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A BUOY SYSTEM FOR AIR-SEA INTERACTION STUDIES

BUOY DESIGN AND OPERATION

By
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ADMINISTRATIVE STATEMENT

The study and research resulting in this report on "A Buoy System for Air-Sea Interaction Studies, Buoy Design and Operation" was carried out at M.I.T. under the sponsorship of the Office of Naval Research and the National Science Foundation.

The study presents the description of a successful spar buoy used for research on air-sea interaction studies for an eight-month period and under extremes of weather. This buoy design is adaptable for a wide variety of at-sea oceanographic and ocean engineering research efforts. It is currently being used for the continuing air-sea interaction studies under ONR and NSF sponsorship and in conjunction with one of M.I.T.'s 1971-72 Sea Grant Projects entitled, "The Sea Environment in Massachusetts Bay and Adjacent Waters."

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Director

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ABSTRACT

Mechanical description of a spar buoy used for research on air-sea interaction. Dimensions: Overall length 114 ft; Submerged length 65 ft; and weight 18,000 lbs.

Buoy has been in operational use for eight months and performed satisfactorily.

TABLE OF CONTENTS

I. INTRODUCTION

This report describes a spar buoy built in 1969 and modified in 1970 on the basis of operational experience. The present design may be found useful by others. This consideration is the reason for the present report. The buoy was designed as an instrument platform for air-sea interaction measurements. Convenience of setting and of instrument replacement was an important design criterion, as was instrument exposure.

This report describes the mechanical design of the buoy, its performance and some operational experience with the buoy.

II. DESIGN CRITERIA

The design criteria were rather loosely stated, since it was designed by the user rather than another party. They were:

High pitch and roll stability.

A heave period in excess of 20 seconds.

Minimum yaw oscillations.

Horizontal towing to site and erection on site.

Ease of mooring attachment.

Stable orientation with respect to mean tidal current.

Provision for replacement of underwater instruments from buoy platform.

Ease of boarding.

Minimum draft in towed position.

Heavy weather survival capability.

Instrument placement for minimum interference generated by the buoy.

Instrument location from 10m below to 10m above the waterline.

The reason for requirements of minimum roll, pitch and heave motions was to permit measurements of turbulent fluxes, which include the measurement of vertical velocity of air and water. The frequencies of interest in vertical velocity fluctuations were all above 5×10^{-2} Hz; therefore the buoy should act as a low-pass filter, not responding to excitation above this frequency, while maintaining a minimum average angular displacement from the vertical.

These criteria all demand maximum metacentric height and decoupling from the surface wave field by minimum cross-section at the waterline. The next section describes the buoy, and the stability and response calculations are given in a later section.

III. BUOY DESCRIPTION

The buoy is shown assembled in Figure 1. Table I identifies the component parts. The buoy is a tubular spar buoy; the upper, surface penetrating tube has a diameter of 18", the lower tube has a diameter of 24". Two spheres, 4'10" diameter, are used to provide extra buoyancy and adequate metacentric height. A 50' long triangular radio tower, 14" on the side, is placed 8 ft away from the buoy centerline to serve as an instrument mount. Two 24" spheres at the bottom of the tower bracket provide buoyancy to compensate for the weight of the instrument mount.

A thirty foot radio tower serves as the buoy topmast. The tubes are divided into compartments. Starting from the bottom, there are two water ballast tanks, one 18'7" long and one 12'5" long. Then come the buoyancy tanks, and the top compartment is for batteries and instruments.

The damper plate folds as indicated to serve as a skeg when towing the buoy in its horizontal position.

The mooring bridle is placed approximately 26 ft from the bottom. This is at the center of lateral resistance as determined by tests in a three knot tidal current.

Figures 2 through 11 show design details and operational features of the buoy.

TABLE I

BUOY COMPONENTS

The numbering is as in Figure 1:

1. Meteorological tower, 30 ft high, 14" side triangular radio tower. Vertical legs 9/16" O.D. (Rohn Drawing E640101 SSV 320' Tower, Sect. IW)
2. Platform structure. Covered by 3/4" plywood deck lashed in place with 1/4" hemp line.
3. Support bracket for instrument tower (5) and for temporary horizontal instrument boom.
4. Support bracket for temporary instrument boom.

5. Instrument support, same construction as meteorological tower. Unobstructed face used as track for instrument carts. A separate set of 1/2" tracks is attached to outboard side of tower, to allow two carts on different tracks to pass each other.

6. Upper tube, 18" OD, .375" wall thickness. Bulkhead at B forms floor of instrument compartment. Lower compartment (B to C) contains compressed air at a pressure of 120 psi used to blow ballast tank.

7. Buoyancy spheres. Contain air at atmospheric pressure.

8. Lower tube. 24" OD, .375" wall. Three bulkheads at D, E and F. Upper compartment contains air. Lower part, (11), extending from E to F is flooded completely to erect the buoy. Section from D to E can be used for either ballast or buoyancy.

9. Balancing spheres, 24" dia, provide approximately 300 lbs of buoyancy each to compensate for weight of instrument tower and instruments.

10. Mooring bridle. 3 ft from face of tube at center of lateral resistance. It was installed to be adjustable in vertical and angular position and welded in place when center of lateral resistance and proper orientation to mean tidal current were determined.

11. Ballast tank: Valve H connects tank 11 with either the atmosphere or the compressed air compartment 6, to allow filling or blowing the ballast tank. Valve M, at the bottom of the ballast tank, is a quick shut-off valve which is closed for towing in the horizontal position.

12. Damping plate, 8 ft diameter; halves swing in to form towing skeg. Two ballast weights give buoy roll stability for towing.

13. Electronics and battery compartment: An additional waterproof box is placed between the I-beams of the tower support brackets, and is used for electronics for special instruments such as hot-film anemometers.

14. Air hose, for connecting ballast and air storage tanks.

IV. BALANCE AND DYNAMICS CALCULATIONS

Table II gives the weight, center of mass and buoyancy moments about the platform of the buoy. The table gives a total weight of the buoy, including ballast of 18,427 lbs, with the center of buoyancy 30 ft below the platform and the center of gravity 44 ft below the platform. The metacentric height is thus 14 feet. The incremental buoyancy is 108 lbs per foot submersion and the reserve buoyancy is 1,255 lbs.

The high static stability can be illustrated by calculating the buoy tilt due to a 100 lbs vertical load at the instrument tower, 10 ft from the buoy centerline, which gives a tilt of 0.23°.

The heave response of the buoy is strongly affected by the water mass dragged along by the damper plate, the instrument mast and the spheres. A crude estimate of the virtual mass of water accelerated by the buoy is the mass of a sphere of water of diameter equal to the diameter of the damping plate, and water masses of volume equal to the spheres.

This gives a virtual mass of 23,000 lbs. The total accelerated mass in heave is thus buoy mass plus virtual mass:

$$mg = 40,000 \text{ lbs.}$$

The period in heave T is:

$$T = 2\pi\sqrt{\frac{m}{K}}$$

where K is 108 lbs/ft. One find T = 21.3 sec. Crude experiments show the buoy to be at least critically damped in heave. Assuming the damping to be critical, one finds an amplitude response versus frequency to be:

$$A(\omega) = \frac{\text{Buoy Amplitude}}{\text{Sea Surface Amplitude}} = \frac{1}{1 + \left(\frac{\omega}{\omega_o}\right)^2} ,$$

which for waves of period 6 seconds gives A = .074.

The yaw response of the buoy is difficult to calculate, since it varies with the mean current. The excitation is due to the drag of the instrument tower in the orbital velocity field of the waves and to low frequency oscillations of the tidal current; the restoring force is supplied by the mooring force on the mooring bridle. Field experience indicated maximum yaw at high and low tide (minumum tidal current).

TABLE II

WEIGHTS AND BUOYANCY

No.	Item	Weight lbs	C G from Platform
1	Tower and Instruments	480	-15
2	Propane bottles, generator	50	- 1
3	Platform and assorted equipment	350	0
4	Batteries and electronics	300	2
5	Underwater track and supports	1,025	20
6	18" O.D. tubing	1,650	11.5
7	Upper sphere	650	20
8	Flanges and bulkheads	400	25
9	Lower sphere	650	27
10	24" Tubing	4,850	48.6
11	Damping plate	920	74
12	Supports	180	72
13	Ballast (Iron)	4,650	75
14	Water Ballast	2,272	66

Total Weight	18,427 lbs
Buoyancy	20,082 lbs
Center of Buoyancy	30 ft
Center of Gravity	44 ft
Metacentric height	14 ft
Reserve buoyancy	1,255 lbs.

V. MOORING SYSTEM

The mooring system consists of:

Two 8,000 lbs blocks of chain-filled concrete chained together.

Fifty feet if 1" chain.

Stainless steel swivel, rated at 19,000 lbs.

120 feet of six inch (circumference) braided nylon rope, with eyes with thimbles in both ends.

50 feet of double 1" dia wire rope shackled to the buoy mooring bridle.

The buoy is set in 102 ft water depth, mean low tide. Local tidal difference is less than five feet.

The mooring is thus slack, and since the nylon is heavier than water, the catenary sags down. The site has a rotaty (cum sole) tidal current with normal maximum velocity of 2.7 knots; the buoy rotates once per tidal period with no slack on the mooring line.

VI. INSTRUMENT MOUNTS

The carts used for instrument mounts are worth describing, since they proved convenient and useful. Fig. 12 shows a cart on the tracks. The carts were made from perforated steel angle stock "Dexion", with stainless steel bolts and axles and "Delrin" plastic wheels. One set of wheels was spring mounted, so the cart was held on the tracks by the spring force. The cart was capable of going over a 3/8" rope tied around the track without jumping off. The tracks were tapered at the upper end, so that the cart could be put on and stepped on with one foot to force the cart onto the parallel track section. The carts were connected together as a train using 1 1/2" dia thick wall plastic tubing (polypropylene). The instruments were mounted on the carts ashore, tested on a dummy track lashed to a dock, and then taken out to the buoy. This saved us from having to use divers for mounting and removing underwater instruments. A string of five carts was indeed heavy to pull up by hand, but a simple rope tackle made it relatively easy for one man.

Fig. 14 shows current meters mounted on a cart and Fig.13 shows a cart with instruments at the water surface.

VII. INSTRUMENT INTERFERENCE

The main interference is the distortion of the air and water velocity fields by the buoy at the current meter and anemometer locations. This will be estimated considering the instrument mast as an equivalent four inch cylinder, for which the velocity distortion will vary with distance from the center as

$$\frac{\Delta U}{U} = \left(\frac{4}{r}\right)^2$$

With an 24" arm for the current meter, one obtains

$$\frac{\Delta U}{U} = .028$$

For the anemometers,which have 30" arms, one obtains

$$\frac{\Delta U}{U} = .0178$$

The buoyancy spheres are ten feet away from the nearest current meter, the interference field decays as the inverse cube of the distance measured in radii of the sphere. The velocity field distortion is thus:

$$\frac{\Delta U}{U} = \left(\frac{28}{120}\right)^3 = .0126$$

The 24" tubing is ten feet away from the current meters; the interference decays as the inverse square, so one obtains:

$$\frac{\Delta U}{U} = \left(\frac{12}{120}\right)^2 = .01$$

The interference from the cart on the current meter may be more serious than these effects. An estimate is that the interference is equivalent to the effect of a three inch cylinder eighteen inches away, which gives:

$$\frac{\Delta U}{U} = \left(\frac{1}{6}\right)^2 = .028$$

These interference velocities are the maximum, which occur at right angles to the mean current. The probes were usually placed at thirty degrees forward of this direction. The interference calculated on the basis of potential flow varies as cos 2 θ, Θ being the angle measured from the cross-stream direction. This gives $\cos 2\theta = \cos 60° = .50$. This choice of direction halves the interference estimates quoted.

These estimates are necessarily crude, and especially bad where there is a high vertical velocity shear, such as immediately above the water surface.

VIII. OPERATIONAL EXPERIENCE

The buoy was set in place in July 1970 and has performed well in all types of weather. The maximum wind at the site was 70 knots, estimated maximum wave height was 25 ft. All instruments and electronics survived intact, including the thermoelectric power generator, five cup anemometers, five current meters, two wave gauges and four thermistor probes. The buoy was taken in during February 1971.

IX. CONCLUSIONS

The buoy has proved satisfactory as an instrument platform for air-sea interaction research.

XI. ACKNOWLEDGEMENT

The buoy was built, modified and set in place by Daniel W. Clark, Inc., Marine Contractor. We wish to acknowledge the many suggestions and unstinting willingness to expedite operations on the part of Mr. Dan Clark. This contributed significantly to the success of the project.

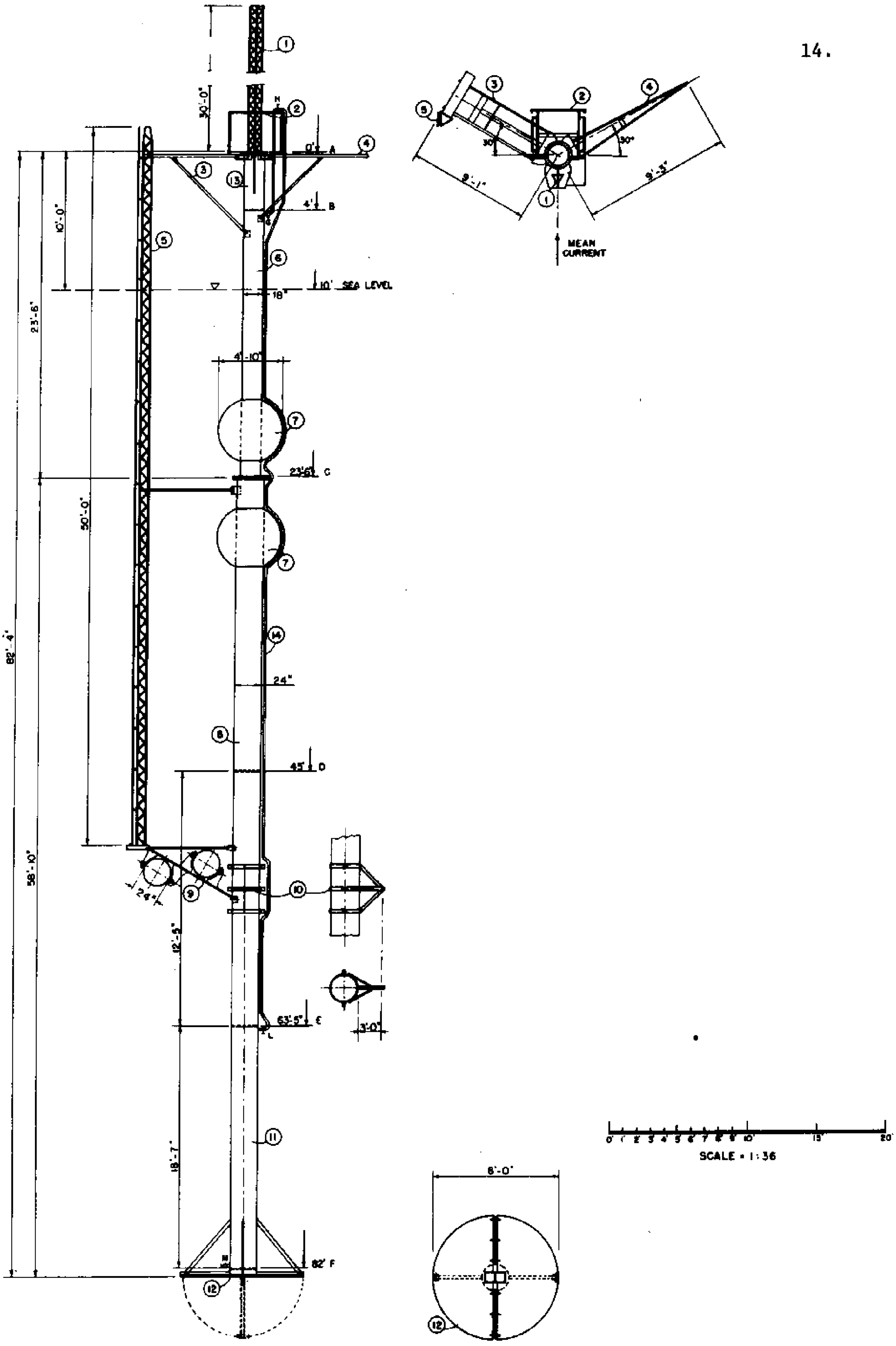

FIG. 1: Spar Buoy

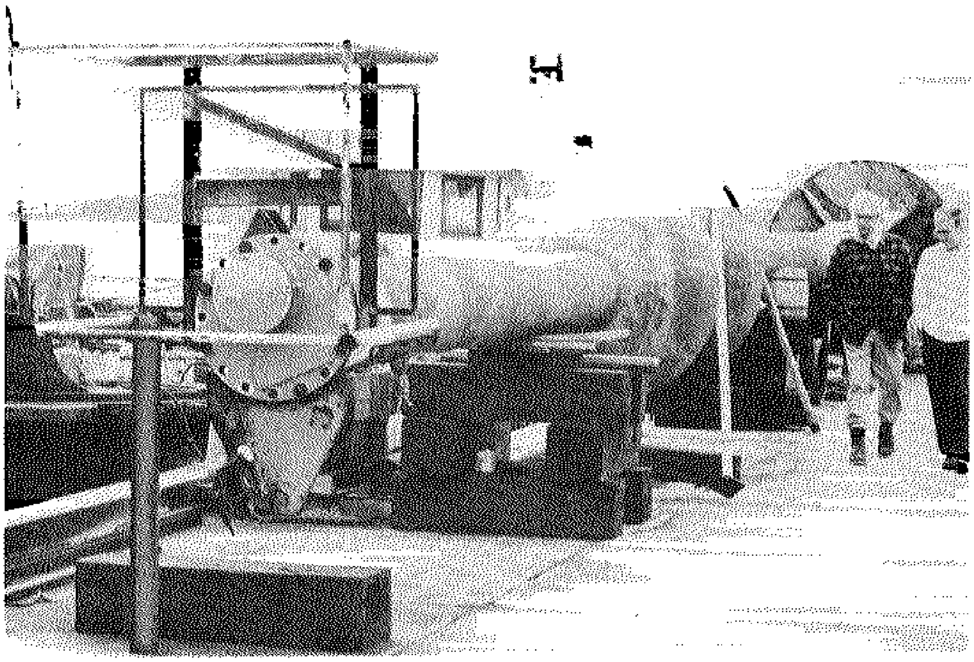

FIG. 2: Buoy under construction. The laterally extending arms and the two radio towers have not yet been mounted.

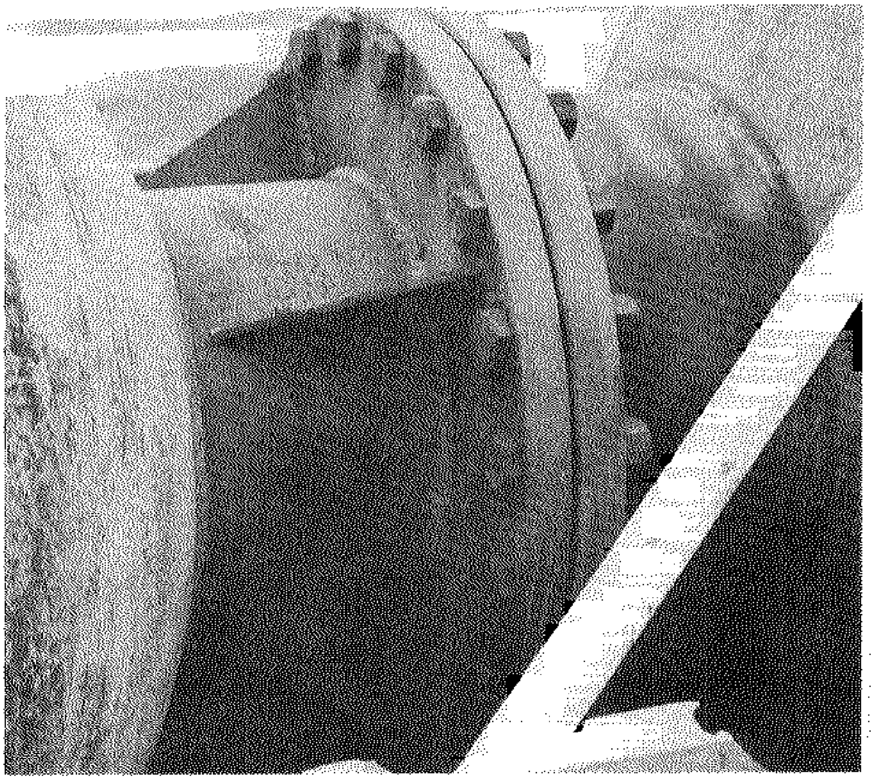

FIG. 3: The flange joining the two tubes. On the two sides part of the two spheres are seen.

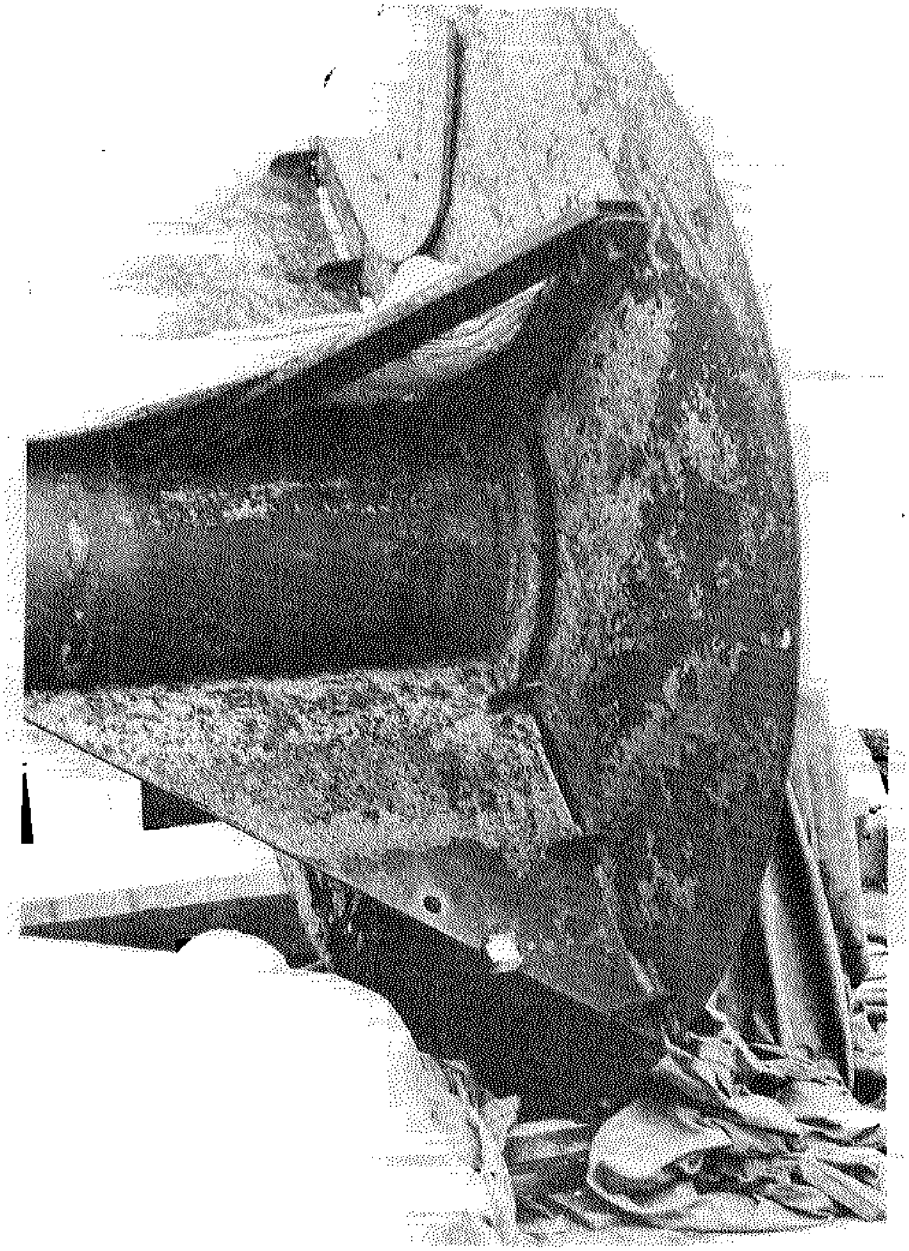

FIG. 4: Damping plate at the bottom of the buoy, note ballast near top.

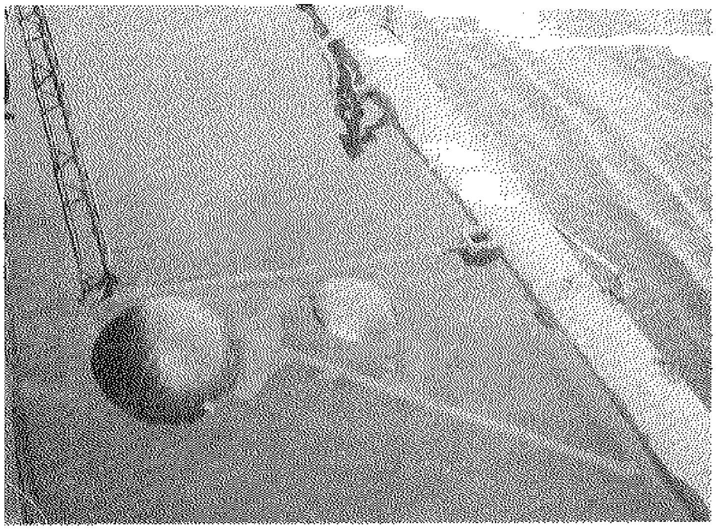

FIG. 5: Base of instrument track, small buoyancy spheres to compensate for track weight.

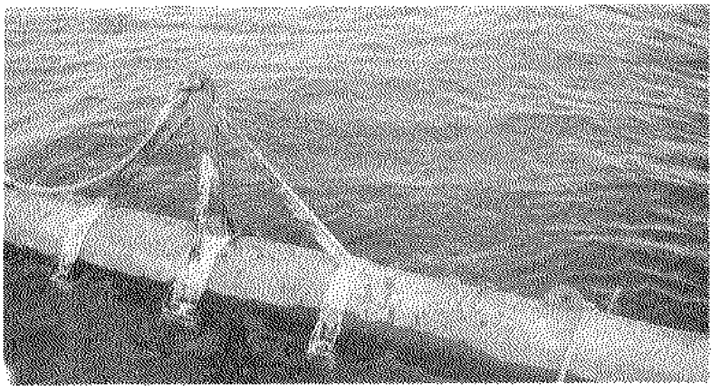

FIG. 6: Mooring bridle bracket.

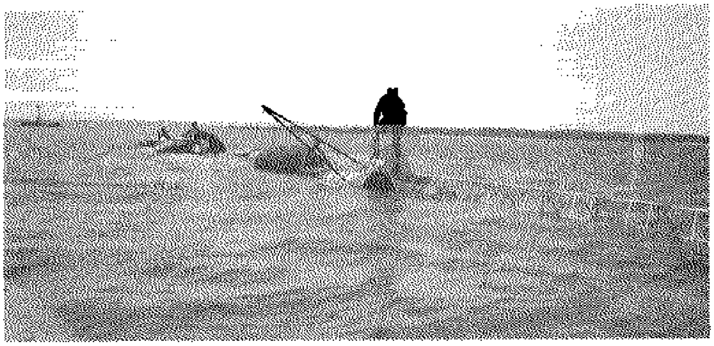

FIG. 7: Buoy in horizontal position.

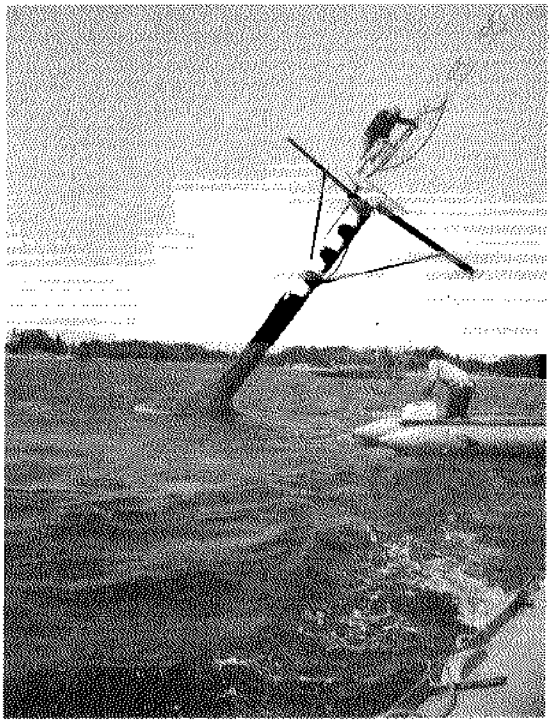

FIG. 8: Erection and stability tests.

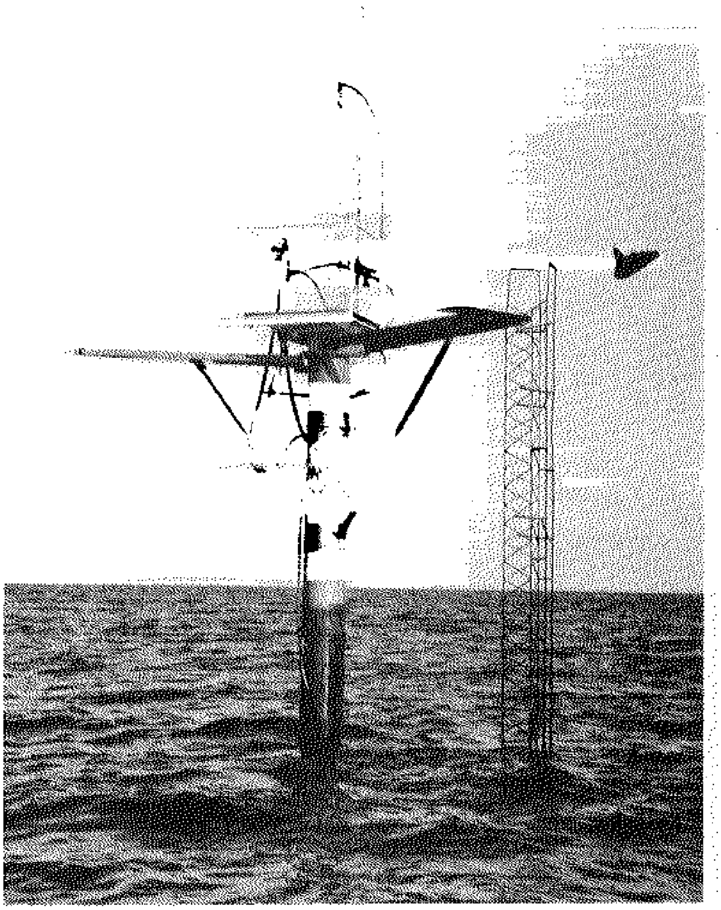

FIG. 9: Buoy on site before instrument installation, showing instrument track; note tapered top of tracks.

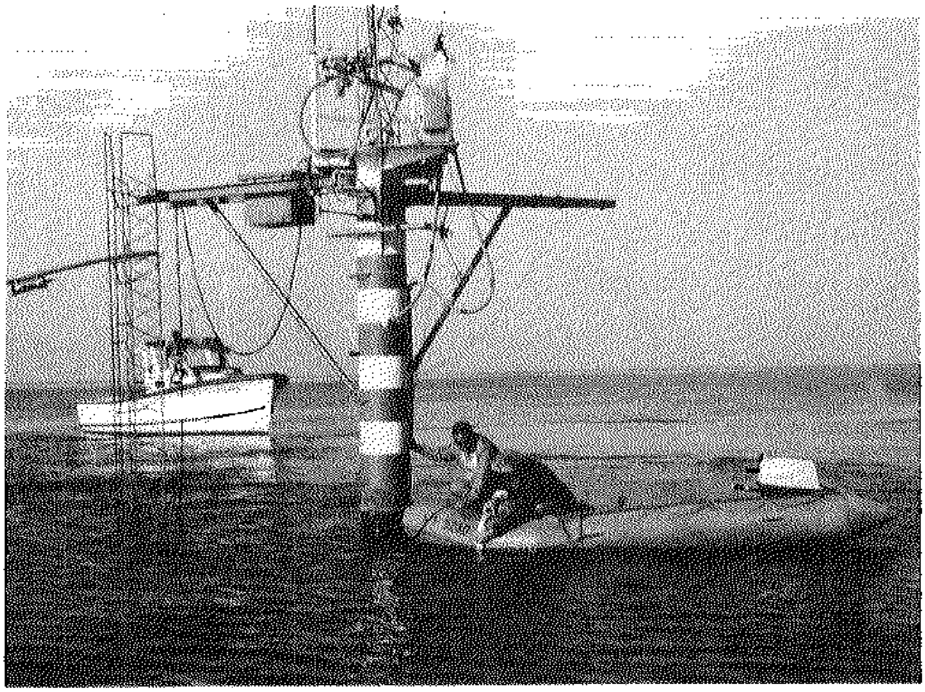

FIG. 10: Anchor line replacement. Note wave gauge on left; hot film anemometer box in platform outrigger; thermoelectric generator on right side of platform.

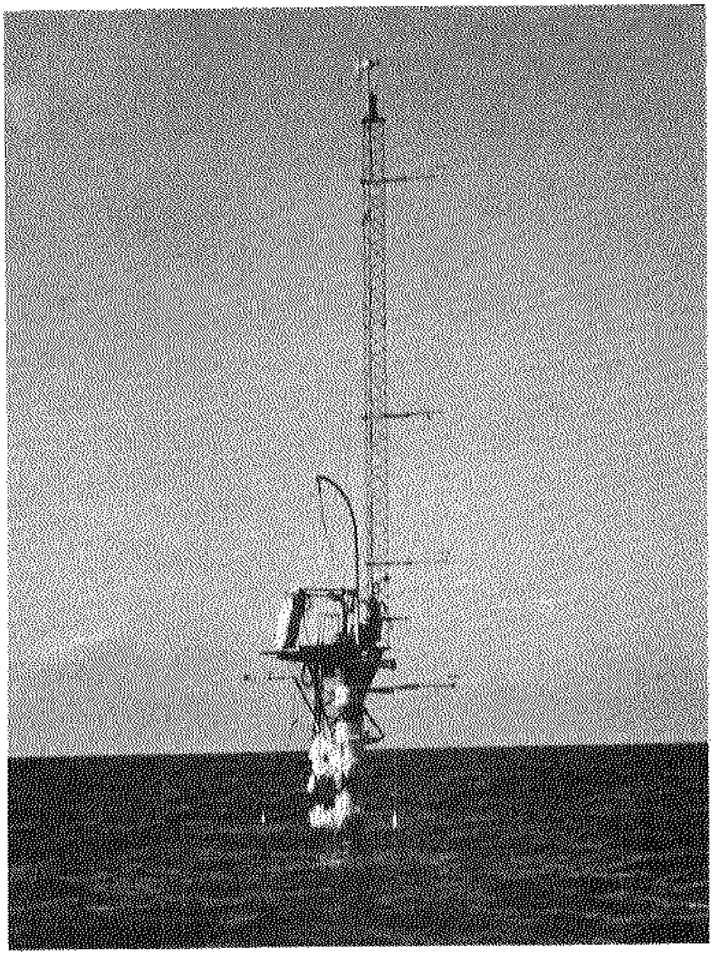

FIG. 11: Buoy on site, October 1970.

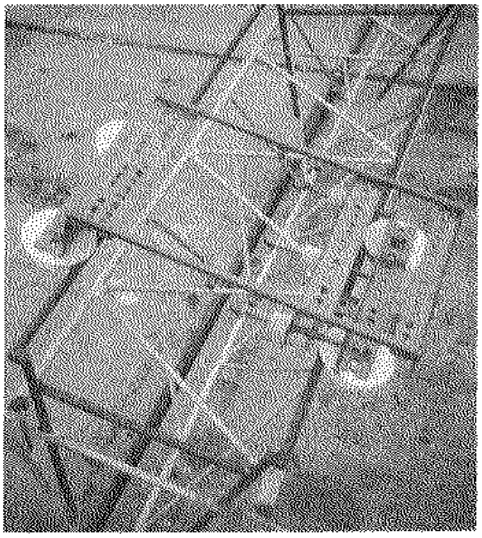

FIG. 12: Instrument cart being tried on track.

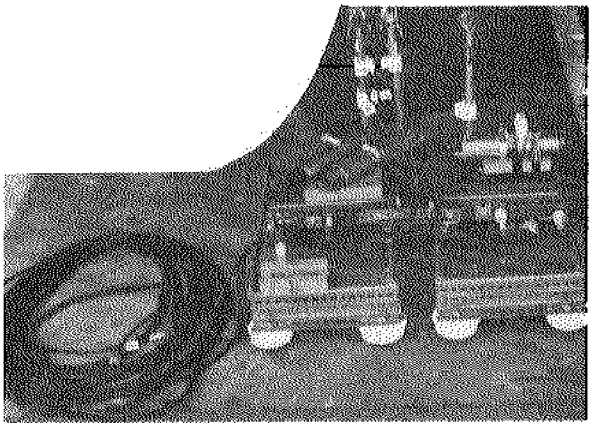

FIG. 13: Current meter and thermistors on carts.

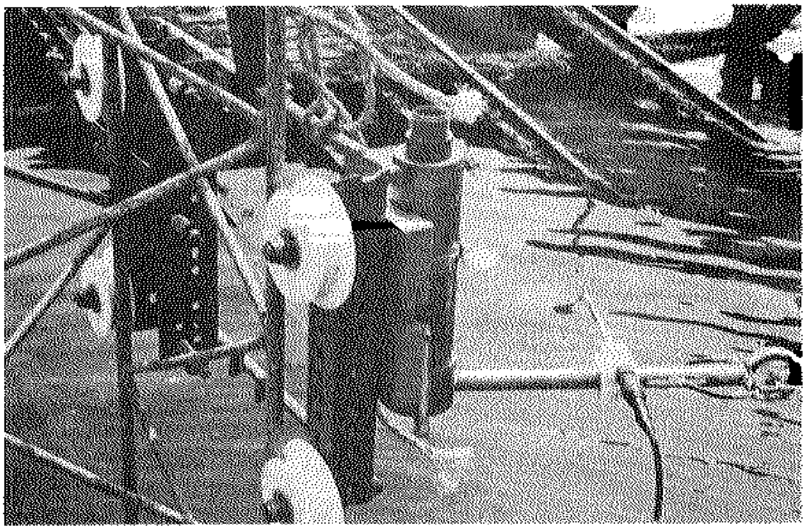

FIG. 14: Current meter and hot film anemometer installed on cart on dummy track at dockside for tests.

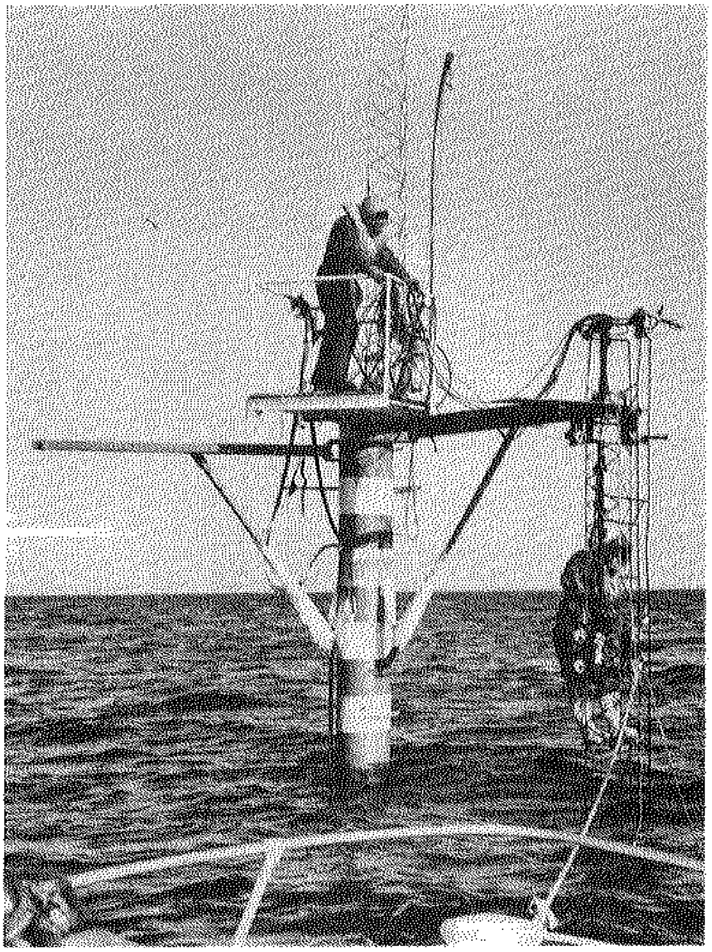

FIG. 15: Hauling up carts with current meters and thermistors installed. Note ice on struts.

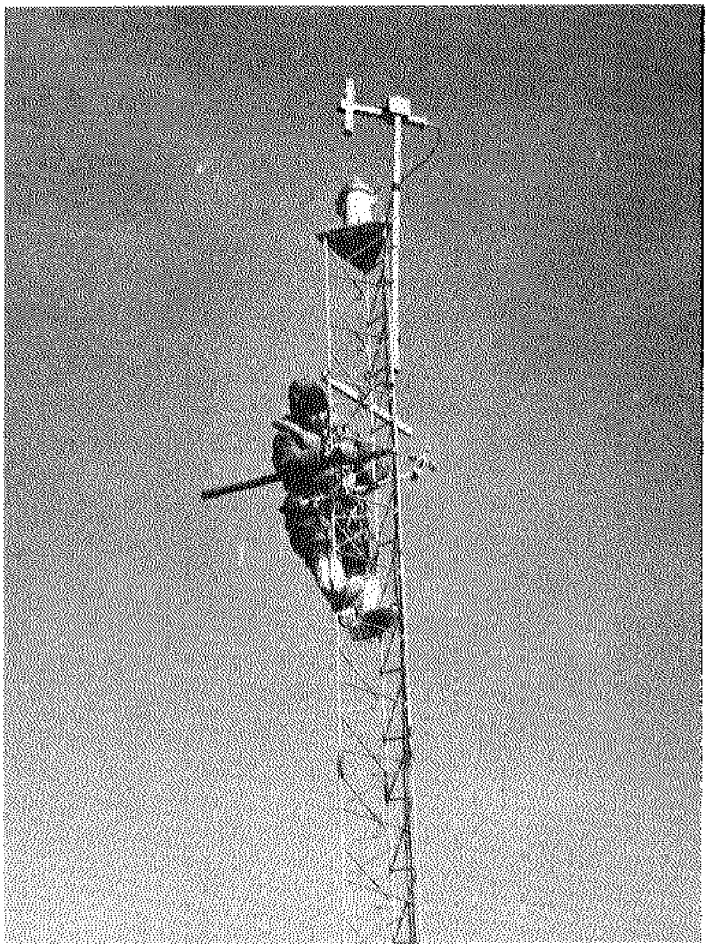

FIG. 16: Antenna and light.

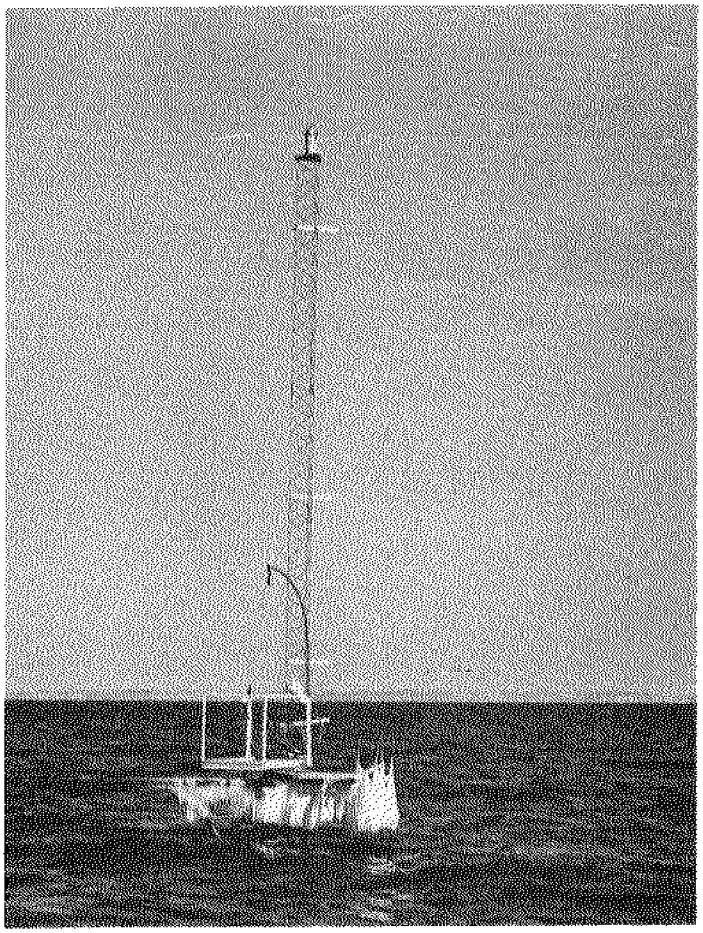

FIG. 17: Buoy stripped, ready for removal, February 1971. Note ice.