HYDRAULICS RESEARCH DIVISION

Technical Note

DATE: 18 May 1978 **REPORT NO:** 78-11

TITLE: "Design of Substitute Drag Device of Neutral Buoyancy"

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REASON FOR REPORT:

This report was written in response to a request by Westinghouse Canada Ltd.

CORRESPONDENCE FILE NO:

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1.0 INTRODUCTION

This short report deals with two separate problems as defined by Westinghouse Canada Ltd.

Part one of the report will deal with problem one and Part two with problem two.

2.0 PROBLEM 1

2.1 Description and Terminology

A sketch of the arrangement is shown in Figure 1. The problem is to devise a "Drag" so that the tension in the substitute cable AC at point C will be the same as the tension in the final system at point C. The substitute Drag and cable will be used to test the balance of forces F, B, Mg, D and T when under tow.

The reference velocity for equivalence is to be 12 knots which is 6.27 m/s.

2.2 Information Supplied by Westinghouse

The tension at points A, B, and C in the Droque Cable System are listed in Table 1 which duplicates that supplied by Westinghouse Canada.

Table 1 Cable Tension as Supplied by Westinghouse Canada

Velocity Knots	Tension @ (lbs. force)		
	Drogue (A)	(B)	Tether (C)
5	3.26	39.00	97.48
10	13.05	149.28	374.67
15	29.37	327.39	824.90
20	52.21	571.56	1439.05
25	81.58	880.61	2212.09
30	117.46	1253.63	3140.48

2.3 Drag Coefficients for Cable

The forces in Table 1 are developed from the equation supplied by Westinghouse.

$$T = C(R)\,\rho\,\frac{V^2}{2}\,\pi\,D\,L \qquad \ldots 1$$

where R is a Reynolds Number

ρ is the fluid density

V is the mean field velocity

D is the cable diameter

L is the length of cable

T is the force required to maintain V

C is a coefficient of tangential drag.

From 1 it follows that:

$$C \rho = \frac{2T}{V^2 \pi D L} \qquad \ldots 2$$

The quantity $C \rho$ must be taken together since the data supplied in Table 1 does not indicate if the forces were derived from salt or fresh water. Values of $C\rho$ are listed in Table 2.

Table 2 Average Values of Surface Drag Coefficient Times Fluid Density for Cable in Figure 1.

Velocity Knots	Values of C		
	½" D Cable Drogue	2.8" D Cable A to B	2.25" D Cable B to D
5	.0140	6.22×10^{-3}	6.19×10^{-3}
10	.0140	5.93	5.96
15	.0140	5.76	5.85
20	.0140	5.64	5.74
25	.0140	5.59	5.64
30	.0140	5.49	5.55

Evidently the thicker parts of the trailing cable are much smoother than the ½" diameter drogue.

2.4 Empirical Law for Tension at Point C

Table 1 provides the values for velocity V and the force at C so that

$$T_c = A V^n \qquad \ldots 3$$

where T_c is the cable tension at point C in lbs. force

V is the velocity in knots

A is a proportionality constant.

By plotting the data on logarithmic paper A and n have been found. It follows that

$$T_c = 4.308\, V^{1.94} \qquad \ldots 4$$

and, therefore, for the reference velocity of 12 knots, T_c=534.42 lbs. force.

2.5 Problem to be Solved

Based on the information supplied, the problem is to find a substitute system composed of a neutrally buoyant cable and drag which will create the same force at C as the proposed towed cable array. The Drag is to be neutrally buoyant.

3.0 DESIGN CONSIDERATIONS

3.1 Wake of Towed Body

As the towed body passes through the water, it will drag some water with it and set up turbulence and movement. These motions take some time to dampen and consequently the Drag will encounter fluid which is not at rest. The typical time for motions to dampen out is about 10 to 20 minutes. It is, therefore, clearly impracticable to avoid wake interference by using a long enough tow rope.

For example, at 15 knots, the Drag covers 100 feet in four seconds.

It is also obvious that in the prototype cable system that the encounter velocity of the cable will be less than the towed velocity by a small but indeterminate amount.

Since precise calculations are out of the question, a tow rope of 100 feet or so seems suitable.

3.2 Reference Velocity

As indicated in 2.4, the new rope and drag are to give the correct force for a speed of 12 knots. This speed refers to the velocity of the towed body.

3.3 Drag Formula

The force exerted on a moving object which is travelling at a uniform speed is generally expressed by

$$T = C_D(R)\, A\, \rho \frac{V^n}{2} \qquad \ldots 5$$

where
T is the force
n is an exponent - generally close to 2
A is the projected area on a plane perpendicular to the velocity vector
ρ is the fluid mass per unit volume
V is the velocity of the object relative to the water
$C_D(R)$ is a coefficient of proportionality which is also a function of the Reynolds Number
R is the Reynolds Number given by $Vd\rho/\mu$ where d is a typical linear dimension and μ is the coefficient of viscosity

For many objects, C_d falls in value as N increases but it may also behave rather irregularly depending on the body geometry.

For objects which have sharp discontinuities, so that the flow separates at a fixed point over a large range of Reynolds Number, the value of C_d tends to be a constant, so that

$$T = C_d A \rho \frac{V^n}{2} \text{ for turbulent flow}$$

$$\therefore T = \text{Constant } V^n \qquad \text{...6}$$

The constant for the towed cable array is 4.308 and n=1.94.

In order to retain this simple relationship, the drag coefficient for the Drag must not be a function of the Reynolds Number for the operating range.

3.4 Buoyancy and Trim

In order to have a Drag which will behave predictably, it must keep its horizontal axis level. Design requirements are to have the buoyant force equal the weight. That is, the submerged weight is zero. It is also desirable to have the buoyant force above the centre of mass, so that the body, if disturbed, will tend to return to a horizontal position.

3.5 Stability

Some shapes, notably cylinders, shed vortices in such a way that unequal lateral forces are set up which cause the towed object, or the object anchored in the current, to oscillate, sometimes violently. Examples are, an unsteady kite and galloping transmission cables.

Deterministic theories for bodies likely to oscillate are not available but certain shapes are known to be stable.

3.6 Cavitation

As the water flows around a submerged object, the pressures near the object deviate from the ambient. In the low pressure zones, if the pressure falls below the vapour pressure, gas bubbles are formed accompanied by noise. Over protracted periods, cavitation may damage boundary materials. Over short periods, surface pitting is not a major concern.

Assuming the body has a sharp separation line and has a cavitation number similar to a flat disk of 0.73, the velocities at which cavitation would start to occur are given in Table 3.

Table 3 Critical Velocities for Cavitation

depth (ft)	V_{cr} fps	V_{cr} knots
0	55	32.5
50	86.3	51.0
100	108.8	64.4

From Table 3, it seems unlikely that cavitation will be a factor unless the substitute Drag is operated at very high speeds close to the surface.

4.0 SELECTED DESIGN

4.1 Uncertainties and Alternatives

The substitute Drag is to be designed to equal the tensions in Table 1 at 12 knots. The actual tensions which will develop are not known. Therefore, it may be desirable to arrange for the substitute Drag to provide a range of forces on the towed body. The range should cover reasonable eventualities in view of the uncertainty of the effect of the wake of the towed body.

A range of forces is achievable by,

a. Making one Drag of which the dimensions may be altered
b. Making several, geometrically similar, Drags of different sizes
c. Providing several tow ropes which have different Drag forces. Some enhancement of tangential Drag may be necessary.

The proposed Drag should also be neutrally buoyant and should maintain a horizontal position, if undisturbed. This is difficult to arrange without trial and error.

After some consideration, we believe the Drag design should be kept simple and a number of sizes should be made. Small adjustments in total Drag can be attained by varying the cable length.

4.2 Design of Drag

A suitable Drag form is shown in Figure 2. The final dimensions should be close to that shown. However, a series of tests are required before a substitute Drag can be made to meet the specified Drag force at 12 knots.

The steps are as follows:

1. Select the tow cable and test to find its longitudinal friction coefficient.
2. Compute the force exerted by the cable for the selected tow line length. From Table 1, and Table 2, a ½" diameter cable 100 feet long will cause a force about 38 lbs. at 12 knots and a 1¼" diameter cable 95 lbs. force.
3. Construct a prototype to provide the balance of the Drag force based on estimated Drag coefficients.
4. Obtain the true Drag coefficient by tests.
5. Calculate final dimensions of the Drag for testing in fresh water and or salt water.
6. Construct prototypes for test purposes.

The placing of the buoyant foam will be done by a process of trial and error. All compartments must be permitted to flood.

5.0 PROBLEM TWO

There have been questions raised as to whether the towed body will follow the ship track during a turn, or whether it will swing inside or outside the track.

A supplementary question is the time taken for the towed body to be substantially on track after a turn.

5.1 Forces on the Towed Body

Figure 1 shows the forces as projected on a vertical plane. In general, B and Mg will not act vertically, but the motive force F and the resultant drag force D may act at any angle.

The form and shape of the cable between the towed body and the ship is quite indeterminate and complex. Consequently, a mathematical description of the towed body's track and that of the ship is virtually out of the question.

5.2 Inductive Reasoning

As the ship begins to turn, the towed body is still going straight ahead. When the turn is eventually transmitted down the cable, the ship will be well into the turn and the cable will exert a force component inwards towards the centre of the turn. This effect will be progressive and the lateral force will cause the towed body to accelerate laterally until dynamic equilibrium is reached. It follows, since the effect of the turn is to reduce the straight ahead motive force and to introduce a lateral force, that the body will track inside the ship path.

Another argument is to consider the radius of turn. As shown in Figure 3, when the ship goes straight ahead, i.e. $R=\infty$, the force F' - horizontal component is equal to D'. If the ship could take an instantaneous turn, i.e. $R=0$, then F' would equal zero. An intermediate radius of turn must cause some reduction in F' and consequent deceleration of the towed body. Since the ship and the towed body must complete a turn in the same interval of time, although one lags the other, and since the towed body decelerates, then the towed body must follow a shorter path. It can only do this by following a path of smaller radius.

Consequently, it seems the towed body should track inside the ship path.

5.3 Visual Confirmation

Some simple tests were set up in a flume with still water. A circular track with tangent was marked on the flume bottom. A small bottle, as a drag, was partially filled with water to achieve neutral buoyancy. The bottle was towed along the path scribed on the bottom by hand and photography taken of intervals.

Although the photographs are not of good quality, the pictures, Figure 4 shows quite clearly the bottle as a towed body keeps to the inside of the "ship" track.

5.4 Movement Back to the Centreline After a Turn

If the towed body is displaced laterally, there is a component of force available to accelerate it laterally in the force direction. Fluid friction forces act to oppose the motion and to dampen the oscillations. The basic equation is given by equation 7 which considers only a simple towed object and not a complex system as the prototype.

$$P(y) - C A_y \rho \frac{\dot{y}^2}{2} = M \ddot{y} \qquad \ldots 7$$

where

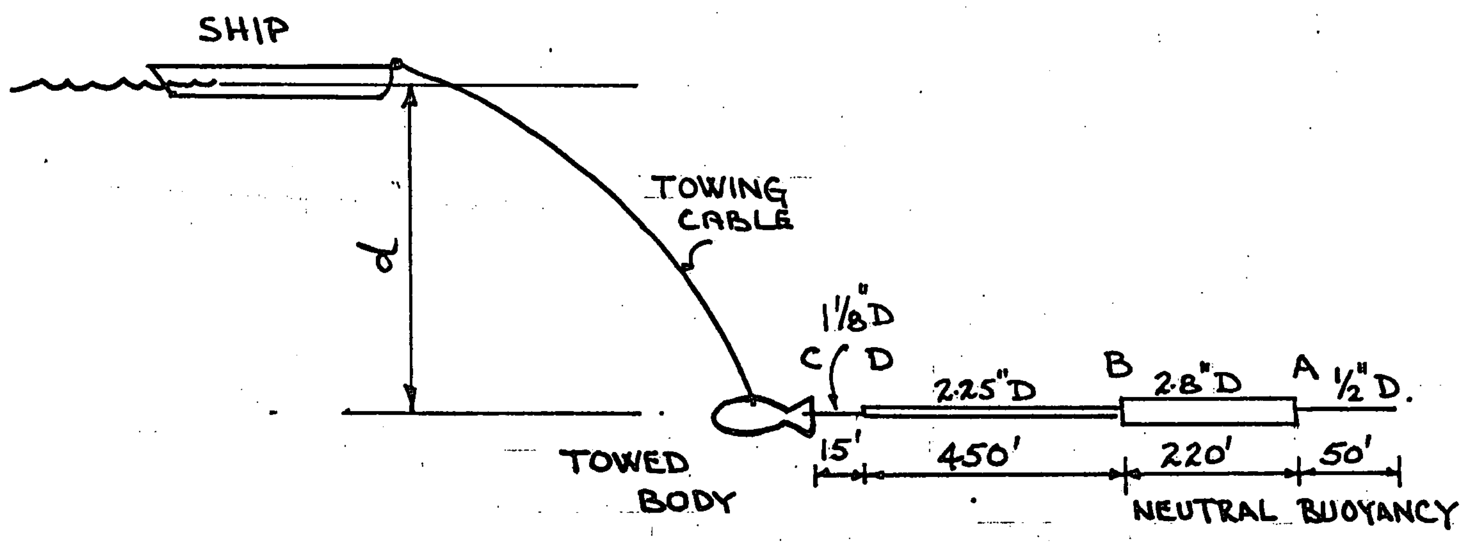
- $P(y)$ is the lateral force, a function of y
- M is the mass of the towed body
- y is the lateral coordinate
- A_y is the area projected on a plane perpendicular to y
- ρ is the water density.

This is a non linear differential equation of the second order. There is no general solution and the usual artifice is to linearize the equation, which basically assumes the dampening drag force is proportiontal to V for small displacements and low velocities.

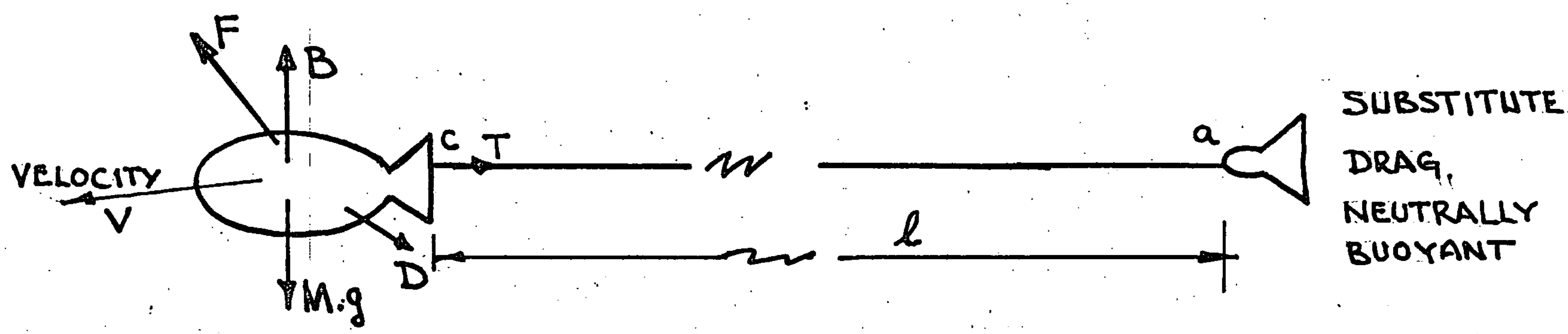
Intuitively, it seems the towed system provides for large dampening forces compared to the disturbing force. Consequently, the system should behave as an overdamped system and converge close to the neutral point quite quickly and without oscillations provided the towed body is itself stable.

6.0 SUMMARY

1. A possible design for a substitute drag is proposed.
2. The procedure to reach the final design or designs are outlined.
3. Arguments are presented for the path of the towed body and its return to the neutral position after a turn.



ELEVATION GENERAL ARRANGEMENT



ELEVATION SUBSTITUTE SYSTEM.

T. TENSION FORCE IN CABLE AT C
F TOWING CABLE FORCE
B BUOYANT FORCE
M MASS OF TOWED BODY
g GRAVITATIONAL CONSTANT
D. TOTAL FLUID DRAG ON BODY.

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TITLE GENERAL ARRANGEMENT.		
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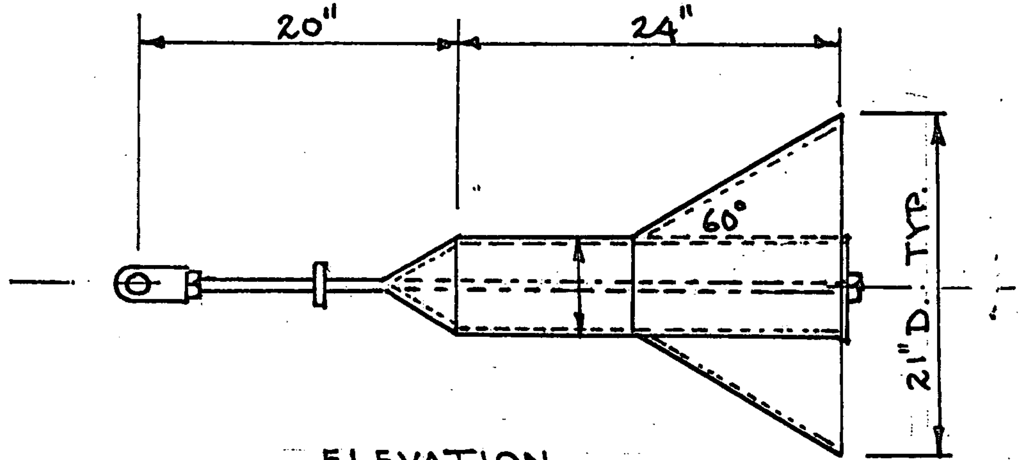
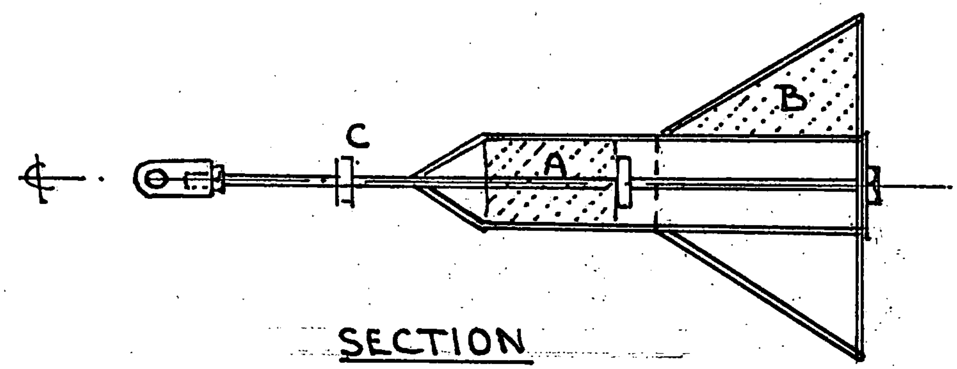
SCALE N.T.S	DATE 18 MAY 78	SHEET OF



ELEVATION



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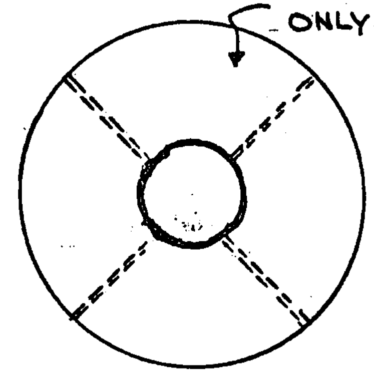

MATERIAL. ALUMINUM OR STAINLESS STEEL

NOTES.

1 CLOSED CELL FOAM B
2 CLOSED CELL FOAM A ADJUSTED TO GIVE ZERO BUOYANCY.
3 BALANCE WEIGHT C - MOVABLE FOR TRIM.
4 FINAL DIMENSIONS DEPEND ON TESTS
5 ALL COMPARTMENTS ARE FLOODED.

Environment Canada Hydraulics Research Division C.C.I.W.	Environnement Canada Division de la Recherche Hydraulique C.C.E.I.	
TITLE SUBSTITUTE DRAG		
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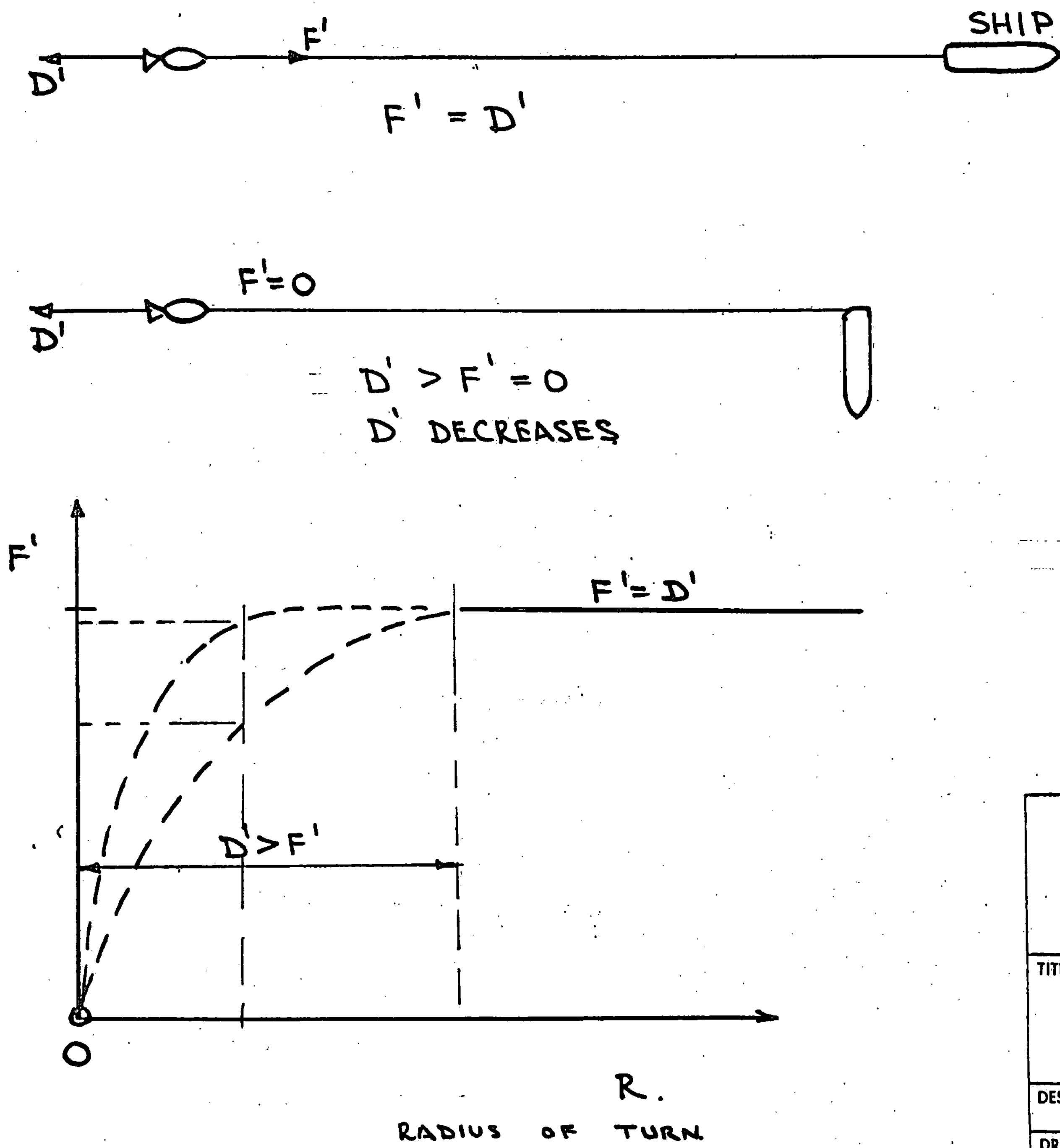

R = ∞
SHIP GOES STRAIGHT AHEAD.

R=0
SHIP MAKES IMAGINARY ZERO RADIUS TURN.

D' REPRESENTS DRAG FORCES
F' REPRESENTS CABLE FORCE.

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TITLE
EFFECT OF TURN RADIUS ON CABLE FORCE

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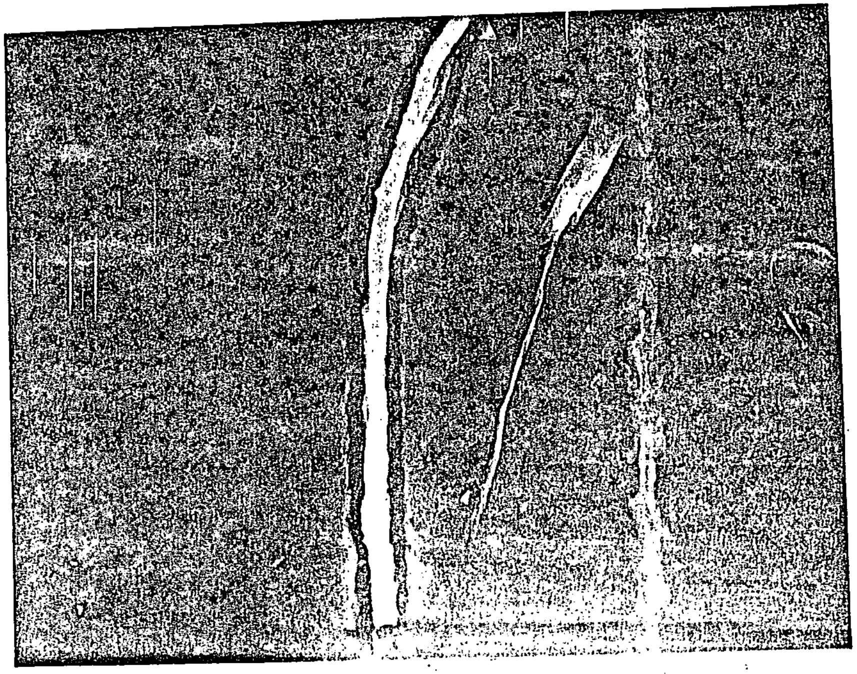

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TITLE

PHOTOGRAPHS OF MODEL TEST OF DRAG. LOCATION.

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