Naval Submarine Medical Research Laboratory

NSMRL/TR--2007-1252 **March 28, 2007**

Results of Inspections of MK-10 Submarine Escape and Immersion Equipment Life Rafts Following Leeway Testing

by

Anthony J. Quatroche
SurgCDR Paul S. Turnbull
Dr. Wayne G. Horn

Released by:
D.G. Southerland, CAPT, MC, USN
Commanding Officer
Naval Submarine Medical Research Laboratory
Groton, Connecticut

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
28-03-2007	Technical Report	2005-2006

4. TITLE AND SUBTITLE

Results of Inspections of MK-10 Submarine Escape and Immersion Equipment Life Rafts Following Leeway Testing

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Anthony J. Quatroche
SurgCDR Paul S. Turnbull
Dr. Wayne G. Horn

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

NAVSUBMEDRSCHLAB
Box 900
Groton, CT 06349-5900

8. PERFORMING ORGANIZATION REPORT NUMBER

NSMRL/TR--2007-1252

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

NSMRL funded the United States Coast Guard Research &Development Center in Groton, CT to conduct testing to determine the leeway coefficients for the Submarine Emergency Position Indicating Radio Beacons (SEPIRB) and the Mark-10 Submarine Escape and Immersion Equipment (MK-10 SEIE) single man life raft. This report is being generated due to concern for the quality and durability of the MK-10 SEIE life rafts as noted in the USCG R&D Ctr Draft Report of the Leeway Coefficients. Analysis of the leaks indicated that they appeared to have been caused by chaffing of the buoyancy chamber material or the manual inflation tube on objects inside the rafts. No buoyancy chamber seams failed. Conclusions: The raft leaks were caused by the test equipment mounting methods, test equipment or other objects placed inside the rafts chaffing the interior side of the raft buoyancy chamber or manual inflation tube and not due to poor manufacturer workmanship or construction materials.

15. SUBJECT TERMS

life raft, disabled submarine, survivors, Mark-10, Submarine Escape and Immersion Equipment, MK-10 SEIE

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			M. Fitzgerald, Publications Manager
U	U	U	SAR	34	19b. TELEPHONE NUMBER *(Include area code)* (860) 694-2442

[BLANK PAGE]

Results of Inspections of MK-10 Submarine Escape and Immersion Equipment Life Rafts Following Leeway Testing

by

Anthony J. Quatroche, SurgCDR Paul S. Turnbull, Dr. Wayne G. Horn

Naval Submarine Medical Research Laboratory

NSMRL TR--2007-1252

Approved and Released by:

CAPT D.G. Southerland, MC, USN
Commanding Officer
Naval Submarine Medical Research Laboratory
Submarine Base New London Box 900
Groton, CT 06349-5900

ADMINISTRATIVE INFORMATION

[BLANK PAGE]

Table of Contents

[BLANK PAGE]

Executive Summary

INTRODUCTION

In October and November 2005 Naval Submarine Medical Research Laboratory (NSMRL) funded the U.S. Coast Guard Research and Development Center (USCG RDC) in Groton, Connecticut to conduct testing to determine the leeway coefficients for the Submarine Emergency Position Indicating Radio Beacons (SEPIRB) and the Mark-10 Submarine Escape and Immersion Equipment (MK-10 SEIE) single man life raft (Beaufort Single Seat Life raft Type 18). As discussed in the report generated following the testing, "Leeway, defined as the movement of the search object through water caused by the action of wind on the exposed surfaces of the object, is fundamental to search planning."[1] The test results are to be used by search planners to determine potential search areas for survivors who have escaped from a disabled submarine and are floating in the MK-10 life raft based on the casualty position provided by the SEPIRB.

The testing of the MK-10 life rafts was conducted in conjunction with leeway testing of other objects with the cooperation of the Canadian Coast Guard in waters off of St. John's, Newfoundland. Science Applications International Corporation (SAIC) served as the support contractor for the USCG and Oceans, Ltd. served as the support contractor for the Canadian Coast Guard.

As noted in the report, "Following an initial preliminary drift run to check the performance of the targets and equipment on 29 and 30 October, five drift tests (drifts one through five) were conducted from 31 October until 19 November. The duration of each test ranged from 24 hours to approximately 60 hours. Maximum wind speeds (5-minute averages) ranged from just under 20 knots to nearly 40 knots, with gust speeds as high as 43 knots."[1]

This report was generated by the concern for the quality and durability of the MK-10 SEIE life rafts as noted in the following statements found in USCG RDC Draft Report of the Leeway Coefficients:

> From Section 2.1.2 On Site Mobilization, Subsection Preliminary Drift and Drift Target Modifications: "At the end of the preliminary drift, both of the SEIE rafts were partially filled with seawater and the Velcro® seams had been torn open. SAIC made modifications to the rafts to help address some of these problems. A layer of 2-inch thick closed-cell foam was added to the underside of the equipment mounting base inside each raft. Grommets were also added to both sides of the enclosure flap so that this flap would remain sealed and more effectively shed seawater. In addition, a small electric submersible bilge pump was installed in the SEIE life raft that housed the ADCP current meter. Finally, an external bridle and lifting harness was added to each of the rafts to facilitate their deployment and recovery while minimizing the likelihood of damage to the air bladder.

Despite gentle handling, the SEIE life rafts still leaked air on a number of occasions. SAIC responded by attempting to patch the obvious leaks and also by obtaining additional rafts from the RDC during the experiment. Because the SEIE rafts had only a single, continuous air bladder, the leaks greatly compromised their overall buoyancy and performance. Continuing attempts to patch the rafts with a variety of different sealant compounds were mostly ineffective. The added foam flotation did counteract the loss of buoyancy resulting from the loss of air. Over the course of the study, one raft was completely lost at sea, and two rafts were recovered mostly deflated and full of water."

From Section 5.0 CONCLUSIONS: "Significant problems were encountered with the durability and buoyancy of the SEIE rafts during this study. All of the six SEIE rafts used during this study developed some type of leak during the course of the field study. The rafts had only a single flotation bladder, so any leaks in this single bladder greatly compromised the raft buoyancy. This problem of leakage was countered by adding closed-cell foam flotation to the underside of each raft to maintain buoyancy during the drifts. The Velcro® flap designed to keep water out of the raft was also ineffective as a seal. After the first at-sea deployment, both rafts were retrieved full of water with the seals ripped open by the wind. Before subsequent deployments were made, grommets were added to the cover flaps so that the Velcro® seal could be laced shut with a piece of line. A small submersible pump was also installed in the ADCP raft to keep water from accumulating."

OBJECTIVE

Based on the above statements NSMRL requested the return of the remaining rafts for inspection and evaluation to determine the causes of the raft failures.

METHODS

The rafts were returned to NSMRL, cleaned, inflated, inspected to determine leak locations and photographed. Analysis was then conducted to attempt determination of the causes of the leaks.

RESULTS

Inspection and examination revealed the following:

- All rafts had leaks.
- One raft leaked only from the over inflation protection relief valve. That valve is only found on "Training" models of the Beaufort Type 18 life raft and does not exist on production models of the MK-10 SEIE life raft deployed on all U.S. Navy submarines.
- One raft was constructed with two manual inflation tubes. The connection to the flotation bladder for the tube in the non-standard position leaked.
- One raft had a leak located on the plastic hose portion of the manual inflation tube.
- All other leaks were located on the interior side of the flotation bladder.

- Grommets were added by the leeway testing group to the canopy of three of the five rafts.
- The clear plastic face shield of the canopy was torn on three rafts.
- Two canopies had significant tears in them.
- The threaded connection of CO_2 storage bottle to the inflation valve assembly was taped with Teflon tape to stop leakage on all rafts by the leeway testing group. None of those connections leaked.
- All raft floors had numerous holes that were made in order to secure a plywood or plastic composite material instrument mounting sheet to the floor of the raft as well as the added close cell foam added to increase buoyancy.
- The forward (passenger foot end) free flooding stability pocket on four of the five rafts was cut open or ripped open on one side. Based on further discussions with USCG RDC several of the rafts were modified to carry a cylindrical instrument in that stability pocket.

Analysis of the leaks indicated:

- Leaks appear to have been caused by chaffing of the buoyancy chamber material or the manual inflation tube on objects on the inside of the rafts.
- No buoyancy chamber seams failed.

CONCLUSIONS

Conclusions reached:

- The raft leaks were caused by the test equipment mounting methods, test equipment or other objects placed inside the rafts chaffing the interior side of the raft buoyancy chamber or manual inflation tube and not due to poor manufacturer workmanship or construction materials.

COMMENTS AND RECOMMENDATIONS

If humans dressed in MK-10 SEIEs were passengers in the rafts, the leaks found in these rafts would not have occurred.

Modification of the MK-10 SEIE life raft canopy to replace the Velcro canopy seal with a large plastic zipper to keep the canopy from blowing open in high winds should be considered. Several life rafts should be modified with zipper canopy closures and tested.

Introduction

The Mark-10 Submarine Escape and Immersion Equipment (SEIE) manufactured by RFD Beaufort Defence Division, Birkenhead, UK is the standard U.S. Navy submarine escape system that allows escape from a disabled submarine to depths of 600 feet and provides the escaper with an immersion suit to protect against hypothermia in cold water as well as a single seat life raft. The Mark-10 Submarine Escape and Immersion Equipment (MK-10 SEIE) is a significant advance over the U.S. Navy's previous escape system, the Stenkie Hood and corrects all the deficiencies that were inherent in that system. One of the most significant improvements provided by the MK-10 SEIE is the self-inflating single man life raft (Beaufort Single Seat Life Raft Type 18) that includes a canopy to completely enclose the escaper and an inflatable seat cushion to provide additional comfort and thermal insulation from cold seawater. The MK-10 SEIE has been in use by the Royal Navy since 1994.

Despite the widespread adoption of the MK-10 SEIE by submarine forces, no good data on the drift characteristics of the Type MK-18 Single Seat Life Raft exists for use by rescue search planners to develop potential search areas in the case of attempting to locate survivors of a disabled submarine. In October and November 2005 Naval Submarine Medical Research Laboratory (NSMRL) funded the U.S. Coast Guard Research and Development Center (USCG RDC) in Groton, Connecticut to conduct testing to determine the leeway coefficients for the Submarine Emergency Position Indicating Radio Beacons (SEPIRB) and the MK-10 SEIE Type MK-18 single seat life raft. As discussed in the report generated following the testing, "Leeway, defined as the movement of the search object through water caused by the action of wind on the exposed surfaces of the object, is fundamental to search planning."

The testing of the MK-10 SEIE life rafts was conducted in conjunction with leeway testing of other objects with the cooperation of the Canadian Coast Guard in waters off of St. John's, Newfoundland. Science Applications International Corporation (SAIC) served as the support contractor for the USCG and Oceans, Ltd. served as the support contractor for the Canadian Coast Guard.

As noted in the report, "Following an initial preliminary drift run to check the performance of the targets and equipment on 29 and 30 October, five drift tests (drifts one through five) were conducted from 31 October until 19 November. The duration of each test ranged from 24 hours to approximately 60 hours. Maximum wind speeds (5-minute averages) ranged from just under 20 knots to nearly 40 knots, with gust speeds as high as 43 knots."[1]

This report was generated by the concern for the quality and durability of the MK-10 SEIE life rafts as noted in the following statements found in USCG RDC Final Report of the Leeway Coefficients:

> From Section 2.1.2 On Site Mobilization, Subsection Preliminary Drift and Drift Target Modifications: "At the end of the preliminary drift, both of the SEIE rafts

were partially filled with seawater and the Velcro® seams had been torn open. SAIC made modifications to the rafts to help address some of these problems. A layer of 2-inch thick closed-cell foam was added to the underside of the equipment mounting base inside each raft. Grommets were also added to both sides of the enclosure flap so that this flap would remain sealed and more effectively shed seawater. In addition, a small electric submersible bilge pump was installed in the SEIE life raft that housed the ADCP current meter. Finally, an external bridle and lifting harness was added to each of the rafts to facilitate their deployment and recovery while minimizing the likelihood of damage to the air bladder.

Despite gentle handling, the SEIE life rafts still leaked air on a number of occasions. SAIC responded by attempting to patch the obvious leaks and also by obtaining additional rafts from the USCG RDC during the experiment. Because the SEIE rafts had only a single, continuous air bladder, the leaks greatly compromised their overall buoyancy and performance. Continuing attempts to patch the rafts with a variety of different sealant compounds were mostly ineffective. The added foam flotation did counteract the loss of buoyancy resulting from the loss of air. Over the course of the study, one raft was completely lost at sea, and two rafts were recovered mostly deflated and full of water."[1]

From Section 5.0 CONCLUSIONS: "Significant problems were encountered with the durability and buoyancy of the SEIE rafts during this study. All of the six SEIE rafts used during this study developed some type of leak during the course of the field study. The rafts had only a single flotation bladder, so any leaks in this single bladder greatly compromised the raft buoyancy. This problem of leakage was countered by adding closed-cell foam flotation to the underside of each raft to maintain buoyancy during the drifts. The Velcro® flap designed to keep water out of the raft was also ineffective as a seal. After the first at-sea deployment, both rafts were retrieved full of water with the seals ripped open by the wind. Before subsequent deployments were made, grommets were added to the cover flaps so that the Velcro® seal could be laced shut with a piece of line. A small submersible pump was also installed in the ADCP raft to keep water from accumulating."[1]

Objective

The above statements generated significant concern at both NSMRL and at the U.S. Navy program office supervising the MK-10 SEIE program (NAVSEA PMS 392) for the quality of the life raft construction and its open ocean performance. If the life rafts indeed were as fragile as described in the USCG RDC report then further investigation would be necessary to determine the full extent of the problem. A worst case possible outcome from that investigation could be a requirement to recall all MK-10 SEIE units for replacement of a potentially faulty life raft; an effort that would take hundreds of man-hours and possibly millions of dollars to accomplish. As a first step NSMRL requested

the return of the remaining rafts for inspection and evaluation to ***determine the causes of the raft failures***.

Methods

The methods used to determine the sources and causes of the life raft leaks were the simplest, quickest and most straight forward possible. The rafts were returned to NSMRL and first cleaned as they had been transported directly from the Canadian testing location in November 2005 and stored in the uncontrolled atmosphere of a building basement on the campus of the USCG RDC at Avery Point in Groton, Connecticut. The rafts were then inflated using 10 psig compressed air passed through the manual inflation tubes of the rafts. The rafts were then visually inspected to determine overall condition and to locate the repairs and modifications that had been made by SAIC. Following the overall inspection, a detailed visual inspection of the rafts including magnified visual examination of all seams and a leak check was performed to determine the effectiveness of SAIC repairs and to locate any other leaks. The leak checks were conducted by a combination of submersion of portions of the raft in fresh water, observation for air bubbles from leak sites; and application of a mild detergent solution to generate bubbles at leak sites. Leak sites were then inspected using a 3X magnifying glass and based on the appearance of the leak and location in the raft an attempt was made to determine the probable cause of the leak. The rafts and all repairs, modifications, damage and leak sites were digitally photographed.

Results

Raft Serial Number 9835715:

Serial Number Stencil:

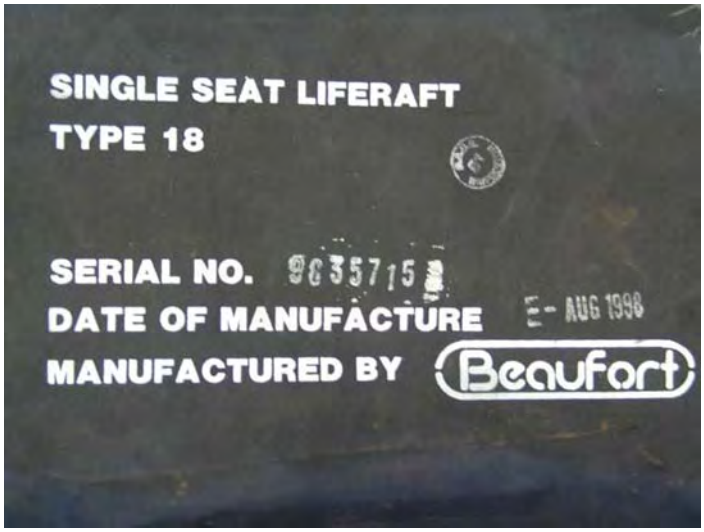


Figure 1: Raft Serial Number 9835715 Manufacturer's Identification Stencil

Figure 2: Raft Serial Number 9835715. Top View left, Bottom View right.

Significant Findings:

- D-rings were added to left side of raft. Grommets were added to the canopy.
- Raft canopy was torn significantly: left side near foot. Plastic face shield torn in center, very jagged tear.
- Electrical tape was placed around the cap on the manual inflation tube to keep it secured in place and possibly to prevent leaking. The manual inflation tube did not exhibit any leaks *without* tape on it.
- No leaks were found on exterior sides of raft.
- The stability pocket at foot of raft had started to tear away from the raft floor at left (as seen from top) end.

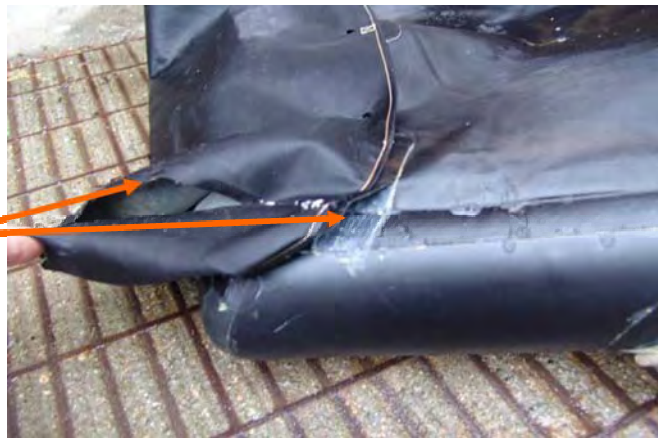


Figure 3: Raft Serial Number 9835715 Forward Stability Pocket Detail (Showing tears)

- Stability pocket at foot end also had an open seam on the left end (as seen from top).
- Two leaks in the buoyancy chamber were located on the inner side of the raft. Both leaks were on right side of the raft in bottom half of buoyancy bladder just above locations where the plywood instrumentation mounting sheet was attached to floor of raft. Both appear to be rub/abrasion locations.

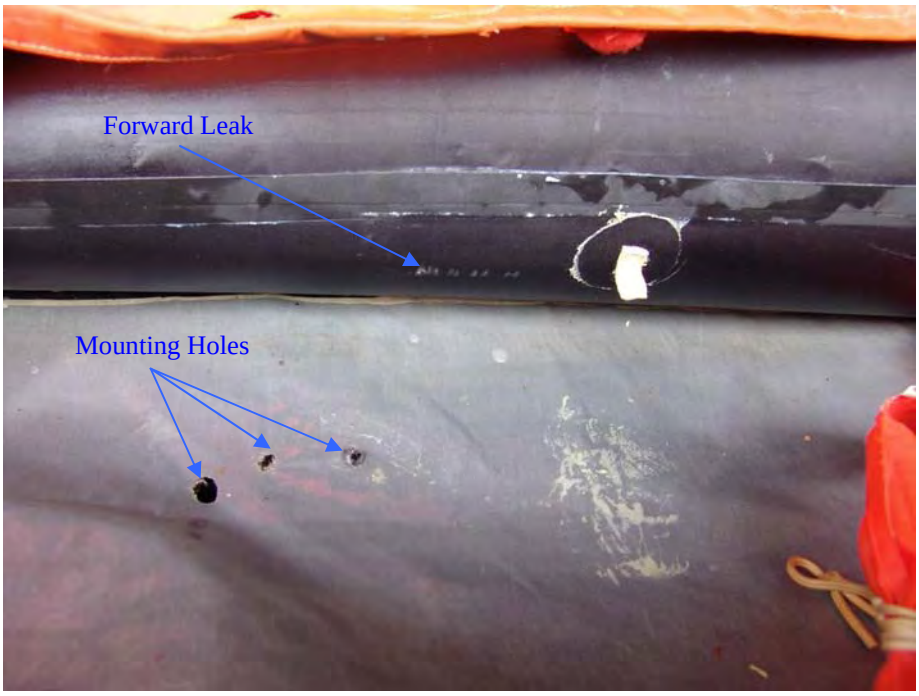


Figure 4: Raft Serial Number 9835715 Detail of Forward Leak

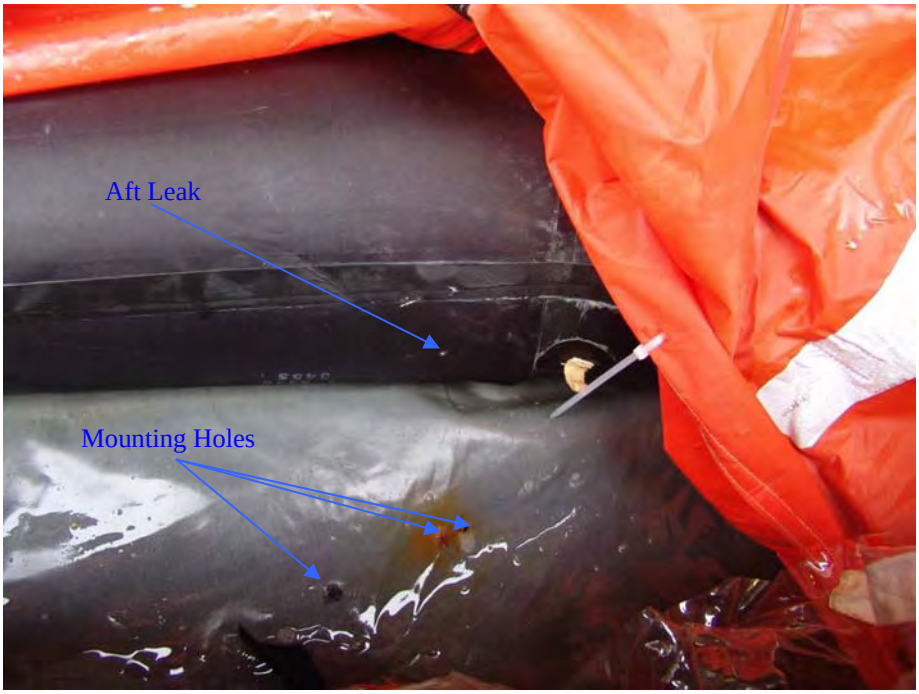


Figure 5: Raft Serial Number 9835715 Detail of Aft Leak

- Raft's CO_2 Bottle had Teflon tape added to the threaded connection to the fill valve assembly. No leakage was observed from that connection during testing.

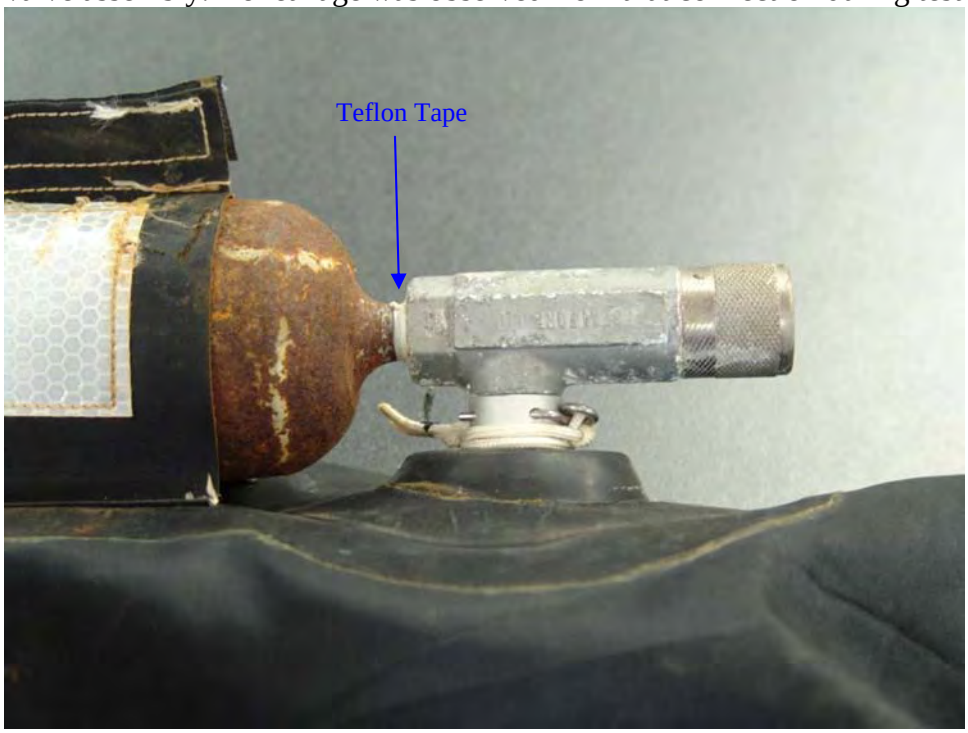


Figure 6: Raft Serial Number 9835715 Detail of CO_2 Bottle Connection

Conclusions:

- Raft canopy and face shield were most probably ripped up by the wind during testing.
- The leaks detected appear to have come from abrasions, especially the forward leak. The proximity to the holes in the raft floor where the plywood instrument sheet was mounted seems to imply that the abrasions came from either the plywood sheet itself or the equipment mounted on it.
- The investigators believe that the raft would not have leaked if a human had been the passenger.

Raft Serial Number 9834882

Serial Number Stencil:

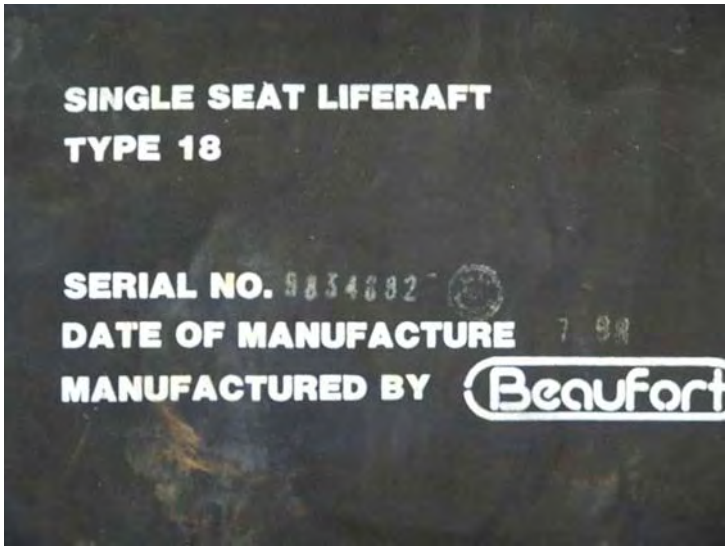


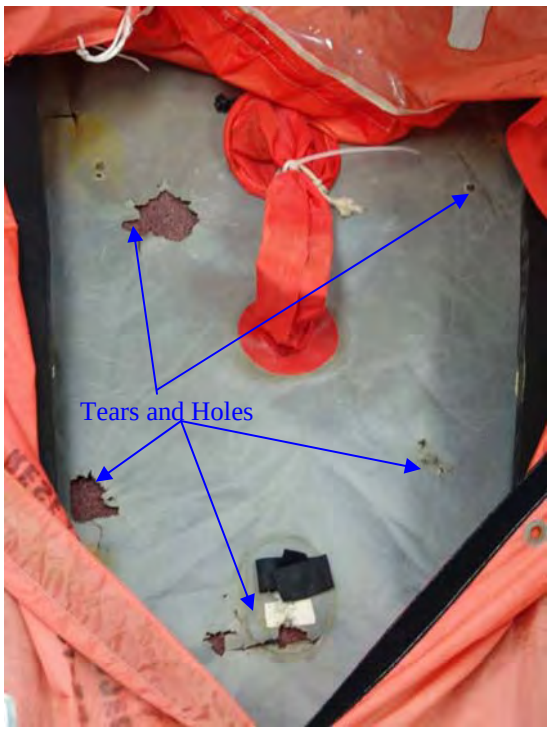
Figure 7: Raft Serial Number 9834882 Manufacturer's Identification Stencil

Figure 8: Raft Serial Number 9834882 Top View (Left), Bottom View (Right)

Significant Findings:

- D-rings were added to the left side of raft. Grommets were added to the canopy.
- Small canopy tears were found around the upper two (aft most) grommets.
- The clear plastic face shield was torn into two pieces. A small part of face shield may be missing. Tear was left/right (horizontal).
- The orange plastic of canopy was significantly sun bleached.
- A significant number of tears and holes were found in the floor of raft associated with points of connection to instrument mounting plate.

Figure 9: Raft Serial Number 9834882 Interior Views



- The forward stability pocket was ripped or cut adjacent to left end seam (as seen from top).

Figure 10: Raft Serial Number 9834882 Forward Stability Pocket Detail

- A significant air leak was found at an abrasion site on the manual inflation tube just below connection to mouth valve. No other leaks found.

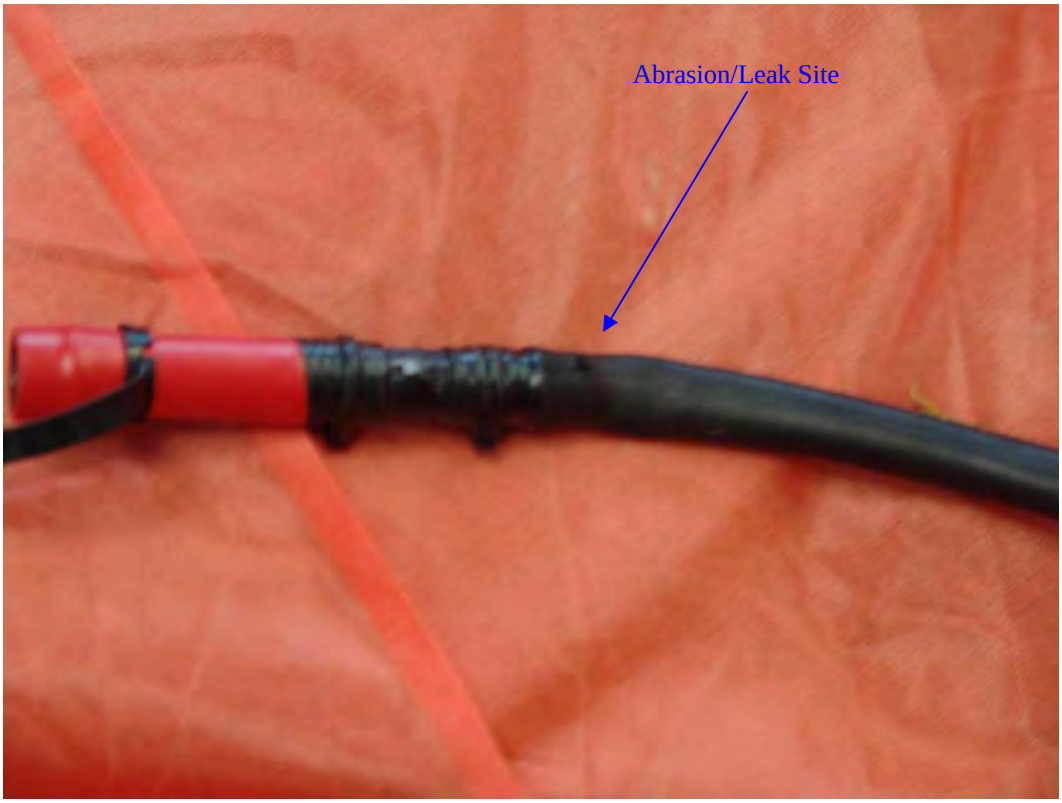


Figure 11: Raft Serial Number 9834882 Manual Inflation Tube Detail

- The CO_2 Bottle had Teflon tape added to the threaded connection to the fill valve assembly. No leakage noted during testing.

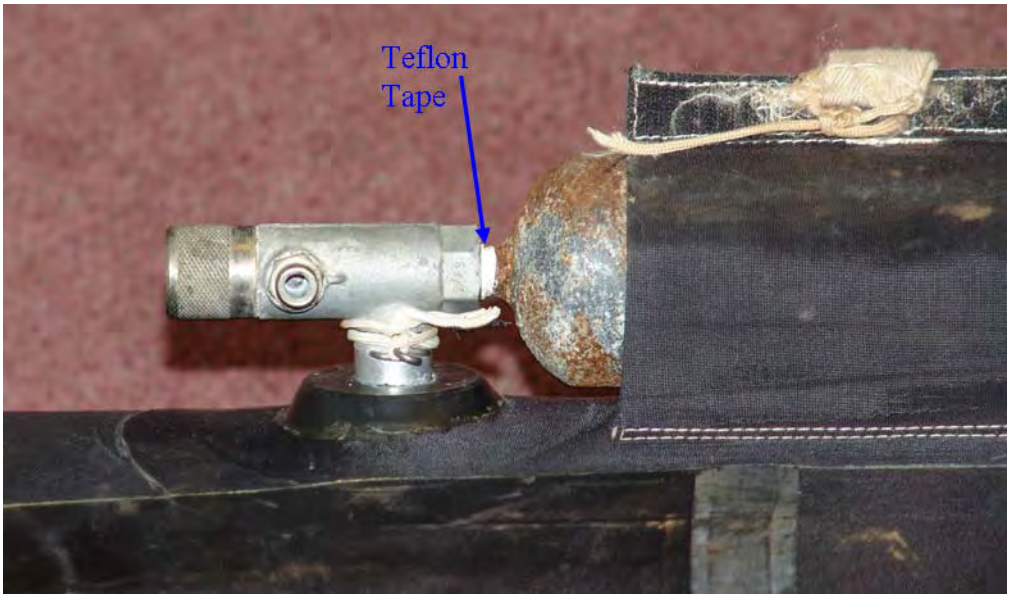


Figure 12: Raft Serial Number 9834882 CO_2 Bottle Detail

Conclusions:

- This raft held air longest when inflated. It had a significant amount of air remaining in it after 18 hours. It could easily have been kept afloat by an escaper. Only location of leak that could be found was the manual inflation tube. The abrasion could have come from contact with equipment inside the raft.
- The holes in the floor of this raft were the largest of the group and would have contributed significantly to water entering the raft.
- The investigators believe that the raft would not have leaked if a human had been the passenger.

Raft Serial Number 0364837

Serial Number Stencil:

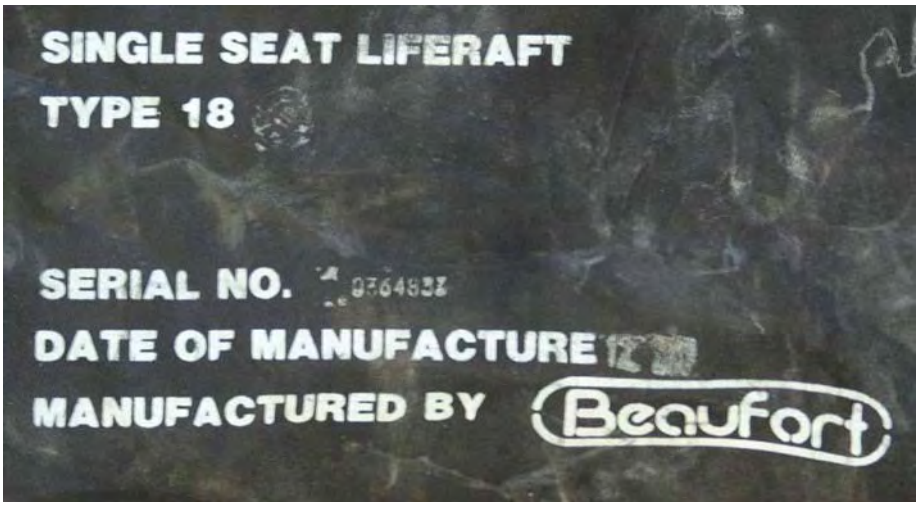


Figure 13: Raft Serial Number 0364837 Manufacturer's Identification Stencil

Figure 14: Raft Serial Number 0364837 Top View (Left) and Bottom View (Right)

- Two D-rings were added to left side. Eight grommets added to canopy.
- Forward stability pocket was torn along right side seam (As viewed from top).

Figure 15: Raft Serial Number 0364837 Forward Stability Pocket Detail

- This was the only raft in the group with two manual inflation tubes. The lower manual inflation tube had white epoxy coated on attachment point to raft buoyancy chamber indicating that a leak had been repaired.

Figure 16: Raft Serial Number 0364837 Manual Inflation Hoses Detail

- SAIC added three patches in the vicinity of the two manual inflation tubes. Only two remained in place. None of the leaks occurred at a seam. The leak that was at one time patched was directly below the forward patch (Green colored rubber) and was very significant. The raft completely deflated in less than 5 minutes due to the size of the leak. The patch that seemed most effective was the one made with hard black resin or epoxy.

Figure 17: Raft Serial Number 036483 Installed Patches

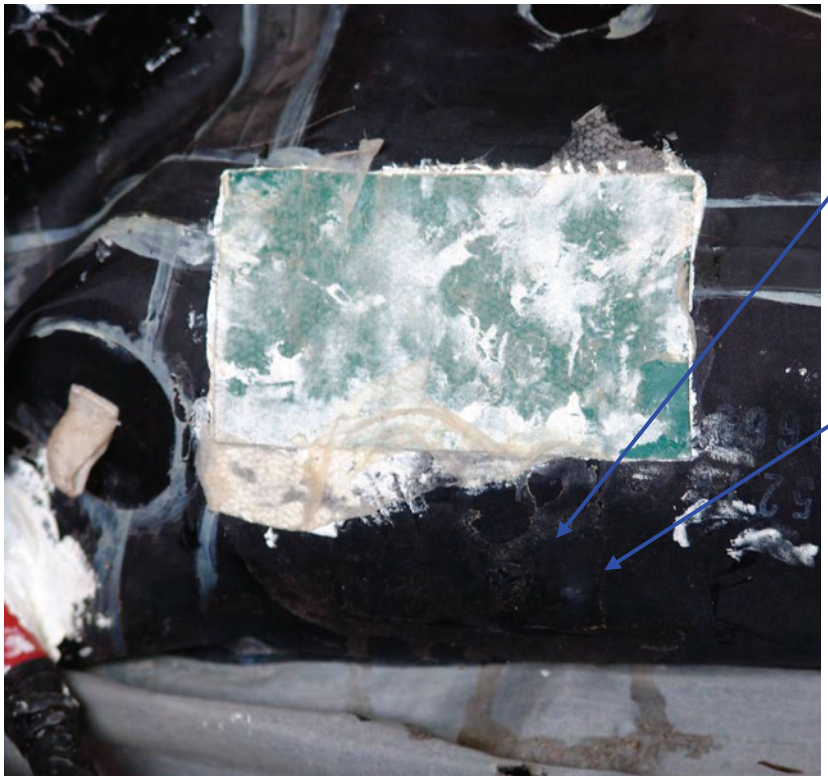


Figure 18: Raft Serial Number 036483 Location of Third Leak

- A fourth pin-hole leak was found about 7 inches forward of the manual inflation tubes on upper half of inflation tube. Slight abrasion of bladder material was noted in the area.
- The CO_2 Bottle had Teflon tape added to the threaded connection to the fill valve assembly. No leakage was noted during testing from the connection.

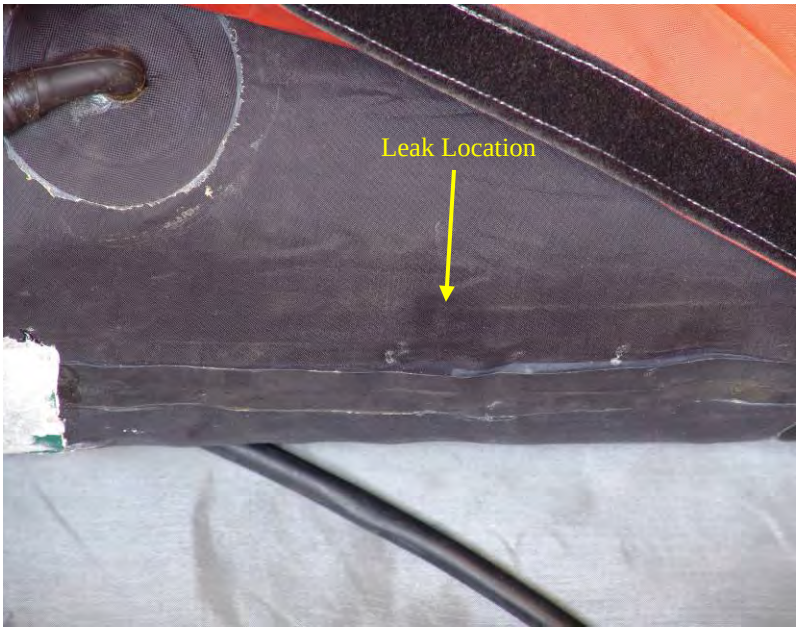


Figure 19: Raft Serial Number 036483 Location of Fourth Leak

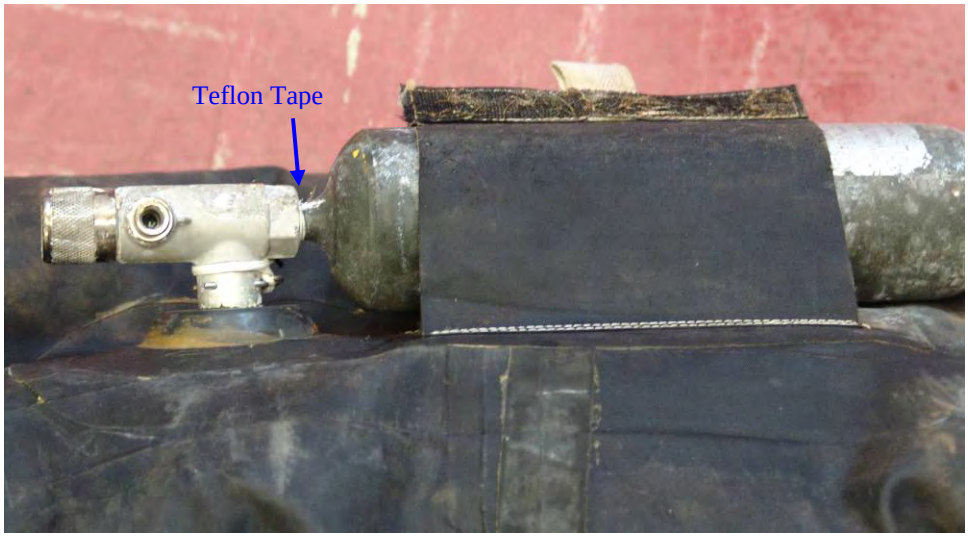


Figure 20: Raft Serial Number 036483 CO_2 Bottle Detail

Conclusions:

- This raft was clearly in the worst condition with at least four leaks and possibly a fifth leak at the connection of the lower manual inflation tube to the buoyancy chamber of the raft.
- Three leaks were patched; one of the patches failed and fell or was removed from the leak site and was not found. The leak that was “un-patched” appeared to have been caused by an abrasion. The leak was almost 0.5 inches long.
- A fourth small leak developed at a very slight abrasion site forward of the manual inflation tubes. None of the leaks were on seams.
- The investigators believe the leaks were caused by the equipment placed in the raft rubbing against the inside surface of the buoyancy chamber.
- The investigators believe that the raft would not have leaked if a human had been the passenger and if it had been constructed with only one manual inflation tube.

Raft Serial Number 0364812

Raft Serial Number Stencil:

Figure 21: Raft Serial Number 0364812 Manufacturer's Identification Stencil

Figure 22: Raft Serial Number 0364812 Top View (Left) and Bottom View (Right)

- Two D-rings were added to the left side of the raft. No grommets added to canopy.
- No patches found.
- No leaks in the seams or fabric of the flotation chamber were detected.
- The Over-Inflation Protection relief valve did function (open) as raft reached full inflation and then did not fully reset. Attempts to reseat the valve by directing a stream of water onto the valve were not successful and the valve continued to leak.

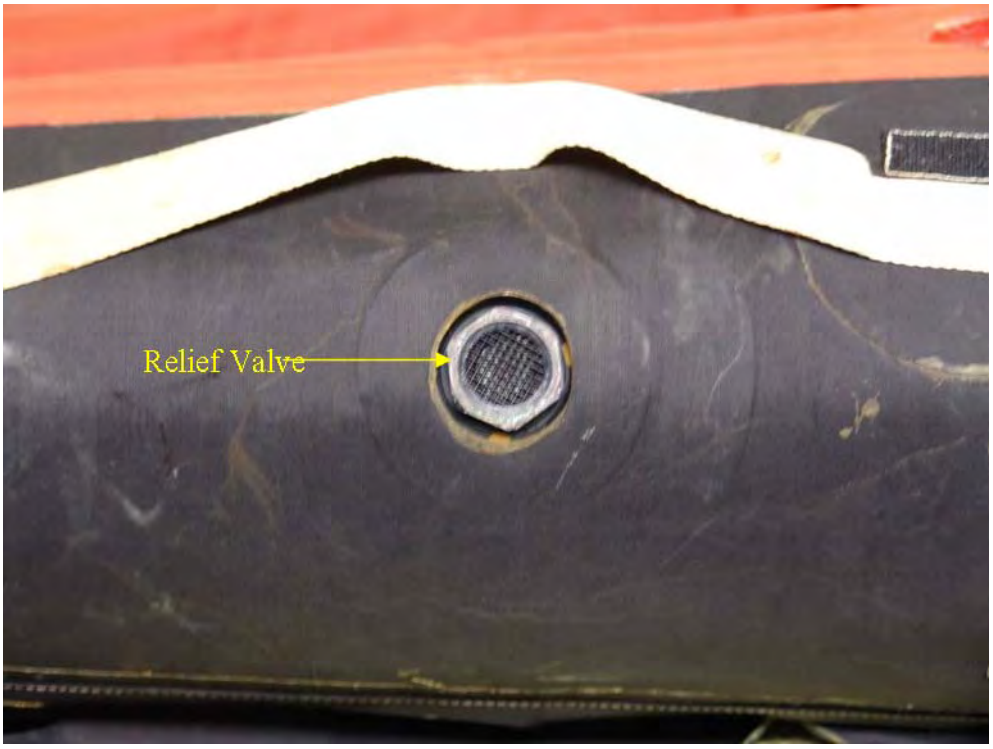


Figure 23: Raft Serial Number 0364812 Over-Inflation Protection Relief Valve

- The CO_2 Bottle had Teflon tape added to threaded connection to the fill valve assembly. No leakage from the connection was noted during testing.

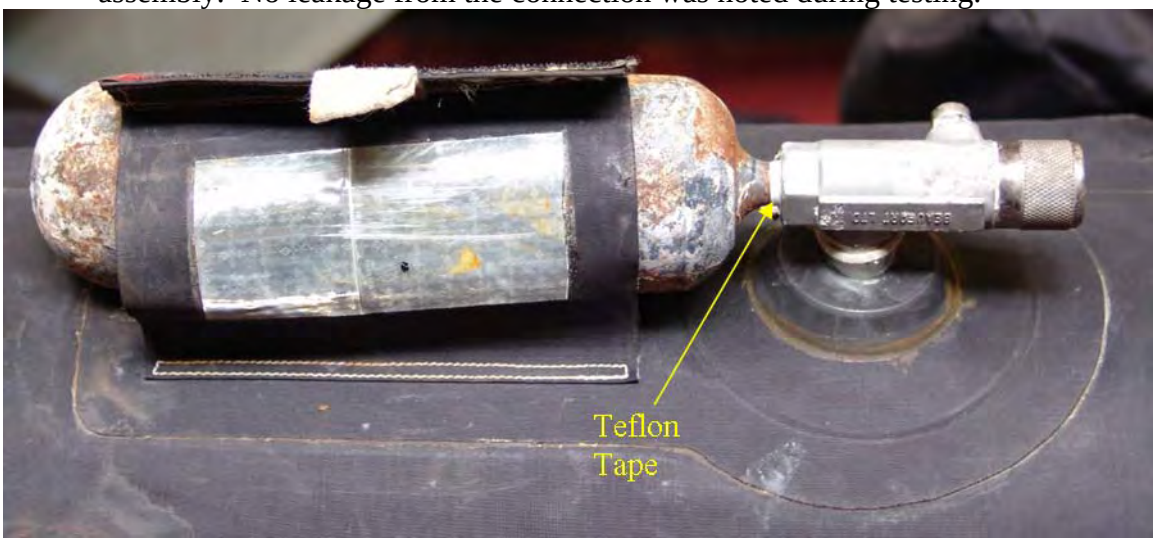


Figure 24: Raft Serial Number 0364812 CO_2 Bottle Detail

Conclusions:

- This raft was in the best overall condition of all five rafts with no leaks found in the seams or fabric of the flotation chamber, the smallest mounting holes in the floor of the raft and the least damaged canopy.
- The only leak that could be found was the slow loss of air from the over-inflation protection relief valve failing to reset after opening during inflation.
- This raft held air the second longest of the five tested. The loss could have been kept up with by an escaper using the manual inflation tube.

Raft Serial Number 2204171

Serial Number Stencil:

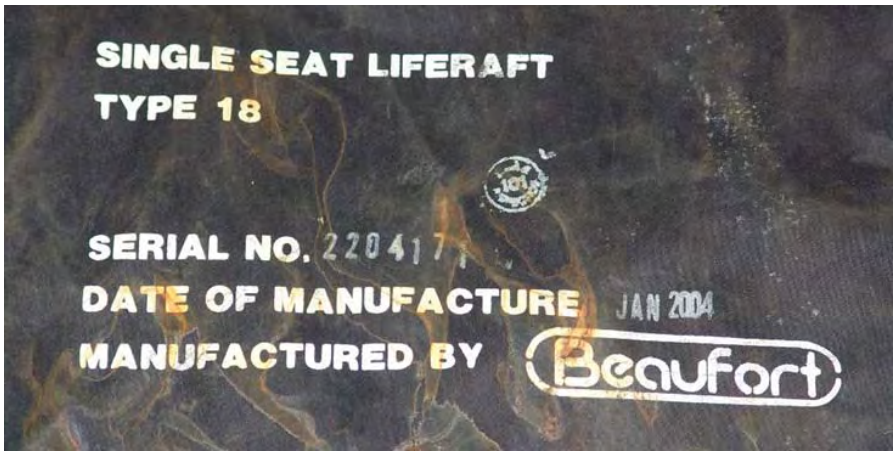


Figure 25: Raft Serial Number 2204171 Manufacturer's Identification Stencil

Figure 26: Raft Serial Number 2204171 Top View (Left) and Bottom View (Right)

- Two D-rings were added on left side. No grommets added to canopy.
- Forward Stability pocket left side seam (As seen from top.) was ripped open for entire length.

Figure 27: Raft Serial Number 2204171 Forward Stability Pocket Detail

- Two patches were added by SAIC on interior right side. The lower patch leaked significantly.

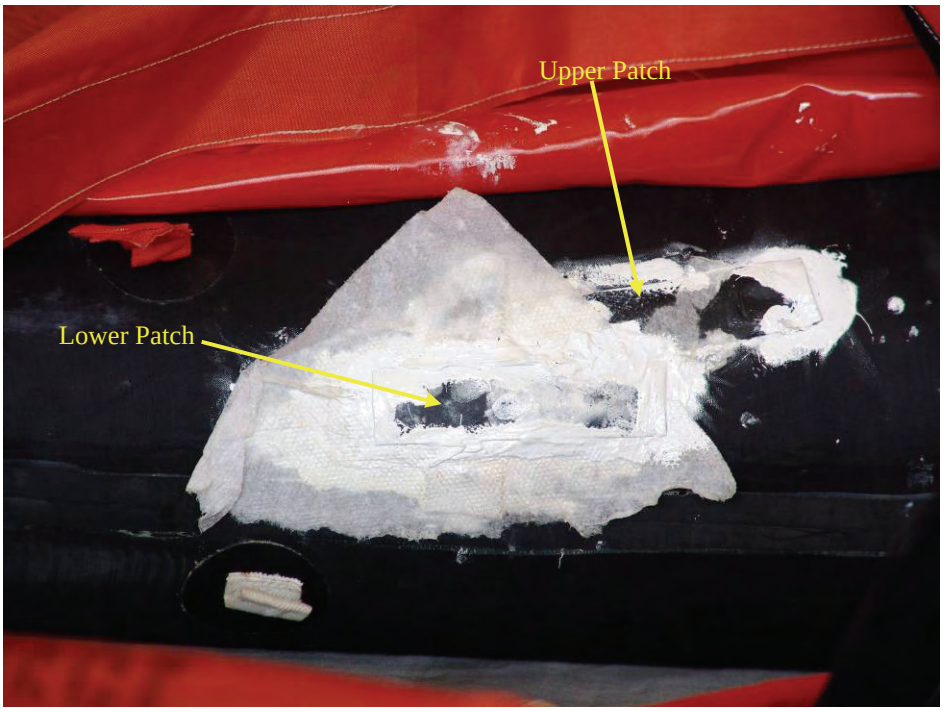


Figure 28: Raft Serial Number 2204171 Patches Detail

- No other leaks found.
- The CO_2 Bottle had Teflon tape added to the threaded connection to the fill valve assembly. No leakage was noted from the connection during testing.

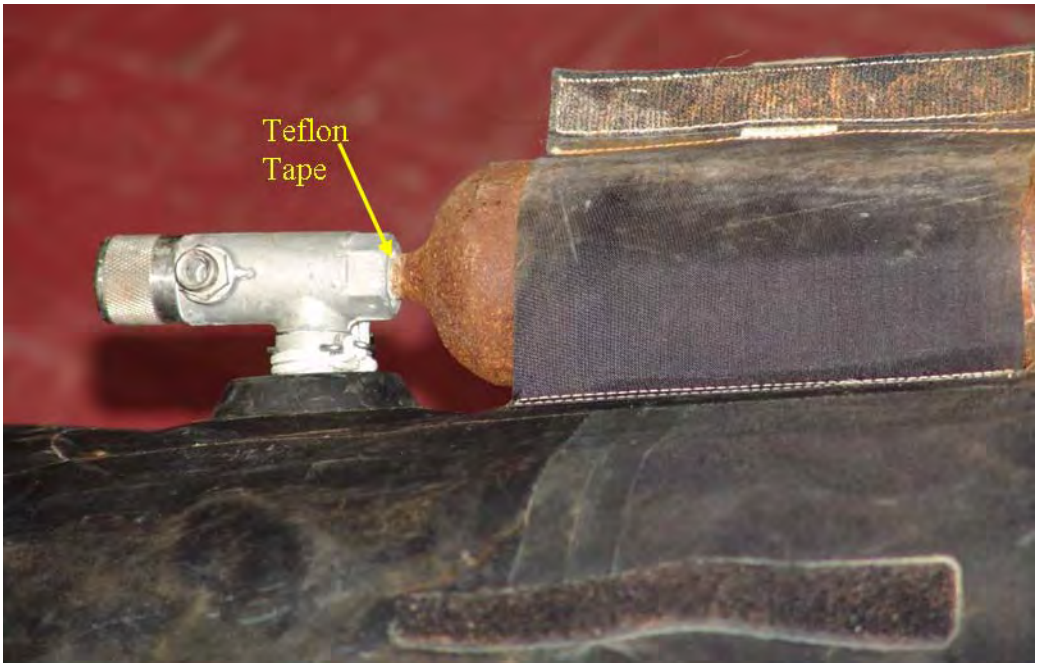


Figure 29: Raft Serial Number 220417 CO_2 Bottle Detail

Conclusion:

- Raft was in good condition other than the patched leak. If the lower patch had not failed the raft would have held air. The patched leak was roughly in the same position fore and aft as the pin-hole leak found on raft serial number 0364837 (Raft with two manual inflation tubes.) and not on or very near a seam.

Overall Conclusions, Comments and Recommendations:

- The life raft leaks were not a result of poor workmanship by the manufacturer as none occurred at seams.
- The only manufacturing related issues were:
    - Raft Serial Number 0364837 which was constructed with two manual inflation tubes. The lower manual inflation tube apparently leaked at the connection to the buoyancy chamber.
    - Raft Serial Number 0364812 Over-Inflation Protection Relief Valve failure to completely reseat after lifting. The production model MK-10 SEIE life rafts issued to the U.S. Navy Submarine Force does not have an over-inflation protection relief valve thus eliminating that possible leak source.

- The leaks appear to have been the result of abrasions or punctures of the interior sides of the buoyancy chamber that most likely were the result of contact with test equipment loaded into the rafts. The high sea states during testing most probably caused relative motion of the equipment secured to the plywood sheet and the buoyancy chambers. Discussions with USCG RDC personnel indicate that pre-formed cylindrical foam hot water piping insulation (identical to that installed by homeowners to insulate domestic hot water and hot water heating pipes) was placed around the edges of the plywood sheet edges to reduce chafing of the buoyancy chambers. The same personnel indicated that there was evidence of the insulation wearing away during the life raft drift runs.
- The method of securing the plywood equipment mounting sheets was probably not optimal. The appearance of rust around the holes cut into the raft floors and discovery of 1-inch washers inside the rafts indicates that steel bolts and medium size steel washers were used to secure the plywood sheet to the floor of the raft. The investigators believe much larger plastic washers should have been used to spread out the shear load. Additionally, some method of waterproofing or making watertight the holes should have been used as it was clear that those holes were a direct path of seawater into the rafts.
- A more realistic life raft configuration may have been achieved if the test equipment had been secured inside a mannequin that was dressed in a MK-10 SEIE. That would have eliminated the problems caused by the plywood mounting system. Additionally, the life rafts have four built in cloth loop tie-down connections (two on each side) on the interior of the raft used to secure the inflatable seat cushion. Those tie-downs could be used to secure the mannequin to the raft.
- The damage to the canopies and face shields by the high winds is an issue that should be researched. A fatigued or injured escaper may not be able to keep resealing his raft's canopy. Consideration should be made to test several life rafts with canopies modified by replacing the Velcro seal with a large plastic zipper. The smooth seal provided by a zipper would remove the material edge that the wind was apparently acting on and then lifting causing the seal to open.
- If humans dressed in MK-10 SEIEs were the passengers in the life rafts the leaks found in these rafts would not have occurred.

Serial Number	Date of Manufacture	Patches/Location	CO_2 Bottle Connection Teflon Taped?	D-Rings Added?	Grommets Added?	Comments
9834882	7 98	No patches	Yes	Yes	Yes	
9835715	AUG 1998	No patches	Yes	Yes	Yes	
0364837	12 2002	2 patches near the ***two*** manual inflation tubes. A third patch appeared to have been placed over a leak and has since disappeared. Epoxy on connection of lower manual inflation tube to buoyancy chamber.	Yes	Yes	Yes	Two Manual inflation tubes. Aft one on bottom half of buoyancy chamber. Upper on forward by about 6 inches on upper half of buoyancy tube
0364812	12 2003 or 2002?	No patches	Yes	Yes	No	Impossible to tell year of manufacture.
2204171	JAN 2004	1 patch on right side (inside) near midpoint fore/aft	Yes	Yes	No	