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he Effect of Bulbous Blade Tips on the Development of Tip-Vortex Cavitation on odel Marine Propellers 29153

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Crump, S. F.

David Taylor Model Basin, Washington, D. C. R-C-99

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Installations Shipborne (28) Propellers, Marine - Performance

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NAVY DEPARTMENT
DAVID TAYLOR MODEL BASIN
WASHINGTON, D.C.

THE EFFECT OF BULBOUS BLADE TIPS ON THE DEVELOPMENT OF TIP-VORTEX CAVITATION ON MODEL MARINE PROPELLERS

by

S. F. Crump

#12

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March 1948 Report C-99

THE EFFECT OF BULBOUS BLADE TIPS ON THE DEVELOPMENT OF TIP-VORTEX CAVITATION ON MODEL MARINE PROPELLERS

ABSTRACT

Tests have been made on sets of model destroyer and submarine propellers to find the effect on tip cavitation and propeller efficiency of the addition of bulbs of various sizes to the tips of the propeller blades. The tests showed that through the addition of bulbs to the blade tips an average maximum increase in calculated ship speed of about 25 per cent could be obtained before the development of visible tip-vortex cavitation. The shape of the bulb is critical, however; with the form employed here, cavitation at the root of the bulb occurred approximately at the same ship speed as without the bulb. The loss of efficiency caused by this modification was not large.

INTRODUCTION

With the idea of reducing the strength of the vortex flow around the tips of propeller blades and thereby deferring the inception of tip-vortex cavitation, which is known to be responsible for sharp increases in propeller sound, the program on the reduction of propeller-excited sound (1)*, has been undertaken. The present report applies to the phase of this program designated "German Noise-Reduction Developments". It is concerned with the addition of bulbs of streamline form to propeller-blade tips as a measure to reduce tip-vortex cavitation. Representative submarine and destroyer propellers were selected and tested in both the model basin and the 12-inch variable-pressure water tunnel at the Taylor Model Basin with an without bulbous tips of various sizes. The results of these tests are here reported.

The bulbous-tip experiment was tried as early as 1942 at the Taylor Model Basin on a model destroyer propeller. At this time no marked effect on the inception of visible tip vortices was noted and no further investigations were made.

In Reference (2), page 28, German experience with bulbous-tip propellers during the war is summarized. It is stated that full-scale tests on propellers with bulged tips were tried on U-Boats on Types 23 and 7C. The tests on the former indicated an increase of 30 per cent in speed without

* Numbers in parentheses indicate references on page 9.

Figures 8 and 9, showing the results of self-propulsion tests 12 and 15 on Model 3803-1, are included for SHP and RPM comparisons of a SS212 Class submarine using both conventional-tipped and bulbous-tipped propellers.

ANALYSIS OF TEST RESULTS

For the destroyer propeller represented by Propeller 2047A, the effect on efficiency and on the inception of tip-vortex cavitation produced by the addition of bulbous tips can be determined from Figures 2 and 3. Figure 2 shows directly that only a slight variation in propeller efficiency is caused by the addition of bulged tips. This variation which favors the bulbous-tip propeller is within the limit of experimental error; thus, it may be concluded in this case that no significant change was made in efficiency by the addition of bulbs to the propeller blade tips.

In Figure 3 the inception of tip-vortex and laminar cavitation is shown to be deferred for the bulbous-tip propeller. Further analysis is needed to determine the amount of this deferment with respect to a particular condition of destroyer operation. As a typical test for this analysis, self-propulsion test 5A of Model 3625, representing the DD445 Class in which Propellers 2047 and 2048 were used, was selected. The diameter of the ship propeller is 11.375 feet and the net pressure on the propeller-shaft centerline* is 43.0 feet of sea water. Table 2 shows the computed cavitation indices, and loading coefficients, and the values of V, T, and H, that were used in computing them.

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* See Reference (5), pages 21 and 23, for method of computation.

TABLE 2

Loading Coefficients and Cavitation Indices for Propellers 2047-48, Model 3625, Self-Propulsion Test 5A

V_S in knots	V in knots	V^2	Thrust in pounds	H* in feet of sea water	H/V^2	T/V^2D^2
40	39.2	1537	211,000	36.55	0.024	1.06
38	37.6	1414	200,000	36.55	0.026	1.09
36	35.65	1271	186,500	36.55	0.029	1.13
34	33.85	1146	170,500	36.55	0.032	1.15
32	31.70	1005	152,900	36.55	0.036	1.17
30	29.55	873	131,900	36.55	0.042	1.17
28	27.15	738	112,900	36.55	0.050	1.18
26	24.9	620	87,600	36.55	0.059	1.07
24	22.8	520	66,200	36.55	0.070	0.98

The values of H/V^2 and T/V^2D^2 from Table 2 have been plotted as crosses in Figure 3 and the propeller loading-coefficient curve has been drawn through them. The significance of this loading-coefficient curve is discussed in connection with Table 5.

A similar analysis can be made of efficiency and cavitation characteristics for the submarine propellers driving a submarine of the SS212 Class. In Figure 4 it can be seen that the bulbous-tip Propellers 2445A-2 and 2446A-2 have a maximum efficiency 3 per cent less than that of the conventional Propellers, 2445A and 2446A. However, at slip ratios from 45 to 50 per cent which is the normal operating range of slip ratios for this submarine when submerged, there is hardly any difference in efficiency.

Tables 3 and 4 give the loading coefficients and cavitation indices computed for the original and modified SS212 Class submarine propellers, based on the self-propulsion tests whose results are shown in Figures 8 and 9.

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* For simulated self-propulsion tests in the 12-inch variable-pressure water tunnel, the net pressure for the model propeller is reduced by an empirical 15 per cent correction in order to produce an average effect of cavitation on the model propeller, as regards thrust loss, corresponding to that found on full scale. Similarly, in the present computations the net pressure for the ship propeller has been reduced 15 per cent in order to obtain H/V^2 values for the model propeller.

TABLE 3

Loading Coefficient and Cavitation Indices for Propellers 2445A-2 2446A-2, Model 3803-1, Self-Propulsion Test 12*

V_S	V	V^2	Thrust	H**	H/V^2	T/V^2D^2
11.5	10.81	116.7	28,600	74.14	0.64	4.04
11.0	10.34	107.0	26,400	74.14	0.69	4.07
10.5	9.87	97.5	24,250	74.14	0.76	4.10
10.0	9.40	88.5	21,950	74.14	0.84	4.10
8.0	7.52	56.5	13,800	74.14	1.31	4.02
6.0	5.64	31.8	7,810	74.14	2.33	4.05

TABLE 4

Loading Coefficients and Cavitation Indices for Propellers 2445A, 2446A, Model 3803-1 Self-Propulsion Test 15^x

V_S	V	V^2	Thrust	H**	H/V^2	T/V^2D^2
11.5	10.2	104.7	28,600	74.14	0.71	4.49
11.0	9.8	95.9	26,400	74.14	0.77	4.54
10.0	9.0	81.0	21,950	74.14	0.92	4.47
8.0	7.2	51.8	13,800	74.14	1.43	4.39
6.0	5.4	29.2	7,810	74.14	2.54	4.41

The values of H/V^2 and T/V^2D^2 from Tables 3 and 4 have been plotted in Figures 5 and 6, respectively, and the curve of the propeller-loading coefficient is drawn for each particular case.

The results of the cavitation-inception characterization on Propellers 2445A-1 and 2446A-1 are shown in Figure 7. As there is no available self-propulsion test on Model 3803-1 using these propellers, both the loading-coefficient curves determined from Tables 3 and 4 are plotted in Figure 7 in order that an estimate can be made of the ship speed at which tip-vortex cavitation may be expected to become visible on these propellers.

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* See Figure 8

** The net pressure at the propeller-shaft certerline for a fully submerged test is 87.22 feet of sea water. The figure shown in each table includes the 15 per cent correction factor; see note on page 5.

x See Figure 9.

A summary showing the computed ship speeds for the inception of tip-vortex cavitation for both the destroyer and the submarine classes mentioned in this report, using either conventional or bulbous-tip propellers, is shown in Table 5. These ship speeds are determined by the intersection of the loading-coefficient curves with the corresponding curves for the inception of tip-vortex cavitation in Figures 2, 4, 5, and 6.

TABLE 5

Computed Ship Speeds for the Inception of Tip Vortices for DD445 Class and SS212 Class Using Propellers of the Design Indicated

Ship Class	Model Propeller	Computed Ship Speed for Inception of Tip-Vortex Cavitation knots	Bulb Size in per cent of Propeller Diameter
DD445	2047A	27	0
D'445	2047 Mod.	34	3½
SS212	2445A, 2446A	10	0
SS212	2445A-1, 2446A-1	11.5	1
SS212	2445A-2, 2446A-2	12.5	2

From Table 5 it appears that the addition of bulbs to the tips of propeller blades should be a successful method of deferring the inception of tip-vortex cavitation. In the destroyer and submarine cases shown the maximum increase in the calculated ship speed at which tip-vortices became visible, using bulbous-tip propellers, was approximately 25 per cent.

However, cavitation at the point where the bulb is faired into the blade tip near the trailing edge is shown in Figures 3 and 5 to occur in certain instances prior to tip-vortex cavitation. The existence of this cavitation may be due to poor fairing of the cylindrical bulb into the tip of the blade. If the bulb is properly located and correctly faired into the blade tip, this cavitation could perhaps be eliminated. In tests reported here, bulb cavitation has no effect on the values shown in Table 5 for the SS212 Class submarine. On the other hand, for the DD445 Class destroyer in Figure 3, the curve for the inception of bulb cavitation is found to intersect the tip-vortex-cavitation curve of the conventional propeller at the operational value of the loading coefficient. This would indicate the inception of cavitation, of some type, and a corresponding rise in propeller-excited sound at 27 knots for both the conventional and the bulbous-tip propellers.

Comparison of the results obtained by the addition of a bulb with those obtained by reducing the pitch toward the tip, as described in reference (6), indicates that comparable delays of tip-vortex cavitation can be obtained by either method. From Table 1 of the report cited it appears that reduction of the pitch by 31.5 per cent at the tip should delay the inception of tip-vortex cavitation in a given case from 11.81 knots to 15.20 knots; this represents an increase of 29 per cent in the critical speed. On the other hand, it appears from Table 5 that the bulb of maximum diameter raised the critical speed, on slightly different assumptions as to ship conditions, from 10 to 12.5 knots, an increase of 25 per cent. It is uncertain which method involves the smaller loss of efficiency; the loss by either method is small.

CONCLUSIONS

1. In the two cases cited, the addition of bulbous tips to the propeller blades allowed an increase of approximately 25 per cent in corresponding ship speed before the inception of visible tip-vortex cavitation.

2. If the bulb is not properly located or is incorrectly faired into the blade tip, cavitation on the base of the bulb itself may occur as soon as tip-vortex cavitation occurs with the conventional blade tips.

3. The bulbs of larger diameter have the most marked effect in retarding tip-vortex cavitation.

4. The effect of the addition of bulbs to propeller-blade tips on the peak of the efficiency curve can not be reliably determined from these tests because the small differences obtained are within the limits of experimental error; but it can be concluded that, at the higher slip ratios where the efficiency curve flattens out, there is at least little difference in efficiency between a conventional and a bulbous-tip propeller.

5. The addition of bulbous tips to a submarine propeller probably would be more effective than would their addition to a destroyer propeller. The submarine propeller operates at much higher slip ratios, at which cavitation on the bulb itself occurs simultaneously with the inception of tip-vortex cavitation.

RECOMMENDATIONS

1. The location and fairing of the bulb should be investigated in order to eliminate bulb cavitation, which has so far been present.

2. The diameter and shape of the bulb most effective in deferring the inception of tip-vortex cavitation should be investigated. An ellipsoidal bulb whose minor axis is 2 per cent of the propeller diameter is recommended.

3. It may be found that the maximum effectiveness in reducing propeller noise will be obtained by combining the addition of ellipsoidal bulbs with reduction of the pitch at the blade tips. Therefore, it is recommended that ellipsoidal bulbs be added to the blade tips of a propeller that has an intermediate amount of pitch reduction at the tips.

REFERENCES

(1) TMB CONFIDENTIAL Project SRD 478/46. Planning Memorandum, Reduction of Propeller-Exicted Sound February 1947. Enclosure (A) to TMB CONF ltr C-H1-16(1), C-S44, C-S68-1, C-DD/S68 of 14 February 1947 to BuShips, Research (330).

(2) "Manufacture and Design of Propellers in Germany" Tech. Report No. 545-45, U.S. Naval Tech. Mission in Europe, October 1945.

(3) "Measurements of Propeller Noise on Three Submarines of the SS212 Class" by M. Strasberg and W. J. Sette, TMB CONF Report R-205, April 1944.

(4) "The Development of Cavitation Noise by Model Propellers", by M. Strasberg, TMB CONF Report 543, September 1946.

(5) "The 12-Inch Variable Pressure Water Tunnel Propeller Testing Procedure", by W. H. Bowers, TMB Report 505, November 1943.

(6) TMB CONFIDENTIAL Report C-58, dated November 1947 entitled "The Delay of Tip-Vortex and Laminar Cavitation on Submarine-Type Model Propellers by the Reduction of Pitch Near the Blade Tips".

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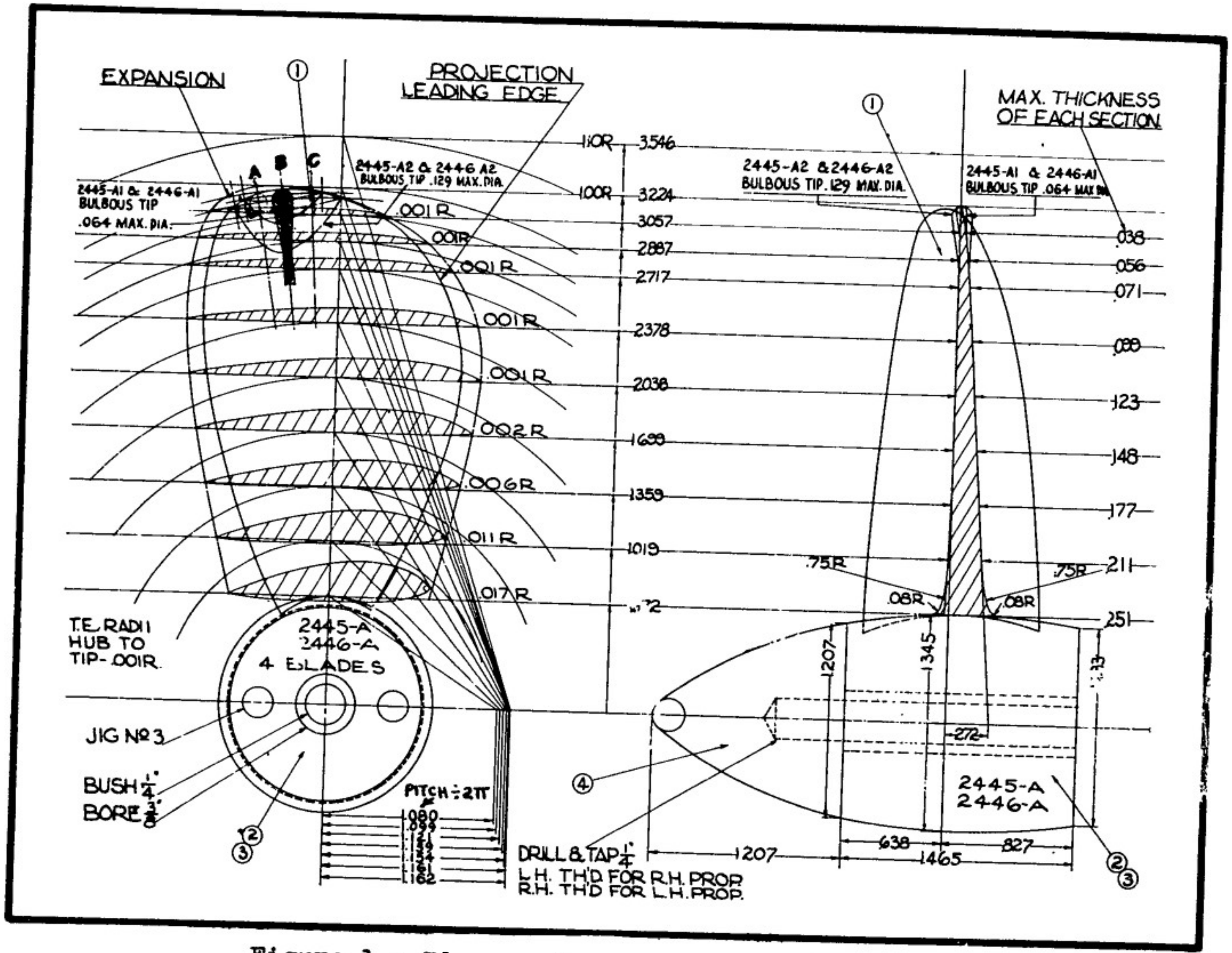

Figure 1 - Plan of Model Submarine Propellers
2445A and 2446A
2445A-1 and 2446A-1
2445A-2 and 2446A-2

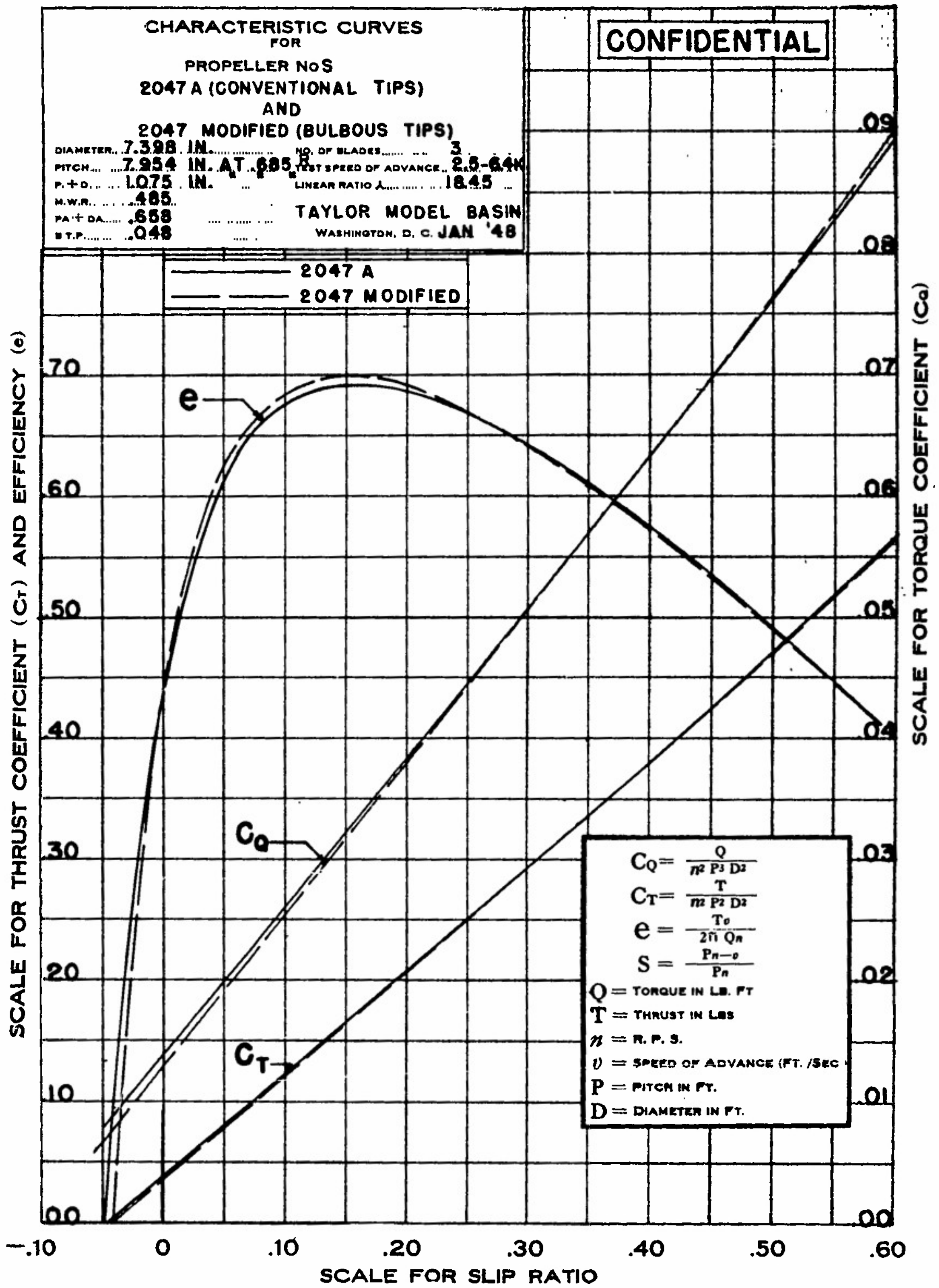

Figure 2 - Open-Water Characteristic Curves for Model Propellers 2047A and 2047 Modified

Propellers are identical except for blade tips. Propeller 2047A has conventional tips. Propeller 2047 Modified has bulbous tips whose diameters are 3.5 per cent of the propeller diameter.

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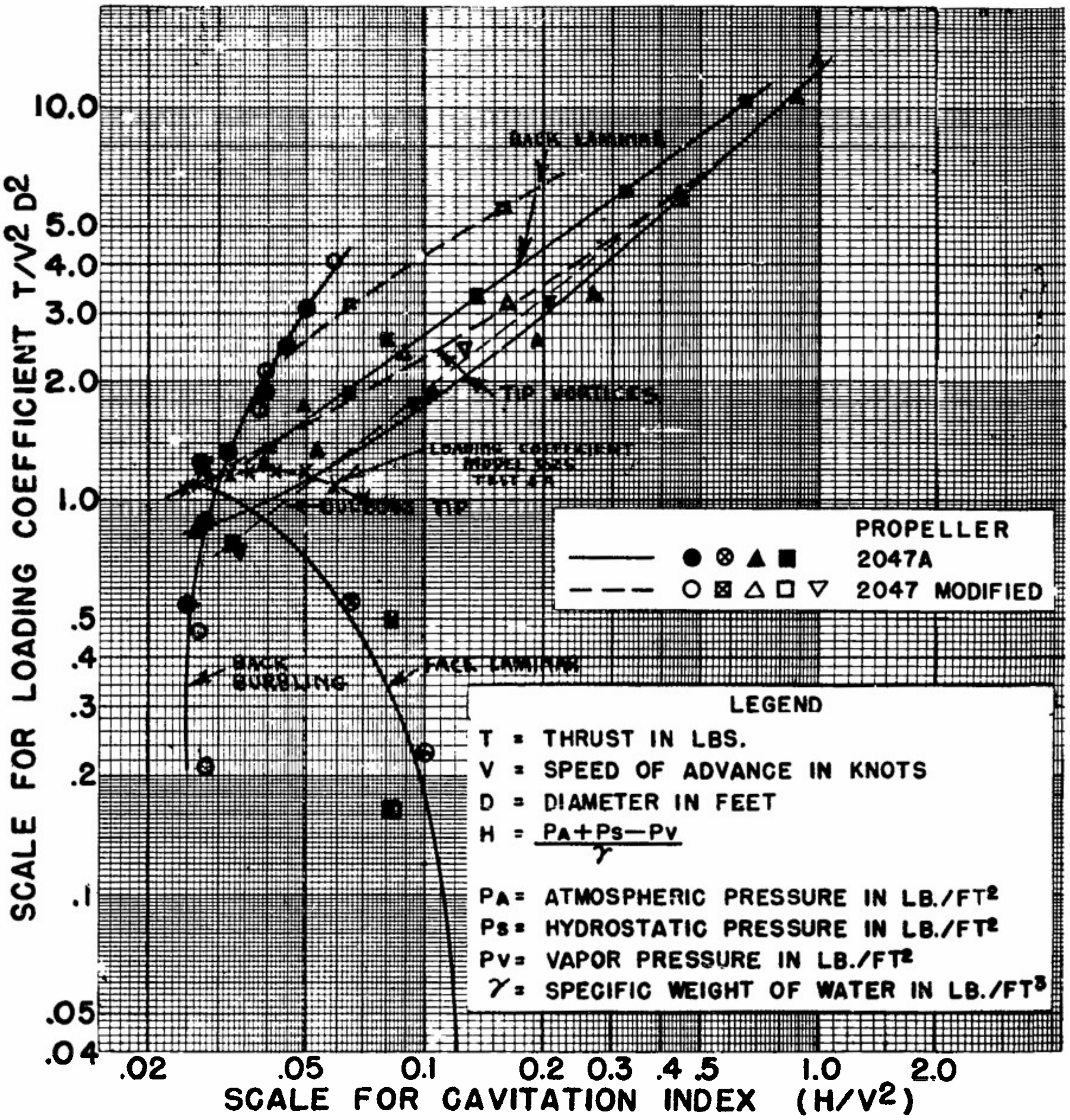

FIGURE 3 – LOADING-COEFFICIENT CURVES FOR THE INCEPTION OF CAVITATION ON PROPELLERS 2047A AND 2047 MODIFIED

PROPELLERS ARE IDENTICAL EXCEPT FOR BLADE TIPS. PROPELLER 2047A HAS CONVENTIONAL TIPS. PROPELLER 2047 MODIFIED HAS BULBOUS TIPS WHOSE DIAMETERS ARE 3.5 % OF THE PROPELLER DIAMETER.

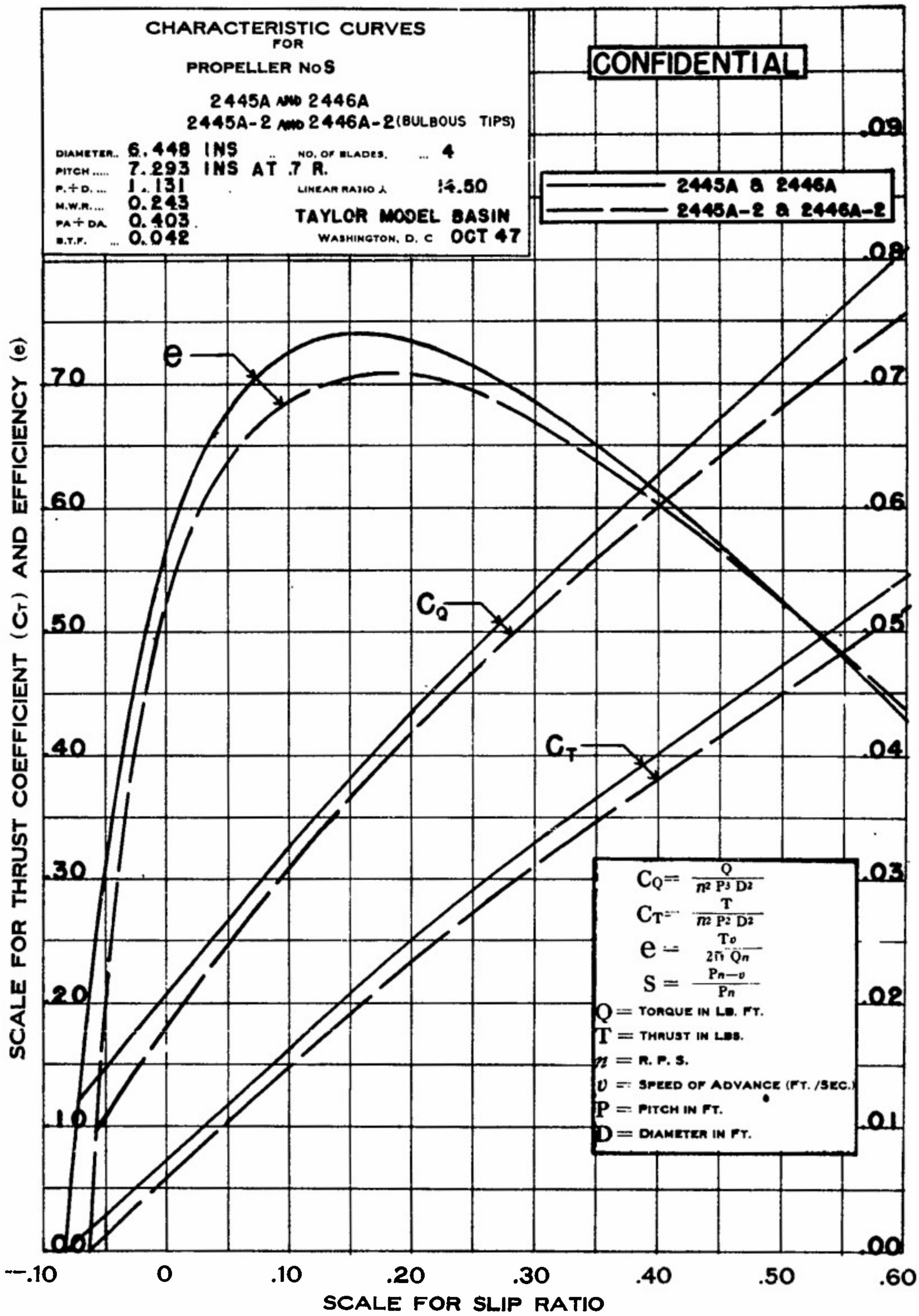

Figure 4 - Open-Water Characteristic Curves for Model Propellers 2445A, 2446A and 2445A-2, 2446A-2

The sets of propellers are identical except for blade tips. Propellers 2445A and 2446A have conventional tips. Propellers 2445A-2 and 2446A-2 have bulbous tips whose diameters are 2 per cent of the propeller diameters.

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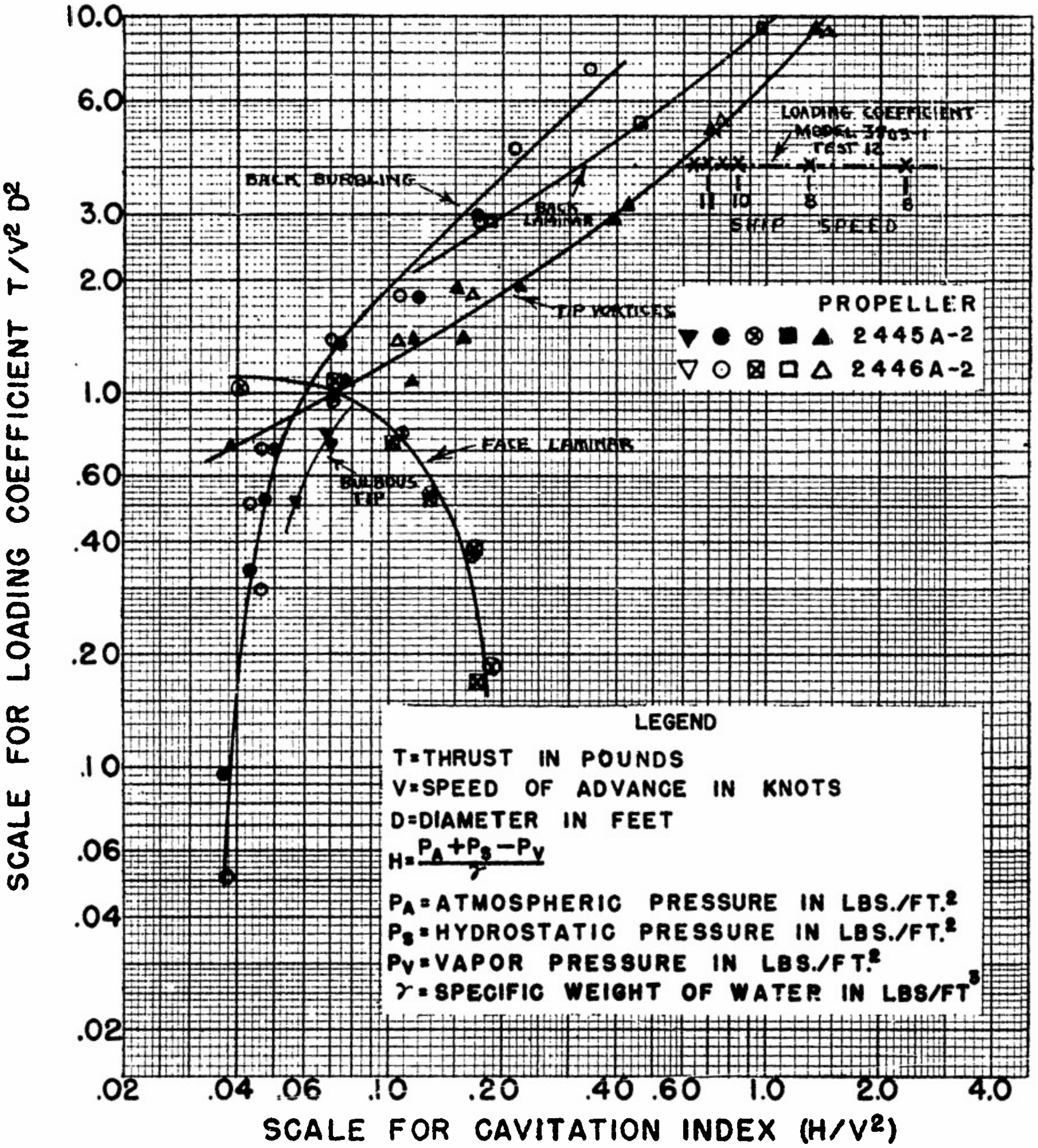

FIGURE 5 – LOADING-COEFFICIENT CURVES FOR THE INCEPTION OF CAVITATION ON PROPELLERS 2445A-2 AND 2446A-2

PROPELLERS 2445A-2 AND 2446A-2 HAVE BULBOUS TIPS WHOSE DIAMETERS ARE 2% OF THE PROPELLER DIAMETER. CURVES ARE AVERAGE OF 2 PROPELLERS.

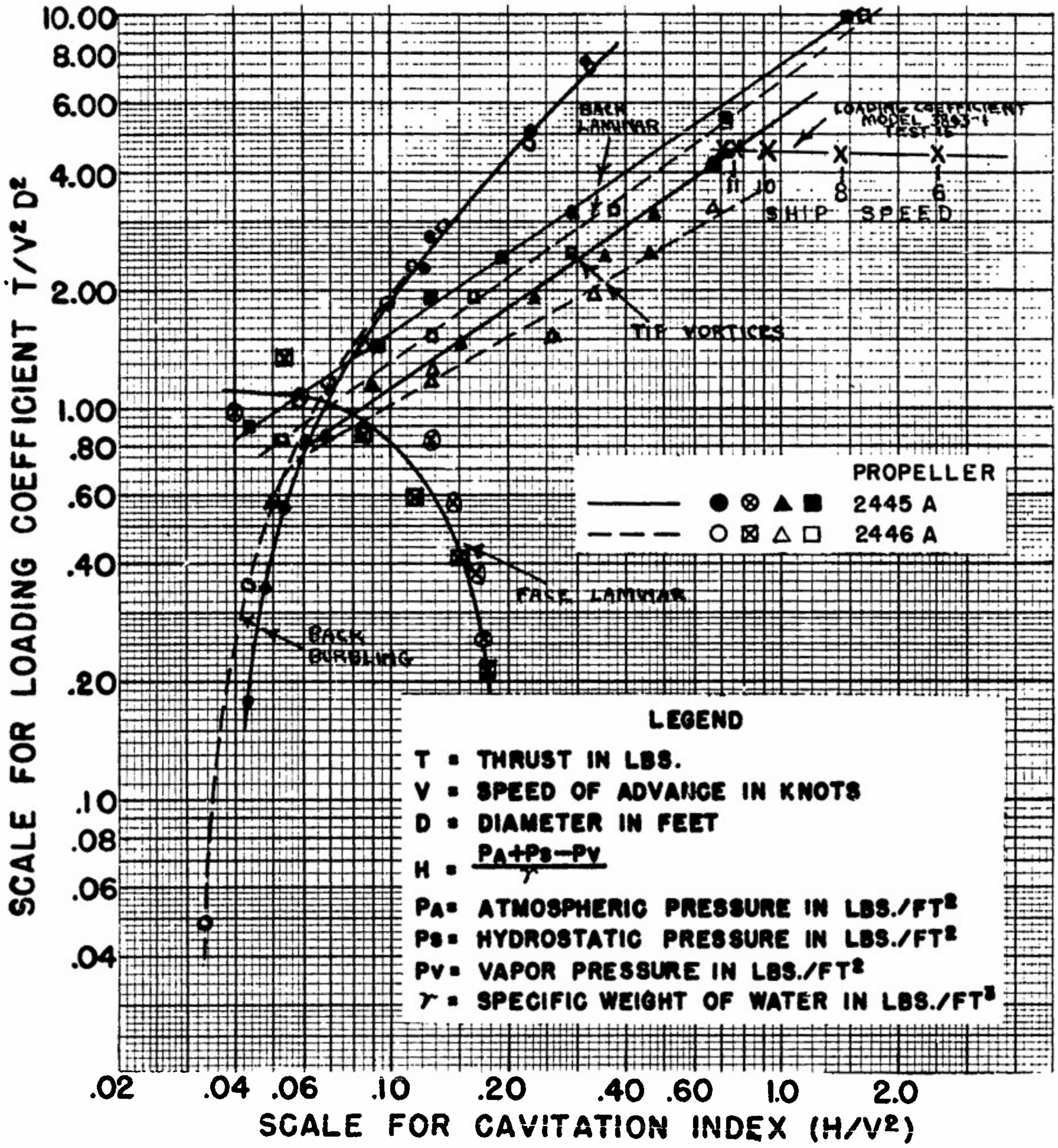

FIGURE 6 – LOADING-COEFFICIENT CURVES FOR THE INCEPTION OF CAVITATION ON PROPELLERS 2445A AND 2446A

PROPELLERS 2445A AND 2446A HAVE CONVENTIONAL TIPS.

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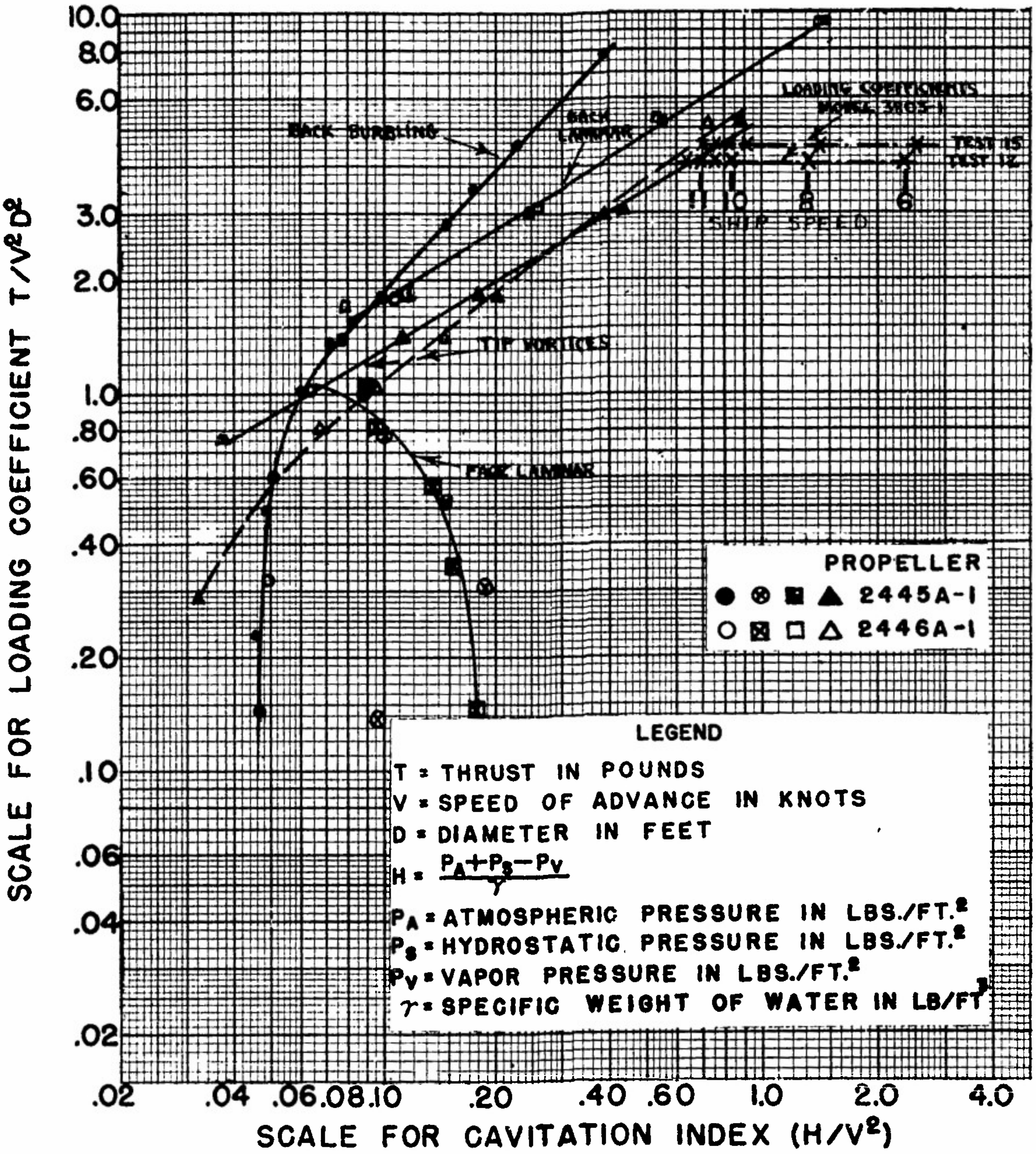

FIGURE 7 - LOADING-COEFFICIENT CURVES FOR THE INCEPTION OF CAVITATION ON PROPELLERS 2445A-1 AND 2446A-1

PROPELLERS 2445A-1 AND 2446A-1 HAVE BULBOUS TIPS WHOSE DIAMETERS ARE 1% OF THE PROPELLER DIAMETER. CURVES ARE AVERAGE OF 2 PROPELLERS.

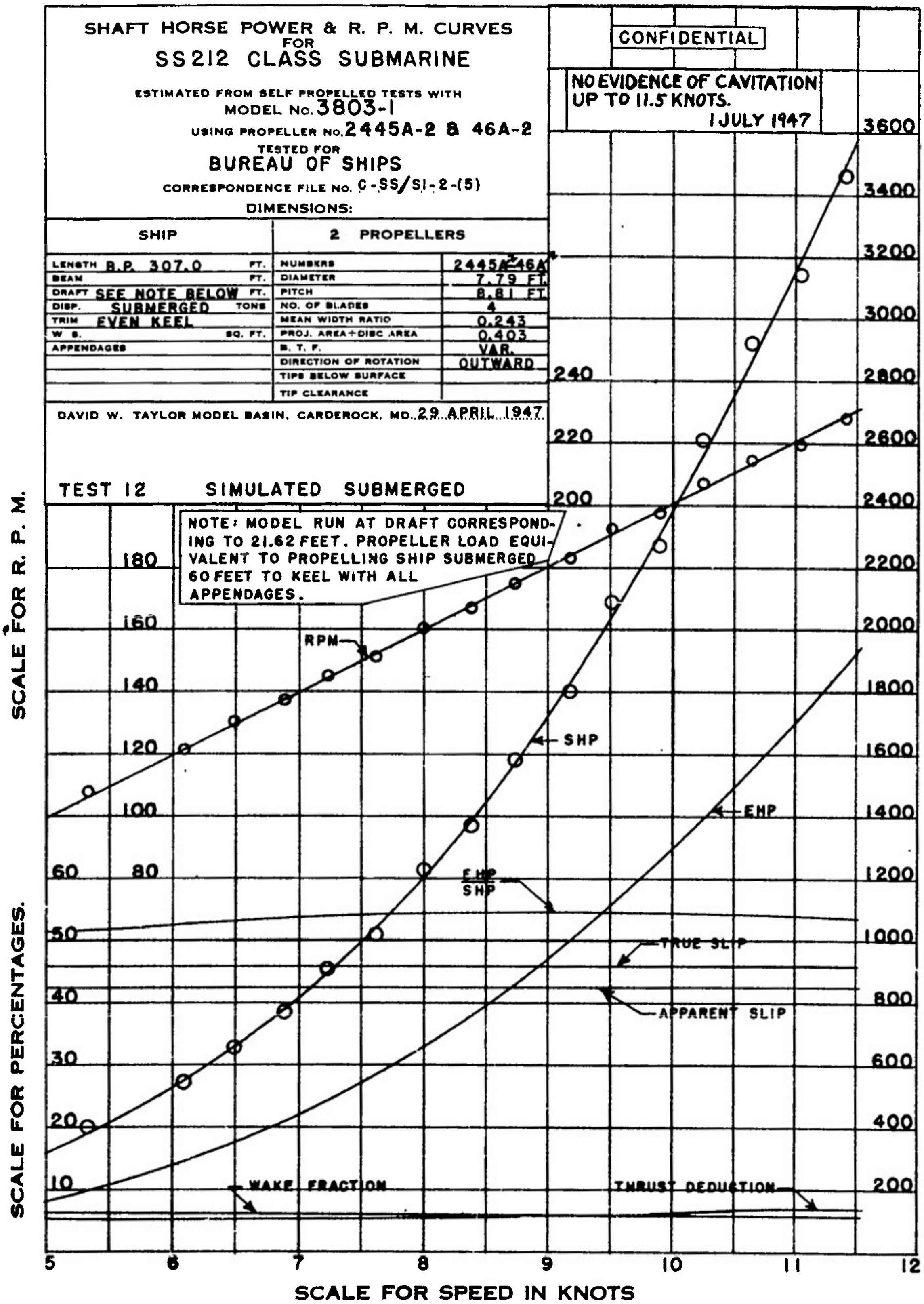

Figure 8 - Curves from a Self-Propulsion Test of Model 3803-1 Using Propellers 2445A-2 and 2446A-2

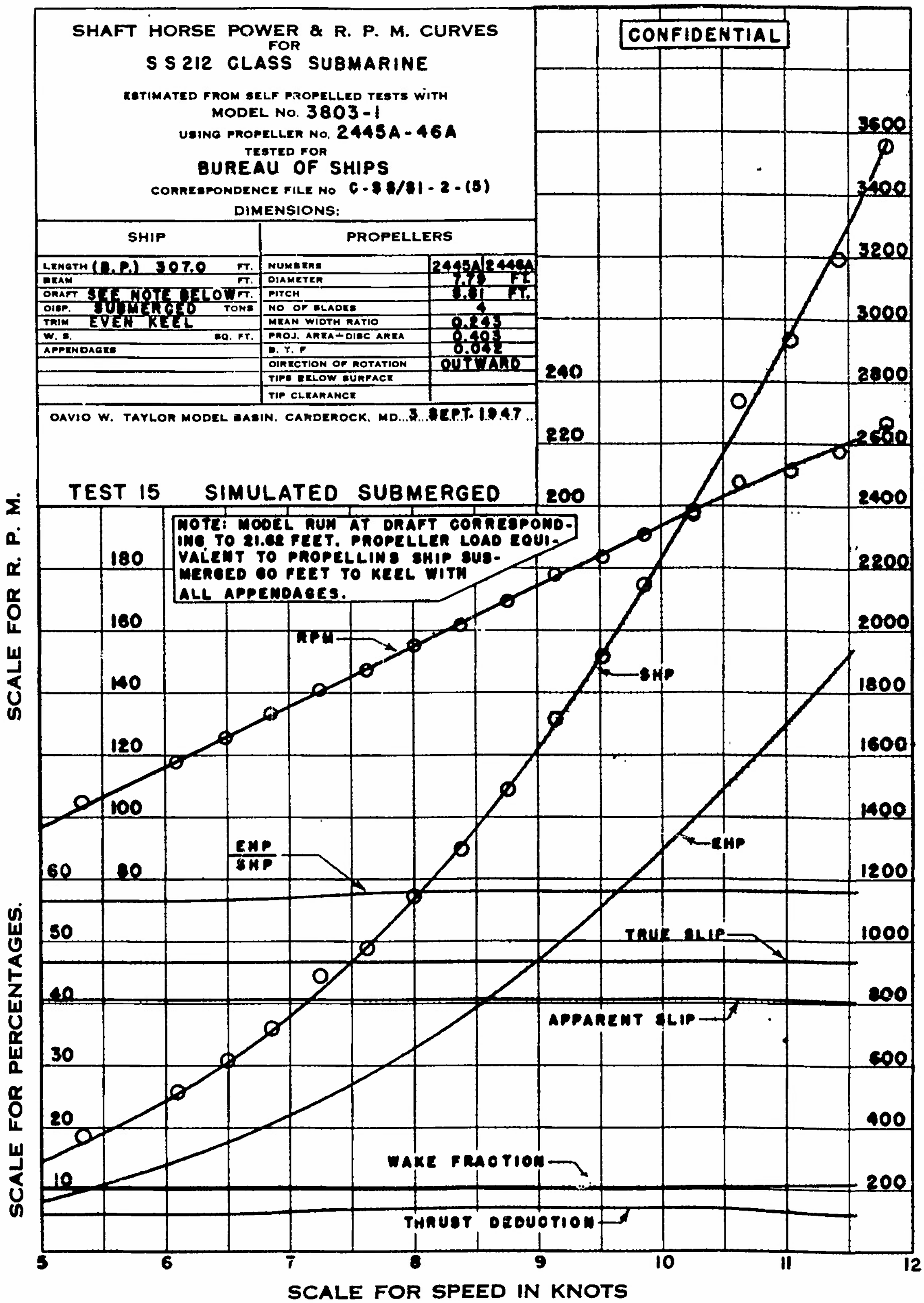

Figure 9 - Curves from a Self-Propulsion Tests of Model 3803-1 Using Propellers 2445A and 2446A