U.S. Department of Transportation
United States Coast Guard

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September 27, 2000

From: Commanding Officer, Coast Guard Marine Safety Center
To: Commanding Officer, Coast Guard Marine Safety Office Milwaukee

Subj: LINDA E MARINE CASUALTY INVESTIGATION TECHNICAL ASSISTANCE

1. As you requested in enclosure (1), we have analyzed the ROV video and additional information provided by your office to assist in the marine casualty investigation. Enclosure (2) contains answers to your questions posed in enclosure (1), along with supporting information and calculations. An electronic version of this report is provided as enclosure (3)

2. If you have any questions or need additional assistance in this matter, please feel free to contact the project officer, Lieutenant DeWane Ray, at either of the above numbers.

A. L. PEEK

Encl: (1) MSO Milwaukee's letter of June 27, 2000
(2) Answers to questions posed in MSO Milwaukee's letter of June 27, 2000
(3) CD Rom with electronic files

Copy: Commandant (G-MOA)
Commander, Atlantic Area (am)
Commander, Ninth Coast Guard District (m)

U.S. Department of Transportation
United States Coast Guard

Commanding Officer
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16730
JUN 27 2000

From: Commanding Officer, Marine Safety Office Milwaukee
To: Commanding Officer, Coast Guard Marine Safety Center

Subj: REQUEST FOR TECHNICAL ASSISTANCE IN SUPPORT OF LINDA E MARINE CASUALTY INVESTIGATION

1. The deployment of the USCGC ACACIA and the University of Michigan's Remotely Operated Vehicle (ROV) to gather visual information about the recently located LINDA E was extremely successful. We are indebted to the Commanding Officer and crew of the ACACIA, and Dr. Guy Meadows and Mr. Hans Van Sumeren of the University of Michigan whose professionalism enabled us to capture this information in such a rapid and efficient manner.

2. While the information obtained from the ROV has greatly furthered our marine casualty investigation, the meaning of this information needs to be interpreted by those with the appropriate technical standing and experience. To this end, I request assistance from the technical experts at the Coast Guard Marine Safety Center to help my investigators answer some of the questions posed in enclosure (1). I have sought Commandant's evaluation of the benefit to this investigation of using outside professional accident reconstruction experts.

3. If you have any questions about the details of our request, please contact the primary point of contact for this investigation, LCDR Bryan Emond. or me!

D. L. LERSCH

Encl: (1) Objectives of Technical Analysis
(2) Survey of Damage to LINDA E taken from ROV Video
(3) Video

Copy: Commandant (G-MOA)
Commander, Atlantic Area (am)
Commander, Ninth Coast Guard District 9 (m)

ENCLOSURE (1)

OBJECTIVES OF LINDA E CASUALTY ANALYSIS

A. VALIDATE CAUSE OF CASUALTY:

1. Is the damage evident in the ROV video consistent with damage from a collision? Why?

2. What else could cause the damage seen in the ROV video? (i.e. hydrostatic crushing from sinking , impact with lake bottom, etc.) Why?

3. What causes for the damage seen can be eliminated based upon the ROV video? (i.e. hydrostatic crushing from sinking , impact with lake bottom, etc.) Why?

B. ASSUMING A COLLSION, ASSIST IN IDENTIFICATION OF 2ND VESSEL:

1. Is the damage in the port side of the LINDA E consistent with the shape of the bow of the tank barge GREAT LAKES O.N. 650771? What is the basis for this determination?

2. What other vessels that operate in this area have similar shapes that are consistent this damage? (MSO will provide a comprehensive list of vessels to consider.) What is the basis for this determination?

3. Based upon the damage seen in ROV video, what is the most likely alignment of the involved vessels immediately before the collision? What is the basis for this determination?

4. Based upon given drafts for both the barge GREAT LAKES and LINDA E (to be provided later), each vessels dimensions, the alignment determined above, and location of damage seen on the ROV video, what is most likely initial point of contact for the involved vessels. Is this consistent with markings found on barge GREAT LAKES?

C. DETERMINE PLAUSABILITY OF A COLLSION SCENARIO:

1. Based upon the displacement and speed of the barge GREAT LAKES and LINDA E. and the alignment determined above, what would be the approximate force upon the hull of the LINDA E at the moment of collision? (i.e. momentum & impact analysis)

2. Placing the impact force calculated above at the location of initial point of contact determined above, estimate:

   a. The initial impact upon the stability of the LINDA E. (angle of heel? capsize? Etc.)
   b. Based upon the above, estimate the rate of downflooding into the LINDA E if the port service door and stem doors were open.
   c. Time for the LINDA E to sink given the above.

(A static analysis considering only the instantaneous effects of this impact should be sufficient for the purposes of this investigation, unless the analyzer deems that dynamic analysis is necessary.)

3. Is damage seen on ROV video consistent with force calculated by impact analysis?

4. What is the likelihood that the ITB MICHIGAN/GREAT LAKES and LINDA E could have collided without someone on towing vessel knowing that a collision had occurred? What is the basis for this determination?

Answers to Questions posed in MSO Milwaukee's letter dated June 27, 2000

A. Validate Cause of Casualty:

1. Yes, the damage in the ROV video is consistent with damage from a collision. The deformation in the side shell is indicative of an externally applied force with the indention shape of a V. Additionally, the antenna, radar mast, and stern navigation light are bent in an orientation that is consistent with the bow flare of a vessel with a V-shaped bow. The specifics of this comparison can be found in the 3D geometry comparison, attachment (1).

2. The damage in the ROV video is consistent with impact of a V-shaped wedge oriented apex down. This wedge-shaped geometry is consistent with the bow flare of a vessel.

3. A. Hydrostatic crushing can be eliminated due to the fact there is no uniform buckling of the side plate. All damage appears to be localized which would not be indicative of hydrostatic crushing.

   B. In addition, hull failure due to insufficient longitudinal strength can be eliminated since the location of the damage is far aft of amidships. Longitudinal strength failure modes typically occur near amidships where stresses are the highest.

   C. Impact with the lake bottom is unlikely to be the cause of the damage. If the observed damage was caused by impact with the bottom, the vessel would have had to land on its starboard side against a V-shaped object on the bottom. Then, an externally applied force would have had to rotate the vessel to port approximately 110 degrees to be in the orientation observed in the ROV video.

   D. An explosion can be eliminated. If an explosion would have occurred, the deformation would have been outward and the glass portholes would have shattered due to the outward expansion of explosive gases. On the LINDA E, most glass portholes are intact and the hull deformation is directed into the hull.

   E. A fire can be eliminated because of the lack of soot marks on the vessel as well as no melting of material. In addition, except in small, localized areas of damage, the paint is relatively intact, making a fire highly unlikely.

B. Assuming a Collision, Assist in Identification of 2nd Vessel:

1. The damage profile on the LINDA E is consistent with the shape of the bow of the tank barge GREAT LAKES, O.N. 650771. The specifics of this conclusion can be found in the 3D geometry comparison, attachment (1).

2. After viewing bow profiles of other vessels provided on your list, we found no other vessel other than the barge GREAT LAKES with the geometry necessary to produce

the damage seen on the LINDA E. The following is a qualitative review of vessel types and specific vessels. Pictures of the vessels analyzed are provided in attachment (2):

a. Commercial Fishing Vessels: These vessel types can be excluded from causing the damage on the LINDA E for the following reasons: 1. Such vessels would have insufficient height above the waterline to cause the damage to topside antennas as seen in the ROV video unless they were to ride over top of the LINDA E. This is not likely since the vessels are relatively slow speed and of comparable size to the LINDA E and thus, are incapable of developing the necessary momentum. In arriving at this opinion the commercial fishing vessels D&S, O.N. 234508; JOLENE, O.N. 248708; SHERRY LYNN, O.N. 234497; and NEESKAY, O.N. 512553, were considered.

b. Towing Vessel/Barge Combinations: The following vessels were analyzed:

   1. Barge INTEGRITY, O.N. 1044267. This barge has a very blunt, almost vertical bow with no bowflare. The deformation seen on the LINDA E topside would require impact with a V-shaped bow. It is unlikely this barge caused the damage on the LINDA E.

   2. Barge L-1010, O.N. 916314. This is a very typical raked barge. A shape like this would not likely cause the deformation noted on the LINDA E. Since the longitudinal sections are fairly flat with not much V-shape, it is unlikely that this barge could have caused the deformation to the antennas seen on the LINDA E without also impacting the stove exhaust, which is intact. Also, the typical operating freeboards of a barge of this size would not likely be high enough to cause the damage seen on the LINDA E.

   3. Tug SUPERIOR, O.N. 210354. This tug has insufficient height to cause the deformations seen on the LINDA E topside.

   4. Tug JAMES A. HANNA, O.N. 298179. This tug has insufficient height to cause the deformations seen on the LINDA E topside.

c. Bulk Cargo Vessel Types: The bulk cargo type vessels analyzed do not have sufficient bow flare and/or rake to distort the topside geometry of the LINDA E as seen in the ROV video. The following vessels were considered: JAMES R. BARKER, O.N. 573682; JOSEPH L. BLOCK, O.N. 574870; and WILFRED SYKES, O.N. 259193.

3. In a collision scenario involving the LINDA E and the GREAT LAKES, the angle of impact is most likely near 90 degrees +/- 15 degrees. This is based upon the damage to the side shell and the orientation of the antennas on the LINDA E as described in attachment (1).

4. The initial contact between the two vessels most likely occurred with the bow stem of the tank barge contacting the starboard side of the LINDA E, just forward of the last portlight. This is consistent with the paint markings found on the GREAT LAKES.

C. Determine Plausibility of a Collision Scenario:

1. 2. and 3. For the GREAT LAKES to impart the damage on the LINDA E seen on the ROV video, the LINDA E would have had to heel to port after impact. Based on the damage to the LINDA E's weather deck and rub rail, the angle of heel was estimated at 51 degrees to port. The heeling moment to heel the vessel 51 degrees is estimated at 36,649 ft-lbs. The complexity of the calculation and the many assumptions that would have to be made preclude a precise estimate of the force necessary to create this heeling moment. However, it is apparent that a barge the size of the GREAT LAKES moving at a reported speed of 12 knots would have sufficient energy to create the heeling moment. When the vessel heels to port 51 degrees, the doors that were open on the port side and stern would be submerged. This would provide an estimated flooding rate of 464 ft^3/s. At this estimated flooding rate the reserve buoyancy would be lost in approximately 2 seconds, at which point the vessel would sink. See appendix C of attachment (1).

4. For the collision scenario to have occurred without the crew on the tug noticing, the deceleration of the barge as a result of the collision would have to be minimal. Given the LINDA E's estimated time to flood and sink of only 2 seconds, as well as your calculations showing only a slight reduction in the speed of the GREAT LAKES, it is quite likely that no one on the tug would have been aware of a collision.

Attachments: (1) Three Dimensional Geometry comparison of the F/V LINDA E and the barge GREAT LAKES
(2) Pictures of various vessels

Three Dimensional Geometry Comparison of the F/V LINDA E and the barge GREAT LAKES

INTRODUCTION

An analysis was conducted on the geometry of the F/V LINDA E and the barge GREAT LAKES to determine if it is physically possible for the barge GREAT LAKES to cause the damage to the LINDA E as seen in the ROV video. Results indicate a collision between these two vessels could indeed have resulted in the damage noted on the LINDA E. This analysis illustrates a plausible collision scenario correlated to the damage witnessed on the LINDA E. Note, the figures referenced in this report are contained in appendix A.

METHOD OF ANALYSIS

A three dimensional (3D) computer model was constructed of the F/V LINDA E and the barge GREAT LAKES. The model of the LINDA E was based upon a survey conducted on a sister vessel, the MERCURY, in December 1998. An additional survey was conducted in July 2000 to establish topside geometry. Where the MERCURY and LINDA E differed in topside arrangements, scaled photographs of the LINDA E were used to establish the geometry. See Figure (1). The drafts of the LINDA E are based on the assumed loading condition in our previous stability analysis of February 26, 1999. This loading condition is included as appendix B. The lines plan of the GREAT LAKES was digitized to create the 3D model of the barge. The drafts for the GREAT LAKES were based on log entries and assumed to be 13' forward and 14' aft.

The deformations of the antennas on the LINDA E's pilot house were modeled on the ROV video pictures. In addition, the point of impact on the LINDA E was determined from the ROV video. The 3D model of the barge was moved in space to establish its probable geometric alignment with the LINDA E.

FINDINGS

1. Prior to Impact with Hull of LINDA E: The alignment of the models was based on the likely point of impact as determined from the damage seen in the ROV video. Figure (2) shows the damage to the starboard side of the LINDA E coincident with the point of impact.

When the stem of the barge is placed in this location longitudinally on the LINDA E some interesting observations can be noted. The initial point of impact is not with the hull of the LINDA E, but with the Loran antenna whip section. Figure (3) shows that the Loran antenna makes its initial contact with the forward-most section of the barge. As this surface of the barge is relatively flat, the most likely direction of displacement for this antenna is to the port side of the LINDA E, bending over the navigation light shield. This is consistent with the antenna deformation observed in the ROV video as seen in Figure (4).

Looking at the profile of the LINDA E as the barge approaches, Figure (5) shows the expected direction of deformation of the topside antennas. Since the Loran antenna support rod lies on the port side of the barge's line of impact, the deformation would be expected to be aft and to port on the LINDA E. This is consistent with observed deformations seen in Figure (6) and Figure (7). The Loran antenna lies on the starboard side of the barge's line of impact, so its deformation would be expected to be forward and to port. This is consistent with the deformation seen in Figure (4). The radar mast would have a similar expected deformation as the Loran antenna due to its location on the starboard side of the line of impact. This is consistent with the noted damage in Figure (8).

By viewing the stove exhaust in 3D, it is apparent the stove exhaust is too far forward to make contact with the barge. See Figure (5). No noticeable damage was observed to the LINDA E's stove exhaust. See Figure (9). In addition, the stern light is too far aft and inboard to make contact with the barge. No noticeable damage was observed on the stern light. See Figure (10).

2. <u>First Hull Contact</u>:

Figure (11) shows the barge's first contact with the hull of the LINDA E would occur at the deck edge. Because of the angle of impact, and bow rake, it is expected that a notched shape deformation would be seen on the LINDA E. This is consistent with observed deformations at this location on the LINDA E, which show a spoon shaped crushing at the deck edge. See Figure (2). The height of this point of contact is also consistent with a set of white marks found on the stem of the barge, noted in Figure (12).

Figure (11) and Figure (13) show that the Loran antenna support rod would begin to make contact with the hull of the barge at this time. As previously noted, because it would be subjected to the barge's bow flare, the rod would bend aft and to port. This is consistent with the deformation observed. The angle of bow flare in this area is approximately 40° and the angle of rake is approximately 45°, both measured from the vertical. The angle this rod on the LINDA E is deformed from the vertical is approximately 45° to aft and 35° to port. See Figure (6) and Figure (7). Thus, the extent of the rod's deformation in both directions is consistent with the flare and rake of the barge's bow.

Note that the upper deckhouse, navigation light shield and stove exhaust are all too far forward to make contact with the hull of the barge.

3. <u>Lower Deck House Contact</u>:

Figure (11) shows that contact with the lower deck house would occur next. Again, because of the angle of impact, and bow rake, it is expected that a notched shape deformation would be seen on the LINDA E, and the lower deck house would be crushed. This is consistent with the damage observed on the LINDA E, which shows the lower deck house deformed downward. See Figure (2). This deformation appears to be

focused at a location several inches wide, approximately the width of the stem of the barge.

Figure (13) shows that the radar mast would be displaced to the port and forward. This is consistent with the radar mast deformation noted. See Figure (8).

This marks the maximum extent of penetration of the barge into the LINDA E in the collision scenario, since any further penetration would damage the upper deck house and navigation light shield. This is consistent with Figure (4), which shows no perceptible damage to either the upper deck house or the navigation light shield.

4. Vessel Roll:

In this collision scenario, the LINDA E would be expected to heel to port due to the location of the collision force imparted by the barge and the moment it would generate. As the LINDA E heels, the area on the vessel's hull in contact with the barge would continue to increase and move downward. This is consistent with deformations observed in way of the inset at the rub rail on the LINDA E. See Figure (14). The width of this inset at the rail is also consistent with the size of the stem of the GREAT LAKES. By analyzing the damage at the deck and noting damage at the rubrail, the LINDA E would have to rotate at least 51 degrees to port for this damage to occur. See Figure (15). At this angle of heel the stern doors and the port service doors, which are open in the ROV video, would be submerged allowing water to rush into the vessel. See Figure (16) and Figure (17). The downflooding through these doors would be massive, driven not only by hydrostatic pressure, but also by the sideways motion of the LINDA E as it is pushed through the water by the barge at 12 knots. See Figure (18) and Figure (19) for representation. As estimated by the calculations of Appendix C, the LINDA E would lose its reserve buoyancy in approximately two seconds, at which point the vessel would sink.

5. Yawing:

In addition to the rolling to port, the LINDA E would also be expected to yaw to starboard in this collision scenario. The collision force from the barge would be imparted at a point on the LINDA E far aft of its longitudinal center of gravity. This would cause the bow of the LINDA E to rotate to starboard as the vessel yaws about its vertical axis. Thus, the area of the LINDA E's hull in contact with the barge would expand forward from the initial point of contact along the starboard side. Similarly, the area on the hull of the GREAT LAKES in contact with the LINDA E would be expected to expand aft from the stem along the barge's starboard side. See Figure (20) and Figure (21). There are markings on the both hulls consistent with this kind of motion. As noted in Figure (22), the upper paint marks on the barge extend approximately 9 feet aft from the set of marks on the stem. This corresponds to similar circular marks on the starboard side of the LINDA E which extend forward approximately 8.5 feet from the point of maximum inset. See Figure (23). These marks appear to be the furthermost damage seen forward of the point of maximum inset. Also, the vertical range of markings on the starboard side

of the barge spans a distance consistent with the vertical height of the LINDA E above the rub rail. These markings would seem to indicate the side of the LINDA E was pressed to the barge side shell.

CONCLUSION

Based on the scenario presented in this analysis, as well as the geometry of the two vessels, the damage witnessed on the LINDA E could reasonably be attributed to a collision with the GREAT LAKES.

Appendices:
A. Figures 1 through 23
B. GHS Output
C. Flooding Calculations

Appendix A

Figures

FIGURE (1): LINDA E TOPSIDE GEOMETRY.

FIGURE (2): PICTURE FROM ROV VIDEO SHOWING LOCATION OF INITIAL IMPACT ON THE STARBOARD SIDE OF THE LINDA E.

FIGURE (3): LINDA E PRIOR TO IMPACT (PERSPECTIVE IS STARBOARD SIDE OF BARGE).

FIGURE (4): LORAN ANTENNA DEFORMATION FORWARD AND TO PORT (PERSPECTIVE IS LOOKING FROM THE STARBOARD SIDE OF THE LINDA E).

FIGURE (5): PROFILE OF THE LINDA E AND THE BOW OF THE BARGE GREAT LAKES.

FIGURE (6): LORAN ANTENNA SUPPORT ROD FACING AFT (PERSPECTIVE IS FROM THE STARBOARD SIDE OF THE LINDA E).

FIGURE (7): LORAN ANTENNA SUPPORT ROD DEFORMED TO PORT (PERSPECTIVE IS FROM THE STARBOARD SIDE STERN LOOKING FORWARD ON THE LINDA E).

FIGURE (8): RADAR MAST AND NAVIGATION LIGHT MAST.

FIGURE (9): INTACT STOVE EXHAUST.

FIGURE (10): INTACT STERN LIGHT.

FIGURE (11): FIRST CONTACT WITH HULL (PERSPECTIVE IS PORT SIDE OF BARGE GREAT LAKES).

FIGURE (12): PAINT MARKS ON STEM OF BARGE GREAT LAKES.

FIGURE (13): FIRST CONTACT WITH HULL OF LINDA E (PERSPECTIVE IS BOW OF BARGE GREAT LAKES).

FIGURE (14): MAIN INSET AT RUB RAIL, ON STARBOARD SIDE OF LINDA E.

FIGURE (15): MEASURED ANGLE OF ROLL.

FIGURE (16): PORT SIDE SERVICE DOOR OPEN ON LINDA E.

FIGURE (17): STERN DOOR ON LINDA E, 2 OF 3 SECTIONS OPEN.

FIGURE (18): LINDA E ROLLED TO PORT (PERSPECTIVE IS PORT SIDE OF BARGE GREAT LAKES).

FIGURE (19): LINDA E ROLLED TO PORT 51 DEGREES (PERSPECTIVE IS FORWARD OF BARGE GREAT LAKES BOW).

FIGURE (20): LINDA E AFTER ROLLING TO PORT AND YAWING TO STARBOARD (PERSPECTIVE IS STARBOARD SIDE OF BARGE GREAT LAKES).

FIGURE (21): LINDA E ROLLED TO PORT AND YAWED TO STARBOARD (PERSPECTIVE FORWARD OF BOW OF BARGE GREAT LAKES).

FIGURE (22): PAINT MARKS ON STARBOARD SIDE OF BARGE GREAT LAKES.

FIGURE (23): CIRCULAR MARK MOST FORWARD EXTENT OF DAMAGE.

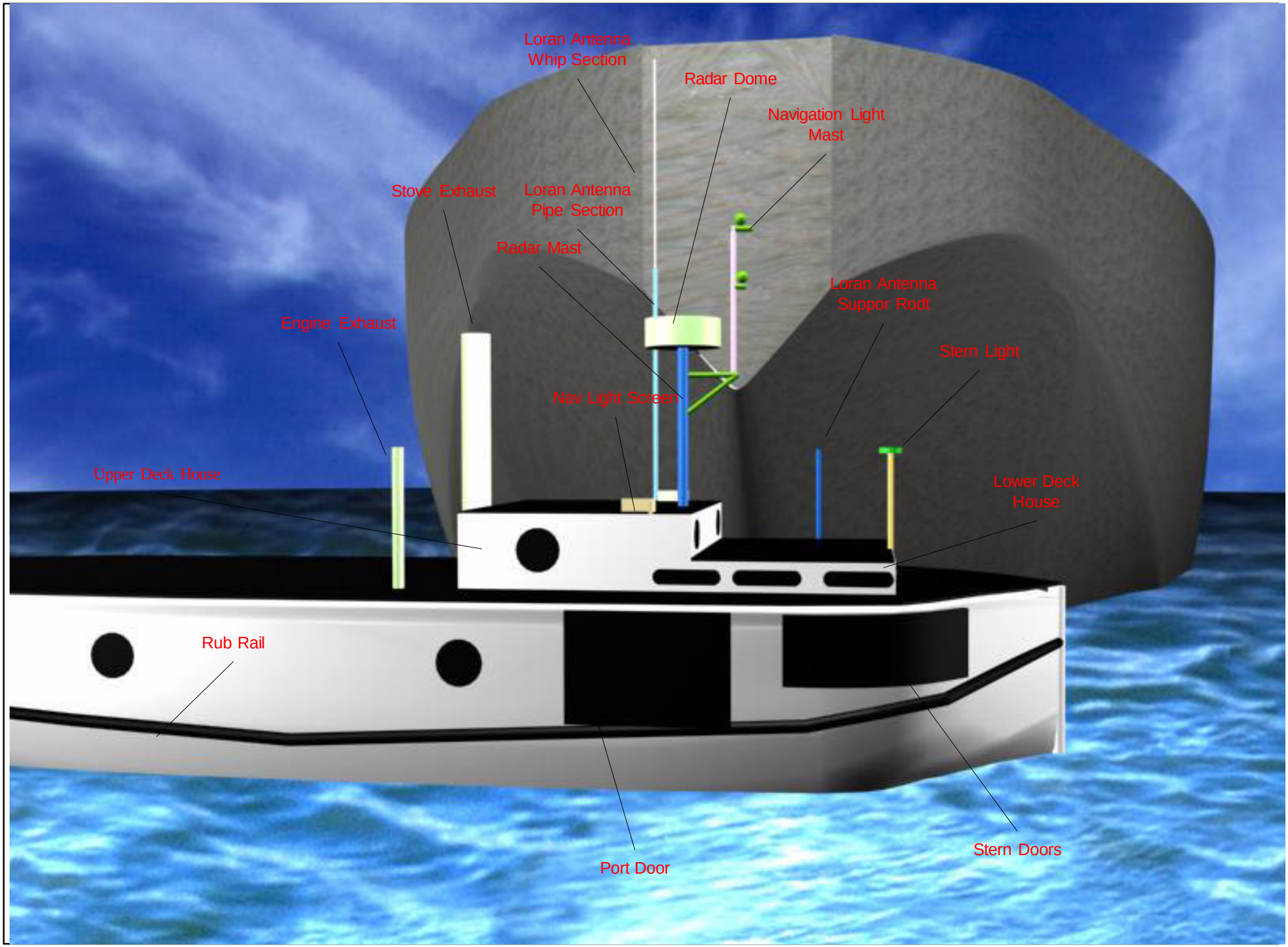

Figure (1): LINDA E topside geometry

Figure (2): Picture from ROV video showing location of initial impact on the starboard side of the LINDA E.

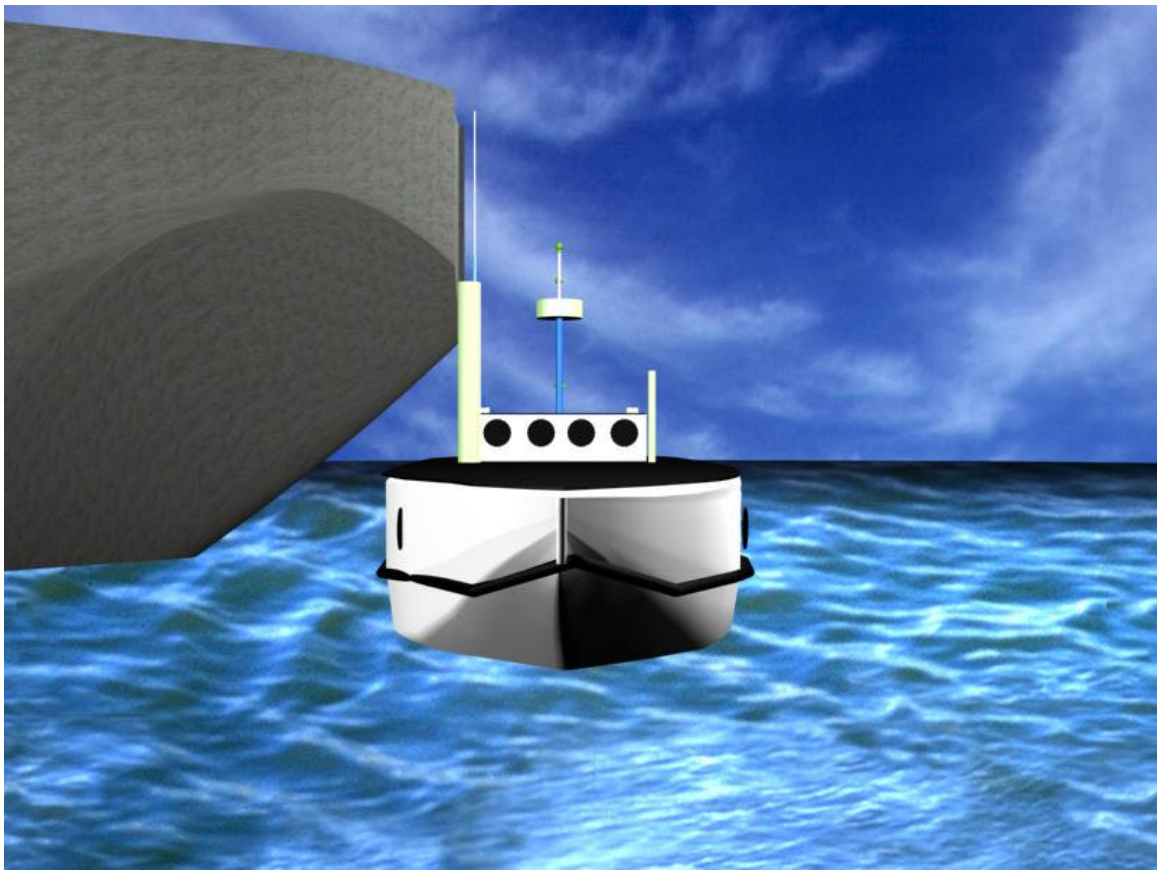

Figure (3): LINDA E prior to impact (Perspective is starboard side of barge).

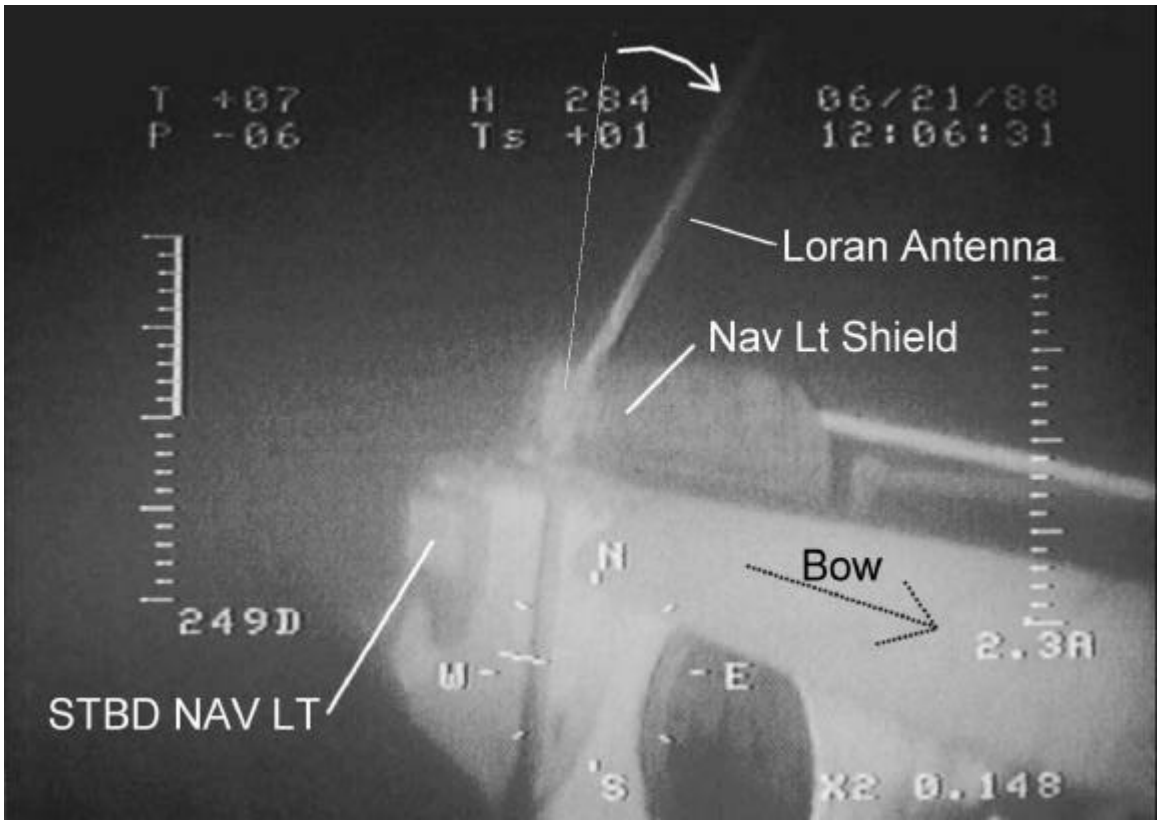

Figure (4): Loran antenna deformation forward and to port (perspective is looking from the starboard side of the LINDA E).

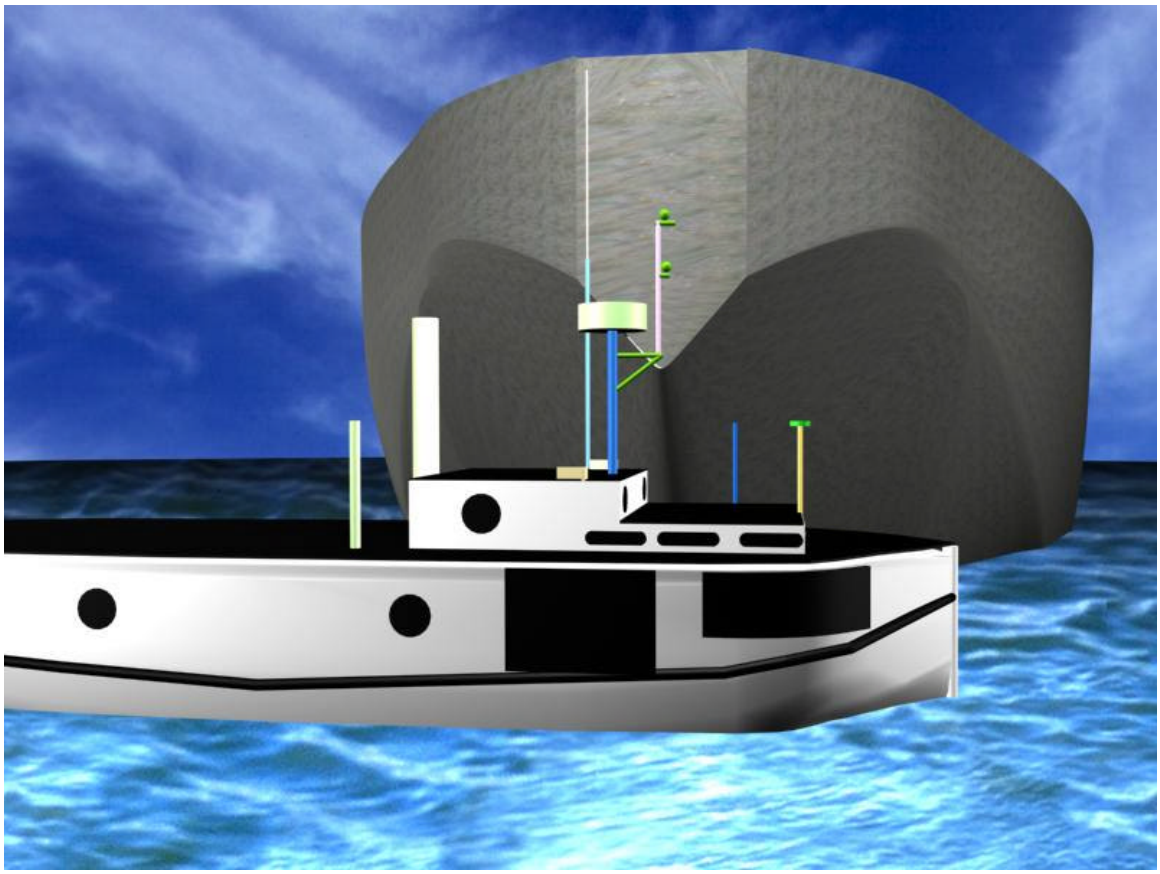

Figure (5): Profile of the LINDA E and the bow of the barge GREAT LAKES.

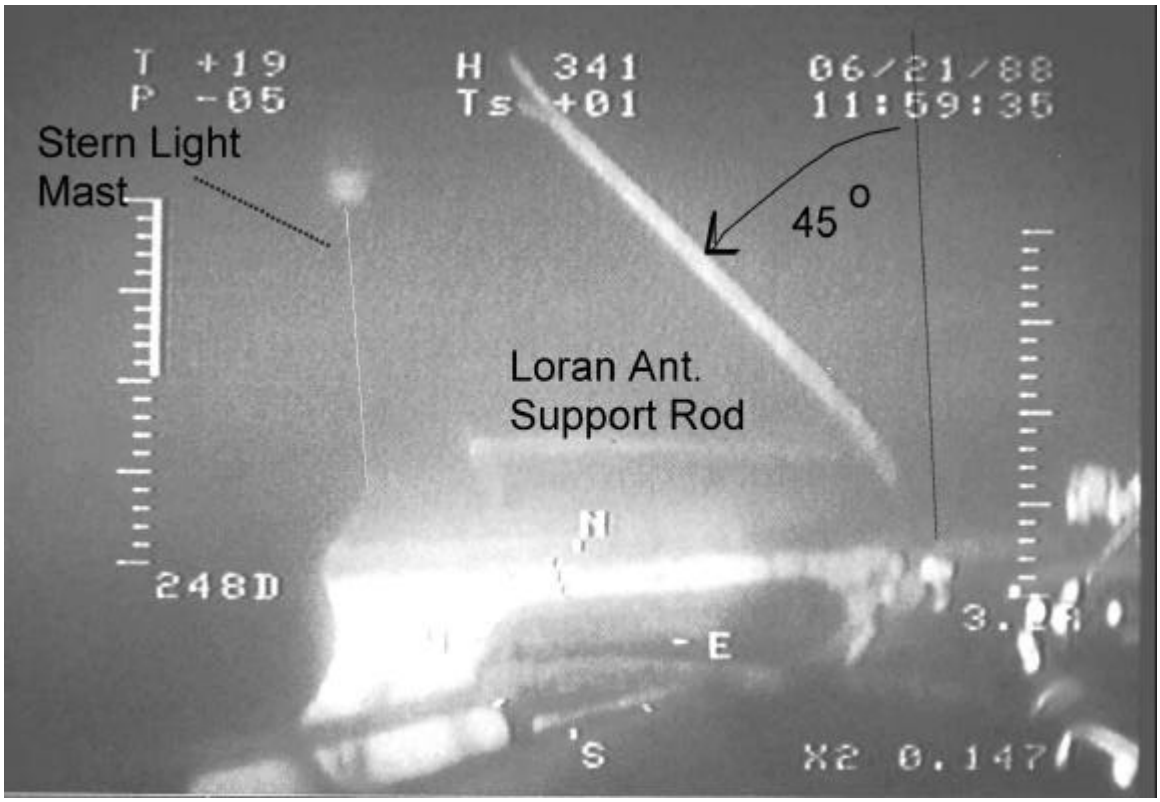

Figure (6): Loran antenna support rod facing aft (perspective is from the starboard side of the LINDA E).

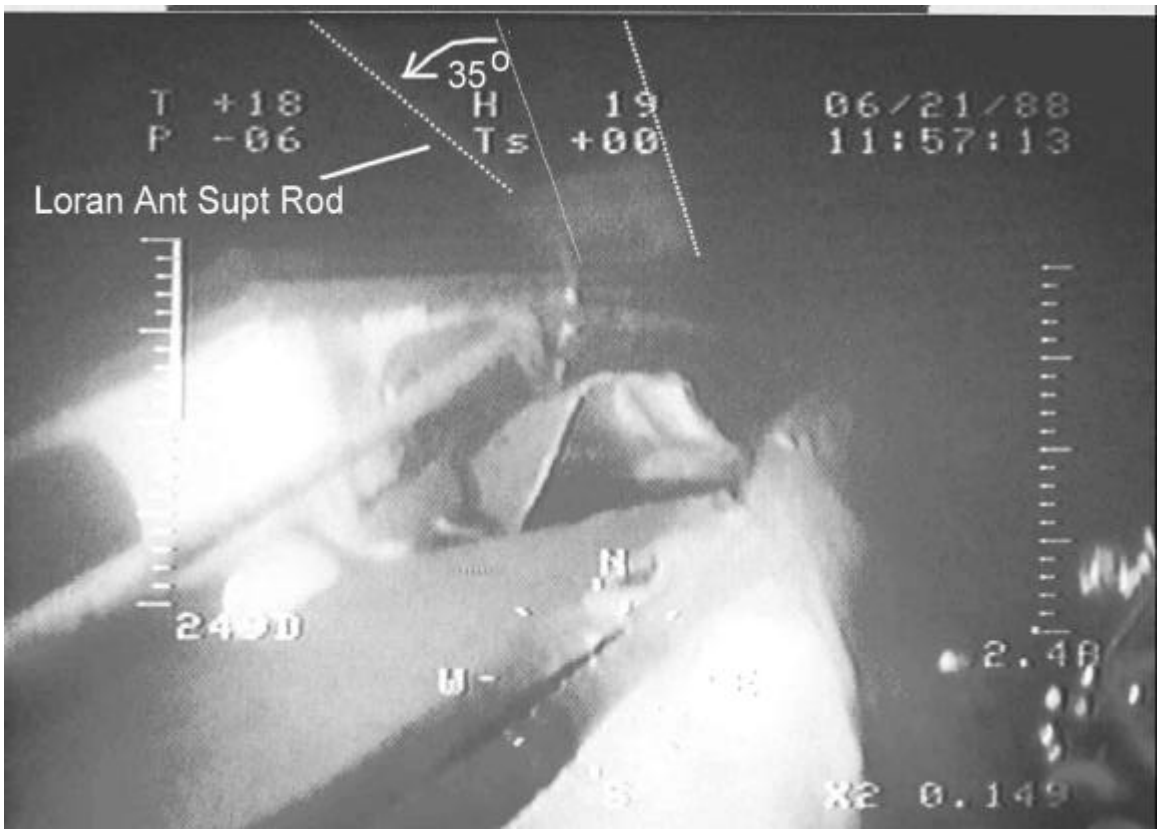

Figure (7): Loran antenna support rod deformed to port (perspective is from the starboard side stern looking forward on the LINDA E).

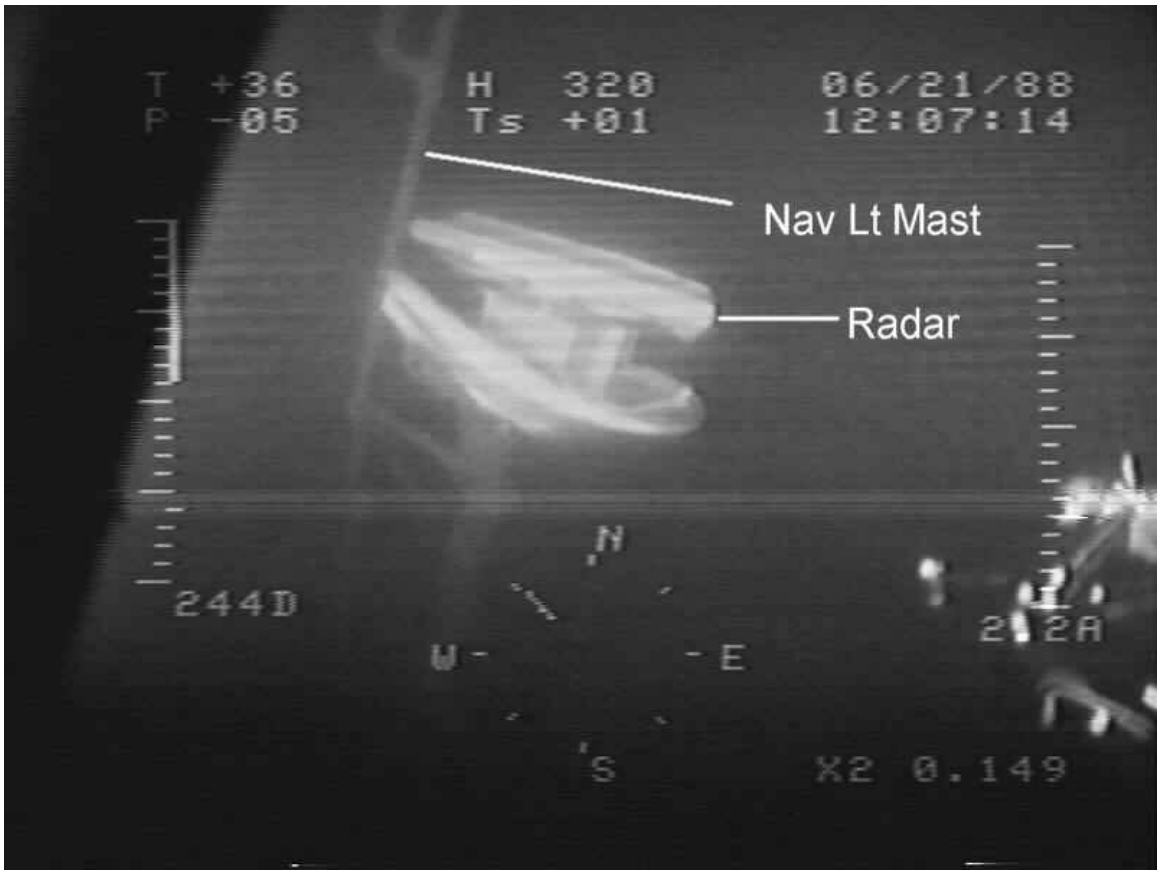

Figure (8): Radar mast and navigation light mast.

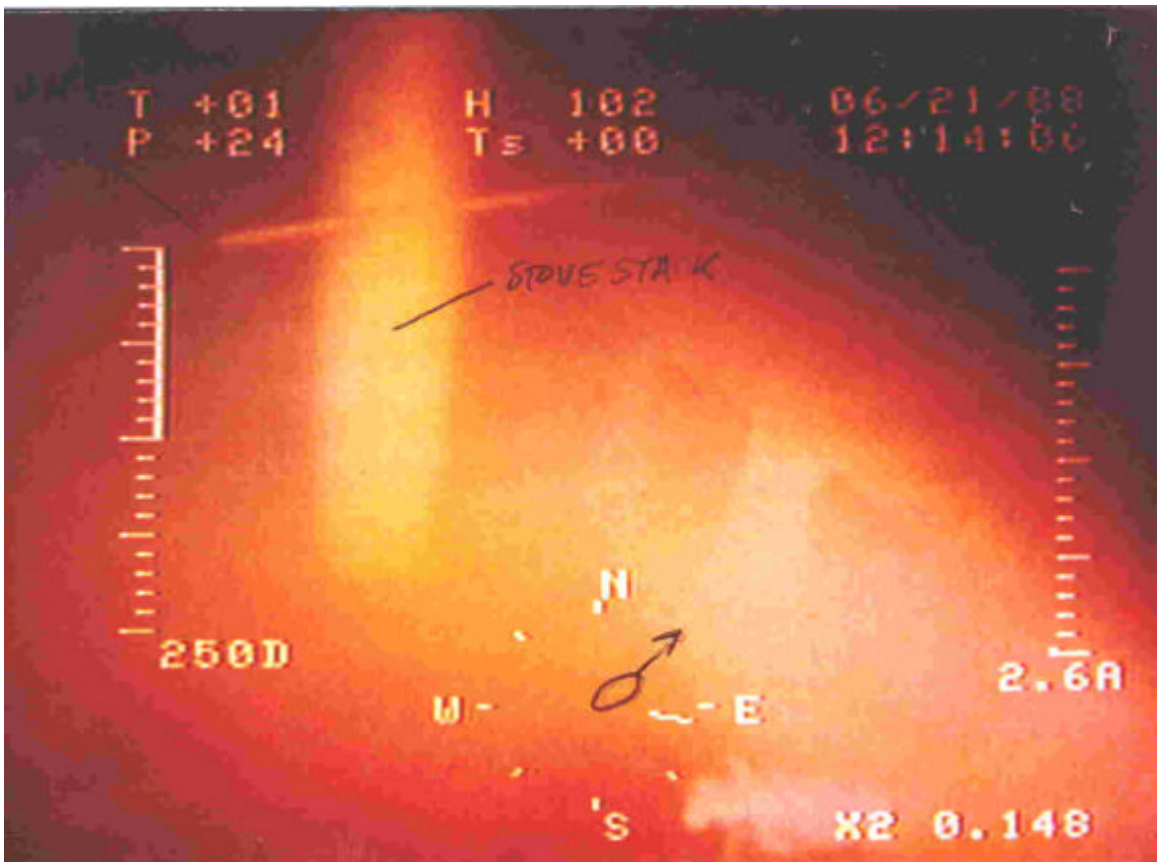

Figure (9): Intact stove exhaust.

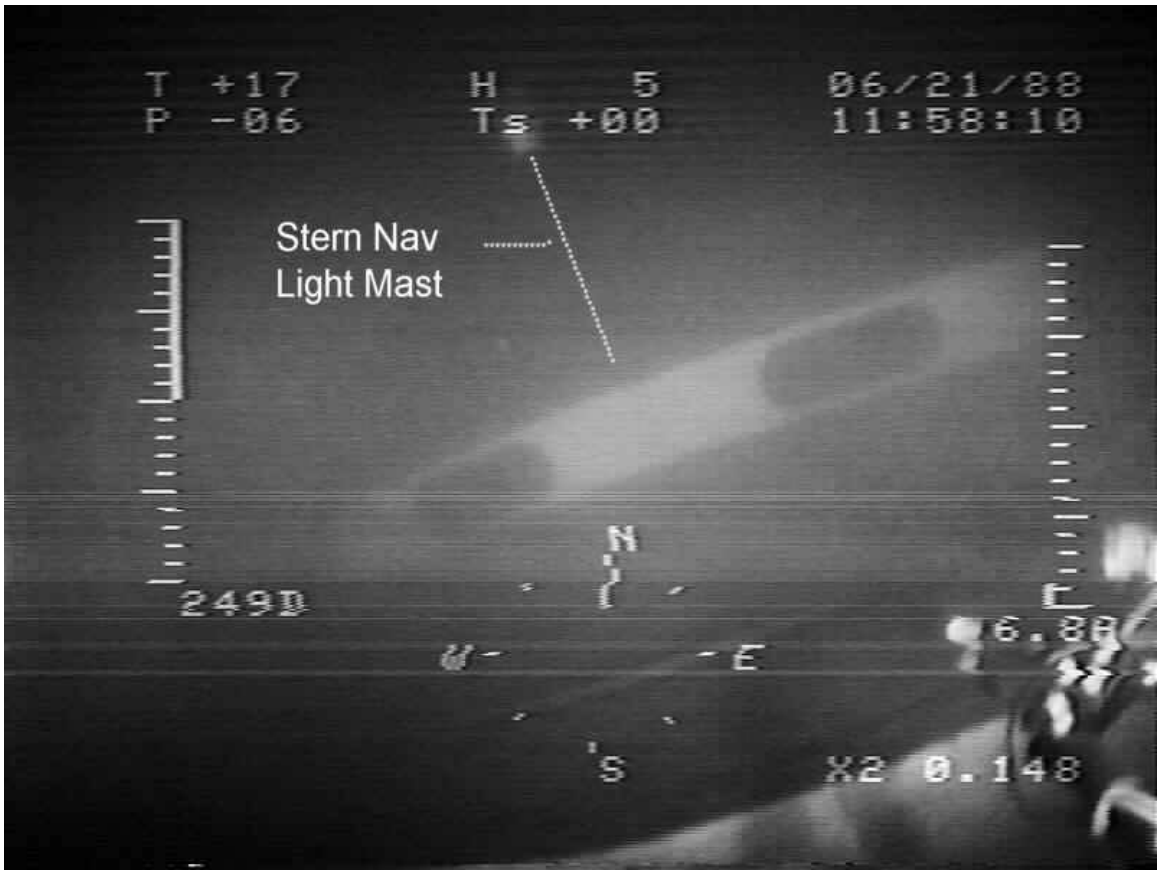

Figure (10): Intact stern light.

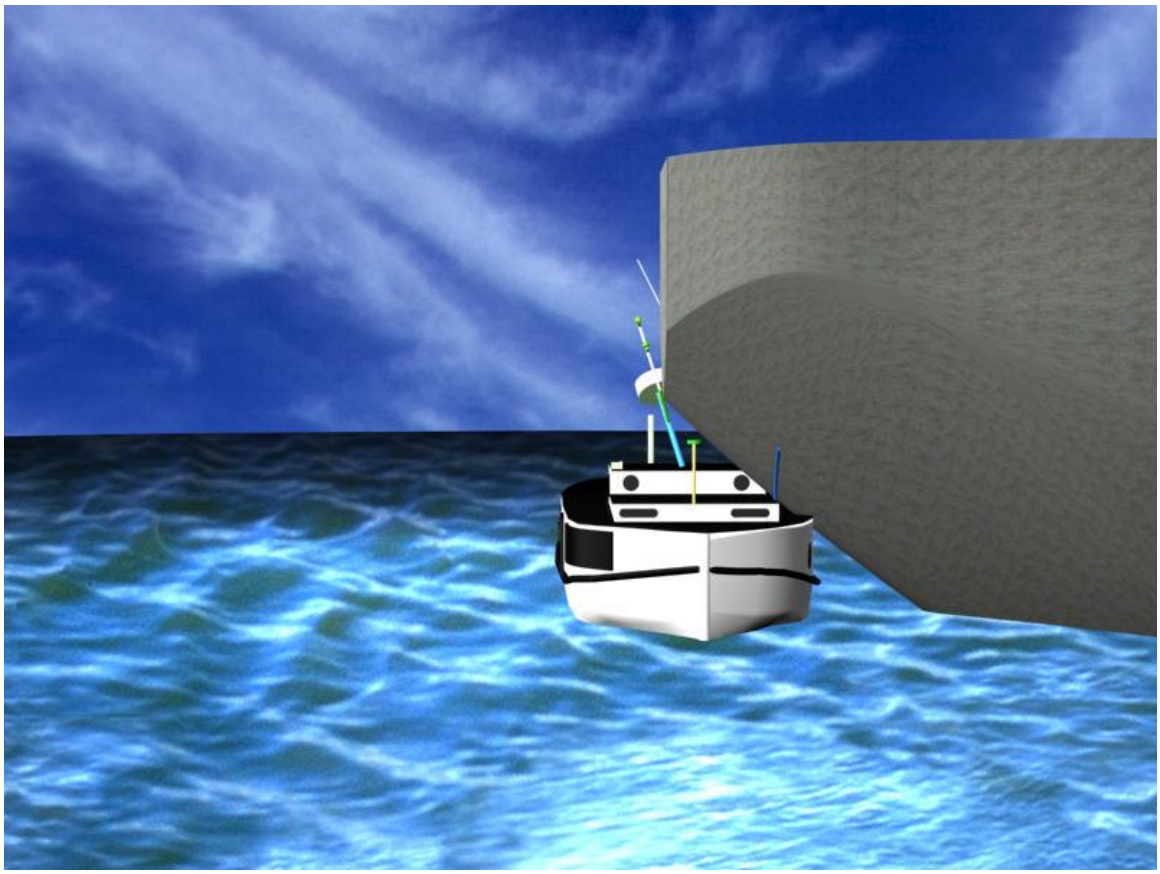

Figure (11): First contact with hull (perspective is port side of barge GREAT LAKES).

Figure (12): Paint marks on stem of barge GREAT LAKES.

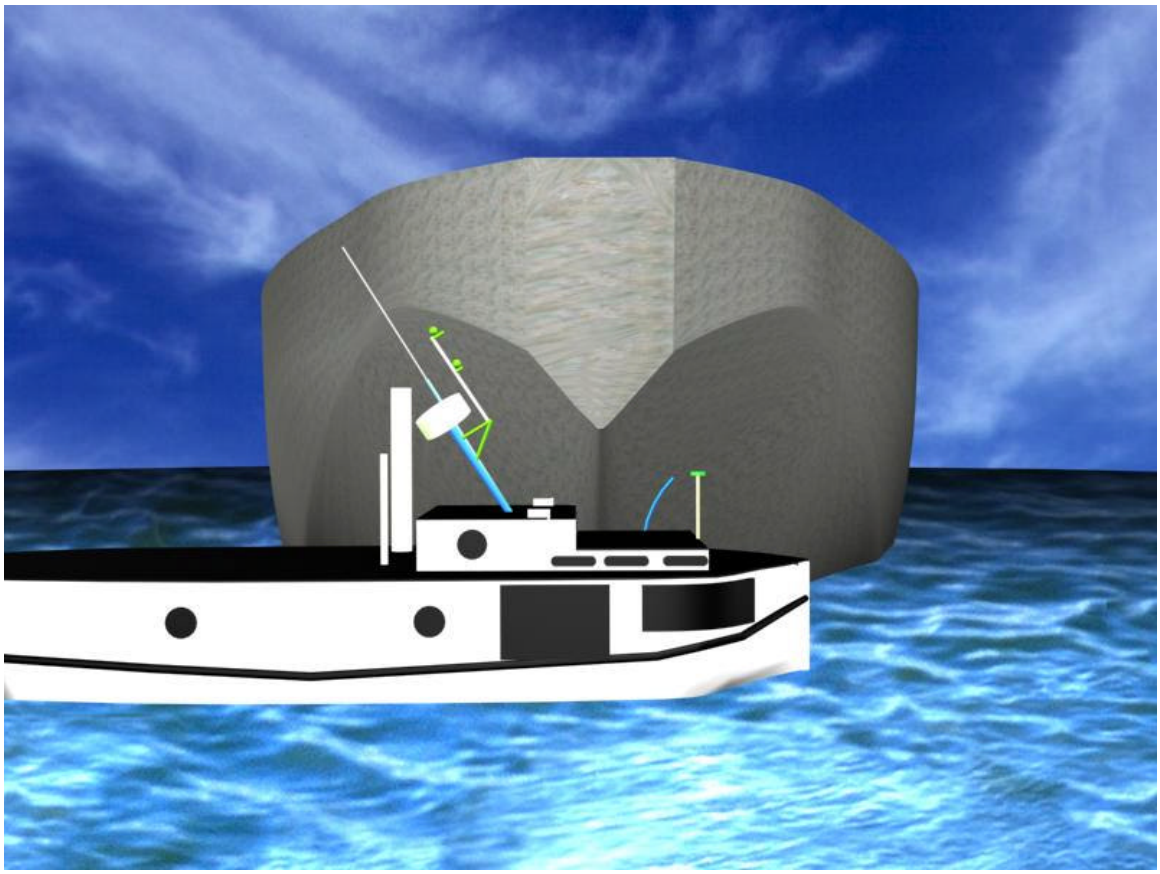

Figure (13): First contact with hull of LINDA E (perspective is bow of barge GREAT LAKES).

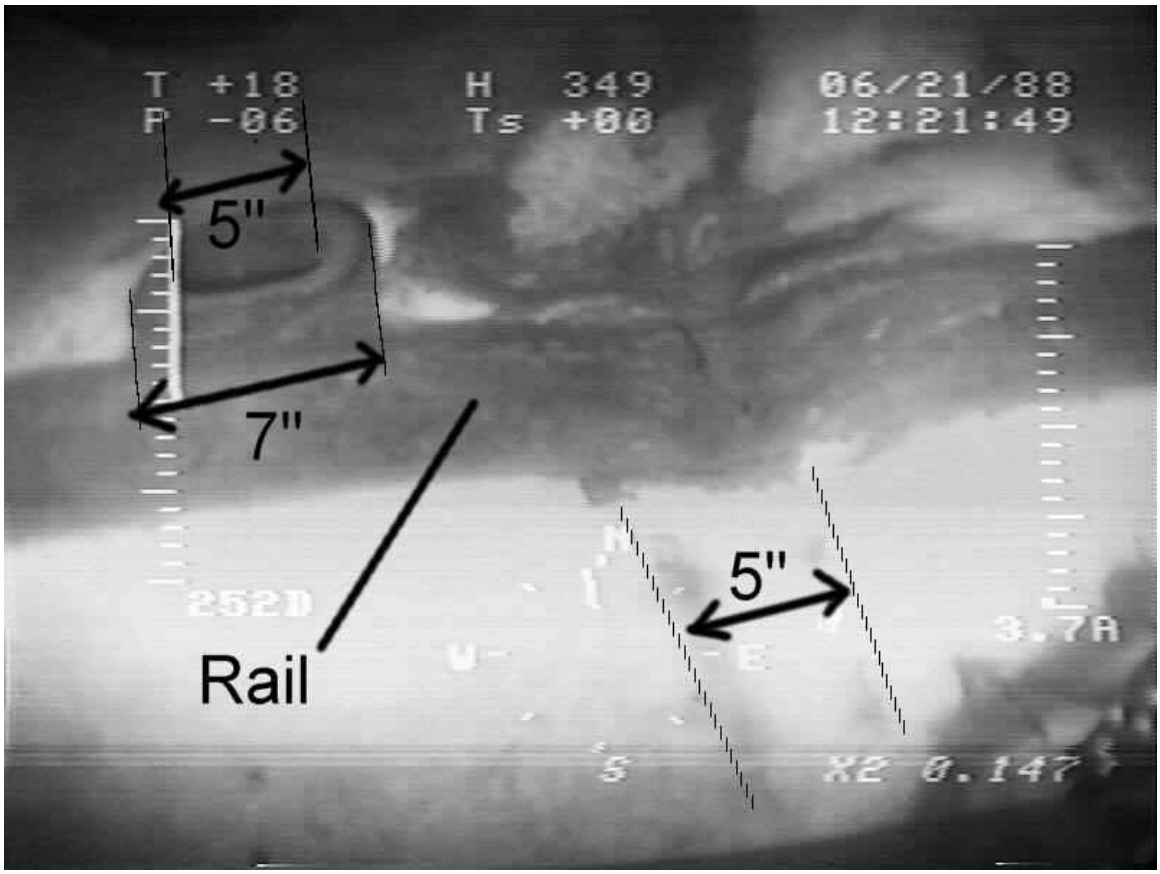

Figure (14): Main inset at rub rail, on starboard side of LINDA E.

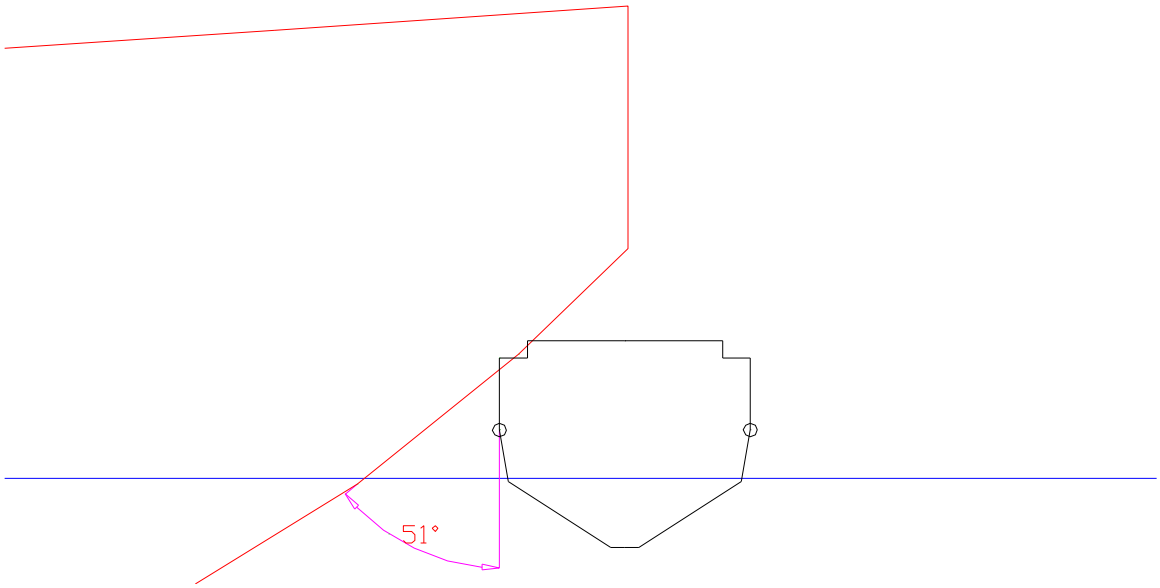

Figure (15): Measured angle of roll.

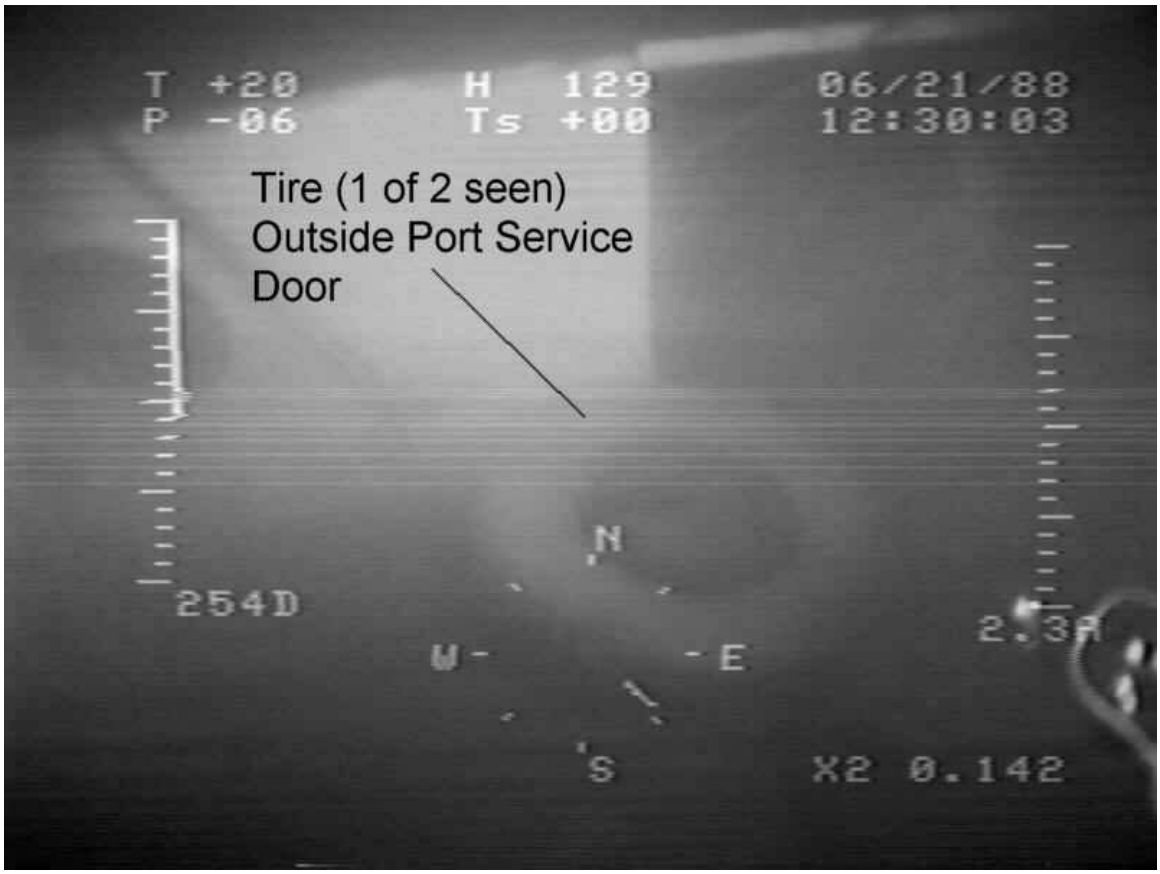

Figure (16): Port side service door open on LINDA E.

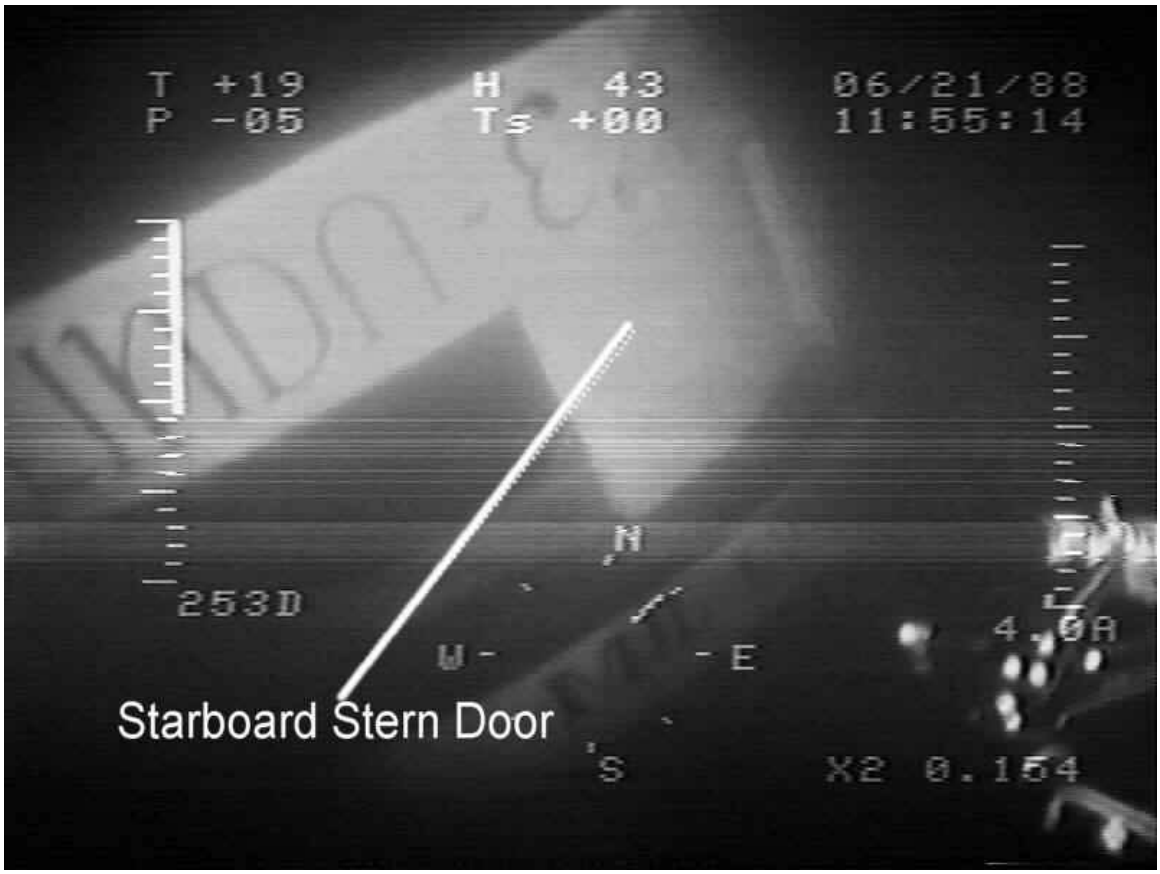

Figure (17): Stern door on LINDA E, 2 of 3 sections open.

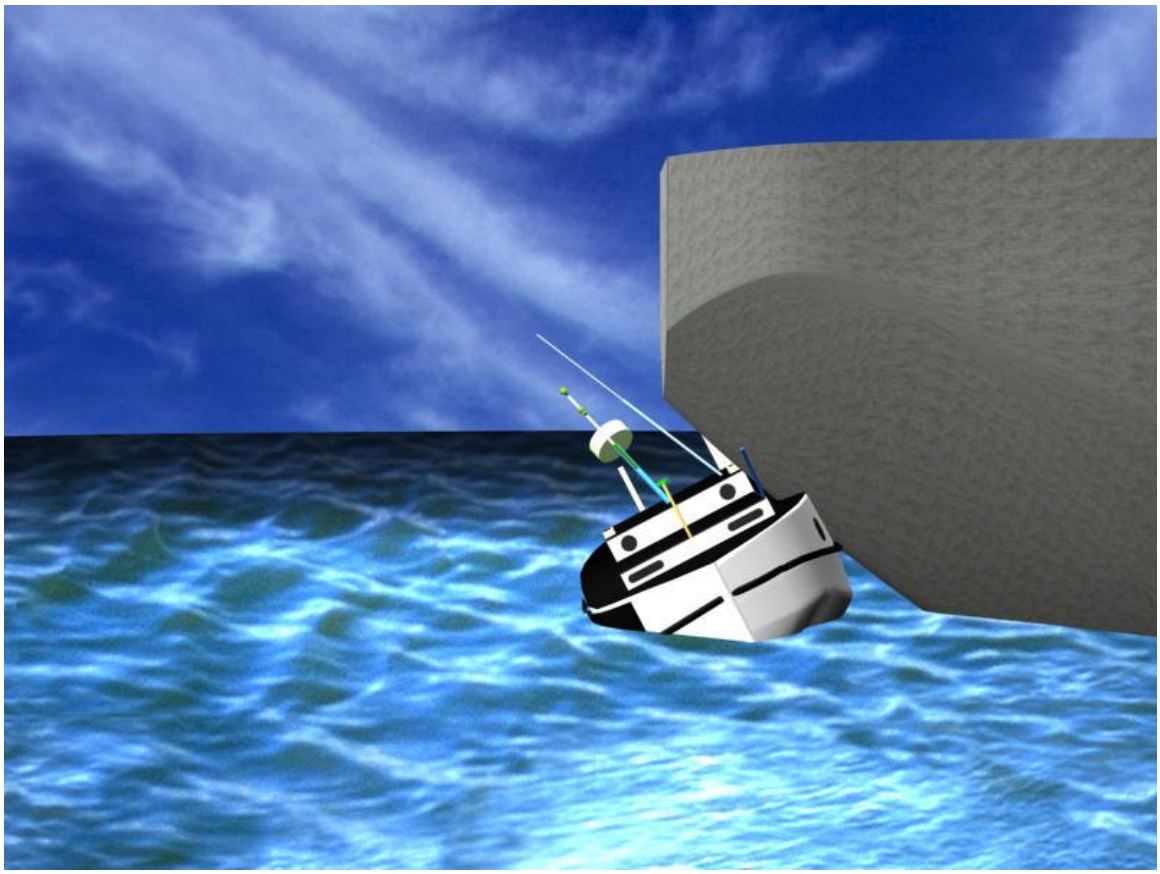

Figure (18): LINDA E rolled to port (perspective is port side of barge GREAT LAKES).

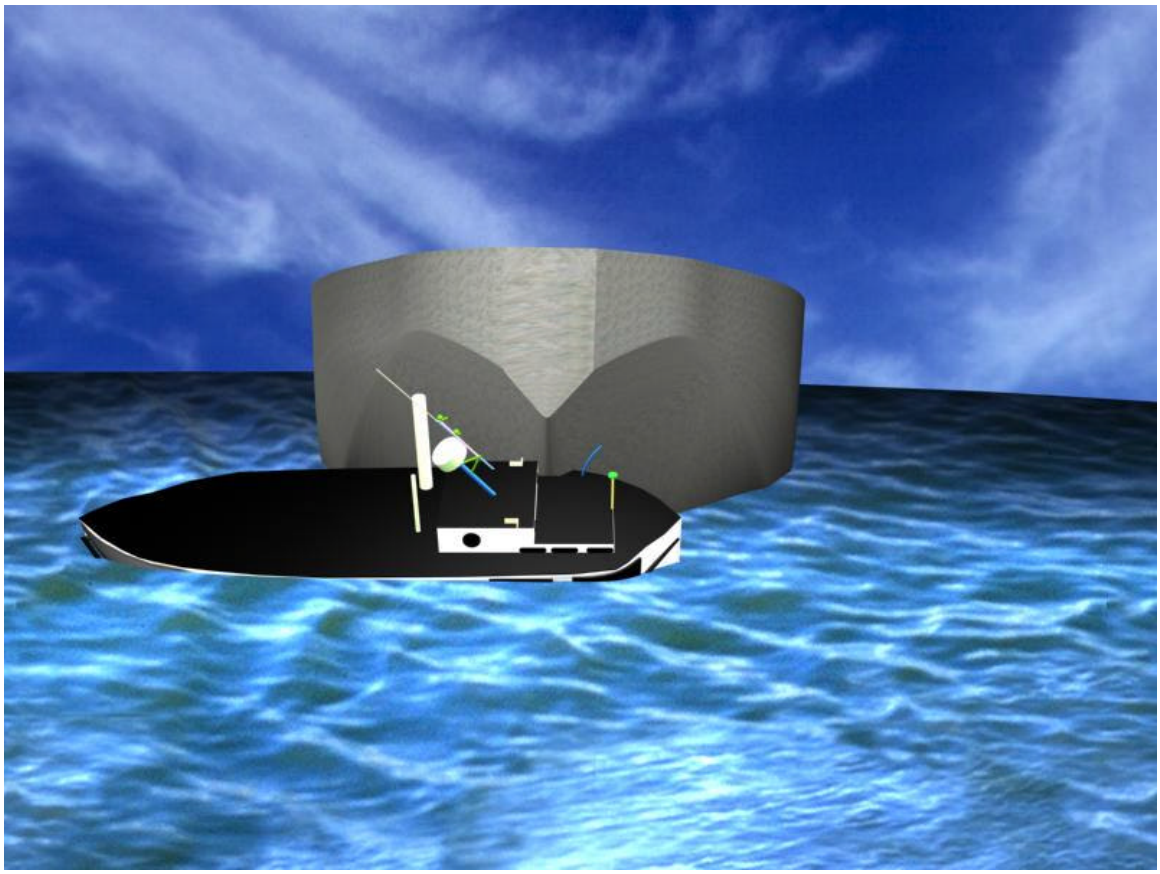

Figure (19): LINDA E rolled to port 51 degrees (perspective is forward of barge GREAT LAKES bow).

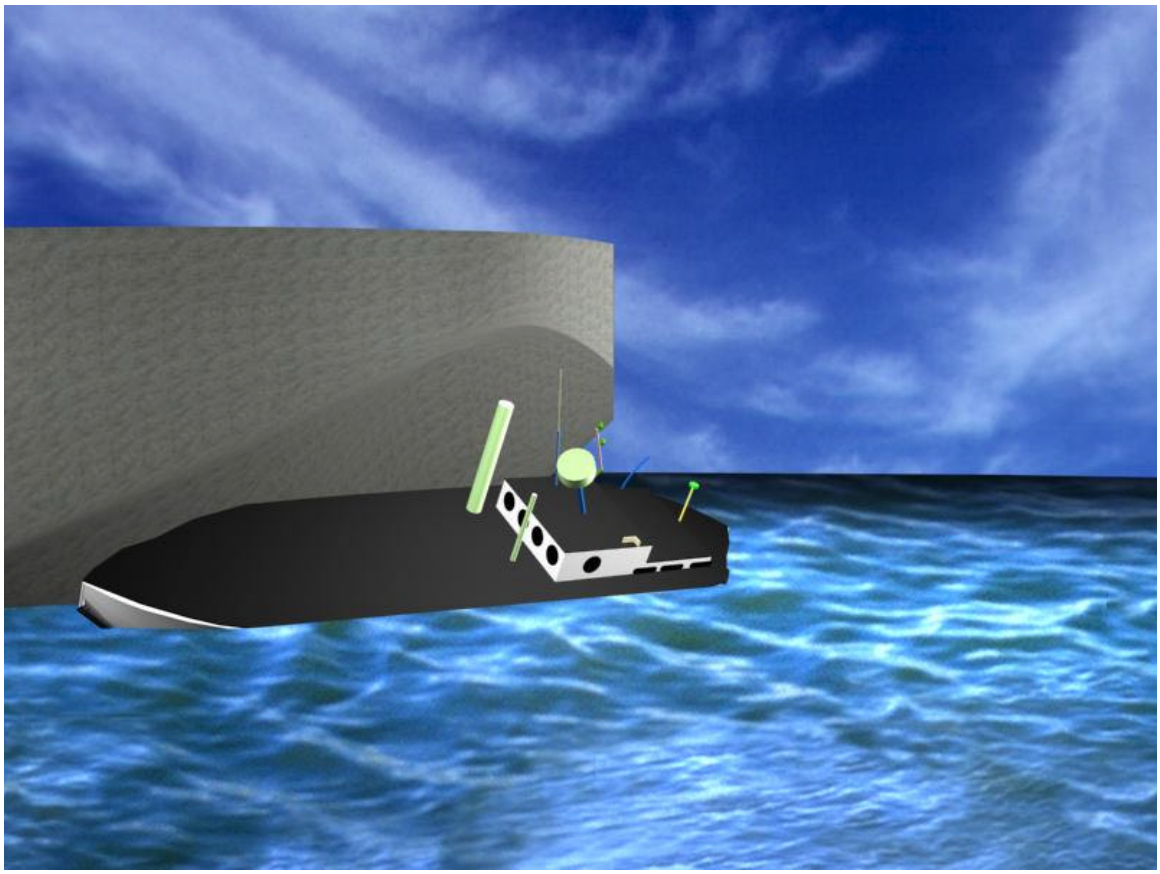

Figure (20): LINDA E after rolling to port and yawing to starboard (perspective is starboard side of barge GREAT LAKES).

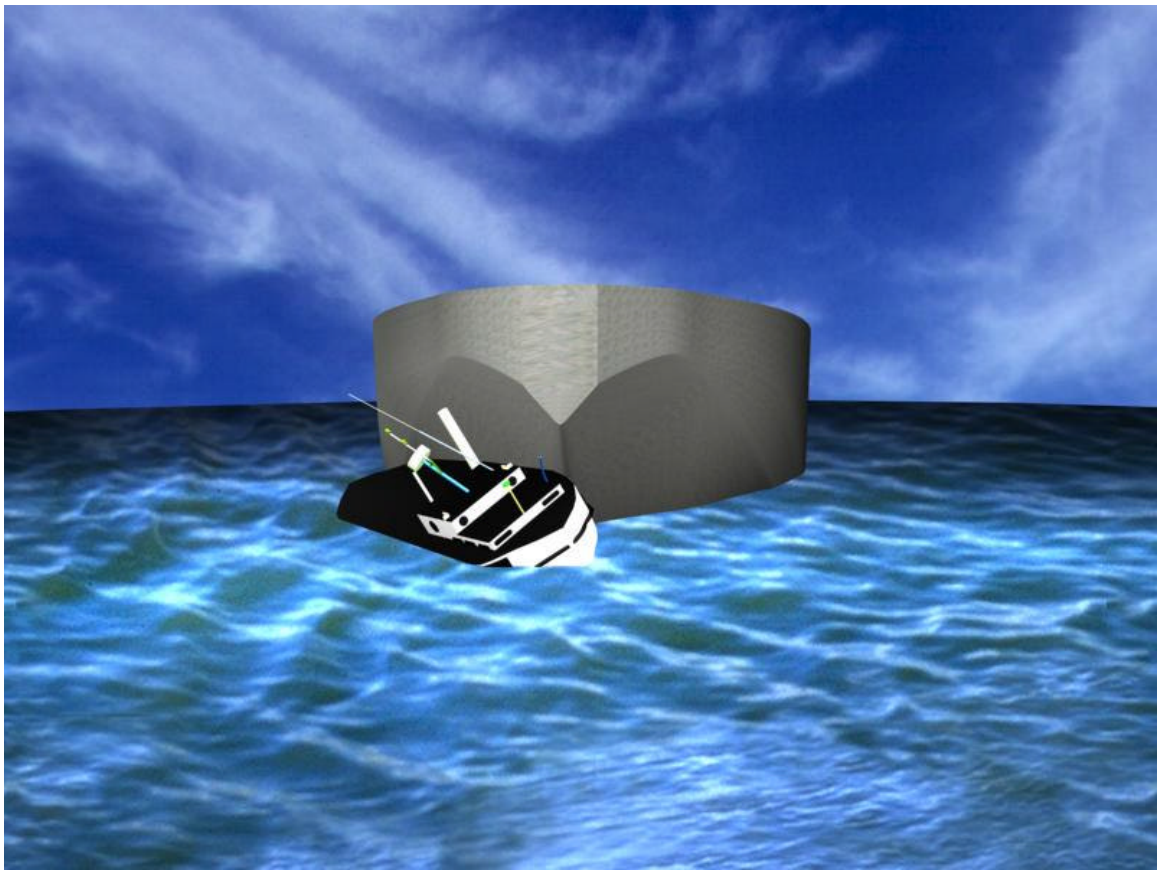

Figure (21): LINDA E rolled to port and yawed to starboard (perspective forward of bow of barge GREAT LAKES).

Figure (22): Paint Marks on starboard side of barge GREAT LAKES.

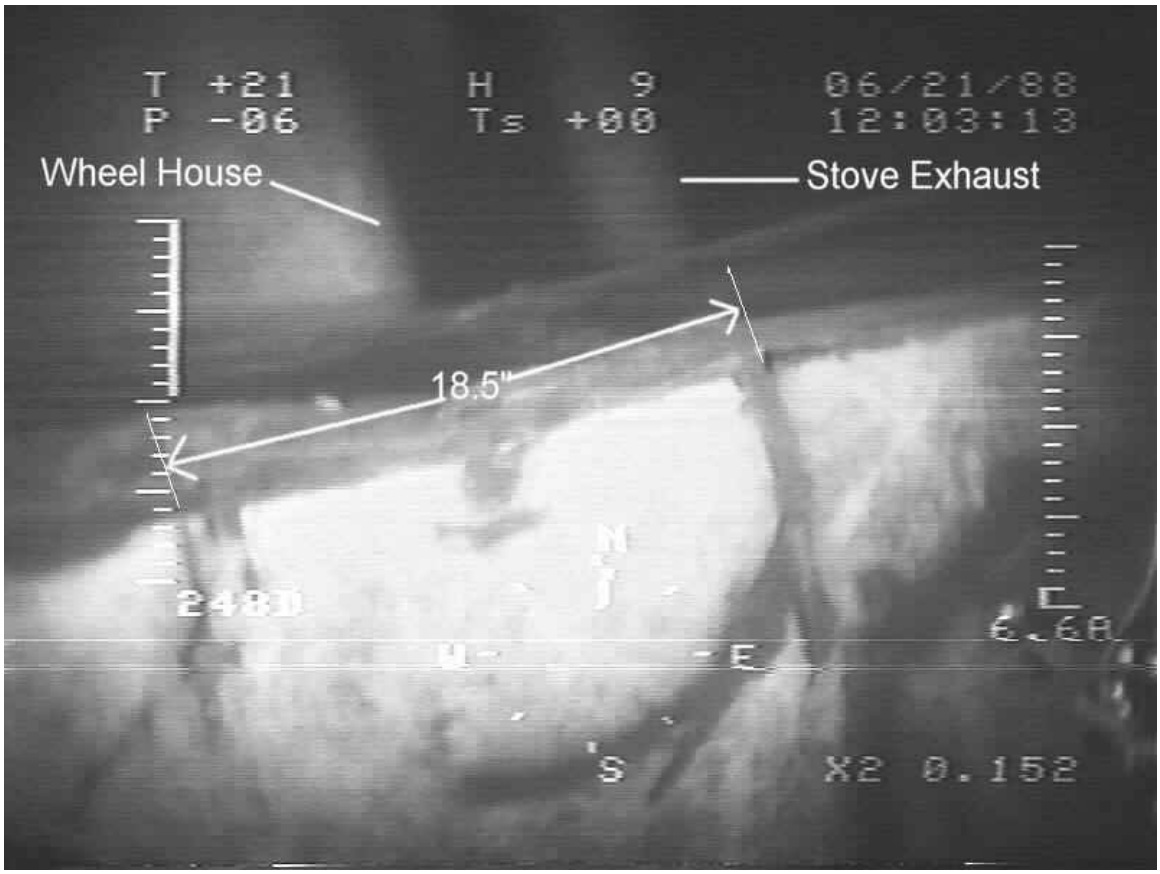

Figure (23): Circular mark; forward-most extent of damage on the LINDA E.

Appendix B

GHS Output

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00-09-13 12:02:57       USCG - MSC, Washington, D.C.                    Page 1
GHS 7.04                           LINDA E

                  ASSUMED LOAD CONDITION FOR F/V LINDA E
                            DECEMBER 11 1998


                       WEIGHT and DISPLACEMENT STATUS
                 Baseline draft: 4.392 @ 38.67f, 4.539 @ 4.75a
                       Trim: Aft 0.15/43.42,  Heel: zero
Part-----------------------------Weight(LB)----LCG-----TCG-----VCG
LIGHT SHIP                           42,369   15.28f   0.00    5.23
FISH & CREW                           2,765    0.52a   0.00    6.59
  Total Fixed--------->              45,134   14.31f   0.00    5.31
                Load-----SpGr-----Weight(LB)----LCG-----TCG-----VCG------RefHt
DOS.S          0.670    0.870           629    9.96f   4.00s   3.56       4.18
DOP.P          0.670    0.870           629   14.97f   4.00p   3.56       4.16
  Total Tanks--------->               1,259   12.46f   0.00    3.56
  Total Weight-------->              46,392   14.26f   0.00    5.27
                                   Displ(LB)----LCB-----TCB-----VCB
HULL                    1.025        46,392   14.26f   0.00    3.16      -4.52
-------------------------------------------------------------------------------
               Righting Arms:                   0.00f   0.00
Distances in FEET.-------------------------------------------------------------

                            CRITICAL POINT STATUS
                 Baseline draft: 4.392 @ 38.67f, 4.539 @ 4.75a
                       Trim: Aft 0.15/43.42,  Heel: zero
                                     +
        Critical Points-------------------- LCP-----TCP-----VCP-----Height
    (1) BTM FWD STRN Dr           FLOOD    0.00    5.50p   6.76       2.24
    (2) TOP FWD STRN DR           FLOOD    0.00    5.50p   8.59       4.07
    (3) BTM MS DOOR AFT P         FLOOD    5.67f   6.20p   6.91       2.41
    (4) TOP MS DOOR AFT P         FLOOD    5.67f   6.20p   9.87       5.37
    (5) BTM MS DOOR FWD P         FLOOD   10.08f   6.43p   6.91       2.43
    (6) TOP MS DOOR FWD P         FLOOD   10.08f   6.43p   9.87       5.38
    (7) FWD DK Height             FLOOD   38.67f   0.00   10.39       5.99
    (8) AFT DK HEIGHT             FLOOD    4.75a   0.00   10.23       5.69
    Distances in FEET.-------------------------------------------------
```

Righting Arms
RIGHTING ARMS vs HEEL ANGLE
Fixed CG: LCG = 14.31f TCG = 0.00 VCG = 5.31

Origin Depth	Degrees of Trim	Heel	Displacement Weight(LB)	Righting Arms in Trim	in Heel	--> Area	Flood Pt --Height
4.523	0.19a	0.00	46,392	0.00	0.000	0.00	2.24(1)
4.494	0.18a	5.00p	46,392	0.00	0.226p	0.56	1.76(1)
4.401	0.13a	10.00p	46,385	0.00	0.434p	2.22	1.30(1)
4.031	0.01a	20.00p	46,393	0.00	0.774p	8.34	0.27(5)
3.888	0.03f	22.74p	46,395	0.00	0.854p	10.57	-0.00(5)
3.481	0.03f	30.00p	46,389	0.00	0.990p	17.31	-0.71(5)
3.248	0.04a	34.13p	46,393	0.00	1.007p	21.45	-1.13(5)
2.915	0.19a	40.00p	46,396	0.00	0.975p	27.30	-1.72(5)
2.324	0.53a	50.00p	46,389	0.00	0.812p	36.35	-2.71(5)
1.712	0.92a	60.00p	46,392	0.00	0.565p	43.30	-3.66(5)
1.079	1.34a	70.00p	46,393	0.00	0.276p	47.54	-4.52(5)
0.522	1.73a	78.82p	46,389	0.00	0.000p	48.78	-5.18(5)

Distances in FEET.------Specific Gravity = 1.025.---------Area in Ft-Deg.
+

Note: The Center of Gravity shown above is for the Fixed Weight of 45134 LB. As the tank load centers shift with heel and trim, the total Center of Gravity varies. The righting arms shown above include the effect of the C.G. variation.
+

Critical Points		LCP	TCP	VCP
(1) BTM FWD STRN Dr	FLOOD	0.00	5.50p	6.76
(5) BTM MS DOOR FWD P	FLOOD	10.08f	6.43p	6.91

LINDA E @ 51 Degrees Heel to Port
WEIGHT and DISPLACEMENT STATUS
Origin Depth: 2.264
Trim: Aft 0.43/43.42, Heel: Port 51.00 deg.

Part			Weight(LB)	LCG	TCG	VCG	
LIGHT SHIP			42,369	15.28f	0.00	5.23	
FISH & CREW			2,765	0.52a	0.00	6.59	
Total Fixed--------->			45,134	14.31f	0.00	5.31	
	Load	SpGr	Weight(LB)	LCG	TCG	VCG	RefHt
DOS.S	0.670	0.870	629	9.90f	3.84s	3.63	-0.63
DOP.P	0.670	0.870	629	14.90f	4.16p	3.63	5.53
Total Tanks--------->			1,259	12.40f	0.16p	3.63	
Total Weight-------->			46,392	14.26f	0.00p	5.27	
			Displ(LB)	LCB	TCB	VCB	
HULL		1.025	46,392	14.23f	2.64p	4.15	-2.26

Righting Arms: 0.00 0.79p
Distances in FEET.

CRITICAL POINT STATUS
Origin Depth: 2.264
Trim: Aft 0.43/43.42, Heel: Port 51.00 deg.

Critical Points		LCP	TCP	VCP	Height
(1) BTM FWD STRN Dr	FLOOD	0.00	5.50p	6.76	-2.28
(2) TOP FWD STRN DR	FLOOD	0.00	5.50p	8.59	-1.13
(3) BTM MS DOOR AFT P	FLOOD	5.67f	6.20p	6.91	-2.67
(4) TOP MS DOOR AFT P	FLOOD	5.67f	6.20p	9.87	-0.81
(5) BTM MS DOOR FWD P	FLOOD	10.08f	6.43p	6.91	-2.81
(6) TOP MS DOOR FWD P	FLOOD	10.08f	6.43p	9.87	-0.95
(7) FWD DK Height	FLOOD	38.67f	0.00	10.39	4.65
(8) AFT DK HEIGHT	FLOOD	4.75a	0.00	10.23	4.13

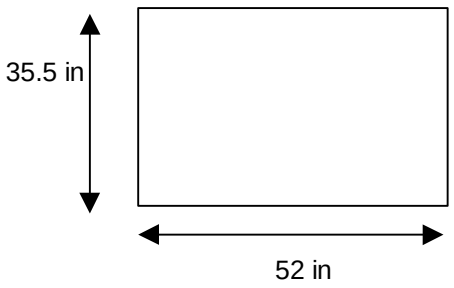
Distances in FEET.

Flooding Calculations For the LINDA E

Assumptions

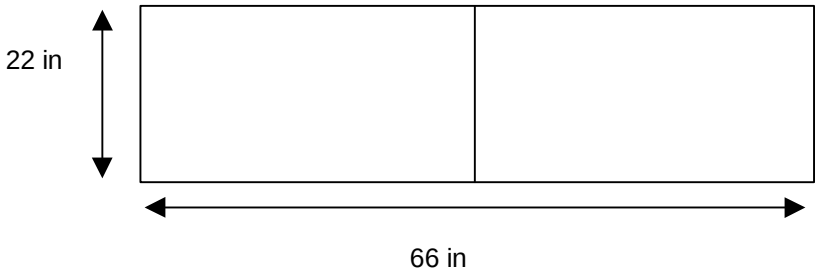
1. Vessels heels to port 51 degrees upon impact and is pushed at 12 knots transversely
2. Port Door aft and Stern doors are only sources of flooding
3. Total Hull volume 1819 ft^3
4. Assumed displacement 725 ft^3

Port Door Area



Port Door Area 12.8 ft^2

Stern Door 2 doors Open



Stern Door Area 10.1 ft^2
Total Area (A) 22.9 ft^2
Velocity (V) 20.25 ft/s

Flooding Rate Q=VA 464 ft^3/s

Reserve Bouyancy 1094 ft^3
Time to exceed Reserve Bouyancy **2.4** seconds

Attachment (2)

Pictures of Various Vessels

Table of Figures

FIGURE (1): D&S O.N. 234508
FIGURE (2): JOLENE, O.N. 248708
FIGURE (3): SHERRY LYNN, O.N. 234497
FIGURE (4): NEESKAY, O.N. 512553
FIGURE (5): BARGE INTEGRITY, O.N. 1044267
FIGURE (6): TUG SUPERIOR O.N. 210354
FIGURE (7): JAMES R. BAKER, O.N. 573682
FIGURE (8): WILFRED SYKES, O.N. 259193
FIGURE (9): JOSEPH L. BLOCK, O.N. 574870

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