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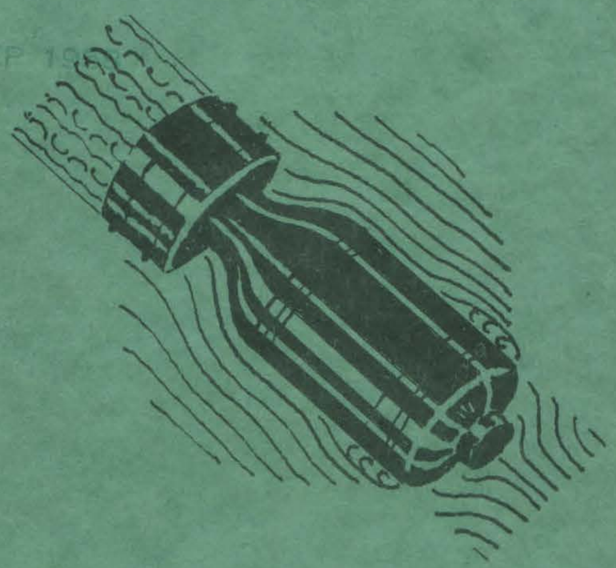
UNDERWATER PERFORMANCE CHARACTERISTICS OF THE MK 13-2A TORPEDO WITH SUSPENSION FITTINGS.



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

SECTION Nº 6.1-Sr 207-1650
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UNDERWATER PERFORMANCE CHARACTERISTICS OF THE MK 13-2A TORPEDO WITH SUSPENSION FITTINGS

BY

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Section No. 6.1-sr207-1650

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ABSTRACT

This memorandum report covers a series of Water Tunnel tests of the Mk 13-2A Torpedo equipped with three different devices designed to facilitate the suspension of the torpedo in standard aircraft bomb racks. The suspension fittings tested were:

(1) Torpedo Suspension Band Mk 11

(2) Suspension Beam for Mk 13 Air Flask, 30" Centers

(3) Suspension Beam for Mk 13 Air Flask, 14" Centers

The objective of these tests was to determine what effect the addition of each of these suspension devices would have on the hydrodynamic characteristics of the torpedo. The tests were made on 2-inch diameter models (model scale ratio of 1 to 11.21) in the High Speed Water Tunnel at the California Institute of Technology. The results of these tests are given in Table I and in the section on cavitation on Page 10 of this report.

The main findings may be summarized as follows:

(1) The addition of any one of the suspension devices tested causes an increase in the static instability of the torpedo. This may adversely affect the behavior of the torpedo without shroud ring tail, since it is already highly unstable. With the addition of the ring tail, the instability of the torpedo is greatly reduced and its performance is improved. It is believed, therefore, that the torpedo with shroud ring could take the slight increase in instability caused by the addition of a suspension device without being adversely affected by it.

(2) Each of the three suspension devices tested causes an increase in the drag of the torpedo of about 10%. This would cause a decrease in speed of 3%, or about one knot. The suspension band, when slightly modified by rounding off its sharp edges, causes no appreciable increase in the drag.

(3) Suspension Band Mk 11, in its present form (with square edges), is so highly susceptible to cavitation that it would cavitate under all normal running conditions, and would further slow down the torpedo. The cavitation is caused by the band's sharp edges. It is believed that, if the edges of the band were rounded, the torpedo with the band would be safe from cavitation under all normal operating conditions. Cavitation tests were not made on the torpedo with either suspension beam, but from their

shape it is evident that they will not cavitate under normal operating conditions except, perhaps, over very small regions around the sharp edges of the suspension lugs. This, however, could not be of sufficient magnitude to affect the performance of the torpedo.

UNDERWATER PERFORMANCE CHARACTERISTICS
OF THE
MK 13-2A TORPEDO
WITH SUSPENSION FITTINGS

I. INTRODUCTION

The tests reported herein were made to investigate the effect on the hydrodynamic characteristics of the United States Navy Torpedo Mark 13, Modification 2A, of the addition of three different external fittings designed to facilitate the suspension of the torpedo in standard aircraft bomb racks. The tests were made on 2-inch diameter models (model scale 1:11.21) in the High Speed Water Tunnel at the California Institute of Technology,(1) and were part of Project NO 141, as authorized by Dr. E. H. Colpitts, Chief of Section 6.1, NDRC, in a letter dated April 16, 1943.

This report is the fifth in a series covering Water Tunnel tests on the United States Navy Torpedo Mk 13, Modifications 1, 2, and 2A. The preceding four reports are listed as References 2, 3, 4, and 5 of Appendix C.

The suspension devices tested were:

1. Torpedo Suspension Band Mk 11 (Naval Bureau of Ordnance Drawings 422317 and 422318).

2. Suspension Beam for Mk 13 Air Flask, 30" Centers (A. O. Smith Corporation Drawing ADM-493). This beam will be referred to hereafter as the 30" beam, this being the distance between the two suspension lugs on this beam.

3. Suspension Beam for Mk 13 Air Flask, 14" Centers (A. O. Smith Corporation Drawing ADM-492), hereafter referred to as the 14" beam.

The tests made included the measurement of yawing and pitching forces up to yaw or pitch angles of 12 degrees, and measurement of the drag as a function of Reynolds number. In addition, a cavitation study was made on the torpedo with Suspension Band Mk 11. A description of the test setup and test procedures will be found in Appendix A. Definitions and symbols are given in Appendix B. References are listed in Appendix C.

(1) Numbers in parentheses refer to references in Appendix C

II. DESCRIPTION OF SUSPENSION FITTINGS

Suspension Band Mk 11 consists of a steel band 3/16" thick and 18-3/8" wide wrapped around the air flask, with its ends bolted together on the top center line, and with a streamlined fitting to cover the bolted ends. Lugs for hoisting into position and for attaching to the bomb rack are located inside a longitudinal groove in the top of the streamlined fitting. The band was located on the model so that it was centered about the center of gravity of the Mk 13-2A prototype. This model is shown in Figures 1 and 2.

The 30-inch suspension beam consists of a steel bar 1" thick and 2" wide spanning the air flask along the top center line, attached at the forward end to the air flask skirt ahead of the bulkhead, and to the midship section at the aft end. Two suspension lugs, spaced 30" on centers, are welded on top of the beam, as shown in Figures 3 and 4.

The 14-inch suspension beam, shown in Figures 5 and 6, is identical with the 30-inch beam, except that the suspension lugs are 14" on centers and a hoisting lug is provided between the suspension lugs.

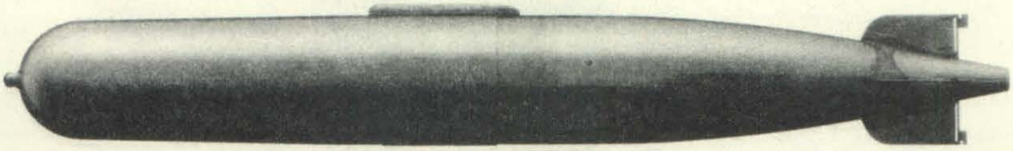

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FIGURE 1

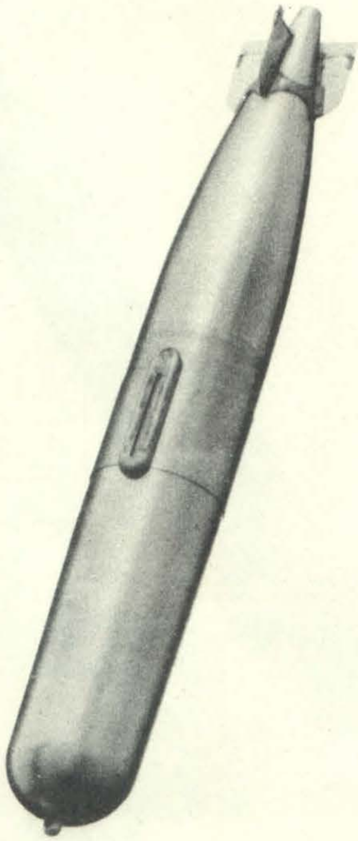

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FIGURE 2

MODEL OF MK 13-2A TORPEDO WITH SUSPENSION BAND MK 11

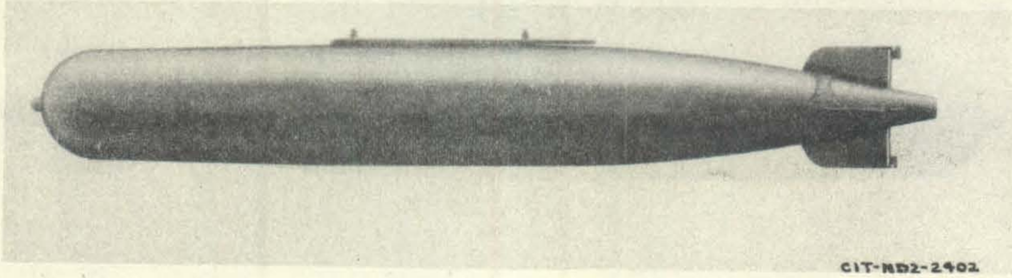

FIGURE 3

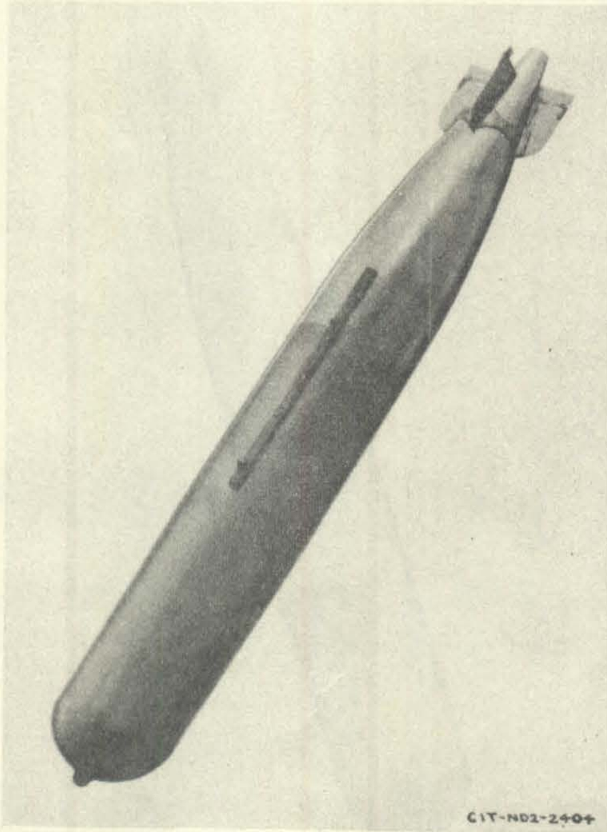

FIGURE 4

MODEL OF MK 13-2A TORPEDO WITH 30-INCH SUSPENSION BEAM

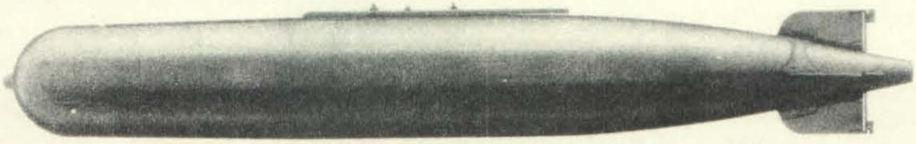

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FIGURE 5

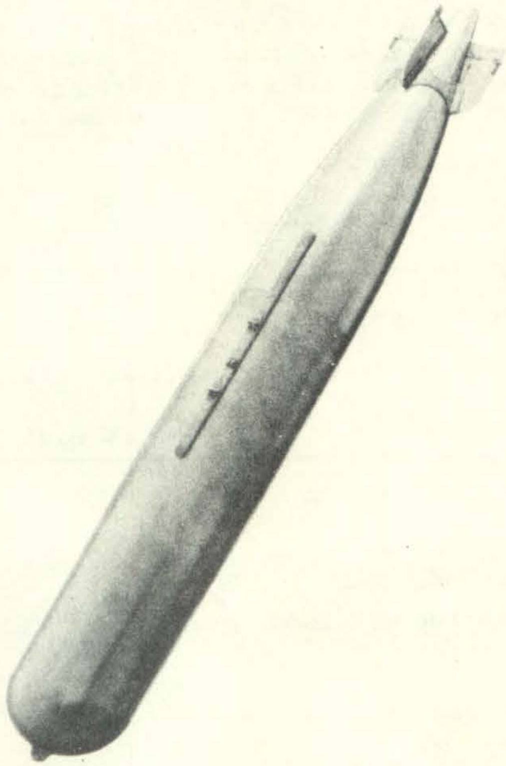

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FIGURE 6

MODEL OF MK 13-2A TORPEDO WITH 14-INCH SUSPENSION BEAM

III. TEST RESULTS

The objective of these tests was to obtain a comparison between the hydrodynamic characteristics of the torpedo with each of the three suspension devices on the one hand, and the standard torpedo on the other hand. To simplify the presentation, the test results are given in tabular form rather than in the form of force and moment coefficient curves.

The various characteristics of the torpedo with each of the suspension fittings are given in Table I in terms of percent of the corresponding values for the standard torpedo without suspension fittings. This form of presentation offers an additional advantage in that the test results, which were calculated for the Mk 13-2A only, are equally applicable to the Mk 13-1 and Mk 13-2. The characteristics of the torpedo without suspension fittings, which were used here as the standard of comparison, are given in Reference 2.

Since these torpedoes normally travel with small yaw or pitch angles, the comparisons shown in Table I were made using the test data for small yaw angles between ± 2 degrees. At larger yaw angles, the effect of the suspension fittings on the hydrodynamics of the torpedo is smaller than shown in the table.

TABLE I

CHARACTERISTICS OF MK 13-2A TORPEDO WITH SUSPENSION FITTINGS COMPARED TO THOSE OF TORPEDO WITHOUT FITTINGS

(Values for torpedo without fittings taken as 100%)

	Mk 11 Band	30" Beam	14" Beam
Instability in vertical plane	112%	120%	120%
Instability in horizontal plane	106%	122%	116%
Rudder effect, horizontal rudders 10° up	86%	100%	--
Rudder effect, horizontal rudders 10° down	106%	96%	--
Rudder effect, vertical rudders 9° port or starboard	100%	--	--
Crossforce	113%	100%	100%
Lift	130%	108%	110%
Drag.	110%	110%	110%

Static Stability

In a normal straight run, the torpedo is operating at or near its equilibrium position. That is, the torpedo is so oriented with respect to its line of travel that the resultant of all forces acting upon it is equal to zero, and the variations from this equilibrium position are slight. The torpedo is said to be "statically stable" if, when disturbed from the equilibrium position, it would tend to return to it even if the rudders did not move, i.e., if the change in moment resulting from the change in orientation is such as to turn the torpedo back toward the position of equilibrium.

In accordance with the sign convention used in presenting hydrodynamic data, a positive moment tends to increase a positive yaw or pitch angle, while a negative moment tends to decrease it. Thus, if the torpedo is to experience a restoring moment after it is disturbed from equilibrium, it is necessary that the change in moment be of opposite sign to the change in yaw or pitch angle produced by the disturbance. Therefore, a negative slope of the moment coefficient curve over small yaw or pitch angles corresponds to static stability, and a positive slope indicates instability. The magnitude of the slope indicates the degree of stability or instability. The values of instability shown in Table I are the slopes of the moment coefficient curves, taken over yaw or pitch angles of -2° to $+2^{\circ}$, expressed as percentages of the slope of the moment coefficient curve of the torpedo without suspension fittings.

Torpedoes, as a rule, are statically unstable. They keep to the desired course by the action of the steering engines and by virtue of dynamic damping. However, excessive instability is detrimental. The data of Table I show that the addition of any one of the three suspension devices increases the instability of the torpedo.

It is known that torpedoes of the Mk 13 series without shroud ring tails are highly unstable. They do run satisfactorily under favorable conditions. However, any unfavorable condition, such as faulty launching or a disturbance due to cross currents, causes them to behave erratically. A further increase in their static instability due to the addition of a suspension device may increase the incidence of erratic runs. The installatiin of shroud ring tails on these torpedoes reduces the instability to less than one half its value without ring and, as a result, their performance is greatly improved. It is believed, therefore, that these torpedoes, when equipped with ring tails, can stand some increase in instability due to the addition of a suspension fitting without being adversely affected by it.

Rudder Effect

The term "rudder effect" may be defined as the change in the moment coefficient produced by a given change in rudder setting. It is a measure of the ability of the projectile to steer itself.

The data of Table I show that with the suspension band, the effectiveness of the horizontal rudders is somewhat reduced for up rudder and slightly increased for down rudder positions. With the 30" beam there is no change in rudder effect for up rudder and a slight reduction for rudders down. Measurements of the rudder effect with the 14" beam were not made.

It should be noted that with the suspension band the moment coefficient is zero at zero pitch with rudders neutral, as it is for symmetrical projectiles. With either beam, the moment coefficient for neutral rudders and zero pitch is not zero, but is approximately the same as with the standard torpedo when the rudder is 1/2 degree up. In other words, the suspension beams produce a slight up rudder effect.

It is believed that the variations in rudder effect mentioned above are not of sufficient magnitude to affect the control of the torpedoes.

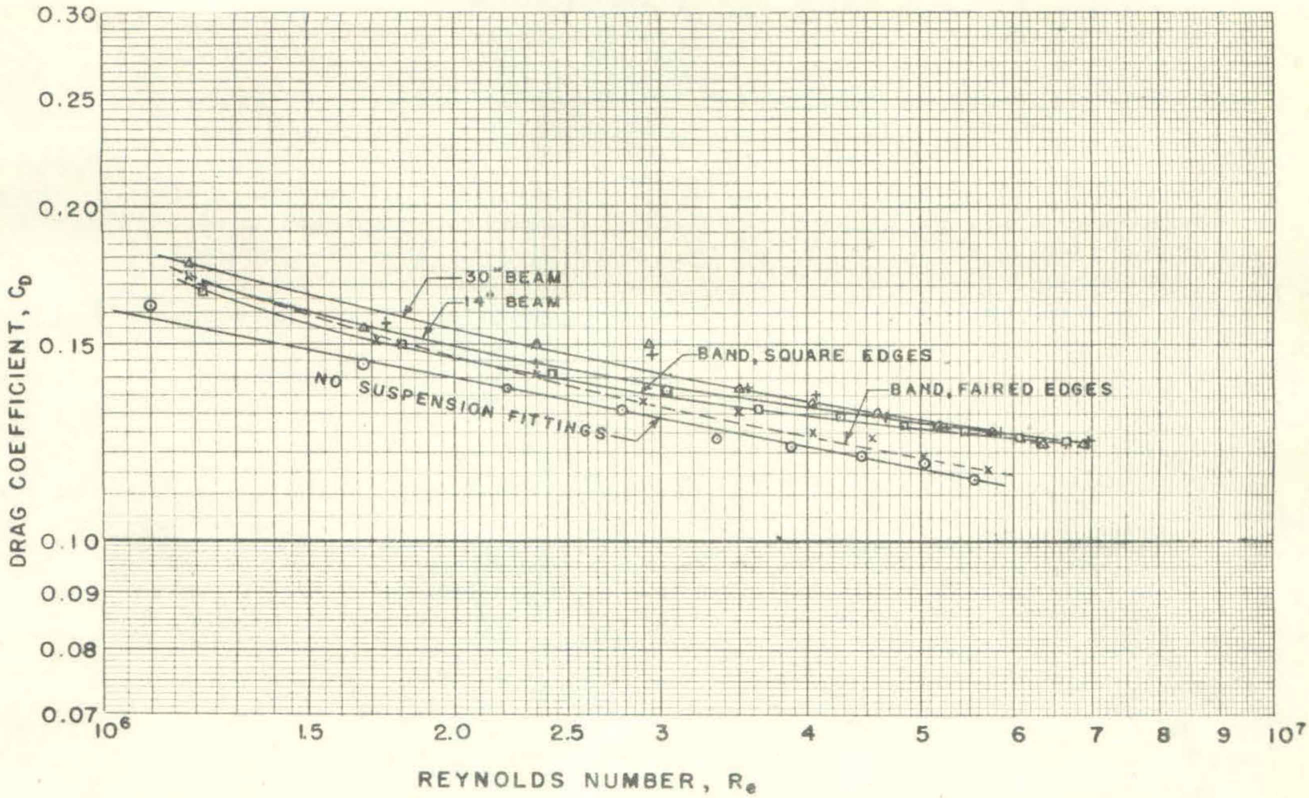
Cross Force and Lift

In Table I it is shown that the addition of any one of the three suspension fittings causes an increase in the lift. The cross force is increased somewhat by the band, but with either beam it is the same as for the standard torpedo. The lift is a measure of the ability of the torpedo to carry negative buoyancy, and the cross force is effective in causing the torpedo to go around a curve, as with angle shots.

Drag

In Figure 7 are plotted against Reynolds number the drag coefficients for the torpedo without any suspension fittings and for the torpedo with each of the three suspension devices tested. The tests were made with water velocities of 10 to 60 fps, taken in 5 fps intervals. The scatter of the test points in the vicinity of $R_e = 3 \times 10^6$ is due to vibration of the model at the corresponding velocity of 25 fps, and does not reflect any irregularity in the behavior of the prototype torpedoes.

An examination of the solid-line curves of Figure 7 shows that all three suspension devices cause approximately equal increases in the drag over that of the torpedo without suspension fittings. This is especially true in the upper range of velocities covered in the tests, where the increase in the drag is approximately 10%. If we make the reasonable assumption that, for



DRAG COEFFICIENT VS. REYNOLDS NUMBER
MK 13-2A TORPEDO WITH AND WITHOUT
SUSPENSION FITTINGS

ALL RUDDERS NEUTRAL
ZERO YAW AND PITCH ANGLES

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FIGURE 7

small variations in speed, the power output of the turbine and the propeller efficiency remain constant, then the speed is inversely proportional to the cube root of the drag coefficient. An increase in the drag coefficient of 10% would, therefore, cause a decrease of 3%, or one knot, in the speed of the prototype torpedo.

One drag test was made on the model with suspension band after rounding off both sharp edges of the band to a radius corresponding to 1-1/2 inches on the prototype, as shown in Figure 8. The results of this test are shown by the dashed curve in Figure 7. It is seen that at the high velocities the drag of this model is nearly as low as that of the torpedo without suspension fittings.

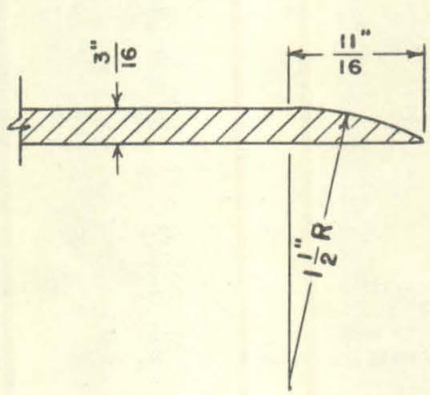

FIGURE 8

Cavitation

Figures 9 to 12 show the development and growth of cavitation on the model with the suspension band. These photographs were taken with the model installed in the High Speed Water Tunnel, at a water velocity of 50 fps and at various pressures, representing a wide range of values of the cavitation parameter K.

Figure 9 was taken at a value of K of 1.20 which, at 33.5 knots, corresponds to a submergence of 27.5 feet. It is seen that even with this high submergence, cavitation is just beginning to appear at the sharp leading edge of the band. In Figure 10, the value of K is 0.91, which corresponds to a submergence of 13 feet at 33.5 knots. Cavitation is now well established all along the leading edge of the band but the nose is still free of cavitation. In Figure 11, K = 0.61. At 33.5 knots, this advanced stage of cavitation cannot occur even in the shallowest runs, but at 40 knots it will occur with a submergence of about 10 feet. It is seen that under these conditions, cavitation on the nose is also well developed. Figure 12 shows an advanced stage of cavitation at K = 0.34. This condition cannot be reached at any submergence even at a speed of 40 knots.

From the foregoing it is seen that Suspension Band Mk 11 in its present form (with sharp edges) is so susceptible to cavitation that it would cavitate at 33.5 knots and normal running depths and would probably slow down the torpedo. However, it is evident that this susceptibility to cavitation is caused by the sharp edges of the band. It is safe to say that, if the edges of the band were rounded as was suggested in the preceding section, the torpedo with the band would be safe from cavitation under all normal operating conditions.

Cavitation tests with the suspension beams were not made. However, because of the good external shape of these beams (rounded shoulders and tapered front end), it is believed that they will not cavitate under normal conditions except, perhaps, over very small regions around the sharp edges of the suspension lugs. This, if it does occur, would be of such small magnitude that it would not affect the performance of the torpedo.

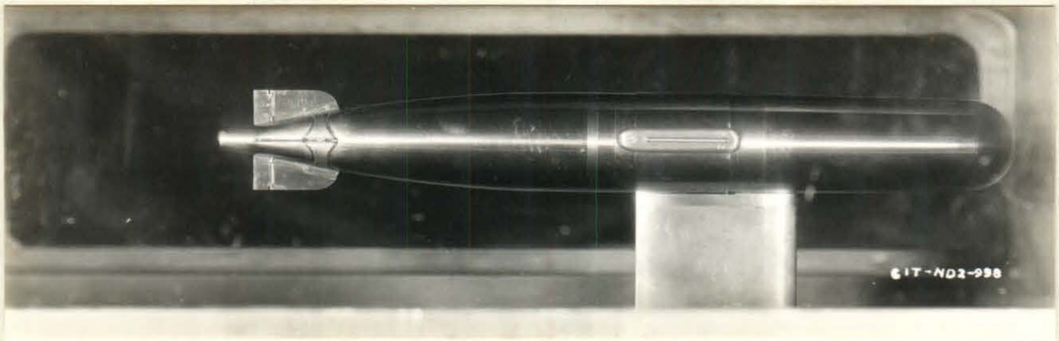

FIGURE 9

K = 1.20, CORRESPONDING TO A SUBMERGENCE OF
27.5 FEET AT 33.5 KNOTS

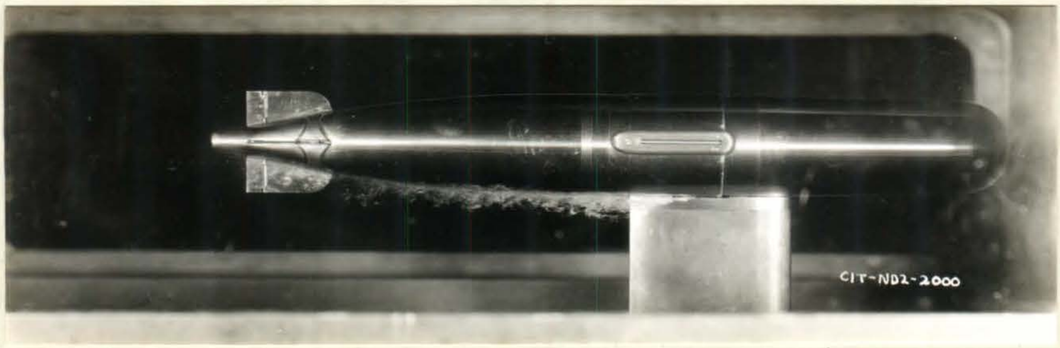

FIGURE 10

K = 0.91, CORRESPONDING TO A SUBMERGENCE OF
13 FEET AT 33.5 KNOTS

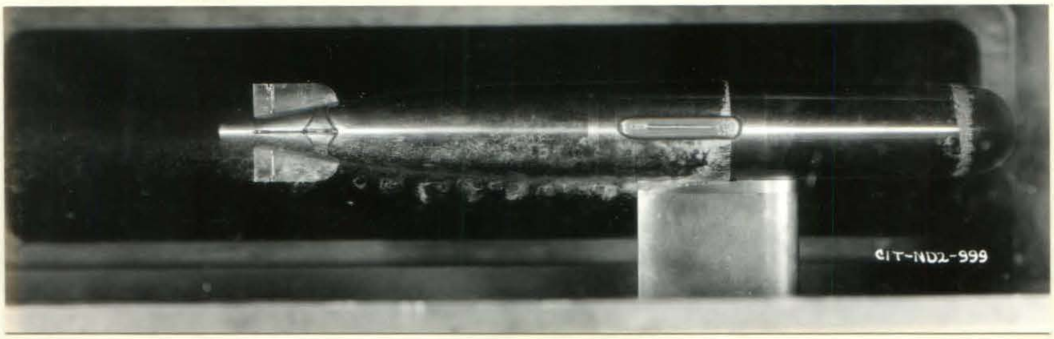

FIGURE 11

K = 0.61. THIS ADVANCED STAGE CANNOT DEVELOP AT 33.5 KNOTS. AT 40 KNOTS THIS CORRESPONDS TO A SUBMERGENCE OF 10 FEET.

FIGURE 12

K = 0.34. THIS CONDITION CANNOT BE REACHED EVEN AT 40 KNOTS AND SHALLOWEST SUBMERGENCE.

APPENDIX A

TEST EQUIPMENT AND PROCEDURES

The tests covered by this report were conducted in the High Speed Water Tunnel at the California Institute of Technology. The following paragraphs contain a brief description of the tunnel and the test procedures employed. A more detailed description of the High Speed Water Tunnel will be found in Reference 1.

MAIN CIRCUIT

The Water Tunnel is of the closed circuit, closed working section type. Figure A-1 shows a profile of the main flow circuit which consists essentially of the working section, the circulating pump, the stilling tank, and the necessary pipe connections. The cylindrical working section is 14" in diameter, 72" long, and is provided with three lucite windows. The propeller-type circulating pump is V-belt connected to a variable speed dynamometer. The speed of the dynamometer is automatically controlled and is held constant within ± 1 r.p.m., which corresponds to a maximum water velocity variation in the working section of 1/30 ft. per sec. While most tests are made with water velocities of 24 to 31 ft. per sec., any velocity between 10 and 72 ft. per sec. is easily obtainable.

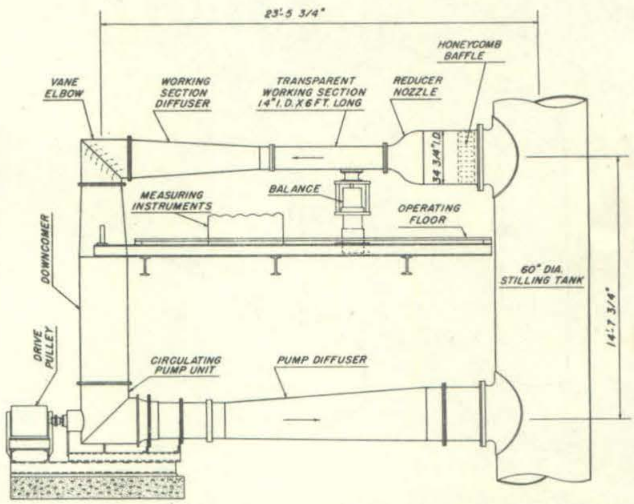

FIGURE A-1

AUXILIARY CIRCUITS

Two auxiliary water circuits, one for pressure control and one for temperature control, are used in conjunction with the main circuit. These circuits are shown in Figure A-2, which is an isometric diagram of the complete water tunnel installation.

To make it possible to induce or inhibit cavitation at will, it is necessary that the pressure in the working section be controllable independently of the velocity. This is accomplished by superimposing the pressure regulating circuit on the main circuit.

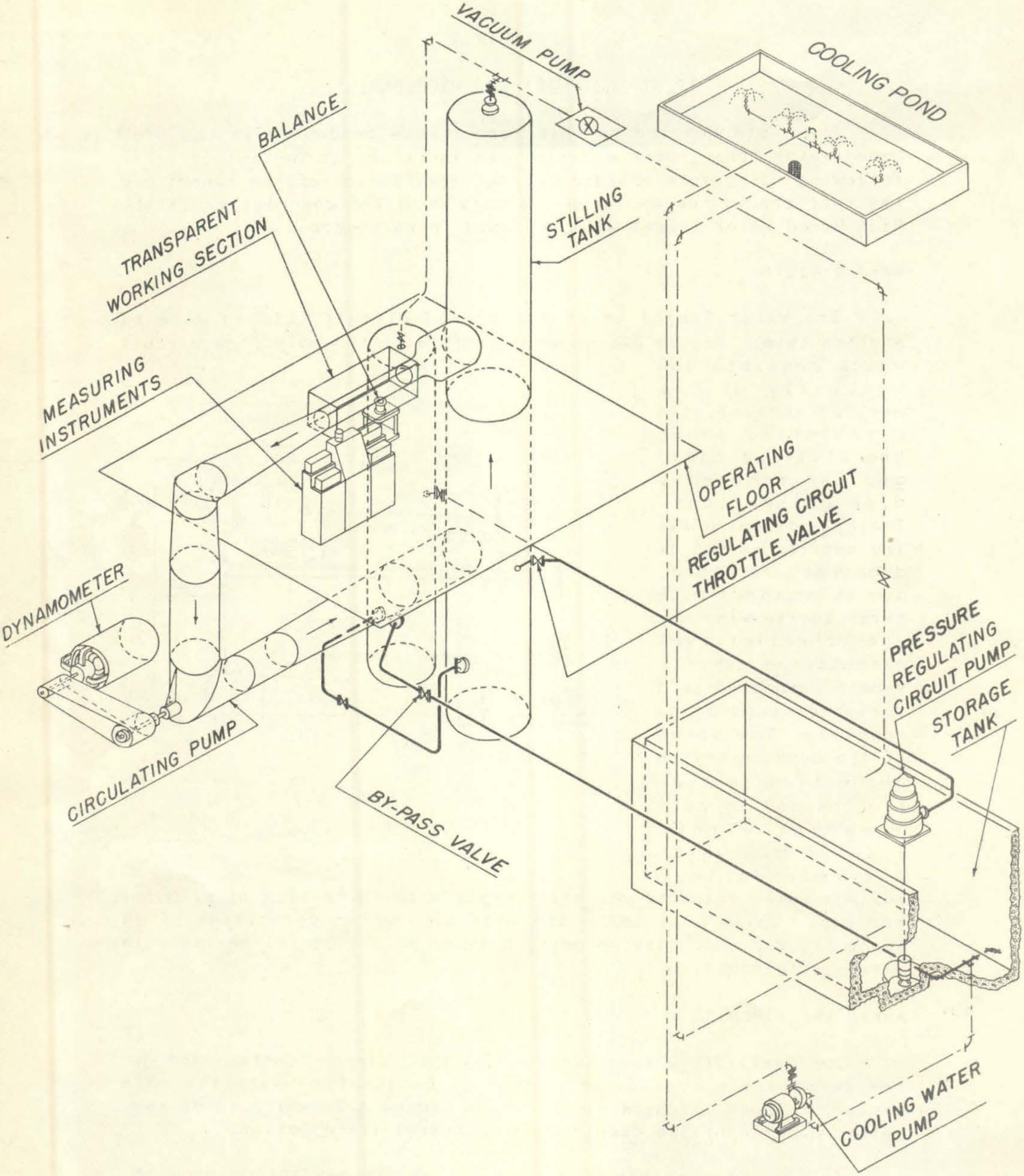
VACUUM PUMP
COOLING POND
BALANCE
STILLING TANK
TRANSPARENT WORKING SECTION
MEASURING INSTRUMENTS
OPERATING FLOOR
REGULATING CIRCUIT THROTTLE VALVE
DYNAMOMETER
PRESSURE REGULATING CIRCUIT PUMP
STORAGE TANK
CIRCULATING PUMP
BY-PASS VALVE
COOLING WATER PUMP

FIGURE A-2

A small flow of water from the sump is forced into the stilling tank by the regulating pump, and is returned to the sump through the by-pass valve. Since the main circuit is closed and completely filled, it is evident that the pressure in it may be controlled by varying the opening of the by-pass valve. A stripping pump (not shown in Figure A-2), in series with the by-pass valve, is used to produce very low pressures. The vacuum pump is used to remove air from the system so as to keep it full of water at all times.

The energy put into the water of the main circuit by the circulating pump (up to 250 HP) is all dissipated in heat. To prevent the temperature of the water from rising to undesirable values, it is necessary to remove this heat by cooling. Part of the water returned through the by-pass valve is picked up by the cooling water pump, circulated through the forced-draft cooling tower on the roof, and returned to the sump. By varying the quantity of water circulated through the cooling system, it is possible to maintain the water in the main circuit at a constant temperature.

BALANCE

The balance, shown schematically in Figure A-3, is designed to measure three components of the hydrodynamic forces acting on the model. These are the drag force parallel to the flow, the cross force normal to the flow, and the moment around the axis of support. The three forces to be measured are transmitted hydrostatically to three self-balancing, weighing type pressure gages. These automatic gages, under glass covers, may be seen in Figure A-4, which is a view of the operating floor of the Water Tunnel. The fourth gage shown in this figure is a weighing type manometer used to determine the velocity in the working section by measuring the pressure drop across the reducing nozzle. The gages are responsive to a change in the drag or cross force acting on the model of 0.02 pounds, and a change of 0.04 inch-pounds in the moment.

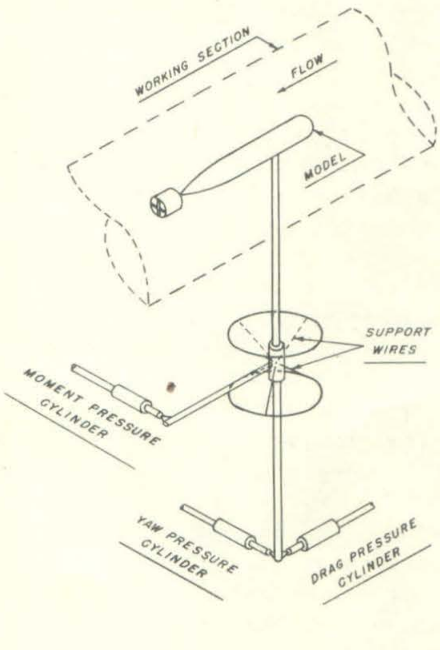

FIGURE A-3

The model is mounted on a shaft which forms the core of the vertical balance spindle shown in Figure A-3. By rotating this shaft within the spindle, it is possible to change the orientation of the model with respect to the direction of flow without altering the direction of the force components measured. Between adjustments, the spindle and shaft are held firmly together by a long, spring-loaded, tapered seat. To change the adjustment, the taper is unseated by an air diaphragm and the shaft is rotated through a worm and gear-sector by a small electric motor (not shown in the figure) mounted on the spindle. A Veeder counter on the worm gear shaft indicates the angle of attack to the nearest 1/10 degree. It should be noted that this whole system forms a part of the spindle assembly, which is pivoted about the point of intersection of the support wires. Thus it does not affect the force measurements in any way.

To reduce the drag tare to a minimum, the portion of the spindle shaft which projects into the working section is protected from the flow by a streamlined shield which extends to within a few thousandths of an inch of the model.

POLARIZED LIGHT FLUME

The Polarized Light Flume is a separate piece of equipment used for studying the flow around submerged bodies. The fluid circulated is water containing 0.2 per cent by weight of Bentonite in suspension. Bentonite has the asymmetrical optical and physical properties required for the production of streaming double refraction. The flow to be studied is made visible by projecting a beam of light across it through a pair of polaroid plates which are oriented to produce a dark field when there is no flow. The observation section is a rectangular channel 6" wide and 12" deep, having glass sides and bottom.

The velocities used in this flume are necessarily lower than those employed in the High Speed Water Tunnel. However, this difference is not sufficient to affect the validity of the flow patterns observed. A knowledge of these flow patterns is found to be of assistance in the interpretation of the dynamic behavior of the projectiles studied. It is very helpful in investigating interference phenomena, the cause and location of separation or flow instabilities, and the behavior of the boundary layer. Care must be exercised in interpreting the observed patterns, both because the flow is three-dimensional, whereas the observed optical effect is an integration of the entire path of the light beam, and because the pattern produced is a shear pattern and not one of streamlines.

TEST PROCEDURES

The facilities of the High Speed Water Tunnel provide for great flexibility in operation and test procedures. Individual test runs are usually made to determine the effect on the hydrodynamic forces of individual variables, although any of the variables may be changed at will independently of the others.

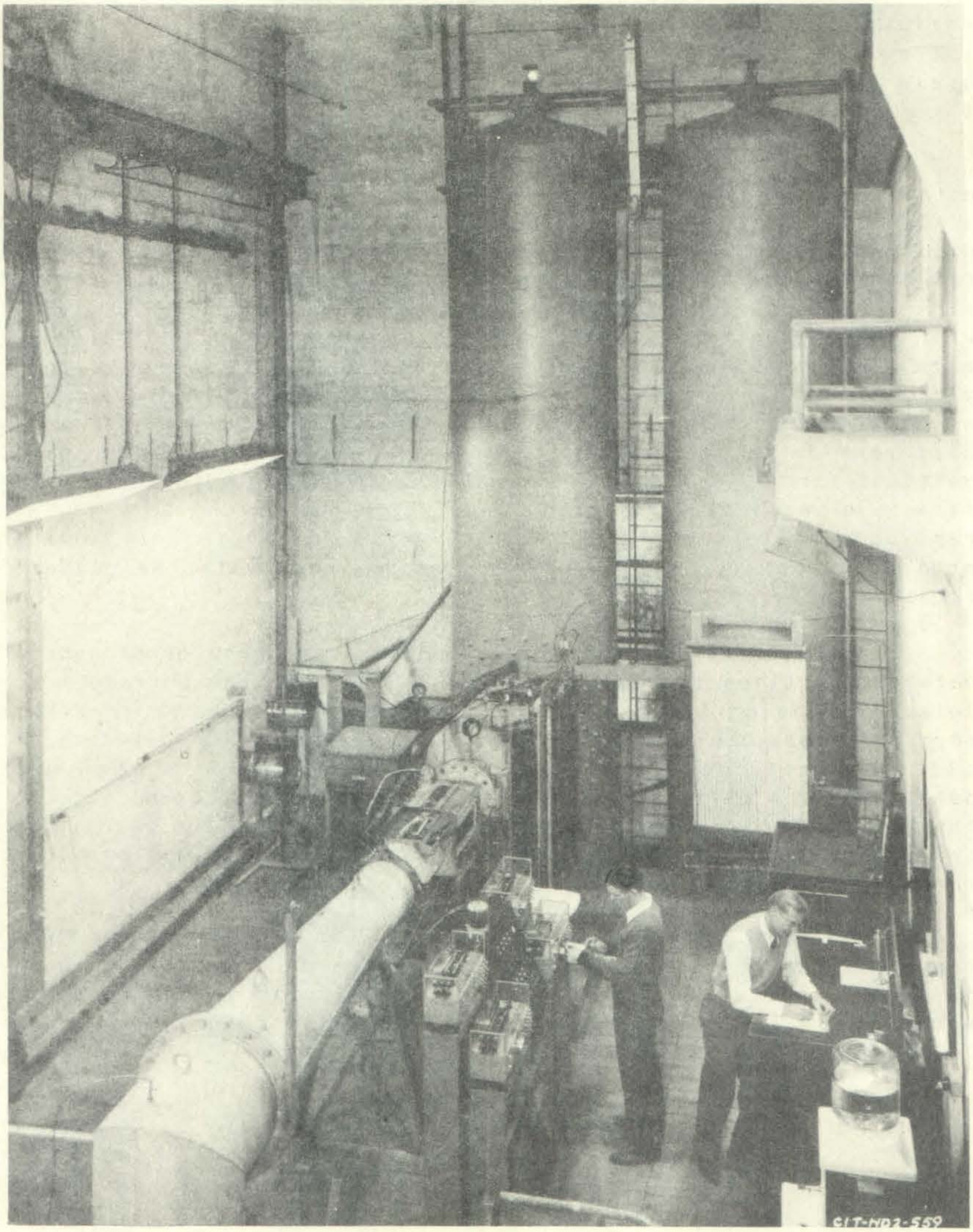

FIGURE A-4

OPERATING FLOOR
OF THE
HIGH SPEED WATER TUNNEL

Constant-velocity tests runs are made to determine the variation of the hydrodynamic forces with changes in the orientation of the projectile with respect to the line of flow. The angle of attack is changed in steps of 1/2 or 1 degree, and the three force components are measured at each step.

A single test, covering the desired range of angles of attack is sufficient to completely determine the yawing characteristics of a projectile which is symmetrical about its longitudinal axis and has no movable control surfaces. A projectile which is not symmetrical about its longitudinal axis (e.g., having unequal horizontal and vertical fins) will show different characteristics when yawed in different planes and, therefore, must be tested in more than one plane. Since the model can be yawed only in a plane normal to the spindle, this is accomplished by making several separate test runs, with the model mounted on the spindle in a different orientation for each run. For instance, one run with vertical fins in a vertical position and another with horizontal fins in a vertical position. These would correspond to a yawing test and a pitching test, respectively. For a projectile with movable rudders, several tests are made, each with the rudders set at a different angle.

Cavitation is an important factor in the behavior of underwater projectiles travelling at high speed near the surface. To determine the cavitation characteristics of such a projectile, separate tests are made during which the pressure is varied while all the other factors are held constant. The inception and development of cavitation may be observed or photographed through the transparent windows of the working section, and the velocities and pressures at which cavitation begins on the various parts of the projectile are measured.

Variable-speed test runs are made to determine the scale (Reynolds number) effect on the hydrodynamic forces. The speed is usually varied in 5 fps steps and the forces are measured at each step. The pressure in the working section is kept high enough to suppress cavitation at the highest velocity.

APPENDIX B

DEFINITIONS

PITCH ANGLE

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

YAW ANGLE

The angle in the horizontal plane which the axis of the projectile makes with the direction of travel. Looking down on the projectile and in the direction of travel, yaw angles to the right are positive (+), and to the left, negative (-).

LIFT

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

CROSS FORCE

The force, in pounds, exerted on the projectile in a direction normal to the line of travel and in the horizontal plane. A positive cross force is defined as one acting in the same direction as the displacement of the projectile nose for a positive yaw angle.

DRAG

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

MOMENT

The torque tending to rotate the projectile about a transverse axis. A positive or clockwise moment tends to increase a positive yaw or pitch angle. A moment, therefore, has a destabilizing effect when it has the same sign as the yaw or pitch angle, and a stabilizing effect when of opposite sign.

COEFFICIENTS

The force and moment coefficients are defined as follows:

Lift Coefficient, $C_L = \dfrac{L}{1/2\ \rho\ V^2 A}$

Cross Force Coefficient, $C_C = \dfrac{C}{1/2\ \rho\ V^2 A}$

Drag Coefficient, $C_D = \dfrac{D}{1/2\ \rho\ V^2 A}$

Moment Coefficient, $C_M = \dfrac{M}{1/2\ \rho\ V^2 A l}$

where

L = lift force, pounds

C = cross force, pounds

D = drag force, pounds

M = moment, foot-pounds

ρ = density of water, slugs per cu. ft.

V = velocity, feet per second

A = area of a crossection taken normal to the longitudinal axis of the projectile at its maximum diameter, square feet

l = overall length of projectile, feet

REYNOLDS NUMBER $R_e = \dfrac{Vl\rho}{\mu} = \dfrac{Vl}{\nu}$

where

V, l, and ρ are as defined above, and

μ = absolute viscosity of water, pound-second per square foot

$\nu = \dfrac{\mu}{\rho}$ = kinematic viscosity of water, square feet per second

CAVITATION PARAMETER $K = \dfrac{P_L - P_B}{1/2\ \rho\ V^2}$

where

ρ and V are as defined above, and

P_L = absolute pressure in undisturbed water surrounding the projectile, pounds per square foot

P_B = absolute pressure within the bubble, equal to the vapor pressure of water, pounds per square foot

APPENDIX C

REFERENCES

(1) For complete description see the following report on file in the office of Section 6.1, NDRC, "The High Speed Water Tunnel at the California Institute of Technology," by R. T. Knapp, V. A. Vanoni, and J. W. Daily, June 29, 1942

(2) "Water Tunnel Tests of the Mk 13-1, Mk 13-2, and Mk 13-2A Torpedoes," Section No. 6.1-sr207-936, November 9, 1943

(3) "Water Tunnel Tests of the Mk 13-1, Mk 13-2, and Mk 13-2A Torpedoes with Shroud Ring Tails," Section No. 6.1-sr207-939, November 24, 1943

(4) "Water Tunnel Tests of the Mk 13 Torpedo with Spade and Stabilizer Ring Noses," Section No. 6.1-sr207-1278, May 30, 1944

(5) "Pressure Distribution Measurements on the Mk 13-1, 13-2, and 13-2A Torpedoes," Section No. 6.1-sr207-1643, June 23, 1944