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# LIFE RAFT STUDY

February 1978







Oceanographic Unit Technical Report 79-1

# LIFE RAFT STUDY - FEBRUARY 1978

BY

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APRIL 1979

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TECHNICAL REPORT 79-1

## ABSTRACT

A life raft study was conducted from the CGC EVERGREEN in February 1978. Of the six life rafts tested, only one was seen capsizing. The Givens life raft suffered the most damage with both the canopy and ballast bag being destroyed. Leeway for life rafts with improved ballast systems was found to follow the equation $U_{life\ raft} = 0.042\ U_{wind} + 0.060$. This type of life raft was noted to drift at a much slower rate when the canopy was not deployed. In over 80% of the cases the life rafts drifted within 45° of the downwind direction.




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LIFE RAFT STUDY - FEBRUARY 1978

## INTRODUCTION

This life raft study was the result of two U. S. Coast Guard Headquarters initiatives and is expected to be the first in a series of similar experiments. In September 1977 the Office of Operations, Search and Rescue Division (G-OSR), requested that the U. S. Coast Guard Oceanographic Unit conduct research on the leeway of drifting objects. It was hoped that such work would result in verification or improvement of the leeway drift tables presented in the National Search and Rescue Manual, CG-308. At approximately the same time, the Office of Merchant Marine Safety, Merchant Marine Technical Division (G-MMT), required data on older life raft designs which have received Coast Guard approval. The Oceanographic Unit was tasked with conducting at sea tests in which life raft leeway and survivability would be studied simultaneously.

## PROCEDURES

### Operating Area

It was important to select an operating area which would allow the collection of a large amount of data in a short period of time. Thus the area had to be one of varying weather conditions. Such an area is in the general vicinity of 30°30'N, 64°00'W. During the winter, storms frequently pass through this area creating rapidly changing wind and sea conditions. Air temperature remains warm all winter in this region which facilitates working on deck. In addition, it is known to be an area of low residual surface currents which greatly simplifies the determination of leeway. This area was selected for these considerations and the probability of a winter deployment.

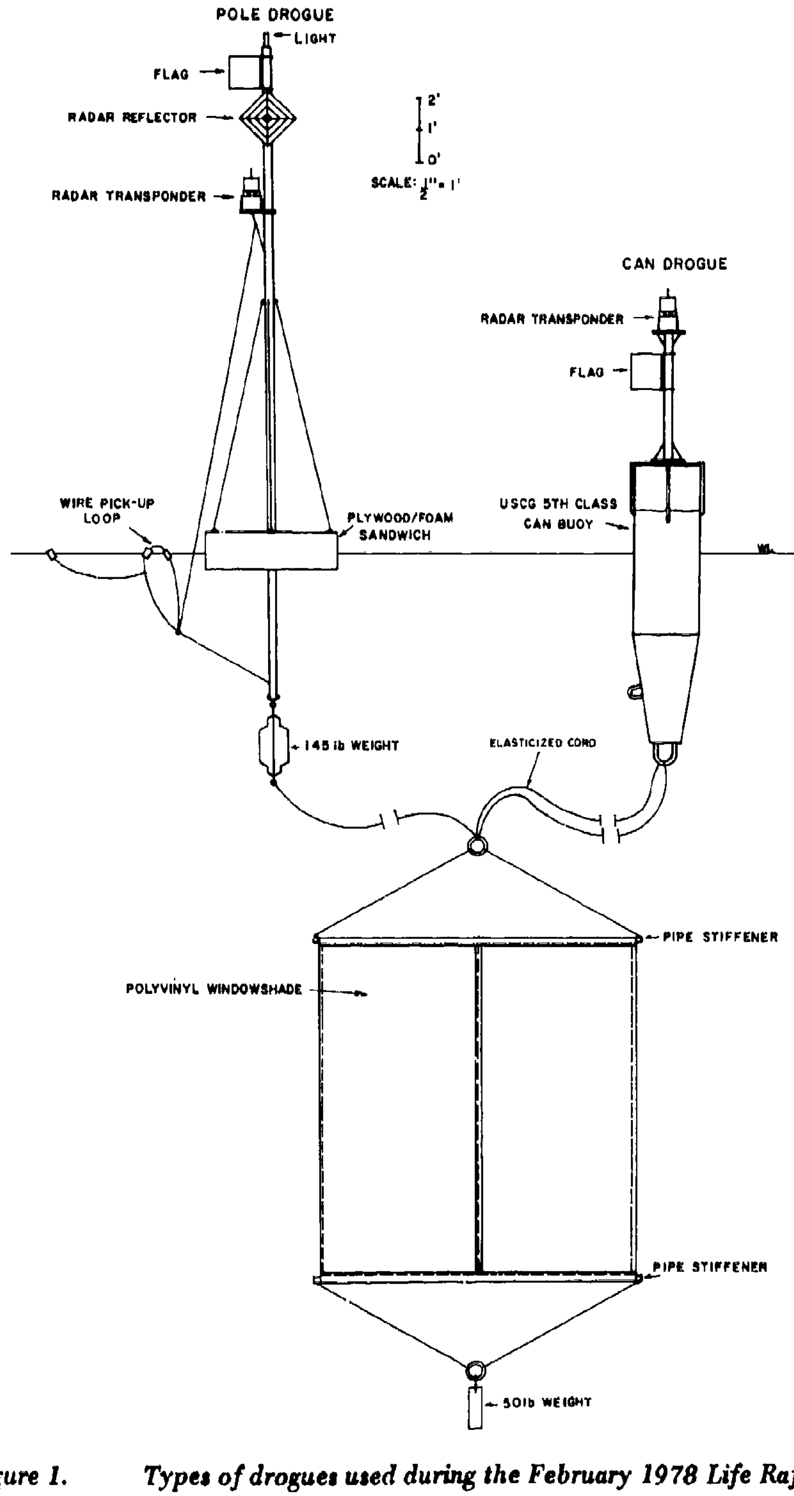


*Figure 1. Types of drogues used during the February 1978 Life Raft Study.*

Study Plan

The basic plan is simply stated, although it was more difficult to implement. Several life rafts would be launched along with a reference marker. This reference marker would drift with the surface current allowing the true leeway to be determined by fixing the position of the life rafts relative to the reference marker. Under ideal conditions, a group of life rafts and a reference marker would be launched in relatively calm conditions just prior to an approaching storm. These drifting objects would then be retrieved in about three days, after the passage of the storm. Each life raft was to be tested with simulated half and full load conditions.

Reference Markers

The results of such studies are highly dependent on the success of the reference markers. Drogued buoys are widely used for this purpose. Although the Oceanographic Unit had only limited success with drogued buoys, it was felt that they had the best potential for a successful project. Two designs were prepared for this work. An old design was significantly modified and a new design was developed.

Although the buoyant portions of these two designs were drastically different, the actual underwater drogues were identical. The drogue consisted of a 10' X 10' piece of polyvinyl cloth (Fig. 1). All edges were double sewn for strength and 1 1/2" diameter pipe was placed along the top and bottom to act as stiffeners. To insure that this cloth remained vertical in the water, a 50 lb weight was attached to the bottom. Such a drogue is usually referred to as a "window shade" drogue. It is considered a good design in that it generally aligns itself at right angles to the current, presents a known unchanging surface area to the current, is easily transported and deployed, and is relatively inexpensive.

The float design that had been previously used is known as a pipe drogue (Fig. 1). Since this design proved to be rather fragile in past experiments, various components were greatly strengthened although the basic design was unchanged. The center post is a 20' 2 1/2" diameter pipe that passes through a 4' X 4' X 1' plywood-styrofoam sandwich. The sandwich was covered with fiberglass to prevent waterlogging and to provide added strength. Attachments were placed on the pole to accommodate a light and radar transponder. To increase stability a 145 lb lead weight was attached between the bottom of the pole and the window shade.

The second flotation design was a modified Coast Guard fifth class radar reflector can buoy (Fig. 1). The modification consisted of a 4' long 2 1/2" diameter pipe, designed to accommodate a radar transponder and light, attached to the top of the buoy.

Tracking Aids

To properly indicate sea current, drogues must have a small surface area above the waterline relative to the underwater surface area. In this case,the drag ratio was 1:61 for the pole drogue and 1:14 for the can drogue. The small above water cross sectional area gives a poor radar image thus creating a problem in tracking the drogue at any significant distance. Therefore two visual tracking aids were incorporated into the design of these drogues. For daytime operation a 1' square international orange flag with a diagonal stiffener was attached near the top of each pole. An Ocean Applied Research, San Diego, CA. daylight controlled xenon lamp strobe (model SF-100-1-P) was selected to assist night time tracking. This light has the advantages of being lightweight, small, durable, waterproof, and highly visible.

Because of their small cross sectional area, radar return from both types of drogues was expected to be poor. Thus two aids were added to enhance the drogues' radar image. The first was a metal radar reflector developed by HMS Technology, Inc., Amherst, NH. It was anticipated that the reflector could be attached to the life rafts as well as to drogues. The second aid was a radar transponder. The transponder of our choice was a newly-developed model 235X transponder marketed by Vega Precision Electronics, Inc., Vienna, VA. These transponders are relatively light-weight, durable, weatherproof, and had a rated battery life of 8 days. They can be tuned to the center frequency of the ship's radar prior to delivery and their signal can be coded allowing for use of several at one time.

Operations Platform

USCGC EVERGREEN (WAGO-295) conducted this study from 15 February 1978 to 7 March 1978. The actual scientific program was conducted by a field party from the Oceanographic Unit with assistance provided by the ship's Marine Science Technicians and other ship's personnel. CGC EVERGREEN has all the facilities needed for conducting such a study including excellent navigation capability, a radar suitable for this type of study, and adequate crane capacity.

Life Rafts

G-MMT requested that various manufacturers supply a total of 25 life rafts for this study. Of these, 9 were received prior to the ship sailing from New London, CT. and an additional one was delivered in New York City prior to sailing to the operating area (Table 1). Loading of the life rafts to simulate personnel on board was accomplished by using sandbags each filled with 55 lbs of sand. One average person was considered to weigh 165 lbs

### *TABLE 1*

### *LIFE RAFTS PROVIDED FOR TESTING*

*B. F. Goodrich*
*Circular 20 person*
*Modified with improved stability system*
*(Goodrich 20)*

*B. F. Goodrich*
*6 person Crewsaver*
*Model MM MK3*

*B. F. Goodrich*
*Standard*
*Circular 25 person*

*B. F. Goodrich*
*Rectangular 4 person*
*Crewsaver Model*
*(Goodrich 4)*

*B. F. Goodrich*
*Circular 25 person*
*Modified with Givens Res-Q-Raft*
*Improved Stability System*
*(Givens)*

*Standard USCG*
*15 person*
*M-15*

*Switlik*
*Oblong 6 person*
*Modified with improved stability system*
*(Switlik)*

*Switlik*
*30 person*
*Model P/N RA-30033*

*Winslow*
*Oblong 4 person*
*with radar reflective canopy*
*Model 40 MCR*
*(Winslow)*

*Avon*
*Circular 6 person*
*No. 17654*
*(Avon)*

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B.F. Goodrich, a 6-person Winslow, and a 4-person Avon life raft were launched 8 miles upwind of the drogues. Despite rough seas and high winds these life rafts were tracked until after dark. By that time the life rafts had drifted well past the drogues. Although weather conditions continued to be severe (Fig. 2) on the 23rd a search was conducted during daylight for the life rafts. The life rafts were not located and the ship stood by the pole drogue throughout that night. It was not until first light on the 24th that the wind conditions had subsided enough that the drogues could be recovered. A final unsuccessful search of the area was made prior to setting course for New York that same afternoon. CGC EVERGREEN arrived in New York on 28 February 1978 to undergo repairs.

On Scene Conditions

As expected weather conditions were other than ideal. The storms did pass through the area but closer together than desired. As a result winds were greater than 20 knots for the majority of the time and gusted to 60 knots on occasion. For only 11 hours were winds of less than 10 knots recorded. Wind speed and direction were recorded each hour on the hour from the ship's anemometer. Winds were generally from the west southwest for the entire period. Seas were from the west averaging about 5 feet and at times reaching 15 feet (Fig. 2). Significant wave height was visually observed every hour on the hour.

Equipment Performance

The severe weather conditions created excellent test conditions for the drogues and tracking aids. Both drogues rode well even under the most adverse weather conditions encountered. No structural damage was done to the can drogue during launch or recovery. However, this drogue proved to be somewhat elusive during recovery in heavy weather as it bounced around in the sea. The pole drogue did suffer structural damage

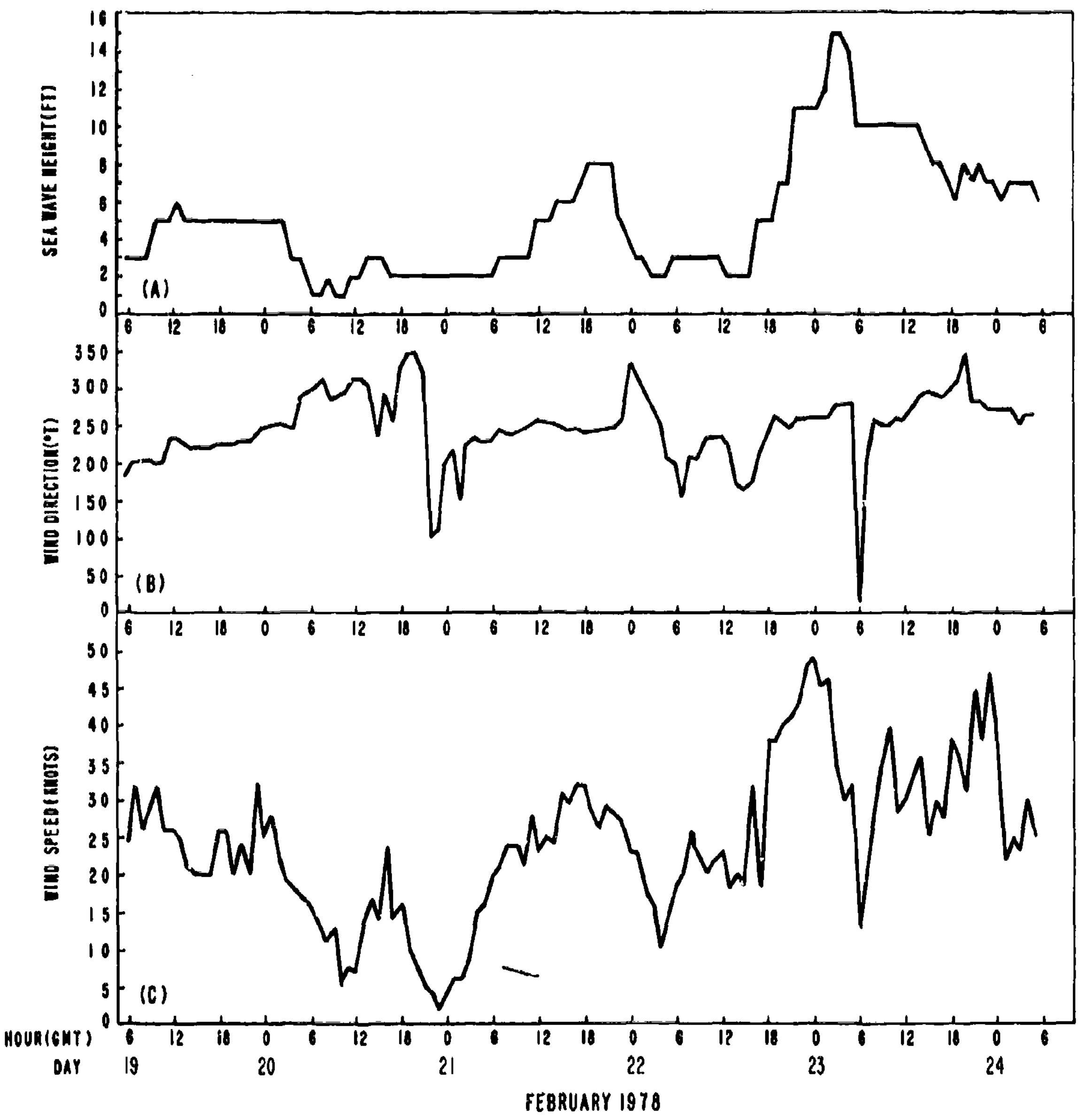


*Figure 2.* ***Sea wave height (A), wind direction (B), and wind speed (C) encountered by CGC EVERGREEN (WAGO 295) during the February 1978 Life Raft Study.***

during both launch and recovery. The fiberglass coating cracked in many places, primarily near the corners of the flotation, when the drogue hit the side of the ship. Recovery was difficult in the heavy seas, causing additional damage. The crane hook was used to snag a guy wire, but then the guy wire eye bolt in the base of the drogue pulled through the bottom plywood sheet when the drogue was lifted. Upon recovery it was discovered that the styrofoam had become partially waterlogged by water entering through the cracks in the fiberglass.

The window shades were not damaged at all. Double sewing the edges and using larger size pipe seem to be the key to durability. Elasticized cord was used between the float and the top of one window shade to dampen the effects of the surface waves on the window shade. As both the window shade with the elasticized cord and the one without suffered no damage, the use of this cord seems unnecessary.

The radar reflectors did not enhance the radar image of the drogues or the life rafts, in any sea conditions encountered. Because of the construction of the life rafts, the reflectors could not be mounted in a manner which would take advantage of their design. The reflectors might be of some use on drogues in calmer seas.

The radar transponders proved to be an excellent means of tracking the drogues. The pole drogue was tracked easily to ranges in excess of 12 nautical miles, and with difficulty the can drogue was tracked up to 11 nautical miles. It is believed that the can drogue was more difficult to track because of its lower "height-of-eye," causing it to frequently disappear behind waves. Since the return pulses were coded, there was no problem distinguishing the two transponders' signals even when drogues were less than half a nautical mile apart. Both transponders worked well throughout the study. However, upon recovery in 30 knot winds the case of the transponder on the can drogue was cracked and the top of the antenna case of the other was broken off. In each case the transponder had slammed into the side of the ship.

## RESULTS

### Survivability

Survivability results are summarized in Table 2 and explained in the text. It should be noted that all rafts were tested under simulated half load condition. Wind speeds and directions listed in Figure 2 are values recorded on the hour each hour. On occasion higher gusts were observed.

Of the life rafts tested, only the Givens life raft was recovered. This life raft was tracked from 2107GMT 19 February until 0554GMT 21 February and was observed to be riding well. The center support for the canopy was noted to be deflated at 0100GMT 21 February causing the canopy to lay on the bottom of the life raft. By 0554GMT the ship was running between three rafts which were some distance apart in heavy seas. On the following pass the life raft was not located and it was decided to standby another life raft that could be located. During daylight hours on the 21st, another fruitless search was made for the Givens life raft. Only after this search had been concluded and a search begun for another life raft was the Givens life raft relocated at 2007GMT 21 February.

As the ship approached the life raft, it was clearly obvious that the canopy was torn in several places from the lifting ring to the upper flotation ring. Although the life raft did not appear to have capsized, it was also very obvious that the ballast bag was totally shredded. The life raft was approximately half filled with water. Although there was an extended period when the life raft was not observed, the damage is certain to be from natural causes as no other ships were seen visually

TABLE 2

RESULTS OF SURVIVABILITY TESTS

| DRIFTING OBJECT | LAUNCH DAY/TIME | LAUNCH LOCATION | RECOVERY/LAST SIGHTING TIME | RECOVERY/LAST SIGHTING LOCATION | WIND SPEED | SEA HEIGHT | COMMENTS |
|---|---|---|---|---|---|---|---|
| B.F. Goodrich Circular 20 person Modified for improved stability | 192100Z | 32-31.0N 63-57.9W | 210426Z | 32-25.6N 63-53.1W | 2-33 kns | 1-5 ft | When last seen riding well - canopy partly deflated. |
| B.F. Goodrich Circular 25 person Modified with Givens Res-Q-Raft Improved stability system | 192107Z | 32-30.9N 63-59.7W | 212007Z | 32-29.1N 63-47.9W | 2-33 kns | 1-8 ft | Recovered - canopy ripped - ballast bag shredded. |
| Switlik Oblong 6 person Modified for improved stability | 20166 Z | 32-26.1N 63-54.3W | 211414Z | 32-29.3N 63-47.7W | 2-33 kns | 1-8 ft | When last seen riding well - appeared fully inflated. |
| B.F. Goodrich Rectangular 4 person Crewsaver model | 221432Z | 32-25.3N 64-17.0W | 222145Z | 32-29.3N 64-07.0W | 18-43 kns | 3-11 ft | When last seen riding well - fully inflated. |
| Winslow Oblong 4 person with radar reflective Canopy 40 MCR model | 221449Z | 32-25.8N 64-16.5W | 222223Z | 32-28.4N 64-08.6W | 18-45 kns | 3-12 ft | When last seen waves were breaking over it. Canopy has blown down - Raft filling with water but riding upright - No radar image. |
| Avon Circular 6 person Life raft in soft valise No. 17654 | 221545Z | 32-26.8N 64-16.9W | 230035Z | 32-29.1N 64-02.5W | 18-50 kns | 3-15 ft | Observed to capsize once. Last seen rolling down wind on its side. |
| Pole Drogue | 191755Z | 32-29.1N 63-59.5W | 201720Z | 32-26.7N 64-07.9W | 5-33 kns | 2-6 ft | Retrieved to be reset. |
| | 202036Z | 32-24.3N | 231303Z | 32-11.0N | 2-50 kns | 1-15 ft | Radar transducer broken on retrieval. One eye bolt partly pulled out. |
| Can Drogue | 191820Z | 32-29.7N 63-59.8W | 201800Z | 32-24.3N 64-07.5W | 5-33 kns | 2-6 ft | Retrieved to be reset. |
| | 201924Z | 32-27.5N 63-56.2W | 231115Z | 32-19.2N 64-09.0W | 2-50 | 1-15 ft | Radar transducer cracker on retrieval. |

or with radar in the immediate area. After assessing the damage the life raft was brought aboard.

The B. F. Goodrich 20-person life raft was tested along with the Givens life raft. This life raft was last seen at 0426GMT 21 February 1978. Although a search was conducted, the life raft was never relocated. The raft rode very steadily during the entire time it was followed. No structual damage was apparent although the light supplied with the raft only lasted about 5 hours.

The Switlik 6-person life raft was launched after the drogues had been repositioned near the Givens and Goodrich life rafts on the 20th. It was tracked throughout the night of 20-21 February after the CGC EVERGREEN lost sight of the other two life rafts. Only when a search for the missing life rafts was made was the position of this life raft lost. This life raft also rode very well and did not suffer any structual damage during the study.

During the second phase of the study, three more life rafts were studied. Weather conditions were worse than during the first phase and were getting increasingly severe as the study ended. The B. F. Goodrich 4-person life raft rode well for the seven hours it was tracked. No structual damage was noted and the life raft was fully inflated when last seen.

The 4-person Winslow life raft was tracked for approximately the same amount of time. Shortly after launching the canopy was blown down. The life raft became filled with water as the waves broke over it. In spite of this condition the life raft did not appear to capsize.

The Avon 6-person life raft was tracked for about 9 hours. Toward the end of the period it was observed capsizing once. A short time later it was sighted rolling downwind over the wave crests on its side.

This was the last life raft sighted during the study as darkness and adverse sea condition prevented further study.

## Leeway

### Method of Analysis

Leeway is the drift of a floating object caused by the wind pushing that object through the water. Thus it was necessary to decide which drogue would be used as the reference point to eliminate the effects of sea currents from all leeway calculations. The two drogues drifted in the same general direction; however, from the plot of the drift, it was apparent that the pole drogue was less affected by the winds and seas. This was expected as its drag coefficient ratio (an indication of how well a drogue is designed to measure the sea current) was much more favorable than that of the can drogue. Therefore the pole drogue was selected as the reference point. It traveled at approximately 15 cm/sec throughout the study indicating that the sea current, as expected, was weak in the study area. The use of a drogue also eliminates any necessity to determine the geographic position of the drifting objects. Thus only the position of each drift object relative to the drogue was needed.

The goal of fixing the position of each life raft relative to the drogue every twenty minutes proved unobtainable. In the sea conditions encountered, the life rafts could not be tracked by radar. Therefore to obtain a fix it was necessary for the ship to come alongside each life raft. This resulted in a random time sampling scheme. As the drifting life rafts diverged, the sampling periods increased.

To analyze these data, it was necessary to fit the randomly obtained data to standard intervals. This was accomplished by plotting the life raft positions relative to the pole drogue. After data points which were obviously erroneous were subjectively eliminated, a cubic spline curve (Conte and deBoor, 1972) was passed through the remaining points. Hourly positions of the life rafts were then determined from this curve along with corresponding speeds and directions of life raft drift. Study of the Givens life raft data indicates a discontinuity at approximately 0100GMT 21 February (the time that the canopy was noted to be deflated). Givens data collected after this were considered separately and were not included in forming the total leeway equation.

The leeway speeds were regressed on the hourly wind speeds obtained with the ship's anemometer using a linear regression analysis which compared drift speeds with appropriate wind values. It was believed that this method would produce the best fit to the data. Following the computation of the regression coefficients, tests using the F statistic were made which indicated that this was the case. All curve fitting, plotting, and linear regression for this analysis was accomplished using a CDC 3300 computer. Documentation for all programs used is available at the Oceanographic Unit.

Because of the wind conditions during the study period, few data points were obtained at low wind speeds. Those that were obtained were widely scattered. Thus all data points corresponding to wind values of less than 10 knots were not considered. Because the second three raft study was shortened, insufficiant data was collected to conduct a useful analysis. Therefore, leeway values for the Goodrich 4-person, Avon, and Winslow life rafts could not be determined.

Speed

Equations relating life raft leeway to wind speed were derived from the linear regression conducted on data obtained from each life raft study (Figs. 3-7). Switlik data covered the shortest length of time and

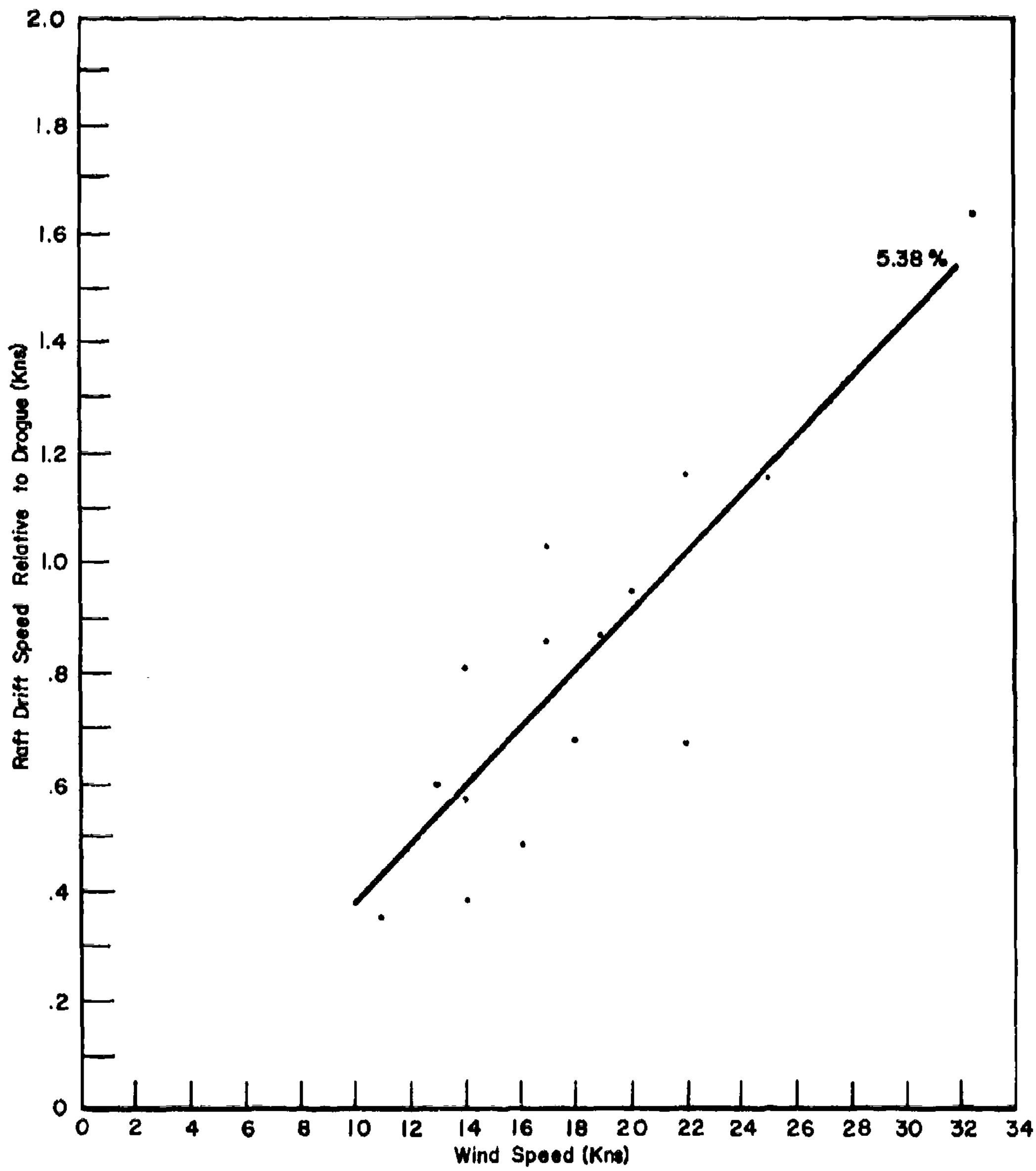


*Figure 3.* *Leeway speed of Givens Life Raft (canopy deployed) as a function of wind speed (wind speed x 5.38% = raft drift speed).*

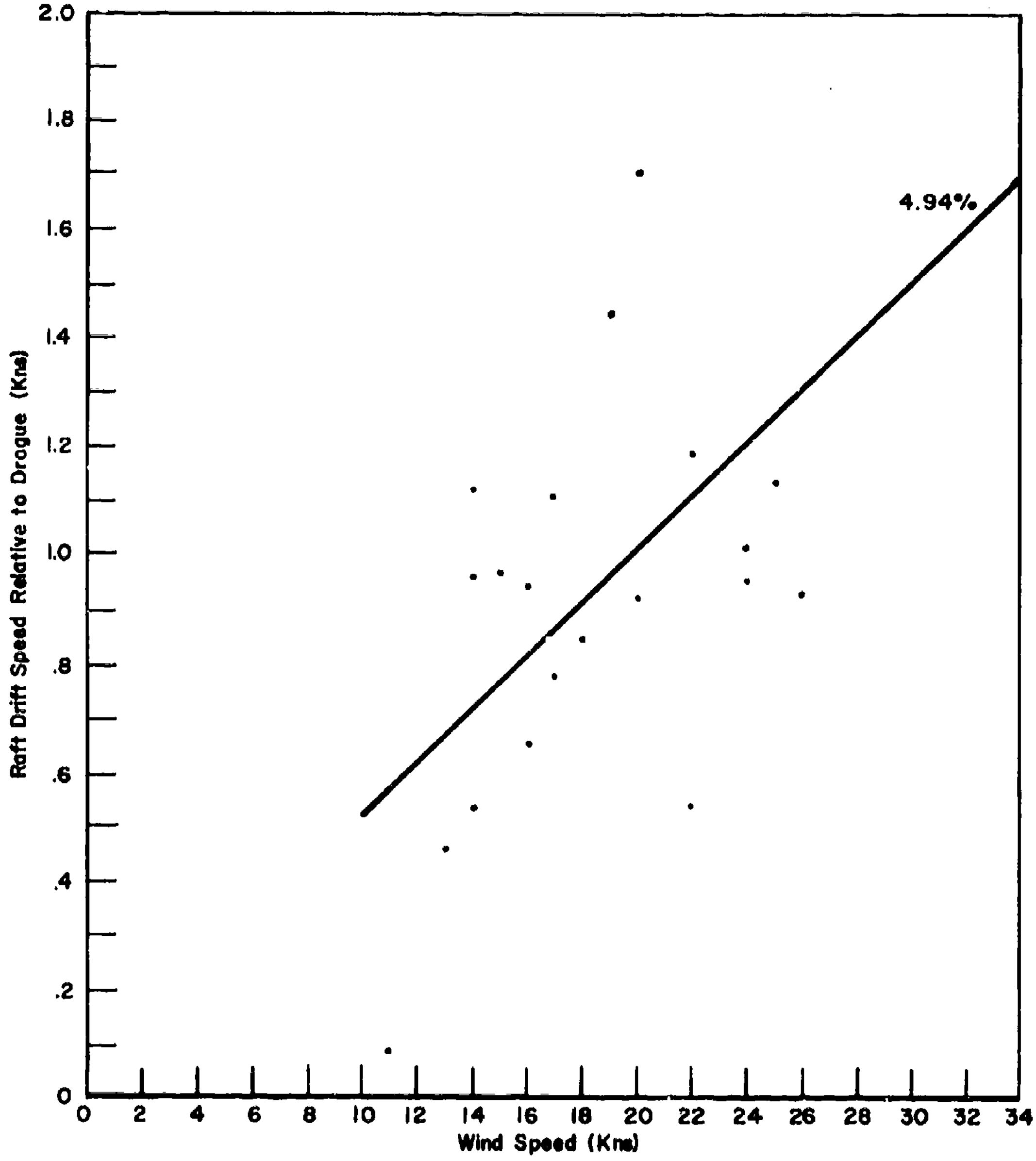


*Figure 4. Leeway speed of Switlik Life Raft as a function of wind speed.*

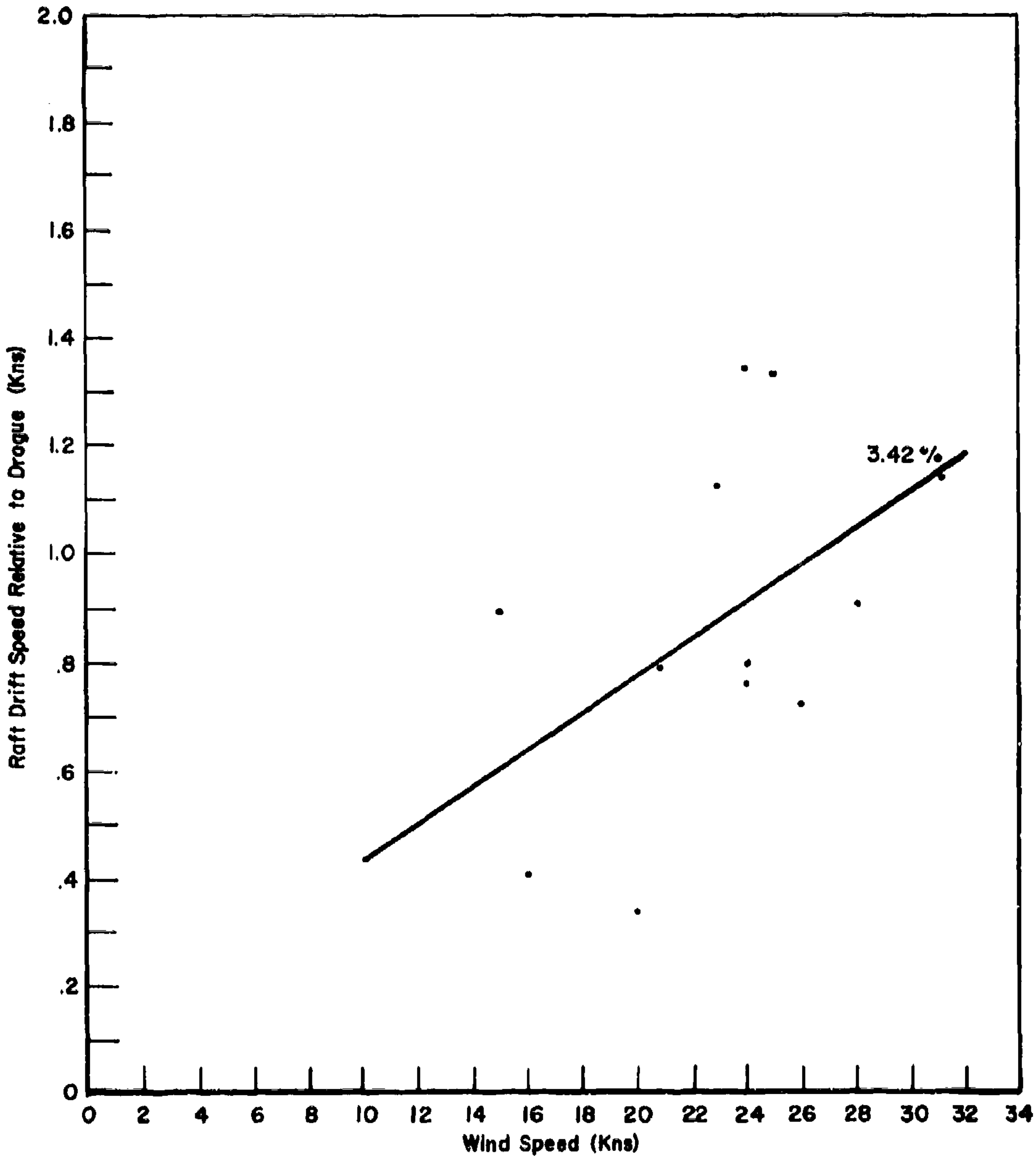


*Figure 5.* *Leeway speed of Goodrich 20 person Life Raft as a function of wind speed.*

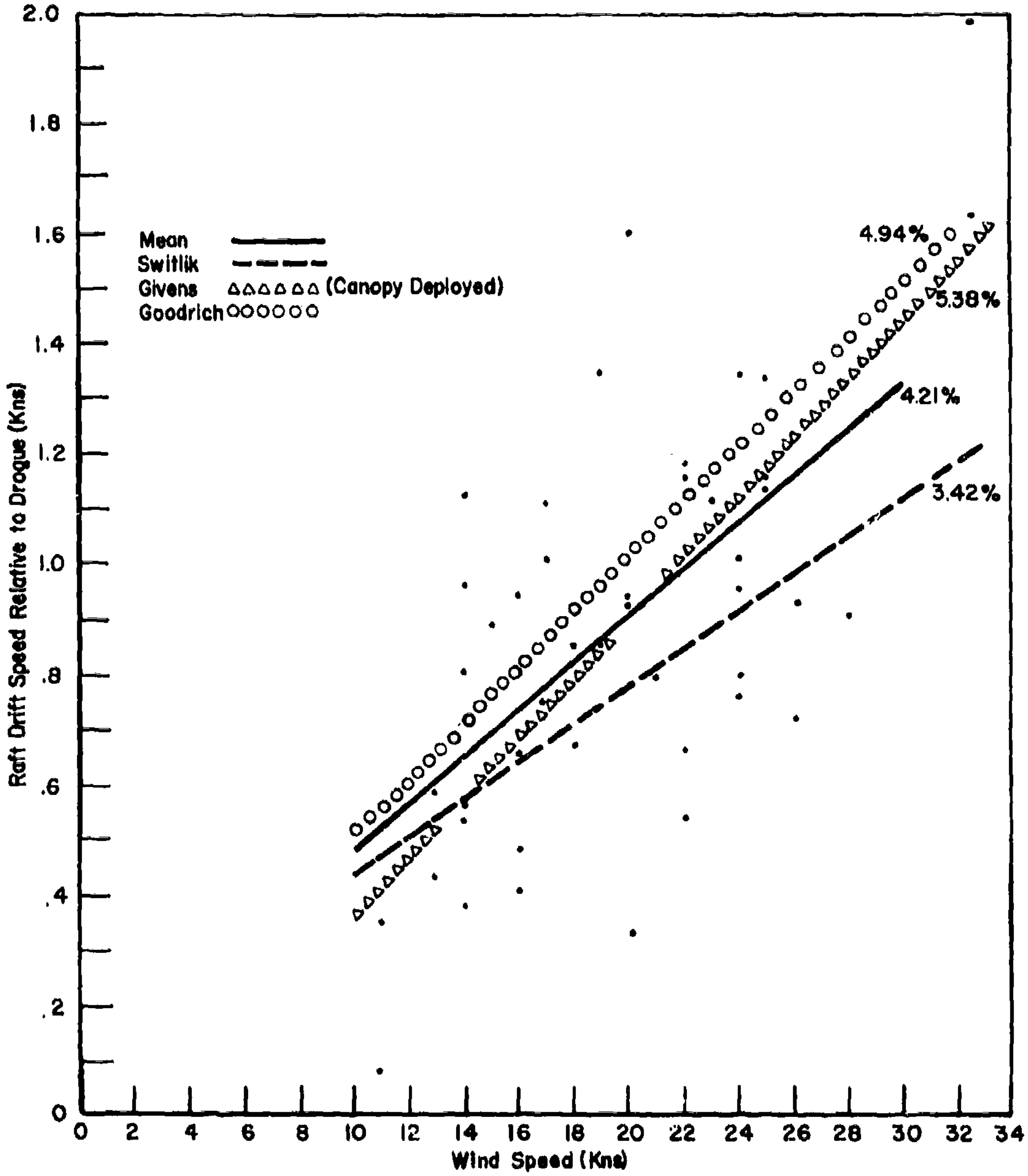


*Figure 6.* ***Leeway speed of combined improved ballast system life rafts as a function of wind speed.***

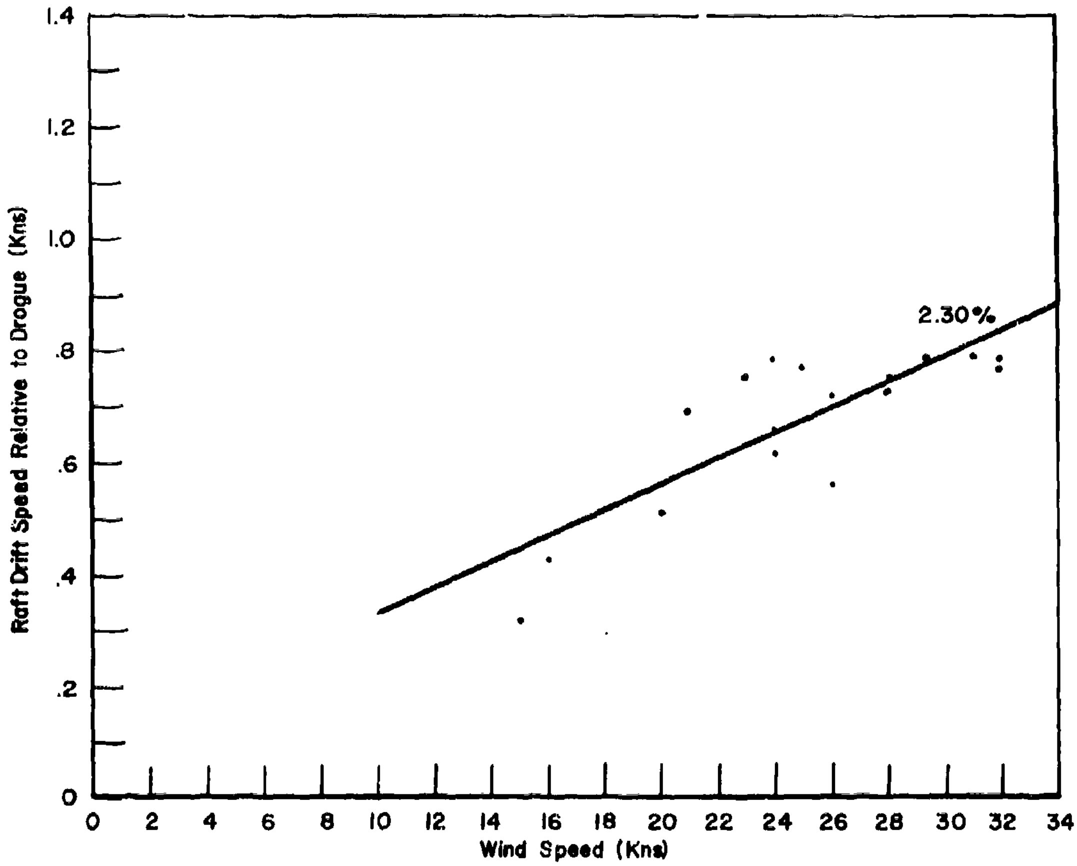


*Figure 7.* ***Leeway speed of Givens Life Raft (canopy not deployed) as a function of wind speed.***

were the most widely scattered. As a result, these linear regression coefficients were determined to be statistically significant at the 90% confidence level. All other linear regression coefficients proved to be statistically significant at the 95% confidence level. Resultant equations are as follows:

TABLE 3

Results of Linear Regression Analysis

| | | Mean | 95% Confidence Limits | |
|---|---|---|---|---|
| $U_{Switlik}$ | = | $.034\ U_w + .090$ | $-.011\ U_w + .090$ | $.079\ U_w + .090$ |
| $U_{Goodrich\ 20}$ | = | $.049\ U_w + .024$ | $.015\ U_w + .024$ | $.083\ U_w + .024$ |
| $U_{Givens}$ | = | $.054\ U_w - .177$ | $.034\ U_w - .177$ | $.074\ U_w - .177$ |
| $U_{Givens}$ (canopy down) | = | $.023\ U_w + .091$ | $.013\ U_w + .091$ | $.033\ U_w + .091$ |
| $U_{total}$ | = | $.042\ U_w + .060$ | $.024\ U_w + .060$ | $.061\ U_w + .060$ |

$U_w$ represents the wind speed in knots. $U_{life\ raft\ name}$ is the leeway speed of each life raft in knots. $U_{total}$ represents life raft leeway in knots for all data collected while the canopies of the life rafts were inflated. A comparison of leeway speeds determined from these equations and those from previous works is presented in Table 4.

Direction

Life raft drift with respect to the downwind direction is presented in Figure 8. Drift direction varies from 120° to the left to 180° to the right of the downwind direction. However, 83% of all drifts are within 45° of the downwind direction and 78% of the points are within 30°. The drift direction did not vary significantly with varying wind speeds. The combined mean drift direction was approximately 3° to the right of the downwind direction of all the life rafts studied, the Givens life raft with canopy down had the least deviation drifting only

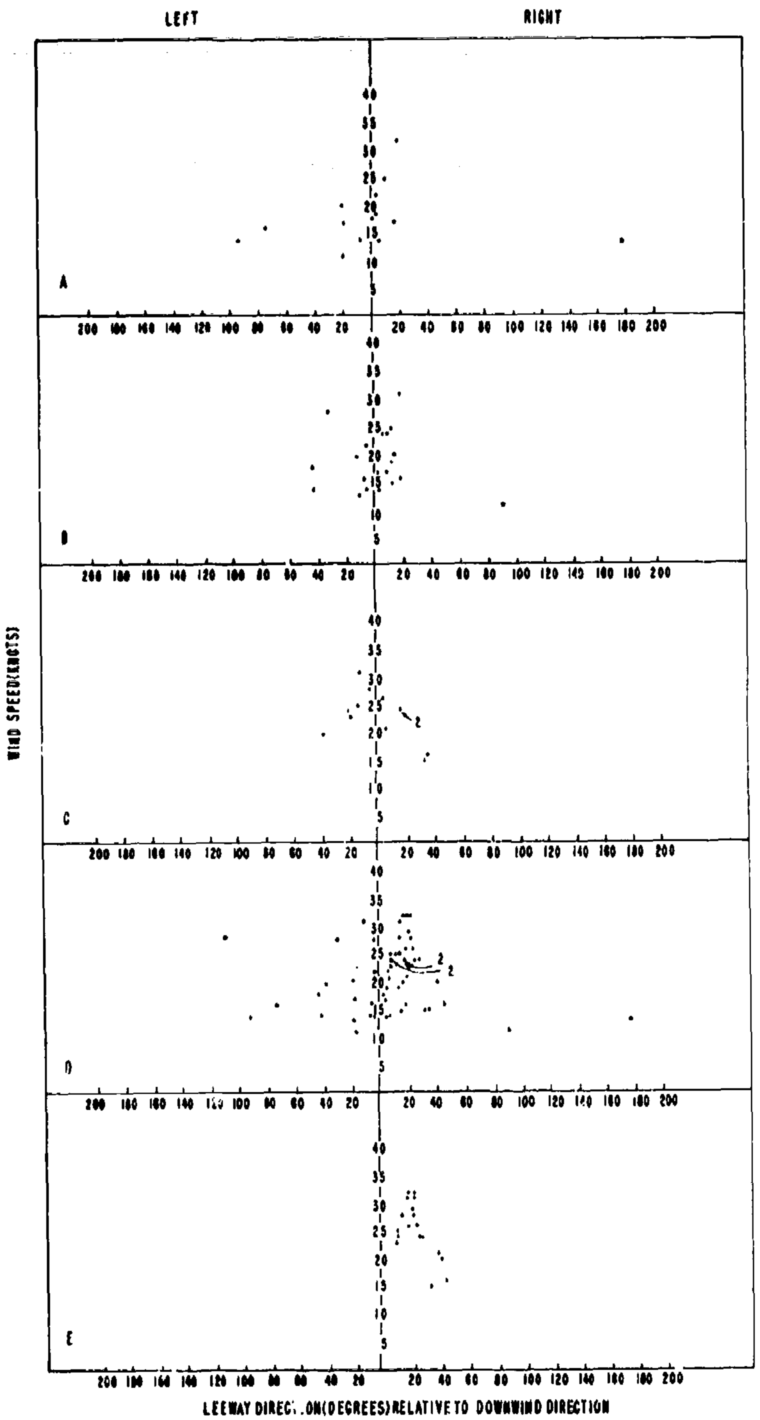


*Figure 8.* *Leeway speed and direction in relation to down wind direction for (a) Givens Life Raft (canopy deployed), (b) Goodrich 20 person Life Raft, (c) Switlik Life Raft, (d) Combination of all improved ballast life rafts, and Givens Life Raft (canopy not deployed).*

between 7° to 43° to the right of the downwind direction. Although the combined mean drift direction was close to the downwind direction over 67% of the drifts were to the right of the wind.

## CONCLUSIONS

### Survivability

The only life raft that was observed capsizing was the Avon life raft. This occurred more than two hours after the other two life rafts in the study were last sighted. During the interim, weather conditions had steadily worsened. By the time of capsizing the winds were gusting to 60 knots and seas were 15 feet high (Fig. 2). Although the 4-person Goodrich life raft and the Winslow life raft remained upright, they did not ride very smoothly. This was not unexpected in the severe conditions encountered. Persons riding in the Goodrich life raft would have at least remained sheltered as the canopy and all other portions of the life raft suffered no apparent damage. The Winslow life raft did not fare as well. Shortly after launching, the canopy was knocked down by the wind which was blowing at about 20 knots. Once this happened, waves broke over the life raft quickly filling it with water. Although the life raft remained upright, it also remained filled with water. This life raft's canopy made of lightweight fabric was designed to act as a radar reflector, but it was never picked up by the ship's radar. Under such conditions it would have been more advantageous to have a stronger canopy.

Testing of the larger life rafts was conducted under less severe weather conditions. Both the Goodrich 20-person life raft and the Switlik life raft rode well in winds up to 33 knots and seas to 5 feet. Neither life raft suffered any apparent damage. The improved ballast systems on these two life rafts appeared to work effectively and contributed to the smooth ride.

Of all the life rafts tested the Givens life raft suffered the most damage. Upon launching a two-foot tear in the outer canopy occurred when it was hit by a swinging crane hook. Whether this was the initial cause of the destruction of both the inner and the outer canopy is unknown. Whatever the initial cause, the wind definitely completed the destruction of the canopy. Of greater concern is the total shredding of the ballast bag. This seemed to be fully functional on launch and on all daylight observations (it could not be seen at night). Only just prior to final retrieval was it noted that the bag was ruined. It is felt that the ballast bag was simply not strong enough to withstand the forces of the wave action. This resulted in the destruction of the bag and the releasing of its designed cargo of 19,800 lbs of entrapped water. The basic concept of such an improved ballast system is certainly appealing. However, this seems to be a case where a potentially good design was carried beyond the strength limits of the material used, especially since the other two rafts with smaller ballast systems rode well and suffered no apparent damage. It is believed that by using stronger material to make the ballast bag, reducing its size and/or using two way valves in it, the dependability of the system could be improved.

Leeway

Leeway speed calculated for a single equation combining the drift data of all of the improved ballast system life rafts compared closely with the equation presently used in the National Search and Rescue Manual for several types of water craft including rubber rafts with drogues. This manual's equation was developed by Hufford and Broida (1974) from experiments conducted with small craft in Long Island Sound

## TABLE 4

### COMPARISON OF LEEWAY RESULTS FROM THE FEBRUARY 1978 CRUISE WITH RESULTS OF PREVIOUS STUDIES (DRIFT FIGURES ARE IN NMI/DAY)

| Wind (KNS) | Switlik 6 Person Life Raft | Goodrich 20 Person Life Raft | Givens 25 Person Life Raft | Combined Improved Life Raft | Hufford and Broida Small Craft | Givens 25 Person Life Raft | Hufford and Broida Rubber Raft | Hufford and Broida Small Craft | Chapline Moderate Displacement (Fishing Vsls, etc.) | Chapline Moderate Displacement (Cruisers) | Chapline Heavy Displacement (Deep Draft Sailing Vsls.) | Pingree Life Raft | Pingree Life Raft |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 10.3 | 12.3 | 8.7 | 11.3 | 9.1 | 7.7 | 4.8 | 17.8 | 9.6 | 12.0 | 7.2 | 6.5 | 19.9 |
| 15 | 14.4 | 18.2 | 15.2 | 16.6 | 15.1 | 10.5 | 9.6 | 26.2 | 14.4 | 18.0 | 10.8 | 8.6 | 23.8 |
| 20 | 18.5 | 24.1 | 21.7 | 21.6 | 21.1 | 13.2 | 14.4 | 34.6 | 19.2 | 24.0 | 14.4 | 11.5 | 25.9 |
| 25 | 22.6 | 30.0 | 28.2 | 26.6 | 27.1 | 16.0 | 19.2 | 43.0 | 24.0 | 30.0 | 18.0 | — | — |
| 30 | 26.6 | 35.9 | 34.6 | 31.7 | 33.1 | 18.7 | 24.0 | 51.4 | 28.8 | 36.0 | 21.6 | — | — |
| Canopy Deployed | Yes | Yes | Yes | Yes | NA | No | No | NA | NA | NA | NA | Probably Not | Probably Not |
| Drag Force | Improved Ballast System | Improved Ballast System | Improved Ballast System | Improved Ballast System | Sea Anchor | Improved Ballast System | Sea Anchor | None | — | — | — | Sea Anchor | None |

(Table 3). Daily drift determined from these two equations varied less than 2.5 nautical miles where the new equation is applicable (10-30 kns). Values from this new equation are greater than Chapline's (1960) values for moderate displacement vessels (sailing vessels, fishing vessels, etc.) and less than his values for moderate displacement cruisers. The drift for the improved ballasted system is greater than expected. The added ballast, especially the nearly 10 tons of water in the Givens life raft, was designed to lessen the drift as well as increase the stability. However, results suggest that once a life raft is ballasted to a as yet undetermined optimum level further increases in ballast result in only limited additional decrease in drift.

The Givens life raft drifted significantly slower after the canopy was deflated (18.7 nmi per day vs 35.9 nmi per day for 30 kns wind speed). This was a result of two factors. First the deflating of the canopy greatly reduced the sail area of the life raft. Second the ballast bag, although probably torn, acted as a large drogue. The resultant drift was similar to Chapline's (1960) drift for heavy displacement deep draft vessels and Pingree's (1944) drift for a rubber raft with drogue. Also it was generally in agreement with the drift determined for a rubber raft with drogue and without canopy (Hufford and Broida, 1974). At wind speeds between 10 and 30 knots, the leeway direction showed no tendency to approach the downwind direction as the wind increased. The vast amount of the drift was within 45° of the downwind direction. Leeway direction showed no dependency on whether the canopy was deployed.

## RECOMMENDATIONS

Even though this was a limited study and the results must be carefully weighed, the following recommendations are made:

- Until more data can be collected leeway drift for improved ballast life rafts should be calculated by continuing to use the equation in the National Search and Rescue Manual for rubber rafts with drogue.

- 45° on either side of down wind direction should be allowed for leeway drift angle of improved ballasted life rafts.

- Separate leeway tables should be developed for life rafts with and without a canopy deployed.

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