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APPLICABILITY OF A SUPERCAVITATING PROPELLER TO A SMALL SPEEDBOAT

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by

E. Venning, Jr., LCDR, USN

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HYDROMECHANICS LABORATORY

RESEARCH AND DEVELOPMENT REPORT

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APPLICABILITY OF A SUPERCAVITATING PROPELLER TO A SMALL SPEEDBOAT

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NOTATION

D	Propeller Diameter
e	Propeller Efficiency $(\frac{K_t}{K_q} \cdot \frac{J}{2\pi})$
H	Total Pressure Head
J	Speed Coefficient $(\frac{V}{nD})$
K_q	Speed Coefficient $(\frac{Q}{n^2 D^5})$
K_t	Thrust Coefficient $(\frac{T}{n^2 D^4})$
n	Rotational Speed of Propeller
p	Hydrostatic Pressure (Submergence)
p_a	Atmospheric Pressure (pressure above water surface)
p_c	Cavity Pressure (same as vapor pressure of water in this work)
Q	Torque
T	Thrust
U	Free-Stream Velocity (assumed equal to V in this work)
V	Boat Speed
ρ	Mass Density of Water
σ	Cavitation Number $(\frac{p_a + p - p_c}{1/2 \quad U^2})$

ABSTRACT

A supercavitating propeller was designed and built to operate under conditions that might exist on a small speedboat. This propeller was later compared against two other types of speedboat propellers in laboratory tests. Computations were then made to predict the performance of a standard propeller. Comparison of the test results with the predicted performance of the standard propeller indicated that the supercavitating propeller was only equal to the standard propeller in efficiency under the conditions specified.

INTRODUCTION

Laboratory experiments have established that there are conditions where the supercavitating propeller shows better efficiency than the standard propeller. However, there is little performance information that is based on a specific design for certain conditions pertaining to a particular craft.

Hence, the objective of this work was to compare the predicted and actual performances of a supercavitating propeller against the performances of two typical speedboat propellers as well as against the predicted performance of a standard propeller. Since the small speedboat conditions placed the supercavitating propeller within an operating region where supercavitating propeller performance usually is not better than that of standard propeller performance, it followed that marginal, limiting data would probably result.

And so, the Bureau of Ships, in early 1959, requested the David Taylor Model Basin (reference 1) to design and test a supercavitating propeller* for certain small speedboat conditions. This work was carried out under Hydromechanic Fundamental Research Program, Project No. SR 009 0101. The work that was done in this project is outlined as follows:

1. A supercavitating propeller was designed and then built.
2. The supercavitating propeller and two speedboat propellers, the Special Equipoise, and the Meyer-Wedge, were tested in the variable pressure water tunnel.

3. The performances of the three propellers were analyzed and compared with each other as well as with the predicted performance of a standard (non-cavitating) propeller.

DETAILS OF SUPERCAVITATING PROPELLER

The design of the supercavitating propeller was based on the following small speedboat conditions:

Boat Speed	67 mph
Propeller Rotational Speed	3500 rpm
Available Shaft Horsepower	350 SHP
Total Absolute Pressure at the Propeller Centerline	34 ft. of water
Effective Wake Fraction	0
Maximum Allowable Diameter	18 inches
Shaft Angle of Inclination	9 1/2 degrees

The procedures set forth in references 2 and 3 were followed in the actual design work, the only exception being the addition of an extra one-half degree to the angle of attack of each blade section in order to take into consideration the inclination of the propeller shaft.

It was evident that the operating conditions placed this supercavitating propeller within a marginal region of practicability. From a study of Figure 1 it is seen that in this case the boat speed and propeller rotational speed combination is too low to place the present propeller within the practical region.

However, from the standpoint of experimental development of the supercavitating propeller, this design did present an opportunity to specifically build and test a marginal propeller, and then to compare it with standard speedboat propellers as to performance. Previously, only one other full-scale supercavitating propeller has been designed and built for the marginal region.

(See point "A" in Figure 1.) And so, the design conditions established a point near the upper limits of the speed coefficient J. It was hoped that possibly some measure of improved performance might result, but the magnitude of possible improvement was expected to be small. A drawing of the designed supercavitating propeller is shown in Figure 2; photographs are shown in Figure 3.

Summarizing the design work, it was predicted that the supercavitating propeller would operate at an efficiency of 76.27 percent under the design conditions previously mentioned. Further, under these conditions, the cavitation number at the 0.7 radius would be 0.0582. Experimental results reported in reference 2 have indicated that in order to have satisfactory supercavitating operation, the cavitation number of the blade section at 0.7 of the propeller radius should be less than 0.045. Since the designed cavitation number at the 0.7 radius is 29 percent too large, it was predicted that fully developed supercavitation over the back of the blades would not occur. Water tunnel tests at the design conditions verified this as can be seen in Figure 4.

DETAILS OF COMPARISON PROPELLERS

As mentioned before, the two speedboat propellers used for comparison with the supercavitating propeller were the Special Equipoise and the Meyer-Wedge propellers. No drawings of these propellers were available; however, some of their more important details as compared with the supercavitating propeller are presented in Table 1. Details of typical cross sections of the three propellers will be noted in Figure 5, and photographs can be seen in Figures 6 and 7.

TABLE 1

Comparison of Propellers

	Super-Cavitating	Special	Meyer-Wedge
Diameter	15.5 inches	16.0 inches	15.0 in.
Pitch at 0.7 Radius	25.24 inches	26.0 inches	25.0 in.
Pitch ratio at 0.7 Radius	1.628	1.625	1.667
Number of blades	3	3	2
Expanded Blade Area	95.457 sq. in.	113.58 sq. in.	59.80 sq. in.
Expanded Area Ratio	0.505	0.565	0.339
Mean Width Ratio	0.305	0.332	0.262
Projected Area	68.103 sq. in.	75.03 sq. in.	42.16 sq. in.
Projected Area Ratio	0.361	0.373	0.2385
Blade Thickness Fraction	0.027	0.03125	0.0375

The Special Equipoise propeller and the supercavitating propeller were designed and built for the same operating conditions. The Meyer-Wedge propeller was originally intended to operate at somewhat different conditions; however, it is used for comparison purposes because of its unusual wedge shape, and also because comparisons will be made on the basis of performances under the individual design conditions rather than under one set of conditions which properly are not applicable to all three propellers.

Regarding the shape of the Meyer-Wedge propeller it should be pointed out that the sport of hydroplane speedboat racing has been one means for testing numerous proposals involving unusual hull shapes, appendages forms and propeller configurations. In 1934 one such configuration was a "wedge-sectioned" propeller which was the work of T.F.W. Meyer. His experiences and observations during development of propellers for Gar Wood's MISS AMERICA X during 1932 and 1933 led Meyer to consider such a "wedge-sectioned" propeller. The MISS AMERICA X employed both a wedge-shaped rudder and propeller shaft struts and from visual observation Meyer noted the vapor cavity that formed over the struts.

Subsequently a "wedge-sectioned" propeller was built for use by the late Samuel Dunsford of Concord, New Hampshire, on the hydroplane SCOTTY II. However, a testing program to optimize the engine-hull-propeller combination was never carried forth, so in 1934 it was not possible to arrive at any conclusions on the worth of the "wedge-sectioned" propeller.

PROPELLER TESTS

SUPERCAVITATING PROPELLER

Routine characterization including both towing tank and variable pressure water tunnel tests at varying cavitation numbers was conducted on the supercavitating propeller. Test results when operating at the originally prescribed design conditions are shown in Figure 8. These curves provide a prediction of approximate performance on the boat. Results of open-water tests and tests at varying cavitation numbers will be found in reference 4 under the discussions of Propeller Number 3820. However, Figure 9 is included herein to show the effect of variation of cavitation number, σ, on the performance of this propeller.

A comparison of the test results with the predicted performance shows that the efficiency was about 7 percent lower than predicted. Further, the thrust coefficient was about 3 percent low, while the torque coefficient was about 8 percent high. These discrepancies may be due to incorrect assumptions in the design phase regarding the lift and drag properties of the supercavitating section, or to the fact that fully-developed supercavitation did not occur at the design conditions. In Figure 4 are shown two photographs of varying degrees of cavitation. The upper photograph shows an example of fully developed supercavitation. The lower photograph shows the limited cavitation that occurs on the present supercavitating propeller at design conditions.

SPECIAL EQUIPOISE AND MEYER-WEDGE PROPELLERS

Tests on the Special Equipoise and Meyer-Wedge propellers were conducted only in the variable pressure water tunnel. Figures 10 and 11 show test results for these two propellers, and a comparison of the efficiency curves of the three propellers will be seen in Figure 12. From these last curves it appears that the efficiency of the supercavitating propeller is 7.2 percent greater than that of the Special Equipoise propeller when both propellers are operating at their design speed coefficients. From Figures 8 and 10 it is evident that both propellers will operate at nearly maximum efficiency at their respective design speed coefficients, hence this difference of 7.2 percent represents the maximum possible expected improvement from use of a supercavitating propeller.

The maximum efficiencies of the Special Equipoise and Meyer-Wedge propellers are essentially comparable, and are about 7.5 percent lower than the supercavitating propeller. What is most interesting about the Meyer-Wedge propeller is that at design conditions about two-thirds of the backs of the blades are covered by a vapor cavity which collapses well aft of the trailing edge (See Figure 13). This approximates the condition of fully-developed supercavitation shown earlier in Figure 4. Perhaps if development of the Meyer-Wedge propeller had continued, specific improvement over the Equipoise propeller might have resulted for the same reasons that the supercavitating propeller is an improvement.

COMPARISON WITH STANDARD PROPELLER

Following the previously described work, calculations were next performed to determine what performance could have been expected from a standard propeller if it had been used in lieu of the supercavitating propeller. The same design conditions specified for the supercavitating propeller were applied to the standard propeller.

First, based on Troost data as found in Reference 5, a maximum efficiency of 78 percent appeared possible from a 15.5-inch diameter propeller having an expanded area ratio of 0.50 and a pitch ratio of 1.38. See Figure 14. However, this high efficiency could be expected only if the propeller were not cavitating. From actual performance curves of closely similar propellers, at the design speed coefficient of 1.305 and at the design cavitation number of 0.226, it appeared that an efficiency nearer 60 percent (which reflected the presence of cavitation) was more realistic.

As a check on the last mentioned efficiency, further calculations based on the work of Gawn and Burrill (reference 6) were made specifically to evaluate the effect of cavitation. From these calculations it became evident that regardless of pitch ratio or expanded area ratio a maximum efficiency of 69 percent was the best that could be expected from a standard propeller designed for the conditions previously mentioned for the supercavitating propeller. See Figure 15. It is interesting to note that in Figure 8 it is also apparent that 69 percent was the best efficiency that could be achieved in tests on the supercavitating propeller. Using Gawn-Burrill data and Figure 15, computations of performance over a range of J values were made for a specific standard propeller having the following characteristics:

Diameter	16.0 inches
Pitch Ratio at 0.7 Radius	1.628
Number of Blades	3
Expanded Area Ratio	1.10

Figure 16 shows the predicted performance of this propeller. The curves are representative of the optimum that can be expected from a standard propeller. Note that its physical dimensions are comparable to the Special Equipoise and supercavitating propeller.

CONCLUSIONS

The subject supercavitating propeller of this report was designed for operation under marginal conditions. As expected this supercavitating propeller showed an efficiency at the design point that was about the same as that of a standard propeller. High forward speed and high rotary speed are the prime factors that will determine the superiority of a supercavitating propeller for a specific application, and in this application the rotary speed was too low.

However, when conditions of high rotary speed and high forward speed are properly matched, a supercavitating propeller designed for such cavitation producing conditions can be expected to show an efficiency that will be significantly better than that of a standard propeller which has been designed for the same conditions. Since the depth of submergence of the propeller on small speedboats is usually not greater than two feet, the effect of propeller submergence is negligible. Therefore, the determination as to the use of a supercavitating propeller on a speedboat depends on what boat speed is possible with the installed power and what the rate of rotation of the propeller is.

ACKNOWLEDGMENT

The willing help of many people has been of inestimable assistance to the author in the work of this report. Appreciation is expressed to Mr. George Reis, Bolton Landing, N.Y., for the loan of his Special Equipoise propeller, and to Mr. T F.W. Meyer, Birmingham, Michigan, for the loan of his Meyer-Wedge propeller. Finally, each member of the Propeller Branch, David Taylor Model Basin, has contributed in some way. To all an expression of sincere thanks is extended.

REFERENCES

1. BUSHIPS ltr S44 (644) Ser 644-974 of 9 January 1959.

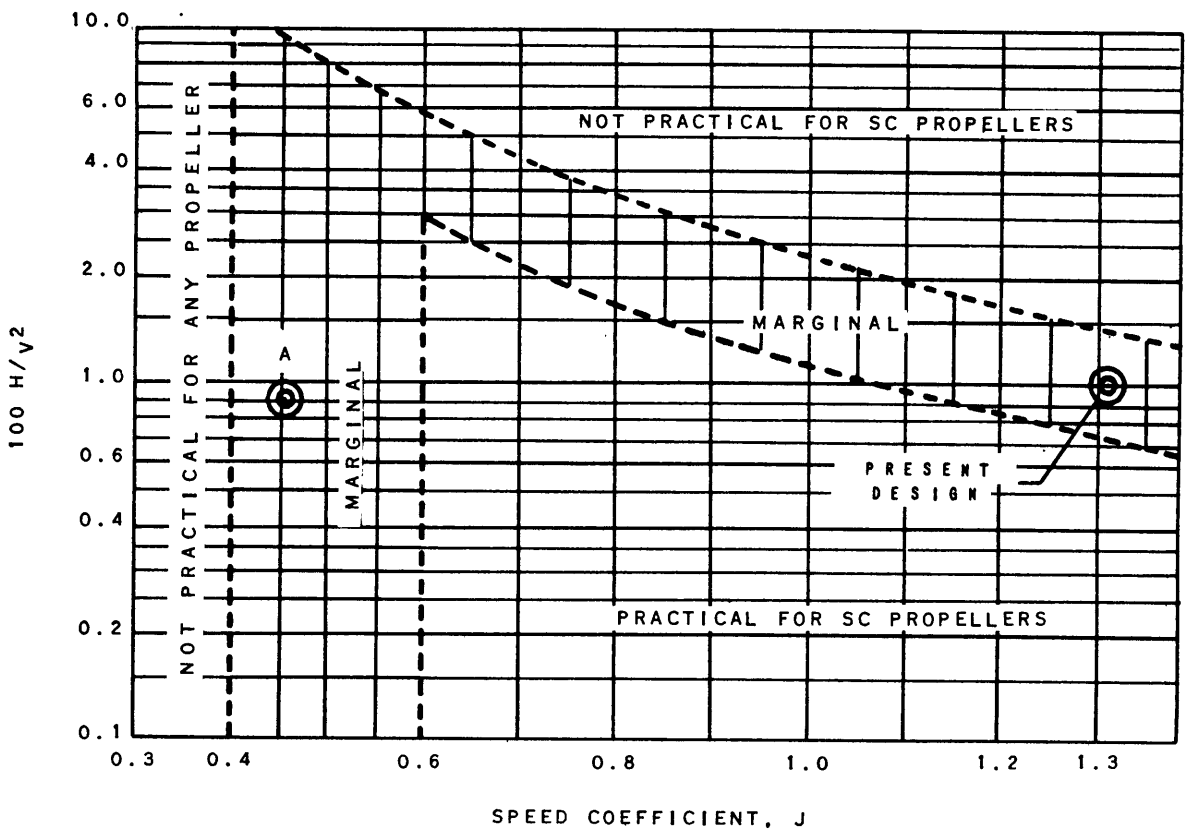
2. Tachmindji, A.J., et al, "The Design and Performance of Supercavitating Propellers," David Taylor Model Basin Report C-807 (February 1957).

3. Tachmindji, A.J., Morgan, W.B., "The Design and Estimated Performance of a Series of Supercavitating Propellers," Proceedings of the Second Symposium on Naval Hydrodynamics, (August 1958).

4. Hecker, R., Peck, J.G., "Experimental Performance of TMB 3-Bladed Supercavitating Propellers," David Taylor Model Basin Report 1432 (in preparation).

5. Troost, L., "Open Water Test Series with Modern Propeller Forms," Transactions, North East Coast Institution of Engineers and Shipbuilders, Vol. 67, 1950.

6. Gawn, R.W.L., Burrill, L.C., "Effect of Cavitation on the Performance of a Series of 16 Inch Model Propellers," Transactions, The Institute of Naval Architects, Vol. 99, 1957.



NOTE: THE ABOVE FIGURE WAS TAKEN FROM REFERENCE 2.

Figure 1 - Practicability of Supercavitating Propellers

PROPELLER 3820

NUMBER OF BLADES............	3
EXP. AREA RATIO.............	0.505
MWR.........................	0.305
BTF.........................	0.027
P/D (AT 0.7R)...............	1.628
DIAMETER....................	15.500 Ins.
PITCH (AT 0.7R).............	25.241 Ins.
ROTATION....................	R.H.

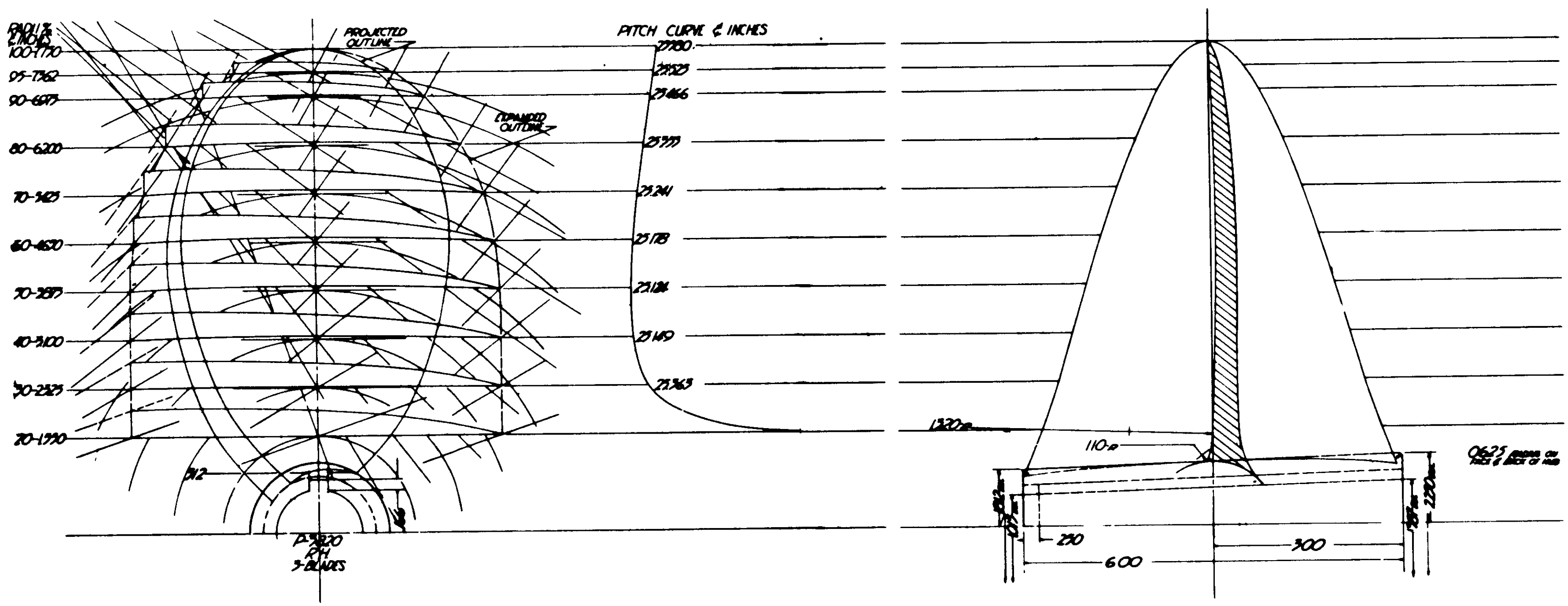


Figure 2 - Design Drawings of the Supercavitating Propeller

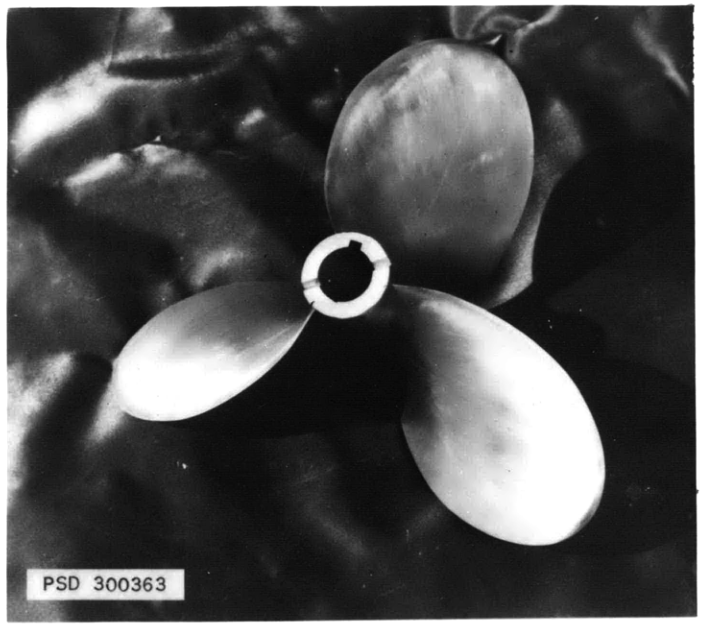
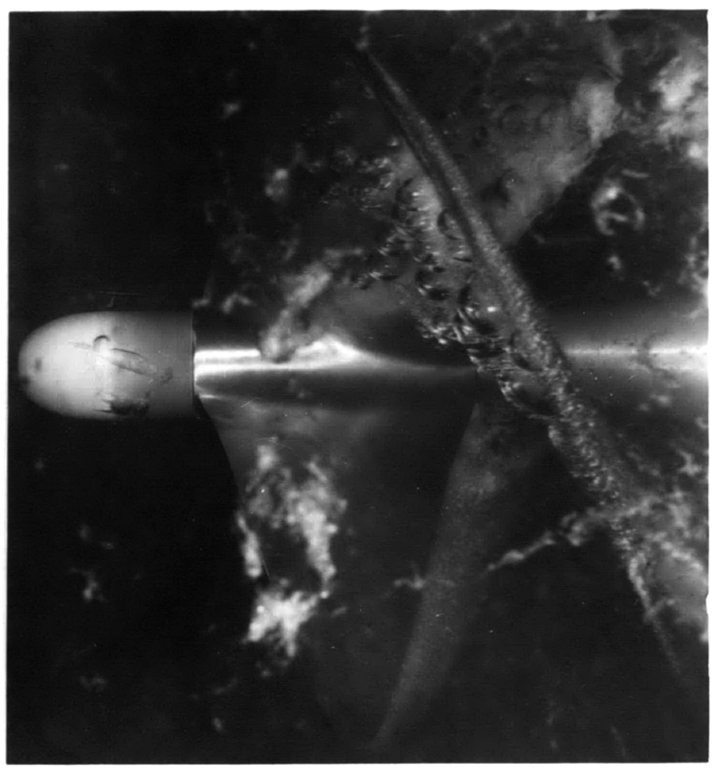


Figure 3 - Photographs of the Supercavitating Propeller

PSD 98793

An Example of Fully Developed Supercavitation on Prop. No. 3770



PSD 98831

Partial Supercavitation on Present Propeller (No. 3820) at Design Conditions

Figure 4 - Degree of Cavity Development on the Supercavitating Propeller

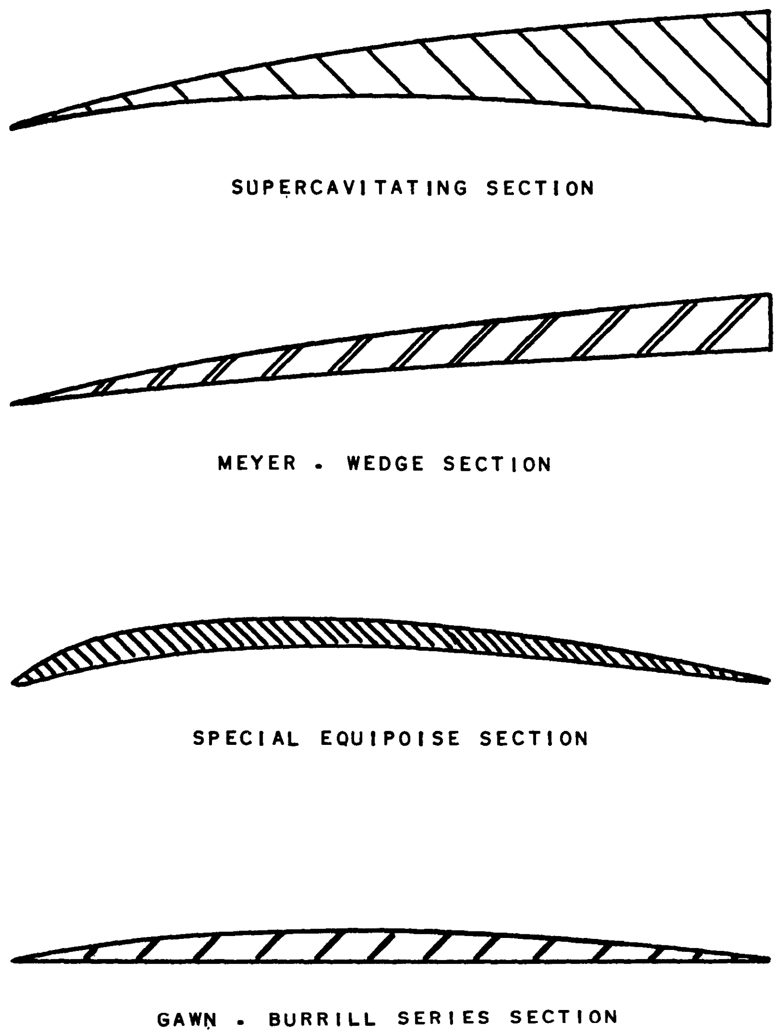
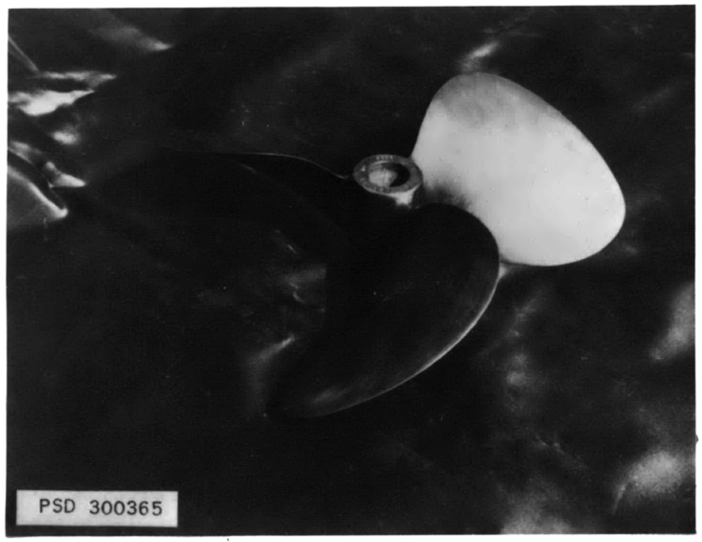


Figure 5 - Comparison of Propeller Cross Sections



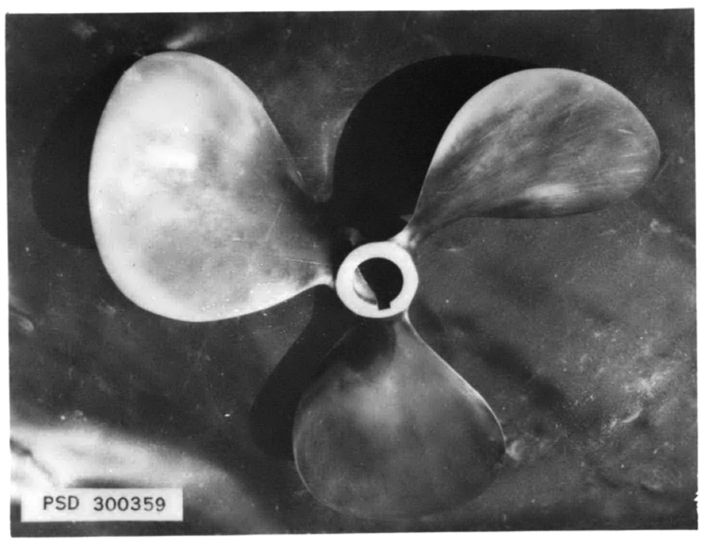


Figure 6 - Photographs of the Special Equipoise Propeller

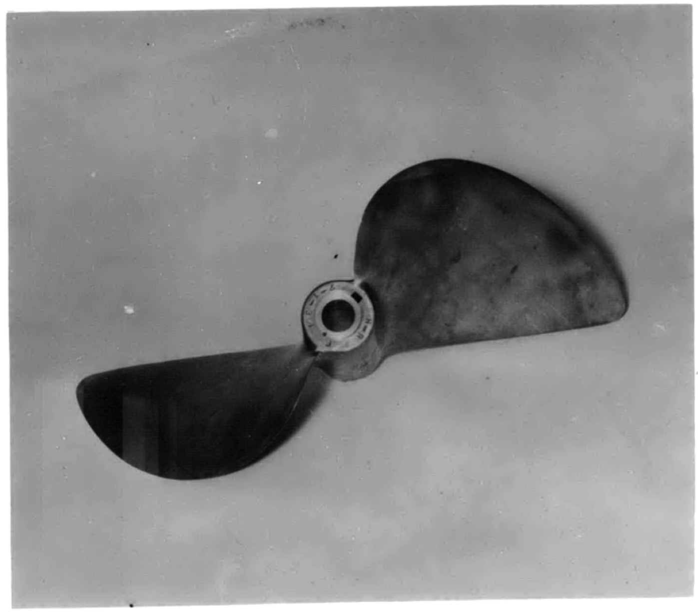


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Figure 7 - Photographs of the Meyer Wedge Propeller

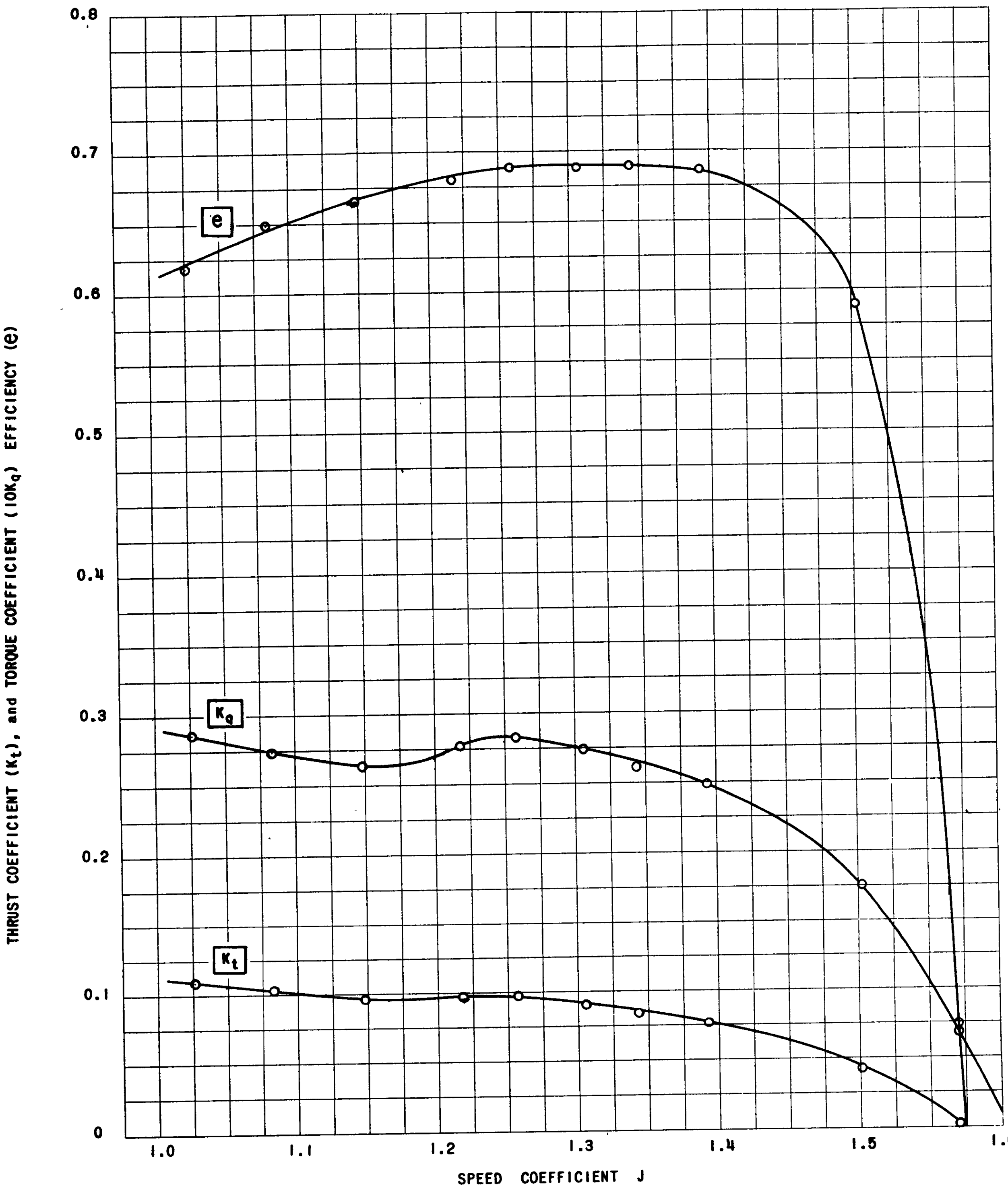


Figure 8 - Results of Water Tunnel Tests on the Supercavitating Propeller

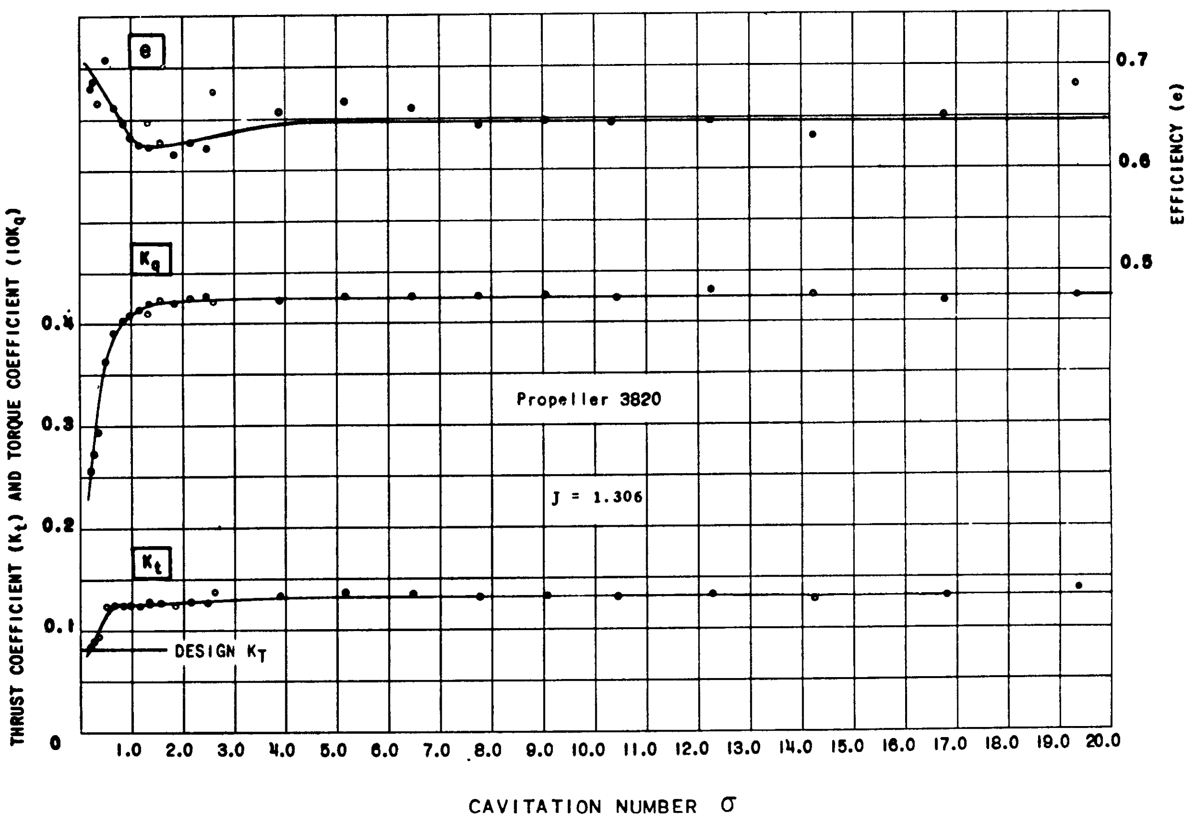


Figure 9 - Performance of the Supercavitating Propeller at Various Cavitation Numbers.

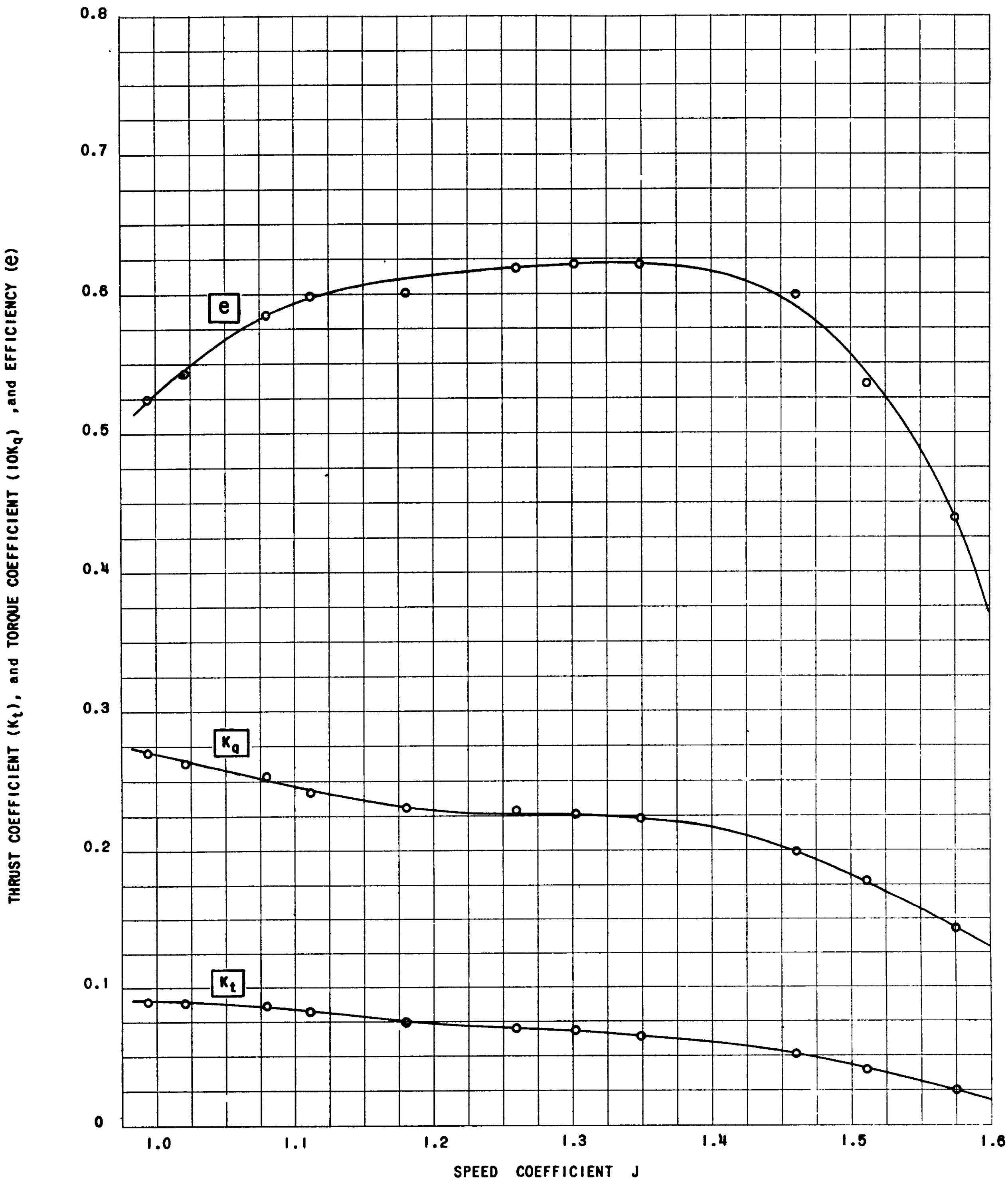


Figure 10 - Results of Water Tunnel Tests on the Special Equipoise Propeller.

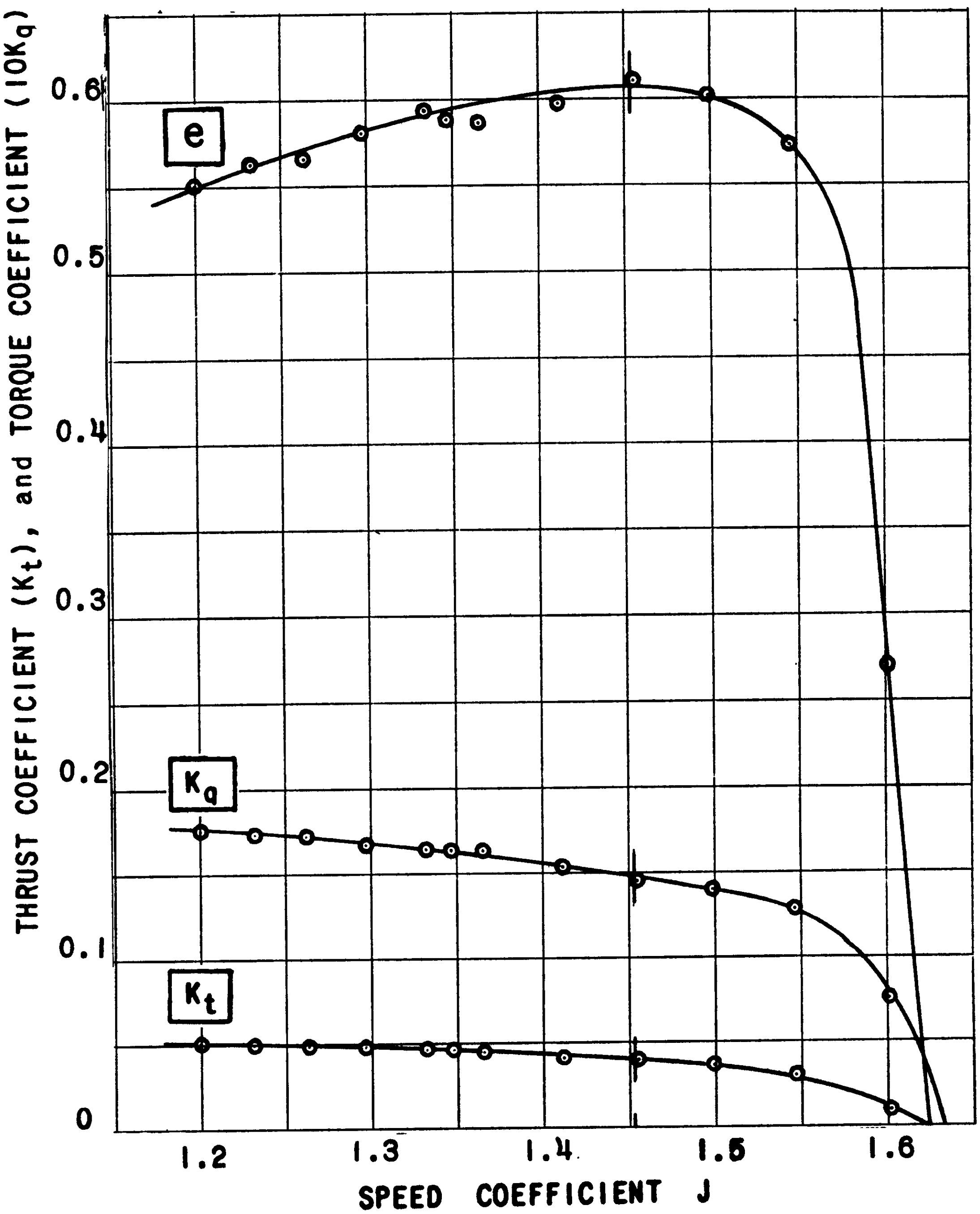
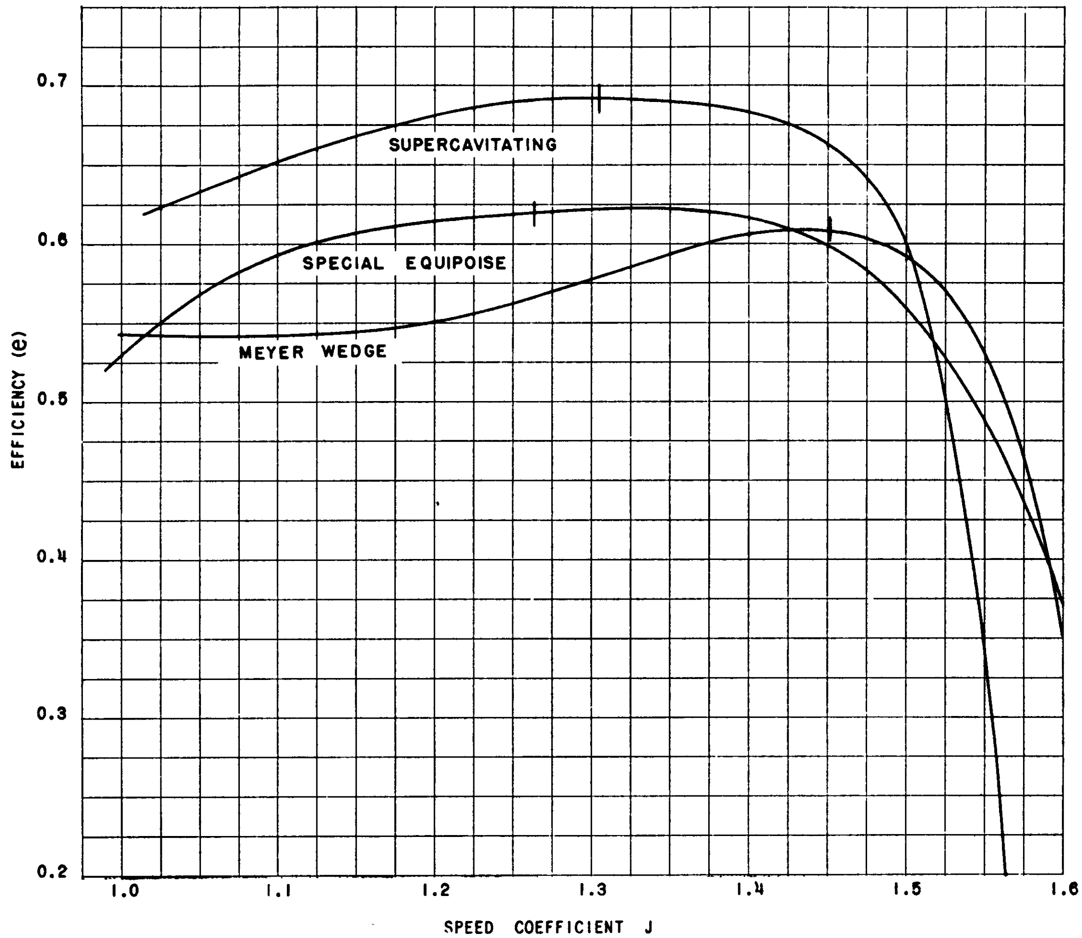


Figure 11 - Results of Water Tunnel Tests on the Meyer Wedge Propeller



	SUPERCAVITATING	SPEC. EQUIPOISE	MEYER WEDGE
DESIGN J	1.305	1.264	1.452
DESIGN CAVITATION NO.	0.226	0.226	0.283
EFFICIENCY AT DESIGN CONDITIONS	69.2 %	62.0 %	60.8 %

Figure 12 - Comparitive Propeller Efficiencies at Design Conditions

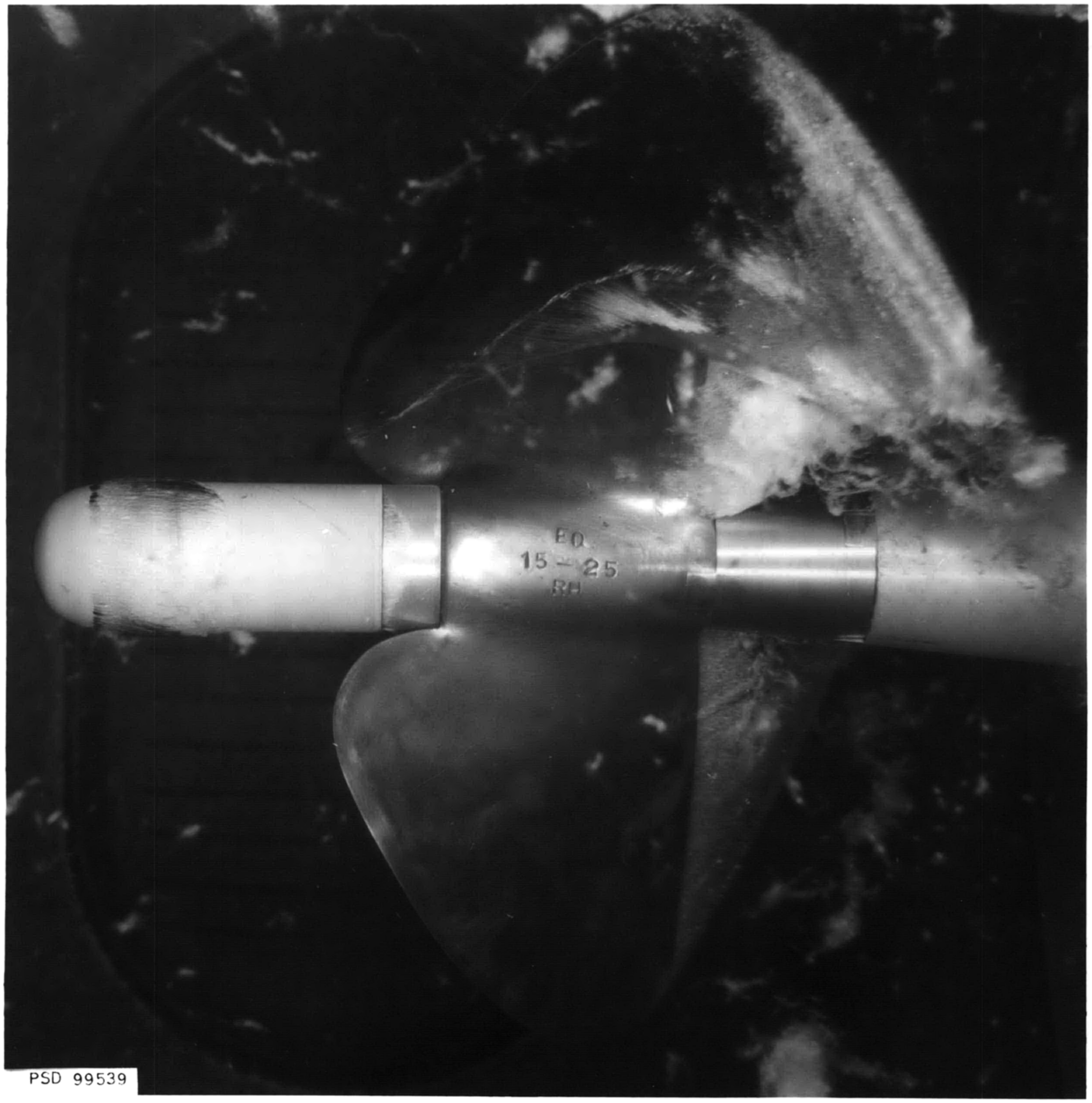


Figure 13 - Partial Supercavitation on the Meyer Wedge Propeller

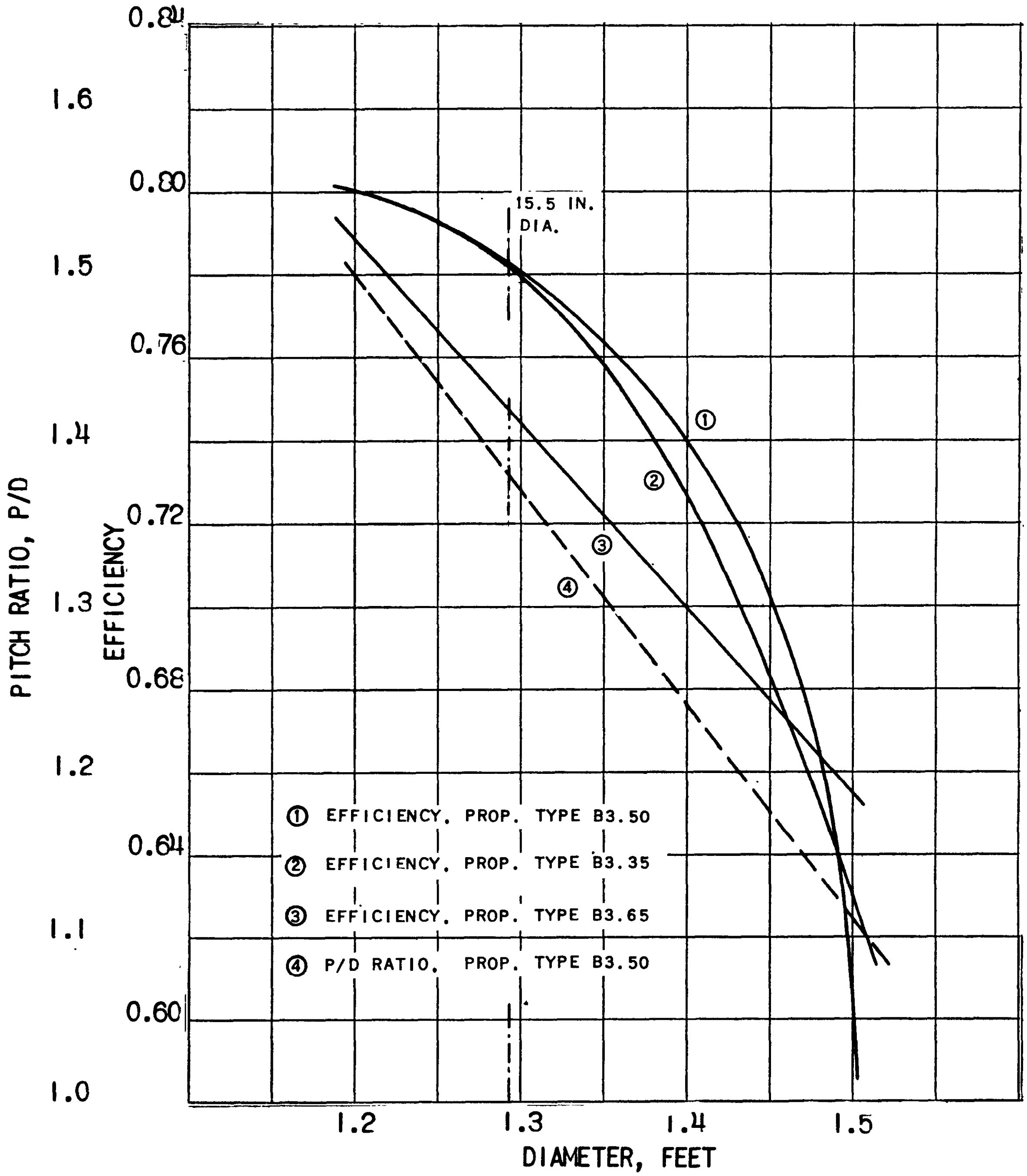


Figure 14 - Efficiency Versus Diameter for Three Expanded Area Ratios Based on Troost Series Data.

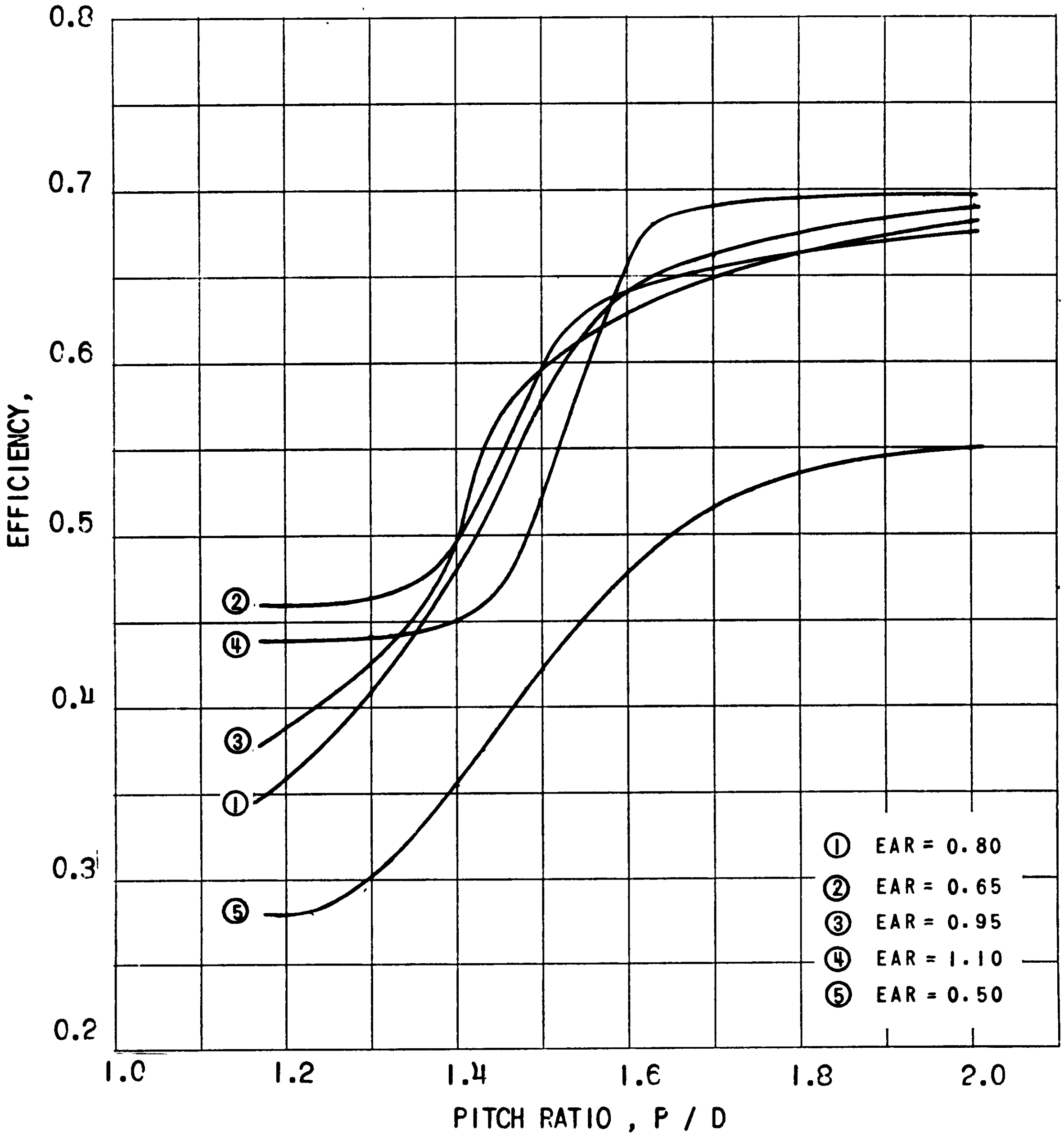


Figure 15 - Possible Propeller Efficiencies Based on Gawn-Burrill Data

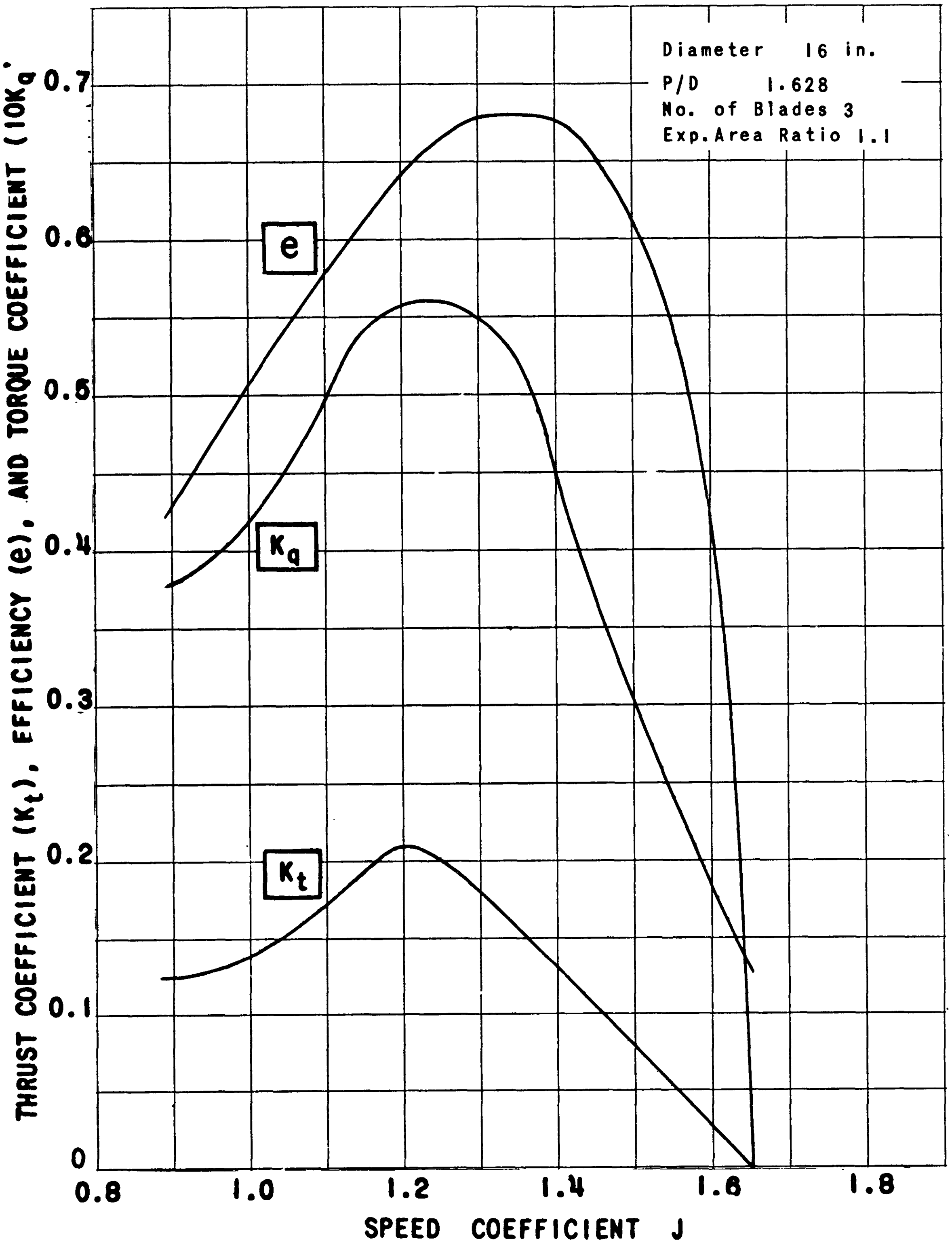


Figure 16 - Predicted Performance of a Standard Gawn-Burrill Series Propeller

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