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NASA TM X- 72817

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(NASA-TM-X-72817) DESIGN, FABRICATION AND SYSTEMS INTEGRATION OF A SATELLITE TRACKED, FREE-DRIFTING OCEAN DATA BUOY (NASA) 24 p HC $3.50 CSCL 08C

N76-16721

G3/48 Unclas 13569

DESIGN, FABRICATION AND SYSTEMS INTEGRATION OF A SATELLITE TRACKED, FREE-DRIFTING OCEAN DATA BUOY

by

John W. Wallace and John W. Cox

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LANGLEY RESEARCH CENTER, HAMPTON, VIRGINIA 23665

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM X-72817		

4. Title and Subtitle	5. Report Date
Design, Fabrication and Systems Integration of a Satellite Tracked, Free-Drifting Ocean Data Buoy	January 1976
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Wallace, John W. Cox, John W.	
	10. Work Unit No.
9. Performing Organization Name and Address	644-02-02-01
National Aeronautics and Space Administration Langley Research Center Hampton, Virginia 23665	11. Contract or Grant No.
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Technical Memorandum
National Aeronautics and Space Administration Washington, D. C. 20546	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This paper presents engineering details of a small free-drifting buoy configuration designed for use in the study of continental shelf water circulation patterns in the Chesapeake Bight of the Western North Atlantic Ocean. The buoy incorporated French instrumentation and was interrogated by the French EOLE (God of the Wind) satellite to provide position and four channels of temperature data. The buoy design included a variable depth drogue (sea anchor) and a power supply sufficient for 6 weeks of continuous operations. Proof tests of the configuration indicated an adequate design and subsequent field experiments verified the proper functioning of the system.

17. Key Words (Suggested by Author(s)) (STAR category underlined)	18. Distribution Statement
Free Drifting Buoys, Ocean Data Systems Oceanography, Physical Sciences, Ocean Buoy Tracking	Unclassified - Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	23	$3.75

*For sale by the National Technical Information Service, Springfield, Virginia 22161

DESIGN, FABRICATION AND SYSTEMS INTEGRATION

OF A SATELLITE TRACKED, FREE-DRIFTING OCEAN DATA BUOY

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SUMMARY

Engineering details and development tests are presented for a small (~250kg) free-drifting buoy system used in water circulation studies on the continental shelf of the United States East Coast. The buoy was designed specifically to incorporate a standard size rack unit of instrumentation obtained from the French Centre National D'Etudes Spatiales (CNES) through the CAS-A office at the National Aeronautics and Space Administration's (NASA) Goddard Space Flight Center (GSFC). Data transmitted from the buoy to the French EOLE satellite included four channels of temperature data and the buoy identification. Buoy position was determined by satellite measurement of range and range-rate plus the satellite orbital parameters determined from ground tracking station data.

High priority was given, during design, to factors influencing ease of deployment and retrieval from ships and helicopters and to planned refurbishment. The resulting system proved to be suitable for the planned missions and were capable of operation for approximately 6 weeks. Although these missions were usually 2 weeks long, on one occasion the system survived a drift of more than 16 months in crossing the Atlantic Ocean from Virginia to Spain.

INTRODUCTION

One of the major goals of NASA for the 1970's is the application of space technology and capabilities to societal needs and environmental problems. Langley Research Center (LaRC), as part of the program, has been working with state and other federal agencies in studying the use of satellites and free-drifting buoy systems for remote measurement of current, temperature, salinity, sea state, and other ocean and air-sea interface parameters.

The measurement of ocean circulation with free-drifting buoys has previously been limited by the high costs of ships tracking the buoys. With the recent availability of satellite tracking systems, the use of free-drifting buoy measurements to obtain circulation features has become more economical. The EOLE (God of the Wind) buoy system used in this investigation included a surface float (buoy) and large crossed plates suspended by a chain to couple the buoy to the water at the depth of interest. This configuration is an acceptable "current drogue" to most of the oceanographic community.

The buoy system was designed to use the existing French EOLE satellite and transponder system to measure water circulation and temperature in the Chesapeake Bight. This area of the Atlantic Ocean, extending from Delaware Bay to Cape Hatteras, has an important role in commerce, fishing, national defense, and recreation, and is a focal point in the search for new oil sources.

Data transmitted from the buoy to the EOLE satellite included four channels of temperature data and the buoy identification. Buoy position was determined by satellite measurement of range and range rate, plus the satellite orbital parameters determined from ground tracking station data. Data from three of the deployments are reported in references 1 and 2. Although these missions were usually 2-week drifts, on one occasion the buoy survived a drift of more than 16 months in crossing the Atlantic Ocean from Virginia to Spain.

This report presents engineering details for the EOLE buoy system. Also described are analytical results and experimental tests designed to insure proper and reliable operation of the system.

BUOY DESCRIPTION

The EOLE buoy system was composed of two units; a surface float-instrument housing (buoy) and a weighted cross-type drogue. The two units were linked by a 0.635 cm galvanized chain of variable length. The total mass of the system was 245 kg. The instrument housing contained the buoy instrumentation and power supplies. The drogue served to couple the instrument housing to the movements of subsurface currents. The chain length could be varied to allow coupling to currents from 5 to 30 meters below the surface. Table 1 is a list of buoy components with the engineering drawing number for each component. Figure 1 shows the major external dimensions of the buoy and drogue. Figure 2 shows an assembled EOLE buoy ready for deployment.

The instrument housing was divided into two compartments with the upper compartment containing the EOLE transponder and the lower compartment containing the power supply and other instrumentation. A flotation disk designed to maintain a low wind profile was atop the instrument housing. The disk was painted with fluorescent paint as a location aid for visual tracking and recovery. A small incandescent light was mounted on the flotation disk for navigational safety and ease in locating the buoy at night. The light flashed once every 3 seconds. A hoisting assembly and an EOLE antenna with housing were attached to the buoy through the flotation disk. Figure 3 shows the surface float-instrument housing with the major components labeled.

The drogue was four aluminum plates, with stiffeners, fastened to form a cross. Self-contained data recorders could be attached to the drogue to provide additional data. Lead ballast was attached to the drogue when less than 30 meters of chain were used to maintain proper buoy flotation. Figure 4 is a closeup of the drogue showing a recording thermograph attached to one of the plates.

Four temperature sensors were attached to the chain linking the instrument housing and drogue. Location of the sensors was variable.

Structural Design

The EOLE buoy structure was designed to incorporate inexpensive materials and fabrication methods in a structure that would withstand harsh environmental conditions. The buoy was designed to operate in a temperature range of -2°C to 35°C, and to withstand 20-25 foot seas (sea state 7) and handling loads of 1 to 2 g's. Relevant structural components and dimensions of the buoy are pointed out in figure 1.

Two methods were used to fabricate the instrument housing. The initial housings, shown in figure 5(a), were made of fiberglass blown onto a wooden mold. In use, the fiberglass housings could not withstand the pounding of the sea and the fiberglass cracked. This resulted in a change to stronger but less expensive housings. The later housings, shown in figure 5(b), were constructed from welded and machined aluminum plates. The housing was a rectangular box with one side open to allow placement and removal of the instrumentation. Interior dimensions of the housing were 0.584 m long, 0.490 m wide, and 0.452 m high. A 0.953 cm thick aluminum cover plate and 0.318 cm nominal diameter O-ring were used to seal the housing. The cover plate is shown in figure 6.

The flotation disk atop the instrument housing was a 91.440 cm diameter cylindrical body with a conical top. The cylinder was 6.350 cm high and the cone was 3.810 cm for a total height of 10.160 cm. The material was a 0.254 cm thick fiberglass shell bonded to a load-carrying structure of wood and phenolic material. The disk was filled with closed cell expandable foam. Four phenolic posts, protruding through the disk, supported the EOLE antenna assembly. Figure 7 is a photograph of the flotation disk opened to show the inner structure.

The hoisting assembly cradled the instrument housing and passed through the flotation disk. The lifting bail, used to deploy and retrieve the buoy, was attached to the top of the hoisting assembly. The lower part of the hoisting assembly was a standard 7.62 cm steel channel to which the drogue chain was attached. In figure 8, a photograph of the bottom of the instrument housing, the steel channel is shown with the chain attached. The chain was 0.635 cm proof coil galvanized steel with a working strength of 5560 newtons. A swivel was used to attach the chain to the drogue so that rotational motion of the drogue was not transmitted to the surface unit.

The drogue was constructed of 0.318 cm thick aluminum plates fastened in the form of a cross and braced with 2.54 cm aluminum angles. The maximum width and height of the drogue was 152.4 cm. Figure 9 shows the assembled drogue with the swivel and braces.

Instrumentation

Instrumentation on the EOLE buoy included an EOLE transponder and antenna, four temperature sensors, recovery beacons, and power supplies.

The transponder (shown in figure 10) was located in the upper compartment of the instrument housing and communicated with the EOLE satellite, transmitting buoy identification, calibration, and temperature data. The transponder had a length, width, and height, respectively, of 50.4 cm, 48.3 cm, and 22.1 cm. The transponder mass was 25 kg. The antenna (figure 11) was a sunk plane, cavity backed spiral type 36.0 cm in diameter and 26.0 cm high. The antenna mass was 5.58 kg.

Each temperature sensor was a standard thermistor with negative temperature coefficient, soldered to the end of an oceanographic cable. The thermistor and connection were encased in epoxy and a protective film of neoprene rubber. The cable connecting the sensor to the transponder was a 2-conductor, 18-gage wire with a neoprene covering. Each cable was secured to the chain independently for ease of replacement.

Figure 12 shows two temperature sensors attached to the chain. The small sensor on the left is the normal, uninsulated sensor and has a quick response to temperature changes. The large sensor has a thick layer of foam insulation to delay its response so it indicates only long-term temperature changes.

The buoy contained two radio transmitters (called recovery beacons) which broadcast on a frequency of 235 Mhz. The first beacon operated continuously while the second operated only on command from the satellite or if there was a power failure to the transponder. Operation of the second beacon was regulated by a solar switch, allowing daylight only operation to conserve battery power. The recovery beacon antennas were wire whip antennas (quarter-wave) soldered to a wire mesh ground plane embedded in the top of the flotation disk. The antennas were coated with silicone rubber for protection from the environment. The beacon antennas are visible in figure 3.

The lower compartment of the instrument housing contained an instrument deck, shown in figure 13, on which were mounted the remaining instrumentation and the power supplies. All power for the buoy system was provided by 1.5-volt dry-cell batteries, divided into four packs. Packs 1, 2, and 3 each contained 12 batteries and provided power, respectively, for the transponder, the continuous recovery beacon, and the daylight only beacon. Pack 4, with 5 batteries, powered two programers mounted on the deck. A checkout plug and two on-off plugs mounted near the front of the deck were accessible through a small port in the instrument housing cover plate. Figure 10 shows the instrument housing with all instrumentation in place.

Physical Properties

Presented in table 2 is a list of buoy components and some of the physical properties of the components used for buoyancy calculations. The dry mass and gravity force are the total mass and force for the component. The buoyant force is calculated for those parts of the system below the water line. The EOLE antenna was completely above water, therefore, it did not contribute to the buoyancy of the system. The flotation disk was partially submerged, therefore, the buoyant force represented only that portion below water. All other components (including batteries, instrument deck, and EOLE transponder) were within the instrument housing and were completely submerged. The instrument housing buoyant force was calculated on the volume of the housing excluding the cover plate which was calculated separately.

Measured values for mass, center of gravity (c.g.), and moments of inertia, Ixx, Iyy, and Izz for the X, Y, and Z axes, respectively, are presented in figure 14 for an aluminum buoy. Figure 15 presents the same values for a fiberglass buoy. By comparing the figures, it can be seen that the change in material produced very little change in the properties. The mass, c.g., and moments of inertia for the drag plates are presented in figure 16. All inertia measurements were taken in air by both the compound pendulum and bifilar methods. The measurements from both methods were in close agreement.

TEST PROGRAM

A series of tests were performed on the components of the EOLE buoy to insure the proper operation of the system. Descriptions of the tests are listed below.

Solar Cell Panel.- To determine any adverse effects of salt deposits on the operation of a solar cell panel, a mockup of the panel area, shown in figure 17, was built and ballasted to give proper flotation depth. The mockup was placed between posts in salt water and tied with enough slack in the lines to allow free movement with the tide and wave action. After 2 weeks the mockup was removed from the water and the solar cell electrical output was measured. The test showed there was not enough material deposited on the panel to significantly affect the solar cell operation.

Thermal Analysis.- The instrument housing was analyzed to determine its adequacy for maintaining temperature limits for the instrumentation. A free convection approach was used in the analysis (ref. 3). Instrument heat dissipations in the standby and transmission modes and varying water temperatures were considered in the calculations. The analysis showed the structural design, using either fiberglass or aluminum, would maintain the proper temperature limits inside the instrument housing in water having a temperature range greater than the range expected in the ocean study area.

Antennas.- Antenna tests were conducted in the LaRC Anechoic Chamber to determine optimum locations for the recovery beacon antennas. The most effective positions were 90° apart on a radius of 26.67 cm from the center of the EOLE antenna. Figure 18 shows the antennas set up in the Anechoic Chamber. The tests also showed distortion of the beacon antenna pattern from two causes. One, the lifting bail caused distortion when in a reclining position on the same side of the buoy as the beacon antennas. This was alleviated by installing retainers on the bail to confine movement to the opposite side of the buoy. The other cause, bolts holding the EOLE antenna assembly, was corrected by insulating the bolts from the EOLE antenna mounting ring.

Flotation Test.- One constraint in the design of the buoy was a low wind profile. The waterline for minimum freeboard of the buoy was located 2.54 cm above the bottom surface of the flotation disk. The buoy, originally designed for proper flotation with 10 meters of chain, needed additional buoyancy when the chain length was increased to 30 meters. To determine needed buoyancy, a buoy with no flotation aids and with weights attached to simulate the drogue and 30 meters of chain was placed in sea water. Blocks of foam were attached to the buoy until it floated at the predetermined water line. Durable flotation blocks were then designed and permanently attached to the buoy. With the flotation blocks, the buoy system maintained 222.42 newtons positive buoyance. Figure 19 shows the buoy rigged for the flotation test.

Warning Light.- A life expectancy test on a continuously-running prototype of the self-contained warning light showed the light could maintain a sufficient light level for 8 weeks. A warning light can be seen mounted on the buoy in figure 3. Figure 20 shows the components needed to construct a warning light and a completed light.

Ground Simulation.- EOLE satellite functions were simulated on the ground by use of a system of packaged units provided by Centre National d'Etudes Spatiales (CNES). The simulation system interrogated the EOLE transponder and relayed coded signals to the transponder to activate buoy subsystems. It also displayed oscillator frequencies which represented the sensor readings. The buoy could either be hard wired to the simulation system for interrogation, or it could be interrogated through the EOLE antenna. The simulation system was used to verify proper operation of all buoy systems before the buoy was deployed.

Prototype Drift Test.- As a field test of the structural and instrumentation systems, a working prototype of the first EOLE buoy was deployed in the Atlantic Ocean on September 26, 1972. While the buoy drifted free for 2 days, the buoy fluid dynamics were visually observed in situ. These observations disclosed that in calm seas the buoy had a freeboard of approximately 3 cm, while in high seas of 1.3 m or more, the buoy was completely submerged on several occasions. There was no indication of rotation of the surface unit or of any unstable pendulum motion. Figure 21 shows the buoy in the water during the test.

After recovery, an inspection of the buoy showed that all instrument components and all exterior structural fittings were still solidly mounted. There was no moisture inside the instrument housing. Buoy positions recorded onboard the vessel which deployed the buoy and positions from satellite data compared favorably. Buoy sensor temperature data relayed by satellite were comparable to data from a thermograph attached to the buoy. The drift test indicated that the EOLE buoy structural and instrumentation designs were adequate for the planned studies of the United States East Coast continental shelf waters.

CONCLUDING REMARKS

The free-drifting EOLE buoy system was designed to utilize the French EOLE satellite and transponder system to study water circulation patterns and temperatures on the continental shelf of the United States East Coast. The buoy system, designed and fabricated at Langley Research Center, has been constructed with both aluminum and fiberglass instrument housings (the fiberglass housing was found to be structurally inadequate). The EOLE satellite and transponder and other instrumentation provided buoy position and four channels of temperature data. An onboard power supply allows all systems to operate continuously for 6 weeks.

A drogue is attached to the buoy by a chain that can be varied in length from 5 meters to 30 meters. The drogue allows the buoy to be coupled with subsurface currents. Thermistors may be attached to the chain to obtain water temperatures to a depth of 30 meters. Recovery beacons are provided to aid in locating the buoy for visual tracking or recovery. All components, as well as the complete buoy system were tested to ensure satisfactory operation and structural integrity.

On deployments to date EOLE buoy systems have been through coastal storms, they have been washed up on beaches, and one buoy survived a 16-month drift across the Atlantic Ocean to Spain. Experience shows that the EOLE buoy system is capable of operating in and withstanding severe environmental conditions.

References

1. Usry, J. W.; and Wallace, John W.: Data Report of Six Free-Drifting Buoys Tracked by the EOLE Satellite in the Western North Atlantic Ocean in the Autumn of 1972. NASA TMX-72645. Undated.

2. Wallace, John W.; and Usry, J. W.: Data Report of Four Free-Drifting Buoys Tracked by the EOLE Satellite in the Western North Atlantic Ocean in the Winter of 1973. NASA TMX-72768. September 1975.

3. Garrett, L. B.; and Pitts, J. I.: A General Transient Heat-Transfer Computer Program for Thermally Thick Walls. NASA TMX-2058. August 1970.

Component	LRC Drawing Number
Instrument Housing	LX 154,872
Cover Plate, Instrument Housing	LX 154,873
Cover Plate, Access Port	LB 154,874
Battery & Instrument Deck	LX 154,876
Internal Structure, Flotation Disk	LX 154,877
Holding Bar	LC 154,878
Lifting Lug	LC 154,879
Holding Rod	LC 154,881
Assembly	LX 154,882
Stand-Off, Antenna	LB 154,884
Mounting Ring, Antenna	LC 154,885
Drag Plate Assembly	LC 154,890
Lead Ballast	LB 154,892
Mounting Plate, Sensor Plug	LB 154,893
Shackel, Drag Plate	LB 154,895
Insulator, Antenna	LB 154,896
Flotation Blocks	LC 154,897
Lifting Bridle	LC 154,898
Retainer, Lifting Bridle	LB 154,903
Flashing Warning Light	LE 155,096
Flotation Disk	LX 155,097
Support Legs	LC 155,098
Bulkhead Sensor Cable Connector Location	LC 155,110
Support Legs Location	LC 155,111
Antenna Mount Back-up Plate	LB 155,129
Warning Flashing Light Mounting Plate	LC 155,130

Table I.- List of buoy components

COMPONENT	LRC DWG. NUMBER	COMPOSITION	DRY MASS	GRAVITY FORCE	BUOYANT FORCE
Flotation Disk	LX154,877	Fiberglass, wood, & foam	15.8 Kg	154.3 N	+ 264.6 N
Instrument Housing	LX154,827 LX154,908	Fiberglass Aluminum	16.9 Kg 18.4 Kg	165.0 N 180.0 N	+ 1225.0 N + 1210.6 N
Large Cover Plate	LX154,873	Aluminum	6.6 Kg	64.7 N	- 40.2 N
Flotation Blocks	LC154,897	Fiberglass & foam	7.5 Kg	73.5 N	+ 307.7 N
Drogue	LC154,890	Aluminum	61.8 Kg	605.6 N	- 387.1 N
Battery & Instrument Deck (Fully Instrumented)	LX154,876	Fiberboard	48.4 Kg	474.3 N	------
EOLE Antenna	---------	Aluminum	5.7 Kg	55.9 N	------
EOLE Transponder	---------	--------	26.1 Kg	255.8 N	------
Chain	---------	Steel	1.0 Kg/M	9.8 N/M	8.8 N/M

Table II.- Componencs used in calculating buoyant force of EOLE Buoy

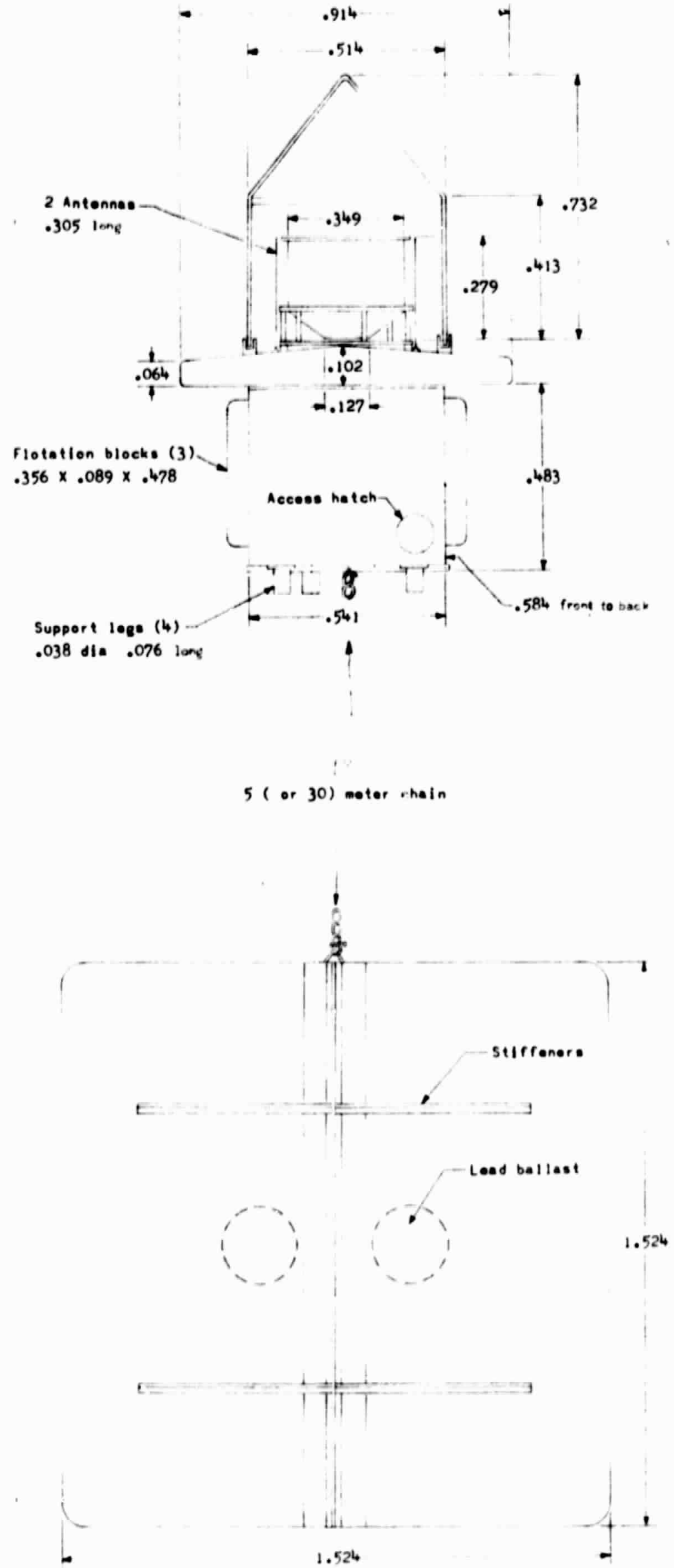


Figure 1.- Sketch of the Buoy System (all Dimensions in Meters)

Figure 2. - Photograph of EOLE Buoy System.

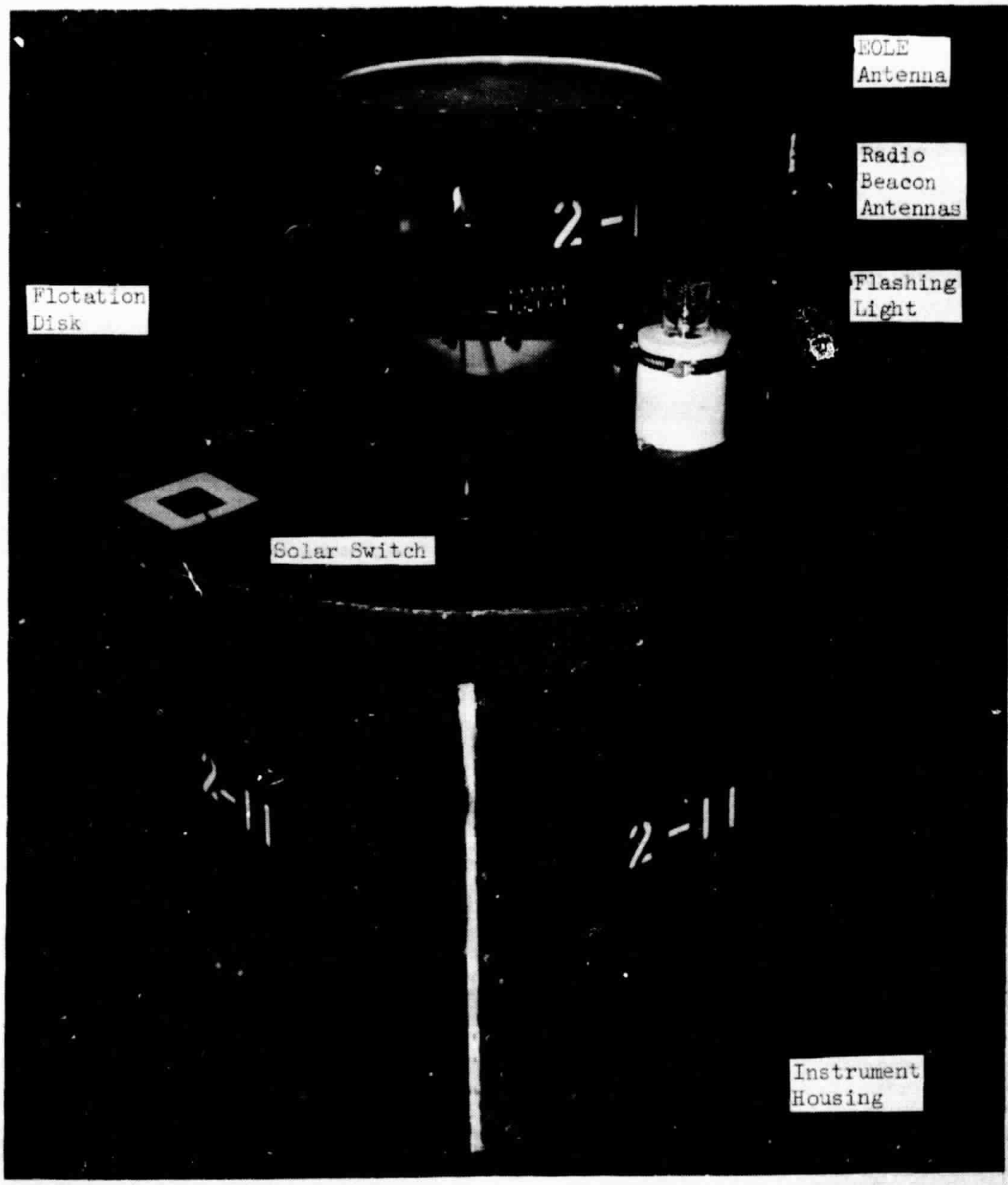


Figure 3. - Photograph of the Surface Float-Instrument Housing

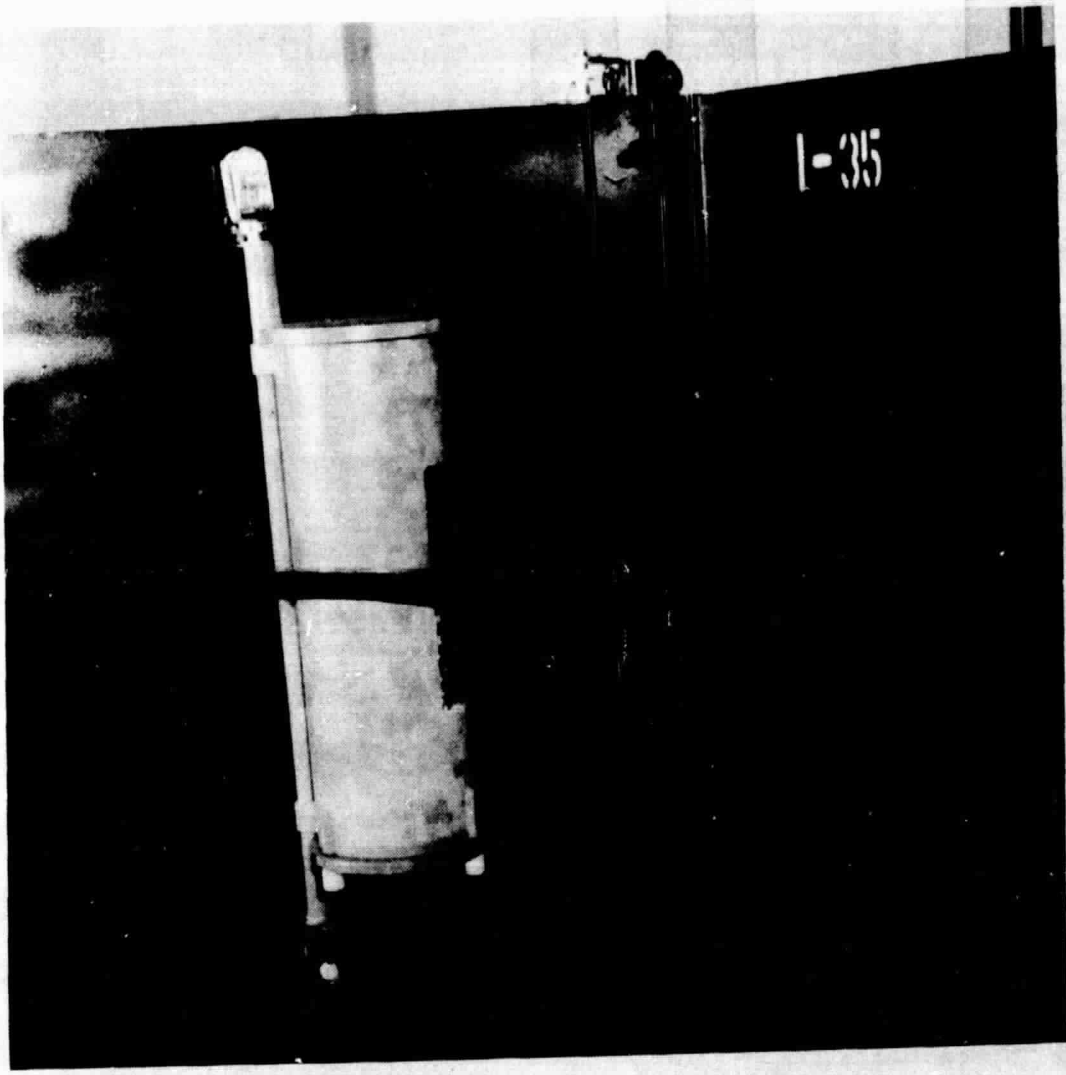
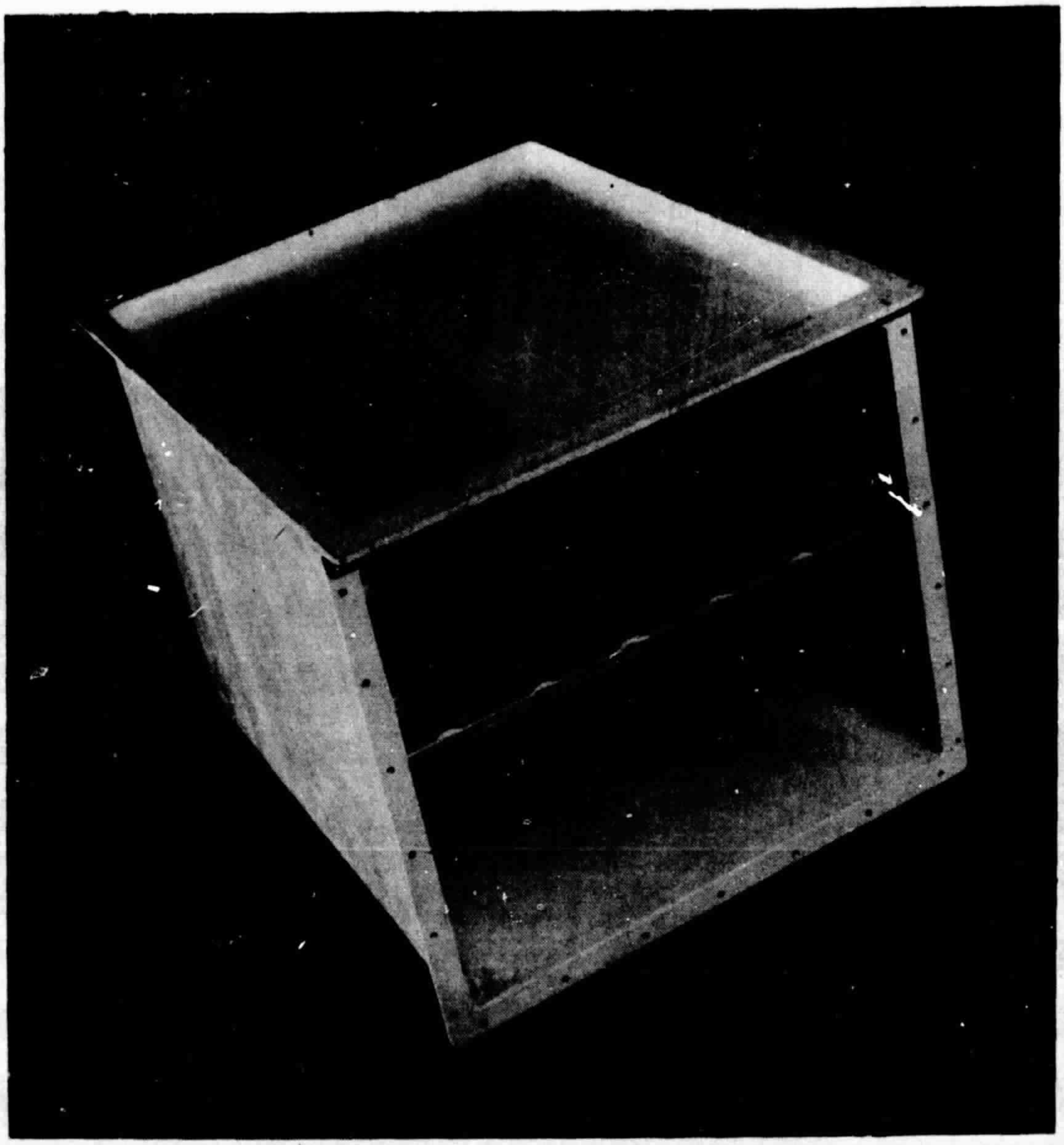
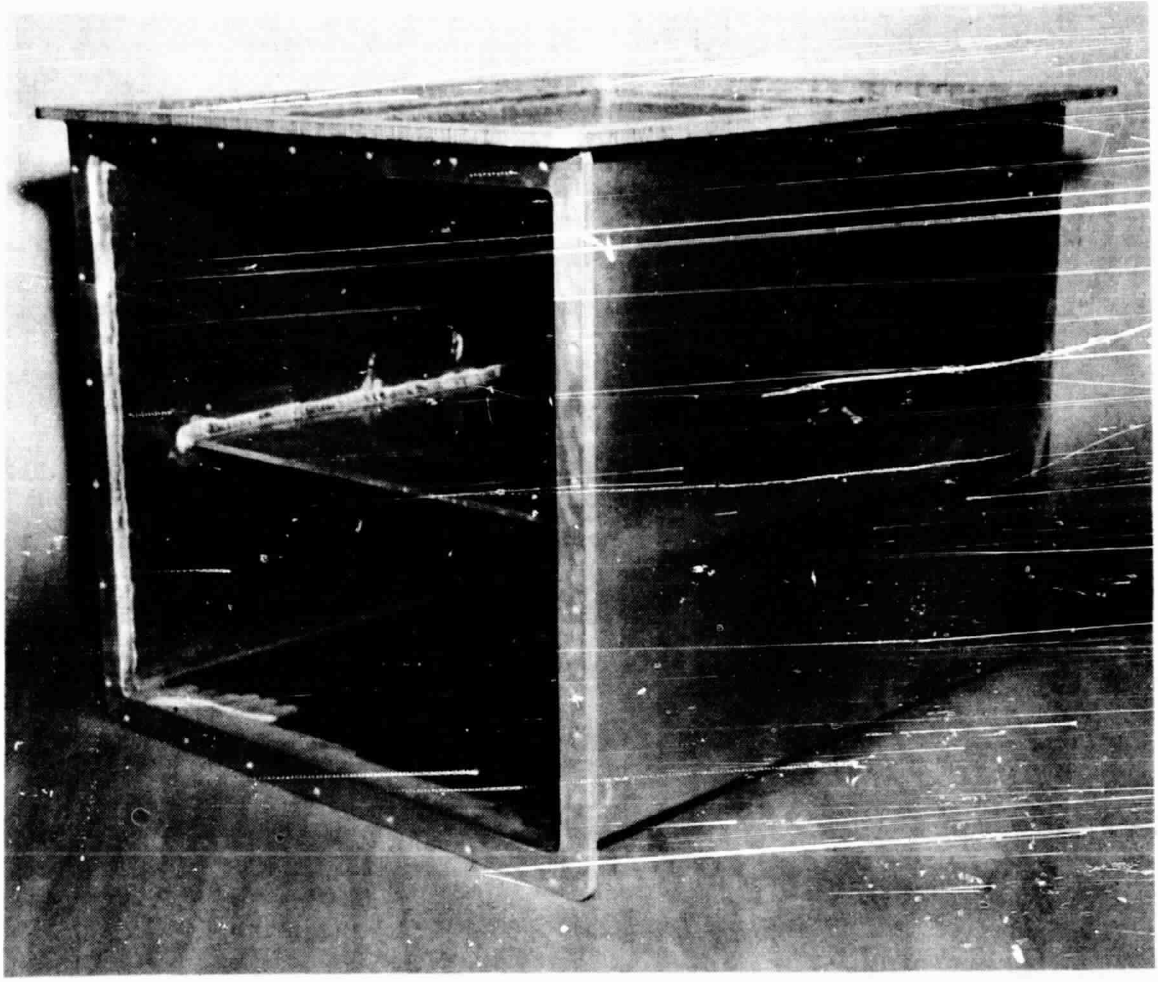


Figure 4. - Photograph of a Recording Thermograph Attached to one of the Drogue Plates.



(a) Fiberglass Housing

Figure 5. - Photographs of the Instrument Housings.



(b) Aluminum Housing

Figure 5. - Concluded.

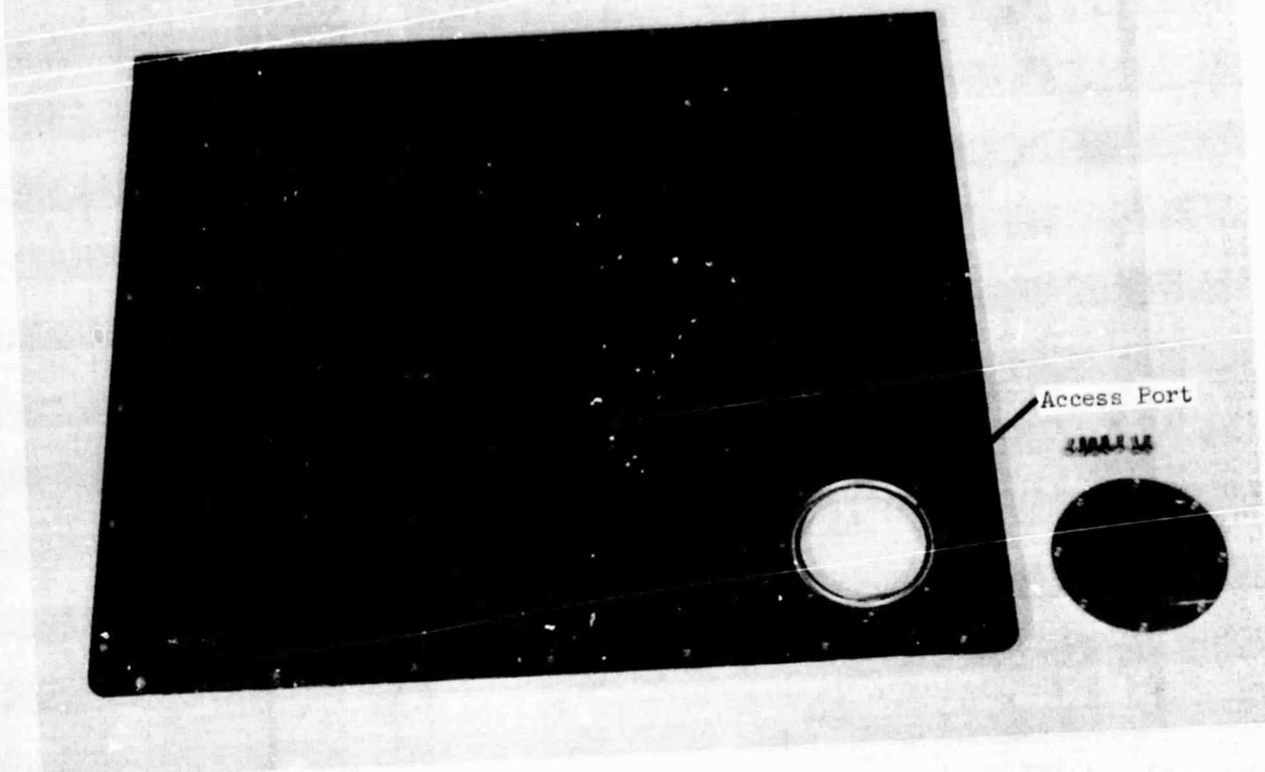


Figure 6. - Photograph of Instrument Housing Cover Plate.

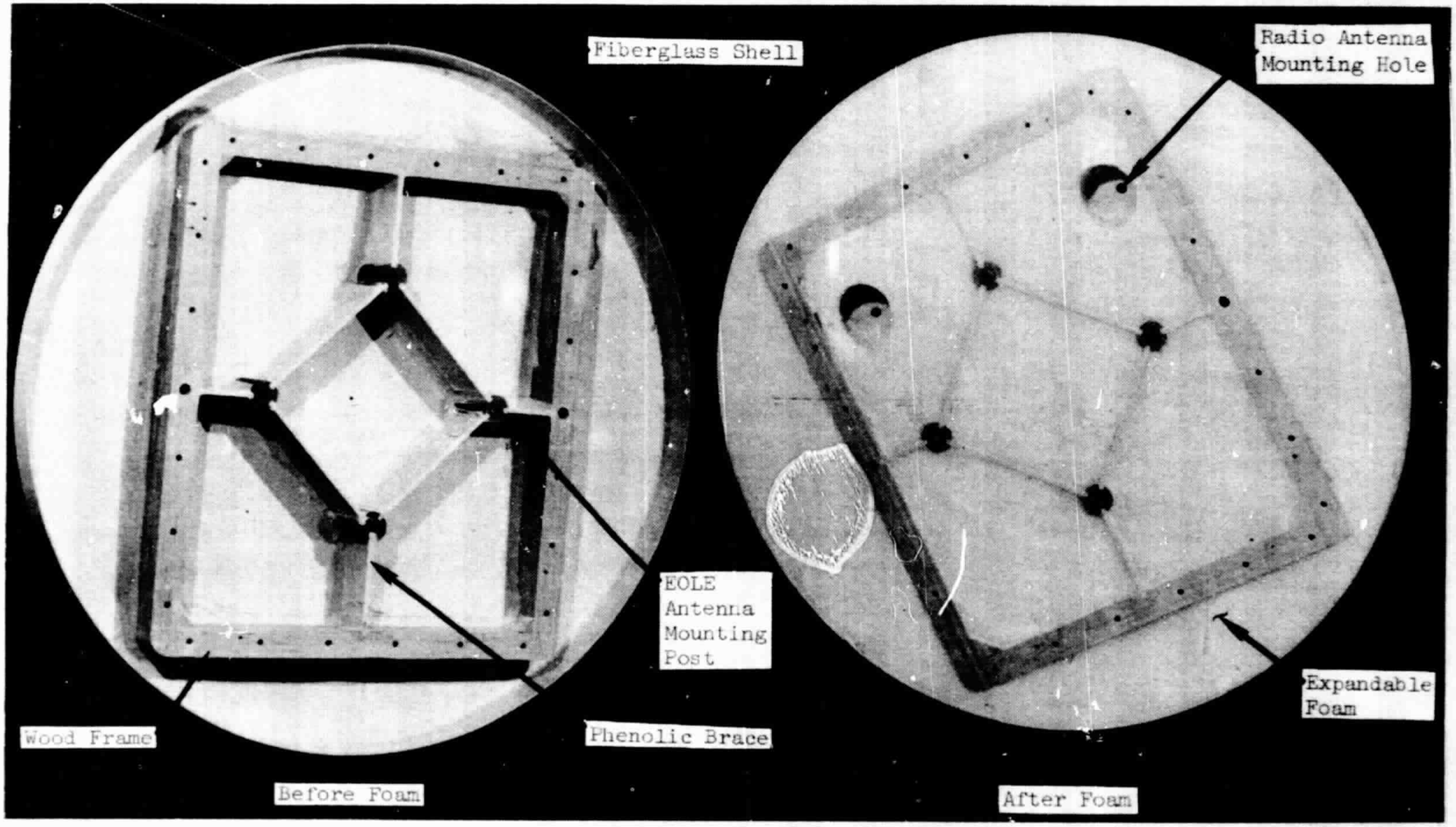


Figure 7. - Photograph of the Interior of the Flotation Disk.

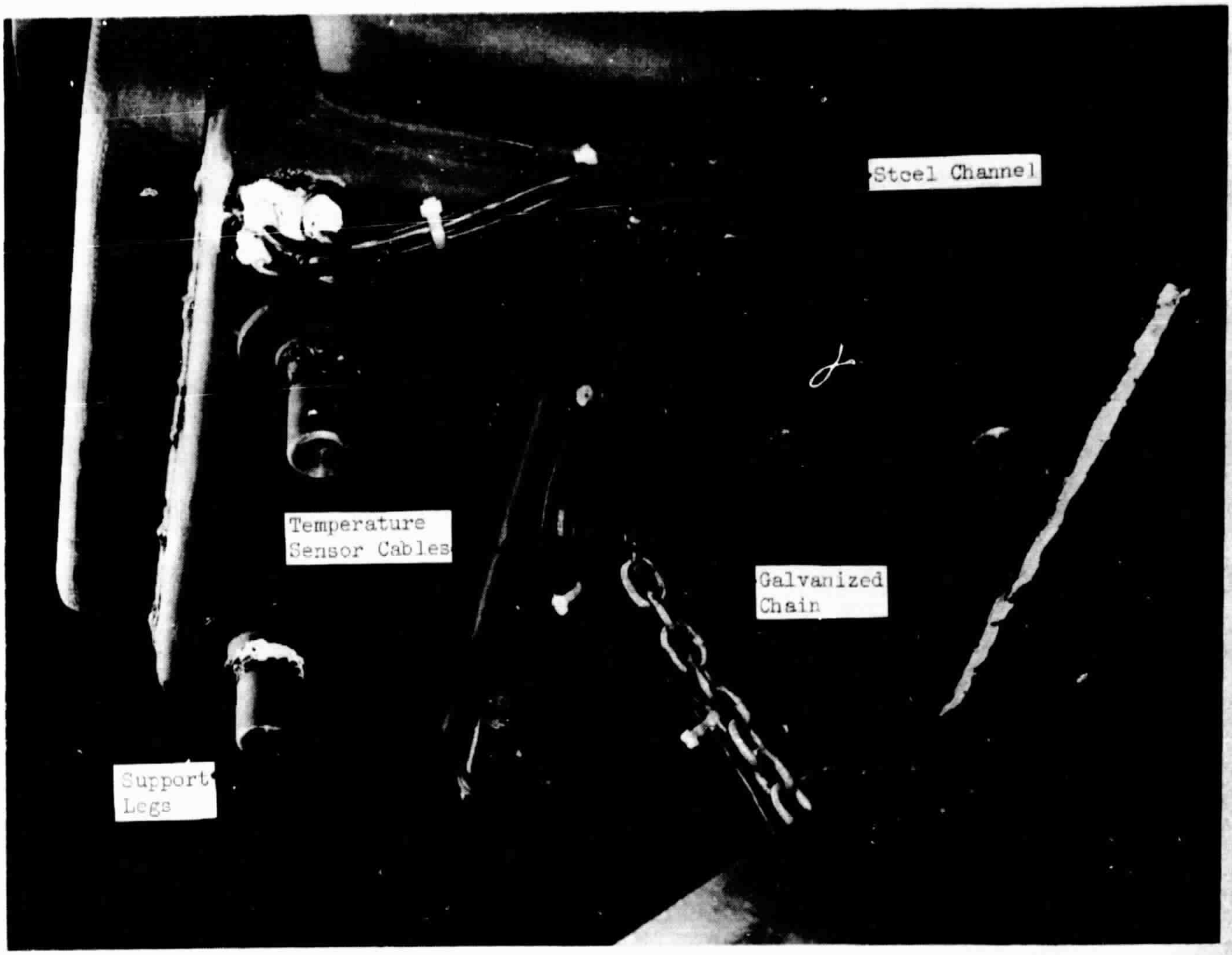


Figure 8. - Photograph of the Bottom of the Instrument Housing.

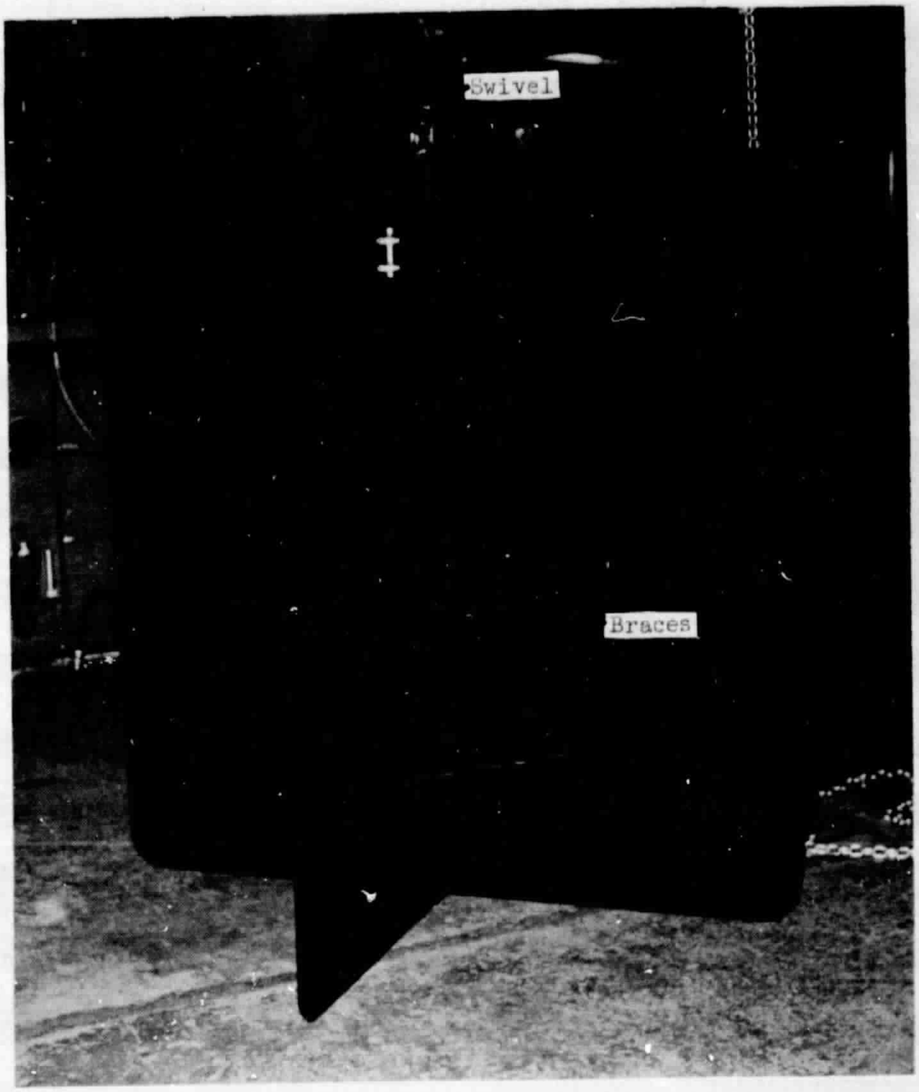


Figure 9. - Photograph of the Buoy Drogue.

Figure 10. - Photograph of the EOLE Antenna.

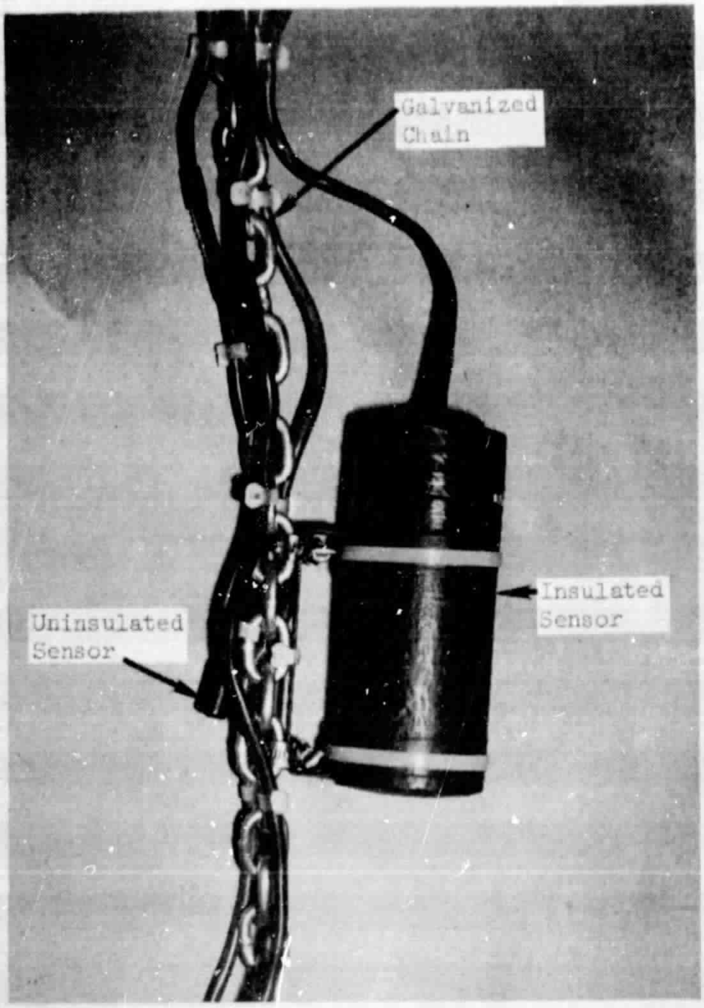


Figure 11. - Photograph of Temperature Sensors.

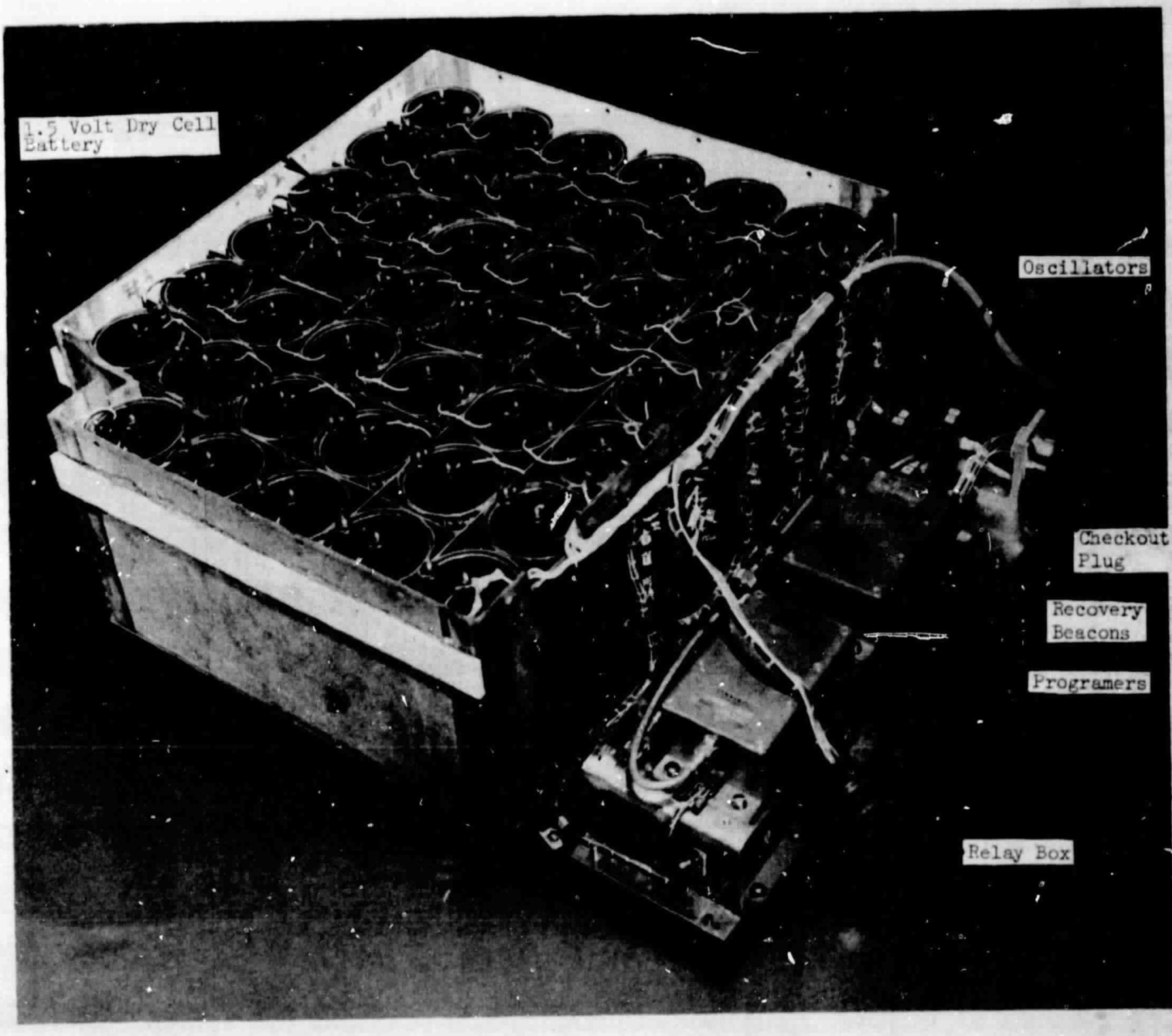


Figure 12. - Photograph of Instrumentation Deck.

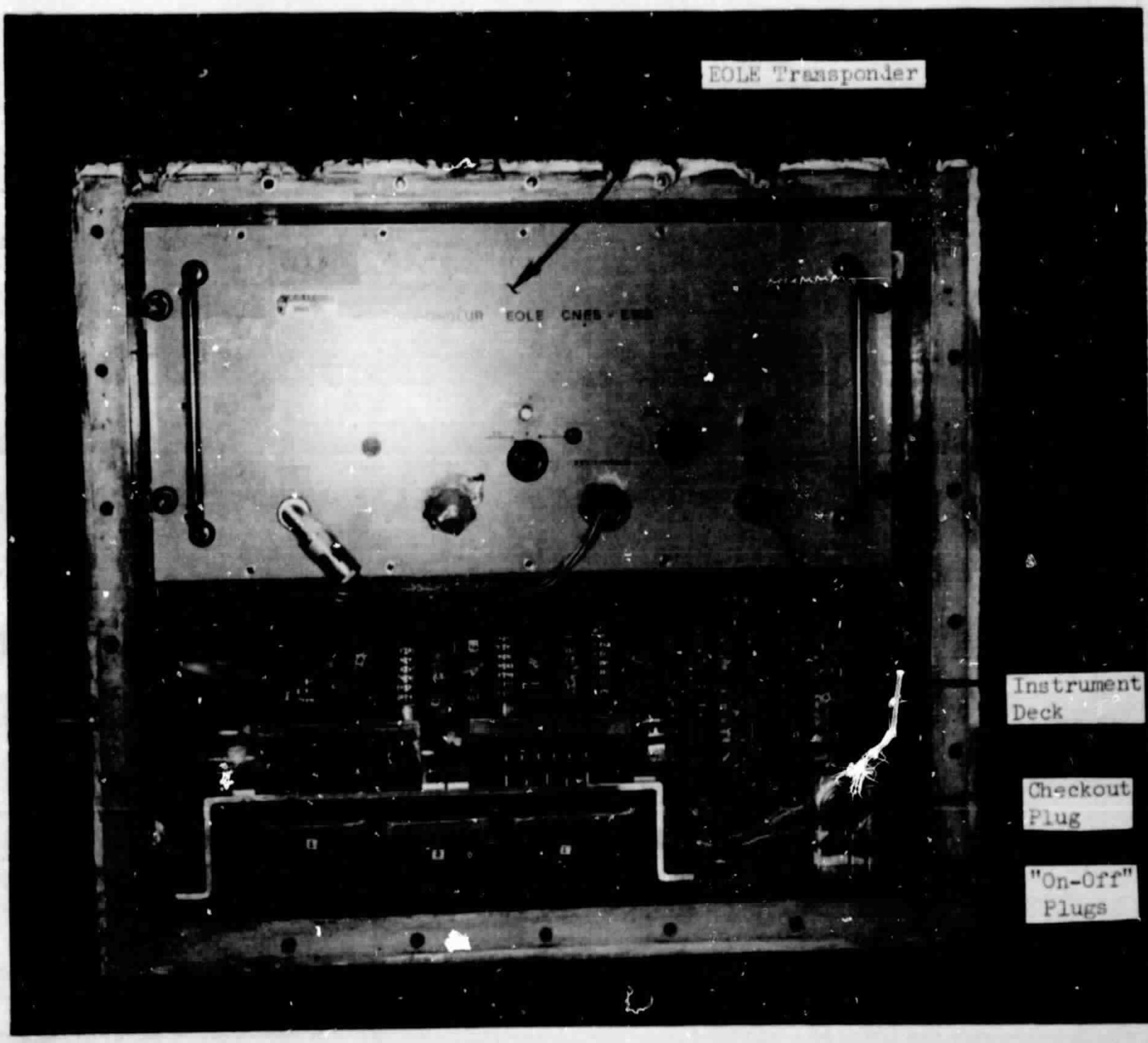
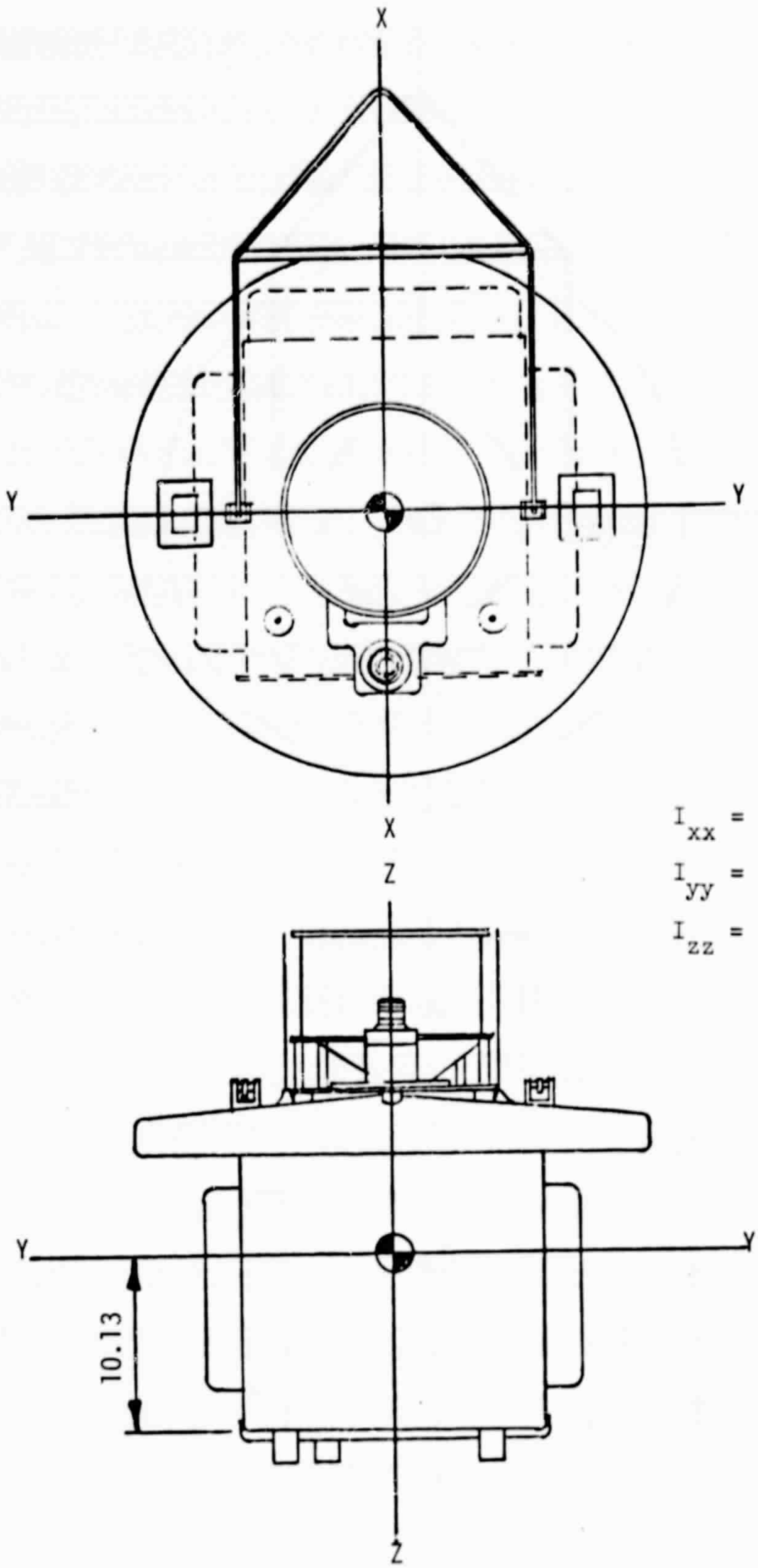


Figure 13. - Photograph of Instrument Housing with Instrumentation in Place.



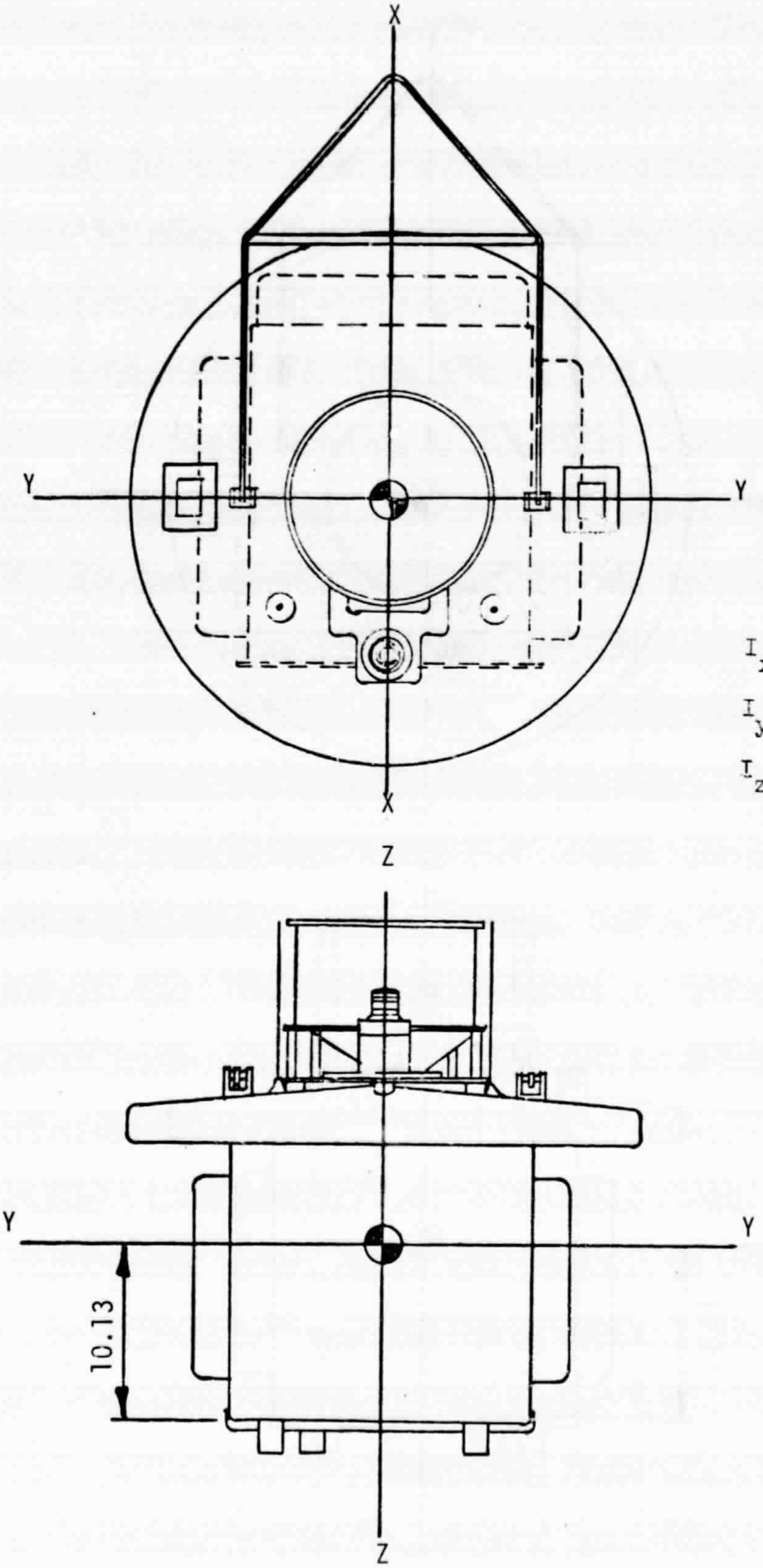
$I_{xx} = 12.42$ Kg - m^2

$I_{yy} = 11.48$ Kg - m^2

$I_{zz} = 10.26$ Kg - m^2

MASS = 156.36Kg

Figure 14.- Physical Properties for an Aluminum Instrument Housing.



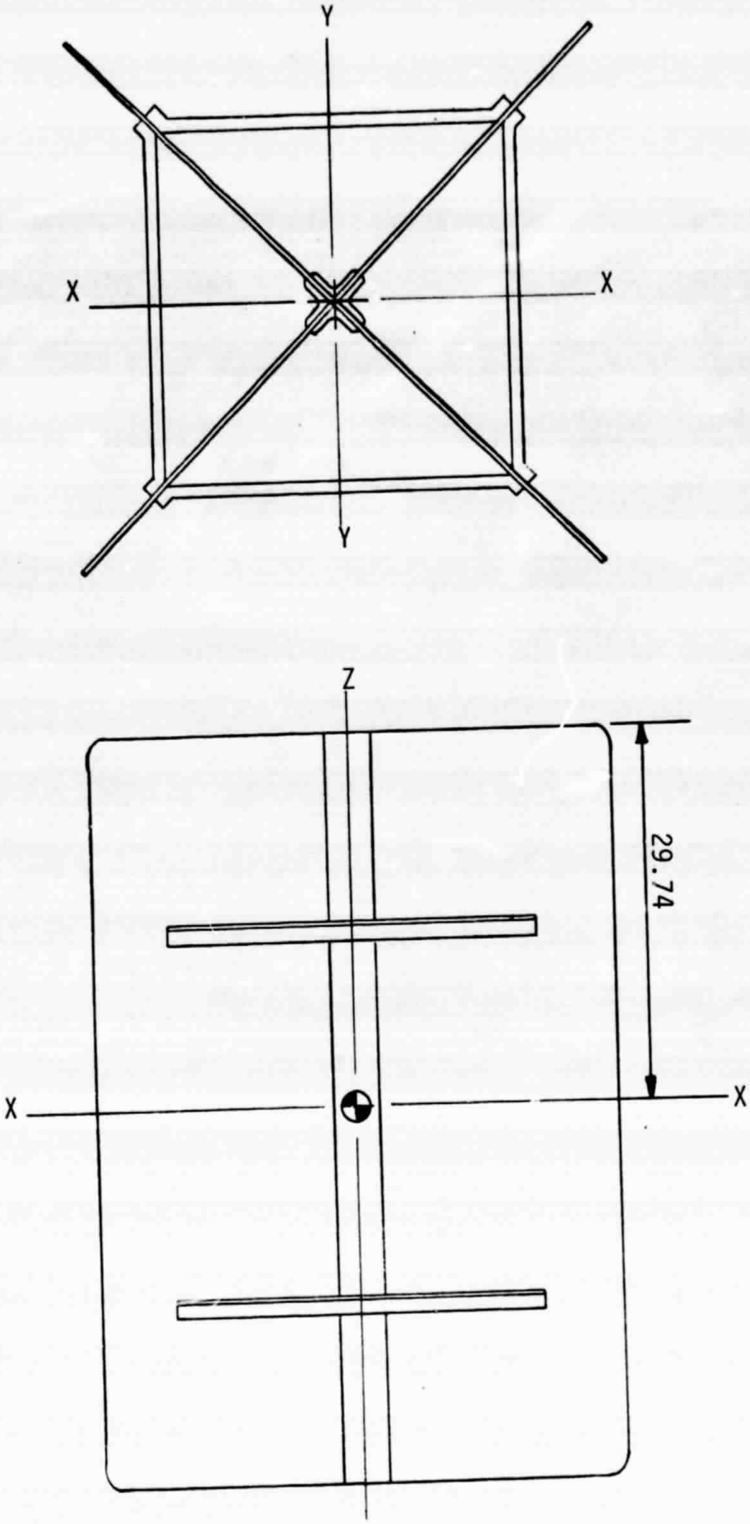
$I_{xx} = 12.23Kg - m^2$

$I_{yy} = 11.30Kg - m^2$

$I_{zz} = 10.10Kg - m^2$

MASS = 154.00Kg

Figure 15.- Physical Properties for a Fiberglass Instrument Housing.



$$I_{xx} = 13.54 \text{ Kg - m}^2$$
$$I_{yy} = 13.54 \text{ Kg - m}^2$$
$$I_{zz} = 9.28 \text{ Kg - m}^2$$

MASS = 61.363 Kg

Figure 16.- Physical Properties for the Drogue.

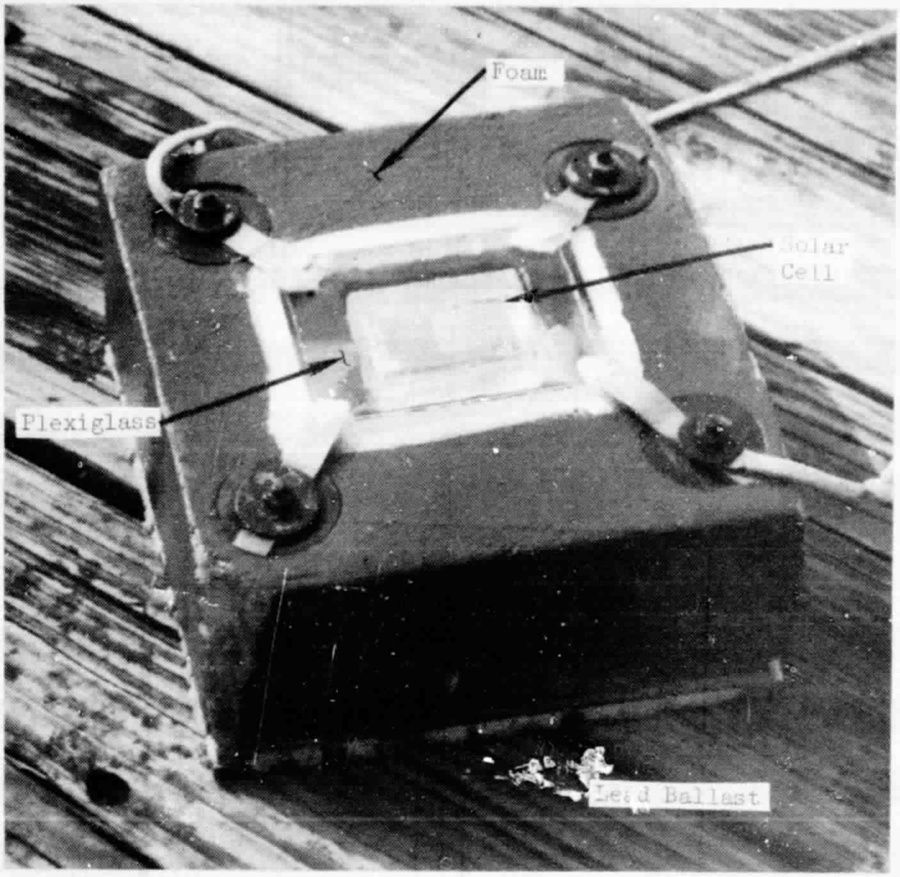


Figure 17. - Photograph of Solar Cell Panel Mock-up.

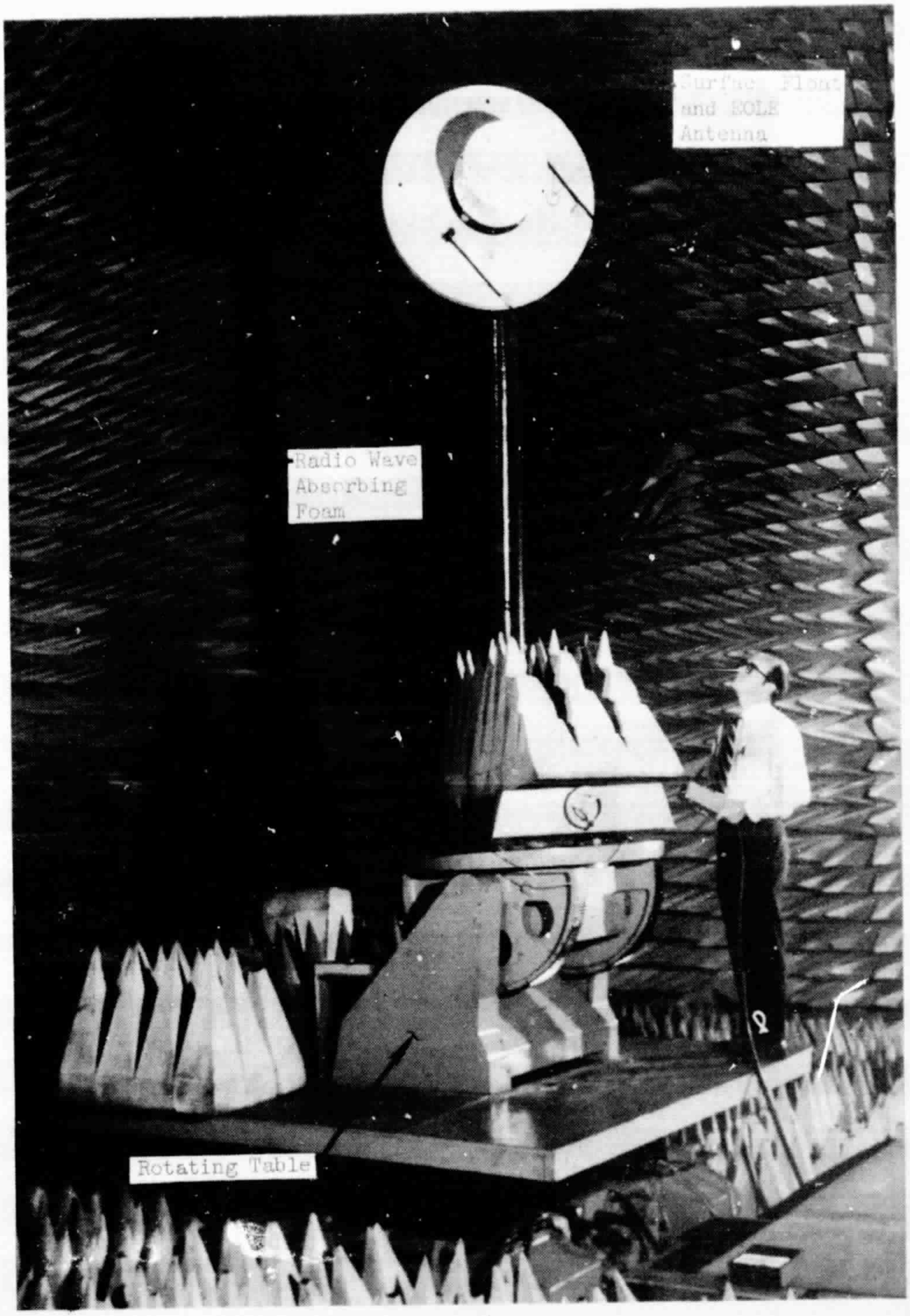


Figure 18. - Photograph of EOLE Antennas Mounted in the Anechoic Chamber for Testing.

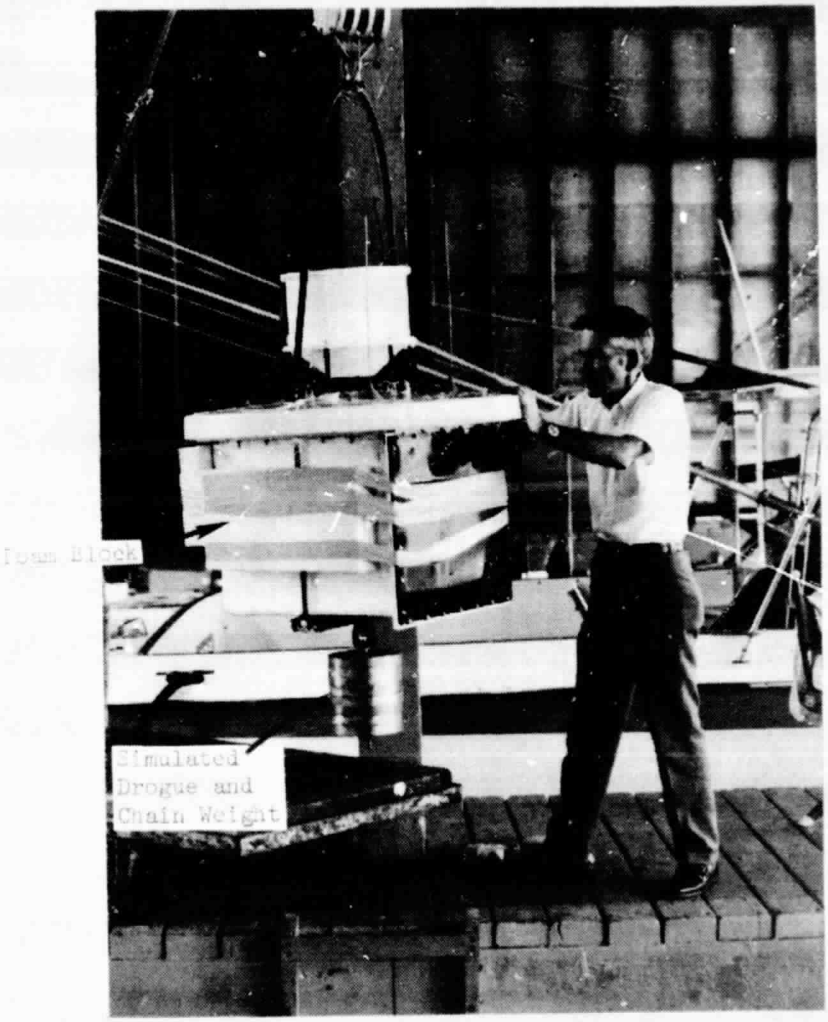


Figure 19. - Photograph of the Buoy Rigged for the Flotation Test.

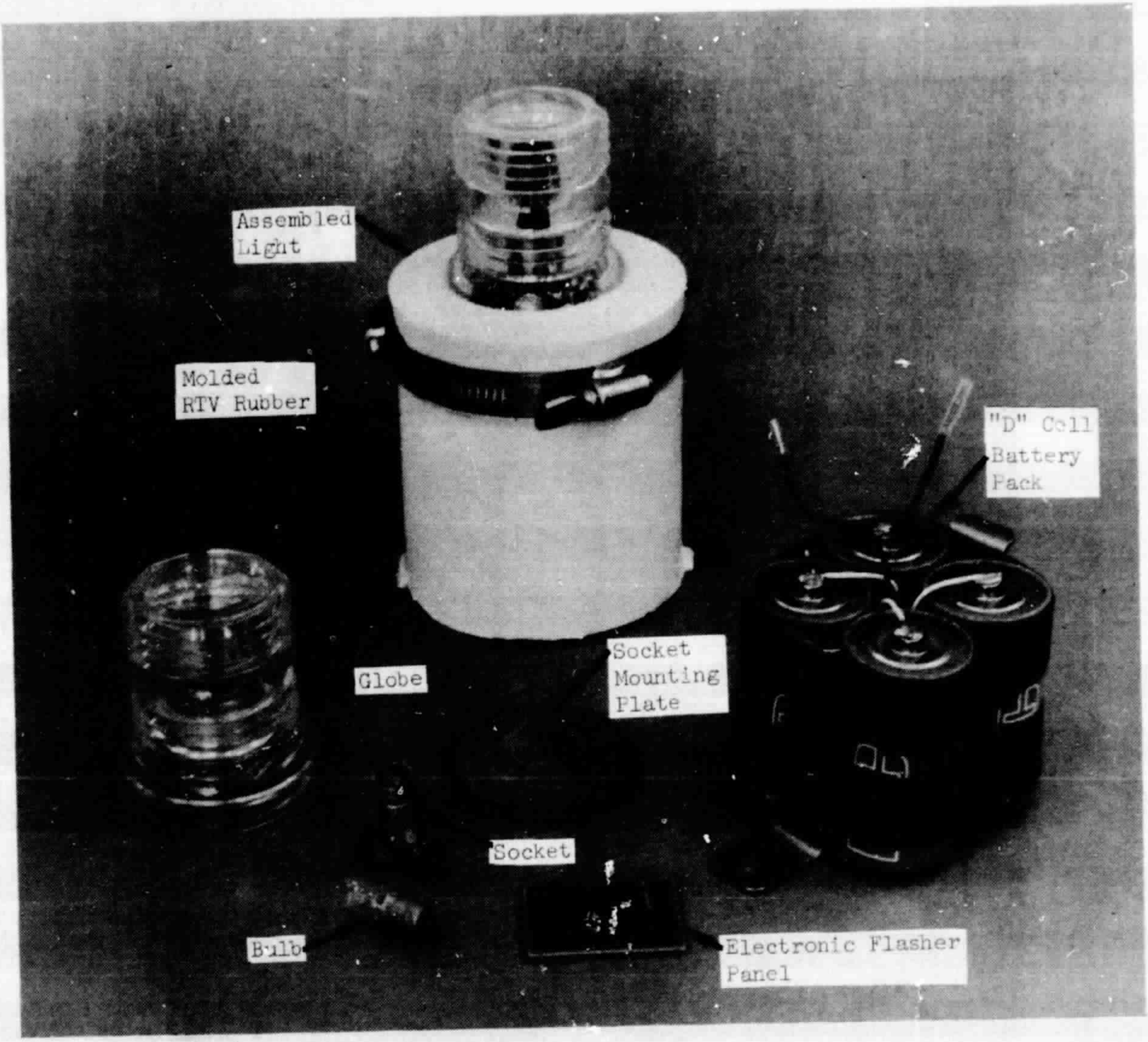


Figure 20. - Warning Light and Components.

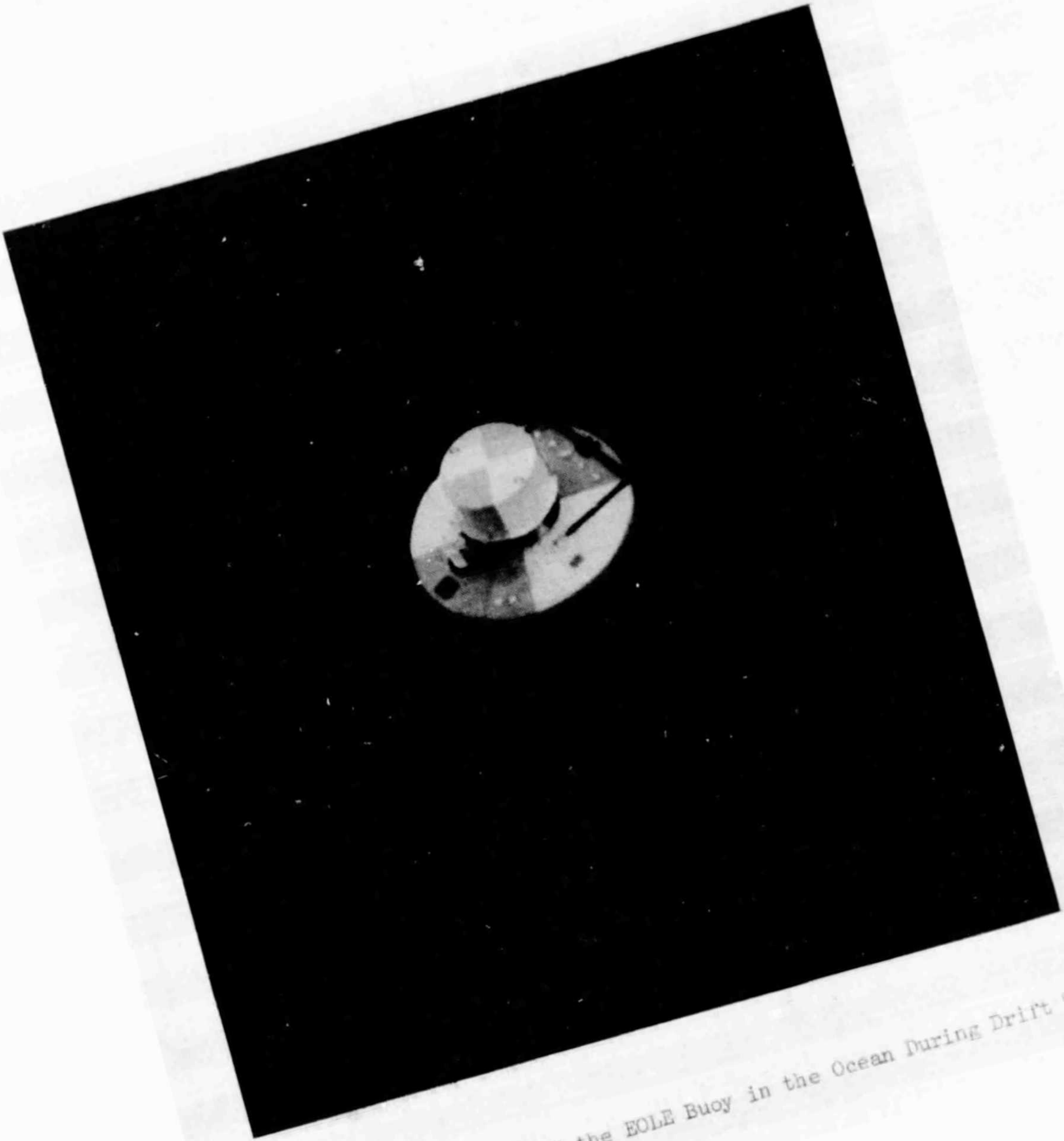


Figure 21. - Photograph of the EOLE Buoy in the Ocean During Drift Test.