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U. S. Navy Underwater Sound Laboratory
Fort Trumbull, New London, Connecticut

AN ANALYSIS OF VDS KITING PHENOMENA

By

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INTRODUCTION

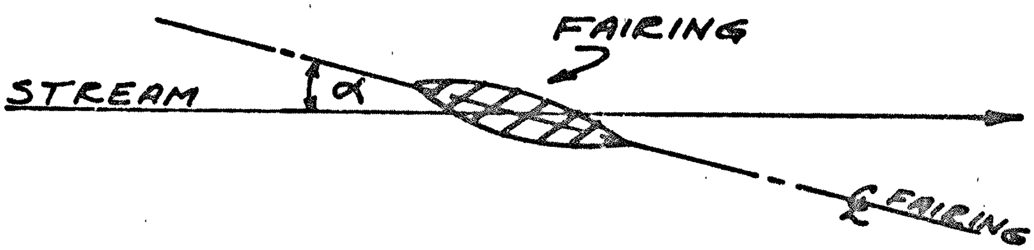
While towing a VDS fish at sea, ideally the towed body should be directly aft of the ship; however, the forces and their components acting on the towline cause VDS fish to veer toward port or starboard of the ship's wake. This memorandum analyzes the forces that act on a faired towcable and demonstrates that kiting is a natural phenomenon.

ANALYSIS

Figure 1 illustrates the towline geometry and the kite angle, drawn viewing the stern of the ship in the direction of motion of the ship. The Z axis, shown in figure 1 directed into the plane of the page is the vertical axis that includes the direction of motion. The towpoint at the ship is the origin of the coordinate system.

Reference (a) defines kite angle as the angle, on a vertical plane perpendicular to the direction of motion, formed by a vertical line drawn through the towpoint and the horizontal projection of the towline in the direction of motion to that vertical plane. In figure 1, the plane of the page is the vertical plane and the angle, θ, is the kite angle.

In the analysis that follows it is assumed that towline kite angles are induced during towing primarily because the angle of attack of each fairing, as shown below, generates lift forces along the faired cable.



α, the angle of attack of the fairing, is the angle formed between the centerline of each fairing and the direction of the stream when the towline is not parallel to the direction of the stream.

Other terms that are used in the analysis are:

A = Projected frontal area of the towline in the direction of the stream (FT^2)

C = 0.208 for the DTMB #7 fairing shape (applicable to the AN/SQA-10 towline)

L = Lift force acting on the towline (Lb/Ft)

ρ = Density of sea-water ((Lb/Ft^3)

R = Resultant of W and L = $(W^2 + L^2)^{\frac{1}{2}}$ (Lb/Ft)

S = Length of cable as measured in the X-Z plane (Ft)

V = Ship speed (knots)

W = Weight of towline per foot (Lb/Ft)

W_b= Weight of towed body (Lb)

θ = X-Z coordinate system transformation angle (degrees)

For the purpose of analysis, the towline curve shown in figure 1 is rotated through an angle, θ , so that R, the resultant of lift on and weight of the towline is parallel to the M-axis of a new M-N coordinate system. (See Figure 2.). It is assumed that the lift and weight forces per unit length are constant and always perpendicular to each other and that the fairing assumes a small angle of attack to the stream.

In the M-N coordinate system shown,

$$R = \sqrt{W^2 + L^2} \quad (1)$$

and and $L = \frac{1}{2}C\rho AV^2$ (2)

For equilibrium of section O-P of the curve,

$$\Sigma F_M = 0, \text{ and } T \sin \theta - RS = 0 \quad (3)$$

$$\Sigma F_N = 0, \text{ and } T \cos.\theta - H = 0 \quad (4)$$

From equations (3) and (4),

$$\tan \theta = \frac{RS}{H} \quad (5)$$

In the M-N coordinate system,

$$M = f(N)$$

$$\frac{dM}{dN} = \tan \theta = \frac{RS}{H} \quad (6)$$

Equation (6) describes the change in angle along the towline. In the M-N coordinate system the initial angle is defined by

$$\text{Cotan } \theta_o = \frac{W}{L}$$

Since the angle of rotation of our coordinate system ρ, is given by

$$\text{Cotan } \rho = \frac{W}{L}$$

the kite angle in the Z-X coordinate system is given by equation (6).

Taking a free-body of section O-Q of the towline shown in the third quadrant of the M-N coordinate system, as shown below

$$\sum F_N = 0 \text{ and } H - W_b \cos \theta_o = 0, \tag{7}$$

so $H = W_b \cos \theta_o$

Rewriting equation (6) in terms of equation (7) yields,

$$\tan \theta = \frac{RS}{H} = \frac{RS}{W_b \cos \theta_o} \tag{8}$$

and the kite angle is given by

$$\theta = \tan^{-1} \frac{RS}{W_b \cos \theta_o} \tag{9}$$

RESULTS

From equation (2), lift forces acting on a 500 foot AN/SQS-10 towline were calculated for various ship speeds and angles of attack and were found by assuming 5°, 10°, 15° and 20° mean trail angles for speeds of 5, 10, 20 and 30 knots, respectively, with 500 feet of towline payed out from the ship. These lift forces are shown in Table I, below.

	SHIP SPEED			
Angle of Attack	5 Knots	10 Knots	20 Knots	30 Knots
0.25°	0.456 lb/ft.	1.855 lb/ft.	7.369 lb/ft.	16.705 lb/ft.
0.50°	0.912 "	3.711 "	14.739 "	33.411 "
0.75°	1.368 "	5.567 "	22.108 "	50.116 "
1.00°	1.825 "	7.423 "	29.478 "	66.822 "

TABLE I
Lift Forces vs. Angles of Attack

Kite angles were calculated for an angle of attack of 0.25° and found to be in agreement with those observed at sea for 10, 20 and 30 knot speeds. They are shown in Table II below.

V (knots)	Z (ft)	S (ft)	R (#/ft)	W/L	θ_o (degrees)	θ (degrees)
10	98.68	100	3.71	1.730	60	8.1
"	327.25	350	"	"	"	25.6
"	450.66	500	"	"	"	32.6
20	83.97	100	8.06	0.434	24.5	13.04
"	198.73	350	"	"	"	28.75
"	239.49	500	"	"	"	33.40
30	70.24	100	17.02	0.019	1.9	13.08
"	170.00	350	"	"	"	21.5
"	208.70	500	"	"	"	25.9

TABLE II
Kite Angle vs. Ship Speed for 0.25° Angle of Attack

Z in Table II is the towline depth below the water surface. The values for lift forces were taken from those calculated in Table I. W and W_b are values measured for the AN/SQA-10 sectional, complete towline and towed body.

The results are shown graphically in Figure 3 for towline lengths of 100, 350 and 500 feet.

DISCUSSION

From reference (a), it is found that C_L (coefficient of lift) of equation 2 is a function of α, the angle of attack of the fairing into the stream. It is emphasized that the solutions are based solely on the premise that the fairing assumes some small angle of attack into the stream. There are several possible causes: the fairing may assume this angle, α, as compressive loads build up because of tangential forces on the towline; the fairings may not swivel properly about the cable because of rust on the cable; and, slight asymetries in the fairing may cause the fairing to assume small angles of attack while towing. Also, if fish motion causes the towline to move in the X-Z plane, the towline will not remain parallel to the stream but will assume some initial kite angle; as a consequence, lift forces are generated that induce further kiting.

CONCLUSION

It is deduced that very small angles of attack of the fairing will result in lift forces that cause kiting conditions.

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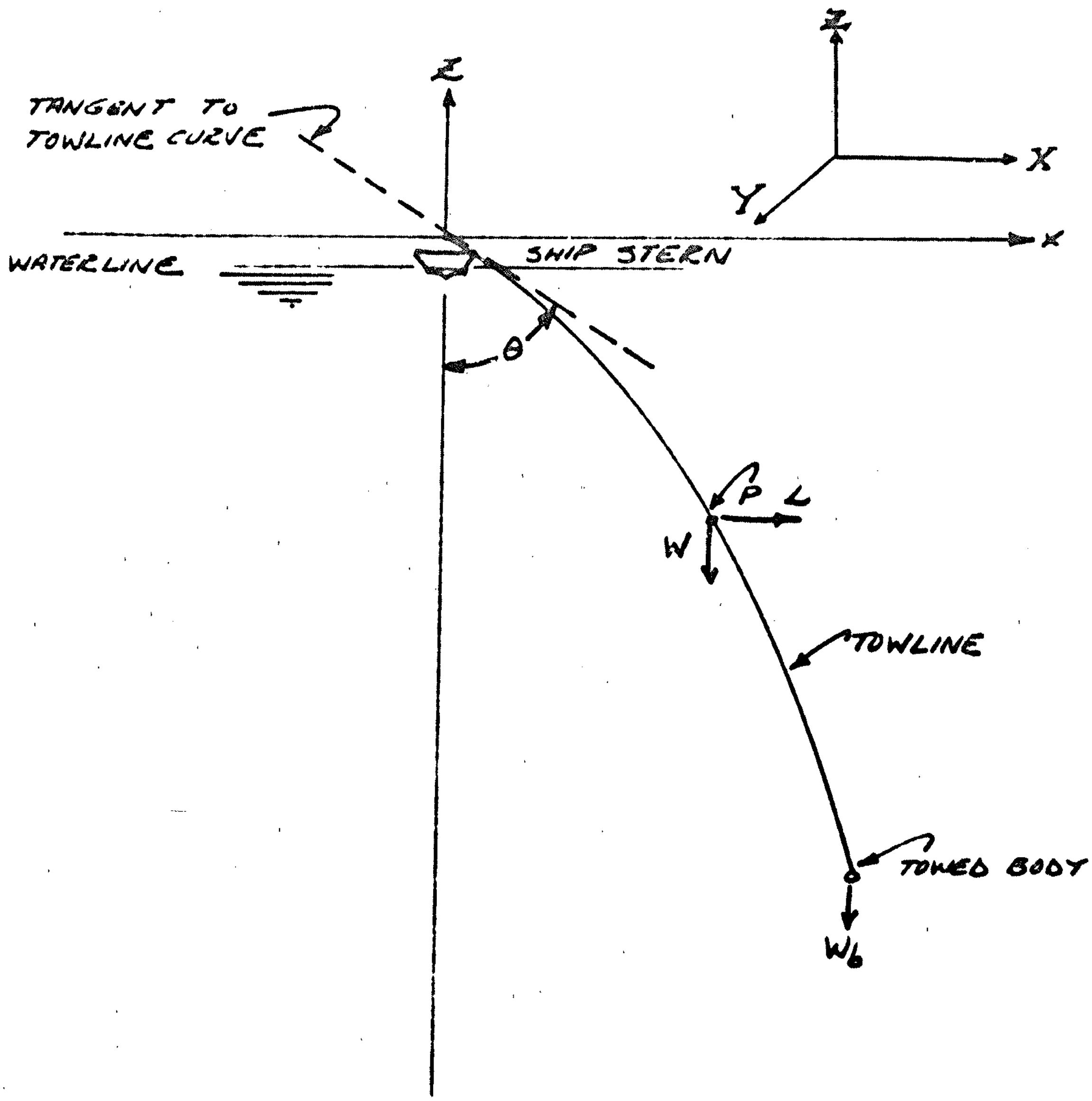
Student Trainee

LIST OF REFERENCES

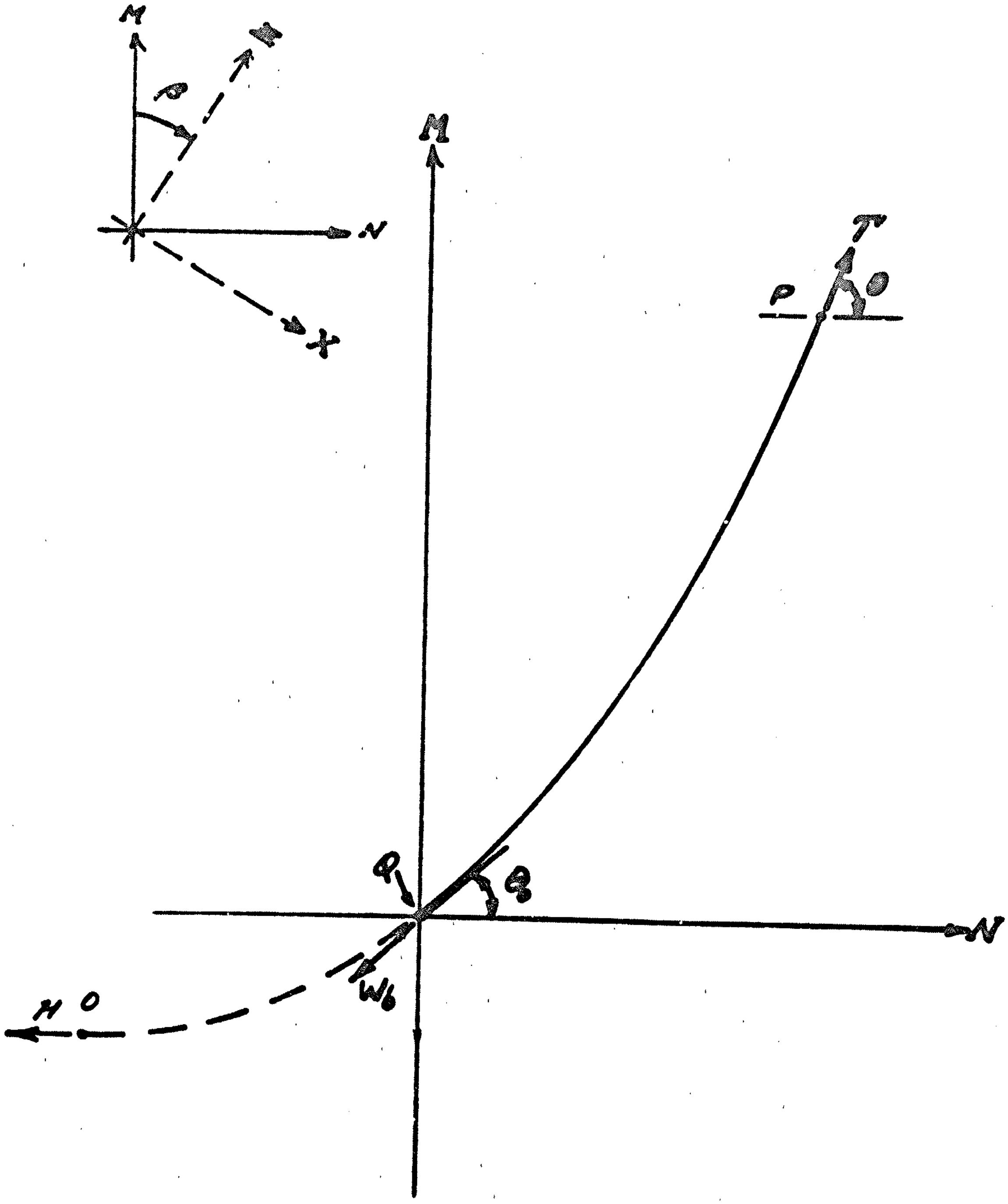
(a) USL Tech. Memo. No. 933-164-65, "Definition and Measurement of VDS Towline Kite Angles", by D. A. Nichols, 24 April 1965.

(b) DTMB Report No. C-455, "The Development of a Fairing for Tow Cables", by Leo F. Fehlner and Leonard Pode, January 1952.



GEOMETRIC REPRESENTATION

Figure 1



GEOMETRIC REPRESENTATION

Figure 2

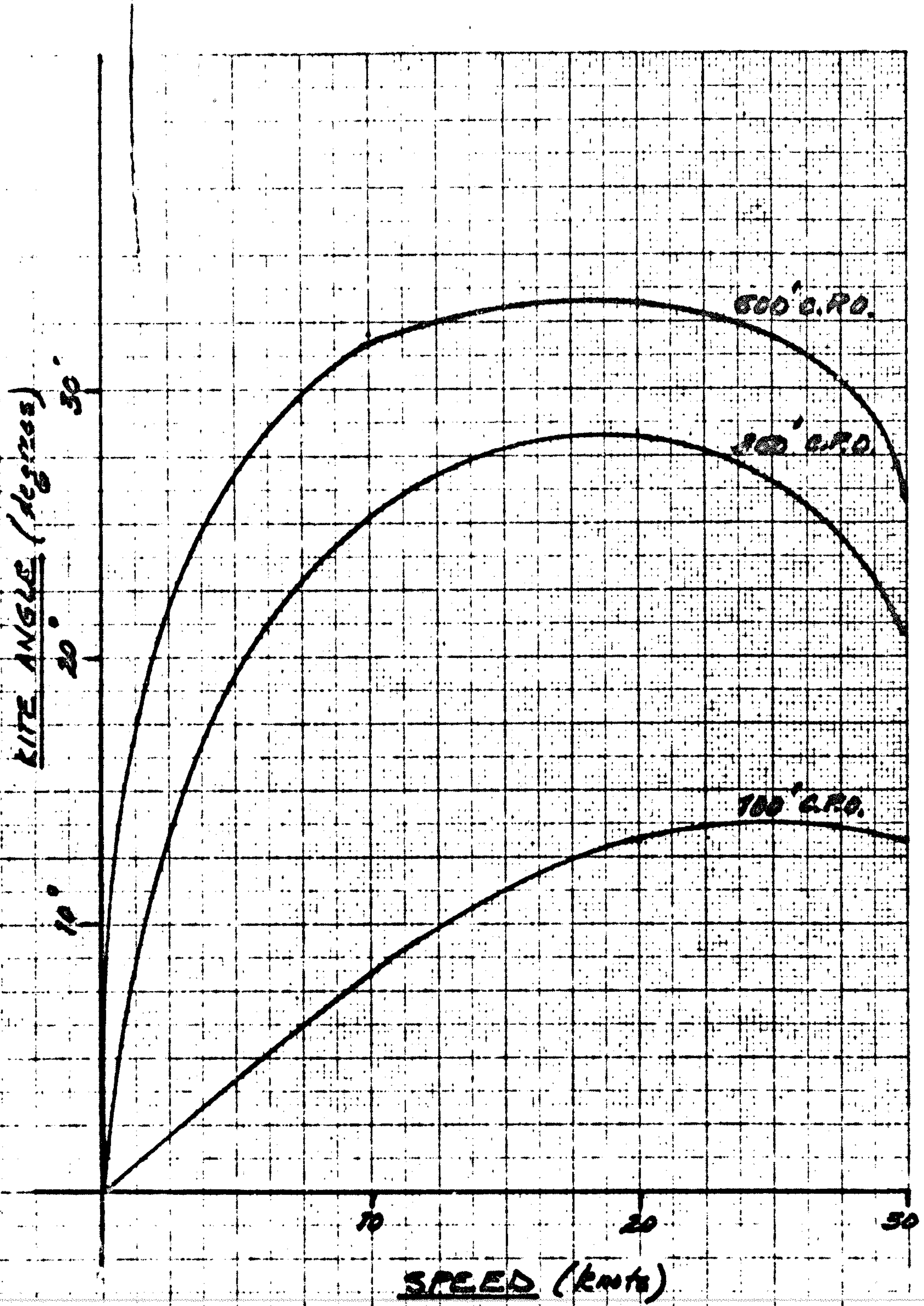


Figure 3

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