U.S. Department of Homeland Security
United States Coast Guard

Commandant
Un ted States Coast Guard

Outer Cont nenta She f
Nat ona Center of Expert se
425 Lafayette St., Su te 126
Morgan C ty, LA 70360 4800
Phone: (985) 850 6465
HQS DG OCS NCOE@uscg.m

16732
08 May 2020

MEMORANDUM

From: [redacted]
CG OCSNCOE

To: [redacted]
CG INCOE
Lead Investigator, FPS AUGER 30 June 2019 Lifeboat Casualty Investigation

Subj: USCG TESTING OF SCHAT-HARDING LHR 3.5M2 RELEASE MECHANISM

1. Additional testing of the Schat-Harding LHR 3.5M2 (SeaCure®) lifeboat release mechanism was conducted on 14 January 2020 at Marine Survival Training Center (MSTC) in Lafayette, LA. Testing was conducted in support of the 30 June 2019 FPS AUGER Lifeboat 6 casualty investigation with the intent to further investigate theories related to the release gear control cables.
2. A detailed report is attached as Enclosure (1) and documents the equipment tested, tests conducted, observations and conclusions. The report documents similarities and differences noted between AUGER Lifeboat 6 and MSTC Lifeboat 1 that was utilized for the testing, and their respective installed equipment. Descriptions of the release mechanism components, control cable construction and how the components interact as a system are also included within the report.
3. The purpose of the testing was to determine the following:
    a. The force required to operate the release unit with various loads on the hooks, as the force required to operate the release unit translates into force applied to/through the control cables;
    b. How the operation of the release lever would affect the polyethylene (white) liner of the control cable (e.g. stretch, distortion and/or breakage) with the outer layers of the cable conduit in a damaged/compromised condition; and
    c. How a separated polyethylene liner affects the position of the locking shaft (cam) of the hook, with the control cable installed in the same model boat and routed in the same manner as that of AUGER Lifeboat 6.
4. The testing revealed that a compromised control cable could contribute to the unintentional opening of a single hook in the Schat-Harding/Palfinger LHR-series release mechanism with the following conclusions:

a. The results of these experiments show that damage to the conduit and polyethylene liner can result in failure of the cable. With damage present, a combination of the force required to open the locking shaft and the friction force in the cable itself produces a tensile force in the polyethylene liner that can cause it to fail completely. If the failure occurs while cycling the release lever, it can result in the hook locking shaft stopping between the open and closed positions ("**B**" and "**C**" positions, respectively, on Figure 34).

b. With the locking shaft in a partially-closed position immediately following conduit separation, the hook can still support the weight of the lifeboat and the occupants. Additionally, if the locking shaft is in a position that is relatively close to the open position, but still allows the hooks to be locked, the hooks can support the weight of the boat, though an additional load can cause the locking shaft to rotate and allow the hook to open.

c. It must be emphasized that after the initial liner failure and separation, any further cycling of the system will result in the locking shaft remaining in the fully open position. With a failed liner, the cable conduit freely extends, rendering the system unable to rotate the locking shaft to the closed position. This prevents the hooks from locking, rendering them unable to hold any load (see the observations for Experiment 2, Step 15).

d. The results of the testing show that a compromised control cable can place the locking shaft in a position that could be forced to open with application of an increased load.

5. Should you have any questions related to the report, please contact myself or one of the members of my staff attached to your investigations team.

#

USCG Testing of Schat-Harding LHR 3.5M2 Release Mechanism

Conducted at Marine Survival Training Center (MSTC) Lafayette on January 14, 2020

Purpose

The measurements and tests conducted and detailed in this report were developed with the intent to obtain data for the Schat-Harding LHR 3.5M2 release mechanism related to the following:

1) The force required to operate the release unit with various loads on the hooks,
2) How the operation of the release lever would affect the polyethylene (white) liner of the control cable (e.g. stretch, distortion and/or breakage), and
3) How a separated polyethylene liner affects the position of the locking shaft (cam) of the hook with the control cable installed in the same model boat and routed in the same manner as that of AUGER Lifeboat 6 (based on photographic evidence that provides the majority of the cable routing).

Further tests were developed to document what would happen when additional force was applied to the hook with the release system in a compromised state (i.e., locking shaft rotated between the closed and open positions due to a separated polyethylene liner in the control cable).

Personnel Involved

This testing was conducted/witnessed by the following U.S. Coast Guard personnel:

LCDR [redacted], Investigations National Center of Expertise, Lead Investigator for the FPS AUGER Lifeboat 6 Casualty Investigation

LCDR [redacted], P.E., Detachment Chief, Outer Continental Shelf National Center of Expertise (OCSNCOE)

LT [redacted], Naval Architect, OCSNCOE

[redacted], OCSNCOE, assigned as Subject Matter Expert for the AUGER Lifeboat 6 Casualty Investigation

[redacted], OCSNCOE, assigned as Subject Matter Expert for the AUGER Lifeboat 6 Casualty Investigation

Contributors

Marine Survival Training Center, Lafayette (Mr. [redacted]) for the use of a Watercraft EL-24 lifeboat outfitted with Harding Safety LHR3.5M2 Release Mechanism for testing.

Palfinger Marine USA, New Iberia (Mr. [redacted]) for the verification of control cable part numbers, use of a hydraulic hook testing apparatus and supporting documentation/formulas and providing a technician to install and adjust new control cables after testing.

Total Safety, Broussard (Mr. [redacted]) for the use of a calibrated/certified scale for testing.

USCG District Eight Public Affairs Office (PA3 [redacted]) for assistance with video and photo documentation of the testing conducted.

This report contains the following sections:

Incident & Test Lifeboat Data

Table 1 documents USCG Type Approval information for the lifeboat involved in the incident and the MSTC Lafayette lifeboat utilized for this additional testing. See Figure 1 for the data plate on AUGER Lifeboat 6.

	FPS AUGER, Lifeboat 6	MSTC, Lifeboat 1
Lifeboat		
Make	Watercraft America	Watercraft America
Model	EL24 (33-Person)	EL24 (33-Person)
USCG Type Approval No.	160.035/487/0	160.035/487/0
Serial No.	EL24-874/3/84	EL24-0010179
Build Date	March 19, 1984	January 31, 1979
USCG Inspection Office	JAC	JAC
Release Mechanism		
Make	Schat-Harding	Schat-Harding
Model	LHR3.5M2	LHR3.5M2
USCG Type Approval No.	160.133/52/0	160.133/52/0
Forward Hook Serial No.	1008/11	1003/11
Aft Hook Serial No.	1001/11 (S/N changed to 1004/11)	1007/11
Build Date	April 21, 2011	April 21, 2011
USCG Inspection Office	ACTEUR	ACTEUR

Table 1: USCG Type Approval information for incident and tested lifeboats.

Figure 1: FPS AUGER Lifeboat 6 data plate. Credit: CG.

Release Mechanism Components and Operation

The LHR3.5M2 release mechanism is rated for 3.5 tonnes (metric tons) and is the smallest of the dual-fall release mechanism systems in the "SeaCure" line manufactured by Schat-Harding. The system consists of two hooks (Figure 2), a release unit (i.e., control station; Figure 3), a hydrostatic unit and three separate control cables that connect the hooks and hydrostatic unit to the release unit. The control cables are discussed in greater detail in the next section of this report. See Figure 4 for the location of the components in the Watercraft EL24 lifeboat.

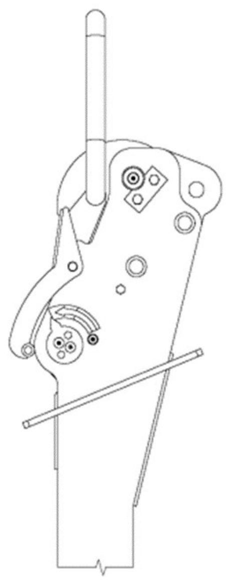


Figure 2: Profile view of LHR hook. Credit: Palfinger.

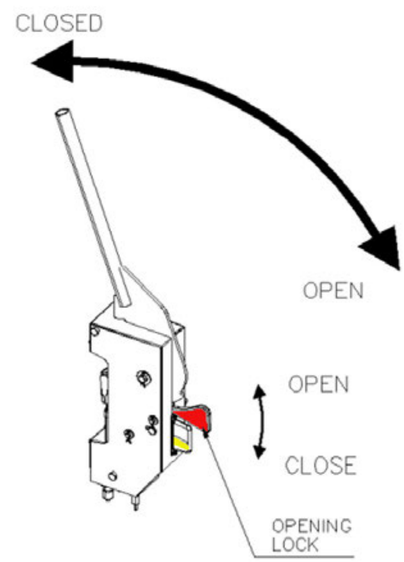


Figure 3: Release unit with safety lock (opening lock) shown in red and hydrostatic locking lever shown in yellow. Credit: Palfinger & CG.

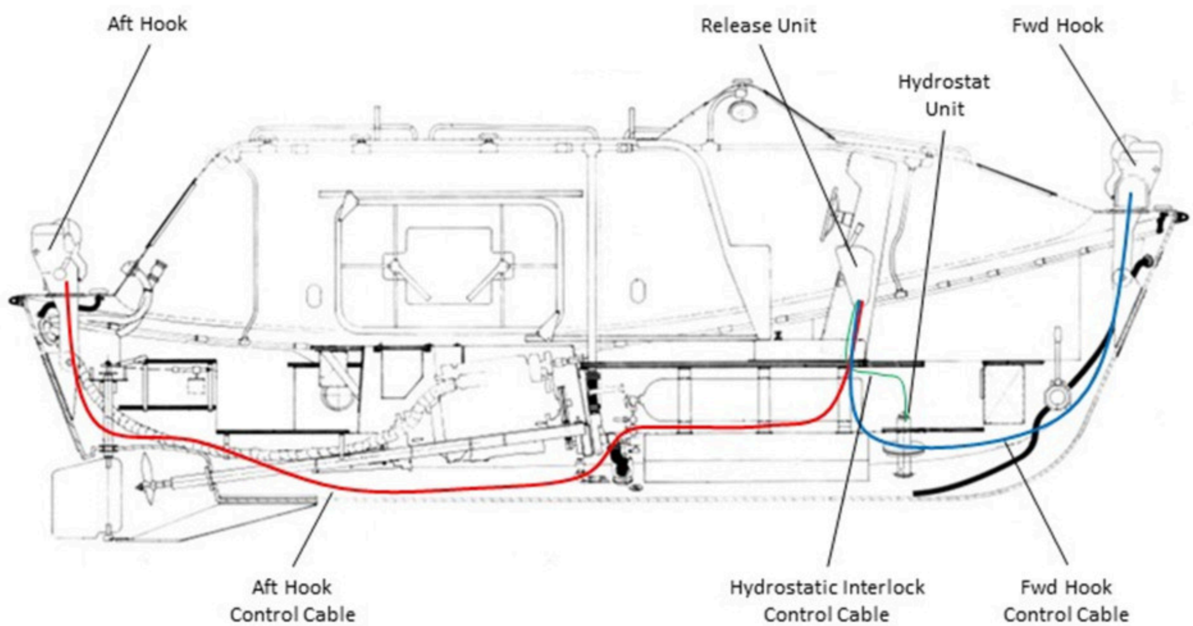


Figure 4: Release mechanism components and locations. Credit: Palfinger & CG.

The operation of the release lever on the release unit rotates the locking shafts of the hooks (Figure 5) via the forward and aft hook control cables. The opening action of the lever pulls the control cables, rotating the locking shaft to the open position, allowing the hook roller to pass through the opening (i.e., notch) in the locking shaft (Figures 6 and 7), releasing the hook from the davit falls. The closing action of the lever on the release unit pushes, rotating the locking shaft to the closed position when resetting the hooks. The release unit is designed in a way that the hooks are to open simultaneously, and the release lever will lock in both the closed and open positions, when the system is properly adjusted.

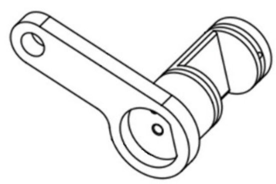


Figure 5: Locking shaft with locking arm. Credit: Palfinger & CG.

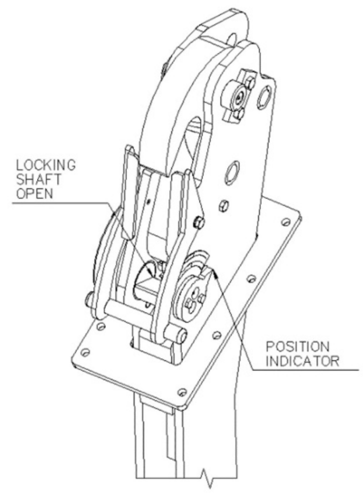


Figure 6: Locking shaft in the open position. Credit: Palfinger.

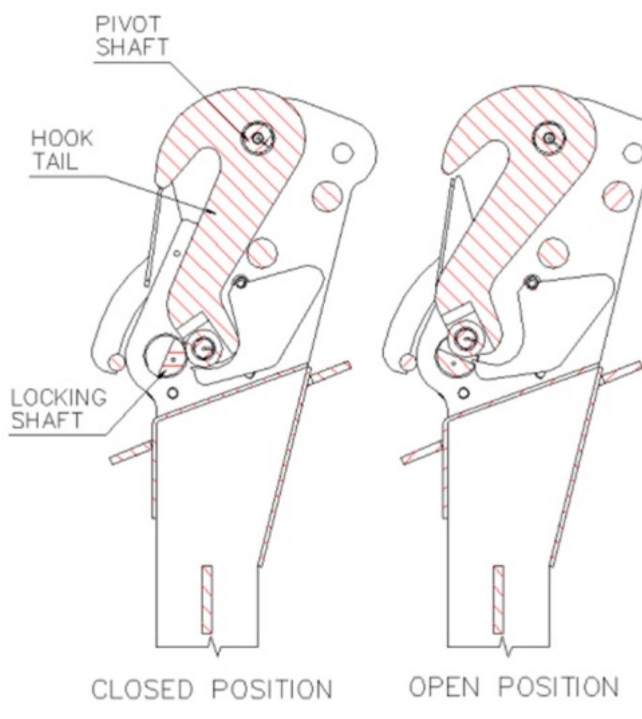


Figure 7: Locking shaft depicted in the closed (left) and open (right) positions. Credit: Palfinger.

Control Cables

Tests were conducted using the control cables (forward hook, aft hook and hydrostatic interlock) that were already installed in MSTC Lifeboat 1. The date of control cable installation was not available, but the MSTC Director recalled the control cables being replaced '4-to-5 years ago'. No compromising damage was noted on any of the control cables prior to the start of this testing (only minor nicks were noted in the cable's outer jacket, none of which totally penetrated the outer jacket).

MSTC Lifeboat 1 is MSTC's primary dual-fall training boat that is utilized during three (3) classes per month, every month of the year. The hooks are cycled (opened/closed) an average of forty (40) times per class. In terms of usage, the control cables in MSTC Lifeboat 1 could see more use in a 1-week class than a typical offshore lifeboat could see over the recommended life of the cables (5-years for this particular lifeboat/release mechanism manufacturer) when following recommended launch/maintenance frequencies.

Tests were conducted with the existing cables due to similar age, although exposed to a much higher rate of usage. Used control cables were chosen over new cables for these experiments with the following considerations:

a) Existing cables were protected from direct sunlight/UV degradation, designed to prevent/minimize water intrusion and showed no compromising damage to the outer jacket; and
b) A new cable could possibly affect the results due to having no wear or usage prior to the experiments.

AUGER Lifeboat 6 control cables were installed during 2012 and had been in service for 7 years, while the control cables in MSTC Lifeboat 1 had been in service for a minimum of 4 years.

Table 2 documents control cable manufacturer and specifications.

Cablecraft® Control Cable Data https://www.cablecraft.com/cables/control-cable-assemblies/ https://www.cablecraft.com/wp-content/uploads/2018/03/CMC9008_Push-Pull-Standard-Flyer.pdf		
Cable Use	Model No.	Description
Forward Hook	315HTT-4-158-10mm	Low Friction EXT Cable with stainless steel exposed fittings, threaded rod ends (M10 x 1.5), 4" cable travel & 158" overall length
Aft Hook	315HTT-4-276-10mm	Low Friction EXT Cable with stainless steel exposed fittings, threaded rod ends (M10 x 1.5), 4" cable travel & 276" overall length
Hydrostatic Interlock	315LTT-2-59-6mm	Low Friction EXT Cable with stainless steel exposed fittings, threaded rod ends (M6 x 1.0), 2" cable travel & 59" overall length

Table 2: Control cable information.

Control Cable Routing

The control cable for the aft hook in MSTC Lifeboat 1 was re-routed to closely match that of AUGER Lifeboat 6 prior to the incident as shown in Figure 4.

The routing of the aft cable was documented in pictures provided by Palfinger Marine taken during the June 2016, May 2019 and June 2019 servicing visits (mostly in the background of other components that were being documented at the time). The cable was visible as it ran under the front of the engine and exited near the shaft coupling, but was not visible beneath the engine and reduction gear. For the experiments, the cable was routed to mimic that of photo documentation for AUGER Lifeboat 6 and allowed to lay naturally in the bilge area beneath the engine.

Aft cable routing was as follows:

- From the release unit to the cableway in the fuel tank/compressed air bottle rack (positive pressure air system) assembly with a natural bend radius (one difference is that AUGER Lifeboat 6 was modified with a notch cut into the bench/base of the coxswain's console that the cables passed through, while the cables laid against the bench in MSTC Lifeboat 1; see Figures 8 and 9 for a comparison),
- Through the cableway below the starboard side air bottle,
- Through the old Viking release mechanism cable guide forward of the engine,
- Crossing toward the port side of the bilge and fastened to the water spray (sprinkler) pump suction hose with a nylon cable-tie,
- Crossing from port back to starboard in the bilge below the shaft coupling, and
- Running along the starboard side of the tunnel and rudder post up to the aft hook (aft Viking release mechanism cable guide was not utilized for routing on either lifeboat).

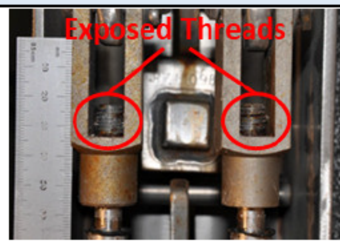
Figure 8: AUGER Lifeboat 6 cable routing at release unit (circa 2014). Credit: Shell.

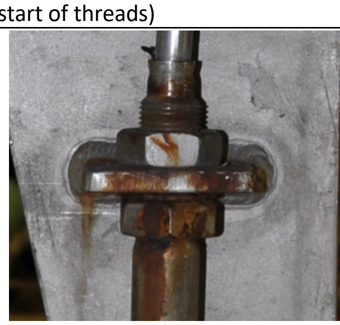
Figure 9: MSTC Lifeboat 1 cable routing at release unit. Credit: CG.

Control Cable Adjustments

The forward and aft control cables were adjusted to match the "as-found" condition of AUGER Lifeboat 6 after the incident.

Table 3 contains a summary of adjustments, using the number of exposed threads as a reference point. After adjusting the control cables, the operation of the system was tested to verify simultaneous opening of the hooks.

Summary of Control Cable Adjustments		
Component	**FPS AUGER, Lifeboat 6 As-Found[1]**	**MSTC, Lifeboat 1 Adjustments**
Release Unit		
Release Unit Forward Cable Clevis	 7 threads exposed (inside of clevis)[2] *Left is the forward hook cable/Right is the aft hook cable*	Removed lock nuts; adjusted to 7 threads exposed (inside of clevis)
Release Unit Aft Cable Clevis	8 threads exposed (inside of clevis)[2]	Removed lock nuts; adjusted to 8 threads exposed (inside of clevis)/bottomed against shoulder
Release Unit Forward Cable Bulkhead Connection	 7 threads exposed (between bottom nut & thread shoulder) *Left is the forward hook cable/Right is the aft hook cable*	Adjusted to 7 threads exposed (between bottom nut & thread shoulder)
Release Unit Aft Cable Bulkhead Connection	7 threads exposed (between bottom nut & thread shoulder)	Adjusted to 7 threads exposed (between bottom nut & thread shoulder)
Hooks		
Forward Hook Cable Clevis	 Disconnected[3]	Connected[4]

Aft Hook Cable Clevis	 Lock nut loose with 4 threads between the thread shoulder & the nut and 6 threads between the nut & the clevis)	Loosened lock nut; adjusted to 4 threads between the thread shoulder & the nut and 6 threads between the nut & the clevis)
Forward Hook Cable Bulkhead Connection	 5 threads exposed (between the top nut & start of threads)	Adjusted to 5 threads exposed (between the top nut & start of threads)
Aft Hook Cable Bulkhead Connection	 5 threads exposed (between the top nut & start of threads)	Adjusted to 5 threads exposed (between the top nut & start of threads)

[1] The as-found conditions were documented by the DNV-GL Lab in Columbus, OH (DNV-GL USA, Inc. (Oil and Gas), Pipeline Services Dept, Incident Investigation). Table Photo Credits: DNV-GL.
[2] No lock nuts (jam nuts) were found installed for cable clevises at the release unit. Both clevises were threaded to the shoulder at the bottom of the threads.
[3] The forward hook cable clevis was found disconnected after recovery, with evidence indicating this occurred post-incident and was not a causal factor.
[4] Forward hook clevis was adjusted after all other adjustments were completed and, in a manner, to allow the release unit to function in the as-found condition (i.e., release handle locks in the closed position, but not in the open position) and allow the hooks to open simultaneously.

Table 3: Summary of control cable adjustments.

Control Cable Components

The construction and components of the control cables are shown in Figures 10 and 11. All external components (conduit cap, support tube and end rod) are stainless steel. The metal components in the conduit (steel band and steel strands) are galvanized and sealed from the outside environment by the outer jacket (cover) and a series of seals from the conduit cap to the end rod. The inner member consists of steel strands and banding, with a thin outer cover, that is hydraulically-crimped to the end rods and moves within the polyethylene liner of the conduit.

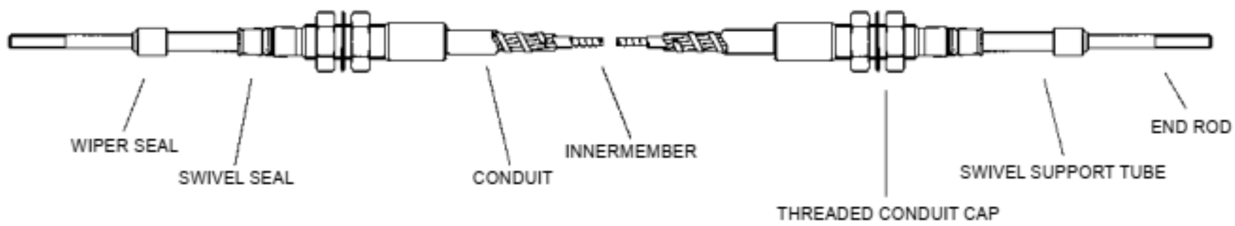


Figure 10: Control cable components. Credit: Cablecraft, modified by USCG to represent cables in Lifeboat 6.

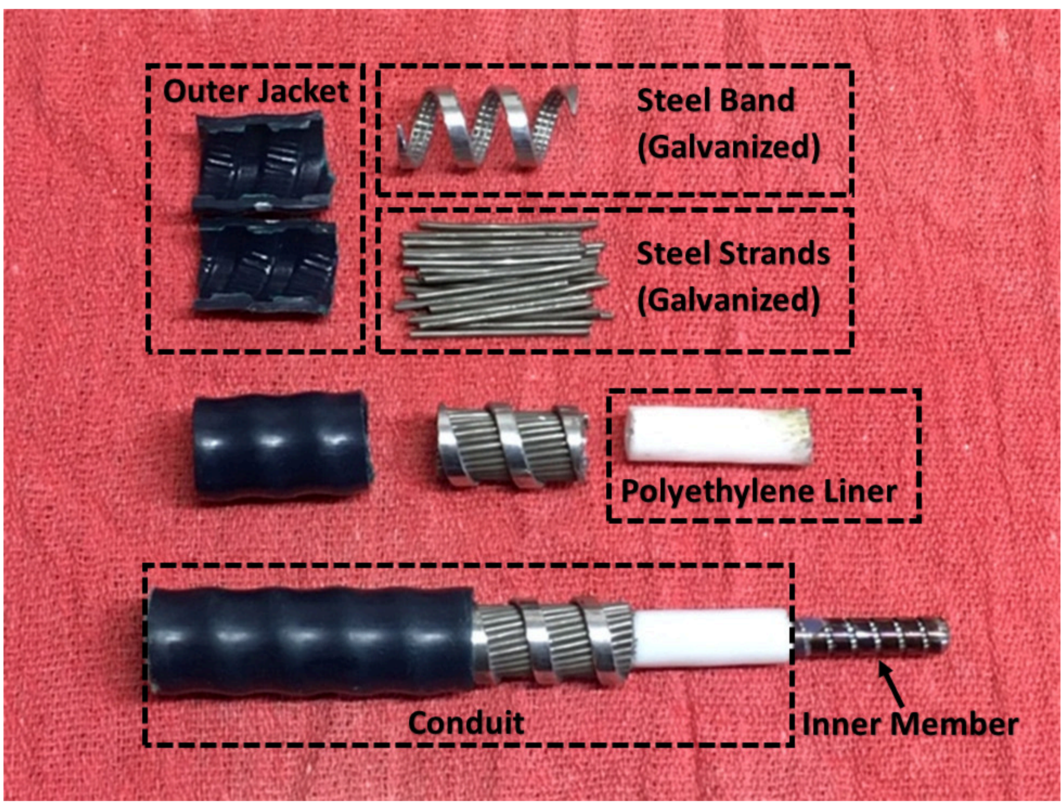


Figure 11: Control cable cutaway and conduit components. Credit: CG.

Assumptions

Control Cable Routing: While pictures and evidence provide for the majority of the aft control cable routing, various factors (i.e., subtle differences between the two lifeboats and the natural lay of the control cables) influence cable routing. The aft control cable routing for these experiments, as documented in the control cable section above, are as similar as possible to that of AUGER Lifeboat 6.

Control Cable Selection: Release cables are typically marked with a part number on a tag affixed to the cable. The cables on Lifeboat 6 did not have tags, so the part numbers could not be verified. However, part numbers were provided on the installation record for the cables and these part numbers were used to match the release cables on MSTC Lifeboat 1.

Weights:

Lifeboats are required to document both a Condition A weight, and a Condition B weight. For U.S. Coast Guard approved lifeboats, the Condition A weight is comprised of the weight of the boat, without fuel or supplies. The Condition B weight includes required supplies (often referred to as "outfit"), fuel and the maximum weight of personnel onboard. The weights for these tests were taken from the AUGER Lifeboat 6 (EL24-874) data plate (Figure 1).

Weight Description	Weight (pounds)
Condition B Weight	13,306
Condition A Weight	- 7,212
Passenger Weight (33 x 165 pounds)	- 5,445
Assumed Weight of Outfit/Liquids	= 649

Table 4: Calculation of outfit/liquids weight.

The assumed weight of the lifeboat's outfit and fuel were found by deducting the passenger weight and Condition A weight from the Condition B weight (Table 4).

At the time of the casualty, there were four persons onboard. While the assumed weight in regulation is 165 pounds per person (based on the lifeboat type approval requirements at the time of construction), the assumed weight for this investigation is 230 pounds per person, as provided by the Shell investigation team for the incident. While an average only, this weight has been utilized throughout the course of the investigation for consistency. The total weight of personnel onboard at the time of the casualty was assumed to be 920 pounds.

Water intrusion into the lifeboat hull and foam is a common occurrence. Inspection of the lifeboat evidence during a later stage of the investigation revealed indications of water intrusion into the foam of the lifeboat prior to the incident. While water intrusion would add weight to the lifeboat, the amount and corresponding extra weight are unknown and are not accounted for in the weights associated with these experiments. The lifeboat is assumed to have no water intrusion for the purpose of these experiments.

The weight at the time of the casualty was assumed to be 8,781 pounds, taking the sum of the Condition A weight, outfit, liquids and personnel onboard at the time of the casualty (Table 5).

Lifeboat plus 4 persons (day of the incident)	Weight (pounds)
Condition A Weight	7,212
Assumed Weight of Outfit/Liquids	+ 649
Passenger Weight (4 x 230 pounds)	+ 920
	= 8,781

Table 5: Calculation of weight on the day of the incident.

Force Required to Operate the Release Unit

Purpose:

Determine the required force to pull the release handle[1] with loads applied to the hooks, simulating various operational weights of Lifeboat 6.

Due to the mechanical advantage in the lever system, the actual linear force applied to the release cable is 4.8 times[2] the force required to actuate the release handle. The cables are not 100% efficient, meaning there will be some additional force needed to overcome the friction forces between the inner member and conduit.

Table 6 summarizes the force observed at the release unit handle, and the estimated force imparted to the control cable for each operational weight tested. Figure 12 demonstrates how the force was measured with a calibrated scale[3].

Hook Loading	Total Weight Applied	Force to Actuate Release Handle[1]	Force Imparted to Cable[2]
a) Offload Condition (no load applied)	0 pounds	14.5 pounds	69.6 pounds
b) Day of the incident weight (Table 5)	8,781 pounds	56.0 pounds	268.8 pounds
c) Condition B Weight, plus 10%	14,637 pounds	67.0 pounds	321.6 pounds
[1] Observed/measured; [2] Estimated			

Table 6: Forces at operational weights.

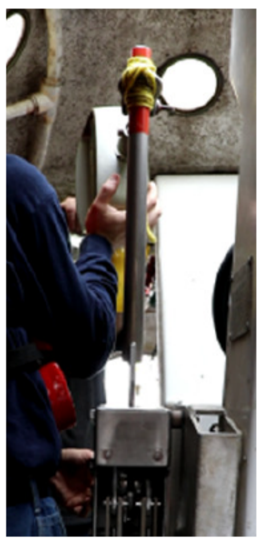


Figure 12: Measuring required operating force (looking aft). Credit: CG.

[1] The point of measurement for all three of the required pull forces obtained above were taken 631.8 mm (24 7/8") from the center of the lever pin, which corresponds to approximately the middle of the painted handgrip area.
[2] The cable actuation force was calculated based on the length of the lever arm (631.8 mm from the center of the release unit lever shaft) divided by the offset from the center of the lever shaft to the center of the pin at the control cable clevis (131 mm).
[3] CAS Corporation Model No. NC-1; Capacity: 1000 x 0.5 lb; Serial No. NC10507880; Owned by Total Safety in Broussard, LA; Calibrated by Cochran Scales in Lafayette, LA July 19, 2019

Experiment 1

Purpose:

a) **Determine the amount of cable travel needed to rotate the locking shaft (cam) from a fully closed position to the open position (that would allow the tail of the hook to pass through), and**
b) **Determine the closed locking shaft (cam) position when utilizing the release unit to close (reset) the hook.**

Steps completed:

1. The aft control cable was <u>disconnected</u> from the release unit (removed clevis pin only).
2. The aft hook locking shaft was rotated (by hand) to the fully locked position (locking shaft lever against the stop).
3. The length of the inner member and swivel support tube of the cable was measured at the release unit at **160 mm** (Figure 13).
4. The distance from the flat of the locking shaft to the hook roller was measured at **17 mm**.

The circumferential distance of the hook roller from the opening in the locking shaft was obtained by coating a portion of the hook roller with a thin layer of Permatex® Prussian Blue which transferred a blue mark (line) to the locking shaft (Figure 15). The distances were then measured from the center of the fillet (i.e., rounded transition from the outside diameter to the flat) of the locking shaft (Figure 14) to the center of the transferred blue mark (Figure 15) using a flexible tape measure to follow the circumference of the locking shaft.

Figure 13: Measuring cable travel at the release unit (aft hook clevis is disconnected from the release unit). Credit: CG.

Figure 14: Measuring from locking shaft opening (notch) fillet/radius (looking down from the front side of the hook). Credit: CG.

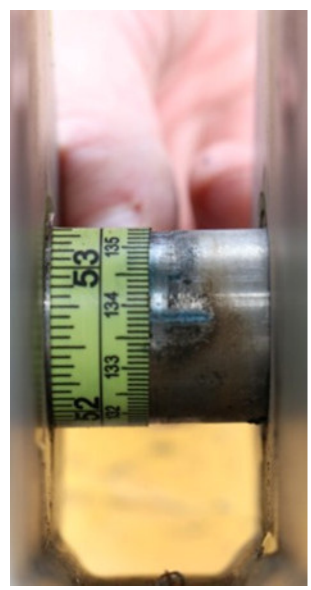


Figure 15: Transferred blue mark showing hook roller contact (looking forward from the back/aft side of the hook). Credit: CG.

5. The hook was marked with a **black** marker (labeled as "**A**") to show the fully (maximum) closed position. All reference marks were placed on a piece of translucent painter's tape affixed over the installed indicator on the aft hook (Figure 16).
6. An upward force (by hand only) was applied on the aft hook, while rotating the cam to the open position. Rotation was stopped as soon as the hook roller crossed the fillet and began to pass through the opening in the locking shaft.
7. The length of the inner member and swivel support tube was measured at the release unit at **255 mm** (95 mm; 3.74") of inner member travel when compared to Step 3).
8. The hook was marked with a **red** marker (labeled as "**B**") to show the open position (Figure 16).
9. The aft hook cable clevis was reconnected to the release unit.
10. The release station was cycled to the open position and back to the closed position.
11. The length of the inner member and swivel support tube was measured at the release unit at **182 mm** (22 mm; 0.87") of inner member travel when compared to Step 3.
12. The distance from the flat of the locking shaft to the hook roller was measured at **12 mm**.
13. The hook was marked with a **green** marker (labeled as "**C**") to show the closed position of the aft hook in the as found condition (Figure 16).

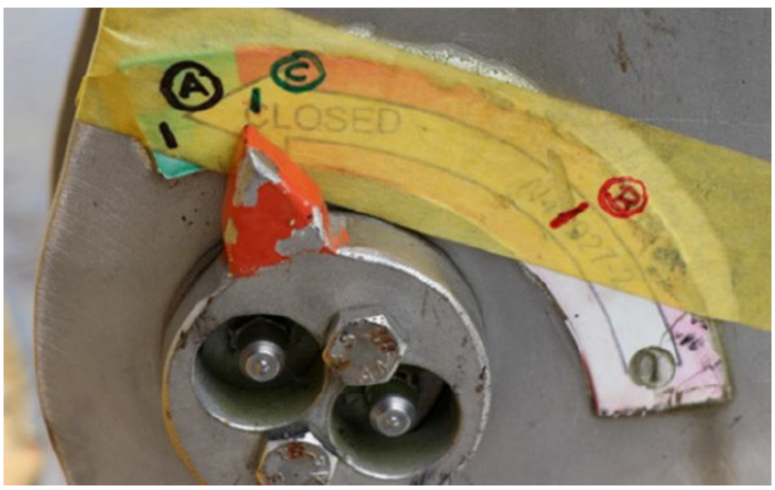


Figure 16: Locking Shaft Positions: A = maximum closed position (against the stop), B = Open (no load applied), and C = as found closed position for Auger Lifeboat 6. Credit: CG.

Table 7 summarizes the results of this experiment.

Measurement Description	Locking Shaft Position	Position Indicator Mark	Release Unit Condition	Distance (mm)
Cable length at release unit	Max closed	A	Disconnected	160
Cable length at release unit	Open (no load)	B	Disconnected	255
Cable length at release unit	Closed (as found)	C	Connected	182
Locking shaft fillet to hook roller	Max closed	A	Disconnected	17
Locking shaft fillet to hook roller	Open (no load)	B	Disconnected	N/A
Locking shaft fillet to hook roller	Closed (as found)	C	Connected	12

Table 7: Summary of Experiment 2 results.

Experiment 2

Purpose:

a) **Determine and document the locking shaft (cam) movement with control cable damage, and**
b) **Determine and document the control cable reaction and/or failure through release unit actuation (hook open/close cycles) with various levels of cable damage.**

All tests for this experiment were conducted on the aft control cable and aft hook. The forward hook was connected to the release unit and adjusted as previously documented.

Steps completed:

1. The hook was closed utilizing the release handle.
2. The distance from the flat (fillet) of the locking shaft to the hook roller was measured at **12 mm**. It was noted that there was a slight difference in the measurement, dependent on how forcibly the release handle was closed. 11.5 mm was observed with a light closing action, whereas 12 mm was observed with a more forceful action that would be considered as a typical force applied by the lifeboat coxswain.
3. The aft hook control cable was marked for cutting (simulated damage) in way of the bench boards and bottom of the console (Figure 17). This is the location where chaffing was observed on the evidence after the incident (Figure 18) and cable damage/deterioration was noted prior to the incident (Figure 19).

Figure 17: Aft hook control cable marked for simulated damage. Credit: CG.

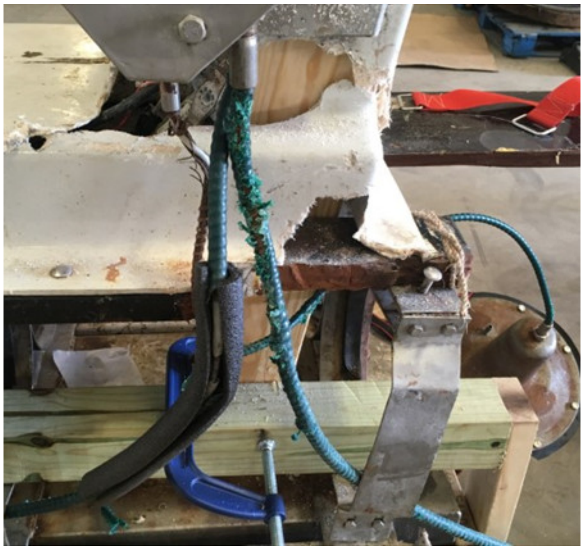


Figure 18: Damaged area of the AUGER Lifeboat 6 control cables post-casualty (aft hook cable is protected for further examination by the foam insulation during evidence/console area reconstruction; forward hook & hydrostatic interlock cables were determined to be collateral/post-incident damage). Credit: CG.

Figure 19: Condition of the aft hook control cable & location in relation to the bottom of the coxswain's console as documented Jun2019, prior to the incident. Credit: Palfinger.

4. A section of the green outer layer (cover), steel binding and steel strands were removed to expose the white polyethylene liner. A 9 mm section was removed to simulate the deteriorated section shown in Figure 19. The outer jacket was cut with a razor and the steel binding and strands were removed with a DREMEL® tool with cutting wheel. Extreme caution and slow, deliberate cuts were made in an effort to prevent any nicks to the polyethylene liner or heat transfer to the galvanized steel strands as they were being cut (Figures 20, 21 and 22).

Figure 20: Section of conduit cover removed. Credit: CG.

Figure 21: Measurement prior to removing the last few steel strands (9 mm). Credit: CG.

Figure 22: Measurement with all layers of the conduit removed and no damage to the PTFE liner (9 mm). Credit: CG.

*Note: The reference points for measurements of cable separation in the following steps were taken from the edges of the tape applied to mark the simulated damage. <u>Prior to any movement of the release handle</u>, the separation was measured at **9 mm**.*

5. The release handle was moved to the open position and the separation of the outer jacket was measured and found to have reduced to **6 mm** (due to compression of the polyethylene liner).
6. The release handle was actuated for twelve (12) cycles and ended in the closed position for each cycle (i.e., closed-to-open and open-to-closed as one release cycle). The separation noted at the end of each open/close cycle was measured as follows:

(1) 12 mm,	(4) 14 mm,	(7) 15.5 mm,	(10) 15.5 mm,
(2) 13 mm,	(5) 14 mm,	(8) 15.5 mm,	(11) 16 mm,
(3) 14 mm,	(6) 15 mm,	(9) 15.5 mm,	(12) 16mm,

The following observations were noted during the open/close cycles:

a. The polyethylene liner was compressed as the outer layers of the conduit pulled together during the opening action of the release lever (Figures 23 and 25).
b. A compression ring/mark developed in the polyethylene during the first opening action and was further defined during the second opening action of the release lever (Figure 24).
c. The polyethylene liner was stretched during the closing action of the release lever (approximately 1 mm beyond the settling point after the release lever locked in the closed position; Figure 26).
d. The ring became more defined through subsequent cycles.
e. Translucent lines began developing near the base of the compressed area after 5 cycles, becoming more pronounced during the remaining cycles (Figure 27).

The locking shaft position was marked on the hook after completion of the 12 cycles, showing the creep of the locking shaft toward the open position (Figure 28).

Figure 23: Compression of PTFE liner during the first open cycle of the release handle (outer conduit separation reduced to 6 mm). Credit: CG.

Figure 24: Distortion of PTFE liner after the first open/close cycle of the release handle (outer conduit separation increased to 12 mm). Credit: CG.

Figure 25: Compression of PTFE liner during the third open cycle of the release handle (outer conduit layers are now nearly touching). Credit: CG.

Figure 26: Maximum separation of the outer conduit layers and corresponding polyethylene stretch during the third close cycle of the release handle. Credit: CG.

Figure 27: Translucent lines near the base of the compressed area of the polyethylene liner(after 12 cycles; started at 5 cycles). Credit: CG.

Figure 28: Locking shaft positions observed:
A = maximum closed position
C = as found closed position for Auger LB6
2x = movement toward open after 2 cycles,
12x = movement toward open after 12 cycles; locking shaft is shown in the closed position (picture taken after testing). Credit: CG.

Additional notes:

Measurements 3 through 12 for Step 6 above were documented by video. The open/close cycle of the release handle was completed, measurement made and subsequent cycles with measurements were conducted.

Twelve (12) open/close cycles were chosen to determine if the polyethylene liner would break. This number is estimated to exceed the number of cycles that the cable would have been subjected to in 1-year of time in a deteriorated condition. These 12 cycles were derived from 2 open/close cycles on June 30, 2019, 2 open/close cycles during the annual service (June 2019; the cables were stated to have been functioning at the time that Figure 19 was taken), 2 open/close cycles during fall cable replacements (May 2019) and 6 open/close cycles from the three previous quarterly launches (2 cycles during each launch). Two open/close cycles per quarterly launch is conservative, as a typical launch may only have one open/close cycle of the release mechanism. While it is unknown, it is possible that it could have taken over a year for the hooks to have been cycled 12 times.

It is also unknown if the deterioration documented during the June 2019 servicing (Figure 19) was allowing movement of the polyethylene liner inside of the compromised steel layers of the cable conduit.

The hooks were opened (via the release handle) after the 12 cycles for Step 6 above to allow for marking of the aft hook roller with Prussian Blue for the remaining tests and then the hooks were closed (via the release handle).

7. Verified that the release handle was in the closed (locked) position.

8. A small cut (approx. 1/8 of the circumference) was introduced to the polyethylene liner by pressing a razor blade through the polyethylene until it contacted the inner member.
9. The release handle was actuated through two (2) open/close cycles with the following observations:
    a. The separation in the outer layers of the conduit was measured at **17 mm** (Figure 29).
    b. The cut in the polyethylene liner was distorted; the cut area began to open and conduit separation increased by approximately 1 mm (Figure 30).

Figure 29: Separation after two activation cycles with the first cut in the polyethylene liner (increased by 1 mm). Credit: CG.

Figure 30: Distortion of the cut area (first cut) after two activation cycles. Credit: CG.

10. A 2nd small cut (an additional 1/8 of the circumference) was introduced to the polyethylene liner (extension of the first cut).
11. The release handle was actuated and the polyethylene liner **separated during the closing action of the release handle** (Figure 31). The separation of the outer conduit was measured at **48 mm** (Figure 32). The position of the locking shaft was observed approximately halfway between the "**C**" (closed, as adjusted) and "**B**" (open, no load) marks (Figure 34; marked as "2nd Cut/Break").

Figure 31: Broken polyethylene liner. Credit: CG.

Figure 32: Conduit separation upon polyethylene liner breakage (closing action). Credit: CG.

Note that this corresponds to approximately 1.5" of inner member travel (just as if the inner member was moved with the release handle in an uncompromised control cable). 48mm separation - 9 mm of initial separation (before distortion of the polyethylene *liner) = 39 mm of inner member movement in relation to the fixed ends of the control cable.*

Continued cuts of 1/8 of the circumference of the polyethylene liner were planned until liner separation occurred. The liner separated with approximately 1/4 of the circumference fully compromised (cut) and the remainder in a weakened state from the open/close cycles that resulted in repeated compression/tension stresses to the liner.

12. The locking shaft position was marked on the hook, showing movement toward the open position (Figures 33 and 34; "2nd Cut/Break" shows the position upon completion of Step 11). Note that the locking shaft is shown in the fully closed position in Figure 34 and the reference marks indicate the positions observed.

Figure 33: Locking shaft (cam) position upon breakage of the polyethylene liner and separation of the cable conduit. Credit: CG.

Figure 34: Locking shaft positions observed – the "break" observed in Step 11 put the locking shaft approx. halfway between closed ("C") and open ("B"); locking shaft is shown in the closed position. Credit: CG.

13. The release handle was actuated from closed to open. Conduit movement was observed in the area surrounding the conduit break only.
14. The release handle was moved back to the closed position and the cable conduit separated to a distance of **91.5 mm** (Figure 35). At this point, the locking shaft remained in the fully open position, preventing the hook from resetting.
15. The release handle was cycled several more times, however, every time the release handle returned to the closed position, the cable conduit separation remained constant at **91.5 mm**.

Figure 35: Conduit separation after cycling the release handle with a broken cable conduit/liner. Credit: CG.

This corresponds to approximately 3.25” of inner member travel (just as if the inner member was moved with the release handle in an uncompromised control cable). 91.5mm separation - 9 mm of initial separation (before distortion of the polyethylene liner) = 82.5 mm of inner member movement in relation to the fixed ends of the control cable. The control cable is designed/assembled with a 4” travel of the inner member.

Note: Additional measurements of the hook roller to locking shaft opening radius were intended, but not taken due to the need to manipulate the hook to transfer and read the measurements. All control cables and hooks were left in this state to move into the next experiment.

A graphic depicting the control cable observations during this experiment is shown in Figure 36.

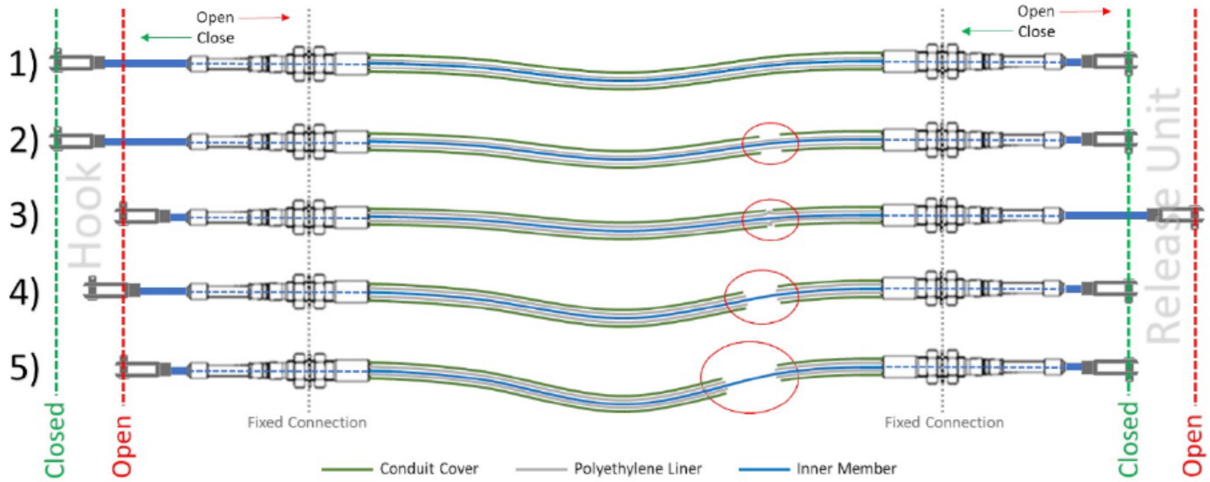


Figure 36: Graphical representation of control cable observations:
1) Hook closed with release handled locked in closed position (cable intact).
2) Hook closed with release handle closed. Conduit cover and steel layer removed (9 mm) with liner intact.
3) Hook open with release handle open (liner compression noted during testing).
4) Polyethylene liner failed during closing with 48 mm of conduit separation and locking shaft in partially-closed position (i.e., closed/locked, but almost open).
5) Subsequent release unit actuation after initial liner break extended conduit separation to 91 mm and would not rotate the locking shaft (i.e., hook remained open).
Credit: CG.

Table 8 summarizes the results of this experiment.

Measurement Following:	Release Handle Position	Conduit Separation[1] (mm)	Position Indicator Mark	Locking Shaft Position
Initial removal of conduit cover, steel band & steel strands	Closed	9	C	Closed
First open action (liner compression)	Open	6	-	Open
First close action (liner tension)	Closed	12	-	-
Two (2) open/close cycles	Closed	13	2x	Closed[3]
Twelve (12) open/close cycles[2]	Closed	16	12x	Closed[3]
Cut 1/8 of the liner circumference & two (2) open/close cycles[4]	Closed	17	-	Closed
Cut an additional 1/8 of the liner & completed one (1) open/close cycle	Closed	48	2nd Cut/ Break	Closed[5]
One (1) open/close cycle after liner separation	Closed	91.5	-	Open

[1] Conduit separation was measured between the cuts to the conduit cover
[2] See Step 6 for progression of separation and liner distortion noted
[3] Locking shaft was closed, but creeping toward open (see Figure 34)
[4] Additional liner distortion noted (see Figure 30)
[5] Closed, but nearing open (see Figures 33 & 34)

Table 8: Summary of Experiment 2 results.

Experiment 3

Purpose:

Determine and document if additional forces applied to the hook, with the control cable in a compromised state (locking shaft incrementally rotated closer to an open position) will force the locking shaft to move into the open position and allow the hook to release with the

a) **Lifeboat weight plus 4 persons (weight on the day of the incident),**
b) **110% of the B weight of the lifeboat, and**
c) **150% of the B weight of the lifeboat.**

All tests for this experiment were conducted on the aft control cable and aft hook. The forward hook was connected to the release unit and adjusted as previously documented.

Note: Tests for this experiment began with the locking shaft positioned at the point as marked when the control cable polyethylene liner broke and the conduit separated (see steps 11 & 12 under Experiment 2). Subsequent tests were conducted by rotating the locking shaft so the indicator would be approximately 1 mm closer to the open position until it was observed that the hook would remain closed with the weight calculated on the day of the incident, but would open as weight on the hook increased.

Weights utilized for the loading conditions in this experiment are listed in Table 9.

Loading Condition	Weight Description	Weight[1] (pounds)	Weight (kilograms)
a) Lifeboat plus 4 persons (day of the incident)	Condition A Weight	7,212	
	Assumed Weight of Outfit/Liquids	+ 649	
	Passenger Weight (4 x 230 pounds)	+ 920	
		= 8,781	3,983
b) 110% of the Condition B Weight	Condition B Weight	13,306	
	10% of Condition B Weight	+ 1,331	
		= 14,637	6,639.2
c) 150% of the Condition B Weight[2]	Condition B Weight	13,306	
	50% of Condition B Weight	+ 6,653	
		= 19,959	9,053.2
[1] Weights are based on the weights marked on the data plate for AUGER Lifeboat 6 (Figure 1).			
[2] 150% was chosen as the highest weight applied during the experiment, as the tests were conducted on an operational lifeboat at MSTC.			

Table 9: Calculation of loading condition weights for Experiment 3.

Test weights were applied to the hooks with the hydraulic test apparatus provided by the manufacturer (Palfinger Marine), consisting of adapters (Figure 37) that connect to the hooks (simulating the hooks supporting the weight of the boat on fall cables and D-rings), two hydraulic cylinders (Figure 37), hydraulic hand pump unit[4] (Figure 38) and two hydraulic hoses to connect the pump to the cylinders.

[4] ENERPAC Model No. RC154 hydraulic cylinders; Capacity: 15.7T/142 kN; Owned by Palfinger Marine in New Iberia, LA; pressure gauge calibrated by The Gauge House in Lafayette, LA July 9, 2019.

Figure 37: Test apparatus on aft hook (forward hook set up the same during testing). Credit: CG.

Figure 38: Hydraulic pump unit for hook test apparatus Credit: CG.

The hydraulic unit pressures required to simulate the lifeboat weight in the three condition for this experiment were calculated using Equation 1 that was provided by Palfinger Marine. In the equation, the effective cylinder area (20.3cm^2) is multiplied by two (2) cylinders utilized during testing to obtain the proper pressure to apply to the complete system via two hooks.

$$\frac{Weight\ (kg)}{20.3cm^2\ x\ 2} x\ 0.981 = pressure\ to\ be\ applied\ (bar)\ x\ 14.5038 = psi\ required$$

Equation 1: Conversion of test weight to hydraulic unit pressure.

The weights entered and results of Equation 1 for each of the loading conditions of this experiment are shown in Table 10.

Weight Conditions applied to Equation 1	Weight Entered (kg)	Pressure Required (PSI)	Pressure Applied during Tests (PSI)[1]
a) Day of Incident	3,983	1,396	1,400
b) 110% of Condition B Weight	6,639.2	2,327	2,400
c) 150% of Condition B Weight	9,053.2	3,173	3,000[2]
[1] Pressures were rounded for testing due to gauge resolution (200 PSI increments).			
[2] Tests for 150% of Condition B Weight were stopped slightly below the calculated value.			

Table 10: Results of Equation 1 for the loading conditions of this experiment.

Steps completed:

1. Installed the test apparatus on the forward and aft hooks and adjusted the locking shaft to the position that was marked on the indicator after the polyethylene liner separated in the previous experiment (Experiment 2, Step 11).

Note: The release handle at the release unit was in the closed position and locked with the integrated safety lock (red handle above the hydrostatic interlock), as found after recovery of AUGER Lifeboat 6. The forward hook was connected and remained in the closed position throughout all tests under this experiment.

2. Applied pressure to the hooks via the test apparatus to simulate the weight of the lifeboat as follows:
    a. 1,400 PSI (weight of the lifeboat and occupants on the day of the incident) with hook remaining in the closed position,
    b. Increased pressure to 2,400 PSI (110% of the B weight) with hook remaining in the closed position. Tapped on the hook to simulate jarring/vibration that the lifeboat would experience during contact to the davit bumpers with hook remaining closed.
    c. Increased pressure to 3,000 PSI (150% of the B weight) with hook remaining in the closed position. Tapped on the hook with hook remaining closed.
3. Released pressure and moved the locking shaft indicator 1 mm closer to the open position and repeated steps 2.a through 2.c with the same results.

Note that the incremental rotation of the locking shaft corresponds to incremental (increasing) separation of the broken/separated control cable conduit near the release unit, while the release lever remains in the closed and locked position. Incremental (1 mm) adjustments were marked on the tape affixed to the hook after locking shaft movement and before pressure was applied during each step.

4. Released pressure and moved the locking shaft indicator 1 mm closer to the open position (now 2 mm beyond the position marked on the indicator after the polyethylene liner separated during Experiment 2, Step 11) and repeated steps 2.a through 2.c with the same results.
5. Released pressure and moved the locking shaft indicator 1 mm closer to the open position (now 3 mm beyond the position marked upon polyethylene liner separation during Experiment 2, Step 11) and repeated steps 2.a through 2.c with the same results.
6. Released pressure and moved the locking shaft indicator 1 mm closer to the open position (now 4 mm beyond the position marked upon polyethylene liner separation during Experiment 2, Step 11) and repeated steps 2.a through 2.c with the same results.
7. Released pressure and moved the locking shaft indicator 1 mm closer to the open position (now 5 mm beyond the position marked on the indicator after the polyethylene liner separated during Experiment 2, Step 11). Applied pressure to the hooks with the following results:
    a. 1,400 PSI (weight of the lifeboat and occupants on the day of the incident) with hook remaining in the closed position,

   b. While increasing the pressure to 2,400 PSI (110% of the B weight), the locking shaft rotated under the increasing weight and the hook opened at 2,300 PSI.
8. Repeated step 7 (twice) to verify the results with the following observation:
   a. Slight variations between 4 and 5 mm beyond the position marked at initial polyethylene liner/conduit separation would allow the hook to support the weight on the day of the incident (1,400 PSI), but jarring/vibrations (via taps to the hook body) caused the hook to open.
9. Reset locking shaft at 5 mm beyond the mark at initial conduit separation, verified with measuring tape and tested again with the following results:
   a. 1,400 PSI (weight of the lifeboat and occupants on the day of the incident) with hook remaining in the closed position,
   b. Held this pressure/weight for over two minutes to simulate retrieval time from water to davit,
   c. While increasing the pressure to 2,400 PSI, the locking shaft again rotated under the increasing weight and the hook opened at 2,300 PSI.

Note: Due to the nature of the testing and time constraints, blue marks were not transferred from the hook roller to the locking shaft during Experiment 3.

Figure 39 shows the locking shaft position in conjunction with the tests conducted in steps 2 through 9 of Experiment 3. The tests started at the mark for the 2nd Cut/Break and progressed at 1 mm increments (indicated by the dots marked on the tape), to the point at which the hook would open with no influence other than an increasing load. Figure 40 shows the approximate degrees of rotation corresponding to the positions observed during this experiment.

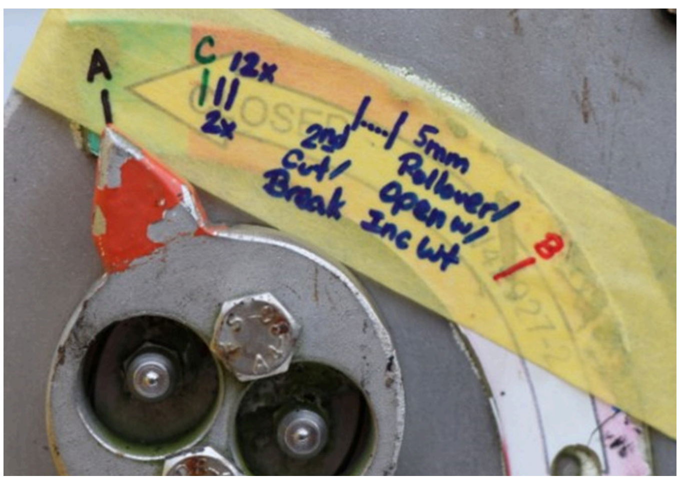


Figure 39: Locking shaft positions observed:
2nd Cut/Break - position upon break of the polyethylene & separation of cable conduit
"B" - open position with no load
Rollover - locking shaft forced to open with increasing weight
Dots: positions that hook supported the test weights applied;
locking shaft is shown in the closed position (picture taken after testing).
Credit: CG.

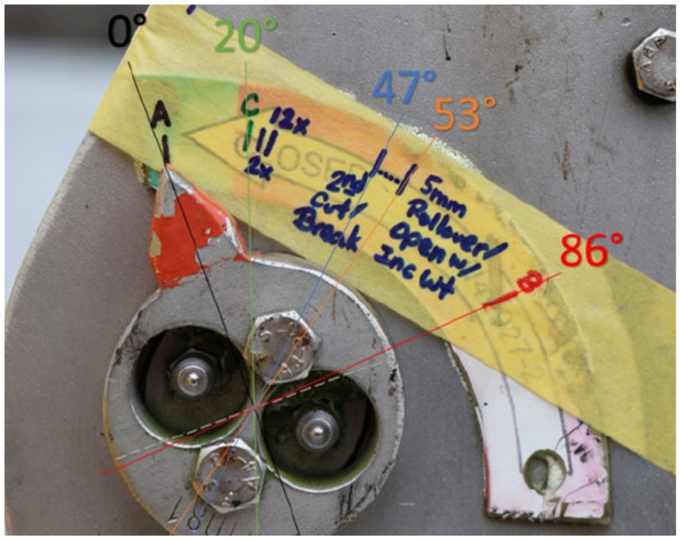


Figure 40: Locking shaft degrees of rotation (degrees are approximate); locking shaft is shown in the closed position (picture taken after testing). Credit: CG.

Table 11 summarizes the results of this experiment.

Locking Shaft/Position Indicator Orientation for Test	Release Handle Position	Test Weight Applied[1]	Position Indicator Mark	Locking Shaft Position
Mark for "Break" from Experiment 2, Step 11	Closed	(a)	Break	Closed[2]
		(b)		Closed[2]
		(c)		Closed[2]
1 mm past break, toward open (B)	Closed	(a)	Dot 1	Closed[2]
		(b)		Closed[2]
		(c)		Closed[2]
2 mm past break, toward open (B)	Closed	(a)	Dot 2	Closed[2]
		(b)		Closed[2]
		(c)		Closed[2]
3 mm past break, toward open (B)	Closed	(a)	Dot 3	Closed[2]
		(b)		Closed[2]
		(c)		Closed[2]
4 mm past break, toward open (B)	Closed	(a)	Dot 4	Closed[2]
		(b)		Closed[2]
		(c)		Closed[2]
5 mm past break, toward open (B), Steps 7-9	Closed	(a)	5 mm	Closed[2]
		(b)	**Rollover**	**Forced Open[3]**
		(c)	N/A	N/A

[1] See Table 9 for weight calculations; (a) = Lifeboat plus 4 persons (day of incident); (b) = 110% of the Condition B Weight; (c) = 150% of the Condition B Weight
[2] Closed, but nearing open (see Figures 33, 34 & 39)
[3] Locking shaft was forced open by increasing weight on the hook and no other forces applied to any component of the system (confirmed results with subsequent tests; see Steps 7-11)

Table 11: Summary of Experiment 3 results.

Conclusions

The results of these experiments show that damage to the conduit and polyethylene liner can result in failure of the cable. With damage present, a combination of the force required to open the locking shaft and the friction force in the cable itself produces a tensile force in the polyethylene liner that can cause it to fail completely. If the failure occurs while cycling the release lever, it can result in the hook locking shaft stopping between the open and closed positions ("**B**" and "**C**" positions, respectively, on Figure 34).

With the locking shaft in a partially-closed position immediately following conduit separation, the hook can still support the weight of the lifeboat and the occupants. Additionally, if the locking shaft is in a position that is relatively close to the open position, but still allows the hooks to be locked, the hooks can support the weight of the boat, though an additional load can cause the locking shaft to rotate and allow the hook to open.

However, it must be emphasized that after the initial liner failure and separation, any further cycling of the system will result in the locking shaft remaining in the fully open position. With a failed liner, the cable conduit freely extends, rendering the system unable to rotate the locking shaft to the closed position. This prevents the hooks from locking, rendering them unable to hold any load (see the observations for Experiment 2, Step 15).

The results of the testing show that a compromised control cable can place the locking shaft in a position that could be forced to open with application of an increased load.