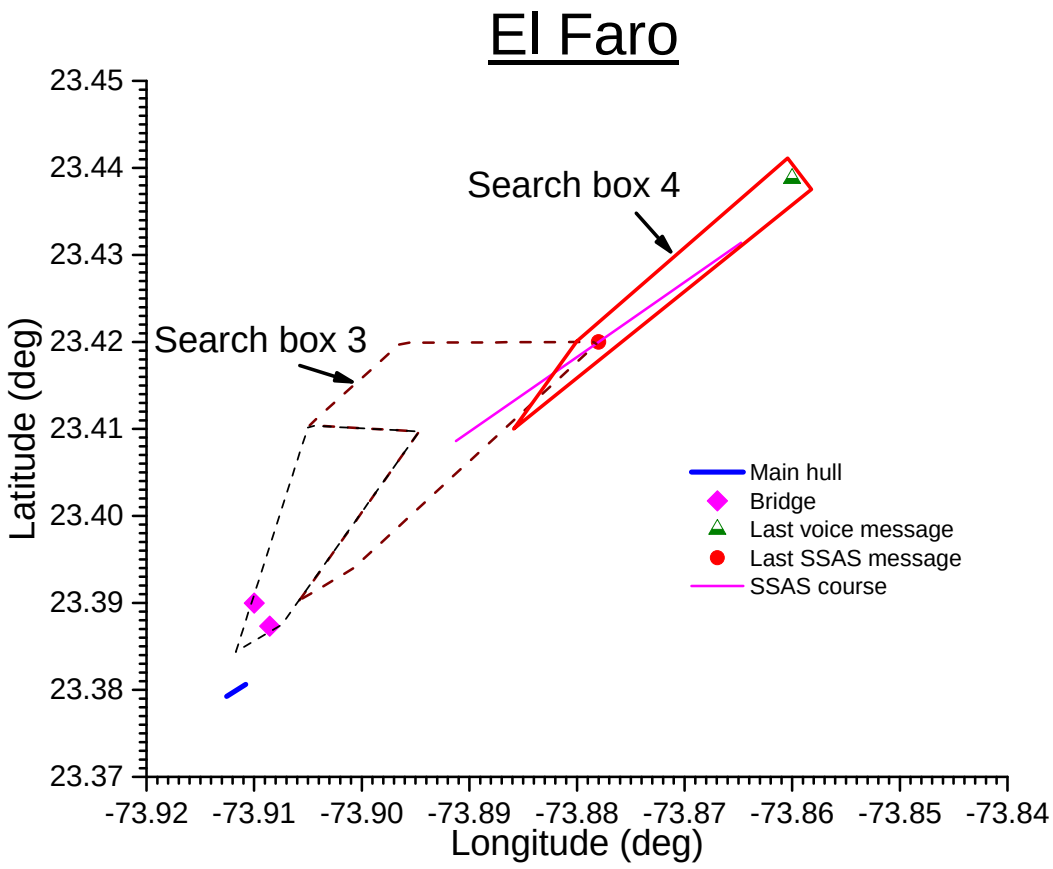

Figure 9 Search box 4 contingency

A search strategy was also established for the case if the mast had been found without the VDR attached. The ballistic locus for the mast and VDR is shown in figure 10 with positions relative to their separation point. Faster sinking objects are on the south end of this locus while slower sinking objects are on the north end of this locus. Accordingly bracketing the sinking modes resulting in a range of possible positions on the locus curve. The ranges of locations on the

locus curve for the VDR alone and for the mast are included in figure 10 assuming that they sank separately but from the same initial position traveling at the same initial velocity.

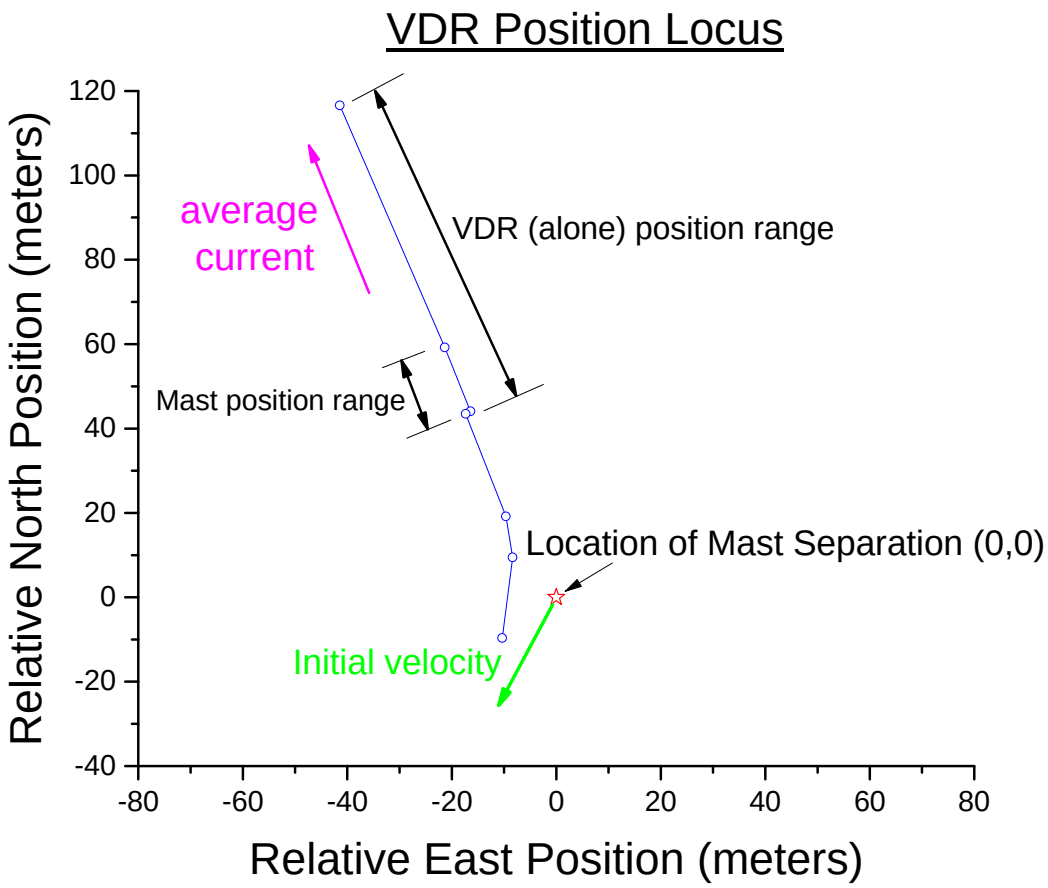

Figure 10 Ballistic locus

The location of the mast separation event in figure 10 is unknown but would have presumably occurred somewhere between the sinking location and the main hull as the ship gained speed sinking to the bottom. If the mast and VDR both sink quickly, they should end up very close to one another, at the southeast end of the areas in Figure 10 labeled “Mast position range” and “VDR (alone) position range.” If the mast sinks quickly but the VDR sinks slowly, the mast will end up at the southeast end of its range, but the VDR will end up at the northwest end of its range, about 80 meters away. Alternatively, if the mast sinks slowly but the VDR sinks quickly, the mast will end up at the northwest end of its range, but the VDR will end up at the southeast end of its range about 18 meters away. Therefore, without knowing how fast each component sinks, if the mast is found by itself, the search box for the VDR should extend from 18 meters southeast of the mast location to 80 meters northwest of the mast location. Adding in some extra margin results in the box in Figure 11. An input file was set up so that if the mast had been

found without the VDR, the latitude and longitude of the search box corners could have been rapidly created given the location of the mast.

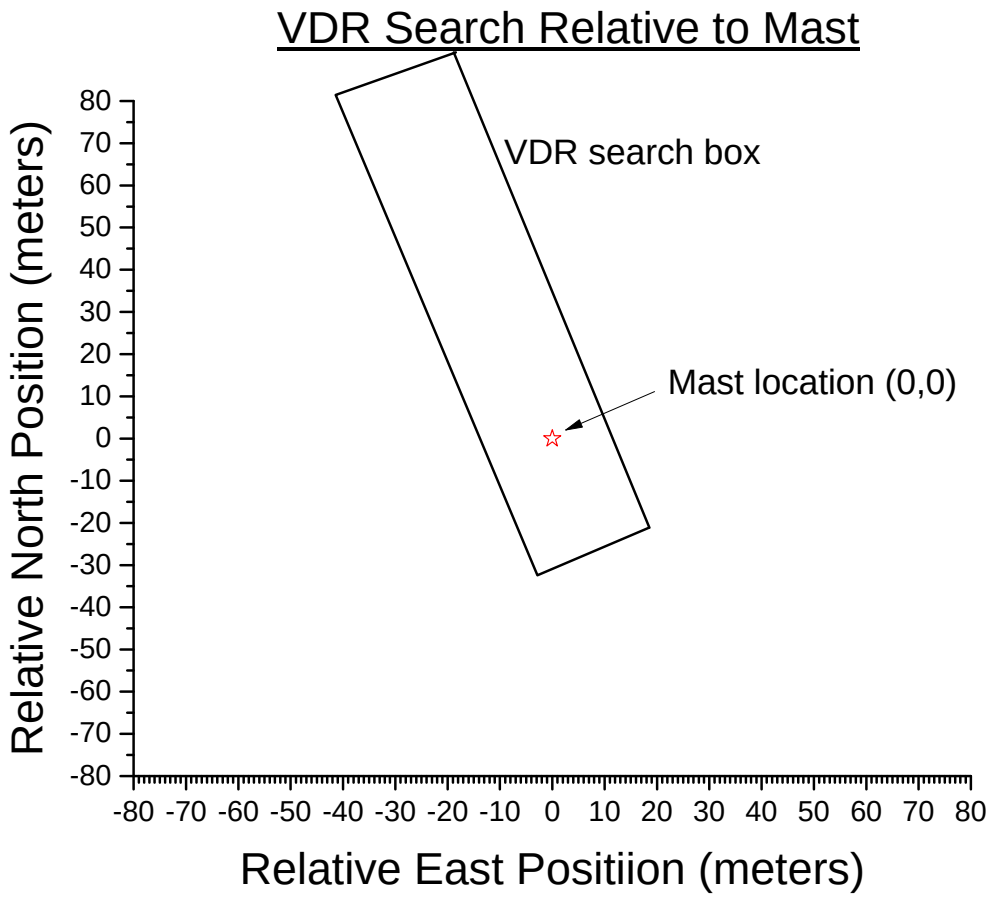

Figure 11 search box relative to the mast

Appendix A, VDR Characteristics

Separate VDR

Wt = 25 lbs (with mounting bracket)
Wt = 21 lbs (without mounting bracket)
Vol_{total} = $3.14 * (0.56/2)^2 * 0.97 = 0.239\ ft^3$

The drag on the VDR alone will be bracketed by the VDR sinking side down with the low weight (slowest sinking) to sinking end down at the high weight (fastest sinking). For the side down the drag and accompanying characteristic area are approximately:

Wt = 21 lbs
Area = $0.56 * 1.2 = 0.67\ ft^2$
C_D = 1.0
W/C_DS = 21/1.0(0.67) = 31.3.

For the end down the drag and accompanying characteristic area are approximately:

Wt = 25 lbs
Area = $3.14 * (0.56/2)^2 = 0.246\ ft^2$
C_D = 0.7
W/C_DS = 25/0.7(0.246) = 145.

VDR with mast

Wt = 9012 lbs
Vol_{total} = $18.4\ ft^3$

The drag on the mast would be bracketed by sinking bottom side down or rear side down. For the rear side down the drag and accompanying characteristic area are approximately:

C_D = 0.7
Area = $189\ ft^2$
W/C_DS = 9012/0.7(189) = 68.12

For the rear side down the drag and accompanying characteristic area are approximately:

C_D = 1.1
Area = $211\ ft^2$
W/C_DS = 9012/1.1(211) = 38.83