EXPERIMENTAL DESIGN

FOR

DRIFTING BUOY LAGRANGIAN TEST

Prepared for

NOAA Data Buoy Office
National Oceanic and Atmospheric Administration

and

National Space Technology Laboratories
NASA

(NASA-CR-146817) EXPERIMENTAL DESIGN FOR DRIFTING BUOY LAGRANGIAN TEST (Woods Hole Oceanographic Institution) 40 p HC $4.00 CSCL 14B

N76-21489

Unclas
G3/35 15125

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September 1975

EXPERIMENTAL DESIGN FOR DRIFTING BUOY LAGRANGIAN TEST

Table of Contents

1.0 Scope

2.0 Context of Experiment

3.0 Some Design Considerations

4.0 Test Instrumentation

5.0 At Sea Experiment: General

6.0 Data Acquisition

7.0 Data Analysis

8.0 Equipment to be Readied

EXPERIMENTAL DESIGN FOR DRIFTING BUOY LAGRANGIAN TEST

1.0 Scope

The experiment described in this document is a test of instrumentation fabricated by the contractor to measure the performance of a free drifting buoy as a (Lagrangian) current meter. Specifically it is proposed to distinguish between the trajectory of a drogued buoy and the trajectory of the water at the level of the drogue by measuring the flow relative to the drogue. It should be emphasized that the experimental goals are first to evaluate the test instrumentation and secondly obtain data on the drogued buoy performance.

2.0 Context of Experiment

The NOAA Data Buoy Office (NDBO) has under development and test a low-cost severe environment drifting buoy to meet the requirements for atmospheric surface pressure and sea surface temperature in the Southern Ocean during the First GARP Global Experiment (FGGE). The buoy system is being developed to be compatible with the satellite location and data retrieval capabilities expected to be available during the FGGE period.

In the data sparse areas where the buoys are expected to be deployed they will provide new data both for meteorologists and oceanographers which will undoubtedly stimulate new studies of the dynamics of these regions. Oceanographers will be interested not only in the wind data as input to their studies but also directly in the ocean drift data. The temptation to identify the trajectory of drogued buoys with the trajectory of the water will be (almost) irresistible: a NDBO program objective of which this experiment is a part, is to determine empirically the magnitude of the discrepancy between these quantities.

3.0 Some Design Considerations

The design of drogued-buoys would be a relatively simple matter if winds and currents were steady (or approximately so): unfortunately waves complicate performance in imperfectly understood and unpredictable ways.

Waves are known to induce added drag on floating structures, such as ships' hulls, and must also produce forces on drifting buoys: because the relative drift of a drogued buoy is designed to be small (circa 5 cm/s) compared with the orbital motion in waves (circa 100 cm/s), even small nonlinear effects can enhance drift significantly.

Wave frequency forces can produce other effects too. Flow-orienting drogues, such as the parachute or window-shade type, can be expected to side-slip if the steady and unsteady forces are not collinear. Such a situation occurs, for example, when wind and swell are of right angles to one another. These considerations require that measurements be undertaken of the open-ocean performance of drogued buoys with the aim of elucidating the role of wave-induced forces on them.

Measurement of the flow relative to a drogue appears the direct line of attack on this problem. Unfortunately a current meter cannot be attached to the drogue or its support cable because, for the NDBO-drogued buoy under test, the drogue, cable, and buoy all closely follow the excursions of the sea surface. Thus a measurement of horizontal velocity with an accuracy of say 1 cm/s must be made in the presence of vertical velocities of order 100 cm/s - an impossible task. Vertical velocities experienced by a current meter can be reduced by supporting it below an independent spar-buoy, tethered to but otherwise decoupled from the drogued-buoy. If vertical velocities can be reduced to only a few cm/s, the required accuracy in horizontal currents can then probably be achieved.

These considerations led the contractor to design and fabricate a lightweight spar buoy (or test instrumentation) from which a current meter can be supported; the spar buoy is to be tethered to the drogued buoy whose performance is being measured. See Figure 1.

4.0 Test Instrumentation

We were required to meet the following characteristics in designing the test instrumentation:

a) Structural integrity in sea conditions: the instrumentation shall be capable of operation and survival under the environmental conditions under which the drifting buoy system will be tested.

b) The instrumentation shall be designed for ease of handling from a ship capable of deploying and handling the NDBO drifting buoy system including a drogue.

c) The instrumentation shall be designed for simplicity, low cost and ease of duplication.

d) The instrumentation shall be designed to measure the Lagrangian tracking performance of the drifting buoy system under test without introducing substantial instrumentation error.

In addition, the test instrumentation to support a self-recording current meter. For the current measurement we selected the Vector-Averaging Current Meter (VACM) manufactured by AMF, Inc.: Institution personnel have considerable experience in readying, deploying, and handling the data from this instrument. Its weight in water is 70 lb. Thus we must add to the above list of requirements

e) A payload of at least 100 lb.

The principal investigator in collaboration with Mr. James Mavor, Ocean Engineer, determined that the above characteristics could be met by employing air-filled PVC tubing manufactured by Deep Ocean Work Systems, California

(Vernon Shelton) with an outer diameter of 2-7/8", wall thickness of 1/4", net buoyancy of 2 lb/ft and tensile strength of 5000 lb. This tubing is manufactured in 20 ft lengths which are J locked together and held in position by O-rings; terminal sections with couplings and lights are also available.

To provide the spar with a long heave period and reduce vertical velocities at the current meter to less than 5 cm/s a series of four damping plates, 30" in diameter and of 1/2" PVC were manufactured. The virtual mass associated with these discs is approximately 2400 lbs and the calculated natural heave period of the spar and current meter is 24 secs. The damping plates afford large virtual mass but small drag in accord with characteristic d. The weight in water of the damping plates (45 lbs), associated hardware (15 lbs), and current meter (70 lbs) totals 130 lbs which can be supported by 4 - 20 ft lenghts of the air filled tubing. Between 10 and 15 feet of pipe is above mean sea level and this will rarely be covered.

The principle difficulty in designing the test instrumentation lies in preventing the tangling of the drogued buoy with the spar buoy. We considered employing a satellite (third) buoy tethered by line to the spar buoy; the wind carries the (undrogued) satellite buoy away from spar buoy as far as the tether between them allows and then further carries the spar buoy away from the drogued buoy as far as their tethering line allows. Such a scheme, although workable, can not guarantee the buoys will not tangle, so that we have chosen to employ a rigid connection between spar and drogue. Again we determined that PVC tubing could be employed: an oil-filled version could be made neutrally buoyant and prudence suggested that it be as long as the spar (viz. 80 ft). To minimize both the steady and transient (wave induced) drag the horizontal tether is placed as deep as possible: viz. it connects between the drogue bridle and a point below the damping plates. Its length ensures that large vertical excursions (3 m) at the drogued bridle will produce only small horizontal excursions (10 cm) at the spar buoy.

Detailed drawings and specifications for the test instrumentation, including horizontal tether, are to be furnished in a separate report.

Steady state calculations reveal that in a given current shear (say 20 cm/s over the nominal depth of the spar) the drag added by the spar will increase the slip of the drogue through the water by only 10 to 20% (depending on the profile of the shear). On the other hand the windage added by the spar is about equal to that experienced by the NDBO surface buoy, so that in the worst possible case, viz. the forces dominated by wind drag, the slippage of the drogue through the water will be increased by 40%. However, given a knowledge of the wind, a correction can be made for the added drag of the test instrumentation. Our calculations further show that in a current shear the spar buoy aligns itself 'downstream' in the surface flow which implies that the current meter supported by the Spar will be upstream in the water approaching the drogue (and not in its wake). This result is intuitively correct - clearly the spar is less well locked to the water motion at the level of the drogue and tries to drift away in the (relative) surface current; consequently the current meter is in a favorable position to record the flow at the level of the drogue.

5.0 At Sea Experiment: General

We propose to launch the NDBO drogued buoy and test instrumentation from a chartered vessel, the JEFF K, a 65 ft stern dragger out of Woods Hole for a period of approximately 18 hours in 100 m of water south of Cape Cod. During the 18 hr period we will measure the mean drift of the buoy (employing Loran A) and with a current meter determine the relative flow of water past the drogue. We do not anticipate working in winds greater than 25 kts and will plan our launch for a wind of less than 15 kts. The ship will maintain station on the drogued buoy for the entire period of the experiment.

In addition to the above quantities we will measure

(1) wind speed and direction (hourly, with standard equipment)

(2) sea state

(3) motion of surface layer relative to the drogued buoy.

Measurements (1) and (3) will enabl' us to estimate the drag forces on the buoy system and compare the VACM measurements with estimates deduced from the drag. Any discrepancies might then be correlated with measurements of sea state (2).

Sea state measurements will be made visually employing the spar buoy as a wave staff. Bands will be painted on the P.V.C. tubing at 30 cm intervals and period and amplitude of dominant waves and swell observed visually. Corrections will be employed for waves or swell whose orbital motions penetrate to the level of the damper plates (>8 seconds). At night the ship will approach and illuminate the spar for this purpose.

The motion of the surface layer relative to the NDBO drogued buoy and test instrumentation will be determined by (expendable) buoys drogued to a shallow depth and recoverable undrogued buoys. These will be launched close to the NDBO buoy and when separated by 500-1000 m will be recovered (or abandoned). The distance travelled will be determined by radar ranging on the NDBO buoy. For this purpose we will install a radar reflector on the NDBO buoy. The drogued buoys will consist of fishing floats 20 cm in diameter and 1.5 m x 2 m window shade drogues hung directly below them. Fluorescein dye packages or personnel survival lights enable them to be located with ease by either day or night. The undrogued buoys will consist of pear-shaped buoys about 1.5 m deep x 1.0 m in diameter carrying OAR radios and lights, chain ballasted to be just awash. We will install an OAR radio direction finder aboard the ship to enable us to track down these buoys.

6.0 Data Acquisition

In addition to the measurements of sea state, wind speed and direction, position of NDBO buoy and range and bearing to the NDBO buoy of other free drifting byoys to be made at least once per hour, we shall measure the drift of water past the drogue with the VACM.

Institution personnel have been instructed to ready an instrument with the following (non-standard) characteristics: a basic recording cycle of 1.78 secs and a work duty cycle of 15 minutes on, 45 minutes off. Choice of 1.78 secs was made to be compatible with the internal clock of the instrument and was dictated by the need to know how much wave frequency motion was present at the VACM. Estimates of the wave frequency flow will enable us to estimate both the engineering performance of the Spar and give us valuable information about the quality of the data from the VACM itself. (Because of the characteristics of the internal recording system of the VACM the 15 minute vector average is not degraded at all by this rapid sampling.) Operating in a continuous mode the rapid data acquisition results in exhaustion of the VACM tape storage capacity in approximately 24 hours; with a work cycle of 1/4 this is stretched out to 4 days and will enable us to cope with contingencies (such as storms) encountered principally during recovery without loss of data.

7.0 Data Analysis

By examining the amplitude and period of the wave frequency motion experienced by the VACM in conjunction with the 15 minute average currents we will be able to assess the quality of the drift measurements. The VACM measurements will then be compared with the drift measurements estimated from wind and current shear forces. Wave forces on the buoy and side slip of the window shade will be examined in conjunction with the sea state data as possible sources of discrepancy.

It is expected that the conclusions reached will dictate the nature of subsequent at-sea experiments.

8.0 List of Equipment to be readied and put aboard JEFF K

Buoy under Test

NDBO buoy

20 m length of nylon line

Drogue

Test Instrumentation

Vertical spar, damping plate assembly

Horizontal spar

Air compressor/pump

Fluid to provide neutral buoyancy

Trimming buoyancy/weights

5 m wire link

VACM

Surface Drift Buoys

2 pear-shaped buoys with chain ballast

2 lights

2 OAR radios

1 OAR radio direction finder with loop (to be installed)

6 floats, shallow drogues, fluorescein dye-packages

2 personnel lights

Miscellaneous

Radar reflector

Radar display overlay

Binoculars

Day glow flags

Hand held anemometer

Plotting sheets (large scale)

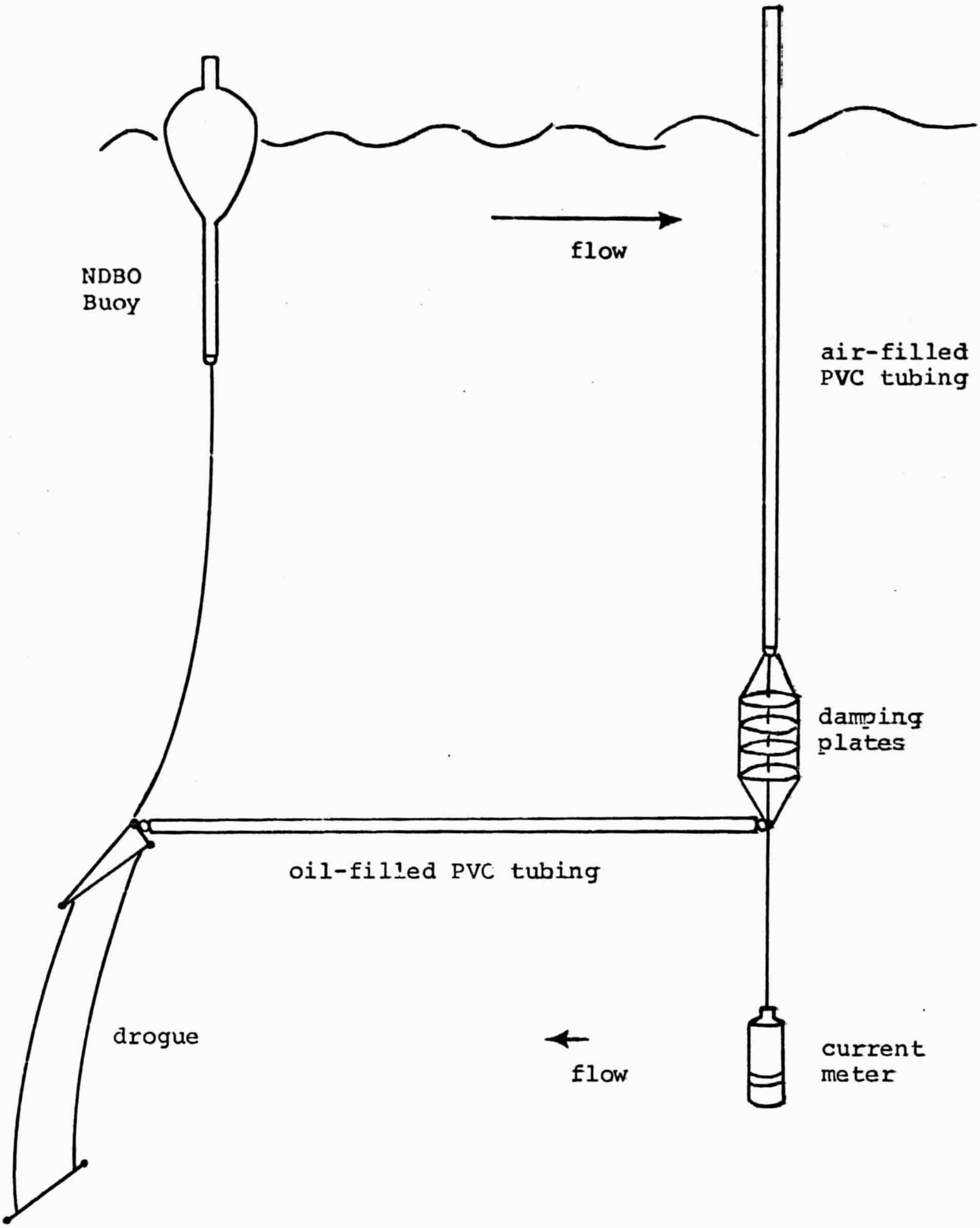

flow
NDBO
Buoy
air-filled
PVC tubing
damping
plates
oil-filled PVC tubing
drogue
flow
current
meter

Figure 1

Drawings and Specifications for Test Instrumentation for Contract NASA NO: 13-NSTL-P-75-5 'Drifting Buoy Lagrangian Test'

The test instrumentation consists of a PVC spar buoy supporting one (or more) current meter(s) whose vertical excursion is made small by a set of damping plates. The vertical spar is connected to the drogue buoy, whose performance is under test, by means of a neutrally buoyant PVC spar or tether. Thus there is no possibility of fouling of the two buoys. The general arrangement during sea-trials is shown in an accompanying drawing 1.

The damping plate assembly was manufactured in house and weighed 90 lbs in air and 40 lbs in water: it provided the spar buoy with a heave period of close to 40 seconds (measured). The damper, current meters, and interconnecting link are shown on drawing 2.

The hardware interconnecting the vertical spar to the damper, the damper to the current meters and the horizontal tether, and the drogue buoy fittings are shown on drawing 3.

The PVC piping used in both the vertical and horizontal spars was manufactured by

Deep Ocean Work Systems
P. O. Box 856
Manhattan Beach, CA 90266

Attn.: V. Shelton

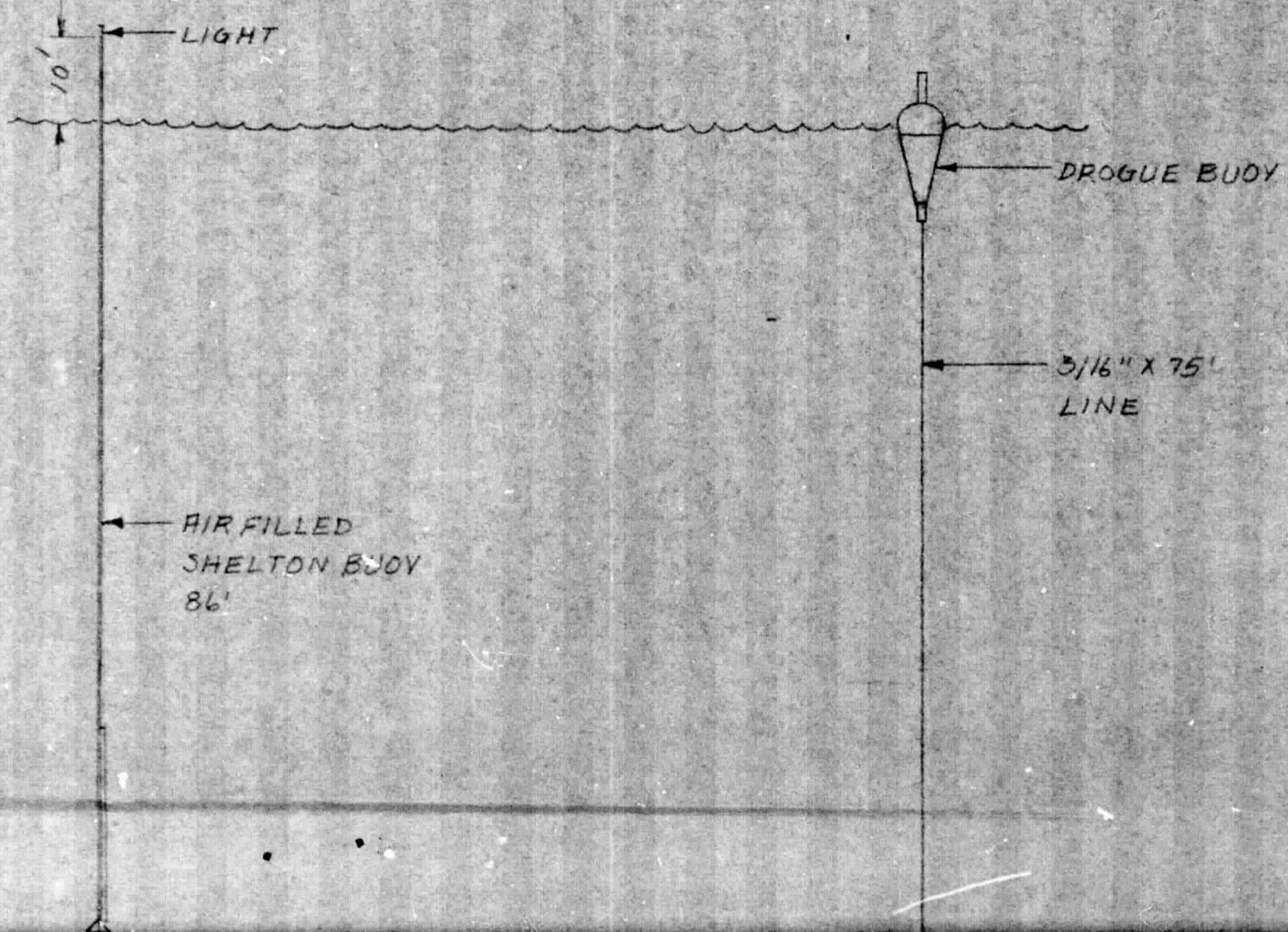
and consisted of 20 ft sections of 2-7/8" OD PVC pipe (approximate cost $80 per section), weighing approximately 15 lbs in air, with coupling sections or end connectors ($50 each). These are shown in drawing 4. For the horizontal tether, twelve 5/8" diameter holes were drilled through the walls of each section approximately 2 ft apart to provide free flooding. Buoyancy was provided for each section by a hard plastic can (trawl net float) 8" in diameter rated for 200 fathoms which were fastened to the tether by a pair of spot welded hose clamps. Natural buoyancy to within 1/2 lb was achieved by trimming with 3/8" shackles.

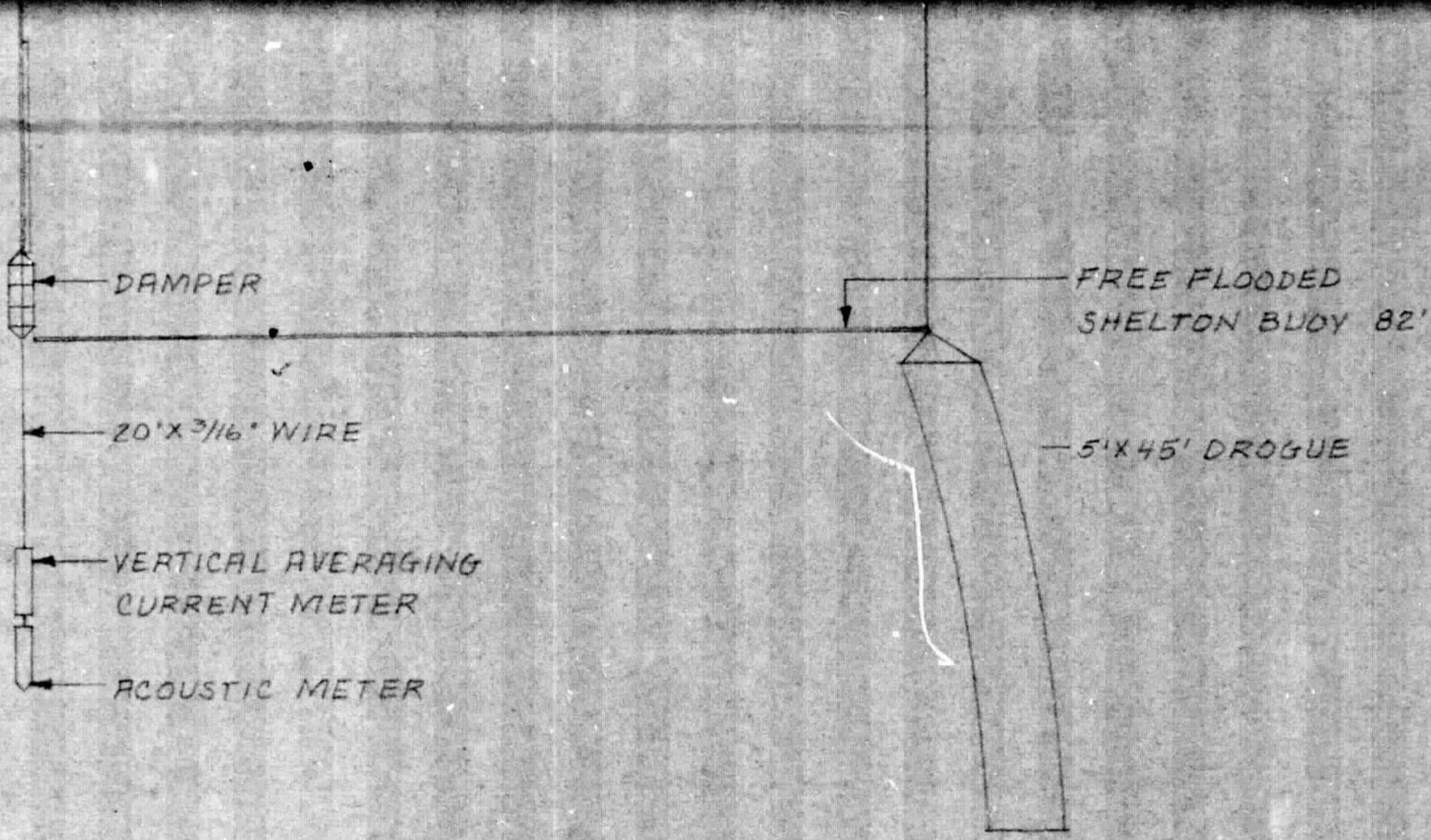
Any inquiries should be addressed to:

James W. Mavor, Jr.
Dept. of Ocean Engineering
Woods Hole Oceanographic Inst.
Woods Hole, MA 02543

FOLDOUT FRAME 1

GENERAL ARRANGEMENT

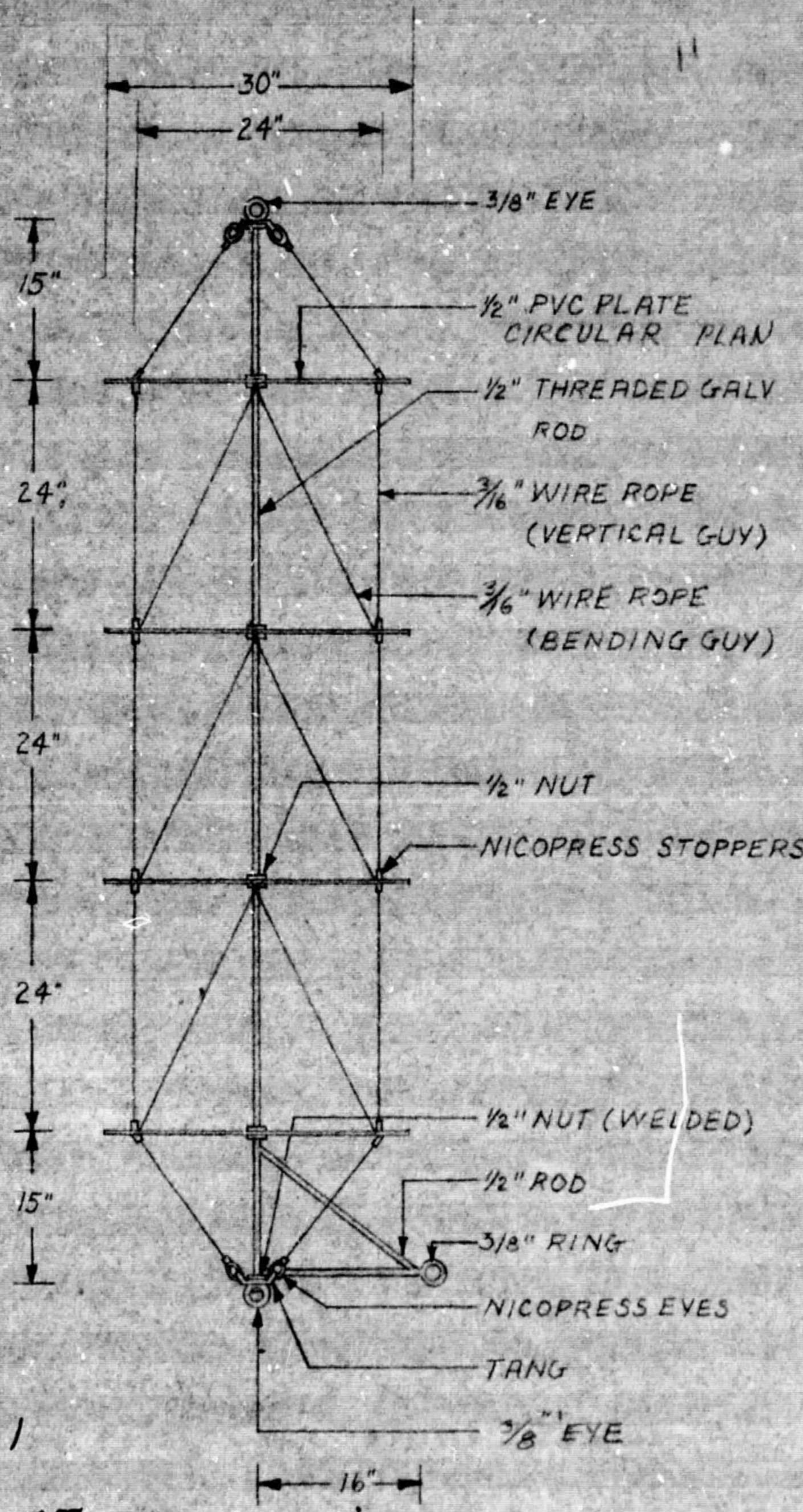


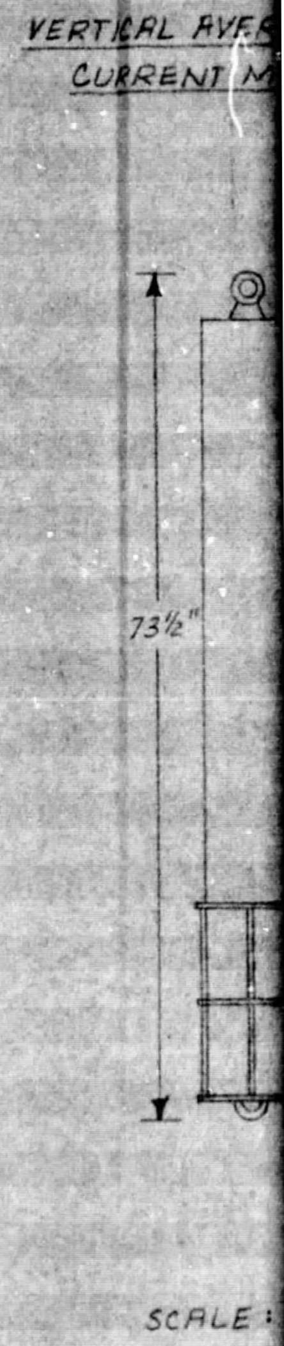


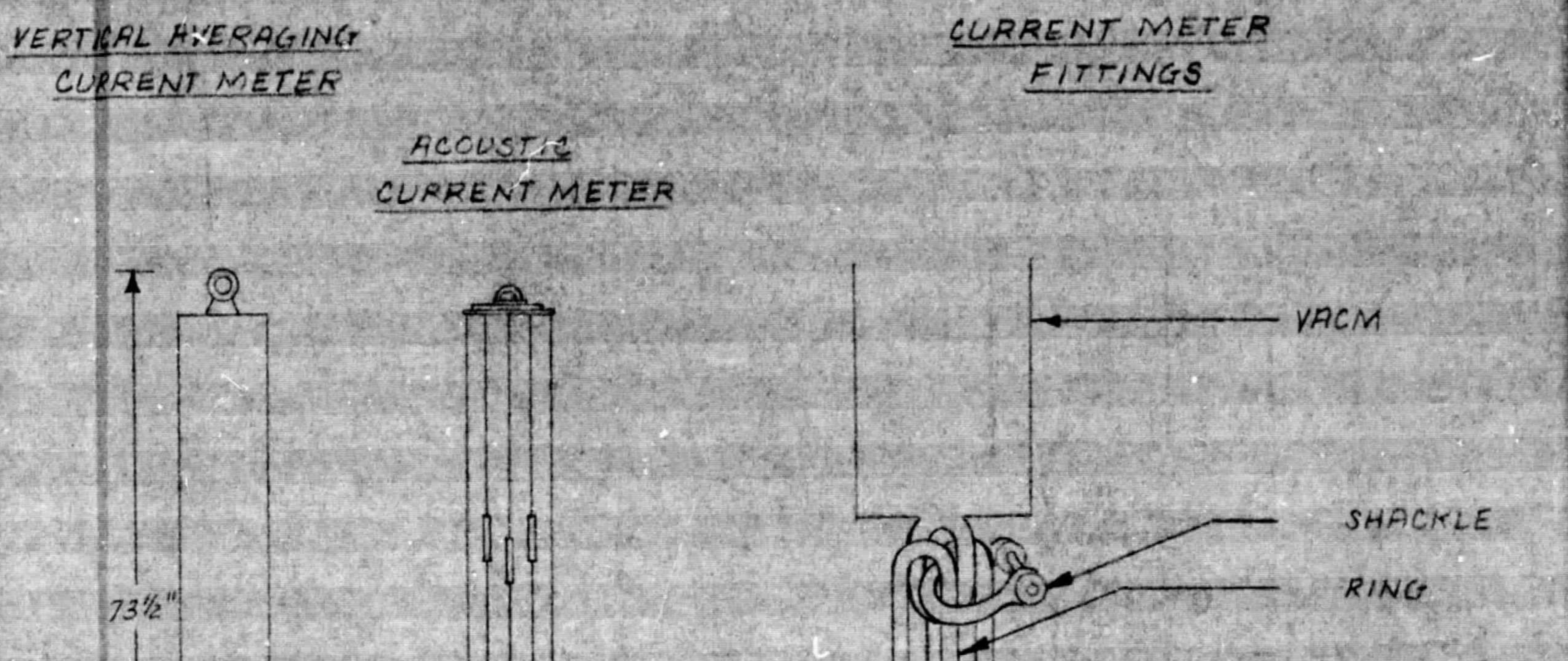
SCALE: 1/8" = 1'

DRAWING 1/4

DAMPER

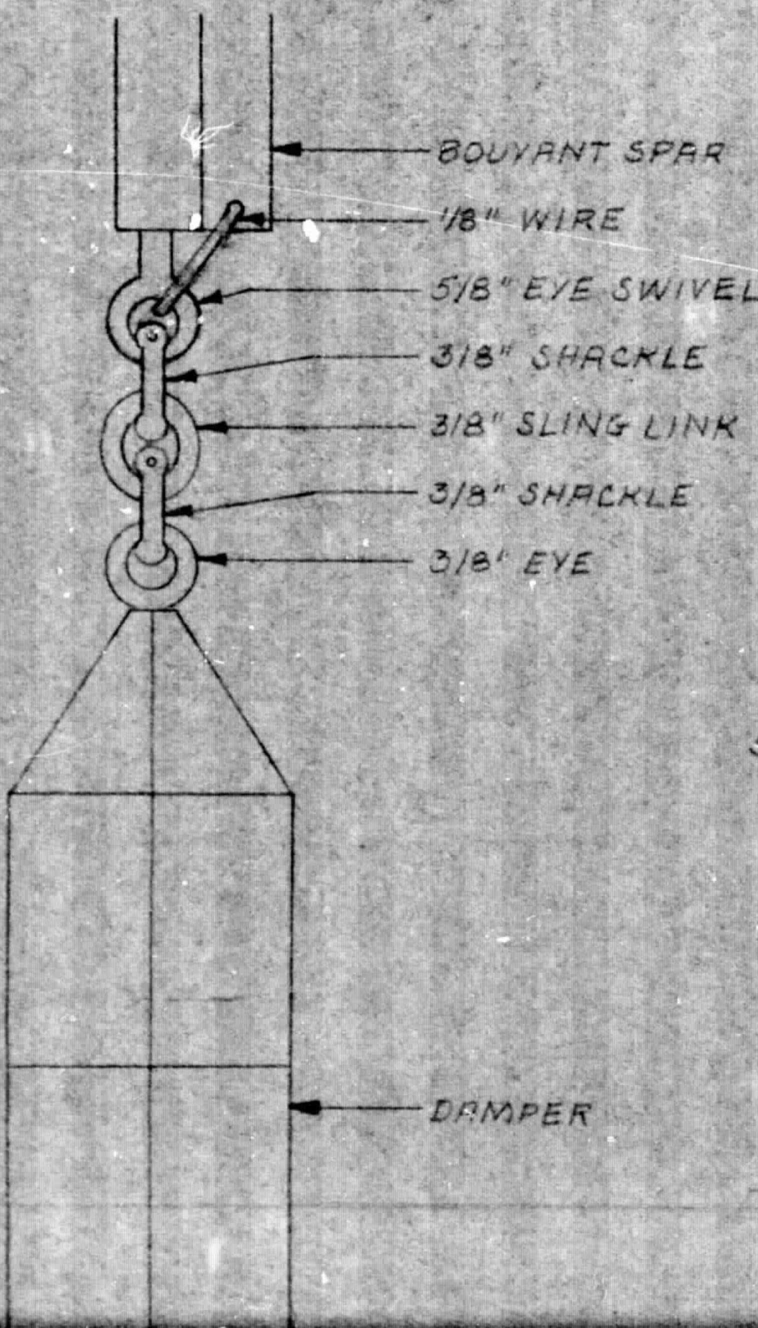

30"
24"
3/8" EYE
15"
1/2" PVC PLATE
CIRCULAR PLAN
1/2" THREADED GALV
ROD
24"
3/16" WIRE ROPE
(VERTICAL GUY)
3/16" WIRE ROPE
(BENDING GUY)
24"
1/2" NUT
NICOPRESS STOPPERS
24"
1/2" NUT (WELDED)
15"
1/2" ROD
3/8" RING
NICOPRESS EYES
TANG
3/8" EYE
16"

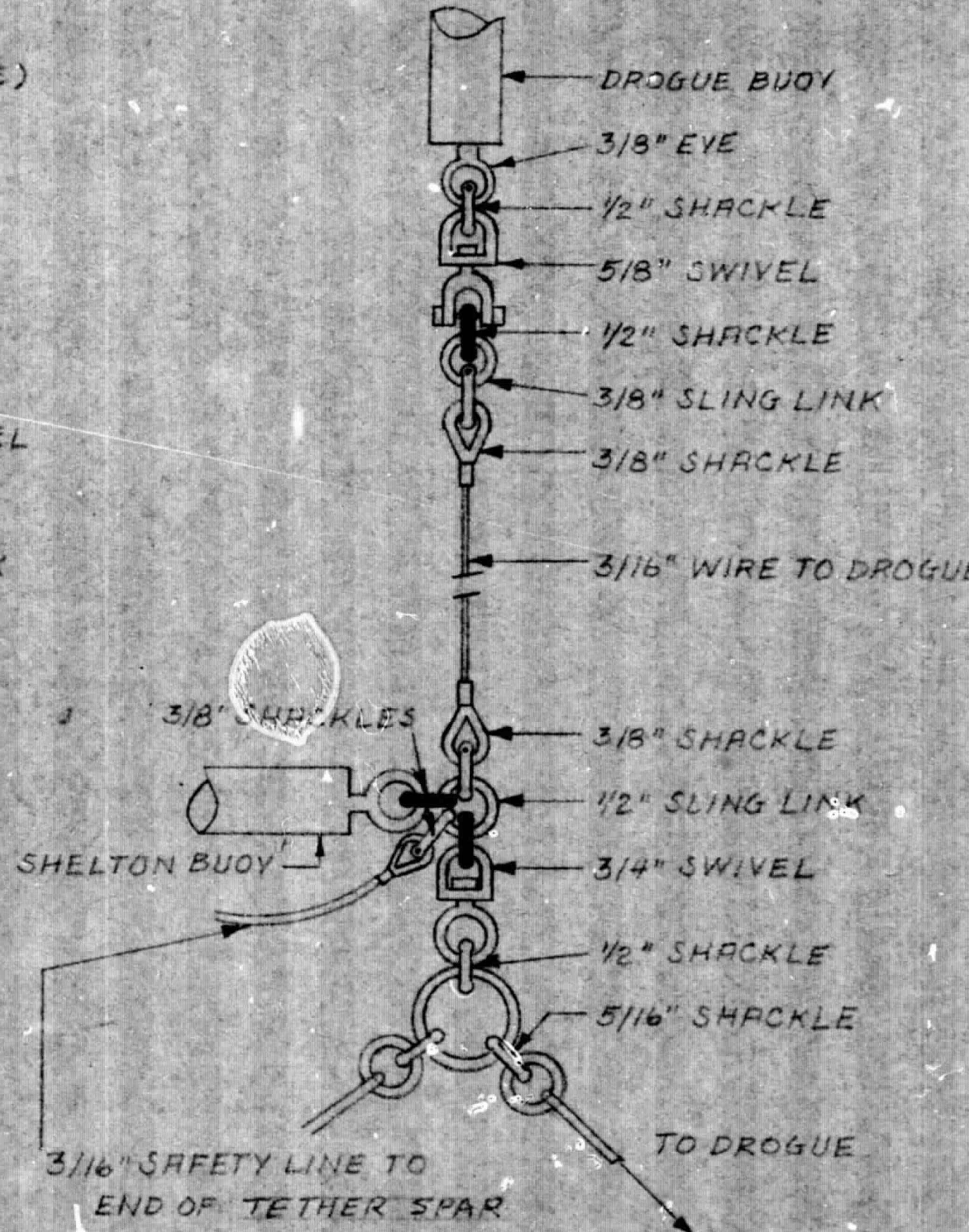

VERTICAL AVER
CURRENT M
73 1/2"
SCALE:


VERTICAL AVERAGING
CURRENT METER
ACOUSTIC
CURRENT METER
73½"
SCALE: 1/8" = 2"
CURRENT METER
FITTINGS
VACM
SHACKLE
RING
RING
SHACKLE
ACOUSTIC
CURRENT METER
(NOT TO SCALE)

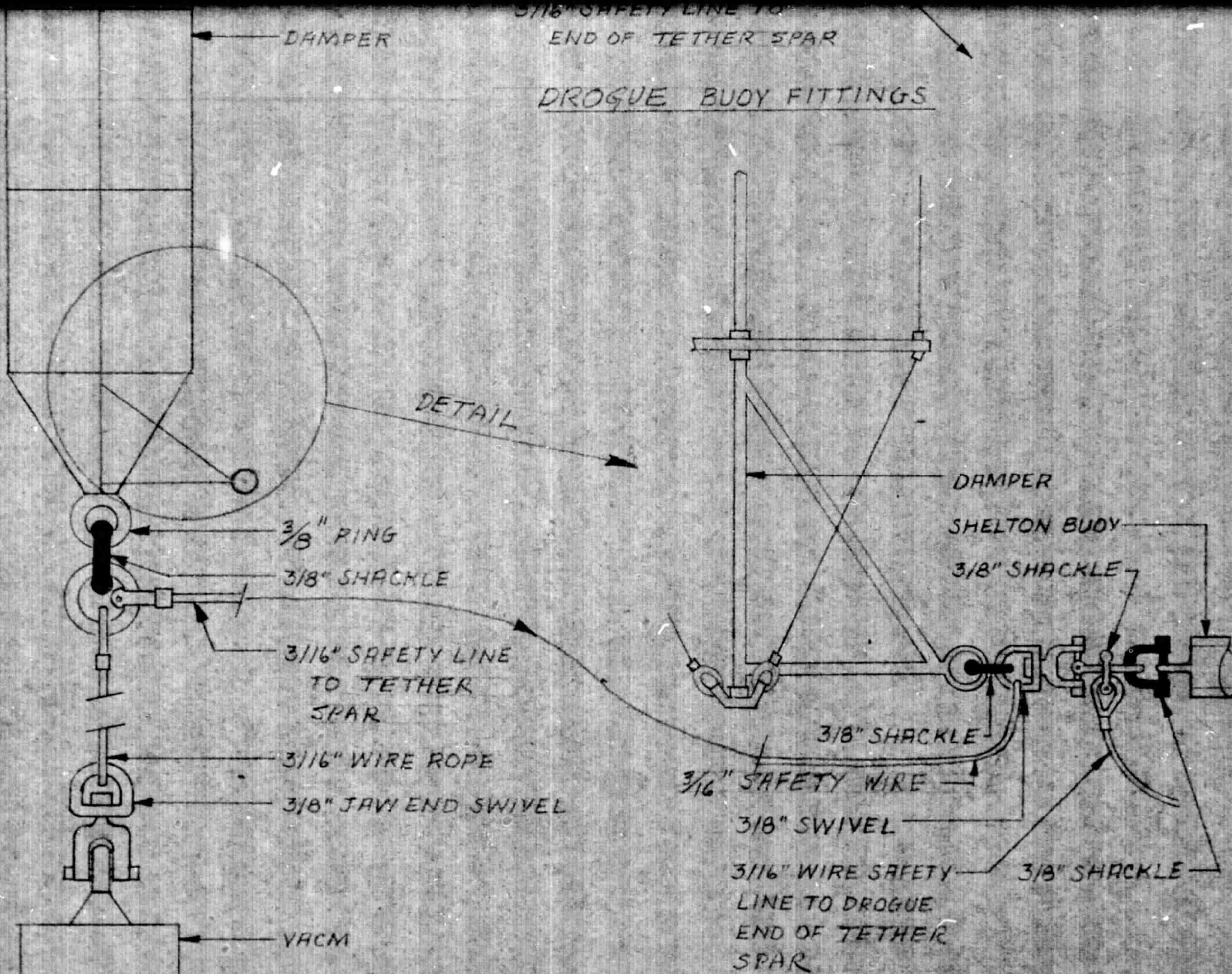
DRAWING 2/4

DAMPER FITTINGS (NOT TO SCALE)



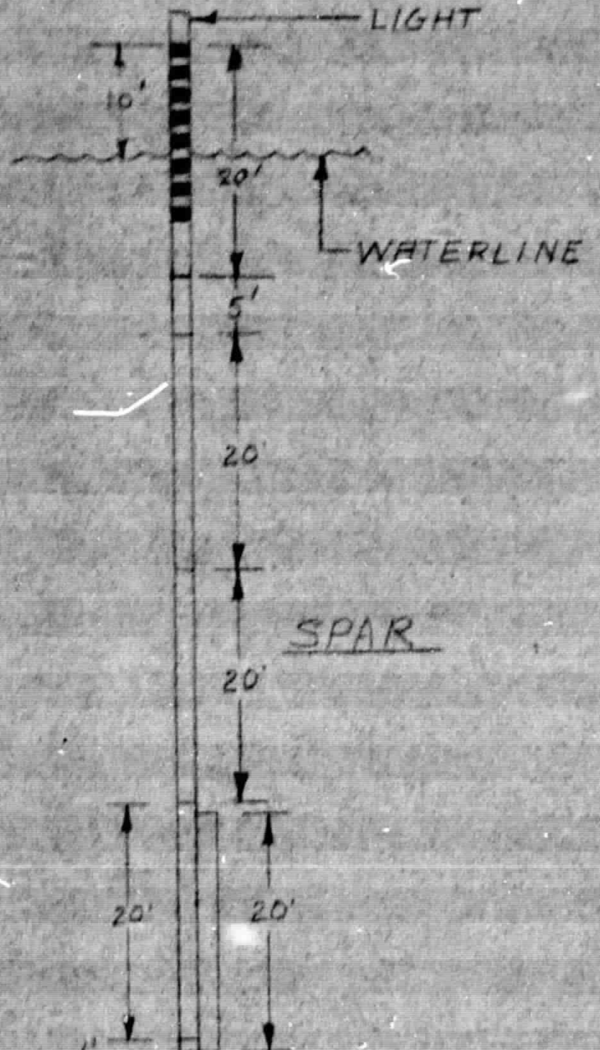


DROGUE BUOY FITTINGS

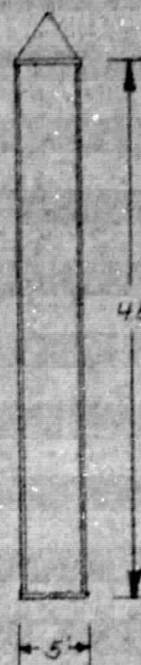


DRAWING 3/4

FOLDOUT FRAME



AIR-FILLED SHELTON BUOY
25 PSI PRECHARGE
2 7/8" O.D.
NET BUOYANCY - 2 LBS/FT.

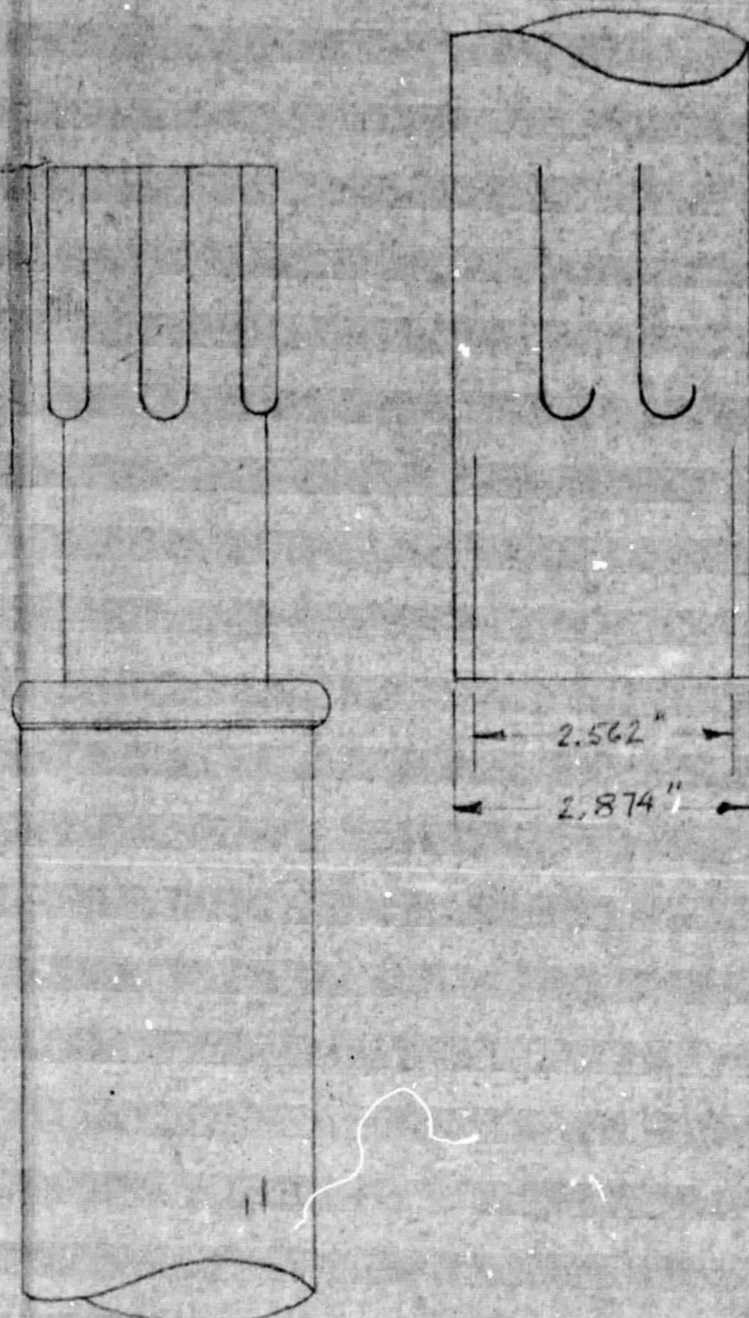


DROGUE

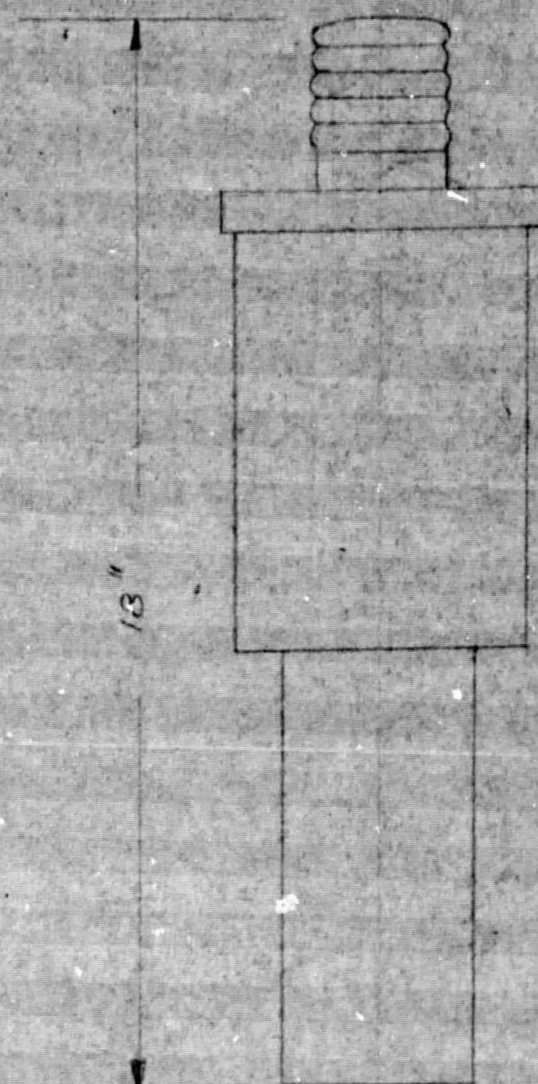
TETHER

FREE-FLOODING SHELTON
BUOY WITH 7# BUOYANCY
TRAWL FLOATS
2 7/8" O.D. NEUTRAL BUOYANCY

FOLDOUT FRAME



SHELTON BUOY COUPLING



LIGHT

DRAWING 4/4

FOLDOUT FRAME 2

Drawings and Specifications for Test Instrumentation for Contract NASA NO: 13-NSTL-P-75-5 'Drifting Buoy Lagrangian Test'

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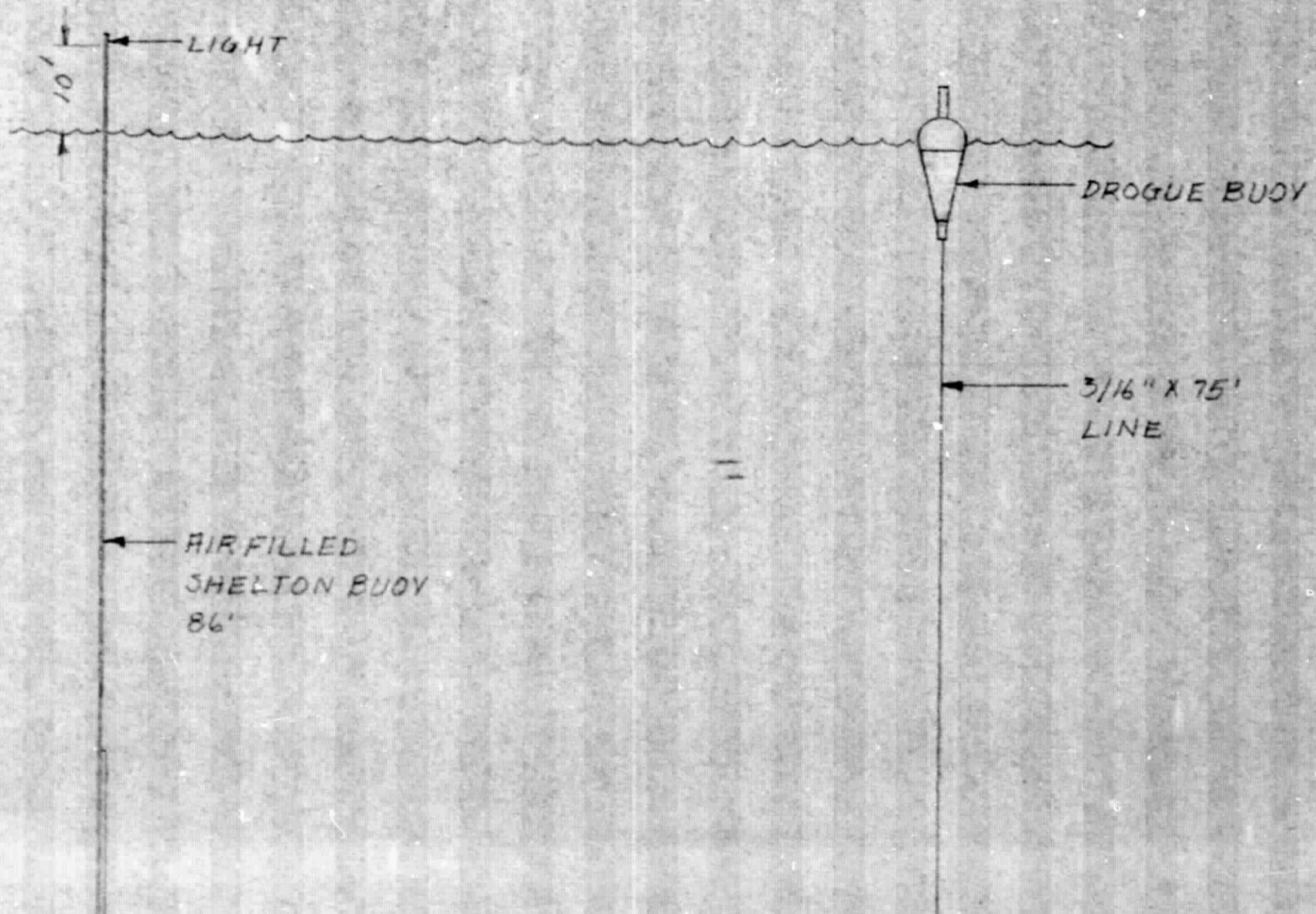
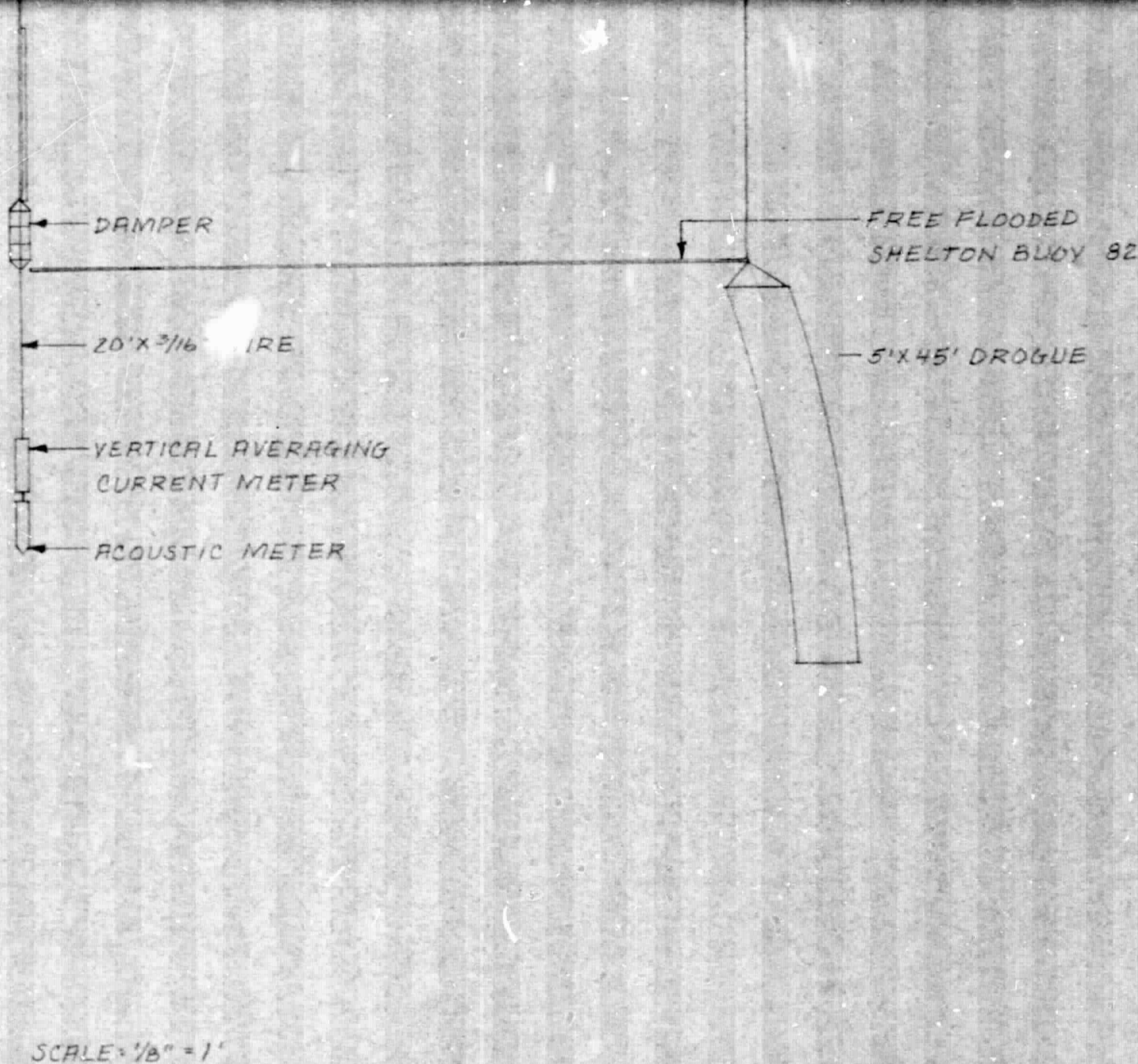
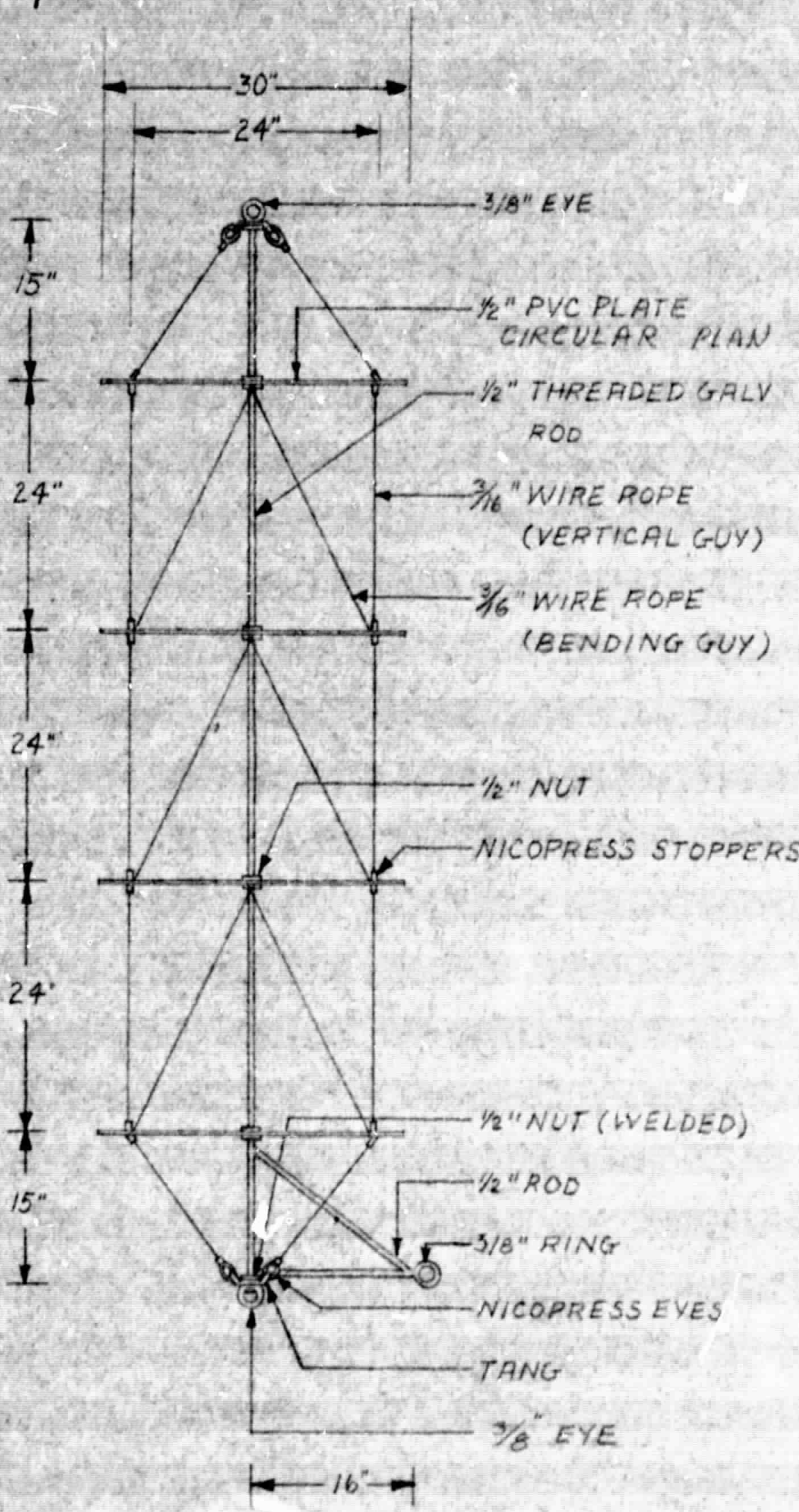
GENERAL ARRANGEMENT



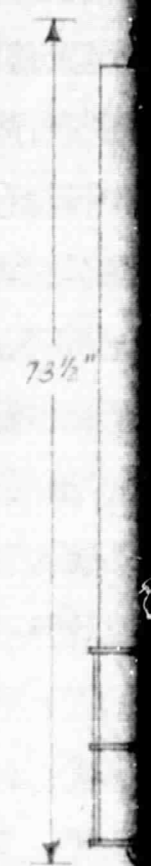

DAMPER
FREE FLOODED
SHELTON BUOY 82'
20'X 3/16 IRE
5'X45' DROGUE
VERTICAL AVERAGING
CURRENT METER
ACOUSTIC METER
SCALE: 1/8" = 1'

DRAWING 1/4

DAMPER

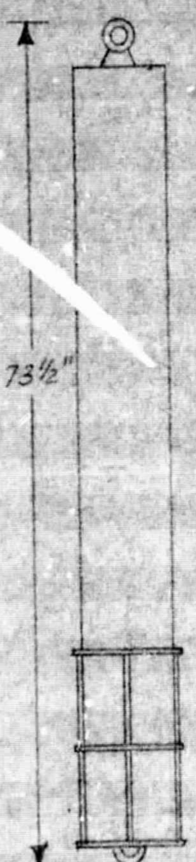


VERTICAL AV
CURRENT



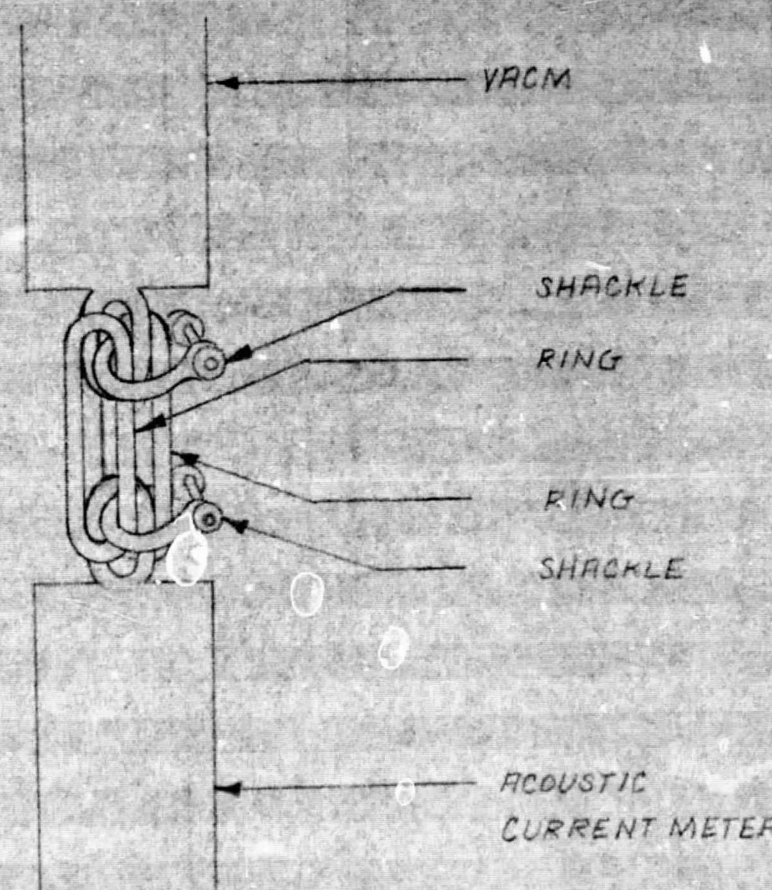
SCALE

VERTICAL AVERAGING CURRENT METER



ACOUSTIC CURRENT METER

CURRENT METER FITTINGS

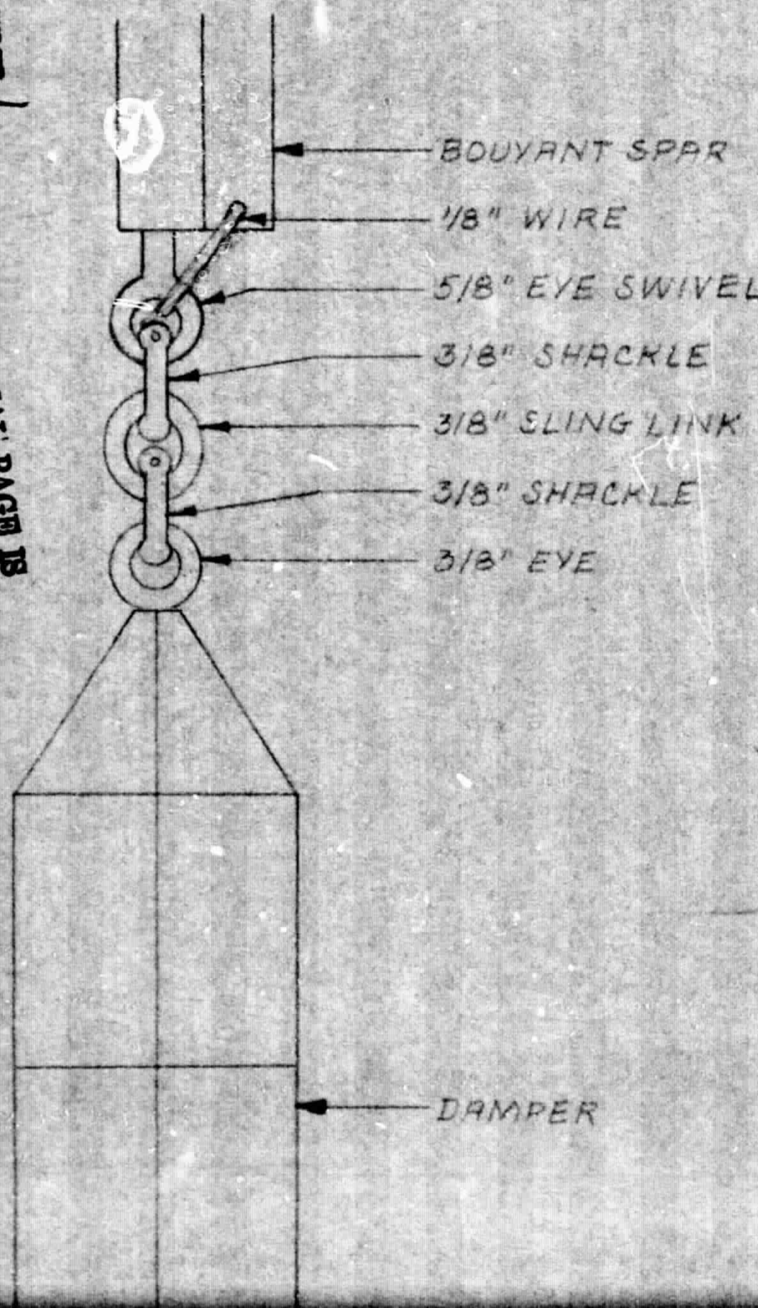


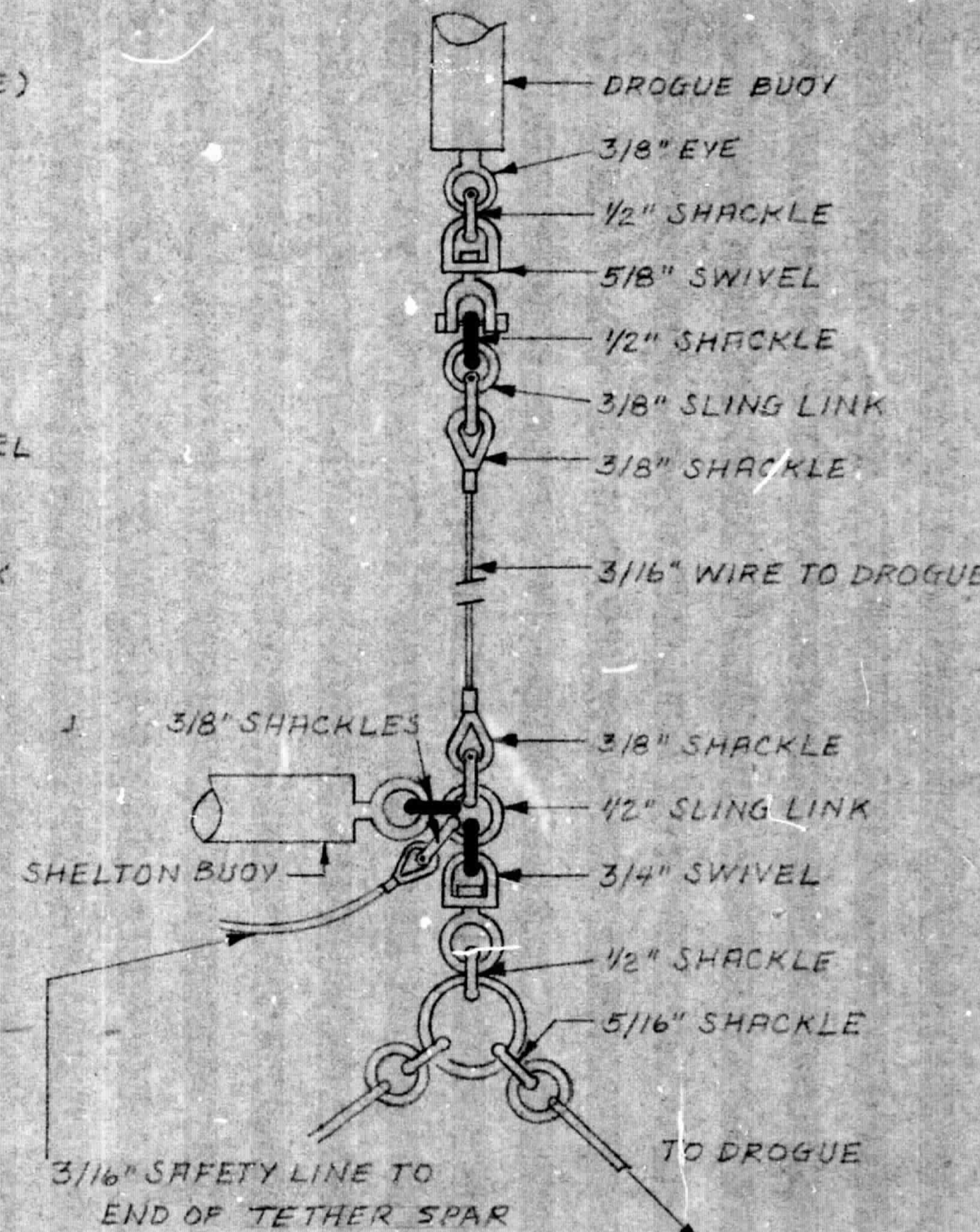
SCALE: 1/8" = 2"

(NOT TO SCALE)

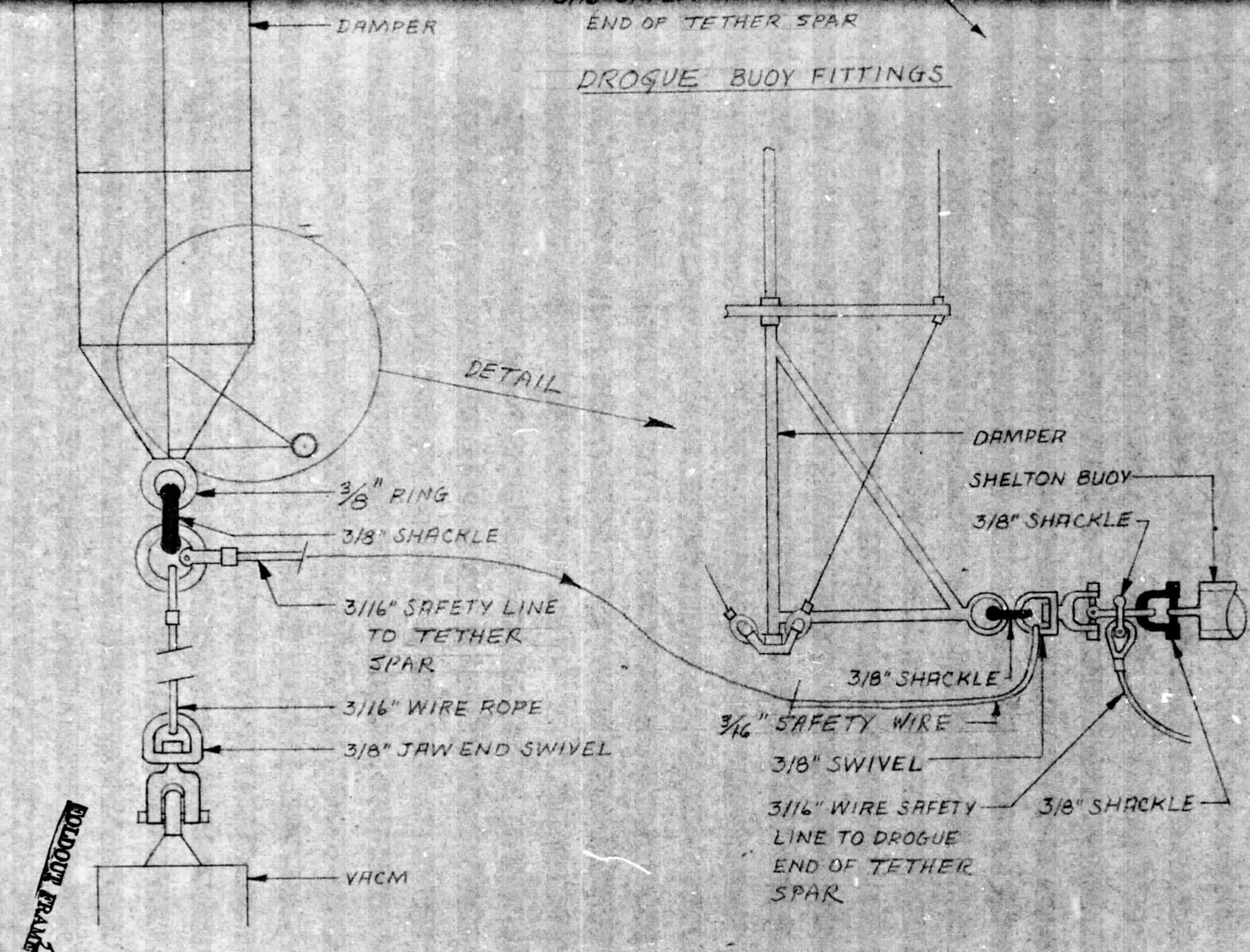
DRAWING 2/4

DAMPER FITTINGS (NOT TO SCALE)



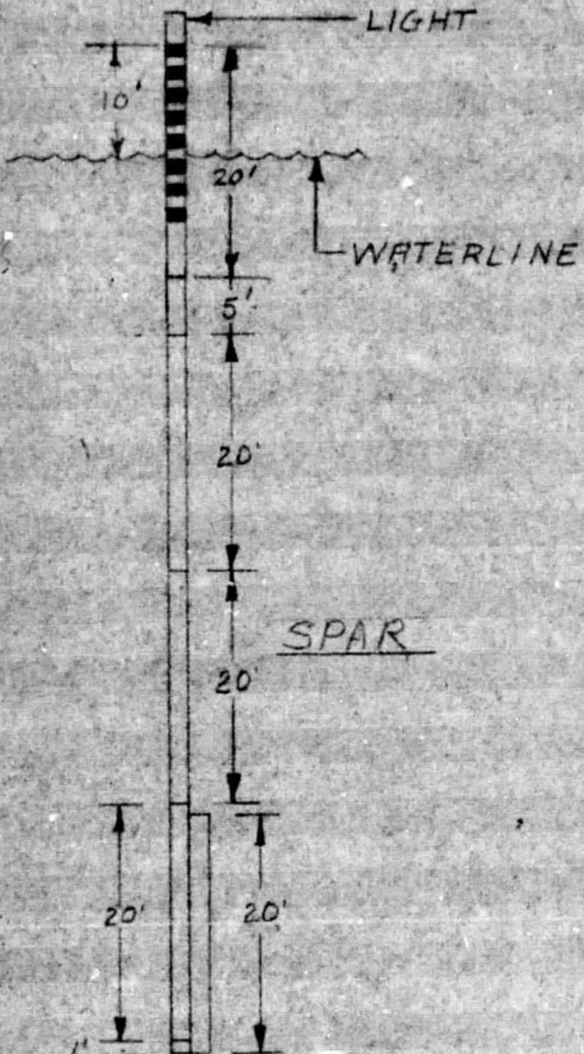


DROGUE BUOY FITTINGS



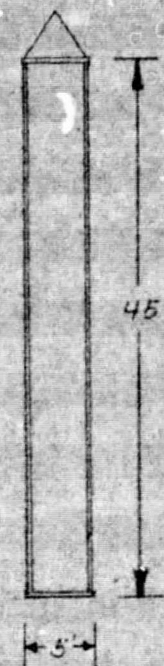
END OF TETHER SPAR
DROGUE BUOY FITTINGS
DAMPER
DETAIL
DAMPER
SHELTON BUOY
3/8" SHACKLE
3/8" RING
3/8" SHACKLE
3/16" SAFETY LINE TO TETHER SPAR
3/8" SHACKLE
3/16" SAFETY WIRE
3/16" WIRE ROPE
3/8" JAW END SWIVEL
3/8" SWIVEL
3/16" WIRE SAFETY LINE TO DROGUE END OF TETHER SPAR
3/8" SHACKLE
VACM
FOLDOUT FRAME

DRAWING 3/4

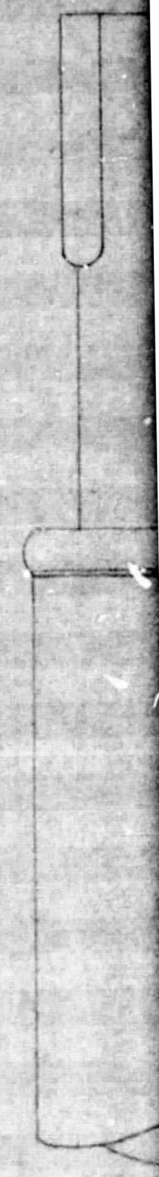


SPAR

AIR-FILLED SHELTON BUOY
25 PSI PRECHARGE
2 7/8" O.D.
NET BUOYANCY - 2 LBS/FT.

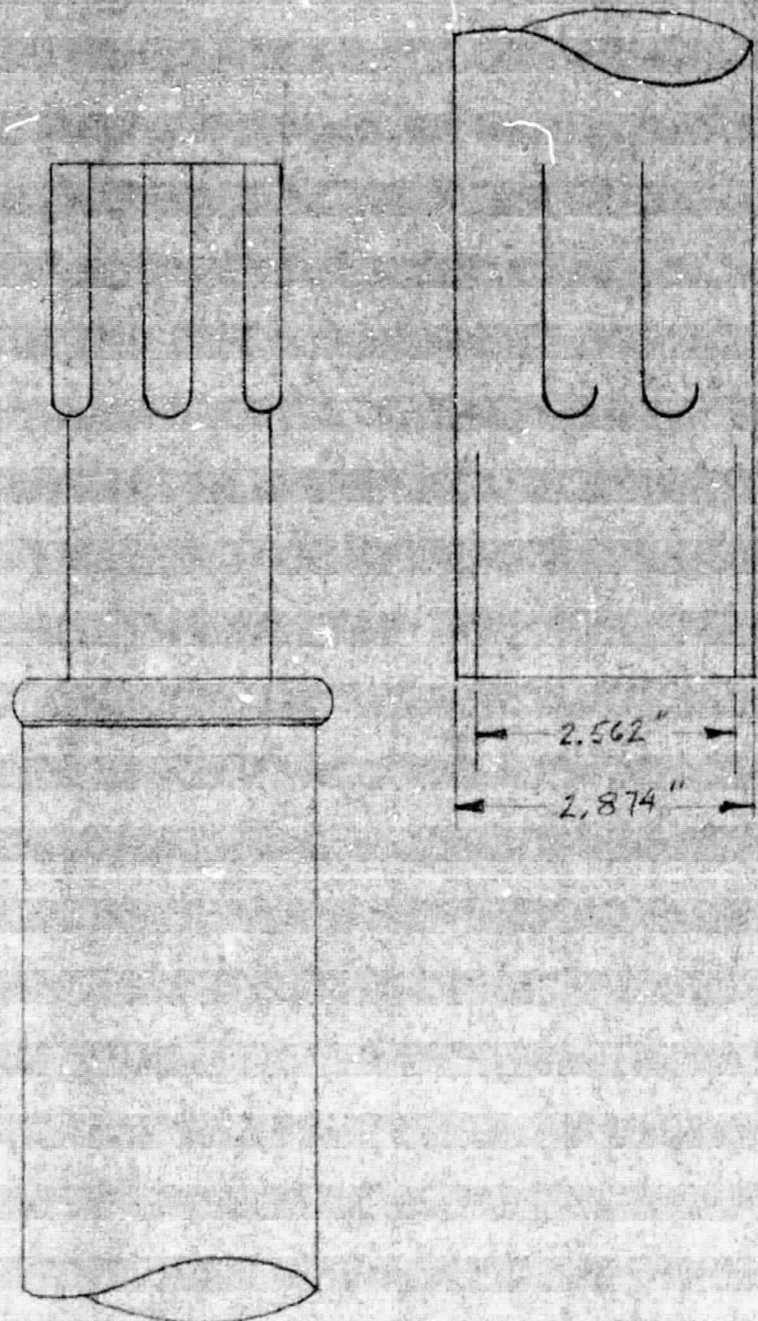


DROGUE

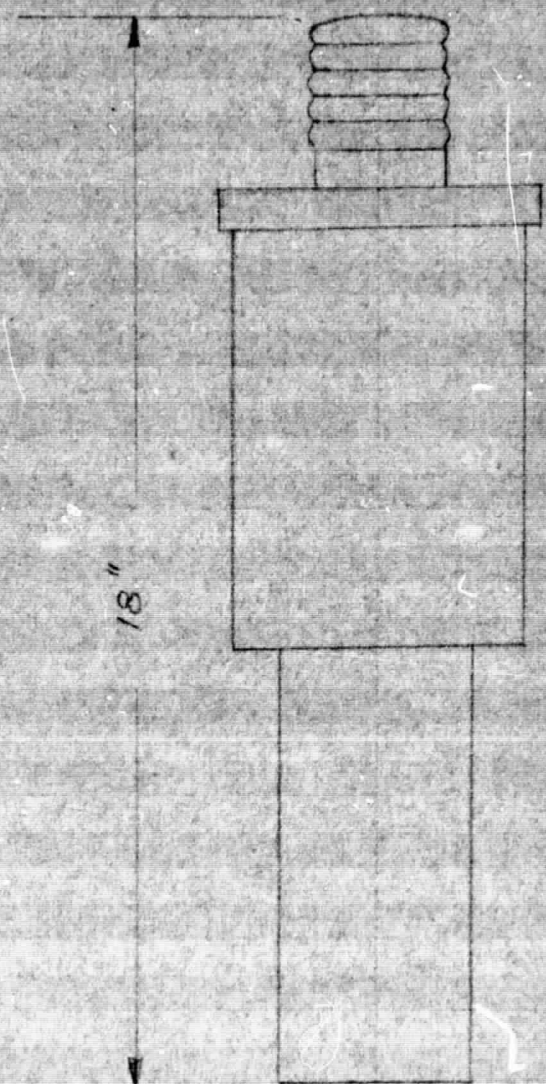


TETHER

FREE-FLOODING SHELTON
BUOY WITH 7# BUOYANCY
TRAWL FLOATS
2 7/8" O.D. NEUTRAL BUOYANCY



SHELTON BUOY COUPLING



LIGHT

DRAWING 4/4

Drawings and Specifications for Test Instrumentation for Contract NASA NO: 13-NSTL-P-75-5 'Drifting Buoy Lagrangian Test'

The test instrumentation consists of a PVC spar buoy supporting one (or more) current meter(s) whose vertical excursion is made small by a set of damping plates. The vertical spar is connected to the drogue buoy, whose performance is under test, by means of a neutrally buoyant PVC spar or tether. Thus there is no possibility of fouling of the two buoys. The general arrangement during sea-trials is shown in an accompanying drawing 1.

The damping plate assembly was manufactured in house and weighed 90 lbs in air and 40 lbs in water: it provided the spar buoy with a heave period of close to 40 seconds (measured). The damper, current meters, and interconnecting link are shown on drawing 2.

The hardware interconnecting the vertical spar to the damper, the damper to the current meters and the horizontal tether, and the drogue buoy fittings are shown on drawing 3.

The PVC piping used in both the vertical and horizontal spars was manufactured by

Deep Ocean Work Systems
P. O. Box 856
Manhattan Beach, CA 90266

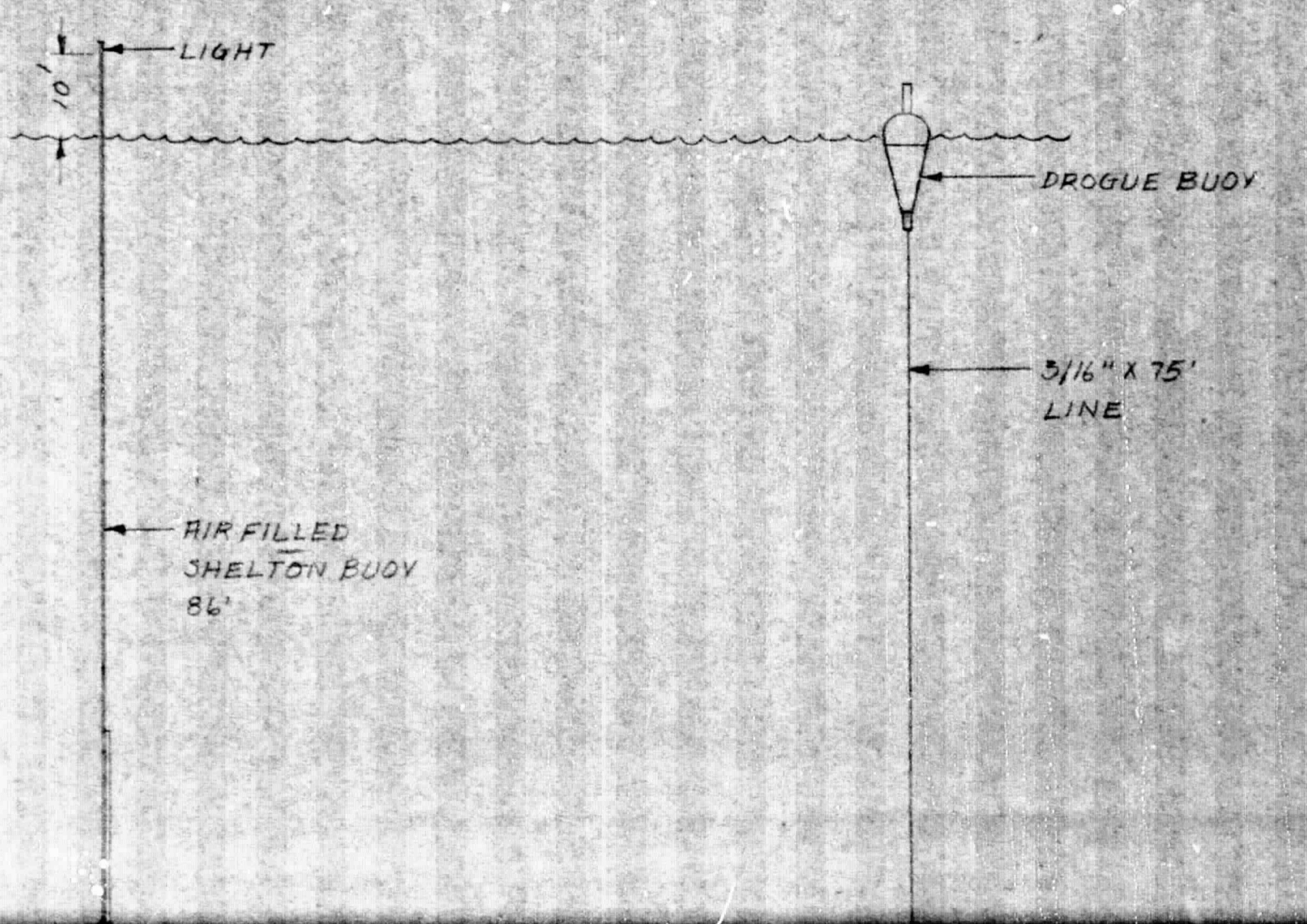
Attn.: V. Shelton

and consisted of 20 ft sections of 2-7/8" OD PVC pipe (approximate cost $80 per section), weighing approximately 15 lbs in air, with coupling sections or end connectors ($50 each). These are shown in drawing 4. For the horizontal tether, twelve 5/8" diameter holes were drilled through the walls of each section approximately 2 ft apart to provide free flooding. Buoyancy was provided for each section by a hard plastic can (trawl net float) 8" in diameter rated for 200 fathoms which were fastened to the tether by a pair of spot welded hose clamps. Natural buoyancy to within 1/2 lb was achieved by trimming with 3/8" shackles.

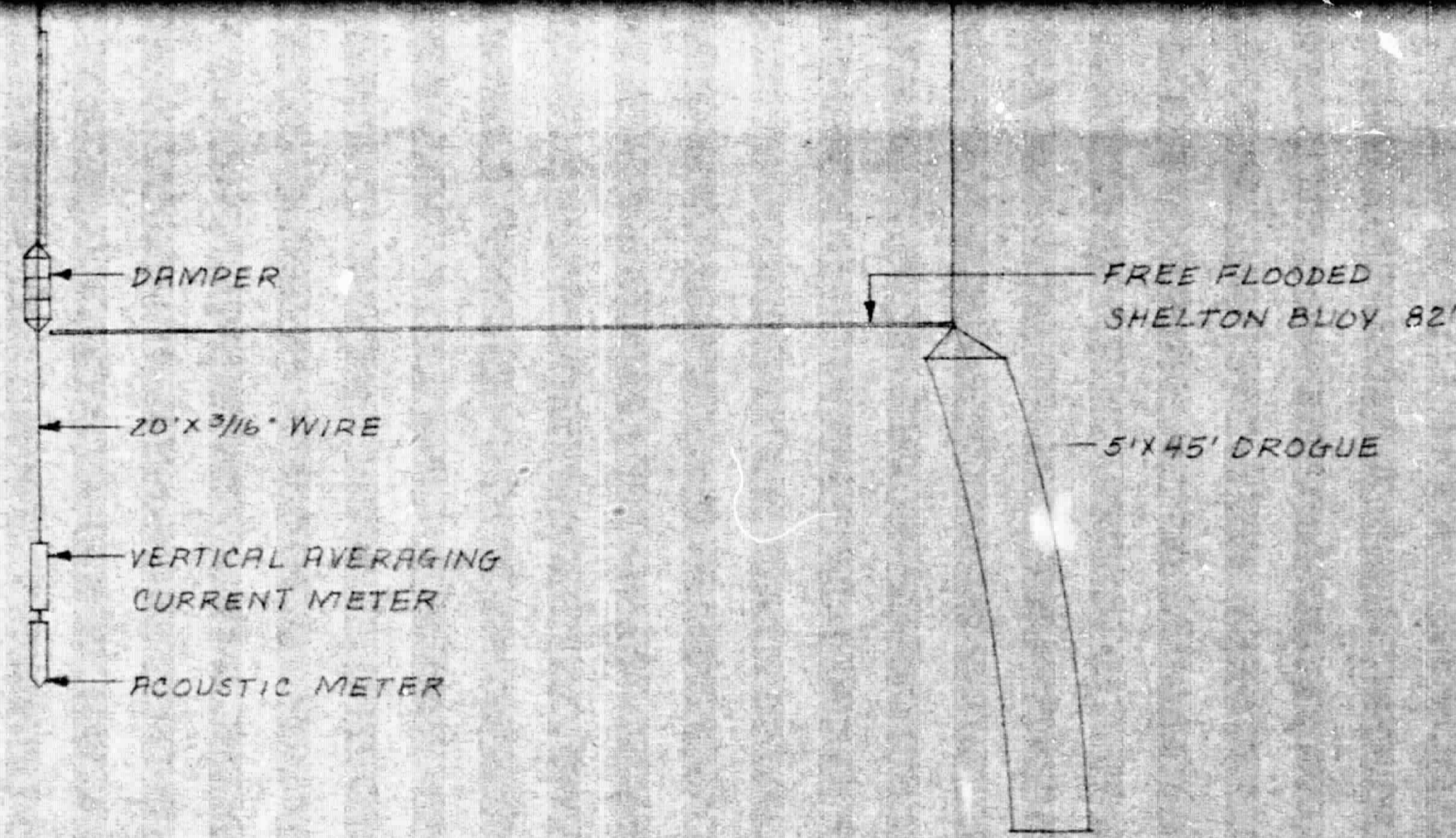
Any inquiries should be addressed to:

James W. Mavor, Jr.
Dept. of Ocean Engineering
Woods Hole Oceanographic Inst.
Woods Hole, MA 02543

GENERAL ARRANGEMENT



FOLDOUT FRAME 1

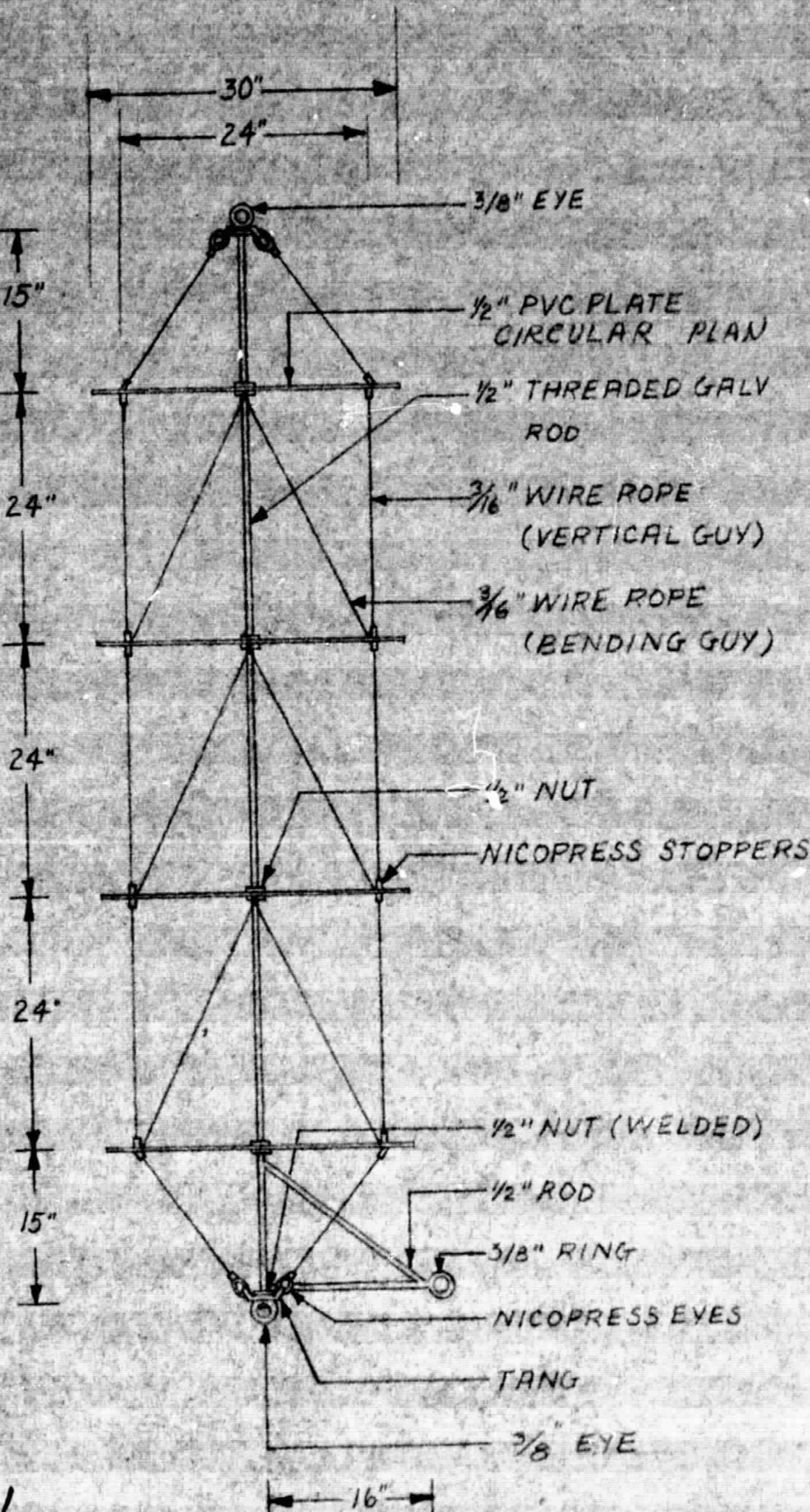


SCALE: 1/8" = 1'

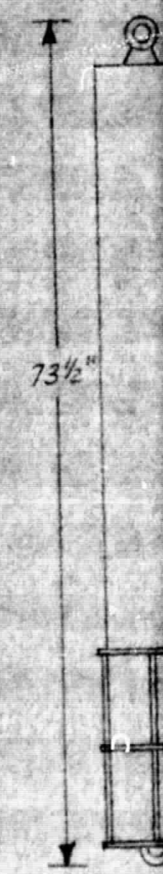
FOLDOUT FRAME

DRAWING 1/4

DAMPER



VERTICAL AVER
CURRENT M

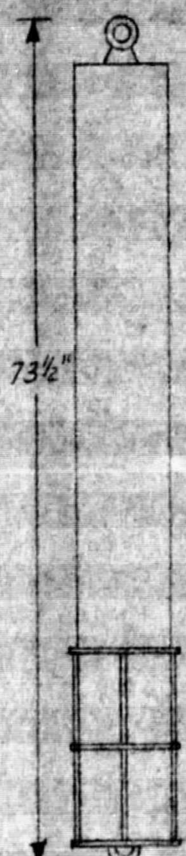


SCALE

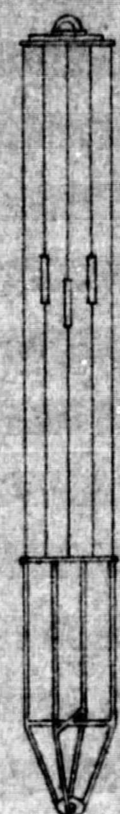
FOLDOUT FRAME 1

ORIGINAL PAGE IS
OF POOR QUALITY

VERTICAL AVERAGING CURRENT METER

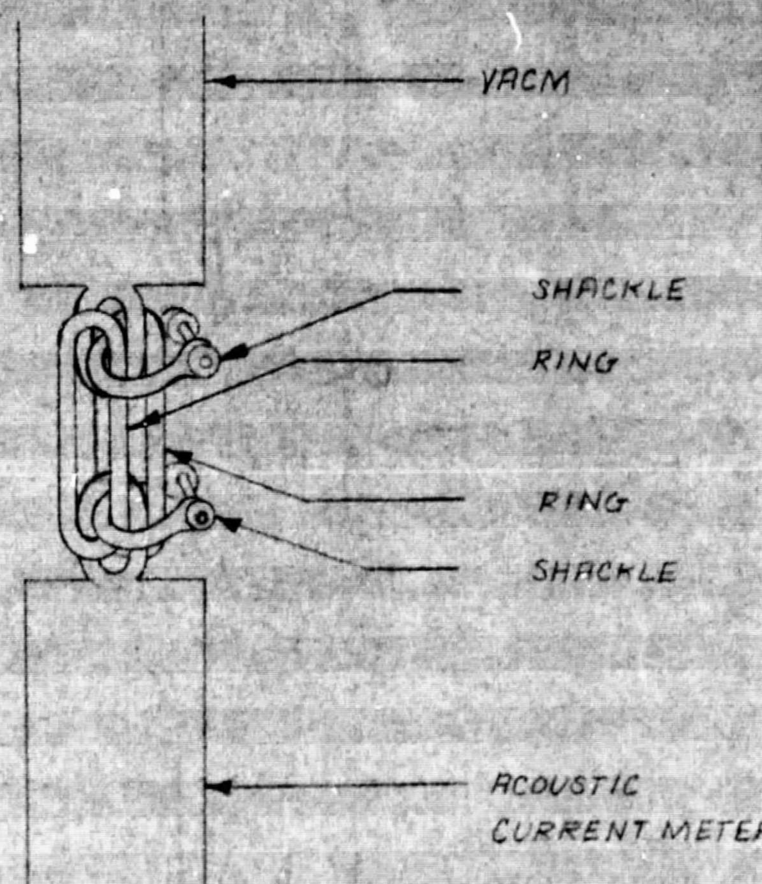


ACOUSTIC CURRENT METER



SCALE: ⅛" = 2"

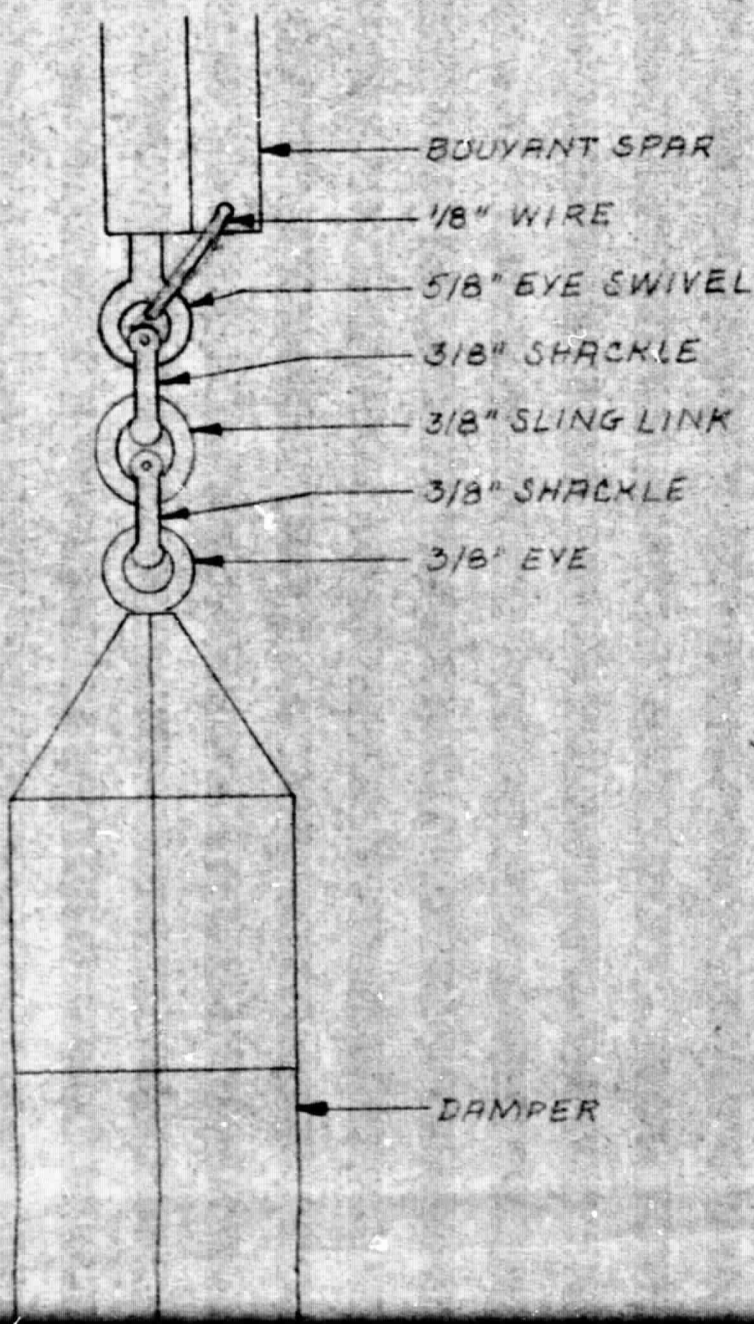
CURRENT METER FITTINGS

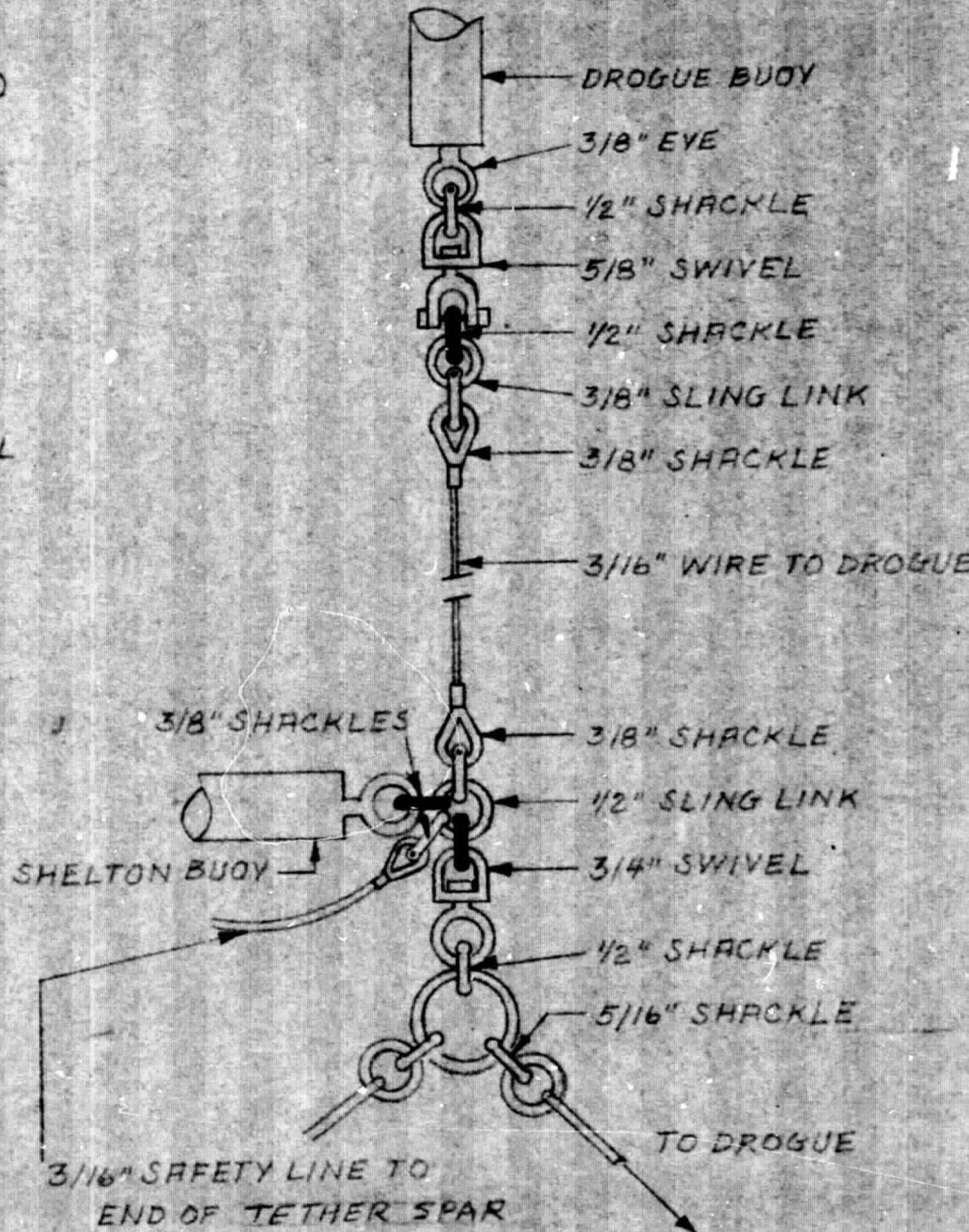


(NOT TO SCALE)

DRAWING 2/4 FOLDOUT FRAME

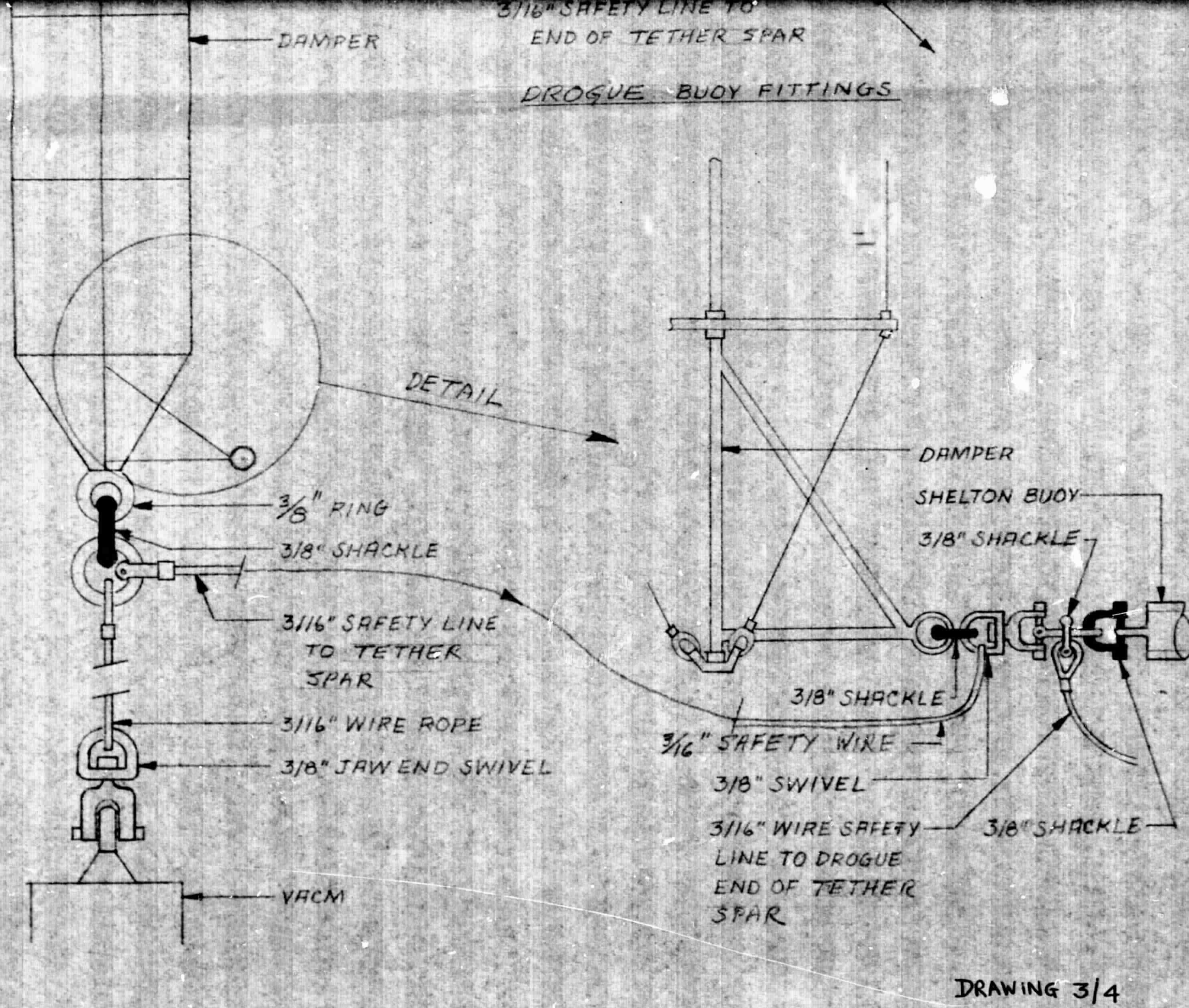
DAMPER FITTINGS (NOT TO SCALE)





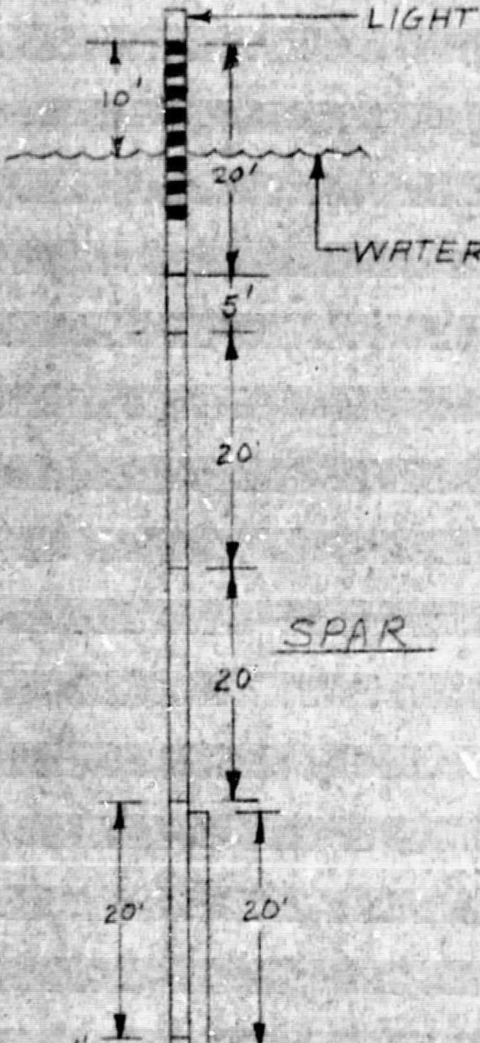
DROGUE BUOY FITTINGS

DROGUE BUOY FITTINGS



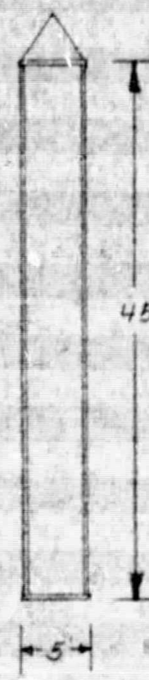
DRAWING 3/4

FOLDOUT FRAME 2



SPAR

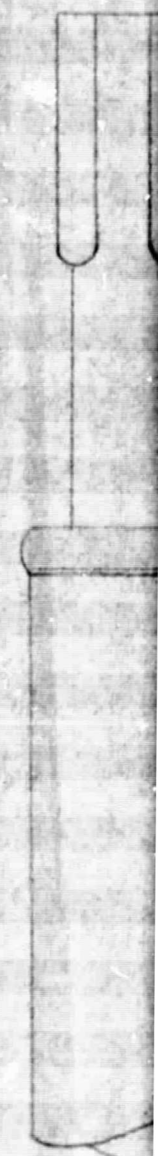
AIR-FILLED SHELTON BUOY
25 PSI PRECHARGE
2 7/8" O.D.
NET BUOYANCY - 2 LBS/FT.

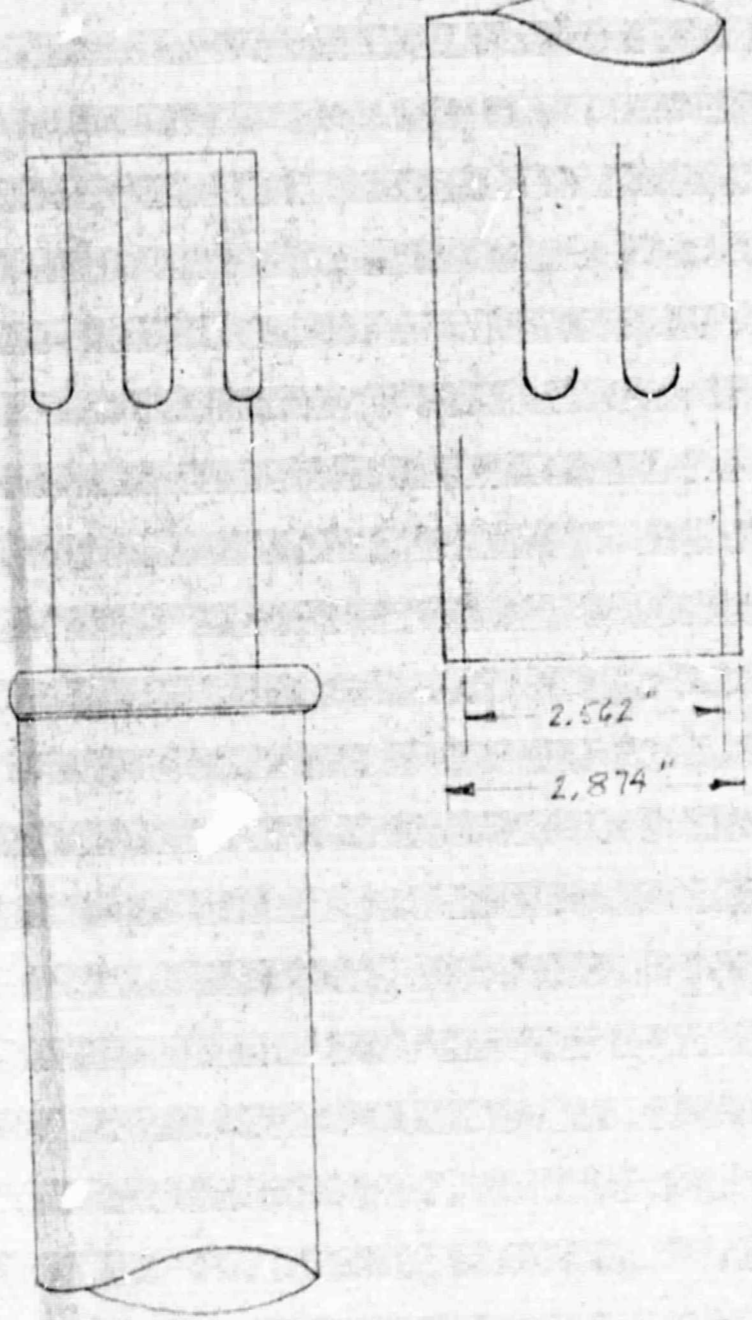


DROGUE

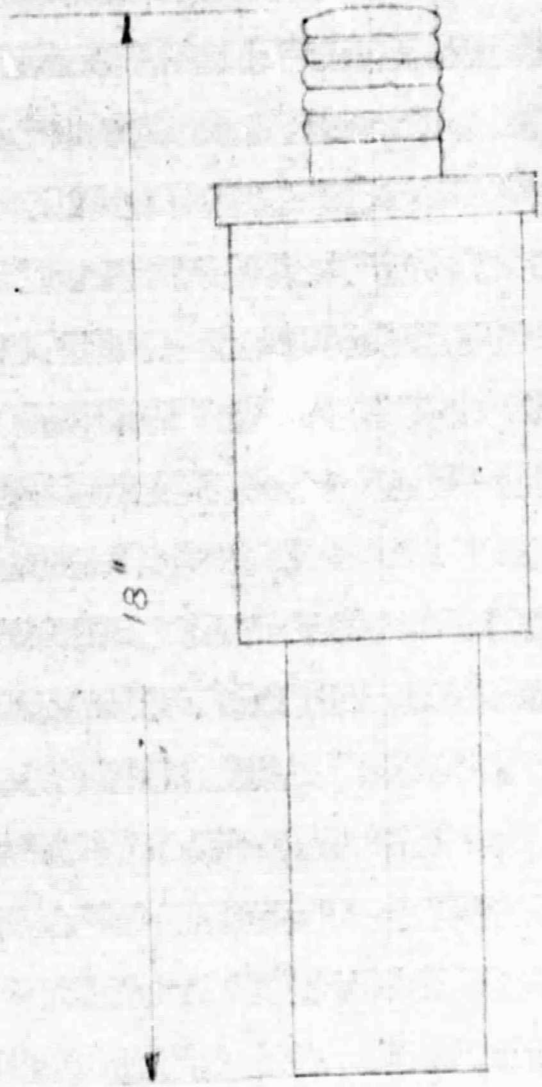
TETHER

FREE-FLOODING SHELTON
BUOY WITH 7# BUOYANCY
TRAWL FLOATS
2 7/8" O.D. NEUTRAL BUOYANCY





SHELTON BUOY COUPLING



LIGHT

DRAWING 4/4