HYDRAULICS RESEARCH DIVISION

Technical Note

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TITLE: Stability and Drag Tests on Submerged Floats - 1/2 Scale Subsurface Float.

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REASON FOR REPORT: Written at the request of the Bedford Institute of Oceanography as part of Hydraulics Research Division Study H 77 050 - "Towing Tests - Bedford Institute of Oceanography."

This is the first in a series of reports related to the above study.

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Stability and Drag Tests of Submerged Floats

Purpose :

1. To find the drag force as a function of velocity over a range of 0 to 4 knots, acting on a variety of subsurface floats.
2. To determine the stability of all floats throughout the velocity range of 0 to 4 knots.
3. To determine the behaviour of these floats when the current is reversed.

Specifications of Test Apparatus :

1. Towing mast (see Figure 1) - this was manufactured by CCIW staff using aluminum sailboat mast sections for the main spar. This mast is "L" shaped, has a movable friction free pivot on the vertical portion of the "L" and has attachment brackets for support and measuring lines. Mast dimensions are :-

   Vertical section - 457.00 cm

   Horizontal section - 153.00 cm

   Cross section - 10.10 cm x 7.60 cm
2. Pivot bearings Seal Master SF 12-3/4".
3. Strain wire guide pulley bearings - McGill MB25-5/8".
4. Tension measuring dynamometer - Dillon, 1000 lb capacity, 5 lb divisions.

5. Float attachment and tension measuring cable - .100" diameter.
6. Length measuring cable - .030" diameter.
7. Mast level - Sand's Craft No. SC 50
8. Towing device - Kempf and Remmers Modified C 102 Carriage.

Procedure :

The test apparatus was set up in the following manner :

- The dynamometer was suspended from the carriage mounted hoist.
- The strain wire guide pulley was bolted to the carriage platform.
- The mast assembly was bolted to the rear edge of the carriage so that the mast bottom was approximately 20 cm above the tank bottom and the mast was perpendicular to the water surface.
- The strain wire was attached from the bottom forward edge of the mast through the guide pulley to the bottom of the dynamometer. (See Figure 3)
- The strain wire was slackened and the mast was tilted until the tip of the "L" came to the water surface.
- A premeasured mooring line was attached from this tip of the mast to one of the mooring points on the underside of the float. (See Figure 3)
- The "Length measuring cable" was attached from the float mooring point, through the cable guides, to the top of the mast.

- The carriage mounted hoist was operated to bring the mast to its upright position perpendicular to the water surface and to submerge the float to its test position. This position was maintained throughout the tests with the aid of a level strapped to the upper portion of the mast and adjusting with the hoist.
- The length measuring cable was pulled taut and a reference mark was affixed to it.

Test were then commenced by dragging the float through the water at preselected velocities over the full range required. Once the float stabilized at each speed, a reading was taken from the dynamometer to obtain tension and a measurement made of the taut measuring cable length to provide the remaining information required. At least five runs were made at each velocity in order to minimize any human or equipment errors.

Calculations were then made to compute the drag force on the float, the drag coefficient of the float and the Reynolds No. throughout the tested velocity range.

Calculation of drag force

Referring to Figure 1, the sum of moments about the pivot results in the following equation : -

$$(1)\ldots\ldots\ldots(D_c \cos\phi)L_1 = D_s L_2 + T \cos(180 - \theta)L_3 + T \sin(180 - \theta)L_4$$

Where D_c = tension in the cable measured by the dynamometer.

D_s = drag force on the towing apparatus.

T = tension in the cable to the float.

L_1, L_2, L_3, L_4 = fixed distances as given in Figure 1.

ϕ, θ = angles as specified in Figure 1.

From equation (1)

$$(2)\ldots\ldots\ldots\ldots\ T = \frac{D_c \cos\phi\ L_1 - D_s\ L_2}{\cos(180 - \theta)L_3 + \sin(180 - \theta)L_4}$$

By measuring the cable length to obtain ℓ_1, Figure 1, and knowing the lengths of ℓ_2 and ℓ_3, the angle θ was calculated using the law of cosines. The drag on the strut, or towing apparatus, was measured in a seperate towing test without the float. It can be seen from equation (1) that, when $T = 0$

$$(3)\ldots\ldots\ldots\ldots\ D_s = \frac{F \cos\phi\ L_1}{L_2}$$

Where F is the cable tension measured by the dynamometer when towing the strut alone.

Substituting equation (3) into equation (2)

$$(4)\ldots\ldots\ldots\ldots\ T = \frac{(D_c - F) \cos\phi\ L_1}{\cos(180 - \theta)L_3 + \sin(180 - \theta)L_4}$$

The drag force on the float D_f = T Cos(180 - θ)

The drag coefficient C_D was defined as $C_D = \frac{D_f}{\rho \cdot A \frac{U^2}{2}}$

Where U = velocity of the float

A = cross-sectional area of the float

and ρ = density of the water

The Reynolds number, Re was also calculated,

$$Re = \frac{UD}{\nu}$$

Where D = float diameter

and ν = kinematic viscosity of water

Test # 1 - Drag Force, Stability & Current Reversal of 1/2 Scale Subsurface Float

Drag force tests were made with this 35.79 cm diameter, 1.5m long float moored from mooring hole #8 (See Figure 4) as this is normally used in operation. The mooring holes number 1 through 14 starting at the nose of the float. The towing velocity range tested covered 0 to 232 cm/s (4.5 kts) and data was collected at 26 cm/s (1/2 kt) increments.

The results of these tests are shown in the attached Figures.

Figure 1 is a descriptive drawing showing the test apparatus, as used, plus the symbols and measurements used in the calculations.

The test data and results are summarized in Table 1.

Figure 2 is a graph of drag coefficient versus Reynolds numbers.

With the float at rest in the submerged test position, it was approximately 3^{o} to 5^{o} nose down from the horizontal. As the towing speed increased, this angle decreased to almost 0^{o} at 206 cm/s (4 kts).

The float was very stable throughout this test and responded quickly and smoothly to return to pre reverse attitude during current reversing tests.

Test # 2 - Stability & Current Reversal of 1/2 Scale Subsurface Float

Mooring hole #7 (See Figure 4) was used for this test with the following results:

1. With the float at rest in the submerged test position, it was approximately 25^{o} nose down from the horizontal. As the towing speed increased this angle decreased to approximately 5^{o} at 206 cm/s (4 kts).
2. The float was very stable up to 103 cm/s (2 kts) when it began to yaw slightly but continuously. From 129 cm/s (2½ kts) through 155 cm/s (3 kts), there were occasional larger yaw motions, reducing again to continuous but slight yawing through 206 cm/s(4kts).
3. When the towing direction was reversed the float responded quickly and smoothly, throughout the 0-4 kt velocity range, to return to its pre reverse attitude.

Test # 3 - Stability & Current Reversal of 1/2 Scale Subsurface Float

Mooring hole #6 (See Figure 4) was used for this test with the following results:

1. With the float at rest in the submerged test position, it was approximately 35^{o} nose down from the horizontal. As the towing speed increased, this angle decreased to approximately 15^{o} at 206 cm/s.
2. The float was stable up to 51.5 cm/s when it took on a rapid, continous but slight yawing motion. This motion became very slight and fluctuating at 103 cm/s, slight, slow and continous at 129 cm/s then dropped off gradually to very slight, slow and continous at 206 cm/s.
3. When the towing direction was reversed, the float responded quickly and smoothly up to 77 cm/s. Gradually, from 77 cm/s to 206 cm/s, the reversing action became jerky, slower and more violent. At the beginning of the direction change, for speeds from 103 cm/s through 206 cm/s, the float would nose down sharply almost to the point of tumbling the body end over end before rotating horizontally. At all speeds the float eventually returned to the pre reverse attitude.

Test # 4 - Stability & Current Reversal of 1/2 Scale Subsurface Float

Mooring hole #9 (See Figure 4) was used for this test with the following results :

1. With the float at rest in the submerged test position, it was approximately 5^o nose up from the horizontal. As the towing speed increased this angle increased to approximately 10^o at 206 cm/s.
2. The float was stable throughout the velocity range 0 to 206 cm/s, however, it towed at an angle to the flow. From 26 cm/s through 180 cm/s, the float towed at approximately 5^o to the port side off parallel to the flow. This angle decreased slightly to approximately 2^o at 206 cm/s.
3. When the towing direction was reversed, the float responded quickly and smoothly up to 51.5 cm/s to return to the pre reverse attitude. From 51.5 cm/s through 206 cm/s, the reaction was quick and smooth to approximately 30^o off parallel to the flow and then very slow to the pre reverse attitude.

Test # 5 - Stability & Current Reversal of 1/2 Scale Subsurface Float

Mooring hole #10 (See Figure 4) was used for this test with the following results :

1. With the float at rest in the submerged test position, it was approximately 25^o nose up from the horizontal. As the towing

Test # 4 - Stability & Current Reversal of 1/2 Scale Subsurface Float

Mooring hole #9 (See Figure 4) was used for this test with the following results :

1. With the float at rest in the submerged test position, it was approximately 5^{o} nose up from the horizontal. As the towing speed increased this angle increased to approximately 10^{o} at 206 cm/s.
2. The float was stable throughout the velocity range 0 to 206 cm/s, however, it towed at an angle to the flow. From 26 cm/s through 180 cm/s, the float towed at approximately 5^{o} to the port side off parallel to the flow. This angle decreased slightly to approximately 2^{o} at 206 cm/s.
3. When the towing direction was reversed, the float responded quickly and smoothly up to 51.5 cm/s to return to the pre reverse attitude. From 51.5 cm/s through 206 cm/s, the reaction was quick and smooth to approximately 30^{o} off parallel to the flow and then very slow to the pre reverse attitude.

Test # 5 - Stability & Current Reversal of 1/2 Scale Subsurface Float

Mooring hole #10 (See Figure 4) was used for this test with the following results :

1. With the float at rest in the submerged test position, it was approximately 25^{o} nose up from the horizontal. As the towing

speed increased this angle increased to approximately 35° at 103 cm/s and then decreased to approximately 10° at 206 cm/s.

2. The stability of the float changed considerably throughout this test. From 26 cm/s through 51.5 cm/s, stability was good but the float towed approximately 5° to the port side of parallel to the flow. At 77 cm/s stability was fair with the float fluctuating to the port side from 5° to 10°. A slight yawing motion appeared at 103 cm/s and the towing angle decreased to approximately 2° and changed to the starboard side. At 129 cm/s it was slow to stabilize but eventually did so after swinging from a 10° to starboard angle to 10° to port angle. From 155 cm/s through 206 cm/s, the float was slow to stabilize but did so at a towing angle of 5° to the port side of parallel to the flow.

   It should also be noted that the stability was very sensitive to any added motion, such as a sudden speed or direction change. At the 180 cm/s to 206 cm/s portion of the velocity range, considerable vibration occurred in the test apparatus.

3. When the towing direction was reversed, the float responded smoothly but slowly from 26 cm/s through 77 cm/s. From 103 cm/s through 206 cm/s, the reaction was smooth and moderately fast to approximately 25° off parallel to the flow and then slow to the pre reverse attitude.

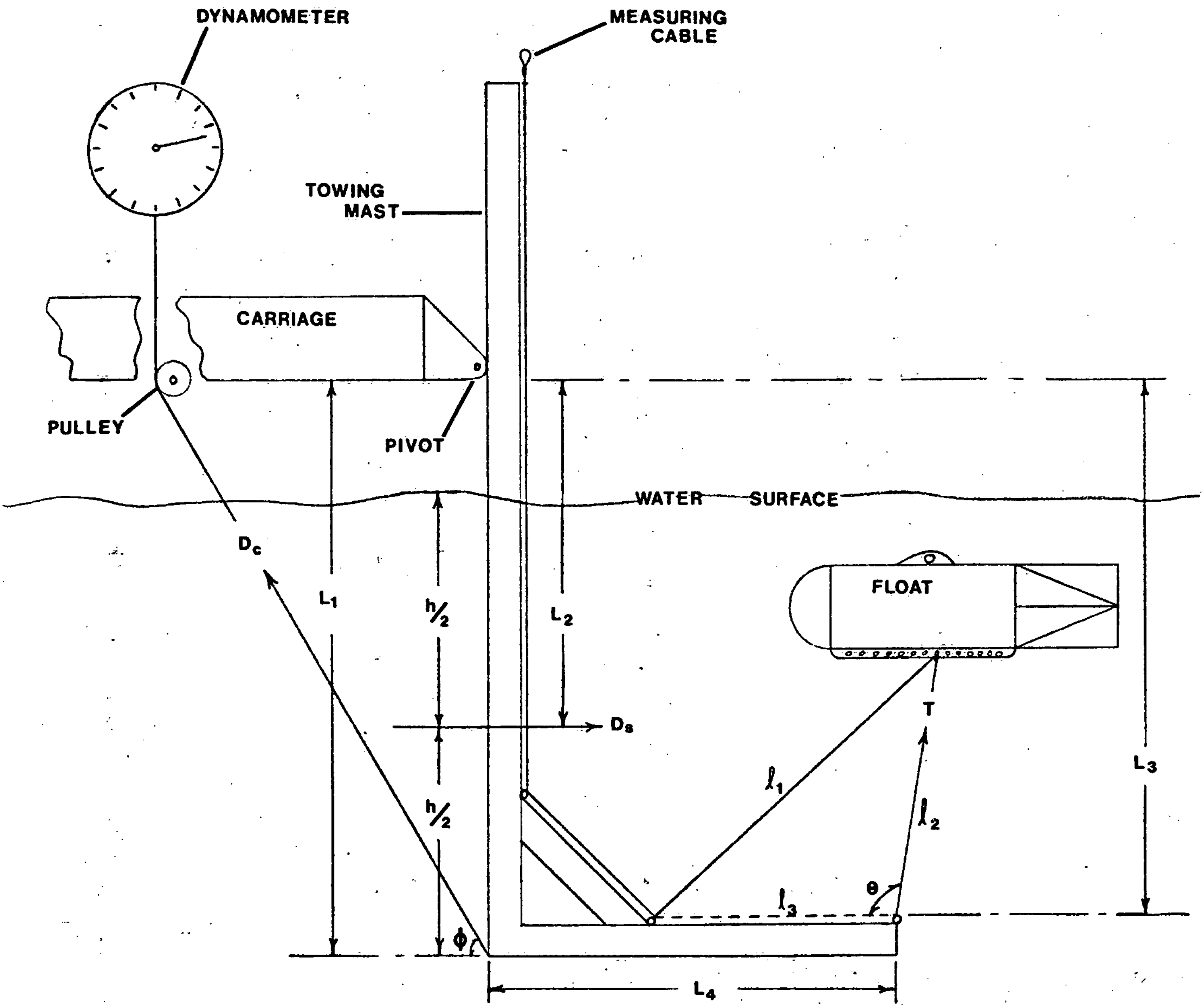
A general note can be made that the quicker the current was reversed the more violent the float reaction was. At the higher velocities, this reaction was violent enough to bend the towing apparatus.

U m/s	D_c (N)	ℓ_1 (m)	cosθ	θ	D_S (N)	T (N)	D_f (N)	C_D	Re
.260	889.6	1.673	.00069	89.96	53.2	858.6			8.23×10^4
.515	929.7	1.680	-.0103	90.59	53.2	881.5	9.08	.681	1.63×10^5
.770	951.9	1.686	-.0198	91.14	57.0	883.6	17.58	.590	2.43×10^5
1.030	963.0	1.6904	-.0268	91.54	64.6	874.6	23.50	.441	3.26×10^5
1.290	967.5	1.6958	-.0354	92.03	76.0	852.7	30.20	.361	4.08×10^5
1.550	1000.8	1.7076	-.0543	93.11	96.5	834.1	45.25	.375	4.90×10^5
1.800	1060.9	1.7216	-.0768	94.41	117.8	835.1	64.21	.394	5.70×10^5
2.060	1085.4	1.7272	-.0859	94.93	167.1	793.5	68.19	.320	6.82×10^5

NOTE: Units are S.I. metric.

TEST DATA

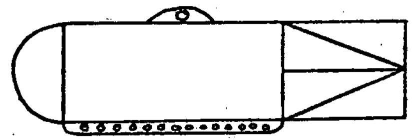
TABLE 1



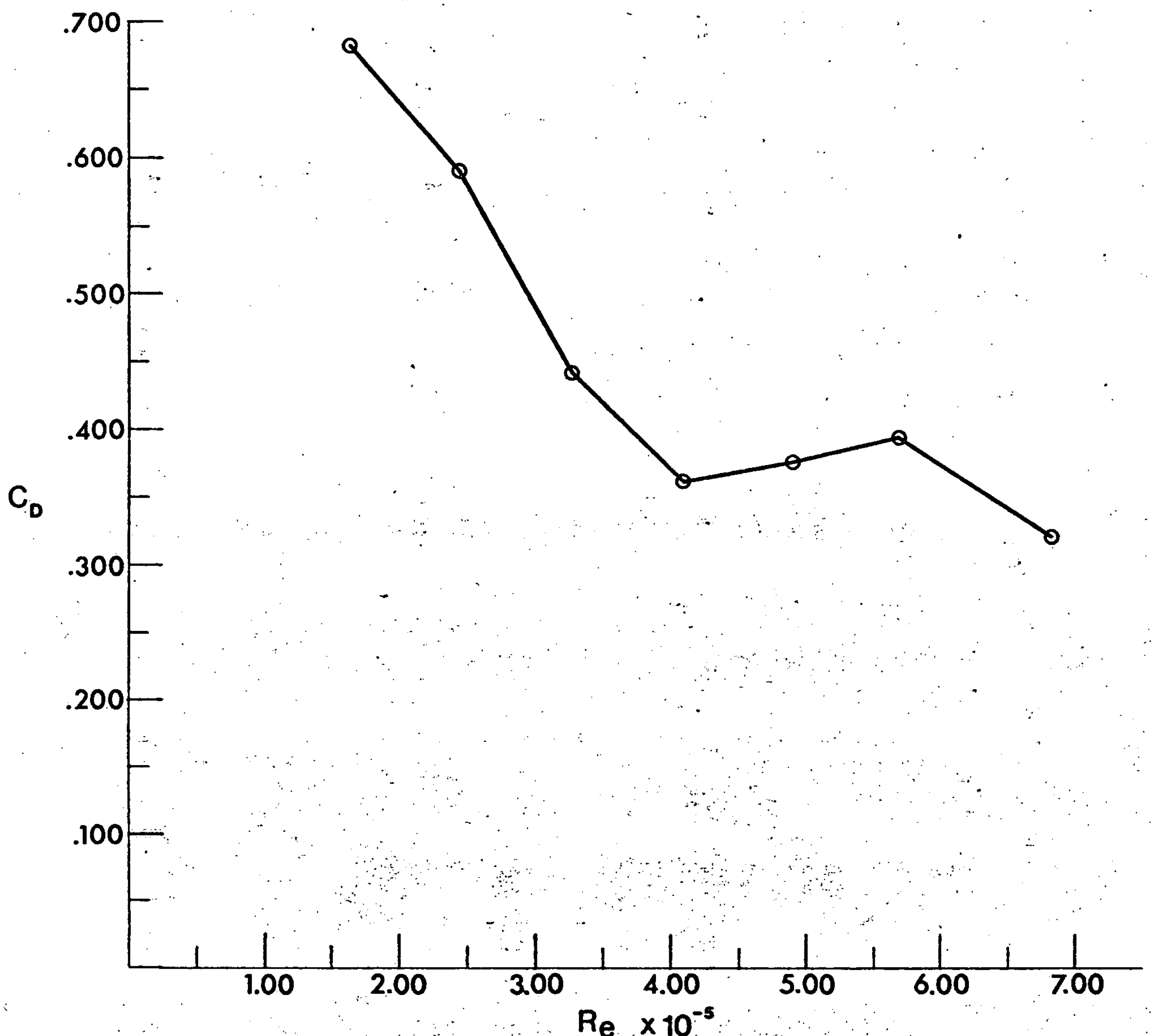
L_1 =	3.038 m	ℓ_1 =	variable (1.673 m at rest)
L_2 =	1.9115 m	ℓ_2 =	1.52 m
L_3 =	3.038 m	ℓ_3 =	.70 m
L_4 =	1.575 m		
$h/2$ =	1.2465 m	ϕ =	57.5°

Schematic View of Test Apparatus

FIG. 1



Float Shape



Mooring Hole 8
Drag Coefficient Versus Reynolds Numbers

FIG. 2

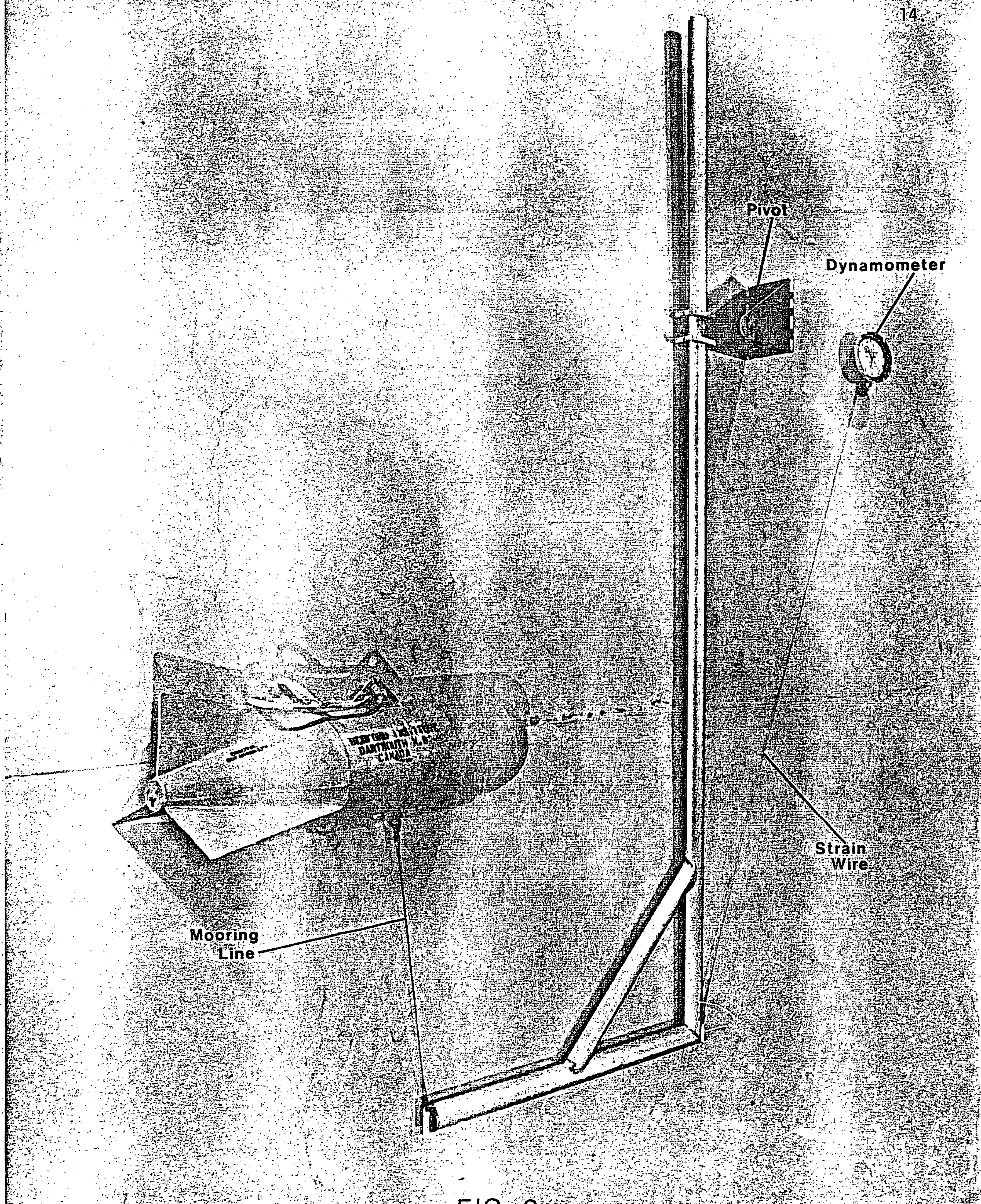


FIG. 3

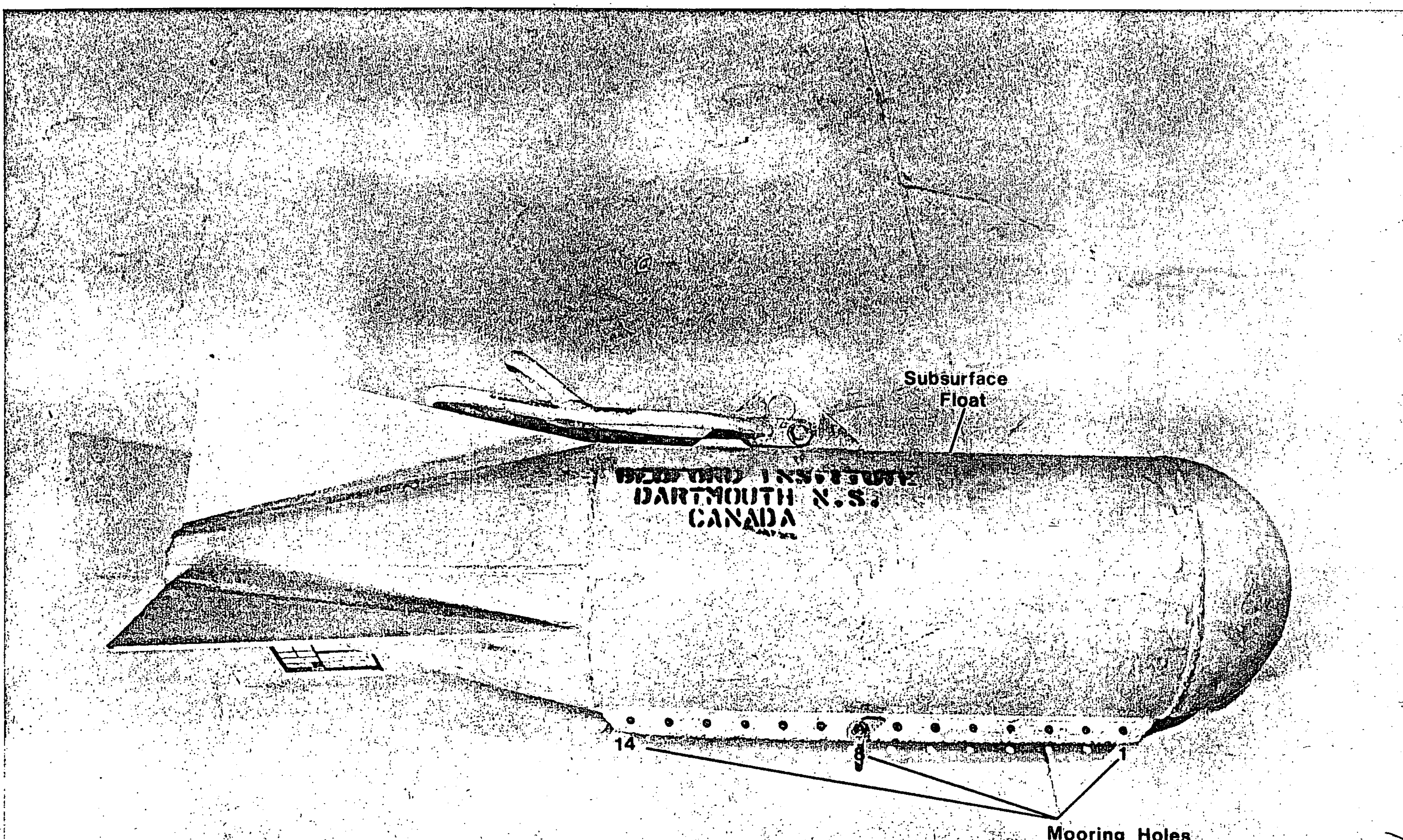

Subsurface Float
BEDFORD INSTITUTE
DARTMOUTH N.S.
CANADA
14
8
1
Mooring Holes

FIG. 4