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OFFICE OF SCIENTIFIC RESEARCH & DEVELOPMENT

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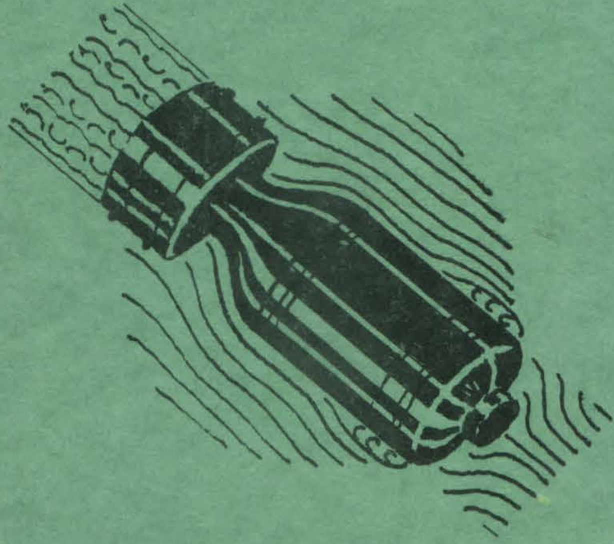
DIVISION SIX-SECTION 6.1

WATER TUNNEL TESTS OF THE MK25 TORPEDO WITH EXPANDING EXHAUST PIPE



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

SECTION Nº 6.1-SR-207-1642
ND Nº 30.2

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WATER TUNNEL TESTS
OF THE
MK 25 TORPEDO
WITH EXPANDING EXHAUST PIPE

BY

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THE HIGH SPEED WATER TUNNEL
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Section No. 6.1-sr207-1642

HML Rep. No. ND-30.2

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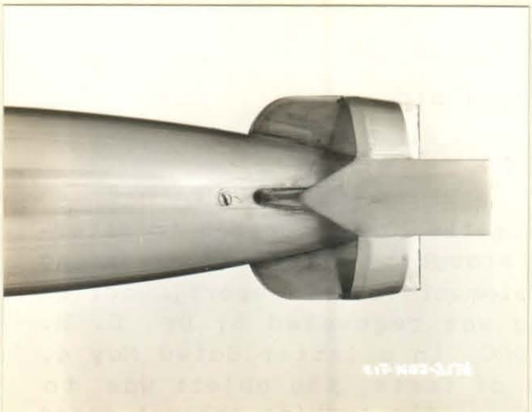
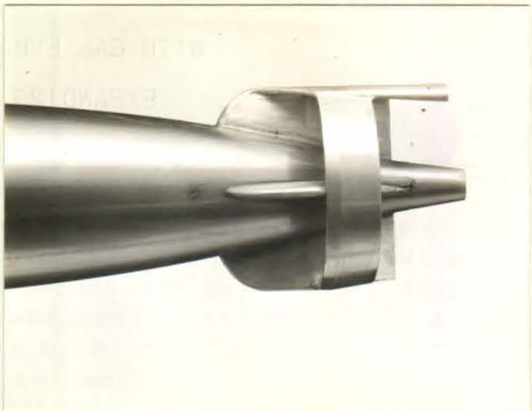
June 20, 1944



TOP VIEW



SIDE VIEW

END VIEW

TAIL STRUCTURE OF MODEL
SHOWING EXHAUST PIPE

FIGURE 1

WATER TUNNEL TESTS OF THE MK 25 TORPEDO WITH GAS EXHAUST THROUGH AN EXPANDING EXHAUST PIPE

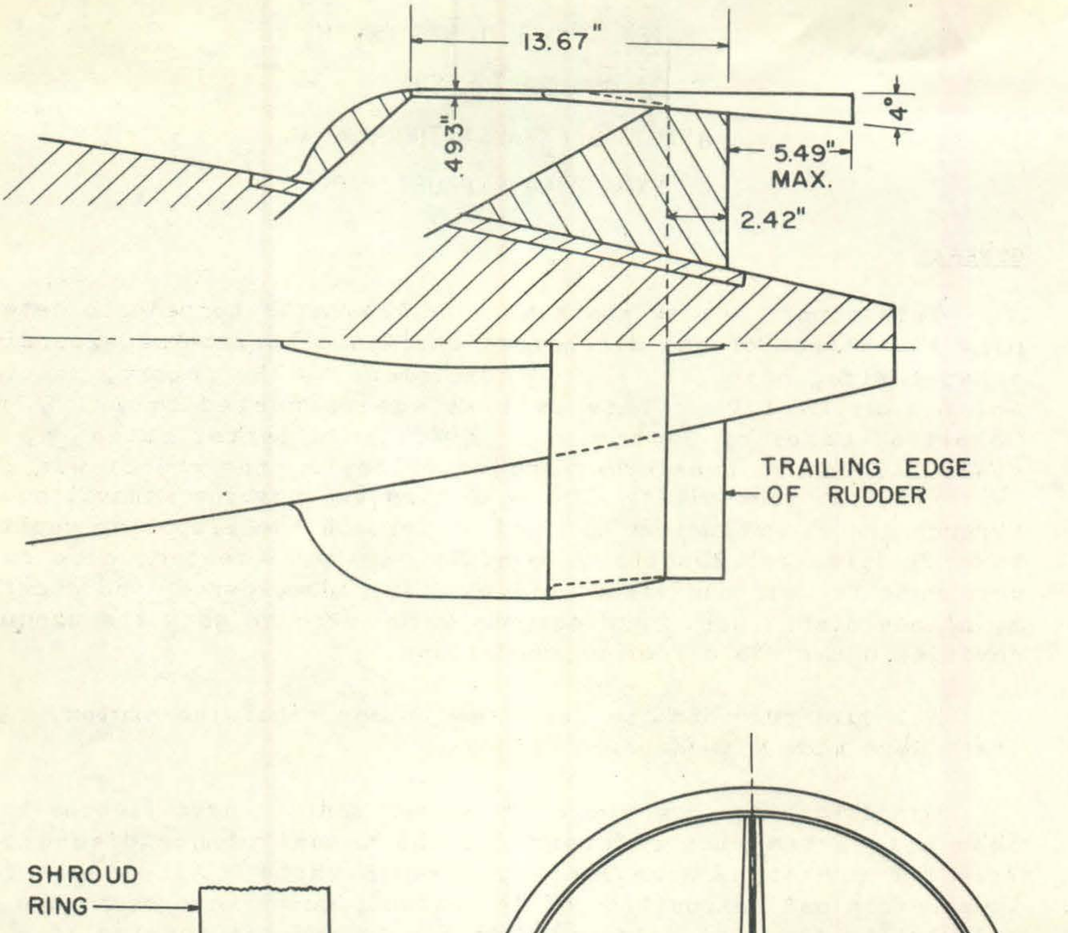
GENERAL

This report covers tests made on the Mk 25 torpedo to determine the effect of gas discharged through a horizontal expanding exhaust pipe, being the second supplement to the report, Section No. 6.1-sr207-1275. This testing was requested by Dr. E. H. Colpitts, Chief of Section 6.1, NDRC, in a letter dated May 4, 1944. As in the two former series of tests, the object was to determine the feasibility of discharging the turbine exhaust gases through the fin structure instead of through the propeller shafts. Several different lengths of exhaust pipe were tested; also runs were made for various values of velocity, submergence, and quantity of gas discharged. Photographs were taken to show the exhaust cavities under the different conditions.

All data refer to the prototype unless otherwise stated. All tests were made with neutral rudders.

Gas discharges are expressed in per cent. These figures have been calculated with reference to the amount of gas discharged from the prototype when running at 40.5 knots. Allowances for temperature and composition of the exhaust gases have been made by calculating the exit velocity when the torpedo is running at 40.5 knots and 15 feet submergence, computing the ratio of this velocity to that of the torpedo, and then calculating the amount of air required by the model to obtain this velocity ratio when operating at the equivalent submergence. This criterion requires that a different rate of air flow be taken as the 100% amount for each torpedo velocity investigated. However, as in the prototype, the mass rate of gas flow in the model is constant for any given water velocity, independent of the changes in the tunnel pressure (i.e., submergence).

Figures 1 and 2 give details of the afterbody used in these tests. The gas exhaust is through an annular shaped expanding exhaust pipe, approximately 8.2" x 1.4", located directly over the vertical fin. This exhaust passage and pipe represent the first attempt of the laboratory to design a discharge that conforms to the condition stated in the Conclusions of the preceding report (Section No. 6.1-sr207-1640, Page 13, last paragraph), namely, "that the exhaust must be discharged into a low-pressure region, separated from the structure of the projectile by zones of higher static pressure, and aft of any low-pressure region that offers a continuous low-pressure path to the fin structure, afterbody, or propeller zones." Note that the inner wall of the exhaust pipe is an unbroken continuation of the inner surface of the tail ring, and the outer wall is cylindrical. This configuration tends



DETAILS OF EXHAUST PIPE

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FIGURE 2

to keep the pressure high on the outside of the pipe, and this forms a barrier to prevent the exhaust bubble from moving forward. Six different lengths of exhaust pipe were tested. The longest extended 5.49" beyond the trailing edge of the vertical rudder and the shortest was flush with the trailing edge of the shield ring.

CAVITATION PARAMETER

The air bubble formed by the discharge of gas from the fin is identical in behavior with the normal cavitation bubble. The shape and size of the cavitation bubbles for a specific projectile are functions of the cavitation parameter, K. This parameter is normally defined as follows:

$$K = \frac{P_L - P_B}{\rho \frac{V^2}{2}}$$

in which

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

P_B = vapor pressure corresponding to the water temperature lb/sq ft

V = velocity, ft/sec

ρ = mass density of the fluid in slugs per cu ft = $\frac{w}{g}$

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, for equal values of K, the behavior of the bubble will be the same whether the bubble is due to cavitation or to the injection of gas as in the present tests.

The chart, Figure 34 shown at the end of this report, gives values of K as a function of velocity and submergence in sea water at a temperature of 50° Fahrenheit. For this chart the pressure in the bubble is assumed to be the vapor pressure for this temperature.

CAVITATION WITH NO EXHAUST

Figures 3, 4, and 5 show the cavitation effects on the model for values of K = 0.49, 0.39, and 0.26. In Figure 3 it is seen that cavitation is well developed on the nose as well as on the leading edge of the shroud ring. There is also apparent a slight trail of cavitation bubbles extending aft of the entire tail structure. The condition shown in Figure 3 corresponds to a submergence of about 2 feet at a speed of 40.5 knots, whereas the normal operating condition for this torpedo is a speed of 40.5 knots and 15 feet submergence, corresponding to a K of 0.67.

EXHAUST CAVITIES

Exhaust Pipe 5.49" Long

Figures 6, 7, and 8 show the exhaust cavities with the longest exhaust pipe, viz. 5.49" beyond the trailing edge of the rudder. The three figures are for values of K of 1.0, 0.69, and 0.49, the gas discharge being approximately 85% of normal. No spreading of the exhaust gas can be noticed in any of these photographs, although there is well developed cavitation along the leading edge of the shroud ring for K = 0.49. It is especially interesting to note the exhaust forming into large bubbles after leaving the exhaust pipe. This action is made visible by the very short exposure at which the photograph was made.

Exhaust Pipe Flush with Shroud Ring

Figures 9, 10, and 11 show the exhaust cavities with the shortest exhaust pipe which was just flush with the trailing edge of the shroud ring, K varying from 0.97 to 0.51 and the gas discharge varying from 85% to 100%. No spreading of the gas can be noticed along the trailing edge of the rudder, although it can be seen that the exhaust gas cavity is in contact with the outer end of the rudder. It is hoped that this would not cause any interference with the satisfactory operation of the rudders.

COMPARISON OF DIFFERENT LENGTHS OF EXHAUST PIPE

Figures 12 to 17 show the six different lengths of exhaust pipe that were tested under conditions of approximately K = 0.50, zero yaw, and a gas discharge 85% to 100% of normal. The sketches show the location of the end of the exhaust pipe with reference to the trailing edge of the rudder. It is seen that the exhaust cavity with this design of exhaust pipe is very compact and has little tendency to spread in the immediate vicinity of the tail structure. While cavitation seems well developed along the leading edge of the shroud ring, none can be noticed on the trailing edges of the ring or the rudder. There does not appear to be any tendency for the exhaust cavity to follow down the edge of the rudder, even with this value of K, which is considerably lower than that corresponding to the normal condition.

All of the pictures in this series (Figures 12 to 17) were taken with zero pitch and zero yaw and even the shortest exhaust pipe is apparently satisfactory under these favorable conditions.

EFFECT OF YAW AND PITCH

Figures 18, 19, and 20 show the performance at 0°, $+3^{\circ}$, and $+5^{\circ}$ yaw angle with approximately 100% gas discharge and the exhaust pipe flush with the shroud ring. The positive yaw angle means that the tail has been moved away from the observer, thus bringing the low pressure on the visible side. There appears to be some spreading of the exhaust bubble along the top of the ring adjacent to the exhaust pipe, although this is not very extensive.

Figures 21, 22, and 23 show the development of the exhaust cavity at -5° pitch angle as K varies from 0.99 to 0.51 or, in other words, as the submergence at 40.5 knots varies from 37 feet to approximately 3 feet. (Negative pitch angle means that the tail is moved *toward* the observer in this case). In Figure 22, it is seen that the gas from the exhaust is beginning to spread along the trailing edge of the ring to the rudder, which is a good indication that this is the condition at which interference with rudder action commences. The picture was taken with neutral rudders and it is quite certain that a rudder setting of a few degrees would considerably increase this interference. In Figure 23, which corresponds to a submergence of approximately 3 feet at 40.5 knots, the propellers could be completely enveloped in the exhaust cavity.

The series of pictures in Figures 24 to 28 show the variation in the exhaust cavities for pitch angles of 0°, $\pm 3^{\circ}$, and $\pm 5^{\circ}$, all being for approximately 100% exhaust gas discharge, a submergence of approximately 3 feet at 40.5 knots, and the exhaust pipe flush with the shroud ring. It is obvious that at this low submergence the discharge from the short exhaust pipe will cause the rudders and propellers to be enveloped even for a pitch angle no greater than -3°.

When the submergence is increased to approximately 15 feet, which corresponds to the normal condition for this torpedo, the performance at various pitch angles is much more satisfactory. This is shown in Figures 29 to 33, which are for the same conditions as Figures 24 to 28, except the value of K has been increased to approximately 0.7 corresponding to a submergence of about 16-1/2 feet at 40.5 knots. In this series of pictures, it is seen that practically no interference is caused by the exhaust cavity except at -5° pitch.

CONCLUSIONS

This series of tests indicates that the expanding type of exhaust pipe herein detailed, cut off flush with the trailing edge of the shroud ring, should prevent the exhaust gas interfering with the rudders and propellers provided the yaw angle does not exceed $\pm 5^{\circ}$ or the pitch angle does not exceed $\pm 3^{\circ}$ and provided, further, that the submergence at 40.5 knots is at least 15 feet.

It must be emphasized that all tests so far made have been on a model without propellers and with neutral rudders. The results of these tests are, therefore, to be taken only as an indication of the effect of certain factors on performance and the final determination of the most satisfactory exhaust pipe design will have to be deferred until the tests with rudder settings and power driven propellers are completed. This work is now under way and results are expected in the near future.

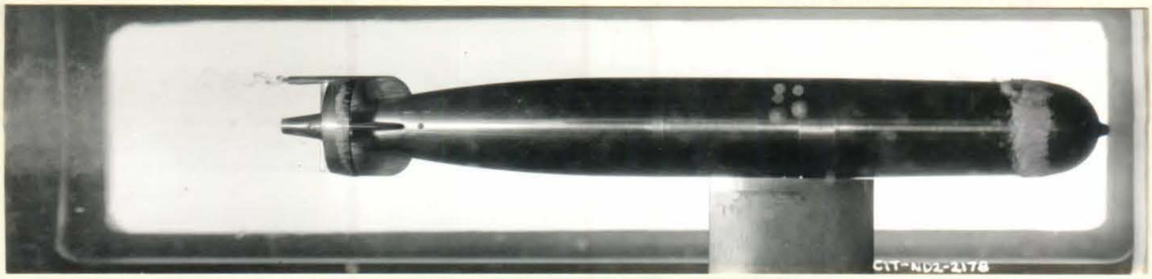


FIGURE 3 K = 0.49

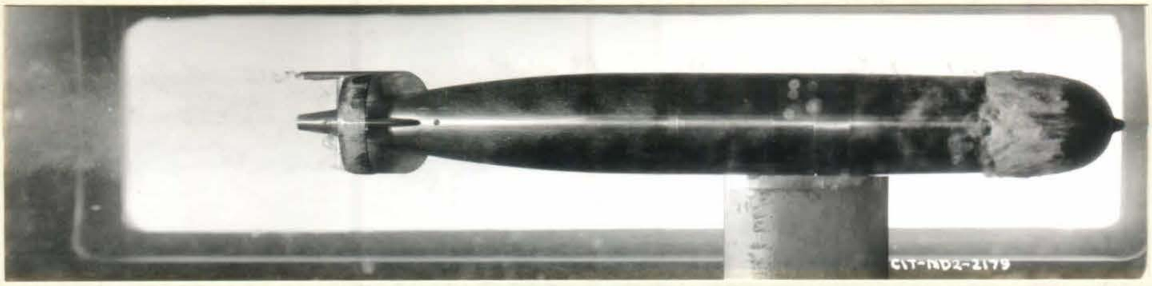


FIGURE 4 K = 0.39

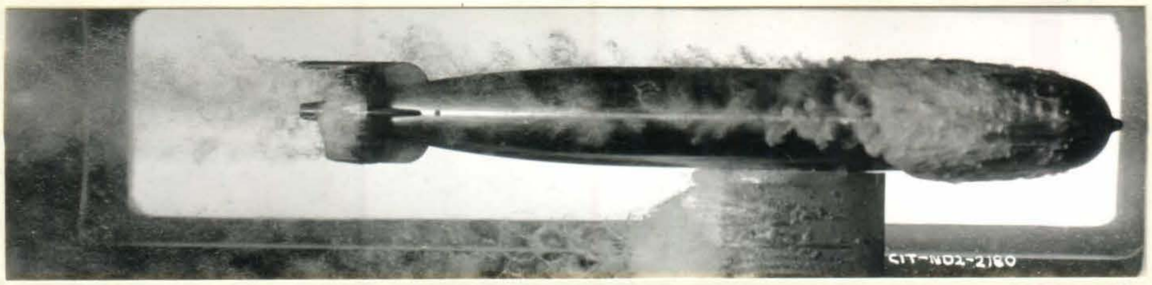
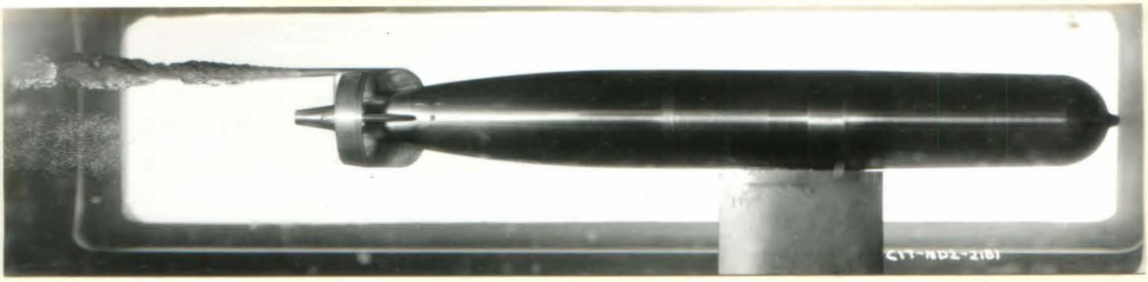


FIGURE 5 K = 0.26

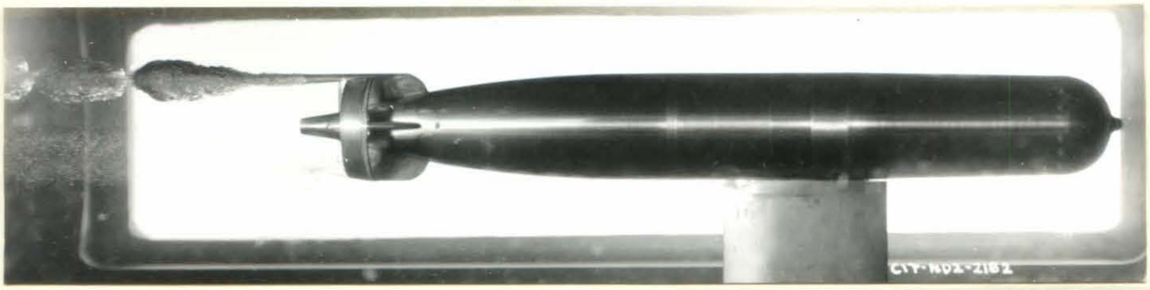
CAVITATION FOR VARIOUS VALUES OF K

NO EXHAUST GAS



Q = 85% ψ = 0 K = 1.0

FIGURE 6



Q = 85% ψ = 0 K = 0.69

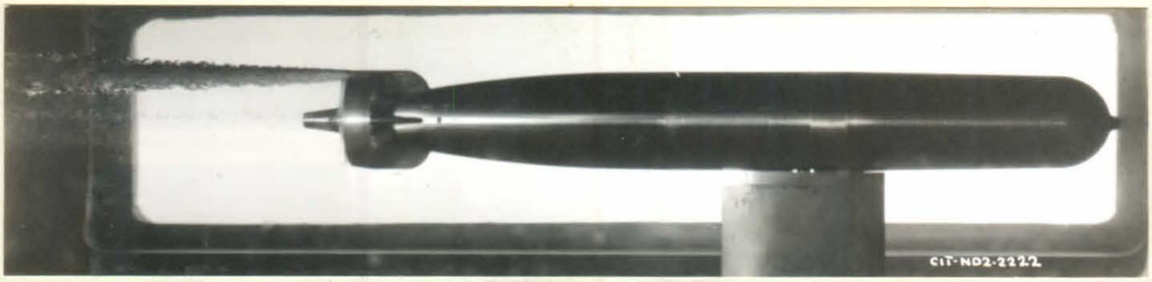
FIGURE 7

Q = 90% ψ = 0 K = 0.49

FIGURE 8
(SAME AS FIGURE 12)

EXHAUST CAVITIES FOR VARIOUS VALUES OF K

EXHAUST PIPE 5.49" BEYOND TRAILING EDGE OF RUDDER

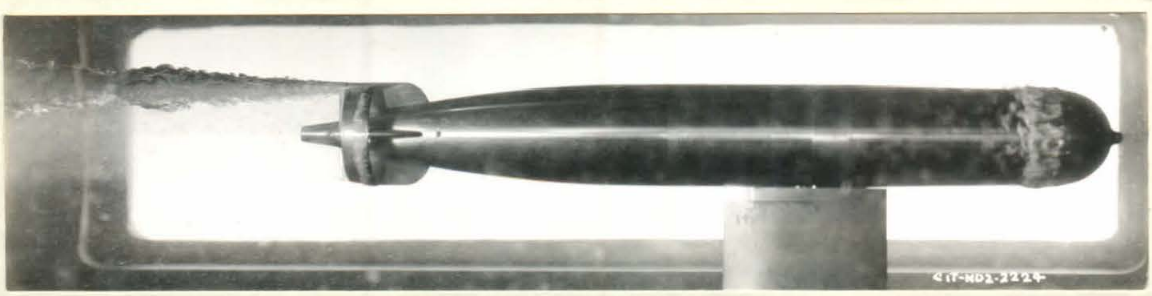


Q = 95% ψ = 0 K = 0.97

FIGURE 9

Q = 100% ψ = 0 K = 0.68

FIGURE 10



Q = 85% ψ = 0 K = 0.51

FIGURE 11
(SAME AS FIGURES 17 AND 18)

EXHAUST CAVITIES FOR VARIOUS VALUES OF K

EXHAUST PIPE FLUSH WITH TRAILING EDGE OF SHROUD RING

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FIG. 12
(SAME AS FIG. 8)
K = 0.49
Q = 90 %

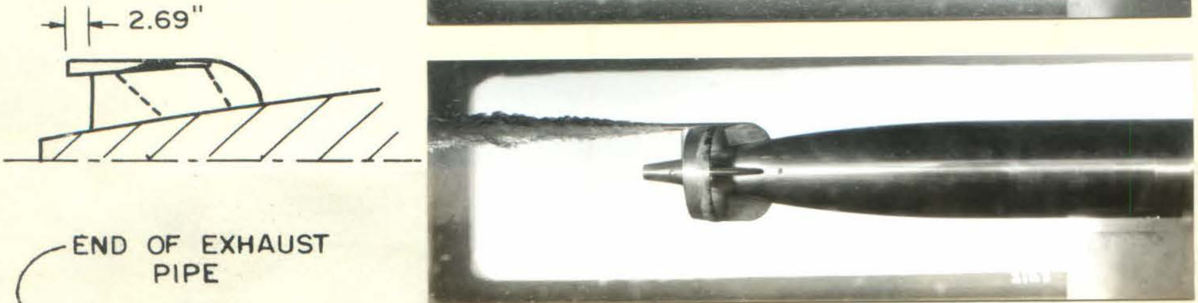

FIG. 13
K = 0.51
Q = 95%

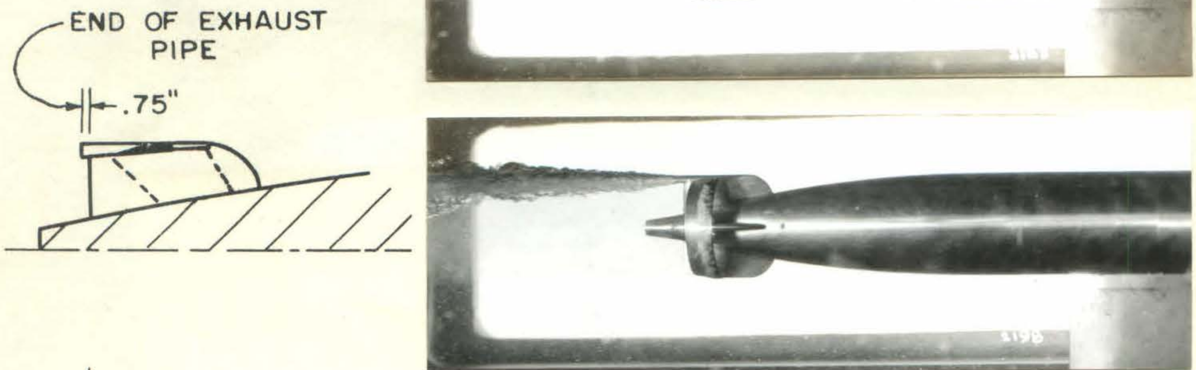

FIG. 14
K = 0.48
Q = 90%

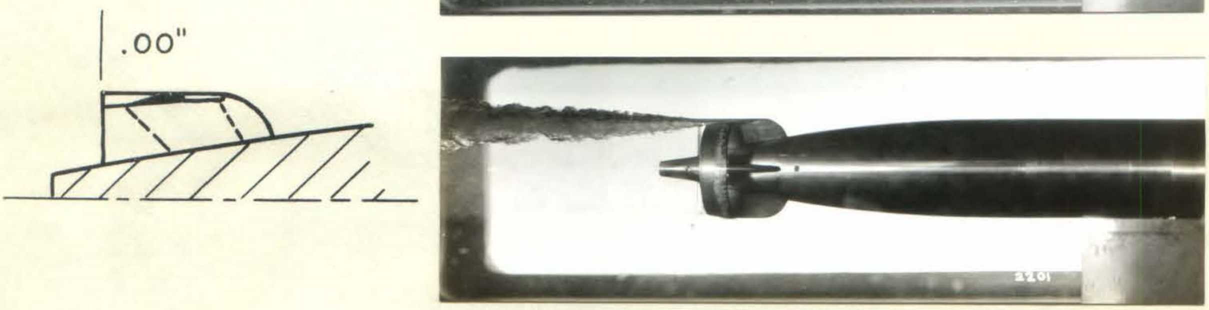

FIG. 15
K = 0.53
Q = 100 %

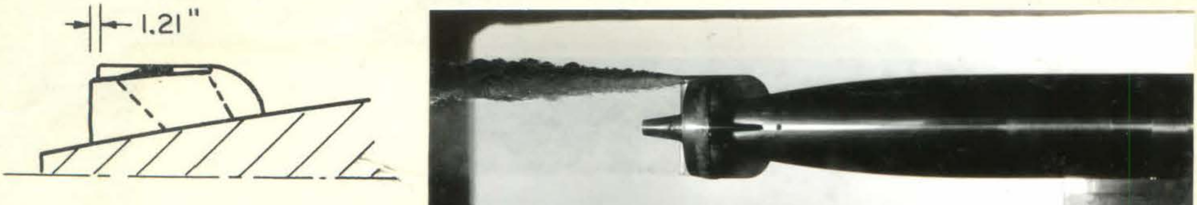

FIG. 16
K = 0.52
Q = 95%

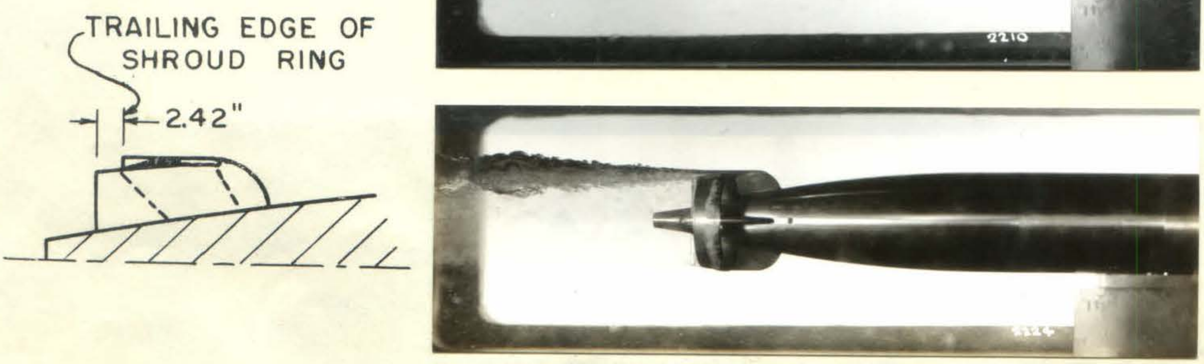

FIG. 17
(SAME AS FIGS. 11 & 18)
K = 0.51
Q = 85 %

EXHAUST CAVITIES FOR VARIOUS LENGTHS OF EXHAUST PIPE

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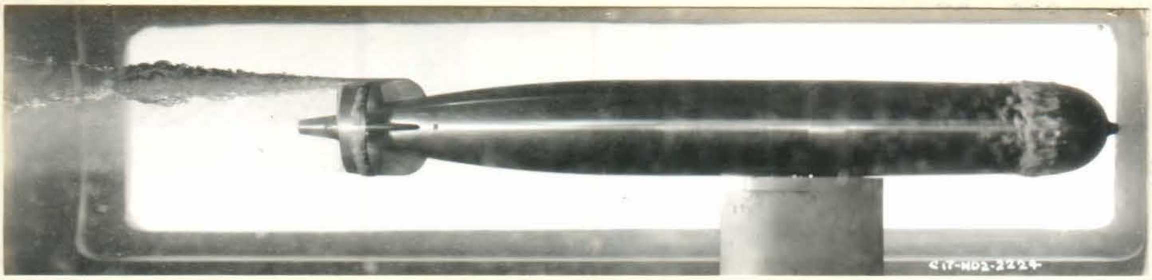
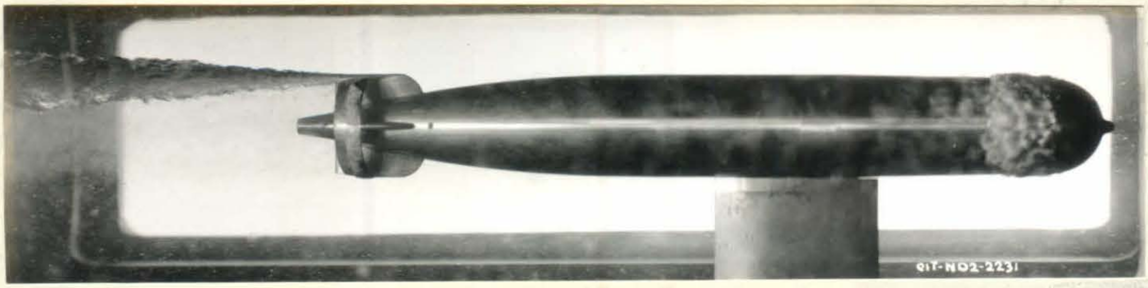


$\psi = 0$ FIGURE 18 $K = 0.51$

(SAME AS FIGURES 11 AND 17)



$\psi = +3^{0}$ FIGURE 19 $K = 0.52$

$\psi = +5^{0}$ FIGURE 20 $K = 0.51$

EXHAUST CAVITIES FOR VARIOUS YAW ANGLES (ψ)

EXHAUST PIPE FLUSH WITH SHROUD RING

EXHAUST GAS APPROXIMATELY 100%

FIGURE 21 K = 0.99

FIGURE 22 K = 0.70
(SAME AS FIGURE 33)

FIGURE 23 K = 0.51
(SAME AS FIGURE 28)

EXHAUST CAVITIES FOR VARIOUS VALUES OF K

PITCH ANGLE, $\alpha = -5^{0}$

EXHAUST GAS APPROXIMATELY 100%

FIGURE 24
$\alpha = 0$
$K = 0.44$

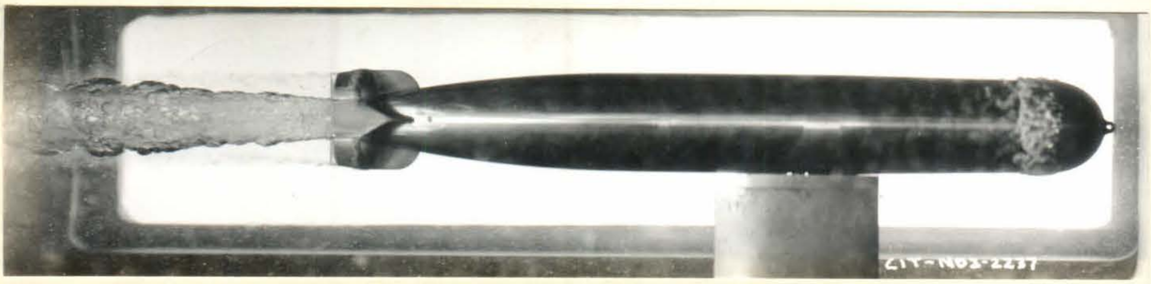


FIGURE 25
$\alpha = 3^{\circ}$
$K = 0.51$

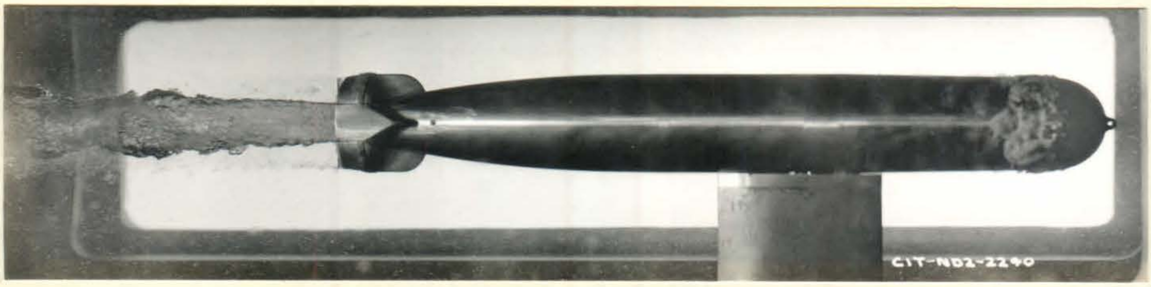


FIGURE 26
$\alpha = -3^{\circ}$
$K = 0.50$

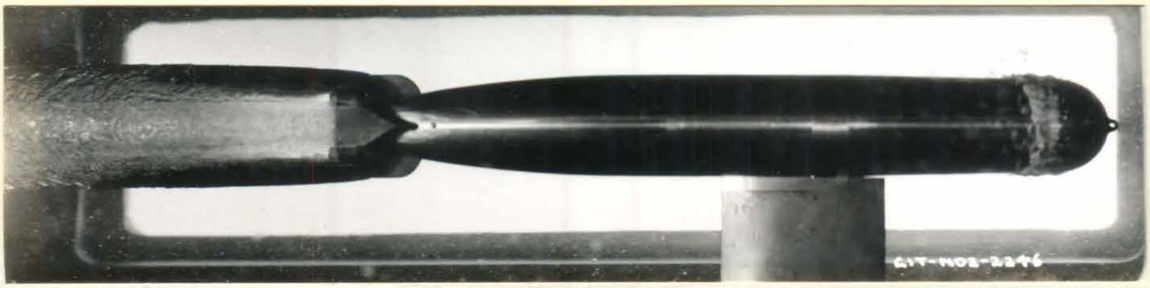


FIGURE 27
$\alpha = 5^{\circ}$
$K = 0.50$

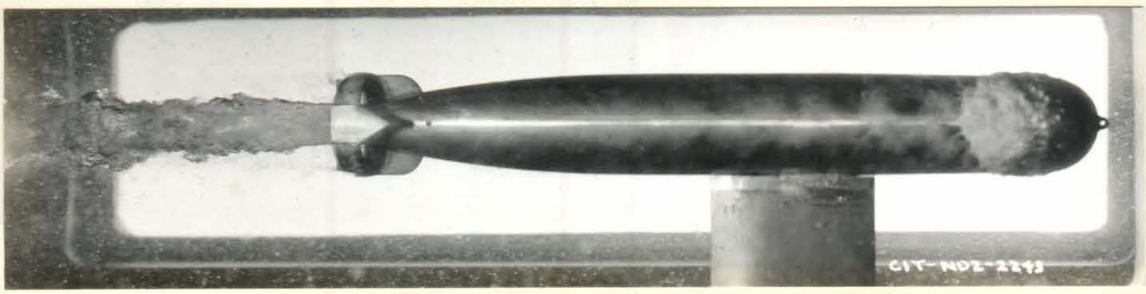


FIGURE 28
(SAME AS
FIG. 23)
$\alpha = -5^{\circ}$
$K = 0.51$

EXHAUST CAVITIES FOR VARIOUS PITCH ANGLES (α)

EXHAUST PIPE FLUSH WITH SHROUD RING
EXHAUST GAS APPROXIMATELY 100%

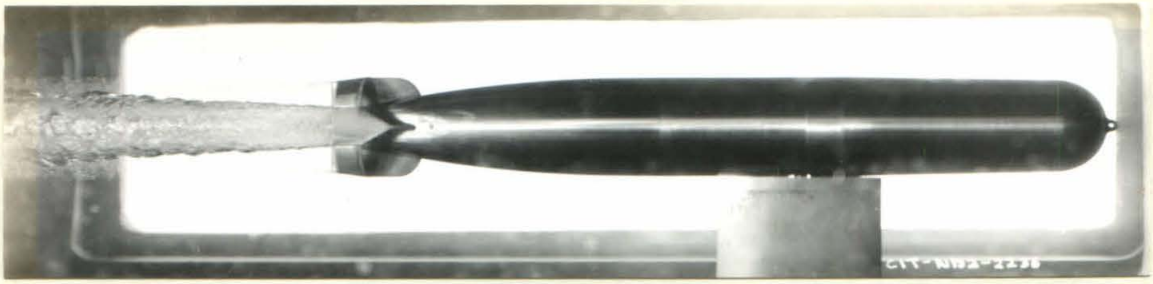


FIGURE 29
$\alpha = 0$
$K = 0.69$

FIGURE 30
$\alpha = +3^{\circ}$
$K = 0.71$

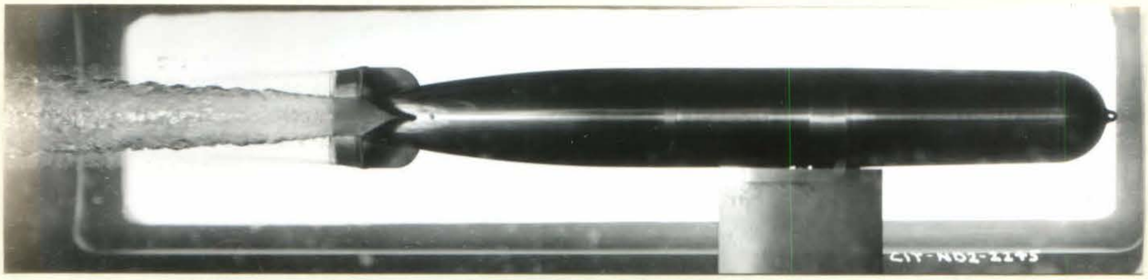


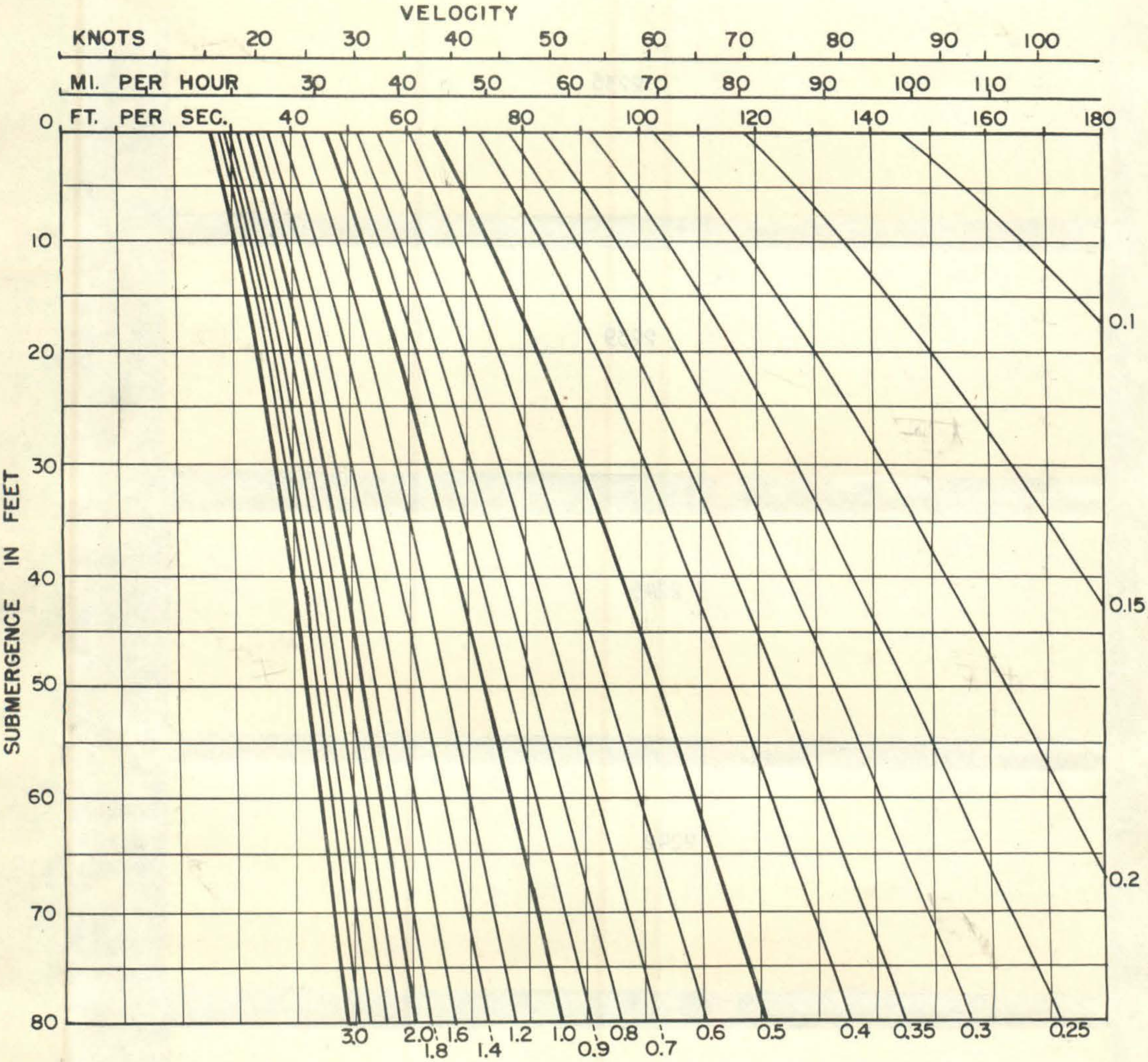
FIGURE 31
$\alpha = -3^{\circ}$
$K = 0.69$

FIGURE 32
$\alpha = +5^{\circ}$
$K = 0.70$

FIGURE 33
(SAME AS FIG. 22)
$\alpha = -5^{\circ}$
$K = 0.70$

EXHAUST CAVITIES FOR VARIOUS PITCH ANGLES (α)

EXHAUST PIPE FLUSH WITH SHROUD RING
EXHAUST GAS APPROXIMATELY 100%



RELATION BETWEEN VELOCITY SUBMERGENCE AND CAVITATION PARAMETER, K

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FIGURE 34