DEPARTMENT OF THE NAVY
DAVID TAYLOR MODEL BASIN

HYDROMECHANICS

AERODYNAMICS

STRUCTURAL MECHANICS

APPLIED MATHEMATICS

CAVITATION PERFORMANCE OF PROPELLERS IN A SUBMARINE WAKE

by

Willard H. Roundy, Sr.

and

James G. Peck

HYDROMECHANICS LABORATORY
EVALUATION REPORT

January 1959 Report No. 1296

PENC-TMB-648a (Rev. 3-58)

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONT.)

NOTATION

$b_{0.7}$	Blade section length at 0.70 radius
D	Diameter of propeller
g	Acceleration of gravity
J	Speed coefficient, $J = \frac{V_a}{n \cdot D}$
K_t	Thrust coefficient, $K_t = \frac{T}{\rho \cdot n^2 \cdot D^4}$
K_q	Torque coefficient, $K_q = \frac{Q}{\rho \cdot n^2 \cdot D^5}$
n	Revolutions per unit time
P	Pitch of propeller at 0.70 radius
p	Absolute static pressure
p_v	Vapor pressure
Q	Torque
R	Propeller radius
r	Radial coordinate of propeller
R_e	Reynolds number, $R_e = \frac{b_{0.7}\sqrt{V_a^2 + (0.7 \cdot \pi \cdot n \cdot D)^2}}{\nu}$
T	Thrust
V	Ship speed, $V = \frac{V_a}{1 - w_x}$
V_a	Speed measured at x = 0.70
$1 - w_x$	Local wake fraction at radius x
x	r/R
ν	Kinematic viscosity
ρ	Density of water
σ	Cavitation index, $\sigma = \frac{p - p_v}{\frac{1}{2} \cdot \rho \cdot V^2}$

ABSTRACT

This report presents the results of the evaluation of three model propellers tested in the 24-Inch Water Tunnel with a simulated wake of a representative submarine in order to determine the cavitation characteristics. Curves are also presented for the inception of cavitation along the radius as a function of the operating conditions.

INTRODUCTION

The Bureau of Ships has submitted three submarine propeller designs for evaluation in their intensive study of methods to increase the quiet ship speed and systematically evaluate new propellers. The Taylor Model Basin was requested[1,2,3] to determine the cavitation characteristics of these three propeller designs. Although these propellers were designed for different submarines, they were tested in the same velocity field. The model propellers 3744, 3745, and 3749 were designed for the SS(N)597, SSGN594, and SS(N)593, respectively. Photographs of these propellers are shown in Figures 1 to 3, inclusive. The drawings and design parameters for these model propellers are shown in Figures 4 to 6, inclusive. The design parameters of these three

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[1]References are listed on page 8

propellers and the eight propellers[4] previously tested in the same velocity field are compared in Table 1. The open water characteristic curves for the three propellers are presented in Figures 7 to 9, inclusive.

INSTRUMENTATION

The evaluation of these single-screw submarine propellers was conducted in the 24-Inch Variable Pressure Water Tunnel, equipped with a radial wake distribution. The ten-horsepower dynamometer was used to measure the thrust, torque, and angular velocity of the propeller.

The desired radial mean wake was first set up in the water tunnel with a dummy hub on the shaft. This wake was simulated by installing a wake producer over a six-inch diameter pipe fairing ahead of the propeller and determined by a pitot tube survey conducted in the plane of the propeller. Photographs of the installation are shown in Figures 10 to 12. The radial distribution of the wake was then adjusted by moving the wake producer away from or closer to the propeller plane and by covering part of the upstream side with screening until the desired distribution was obtained.

Since the three model propellers are of different diameters, the radial wake is slightly different. The wake distribution for the three propeller designs is shown in Figure 13. The velocity field set up in the tunnel, however, is the same as was used with the previous tests[4].

The water velocity during the tests was measured with a pitot tube mounted in a plane through the centerline of the propeller and ten inches from the shaft centerline (see Figures 10 and 11). This speed was reduced by a factor, determined from the wake survey, to obtain the true water speed at the 0.7 radius which was used in all the computations so that the speed coefficient would be comparable with values obtained from the propulsion test in the basin. It should be noted that this factor is different for the three propellers as they are of different diameters.

These propellers were machined from plate aluminum. To permit the detection of the inception of face cavitation on the blade surface, the propellers were anodized and then dyed black. Radial lines were marked on the face and back of all blades with a white pencil.

PROCEDURE

An atmospheric calibration was run in the water tunnel to determine the effect of Reynolds number on scale effect for these propellers. Propeller 3744 which has the smallest diameter was selected for this calibration. The condition, J = 0.60, was setup through a range of rpm from 400 to 1800 and thrust, torque, and rpm were read. The thrust and torque coefficients were calculated and are plotted against rpm in Figure 14.

These propellers were tested at 1400 rpm which is the same angular velocity used in the previous tests and is sufficiently high to minimize scale effect. The propellers were tested at even values of speed coefficient J from 0.3 to about 0.8 or the point of zero thrust. For each value of speed coefficient J tested, the cavitation index σ was varied within the limits which were contingent upon the permissible tunnel pressure for that water speed.

For each speed coefficient the water speed and angular velocity were held constant. Starting with atmospheric pressure on the water surface the tunnel pressure was increased, provided some form of cavitation was visible, until the propeller was free of all cavitation or the maxim permissible tunnel pressure for the water speed was reached With the propeller free of cavitation the thrust, torque, and tunnel pressure were recorded. The tunnel pressure was then reduced by small increments until the inception of cavitation. At this condition thrust, torque, and pressure were read and sketches made of the location and extent of cavitation. This procedure was repeated with the readings recorded at each step until the minimum tunnel pressure was reached. In between spots were run when necessary to deter mine the inception of back cavitation and tip vortices.

The extent of face and back cavitation was plotted aga cavitation index σ. For each even value of x the σ for the inception of face and back cavitation was determined fr these curves and then plotted against speed coefficient J in Figures 15 to 17. Sketches of the cavitation present at selected values of cavitation index for the speed coefficie tested are shown in Figures 18 to 20.

In addition to determining the inception of cavitation at the different speed coefficients, the thrust and torque coefficients were calculated and plotted against cavitation index in Figures 21 to 23. The thrust and torque coefficients for cavitation indices of 4, 6, 10, 20, and 25 from the above curves were plotted against speed coefficient J in Figures 24 to 26.

DISCUSSION OF RESULTS

The cavitation inception curves, Figures 15 to 17, represent the limiting value of σ for cavitation at the section x under consideration; that is, the area above the curve indicates that there was no cavitation present at the given radius x. Below the curve the intensity of cavitation increases with a decrease in sigma. At a given speed coefficient J and cavitation index σ, the type and location of cavitation will be determined by the curves above this point on the chart. An example would be to determine the type and location of cavitation on Propeller 3744 operating at a J of 0.45 and σ = 6.0. Observing the curves above this point on the J of 0.45 ordinate on Figure 15, back cavitation would be present extending from approximately an x of 0.75 to the tip. Tip vortices would also be present.

Although these three propellers were designed for different submarines, they were all evaluated in the same velocity field in the water tunnel. A comparison of the cavitation inception curves (see Figures 15 to 17) for the three propellers show that the J values for minimum cavitation are 0.56 for Propeller 3744, 0.42 for Propeller 3745 and 0.61 for Propeller 3749. To determine when the cavitation effects the thrust and torque or SHP the characteristic curves, Figures 24 to 26, must be consulted. The loss of thrust for Propeller 3744 is much less than for the other two propellers.

It was observed that the black dye was worn off on Propeller 3749 in a similar location on all the blades. Photographs of the back and face of all the blades are presented in Figures 27 and 28. This phenomenon may be similar to cavitation erosion. It will be interesting to observe the cavitation erosion on this full-scale propeller and compare it with the photographs in Figures 27 and 28.

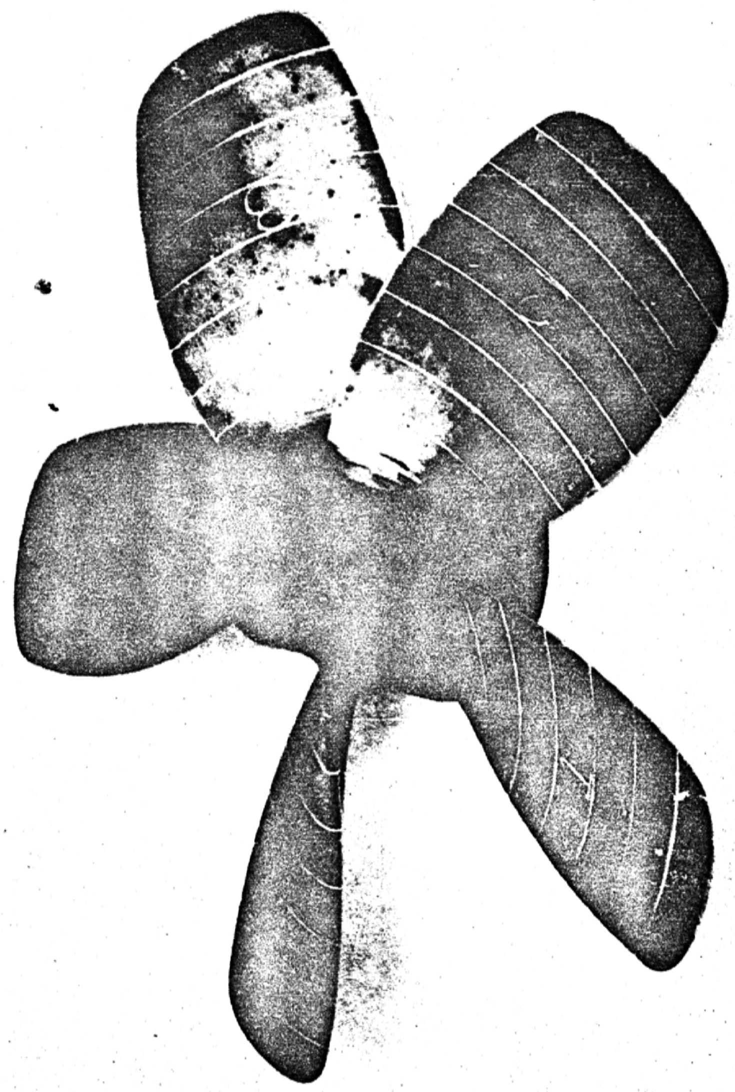
REFERENCES

1. BuShips Letter SS(N)597 (654) Ser. 654-544 to DTMB of 20 June 1958.

2. BuShips Letter SSG(N)594 (654) Ser. 654-602 to DTMB of 30 July 1958.

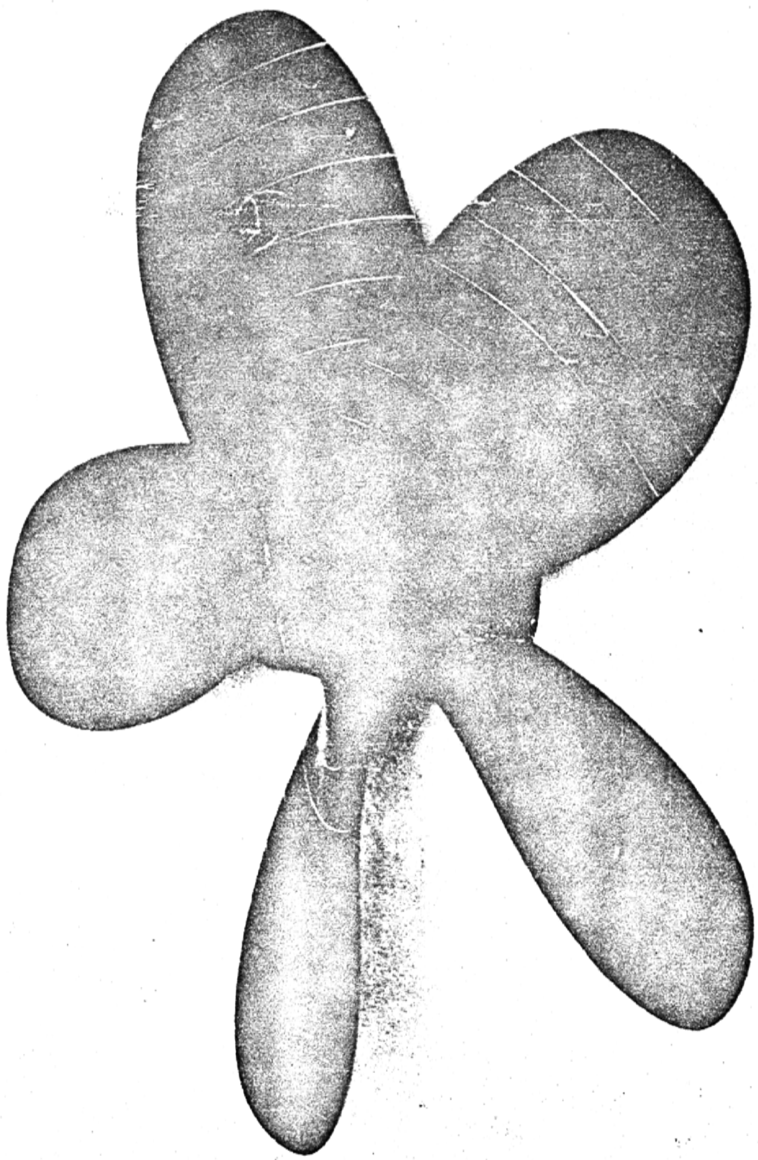
3. BuShips Letter SS(N)593 (654) Ser. 654-732 to DTMB of 26 August 1958.

4. DTMB Report C-983.



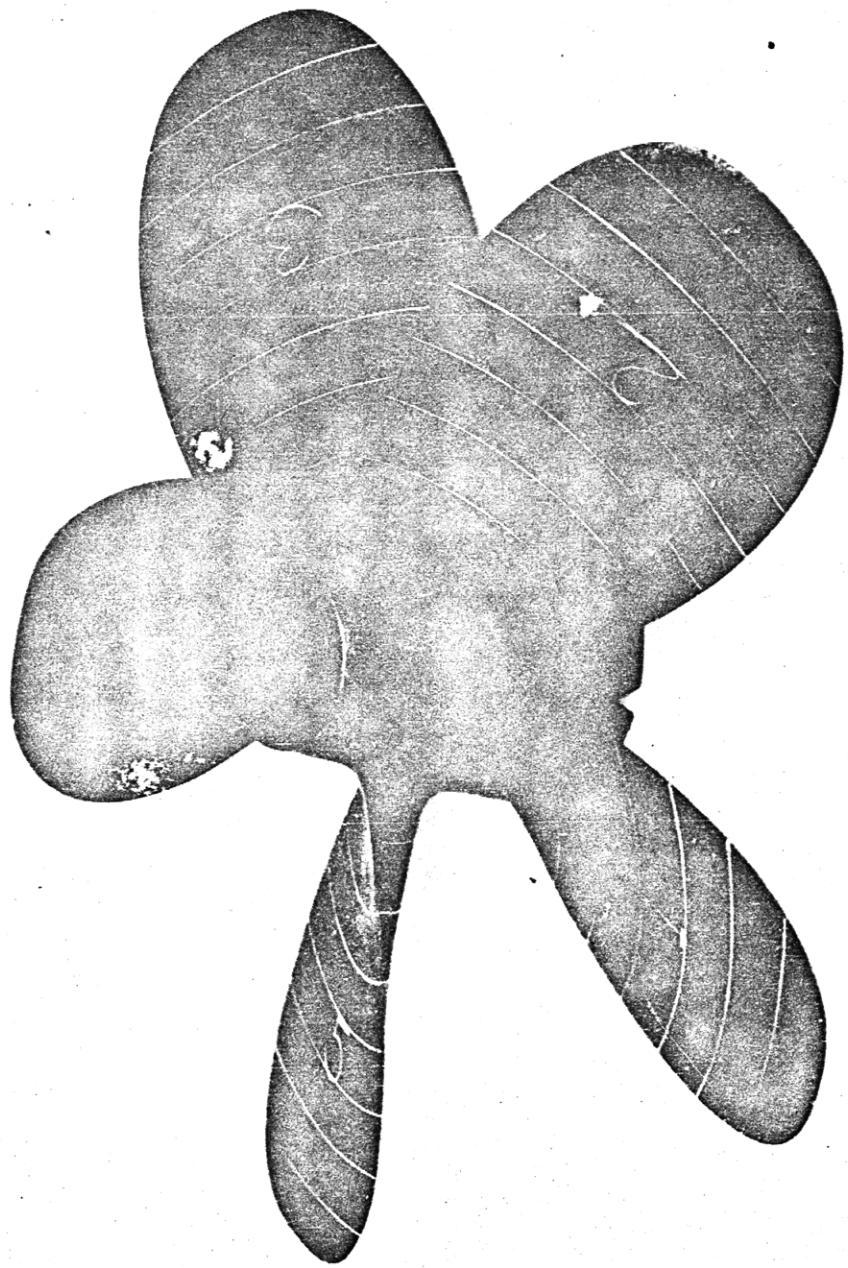
PSD - 94487

Figure 1 - Photograph of Model Propeller 3744



PSD - 94489

Figure 2 - Photograph of Model Propeller 3745



PSD - 94490

Figure 3 - Photograph of Model Propeller 3749

PROPELLER 3744

NUMBER OF BLADES............	5
EXP. AREA RATIO.............	0.530
MWR.........................	0.216
BTF.........................	0.035
P/D (AT 0.7R)...............	0.786
DIAMETER....................	9.181 ins.
PITCH (AT 0.7R).............	7.214 ins.
ROTATION....................	R.H.
TEST n......................	18.5 rps
TEST V_a..............	3.5 to 11.7 fps

TESTED FOR....... BUSHIPS

DESIGNED BY...... BUSHIPS

OFFSETS DATED 13 JUNE 1958

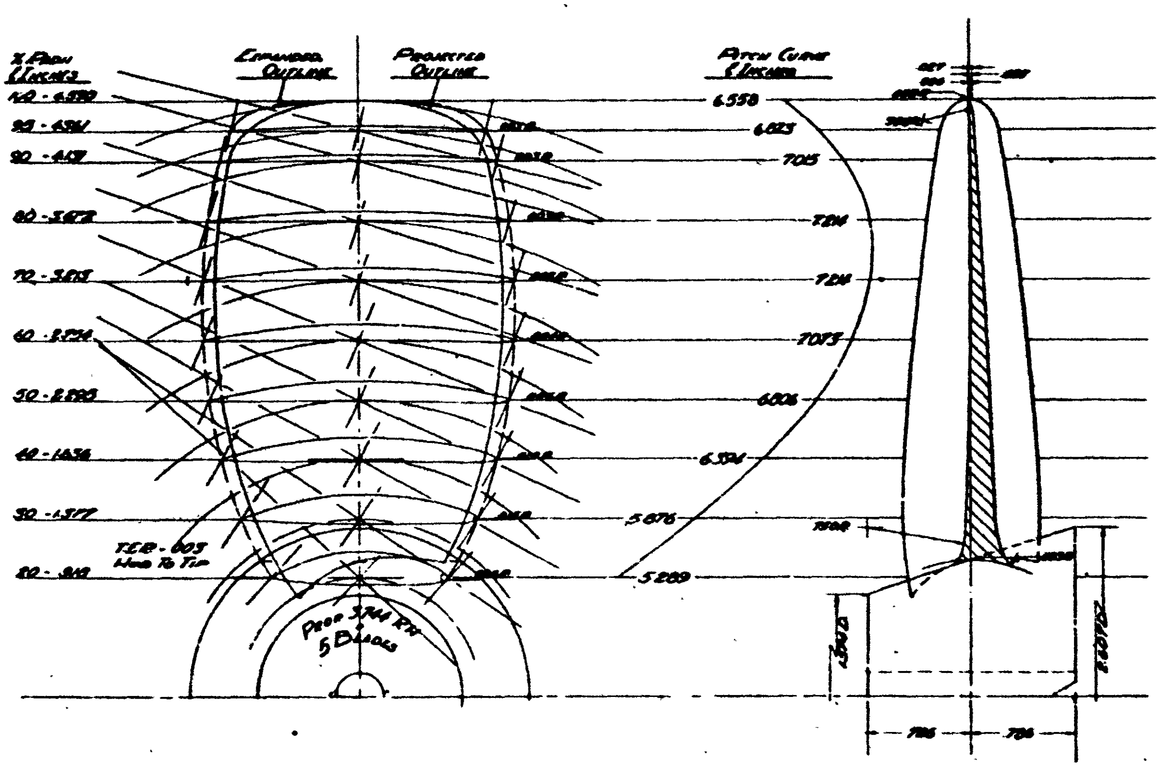


Figure 4 - Drawing of Model Propeller 3744

PROPELLER 3745

NUMBER OF BLADES............ 5
EXP.AREA RATIO.............. 0.621
MWR......................... 0.234
BTF......................... 0.051
P/D (AT 0.7R)............... 0.676
DIAMETER.................... 9.900 ins.
PITCH (AT 0.7R)............. 6.696 ins.
ROTATION.................... R.H.
TEST n................11.5 to 17.6 rps
TEST V_a...............2.0 to 10.5 fps *

TESTED FOR....... BUSHIPS
DESIGNED BY...... BUSHIPS
BUSHIPS OFFSETS DATED 21 JULY 1958

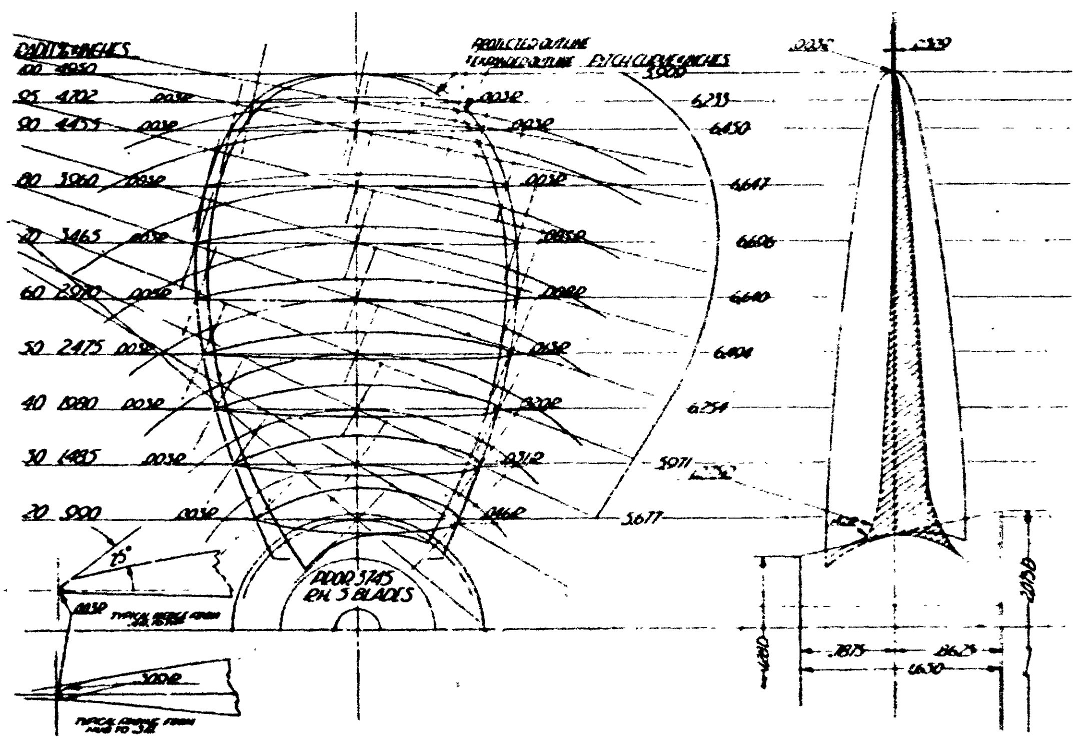


Figure 5 - Drawing of Model Propeller 3745

PROPELLER 3749

NUMBER OF BLADES............ 5
EXP.AREA RATIO.............. 0.625
MWR......................... 0.247
BTF......................... 0.057
P/D (AT 0.7R)............... 0.886
DIAMETER....................10.800 ins.
PITCH (AT 0.7R)............. 9.569 ins.
ROTATION.................... R.H.
TEST n.............. 12.4 to 13.7 rps
TEST V_a.............. 3.0 to 11.3 fps

TESTED FOR....... BUSHIPS
DESIGNED BY...... BUSHIPS
BUSHIPS OFFSETS DATED 7 JULY 1958

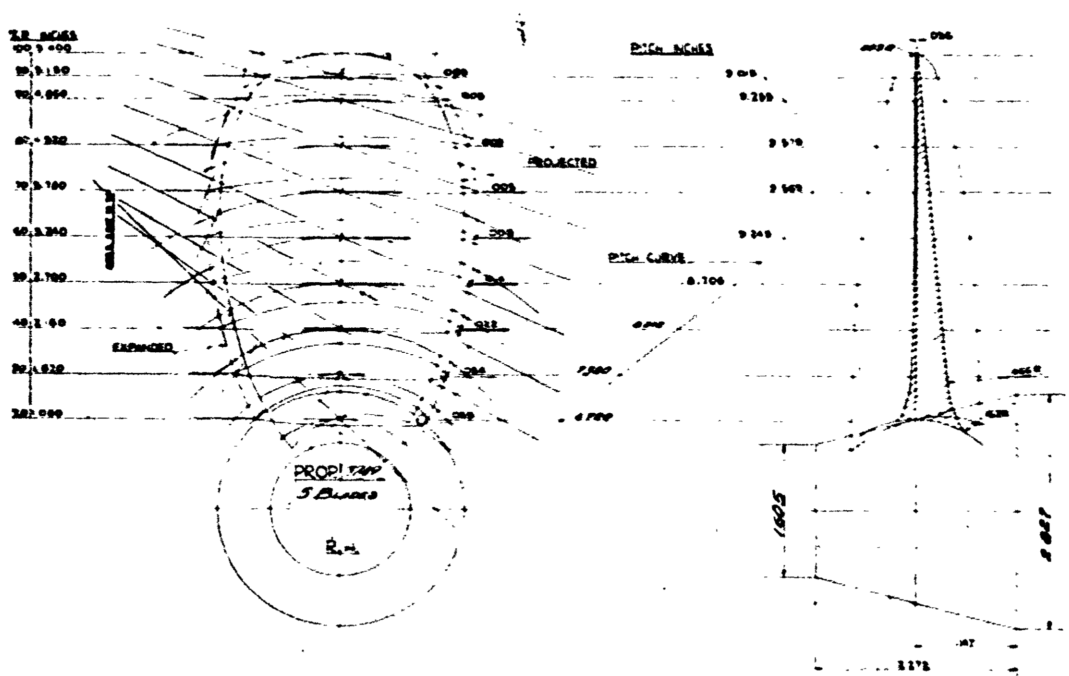


Figure 6 - Drawing of Model Propeller 3749

TABLE 1

GEOMETRIC CHARACTERISTICS OF PROPELLERS

PROP NO	3620	3639	3640	3641	3666	3667	3697	3698	3744	3745	3749
DIAMETER	10.800	10.800	10.800	10.800	10.800	10.800	10.800	10.800	9.181	9.900	10.800
PITCH	8.162	8.456	8.380	8.143	9.569	10.020	9.258	9.450	7.214	6.696	9.569
P/D	0.756	0.783	0.776	0.754	0.886	0.928	0.857	0.875	0.786	0.676	0.886
MWR	0.215	0.216	0.219	0.226	0.250	0.206	0.250	0.250	0.216	0.234	0.247
BTF	Var	0.059	0.059	0.059	0.057	0.057	0.057	0.057	0.035	0.051	0.057
EAR	0.526	0.529	0.538	0.554	0.627	0.518	0.627	0.627	0.530	0.621	0.625
BLADES	5	5	5	5	5	5	5	5	5	5	5

CHARACTERISTIC CURVES
OF
PROPELLER 3744

REYNOLDS NUMBER, $R_e = b_{0.7} \frac{\sqrt{V_A^2 + (0.7\pi n D)^2}}{\nu}$

THRUST COEFFICIENT, $K_t = \frac{T}{\rho n^2 D^4}$

TORQUE COEFFICIENT $K_q = \frac{Q}{\rho n^2 D^5}$

SPEED COEFFICIENT, $J = \frac{V_a}{nD}$

EFFICIENCY, $e = \frac{TV_a}{2\pi Q n} = \frac{K_t}{K_q} \times \frac{J}{2\pi}$

T = THRUST
Q = TORQUE
n = REVOLUTIONS PER UNIT TIME
V_a = SPEED OF ADVANCE
$b_{0.7}$ = SECTION LENGTH AT 0.7 RADIUS
D = DIAMETER
P = PITCH
ν = KINEMATIC VISCOSITY
ρ = DENSITY OF WATER

NUMBER OF BLADES	5
EXP. AREA RATIO	0.530
MWR	0.216
BTF	0.035
P/D (AT 0.7R)	0.786
DIAMETER	9.121 ins.
PITCH (AT 0.7R)	7.214 ins.
ROTATION	R.H.
TEST n	18.5 rps
TEST V_a	3.5 to 11.7 fps

14 AUGUST 1958

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WASHINGTON, D.C.

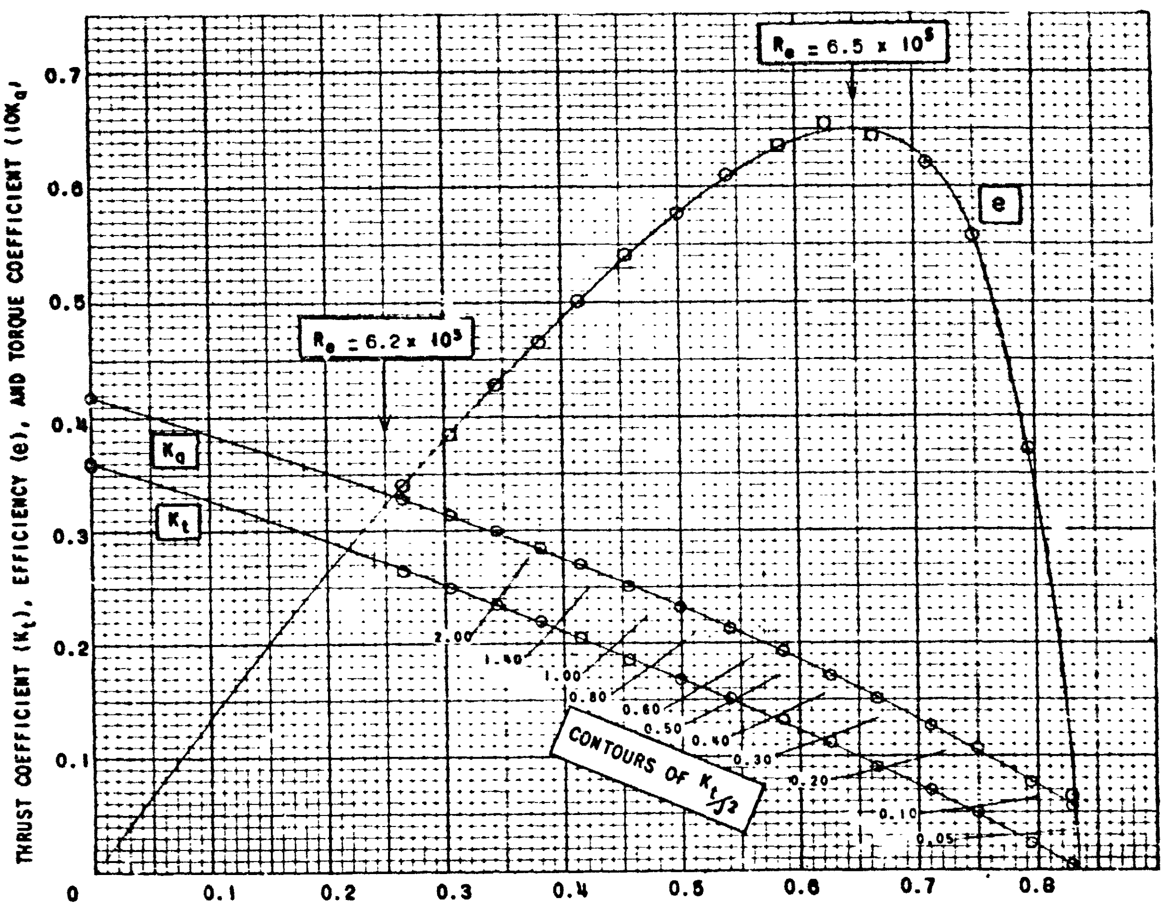

Figure 7 - Open Water Charateristics of Model Propeller 3714

CHARACTERISTIC CURVES
OF
PROPELLER 3745

REYNOLDS NUMBER, $R_e = b_{0.7}\frac{\sqrt{V_a^2+(0.7\pi nD)^2}}{\nu}$

THRUST COEFFICIENT, $K_t = \frac{T}{\rho n^2 D^4}$

TORQUE COEFFICIENT $K_q = \frac{Q}{\rho n^2 D^5}$

SPEED COEFFICIENT, $J = \frac{V_a}{nD}$

EFFICIENCY, $e = \frac{TV_a}{2\pi Qn} = \frac{K_t}{K_q} \times \frac{J}{2\pi}$

T = THRUST
Q = TORQUE
n = REVOLUTIONS PER UNIT TIME
V_a = SPEED OF ADVANCE
$b_{0.7}$ = SECTION LENGTH AT 0.7 RADIUS
D = DIAMETER
P = PITCH
ν = KINEMATIC VISCOSITY
ρ = DENSITY OF WATER

NUMBER OF BLADES.......... 5
EXP. AREA RATIO.......... 0.621
MWR.......................... 0.234
BTF.......................... 0.051
P/D (AT 0.7R)............ 0.676
DIAMETER.................. 9.900 ins.
PITCH (AT 0.7R).......... 6.696 ins.
ROTATION.................. R.H.
TEST n..............11.5 to 17.6 rps
TEST V_a............. 2.0 to 10.5 fps

17 NOVEMBER 1959

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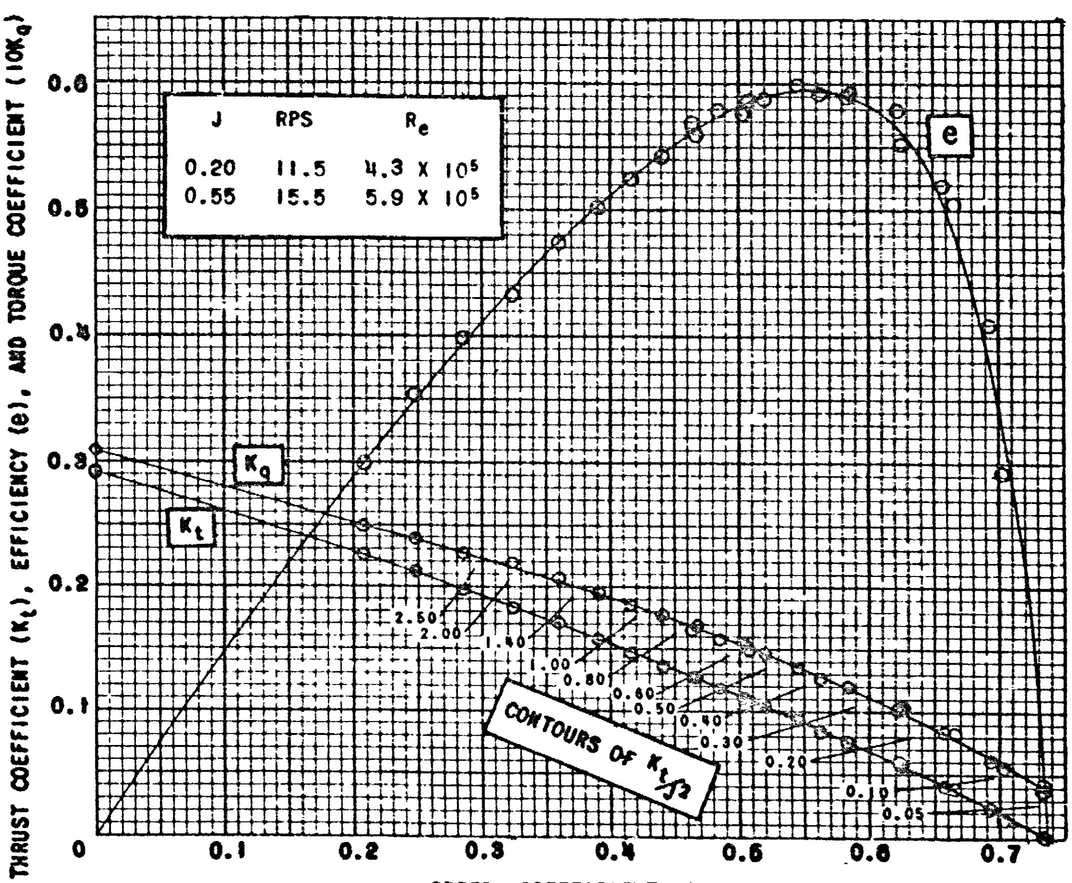

Figure 8 - Open Water Characteristics of Model Propeller 3745

CHARACTERISTIC CURVES
OF
PROPELLER 3749

REYNOLDS NUMBER, $R_e = b_{e.7}\frac{\sqrt{V_a^2+(0.7\pi nD)^2}}{\nu}$

THRUST COEFFICIENT, $K_t = \frac{T}{\rho n^2 D^4}$

TORQUE COEFFICIENT $K_q = \frac{Q}{\rho n^2 D^5}$

SPEED COEFFICIENT, $J = \frac{V_a}{nD}$

EFFICIENCY, $e = \frac{TV_a}{2\pi Qn} = \frac{K_t}{K_q} \times \frac{J}{2\pi}$

T = THRUST
Q = TORQUE
n = REVOLUTIONS PER UNIT TIME
V_a = SPEED OF ADVANCE
$b_{e.7}$ = SECTION LENGTH AT 0.7 RADIUS
D = DIAMETER
P = PITCH
ν = KINEMATIC VISCOSITY
ρ = DENSITY OF WATER

NUMBER OF BLADES	5
EXP. AREA RATIO	0.625
MWR	0.247
BTF	0.057
P/D (AT 0.7R)	0.888
DIAMETER	10.800 ins.
PITCH (AT 0.7R)	9.589 ins.
ROTATION	R.H.
TEST n	12.4 to 13.7 rps
TEST V_a	3.0 to 11.3 fps

24 DECEMBER 1958

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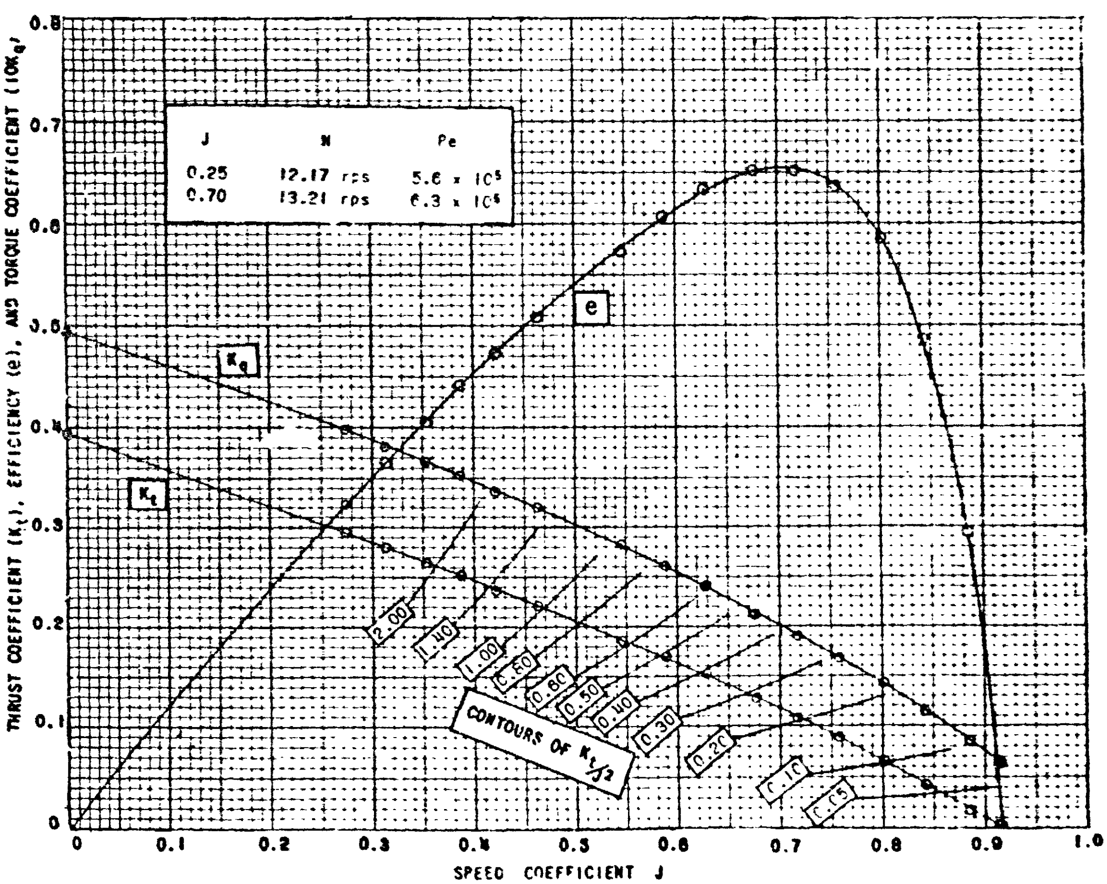


Figure 9 - Open Water Characteristics of Model Propeller 3749

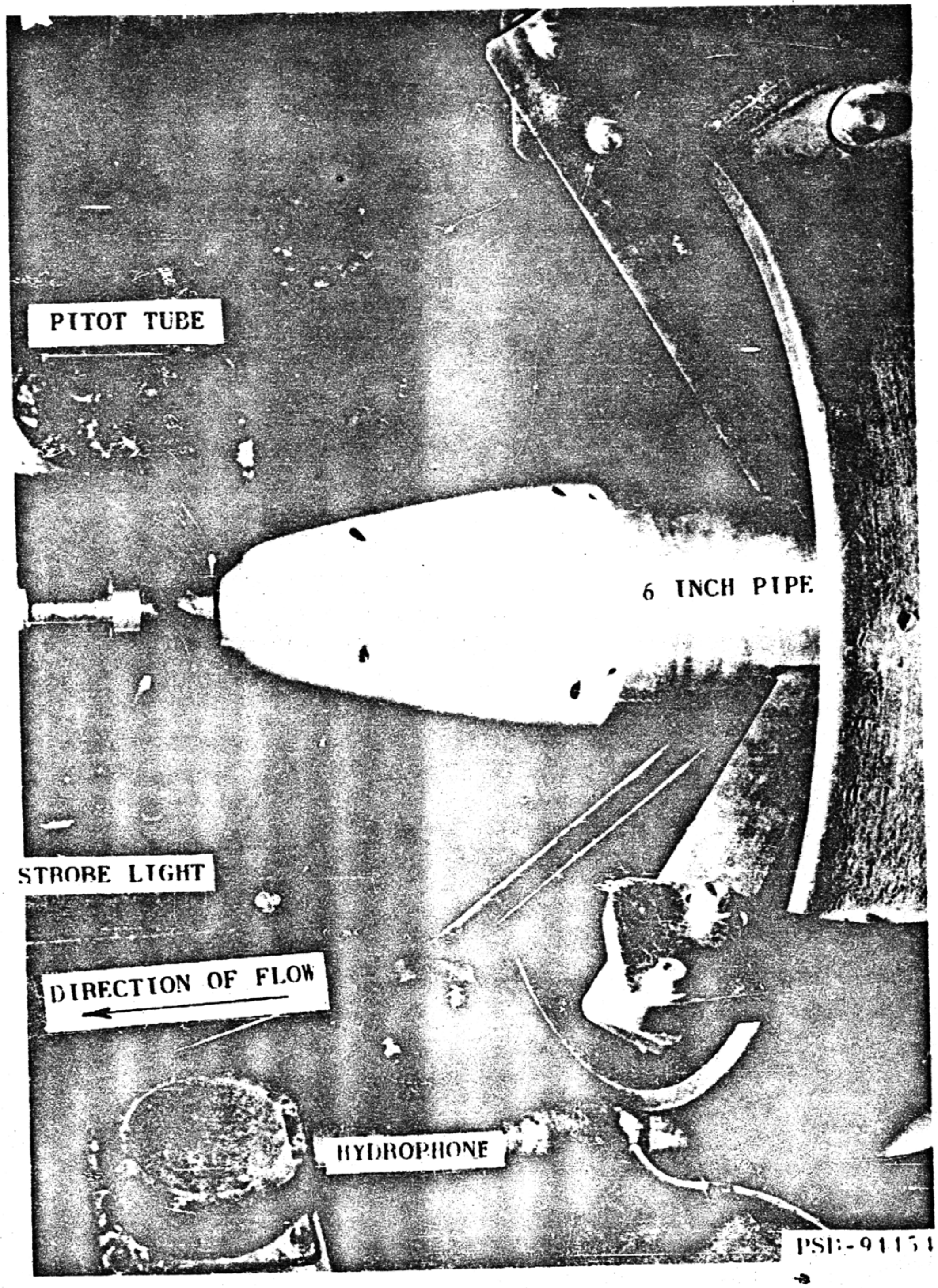


Figure 10 - Photograph Showing Propeller 3744 Mounted in the Tunnel.

Looking into tunnel through access door to the observation window.

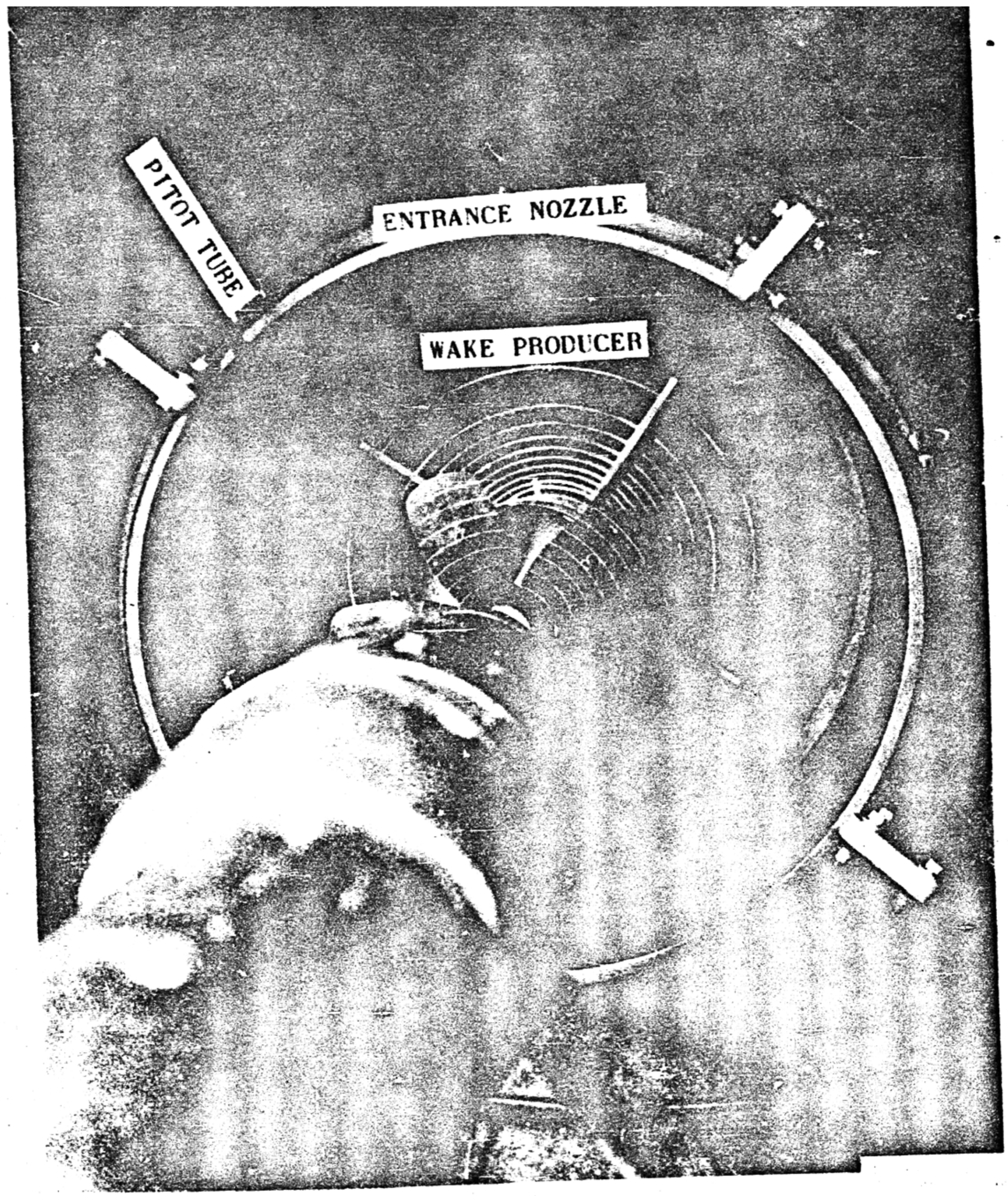


Figure 11 - Photograph Showing Propeller 3741 Mounted in the Tunnel.

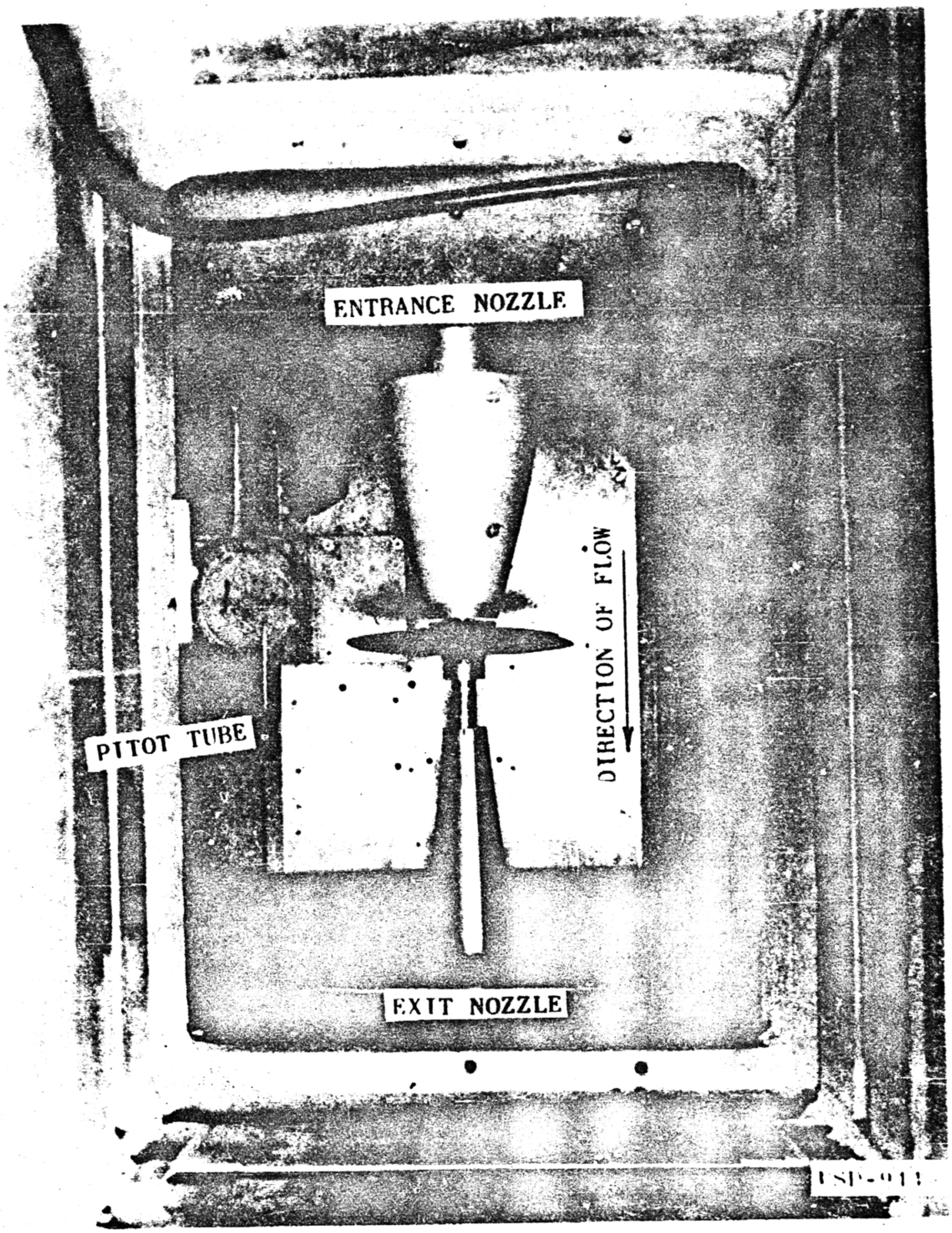


Figure 12 - Photograph Showing Propeller 3744 Mounted in the Tunnel.

Looking down into the tunnel from the hatch above showing the location of the pitot tube relative to the propeller.

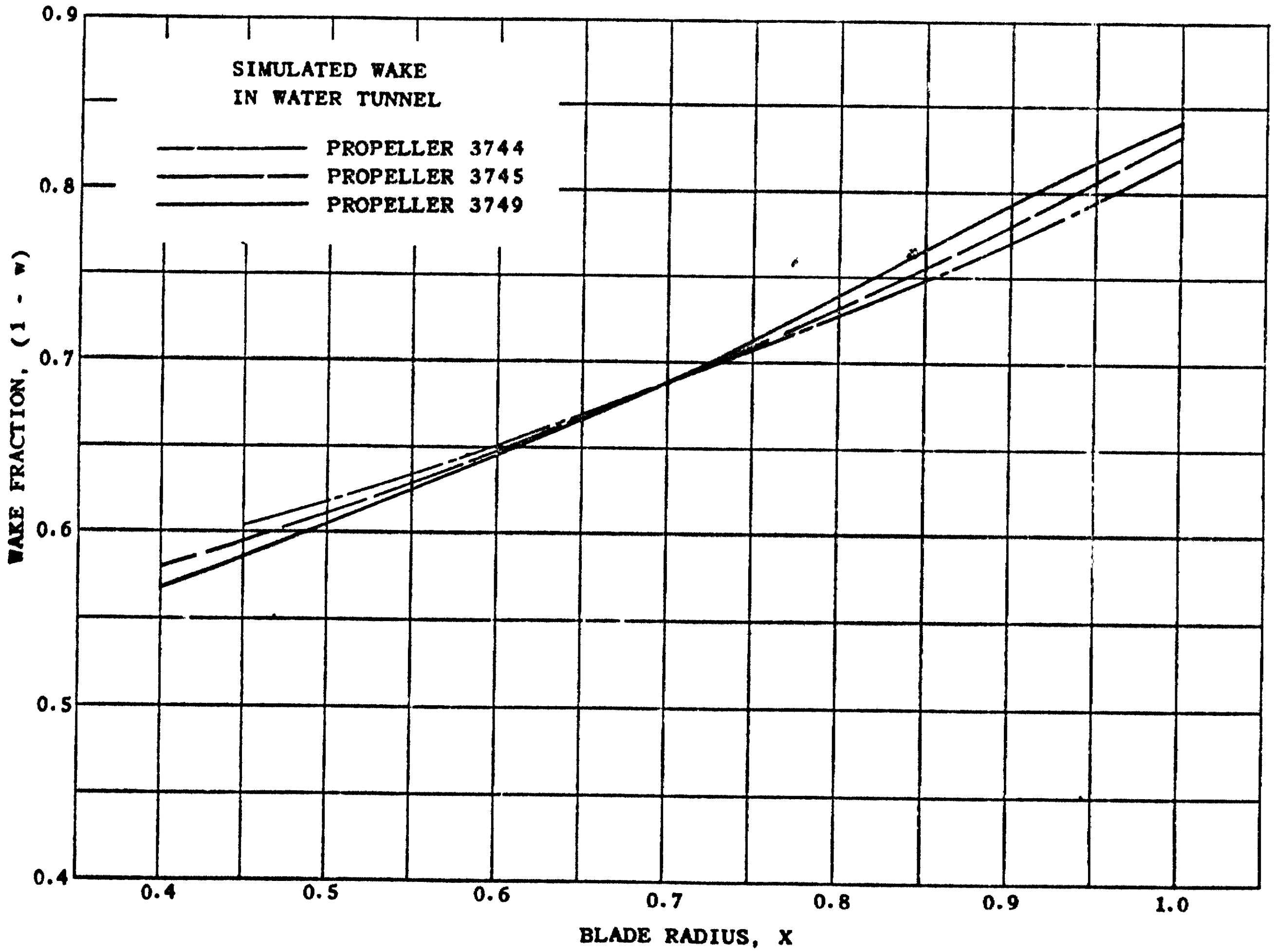


Figure 13 - Wake in 24-Inch Water Tunnel

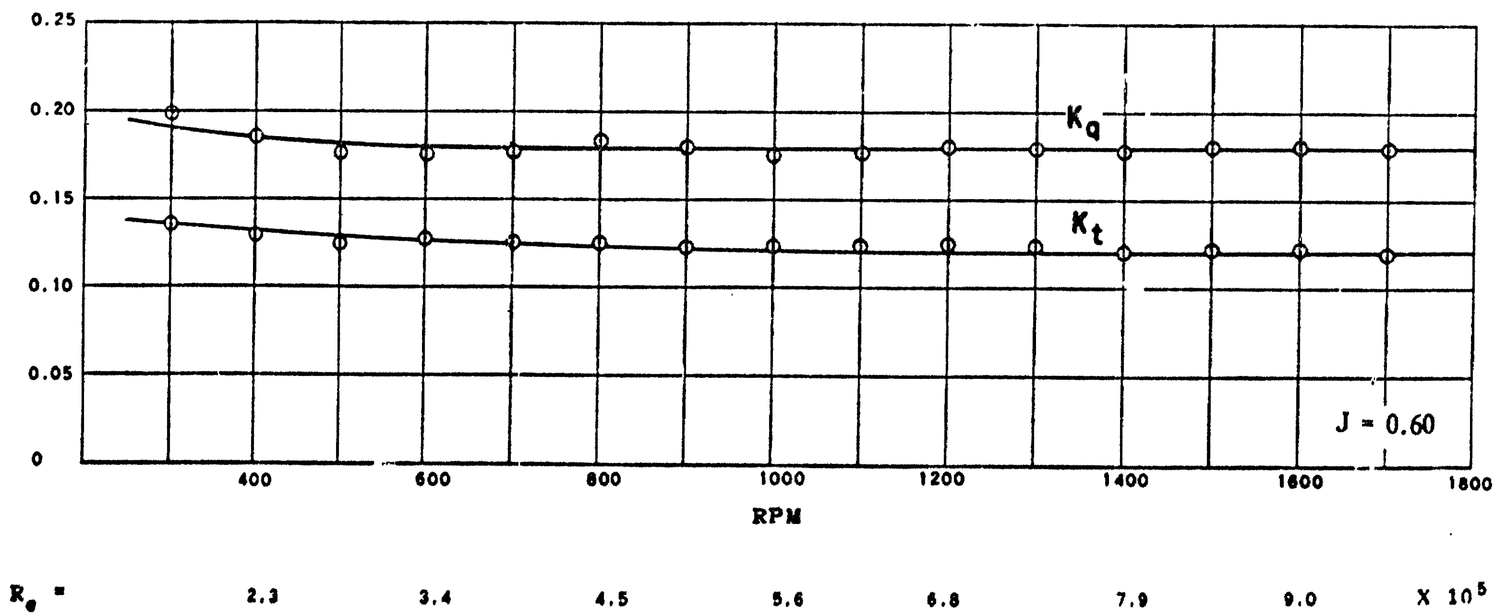


Figure 14 - Atmospheric Calibration on Propeller 3744

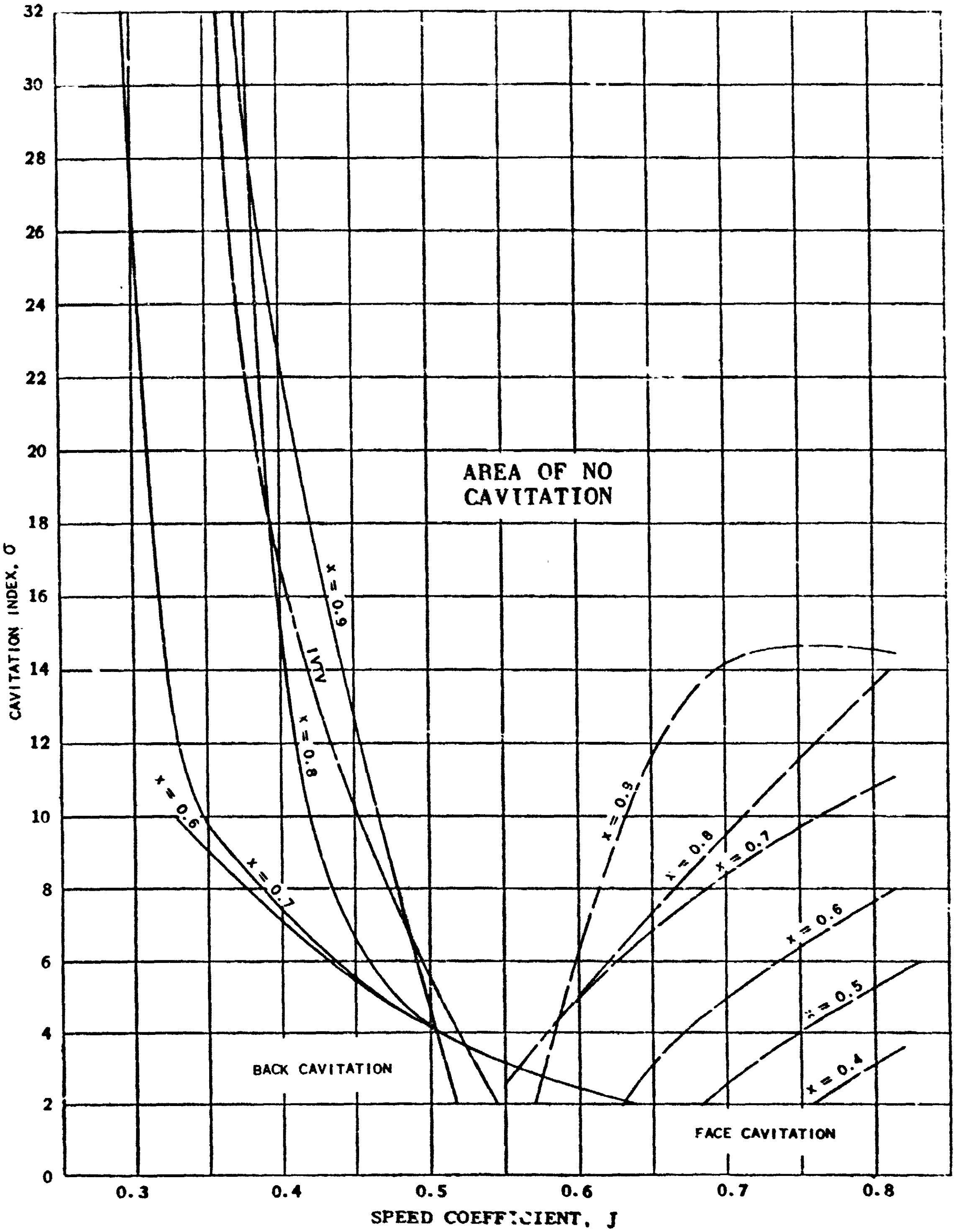


Figure 15 - Inception Curves of Visible Cavitation on Propeller 3744

Cavitation will occur at any point below the curve for the type shown. It is possible to have all types of cavitation present at the same time.

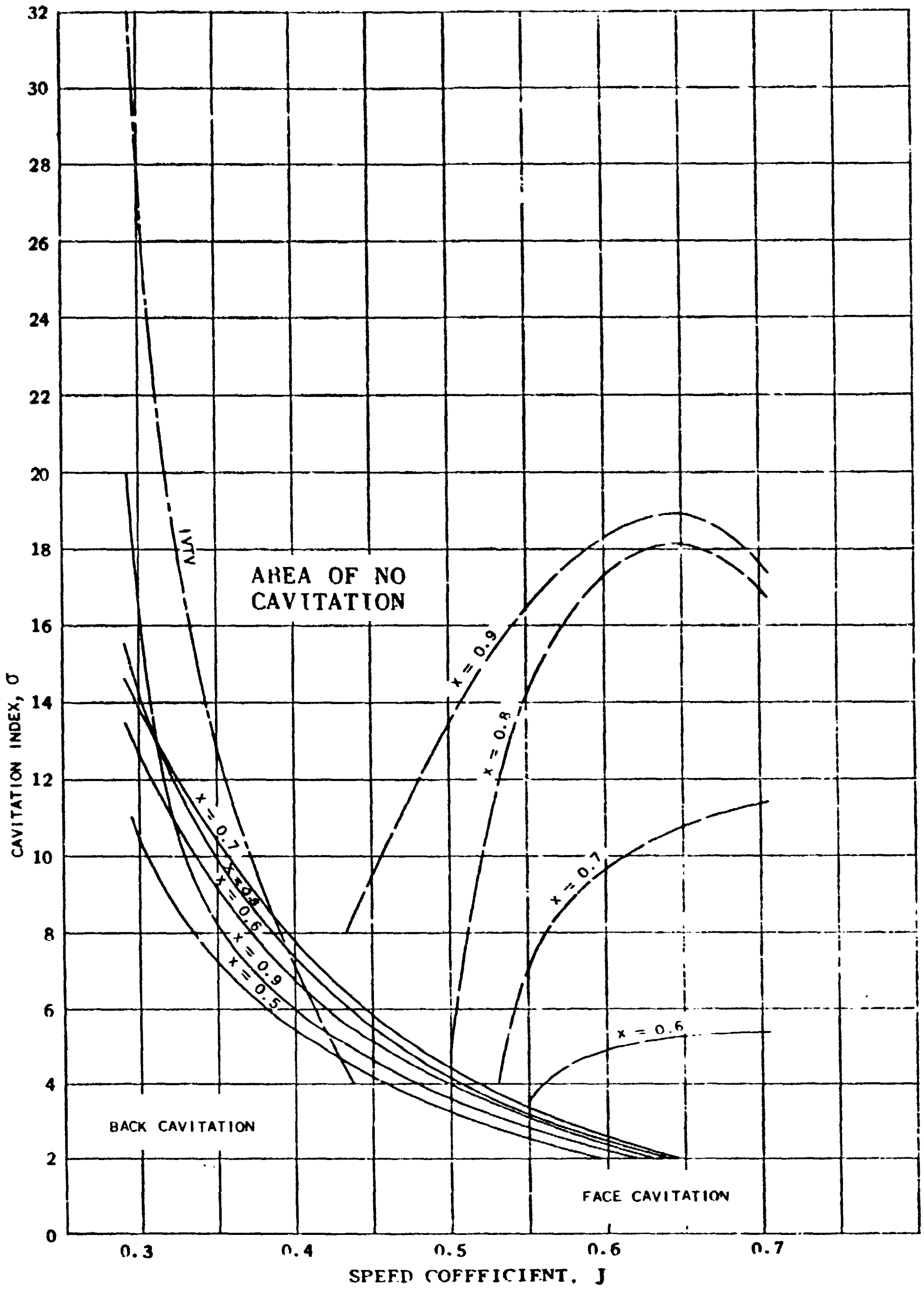


Figure 16 - Inception Curves of Visible Cavitation on Propeller 3715

Cavitation will occur at any point below the curve for the type shown. It is possible to have all types of cavitation present at the same time.

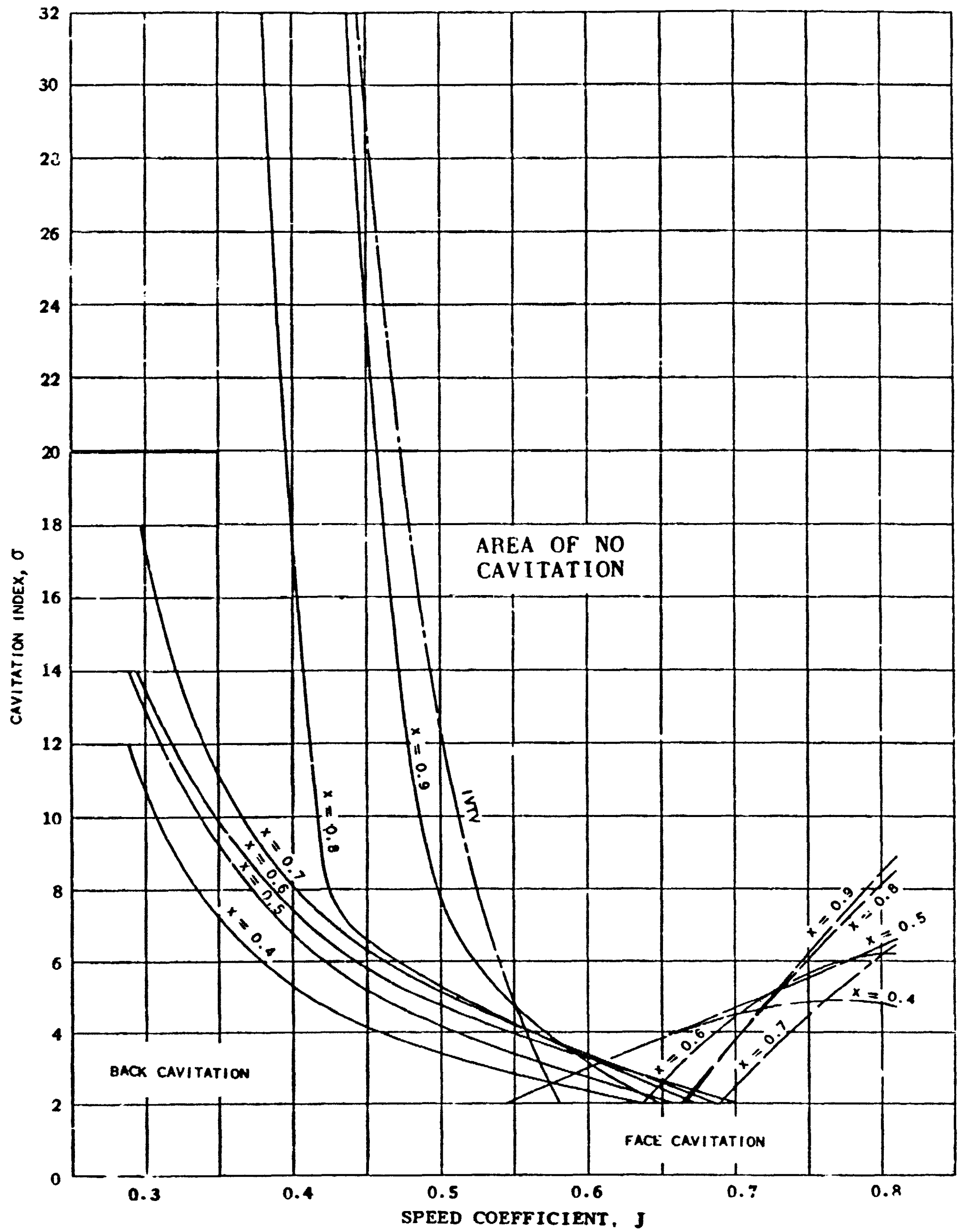


Figure 17 - Inception Curves of Visible Cavitation on Propeller 3749

Cavitation will occur at any point below the curve for the type shown. It is possible to have all types of cavitation present at the same time.

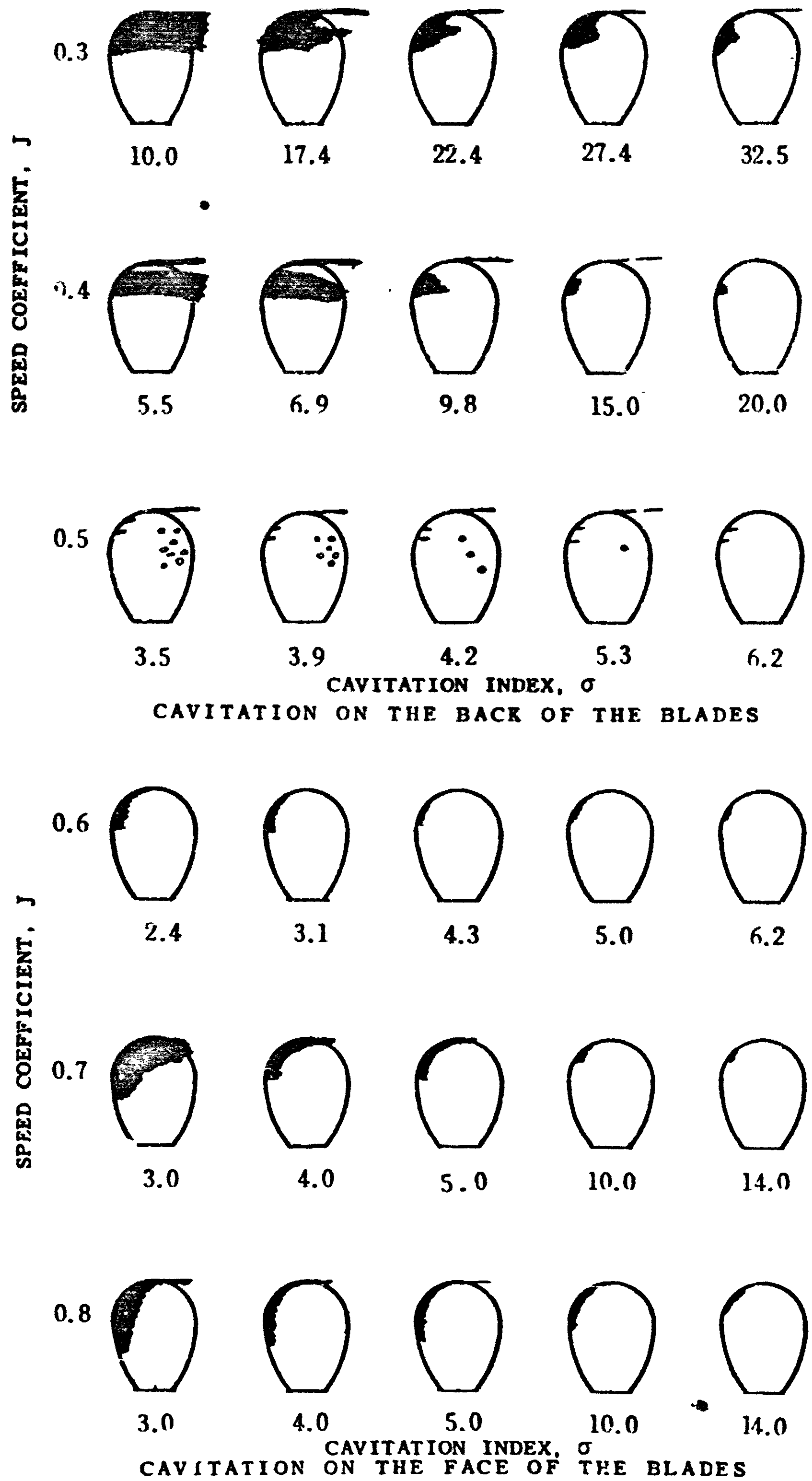


Figure 18 - Visual Observations of Propeller 3744

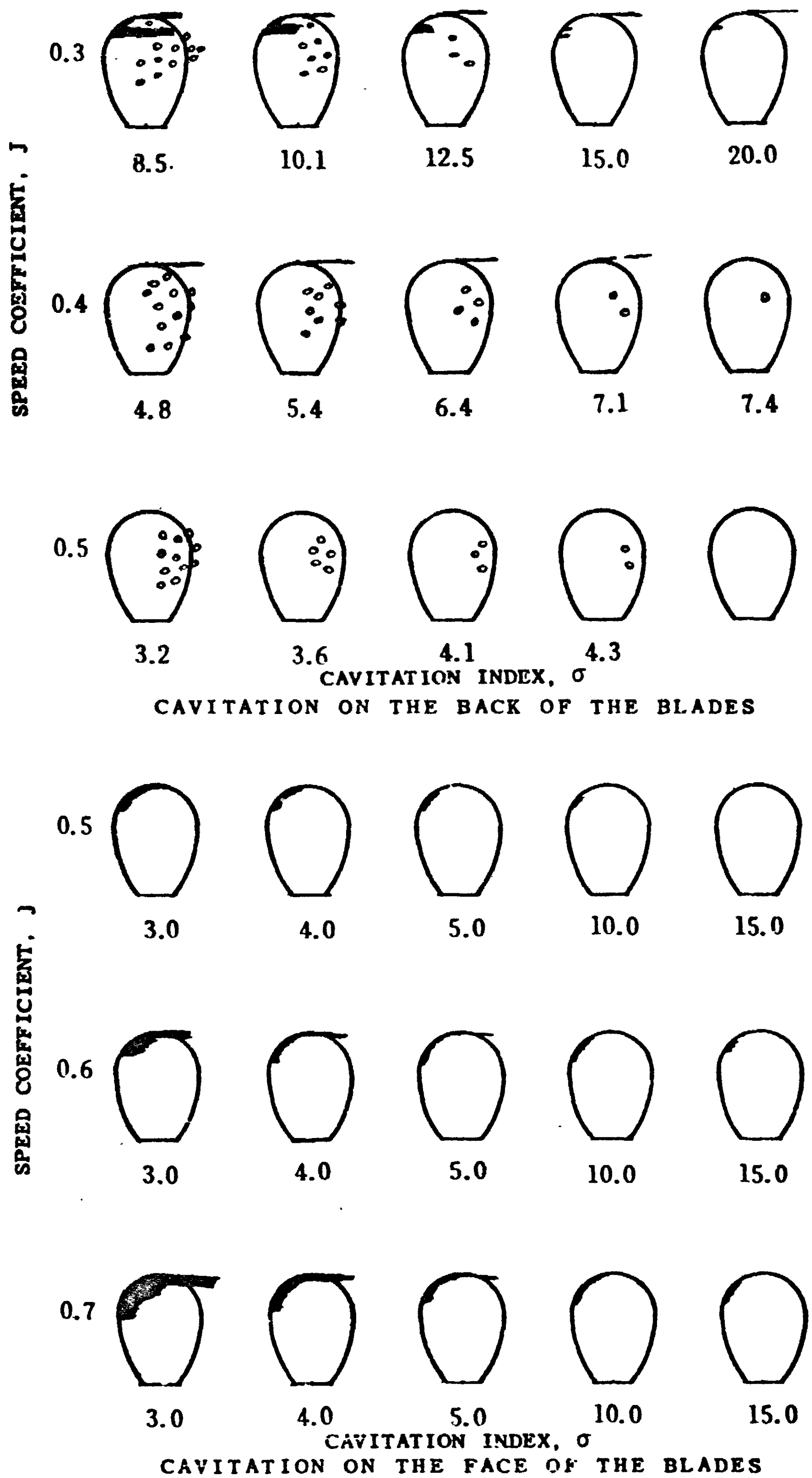


Figure 19 - Visual Observations of Propeller 3745

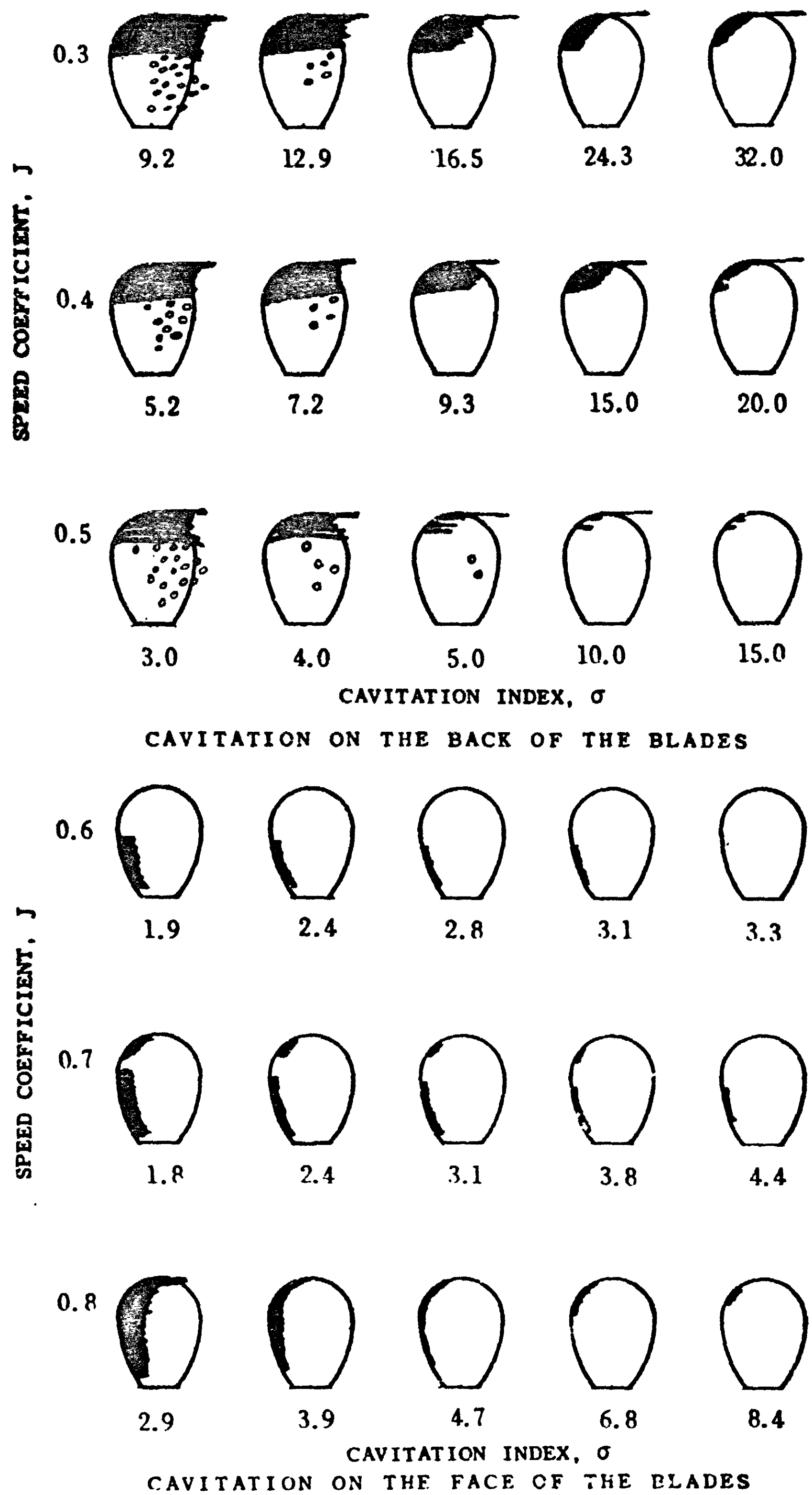


Figure 20 - Visual Observations of Propeller 3749

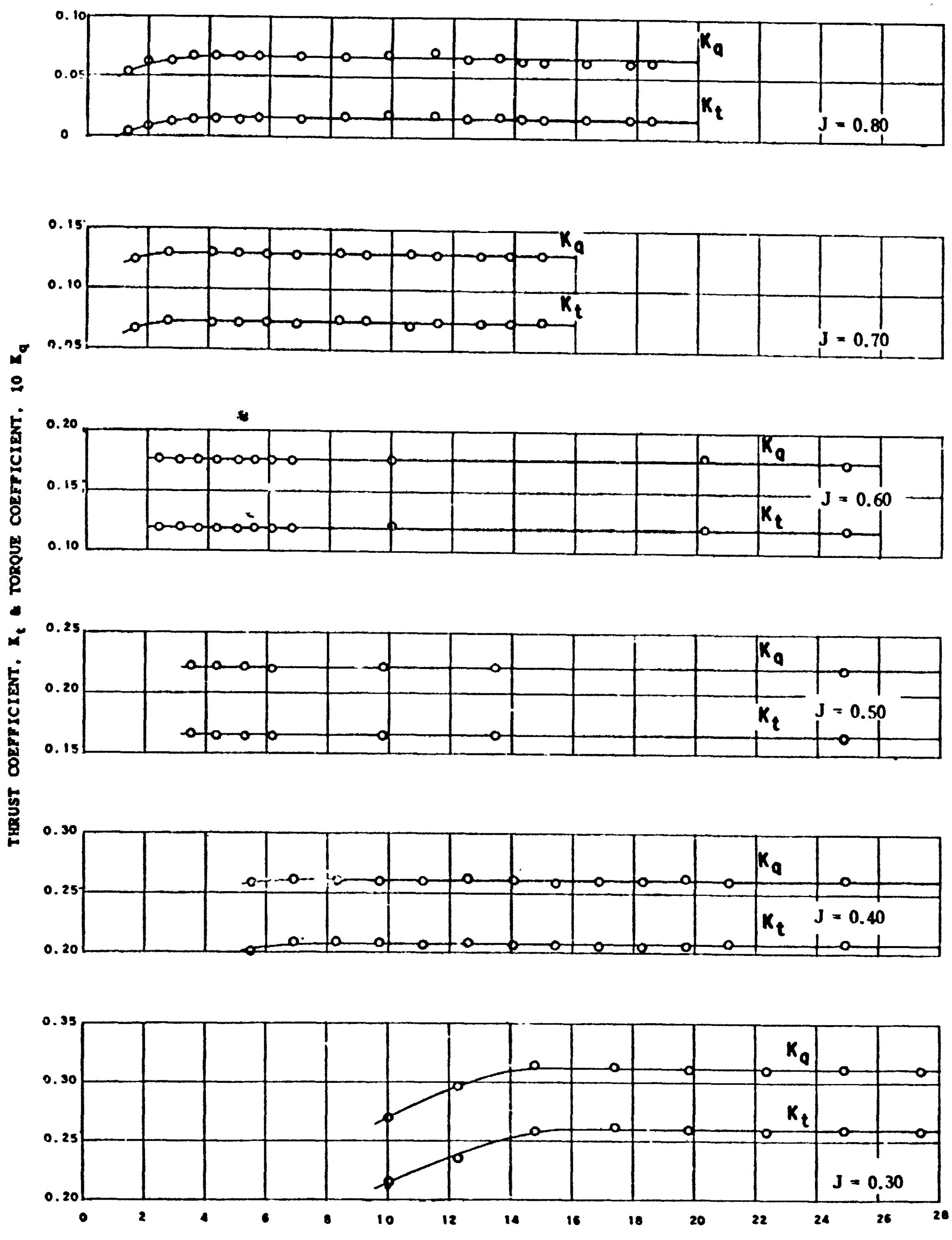


Figure 21 - Variation in Thrust and Torque Coefficients with Cavitation Index for Propeller 3744

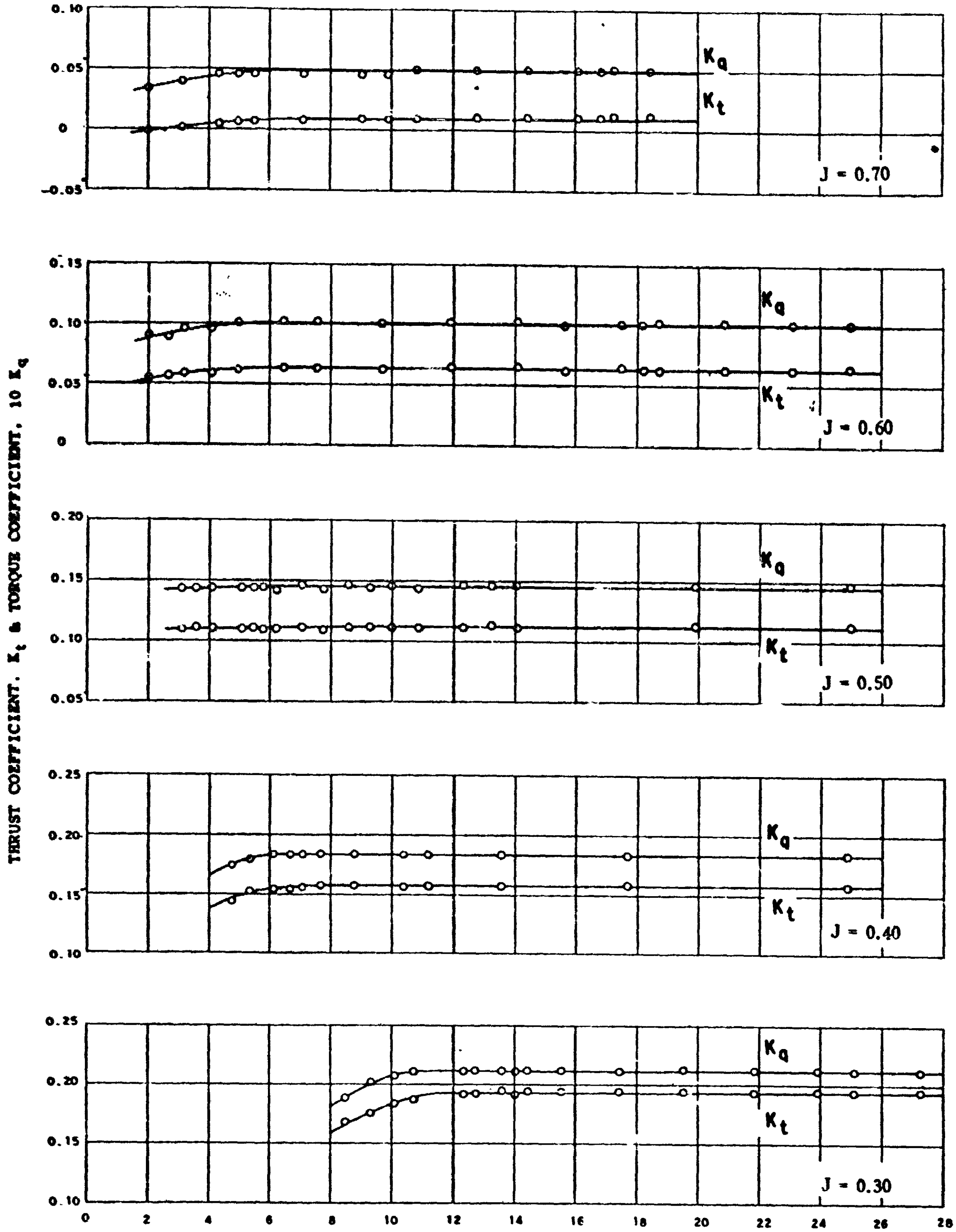


Figure 22 - Variation in Thrust and Torque Coefficients with Cavitation Index for Propeller 3745

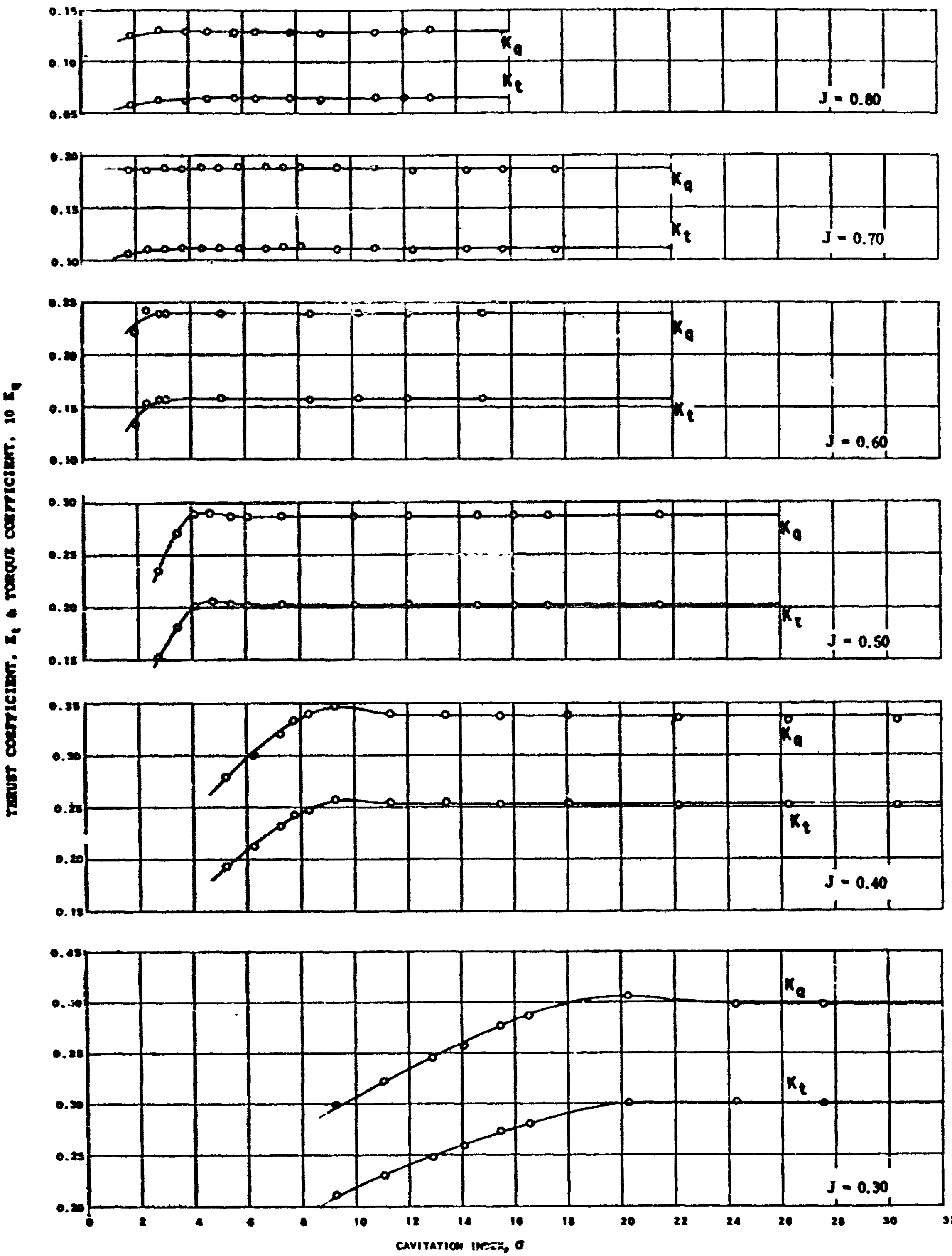
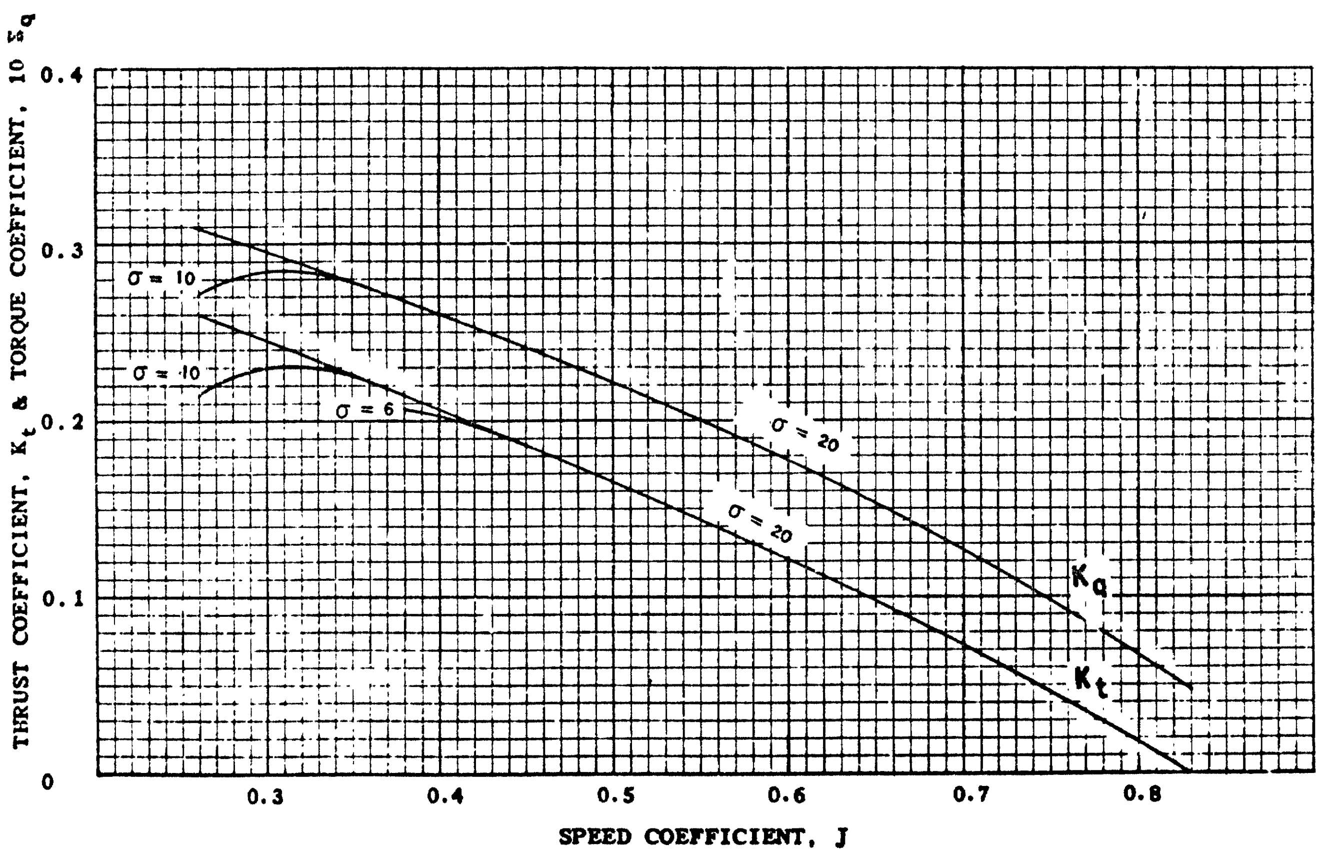


Figure 23 - Variation in Thrust and Torque Coefficients with Cavitation Index for Propeller 3749



THRUST COEFFICIENT, K_t & TORQUE COEFFICIENT, 10 K_q
0.4
0.3
0.2
0.1
0
σ = 10
σ = 10
σ = 6
σ = 20
σ = 20
K_q
K_t
0.3
0.4
0.5
0.6
0.7
0.8
SPEED COEFFICIENT, J

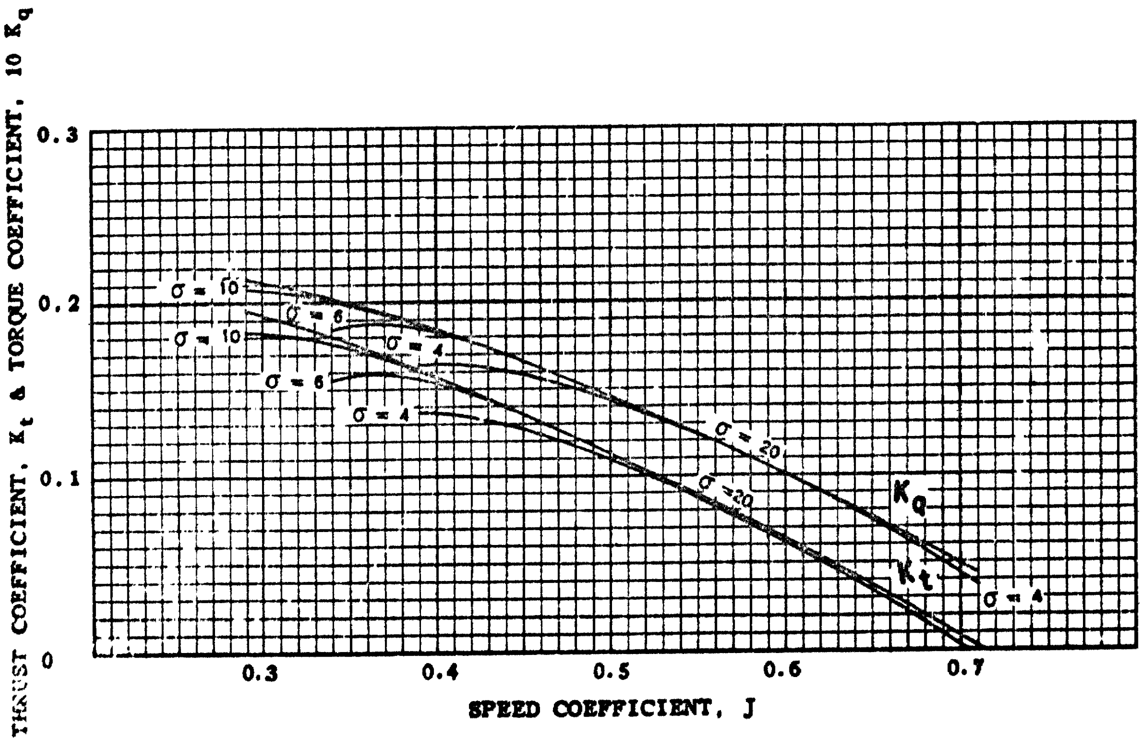


Figure 25 - Cavitation Characteristic Curves of Propeller 3745

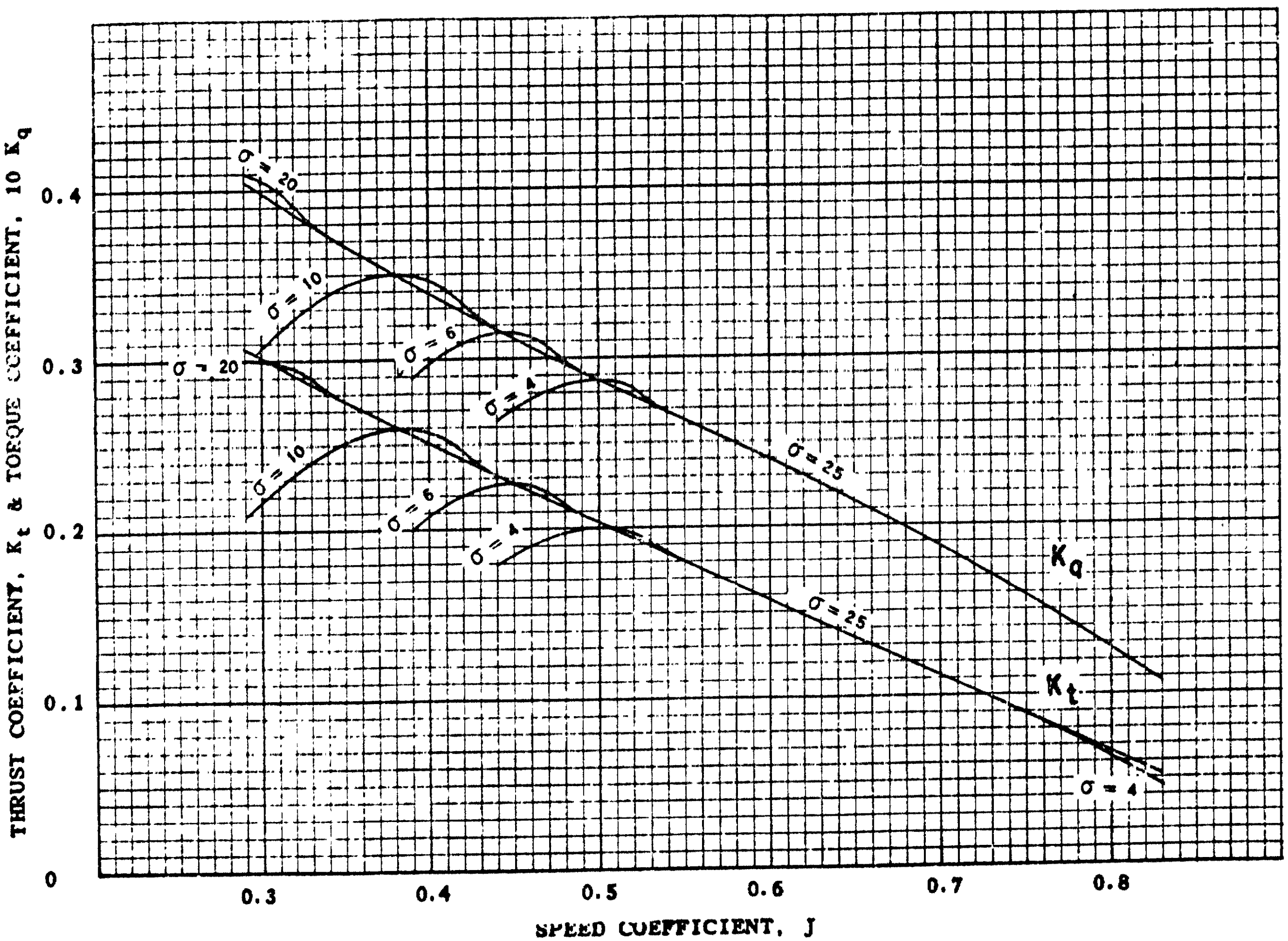


Figure 26. Cavitation Characteristic Curves of Propeller 3749

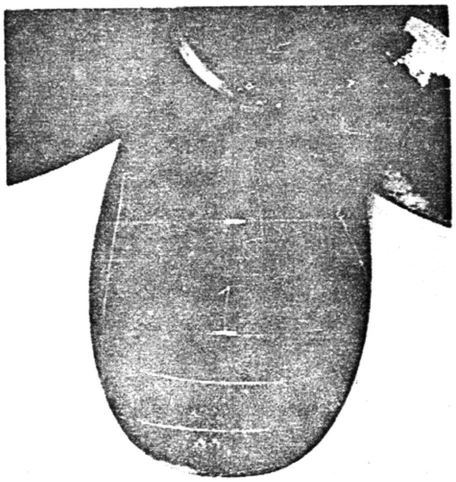


Figure 27a - Blade Number 1

Figure 27b - Blade Number 2

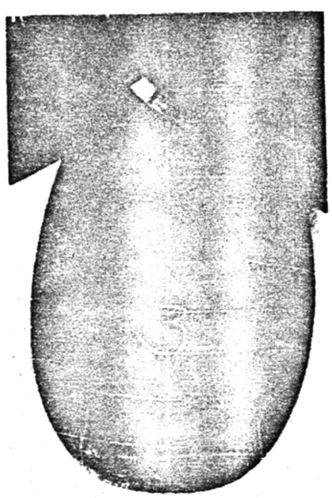


Figure 27c - Blade Number 3

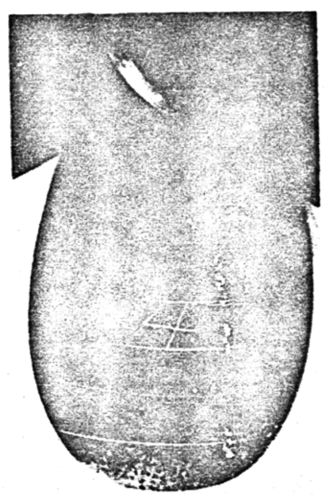


Figure 27d - Blade Number 4

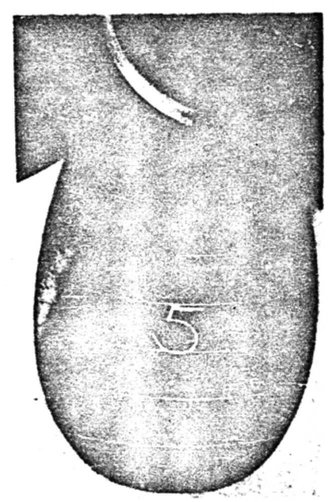


Figure 27e - Blade Number 5

Figure 27 - Photographs of the back of all the blades of Propeller 3749

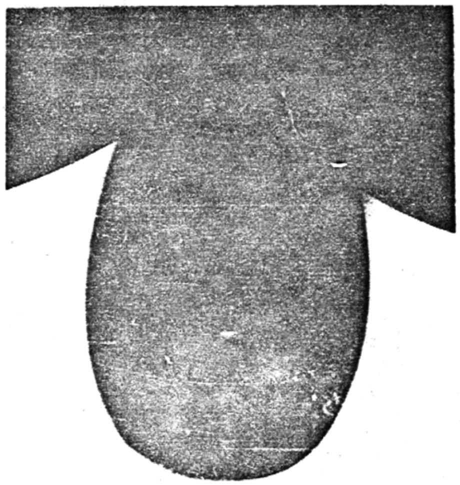


Figure 28a - Blade Number 1

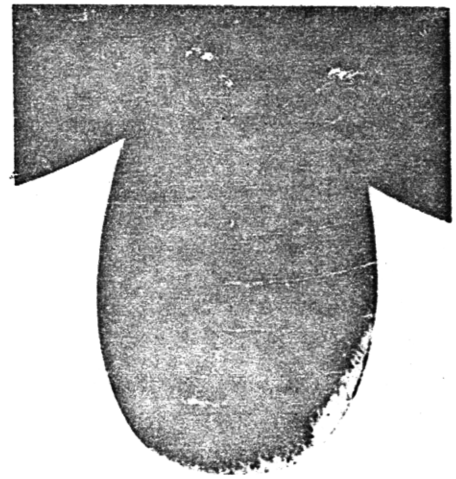


Figure 28b - Blade Number 2

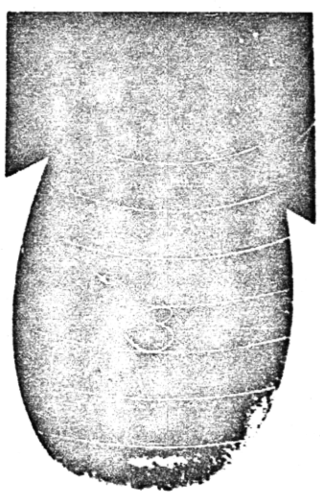


Figure 28c - Blade Number 3

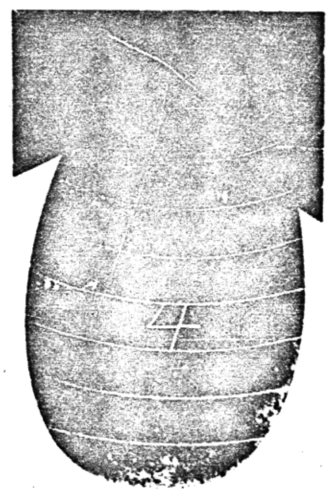


Figure 28d - Blade Number 4

Figure 28e - Blade Numbe

Figure 28 - Photographs of the face of all the blades of Propeller 3749

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CAVITATION PERFORMANCE OF PROPELLERS IN A SUBMARINE WAKE, by Willard H. Roundy, Sr. January 1959.
iv, 38p. photos., diagrs., graphs, tables, refs. UNCLASSIFIED

This report presents the results of the evaluation of three model propellers tested in the 24-Inch Water Tunnel with a simulated wake of a representative submarine in order to determine the cavitation characteristics. Curves are also presented for the inception of cavitation along the radius as a function of the operating conditions.

1. Propellers (Marine) – Cavitation – Model tests
2. Submarines – Wake – Simulation
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