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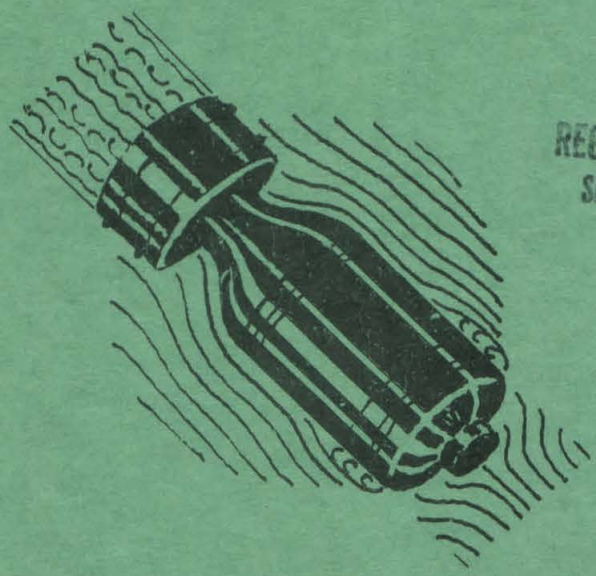
FORCE TESTS OF MK 13-1 TORPEDO WITH SUSPENSION BANDS



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THE HIGH SPEED WATER TUNNEL
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

SECTION № 6.1 - sr 207-2231
LABORATORY NUMBER ND-15.7

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FORCE TESTS OF MK 13-1 TORPEDO WITH SUSPENSION BANDS

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Section No. 6.1-sr207-2231

Laboratory No. ND-15.7

Report Prepared by
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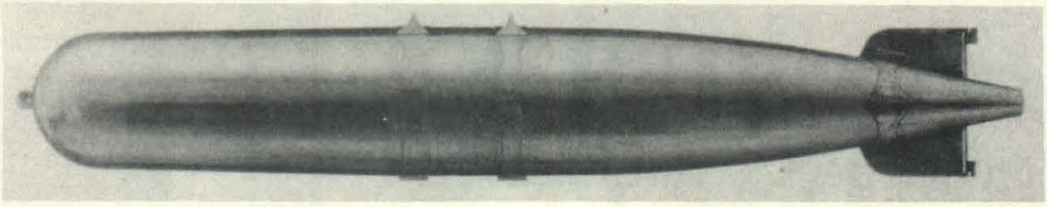
May 17, 1945

ABSTRACT

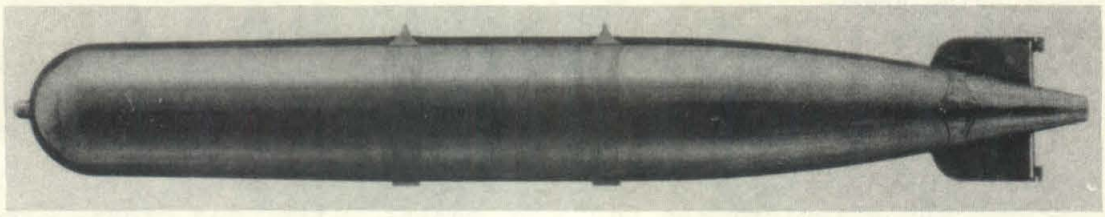
The purpose of the tests reported herein was to determine the effect upon hydrodynamic characteristics of two suspension bands of the same design when placed on the Mk 13-1 Torpedo with band centers spaced 14 and 30 inches and symmetrical about the center of gravity. Particular interest was in the effect upon torpedo running speed.

The tests indicated that the bands would cause a reduction of approximately 2 knots from the normal speed of 33 knots. Cavitation measurements indicated that both of the top and bottom protrusions would cavitate at normal running speeds and depths.

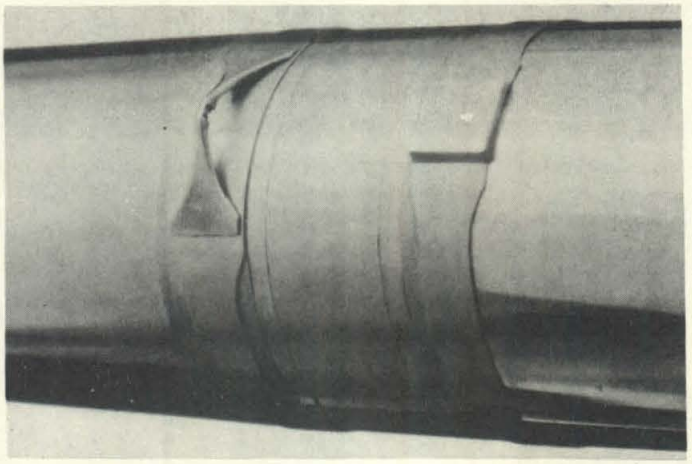
The effect of the bands on moment, lift, and cross force coefficients is, generally, of a minor nature.



(a) Bands with Spacing Equivalent to 14 inches



(b) Bands with Spacing Equivalent to 30 inches



(c) Close-up of one Suspension Lug
and one Bottom Clamp

FIG. 1 SUSPENSION BANDS ON MK 13-1 TORPEDO

FORCE TESTS
OF
MK 13-1 TORPEDO WITH SUSPENSION BANDS

INTRODUCTION

This report covers tests made to determine the effect of two Naval Bureau of Ordnance suspension bands upon the hydrodynamic characteristics of the Mk 13-1 Torpedo when the bands were placed with their centers (a) 7 inches, and (b) 15 inches from the torpedo center of gravity, i.e., with centers of bands spaced 14 and 30 inches, respectively, on the prototype. The tests were made on a 2-inch diameter model in the 14-inch diameter working section of the High Speed Water Tunnel at the California Institute of Technology. The work was authorized as part of Project NO 141 by Dr. E. H. Colpitts, Chief of Section 6.1, National Defense Research Committee, in letters dated April 16, 1943, and January 17, 1944.

The Appendix gives definitions of terms, formulae, brief discussions, and a chart showing the relation between velocity, submergence, and cavitation parameter as used in this report.

DESCRIPTION OF THE MODEL

These bands were designed to permit ready application to Mk 13 Torpedoes for mounting in aircraft and launching therefrom.

Figure 1 shows views of the complete model. In Figure 1 (a) and (b), the suspension bands are located at distances equivalent to 14 and 30 inches, respectively, for the prototype. Figure 1 (c) is a close-up view in which one band has been rotated 180° with respect to the other, solely for the purpose of showing in one picture both the suspension lug and the clamp as reproduced in the model. This clamp was not reproduced exactly because of the minute dimensions involved and because the effect of such departure from exactitude was believed to be negligible for the purposes of the tests. A small flattened area may be observed on both bands in Figure 1 (a) and (b), halfway between the lugs and clamps. These were necessitated for mounting the model in the Water Tunnel. The two views shown are thus from the bottom of the model as mounted for testing.

Figure 2 is an outline drawing with prototype dimensions, but showing the bands as reproduced together with details of the lug and clamp protrusions. The design was based on Naval Bureau of Ordnance Drawings Nos. 145251, 145252, 145253, and 145600. The model bands were not made separable from the body but as body sections. The maximum protrusion of the lug was 3.39 inches; and of the clamp, as reproduced, 0.50 inches (prototype dimensions).

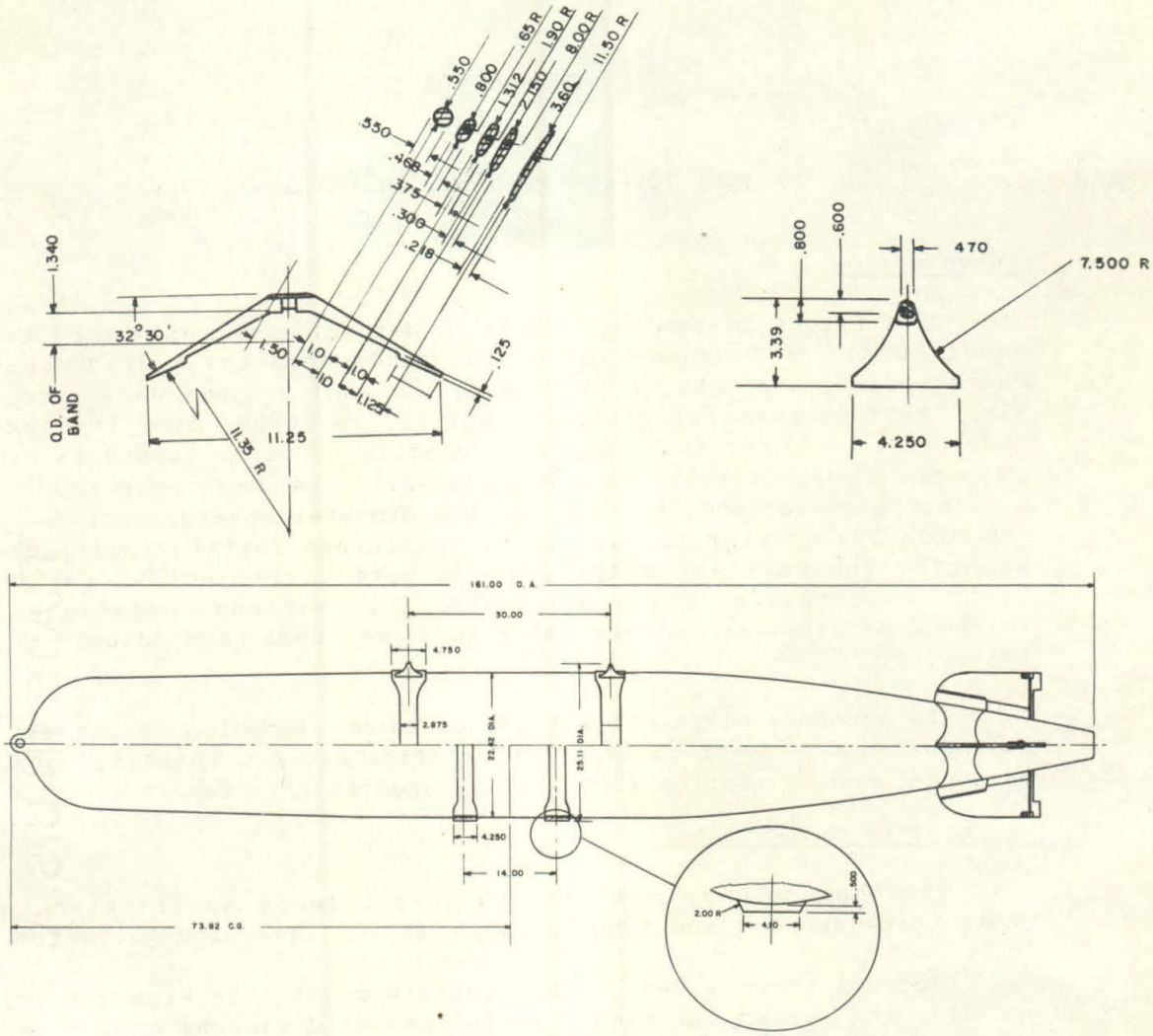
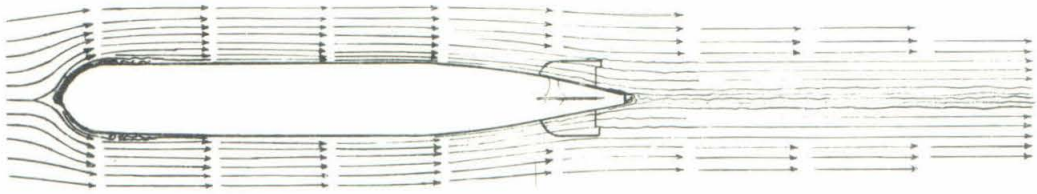


FIG. 2 — OUTLINE DRAWING WITH PROTOTYPE DIMENSIONS

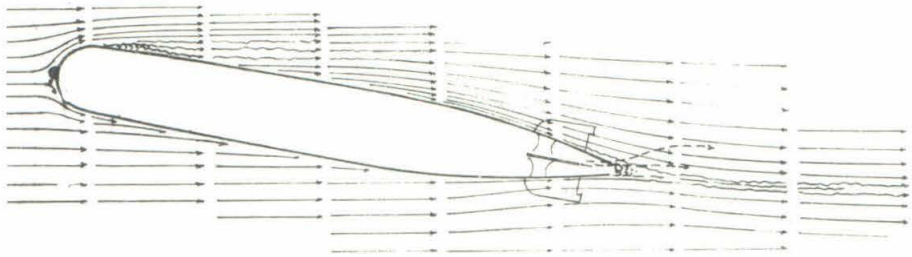
Suspension Bands for Mk 13-1 Torpedo as Reproduced

TESTS MADE

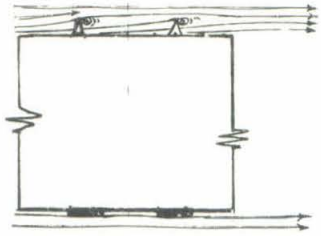
Tests made included studies and flow diagrams from the Polarized Light Flume; cavitation measurements and photographs with bands at 14- and 30-inch spacings; measurement of drag as a function of Reynolds number; measurement of drag for pitch angles of $\pm 10^{\circ}$; measurement of lift and moment about the center of gravity for pitch angles of $\pm 10^{\circ}$, with horizontal rudder settings at 0° and 10° up and down, for no bands, and bands with 14- and 30-inch spacings; measurement of drag for yaw angles of $\pm 10^{\circ}$ with no bands, and with bands spaced 30 inches; measurement of cross force and moment about center of gravity for yaw angles of $\pm 10^{\circ}$, vertical rudder at 0° and 9°, for no bands, and bands 30 inches apart. Interference between the mounting structure in the tunnel and the bands on 14-inch centers prevented yawing tests with this spacing.



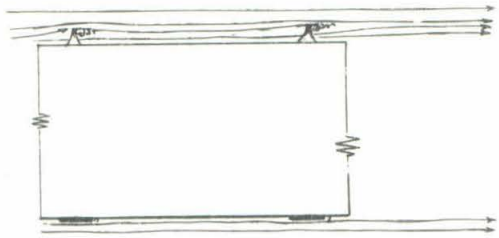
Yaw = 0°



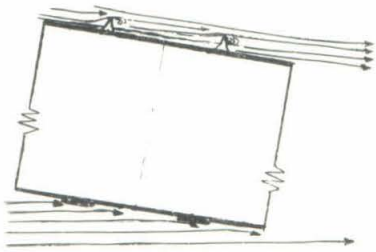
Yaw = 10°



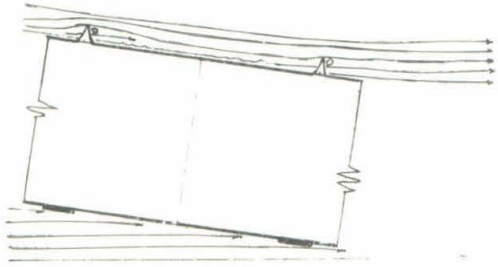
Yaw = 0° 14" Spacing



Yaw = 0° 30" Spacing



Yaw = 10° 14" Spacing



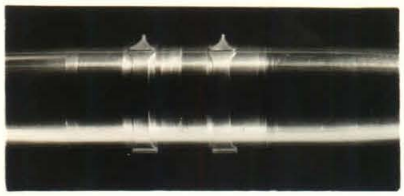
Yaw = 10° 30" Spacing

FIG. 3 – FLOW DIAGRAMS OF MK 13-1 TORPEDO AND SUSPENSION BANDS

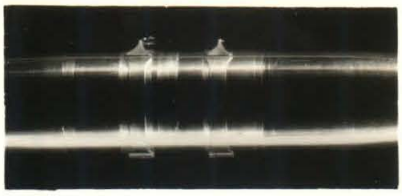
TEST RESULTS

POLARIZED LIGHT FLUME

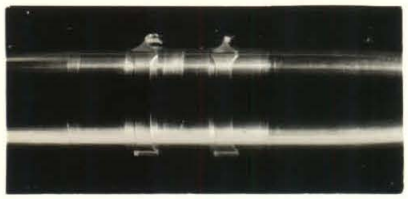
Figure 3 presents flow diagrams of conditions as observed in the Polarized Light Flume for the Mk 13-1 Torpedo without bands, at 0° and 10° yaw angles, and the center body section of the same torpedo with bands at 14- and 30-inch spacing, 0° and 10° yaw. Eddies are particularly notable aft of the suspension lugs and, to a less extent, aft of the bottom clamp protrusion.



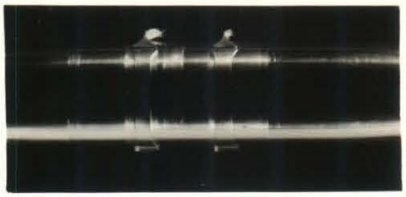
(a) K = 1.87



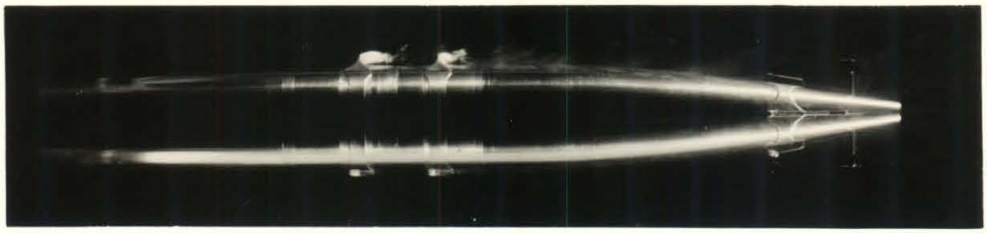
(b) K = 1.43



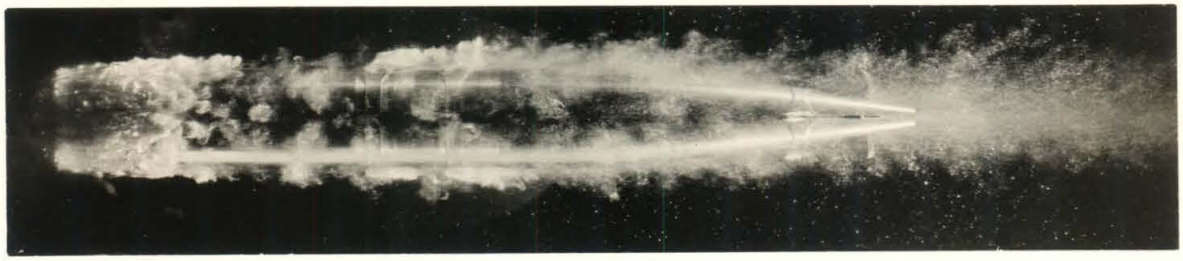
(c) K = 1.12



(d) K = 0.95



(e) K = 0.62



(f) K = 0.33

FIG. 4 — CAVITATION DEVELOPMENT

Band Spacing Equivalent to 14 inches

CAVITATION

Figure 4, (a) to (f) inclusive, shows the development of cavitation with the suspension band spacing equivalent to 14 inches in the prototype. All pictures were taken with zero pitch, yaw, and rudder settings.

View (a) - Steady incipient cavitation first appeared on the forward suspension band lug at a K value of 1.93. This cavitation, though visible to the operator, was too faint to show in the photograph. The running depth necessary to avoid all cavitation from bands with this spacing and for a speed of 33 knots would be about 60 feet in sea water. The K value in the photograph was 1.87.

View (b) - Steady incipient cavitation showed on the rear suspension lug at K = 1.49, equivalent to a submergence of about 39 feet for the stated conditions. Bubbles are visible from both lugs in this picture, which was taken at a K value of 1.43.

View (c) - The beginning of steady cavitation from the forward edge of the bottom protrusion of the forward band showed faintly for K = 1.21, equivalent to a depth of about 25 feet. Picture was taken at K = 1.12.

View (d) - The forward edge of the bottom protrusion on the rear band showed the start of steady cavitation at K = 1.21, equivalent to a submergence of about 25 feet. Picture was taken at K = 0.95.

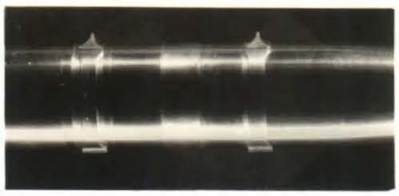
Similar cavitation appeared on all tail fins at points adjacent to their junctures with the band holding them. This cavitation was too faint to show in this photograph, but may be seen in a more advanced stage in View (e). This was the first cavitation of any part of the model exclusive of the suspension bands.

View (e) - Steady incipient cavitation begins on the nose at a K value of about 0.67. This is equivalent to saying that cavitation on the nose will not exist for any depth at a speed of 33 knots, as may be seen by reference to the chart in the Appendix. The view shown reveals this nose cavitation very faintly at the base of the hemispherical portion for K = 0.62. Fin cavitation is also visible at the points mentioned above.

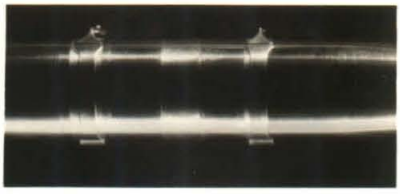
View (f) - This picture shows conditions for K = 0.33, which give a bubble about 20% as long as the torpedo.

Figure 5, (a) to (c) inclusive, shows similarly the development of cavitation for suspension band spacings equivalent to 30 inches on the prototype. Incipient steady cavitation occurred as follows:

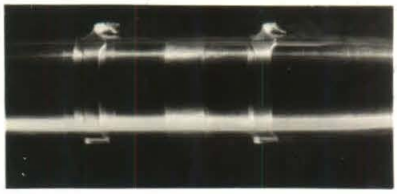
1. Leading edge of lug on forward band at K = 1.96, equivalent to 61 feet submergence at 33 knots.



(a) K = 1.76



(b) K = 1.28



(c) K = 0.87

FIG. 5 — CAVITATION DEVELOPMENT

Band Spacing Equivalent to 30 inches

2. Leading edge of lug on rear bands at K = 1.58, equivalent to 43 feet submergence.

3. Leading edge of bottom protrusion on forward and rear bands at K = 1.34, equivalent to 31 feet submergence.

It may be noted that cavitation appears earlier when the bands are in the more widely spaced position.

View (a) shows an early stage of steady cavitation on the forward band lug for K = 1.760, about 51 feet submergence.

View (b) shows cavitation at all four sources. K = 1.28, equivalent to 29 feet.

View (c) shows cavitation more fully developed. K = 0.87, equivalent to about 9 feet submergence.

It may be concluded that cavitation from both of the upper and lower protrusions will occur for either spacing at normal running depth and speeds.

DRAG COEFFICIENT AND REYNOLDS NUMBER

Figure 6 shows the relationship of the drag coefficient, C_D, to Reynolds number for the Mk 13-1 Torpedo, without suspension bands, all rudders neutral, zero yaw and pitch angles, as previously reported in Report, Section No. 6.1-sr207-936. If this line be taken as a base representing 100%, the C_D obtained with suspension bands installed may also be expressed as a percentage for corresponding Reynolds numbers. The results of the tests showed that the bands with 14-inch prototype spacing caused an average increase in C_D of 16.8%, and the 30-inch spacing gave an

average of 17.8%. If we assume that, for small variations in speed, the power output and propeller efficiency are constant, then the speed is inversely proportional to the cube root of the drag coefficient. For a speed of 33 knots, the percentage increases in drag coefficient given above would then correspond to decreases of 1.66 and 1.78 knots, respectively. These values, of course, do not have the accuracy indicated by the two decimal places since (1) an assumption has been made that the percentage increases in C_D are the same at prototype and model Reynolds numbers, and (2) it has been shown above that some cavitation from protrusions will occur at normal speeds and depths, whereas the drag measurements were obtained without cavitation. At 33 knots and 15 feet submergence the amount of cavitation is between that shown for Figures 4 (c) and 4 (d). This should tend to increase C_D above that measured, but the effect should be small. A conclusion that the running speed would be reduced approximately 2 knots seems to be warranted.

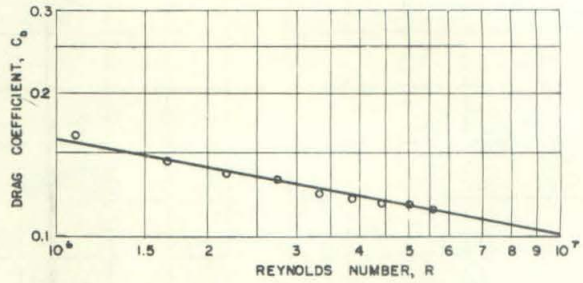


FIG. 6 - MK 13-1 TORPEDO WITHOUT BANDS

EFFECT OF PITCH ANGLE ON FORCE COEFFICIENTS

Figure 7 shows the effect of variation of the pitch angle to $\pm 10^{\circ}$ upon the lift and drag coefficients for the model without bands, and with bands having prototype spacings of 14 and 30 inches, and for horizontal rudder settings of 0 and 10 degrees up and down in the case of the lift coefficient. Data were corrected for shield interference and horizontal buoyancy. The effect of drag coefficient increase with bands has been discussed above. Changes in the lift coefficient may be seen to be of a minor nature.

Figure 8 shows the effect of the same conditions described for Figure 7 upon the moment coefficient about the center of gravity.

EFFECT OF YAW ANGLE ON FORCE COEFFICIENTS

Figure 9 shows the effect of variation of the yaw angle to $\pm 10^{\circ}$ upon the cross force and drag coefficients of the model without bands and with bands having a prototype spacing of 30 inches for vertical rudders at 0 and 9 degrees port. No similar curves were obtained for the 14-inch spacing due to unavoidable interference of bands in such a position with the mount. Data were corrected for shield interference.

Figure 10 shows, similarly, the effect of the yaw angle upon the moment coefficient about the center of gravity. In general, it may be seen to be of a minor nature.

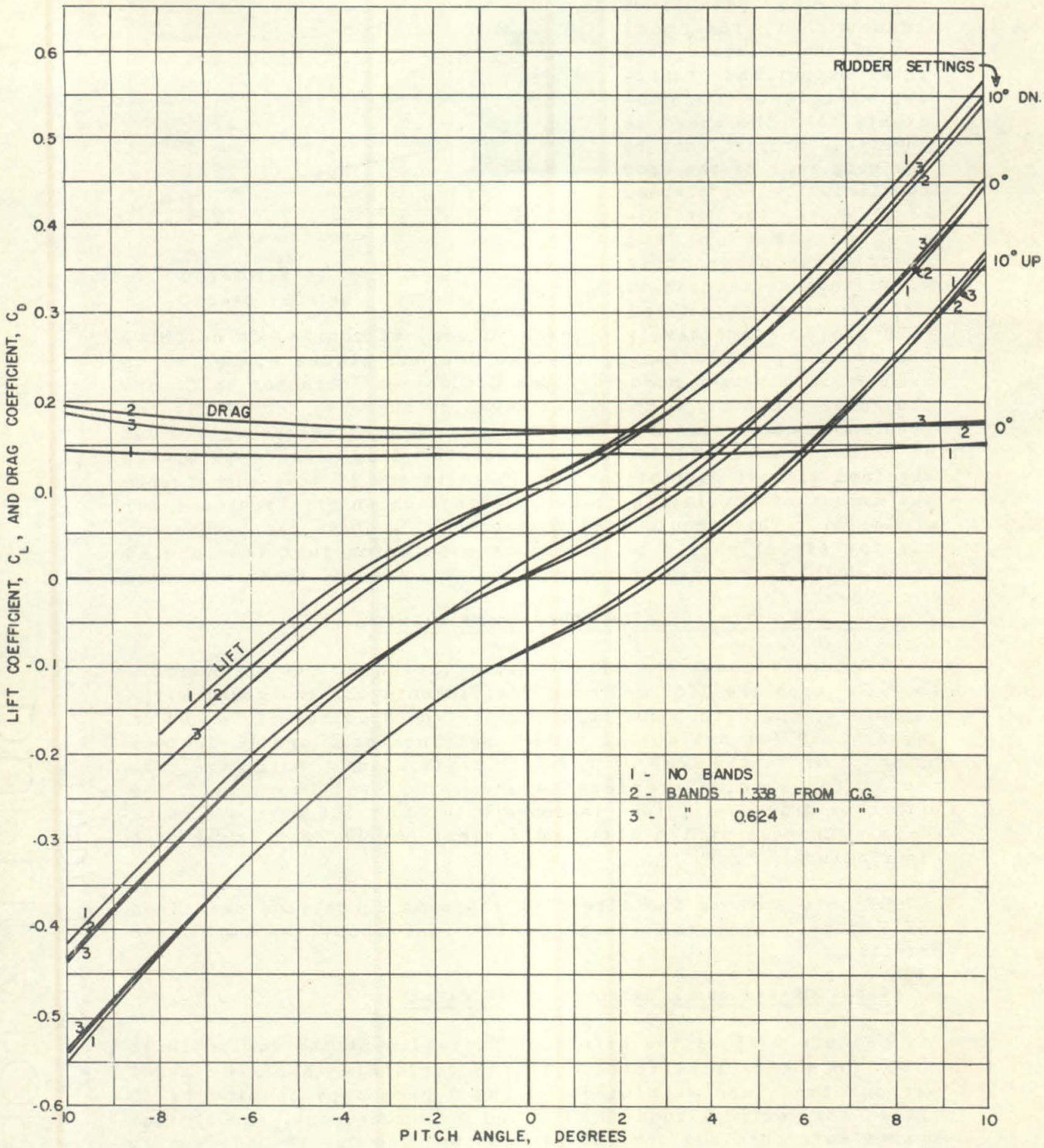


FIG. 7 – MK 13-1 TORPEDO WITH AND WITHOUT SUSPENSION BANDS

Effect of Pitch Angle on C_L and C_D

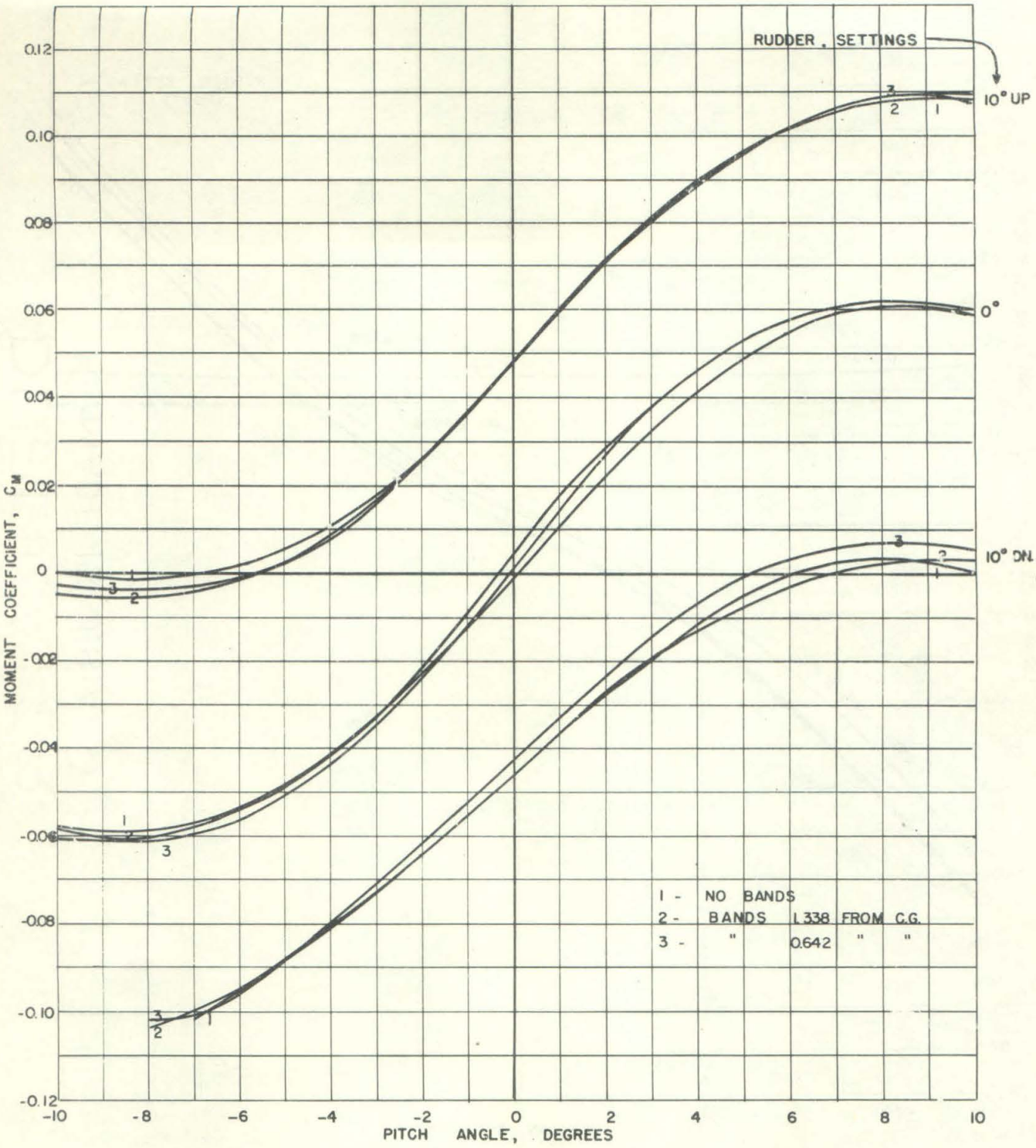


FIG. 8 – MK 13-1 TORPEDO WITH AND WITHOUT SUSPENSION BANDS

Effect of Pitch Angle on C_M

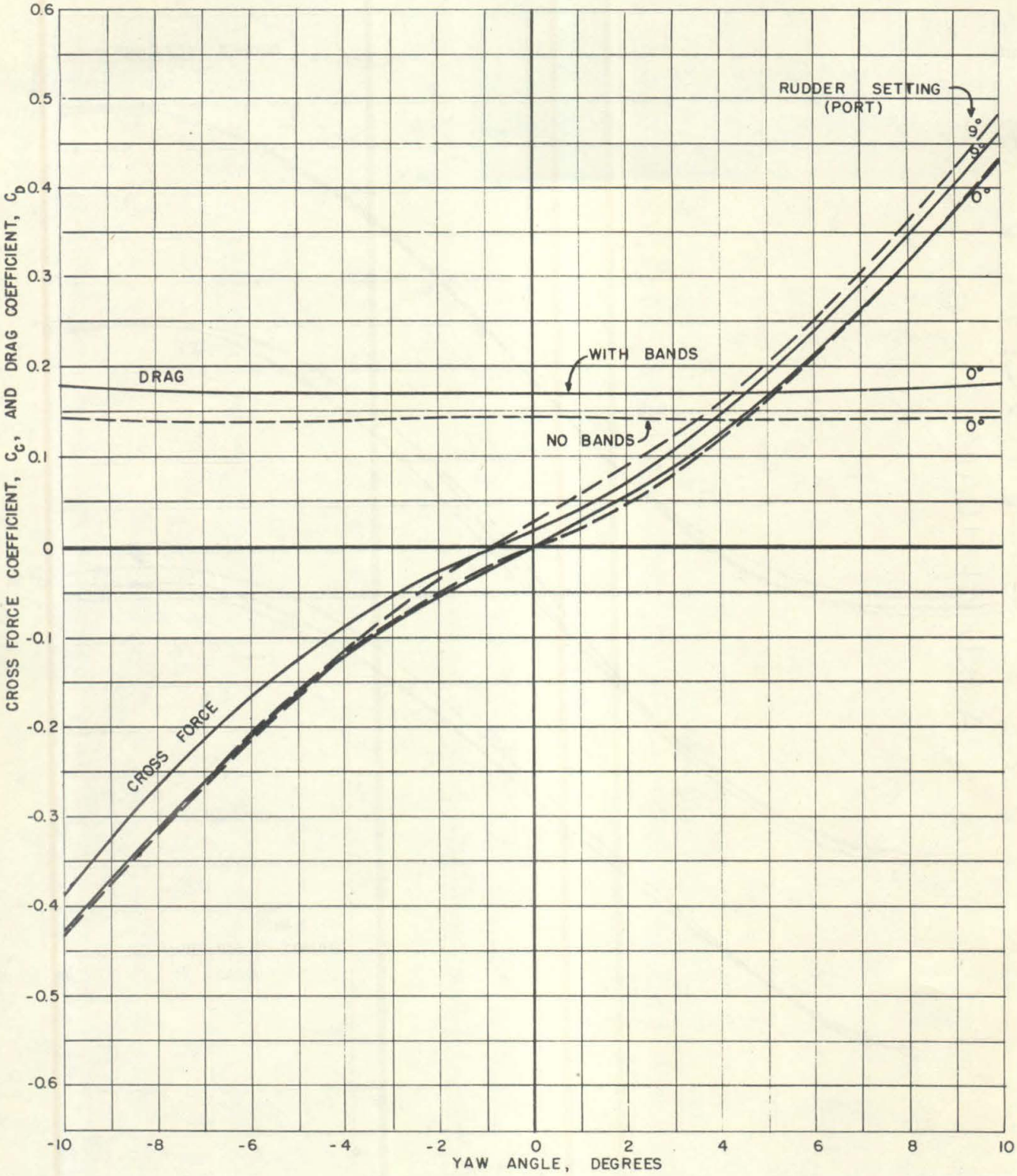


FIG. 9 - MK 13-1 TORPEDO WITHOUT SUSPENSION BANDS AND WITH BANDS AT 30-INCH PROTOTYPE SPACING

Effect of Yaw Angle on C_D and C_C

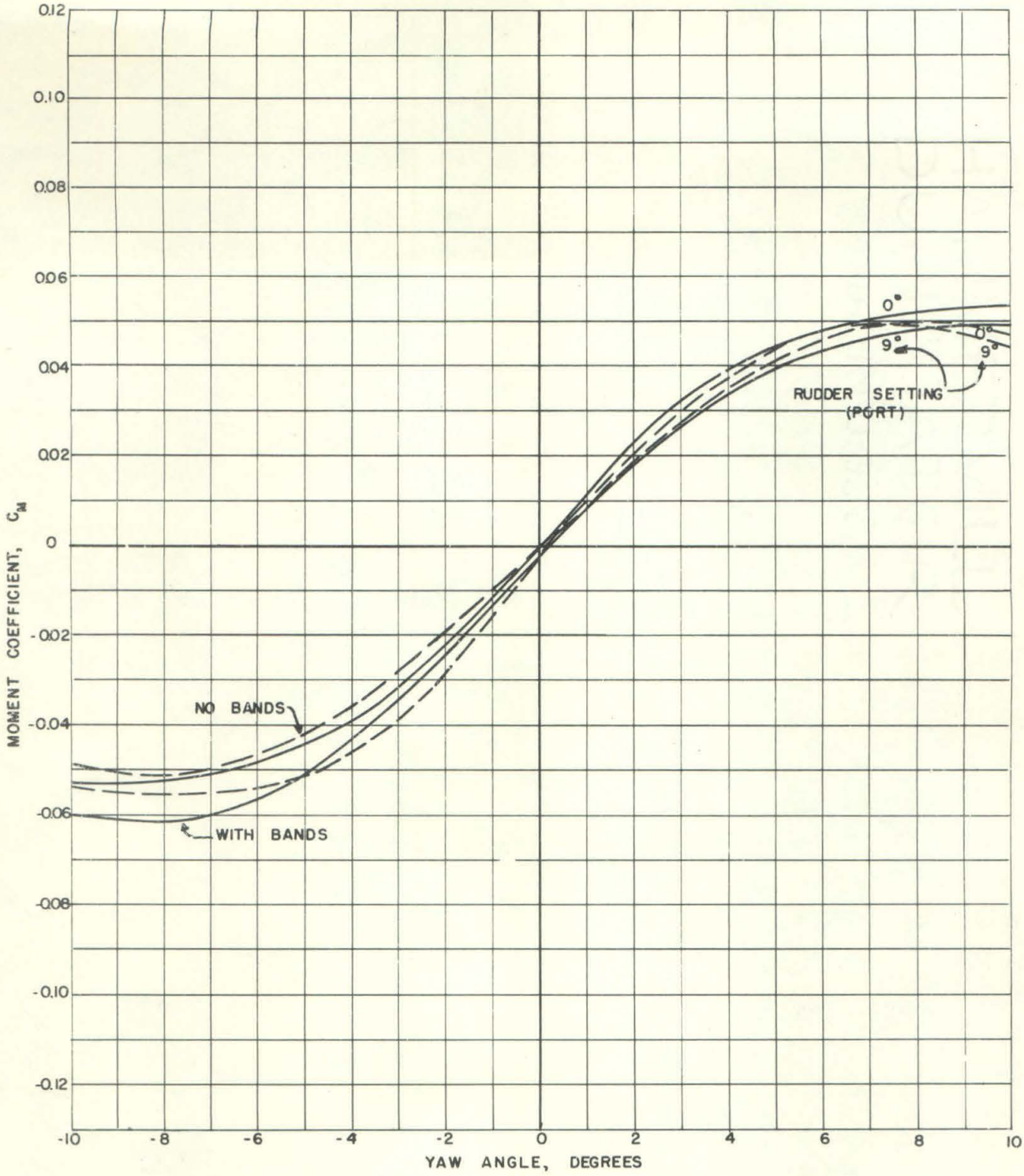


FIG. 10 – MK 13-1 TORPEDO WITHOUT SUSPENSION BANDS AND WITH BANDS AT 30-INCH PROTOTYPE SPACING

Effect of Yaw Angle on C_M

APPENDIX

DEFINITIONS

YAW ANGLE, ψ

The angle, in a horizontal plane, which the axis of the projectile makes with the direction of motion. Looking down on the projectile, yaw angles in a clockwise direction are positive (+) and in a counterclockwise direction, negative (-).

PITCH ANGLE, α

The angle, in a vertical plane, which the axis of the projectile makes with the direction of motion. Pitch angles are positive (+) when the nose is up and negative (-) when the nose is down.

LIFT, L

The force, in pounds, exerted on the projectile normal to the direction of motion and in a vertical plane. The lift is positive (+) when acting upward and negative (-) when acting downward.

CROSS FORCE, C

The force, in pounds, exerted on the projectile normal to the direction of motion and in a horizontal plane. The cross force is positive when acting in the same direction as the displacement of the projectile nose for a positive yaw angle, i.e., to an observer facing in the direction of travel, a positive cross force acts to the right.

DRAG, D

The force, in pounds, exerted on the projectile parallel with the direction of motion. The drag is positive when acting in a direction opposite to the direction of motion.

MOMENT, M

The torque, in foot pounds, tending to rotate the projectile about a transverse axis. Yawing moments tending to rotate the projectile in a clockwise direction (when looking down on the projectile) are positive (+), and those tending to cause counterclockwise rotation are negative (-). Pitching moments tending to rotate the projectile in a clockwise direction (when looking at the projectile from the port side) are positive (+), and those tending to cause counterclockwise rotation are negative (-).

In accordance with this sign convention a moment has a destabilizing effect when it has the same sign as the yaw angle or the opposite sign of the pitch angle.

In all model tests the moment is measured about the point of support. Moments about the center of gravity of the projectile have the symbol, M_{cg}.

NORMAL COMPONENT, N

The sum of the components of the drag and cross force acting normal to the axis of the projectile. The value of the normal component is given by the following:

$$N = D \sin \psi + C \cos \psi \qquad (1)$$

in which

N = Normal component in lbs

D = Drag in lbs

C = Cross force in lbs

ψ = Yaw angle in degrees

CENTER OF PRESSURE, CP

The point in the axis of the projectile at which the resultant of all forces acting on the projectile is applied.

CENTER-OF-PRESSURE ECCENTRICITY, e

The distance between the center of pressure (CP) and the center of gravity (CG) expressed as a decimal fraction of the length (l) of the projectile. The center-of-pressure eccentricity is derived as follows:

$$e = (l_{cp} - l_{cg}) \frac{1}{l} = \frac{1}{l} \frac{M_{cg}}{N} \qquad (2)$$

in which

e = Center-of-pressure eccentricity

l = Length of projectile in feet

l_{cg} = Distance from nose of projectile to CG in feet

l_{cp} = Distance from nose of projectile to CP in feet

COEFFICIENTS

The three force and moment coefficients used are derived as follows:

Drag coefficient, $$C_D = \frac{D}{\rho \frac{V^2}{2} A_D} \quad (3)$$

Cross force coefficient, $$C_C = \frac{C}{\rho \frac{V^2}{2} A_D} \quad (4)$$

Moment coefficient, $$C_M = \frac{M}{\rho \frac{V^2}{2} A_D l} \quad (5)$$

in which

D = Measured drag force in lbs

C = Measured cross force in lbs

ρ = Density of the fluid in slugs/cu ft = w/g

w = Specific weight of the fluid in lbs/cu ft

g = Acceleration of gravity in ft/sec^2

A_D = Area in sq ft at the maximum cross section of the projectile taken normal to the geometric axis of the projectile

V = Mean relative velocity between the water and the projectile in ft/sec

M = Moment, in foot-pounds, measured about any particular point on the geometric axis of the projectile

l = Overall length of the projectile in feet

CONTROL ANGLE

In considering the effect of rudders on static stability, either in yaw or pitch, the term "control angle" is used to denote the yaw below which a given rudder setting with opposite sign to the yaw will tend to return the projectile to zero yaw, and above which the yaw will further increase. The control angle is useful for indicating the effectiveness of rudders and for comparing the static stability of different projectiles with equal rudder settings.

RUDDER EFFECT

The total increase or decrease in moment coefficient, at a given yaw or pitch angle, resulting from a given rudder setting. This increase or decrease in moment coefficient is measured from the moment coefficient curve for neutral rudder setting.

REYNOLDS NUMBER

In comparing hydraulic systems involving only friction and inertia forces, a factor called Reynolds number is of great utility. This is defined as follows:

$$R = \frac{lV}{\nu} = \frac{lV\rho}{\mu} \qquad (6)$$

in which

R = Reynolds number

l = Overall length of projectile, feet

V = Velocity of projectile, feet per sec

ν = Kinematic viscosity of the fluid, sq ft per sec = μ/ρ

ρ = Mass density of the fluid in slugs per cu ft

μ = Absolute viscosity in pound-seconds per sq ft

Two geometrically similar systems are also dynamically similar when they have the same value of Reynolds number. For the same fluid in both cases, a model with small linear dimensions must be used with correspondingly large velocities. It is also possible to compare two cases with widely differing fluids provided l and V are properly chosen to give the same value of R.

CAVITATION PARAMETER

In the analysis of cavitation phenomena, the cavitation parameter has been found very useful. This is defined as follows:

$$K = \frac{P_L - P_B}{\rho \frac{V^2}{2}} \qquad (7)$$

in which

K = Cavitation parameter

P_L = Absolute pressure in the undisturbed liquid, lbs/sq ft

P_B = Vapor pressure corresponding to the water temperature, lbs/sq ft

V = Velocity of the projectile, ft/sec

ρ = mass density of the fluid in slugs per cu ft = w/g

w = weight of the fluid in lbs per cu ft

g = acceleration of gravity

Note that any homogeneous set of units can be used in the computation of this parameter. Thus, it is often convenient to express this parameter in terms of the head, i.e.,

$$K = \frac{h_L - h_B}{\frac{V^2}{2g}} \qquad (8)$$

where

h_L = Submergence plus the barometric head, ft of water

h_B = Pressure in the bubble, ft of water

It will be seen that the numerator of both expressions is simply the net pressure acting to collapse the cavity or bubble. The denominator is the velocity pressure. Since the entire variation in pressure around the moving body is a result of the velocity, it may be considered that the velocity head is a measure of the pressure available to open up a cavitation void. From this point of view, the cavitation parameter is simply the ratio of the pressure available to collapse the bubble to the pressure available to open it. If the K for incipient cavitation is considered, it can be interpreted to mean the maximum reduction in pressure on the surface of the body measured in terms of the velocity head. Thus, if a body starts to cavitate at the cavitation parameter of one, it means that the lowest pressure at any point on the body is one velocity head below that of the undisturbed fluid.

The shape and size of the cavitation bubbles for a specific projectile are functions of the cavitation parameter. If p_B is taken to represent the gas pressure within the bubble instead of the vapor pressure of the water, as in normal investigations, the value of K obtained by the above formula will be applicable to an air bubble. In other words, the behavior of the bubble will be the same whether the bubble is due to cavitation, the injection of exhaust gas, or the entrainment of air at the time of launching.

The following chart gives values of the cavitation parameter as a function of velocity and submergence in sea water.

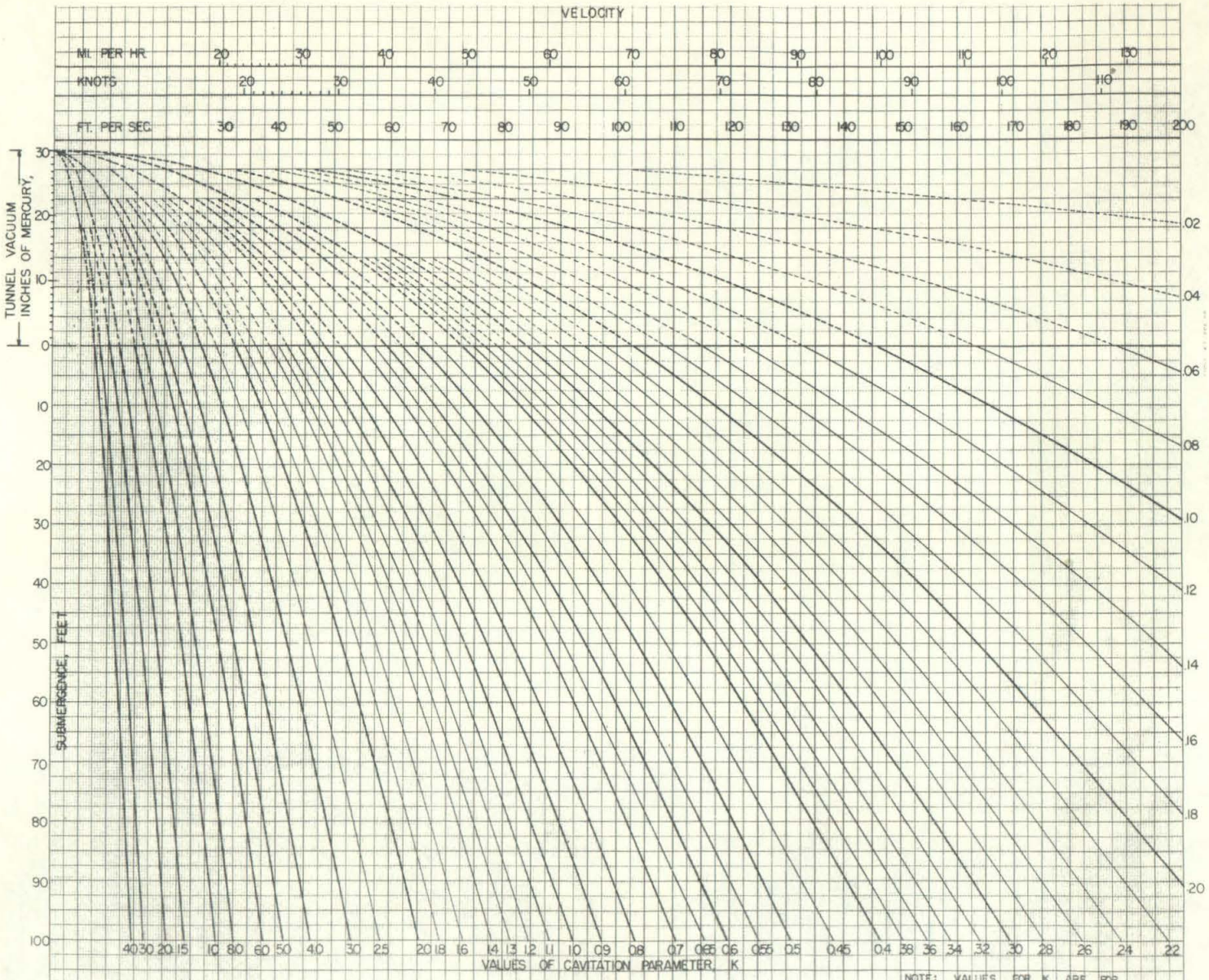
GENERAL DISCUSSION OF STATIC STABILITY

Water tunnel tests are made under steady flow conditions, consequently the results only indicate the tendency of the steady state hydrodynamic couples and forces to cause the projectile to return to or move away from its equilibrium position after a

disturbance. Dynamic couples and forces including either positive or negative damping are not obtained. If the hydrodynamic moments are restoring the projectile, then it is said to be statically stable, if nonrestoring, statically unstable. In the discussion of static stability the actual motion following a perturbation is not considered at all. In fact, the projectile may oscillate continuously about an equilibrium position without remaining in it. In this case it would be statically stable, but would have zero damping and hence, be dynamically unstable. With negative damping a projectile would oscillate with continually increasing applitude following an initial perturbation even though it were statically stable. Equilibrium is obtained if the sum of the hydrodynamic, buoyant, and propulsive moments equal zero. In general, propulsive thrusts act through the center of gravity of the projectile so only the first two items are important.

If a projectile is rotating from its equilibrium position so as to increase its yaw angle positively, the moment coefficient must increase negatively (according to the sign convention adopted) in order that it be statically stable. Therefore, for projectiles without controls or with fixed control surfaces, a negative slope of the curve of moment coefficient vs yaw gives static stability and a positive slope gives instability. For a projectile without controls, static stability is necessary for a successful flight unless stability is obtained by spinning as in the case of rifle shells. For a projectile with controls, stabilizing moments can be obtained by adjusting the control surfaces, and the slope of the moment coefficient, as obtained with fixed rudder position, need not give static stability. Where buoyancy either acts at the center of gravity or can be neglected, equilibrium is obtained when the hydrodynamic moment coefficient equals zero. For symmetrical projectiles this occurs at zero yaw angle, i.e., when the projectile axis is parallel to the trajectory. For nonsymmetrical projectiles, such as a torpedo when the rudders are not neutral, the moment is not zero at zero yaw but vanishes at some definite angle of attack. Where buoyancy cannot be neglected equilibrium is obtained when $C_M = -C_{Buoyancy}$, and the axis of the projectile is at some angle with the trajectory.

For symmetrical projectiles the degree of stability or instability can be obtained from the center-of-pressure curves. If the center of pressure falls behind the center of gravity, a restoring moment exists giving static stability. If the center of pressure falls ahead of the center of gravity, the moment is nonrestoring, and the projectile will be statically unstable. The degree of stability or instability is indicated approximately by the distance between the center of gravity and the center of pressure. In general, for nonsymmetrical projectiles, the cross force or lift is not zero when the moment vanishes so that the center of pressure curve is not symmetrical and the simple rules just stated cannot be used to determine whether or not the projectile will be stable. In such cases careful interpretation of the moment curves is a more satisfactory method of determining stability relationship.



NOTE: VALUES FOR K ARE FOR ZERO BUBBLE PRESSURE. TO OBTAIN TRUE VALUE OF K SUBTRACT BUBBLE PRESSURE, IN FEET, FROM THE SUBMERGENCE. CHART IS CALCULATED FOR SEA WATER.

CHART SHOWING RELATION BETWEEN VELOCITY, SUBMERGENCE & CAVITATION PARAMETER