HYDRAULICS RESEARCH DIVISION

Technical Note

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

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

CORRESPONDENCE FILE NO:

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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

   Horizonatal 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, 100 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 throughtout 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.

Tests 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 I, the sum of moments about the pivot results in the following equation:

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

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 I.

ϕ, θ = angles as specified in Figure I.

From equation (I)

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

By measuring the cable length to obtain ℓ_1, Figure I, 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 separate towing test without the float. It can be seen from equation (I) that, when T = 0

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

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

Substituting equation (3) into equation (2)

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

The drag force on the float $D_f = T \cos(180 - \theta)$

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

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,

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

Where D = float diameter

and γ = kinematic viscosity of water

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

Drag tests were made with this 35.79 cm diameter, 1.5 m long, float with a modified tail section 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 intended velocity range to be covered was 0 to 206 cm/s (4.0 kts), however, at 155 cm/s (3 kts) the float towed 1 m to starboard of the towing point (the point where the float mooring cable is attached to the mast) and at about 35° to the direction of flow. As a result the tests had to be stopped to prevent damage to the towing apparatus and the test velocity range for the test was from 0 to 129.0 cm/s (2.5 kts) in 26 cm/s (.5 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 results are summarized in Table 1.

Figure 2 is a graph of drag coefficient versus Reynolds numbers. The value of C_D for the lowest velocity of 26 cm/s (.5 kt) must be considered doubtful because at that velocity the towing cable was almost still vertical. With the equipment available, it was not possible to obtain accurate values for the angle θ and the drag force at those low speeds. It was also noted at 26 cm/s (.5 kt) that the float towed to starboard (when standing on the carriage looking back at the test apparatus) at about 10° to the direction of flow. The dotted line in Figure 2 indicates the probable trend for the drag coefficient.

1. With the float at rest in the submerged test position, it was 13° nose down. As the towing speed increased this decreased to about 10° at 129 cm/s (2.5 kts).
2. At 26 cm/s (.5 kt) the float towed at about 10° to starboard of the direction of flow and this decreased to 5° at 77 cm/s (1.5 kts). However, after 77 cm/s (1.5 kts) the float started to yaw and as was previously mentioned this increased until it went out of control at 155 cm/s (3.0 kts).

3. The float did respond quickly and smoothly throughout the 0-129 cm/s (2.5 kts) velocity range to return to pre reverse attitude during current reversing tests.

Test #2 Stability and Current Reversal of a Modified 1/2 Scale Subsurface Float

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

It should be noted that the full range of velocities from 0 to 206 cm/s (4 kts) was attained.

1. With the float at rest in the submerged test position, it was 25^{o} nose down from the horizontal. As the towing speed increased, this angle decreased to approximately 15^{o} at 206 cm/s (4 kts).
2. The float was very stable up to 103 cm/s (2 kts) and then it began to yaw slightly but continuously. This yawing increased slightly through to 206 cm/s (4 kts) but did not appear to increase past approximately 10 cm on either side of the towing point.
3. When the towing direction was reversed, the float responded quickly and smoothly, throughout the 0-206 cm/s (4 kts) velocity range, to return to its reverse attitude.

Test #3 Stability & Current Reversal ofa Modified 1/2 Scale Subsurface Float

Mooring hole #9 was used for this test with the following results:

It should be noted that the velocity range attained was from 0 to 129 cm/s (2.5 kts) for this test.

1. With the float at rest in the submerged test position, it was level in the water and remained that way throughout the velocity ranges tested.

2. At 26 cm/s (.5 kts) it towed at approximatley 25° to the direction of flow and this increased to approximately 45° at 129 cm/s. It was also noted that the float started out directly over the towing point and moved 60 cm to the starboard side at 129 cm/s. The float went out of control at 155 cm/s and the tests were stopped.

3. When the towing direction was reversed the float responded quickly and smoothly, throughout the 0–129 cm/s (2.5 kts) velocity range, to return to its pre reverse attitude.

<u>General Comment</u>

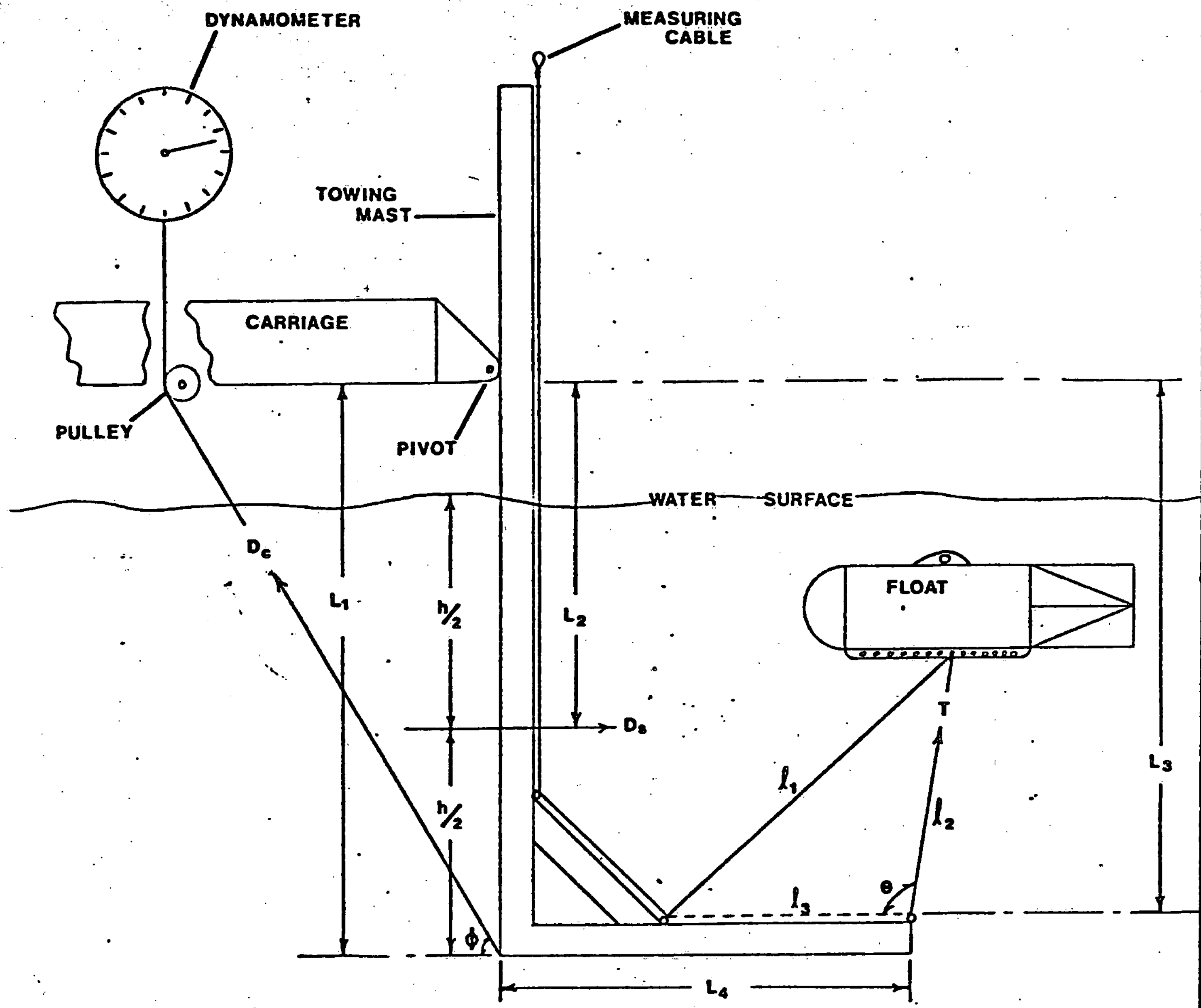
This test was performed in order to have a comparison between the unmodified 1/2 scale subsurface float and the modified version of the same. In general, it was observed that the modified version had a tendency to yaw and pull to one side as the velocity increased whereas the unmodified version towed much better. Both floats, however, did respond smoothly and quickly during the current reversal tests and no difference was apparent.

U m/s	D_c (N)	ℓ (m)	cos θ	θ	D_s (N)	T (N)	D_f (N)	C_D	Re
.260	911.9	1.675	-.0025	90.14	53.2	876.4	2.14	.630	8.23×10^4
.515	923.5	1.682	-.0135	90.77	53.2	870.1	11.69	.877	1.63×10^5
.770	956.4	1.687	-.0214	91.23	57.0	885.6	19.01	.638	2.43×10^5
1.030	992.0	1.698	-.0389	92.23	64.6	884.0	34.40	.645	3.26×10^5
1.290	1000.4	1.700	-.0421	92.41	76.0	874.4	36.77	.440	4.08×10^5

Note: Units are S. I. Metric.

TEST DATA

TABLE I



L_1 = 3.038 m
L_2 = 1.9115 m
L_3 = 3.038 m
L_4 = 1.575 m

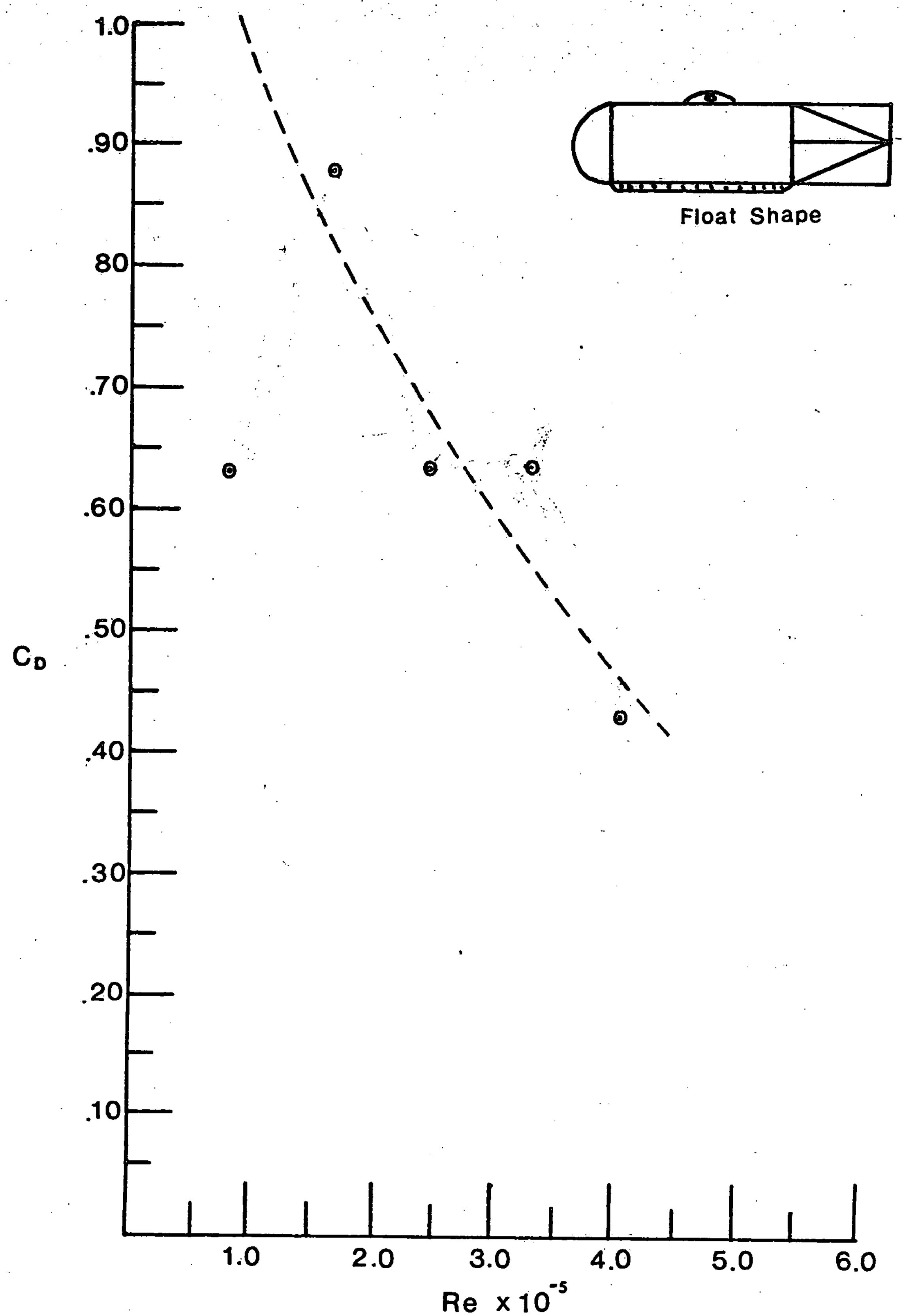
$h/2$ = 1.2465 m

ℓ_1 = variable (1.673 m at rest)
ℓ_2 = 1.52 m
ℓ_3 = .70 m

ϕ = 57.5°

Schematic View of Test Apparatus

FIG. 1



Mooring Hole 8

Drag Coefficient Versus Reynolds Numbers

FIG. 2

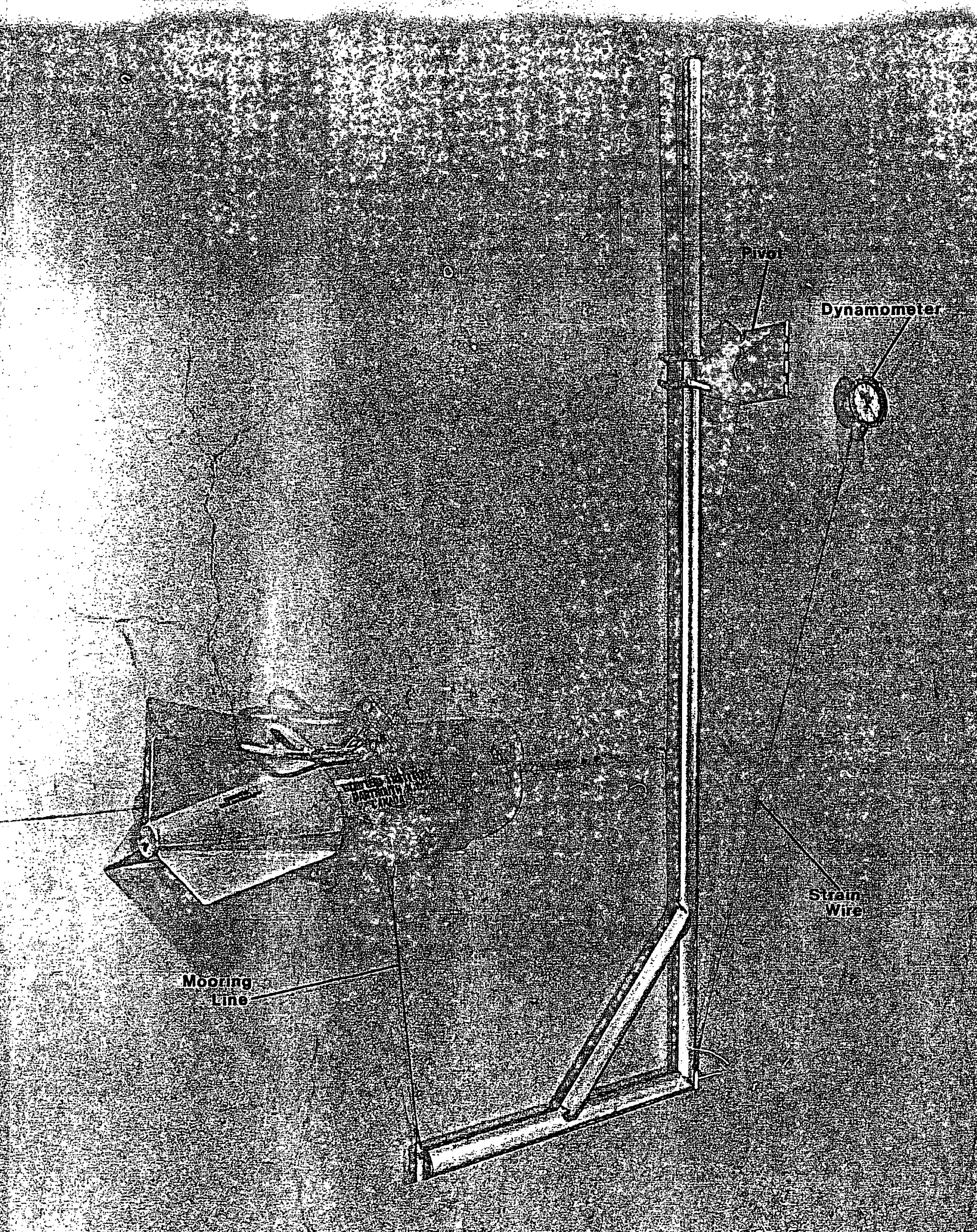


FIG. 3

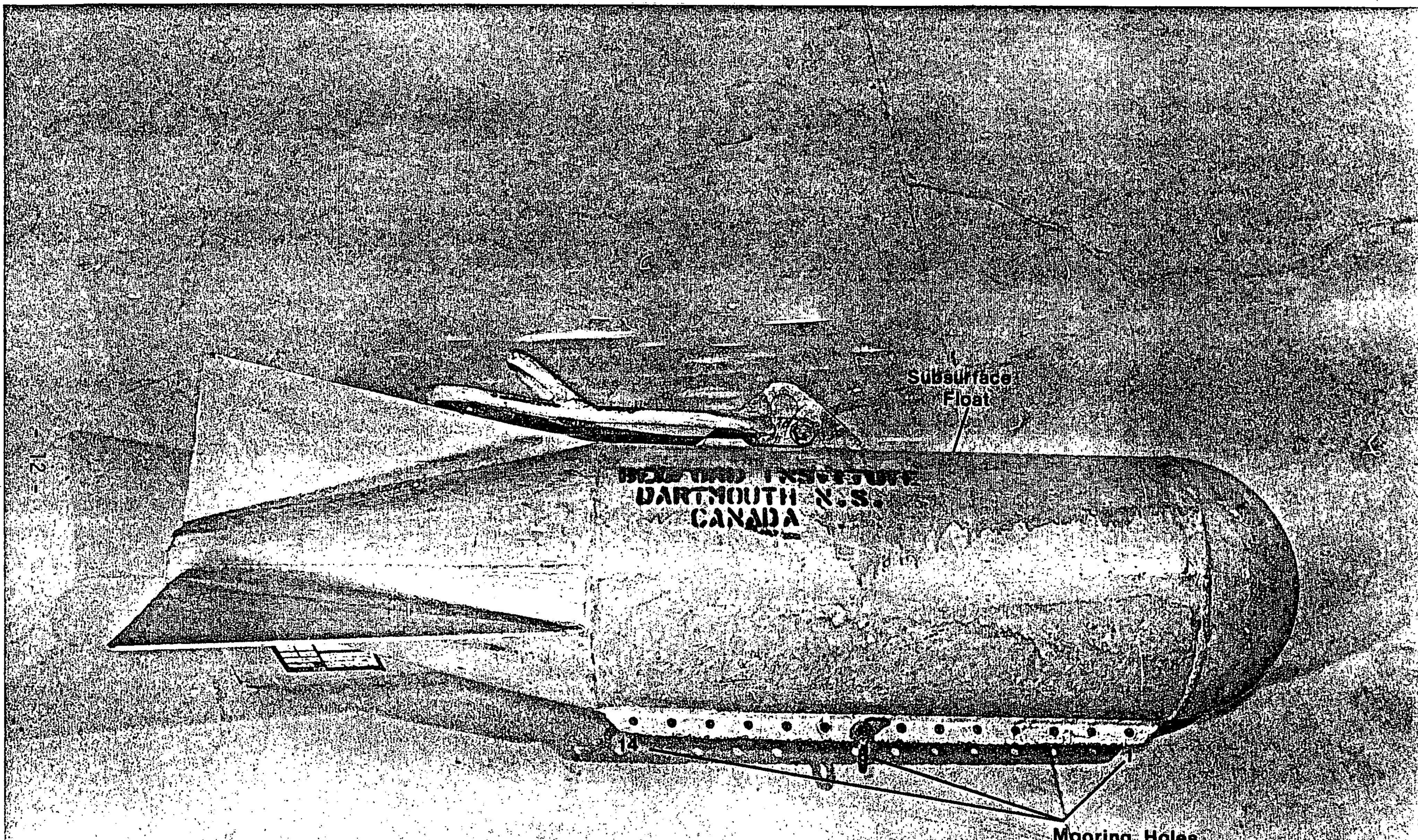


FIG. 4