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Report 1832

TAYLOR MODEL BASIN

DEPARTMENT OF THE NAVY

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INDUCED VELOCITY FIELD OF A FULLY CAVITATING PROPELLER AND INTERACTION EXPERIMENTS WITH A FULLY CAVITATING PROPELLER BEHIND A HYDROFOIL

by

John L. Beveridge

HYDROMECHANICS LABORATORY

RESEARCH AND DEVELOPMENT REPORT

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NOTATION

C_T	Propeller thrust loading coefficient,	$\frac{T}{(1/2)\rho\frac{\pi D^2}{4} v_o^2}$
D	Propeller diameter	
J_a	Propeller speed coefficient,	$\frac{v_o}{nD}$
K_T	Propeller thrust coefficient,	$\frac{T}{\rho n^2 D^4}$
n	Propeller frequency of revolution	
R	Propeller tip radius	
T	Propeller thrust	
U	Propeller induced velocity in z direction as a fraction of v_o	
V	Propeller induced velocity in x direction as a fraction of v_o	
v_o	Ambient velocity	
x	Radial coordinate, r/R_o	
z	Axial coordinate Z/R_o measured from blade centerline (positive ahead of propeller)	
ρ	Mass density	
σ_o	Cavitation index based on v_o	

ABSTRACT

The induced velocity field of a 3-bladed fully cavitating propeller was calculated by considering the combined effects of propeller blade loading and blade cavity thickness. Numerical results for the case investigated showed that forward of such a propeller the total induced axial velocity is quite small, and opposes the ambient axial velocity. This result is consistent with the experimental results presented where the thrust deduction of a fully cavitating propeller behind a hydrofoil was found to be practically zero.

INTRODUCTION

Representatives of the Soviet Union presented a paper[1] at the Tenth International Towing Tank Conference on the subject of propeller cavitation effects on hull and propeller interaction. Experimental results given in the paper indicated a reduction of induced velocity in front of a fully cavitating or ventilated propeller and, in particular, it was indicated that the thrust deduction tends to zero as a limit for fully developed cavitation. Recently, Nelson[2] investigated theoretically by means of an idealized infinitely-bladed propeller: (1) the total induced velocity field of a propeller with blade-cavity thickness and (2) the conditions necessary for zero thrust deduction.

At the David Taylor Model Basin studies dealing with propulsion interaction effects of fully cavitating propellers have been in progress in connection with the Model Basin's hydrofoil program. This preliminary report presents: (1) the calculated induced velocity field of a fully cavitating propeller, and (2) experimental results on the thrust deduction due to a fully cavitating propeller operating behind a hydrofoil at various conditions of cavitation. By an analysis of these results it is shown that the thrust deduction due to a fully cavitating propeller may be essentially zero.

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[1] References are listed on page 5.

DISCUSSION AND RESULTS

Induced Velocities of Propeller

Kerwin[3] has presented a method for calculating the total induced velocity at a propeller blade based on linearized theory for propellers in steady flow. An unpublished numerical program which is based in part on this method and gives the field point velocity was furnished by Professor Kerwin for use on the IBM-7090 computer at the Model Basin. Output from the program includes the propeller induced velocity field due to a bound and trailing vortex system that represents propeller blade loading, and the propeller induced velocity field due to a distribution of sources and sinks that represents propeller blade thickness. For the purposes of this report, only the average component of the propeller induced velocity field is presented and discussed.

Using the subject program the average induced velocity field shown in Table 1 was obtained for TMB Propeller 3768, a 3-bladed fully cavitating design. These results are for the following design conditions:

$$J = 0.65$$

$$C_T = 0.844$$

$$\sigma_o = 0.60$$

The maximum blade thickness used in the calculations was determined from estimates made from photographs (at test conditions in the water tunnel) of the actual cavity thickness at about one chord length behind the propeller blade. The chordwise thickness distribution for design lift and angle of attack was based on the theoretical cavity thickness derived by Tulin and as given in Reference 4. Such a mathematical model of the propeller represents a propeller with geometric thickness equal to cavity thickness and blade section length of twice the chord. This implies that the induced velocities ahead of the propeller associated with the cavity thickness behind the propeller can be sufficiently represented by a portion of the cavity length equal to twice the chord. Furthermore, the cavities appeared unstable at greater distances downstream behind this fully cavitating propeller operating

TABLE 1

Average Induced Velocity Field Calculated for TMB Propeller 3768, Fully Cavitating ($J = 0.65$, $\sigma_o = 0.60$)

	Location of Field Points in Cylindrical Coordinates		Axial Velocity, U (positive downstream)			Radial Velocity, V (positive outward)		
	z	x	Due To Loading	Due To Thickness	Total	Due To Loading	Due To Thickness	Total
Upstream of Propeller	1.5	0.25	0.039	-0.068	-0.029	-0.005	0.009	0.004
		0.65	0.031	-0.059	-0.028	-0.011	0.021	0.010
		0.95	0.022	-0.050	-0.028	-0.012	0.026	0.014
	1.0	0.25	0.072	-0.119	-0.047	-0.008	0.021	0.013
		0.65	0.054	-0.098	-0.044	-0.024	0.043	0.019
		0.95	0.032	-0.075	-0.043	-0.025	0.052	0.027
	0.5	0.25	0.108	-0.217	-0.109	-0.013	0.061	0.048
		0.65	0.107	-0.184	-0.077	-0.044	0.097	0.053
		0.95	0.006	-0.120	-0.054	-0.053	0.119	0.066
Downstream of Propeller	-0.5	0.25	0.133	0.244	0.377	-0.0085	0.060	0.0515
		0.65	0.409	0.198	0.607	-0.031	0.114	0.083
		0.95	0.202	0.124	0.326	-0.048	0.132	0.084
	-1.0	0.25	0.168	0.129	0.297	-0.0045	0.022	0.0175
		0.65	0.440	0.104	0.544	-0.014	0.048	0.034
		0.95	0.222	0.079	0.301	-0.021	0.056	0.035
	-1.5	0.25	0.191	0.072	0.263	-0.0022	0.010	0.0078
		0.65	0.453	0.062	0.515	-0.007	0.022	0.015
		0.95	0.232	0.052	0.284	-0.010	0.028	0.018

in the water tunnel. The velocity field behind the propeller is included in Table 1 for academic interest.

Referring to Table 1, the negative velocity induced by the cavity thickness as compared to the positive axial induced velocity due to loading is clearly evident ahead of the propeller. In fact the total induced velocity is negative and opposes the ambient axial velocity. At an axial distance z of 1.5 propeller radii the total induced axial velocity is only of the order of -0.03 of the freestream velocity and will, of course, approach zero for points further ahead of the propeller disk. The radial induced velocity V is also included in Table 1. It should be noted that the average tangential induced velocity was essentially zero. The axial component of the propeller induced velocity predominates and the interaction (thrust deduction) force is principally determined by the value of this component.

A brief physical description of this phenomenon is as follows: Ahead of a propeller the principal influence on the flow field is the pressure distribution on the back or suction side of the blades. If the propeller has normal airfoil sections, then the pressure distribution is such that the fluid is sucked toward the propeller. On the back of a fully cavitating propeller blade, however, the cavity boundary forms a free-streamline across which no pressure difference can exist. In this case the pressure distribution on the back of a propeller blade may cause the flow to be retarded ahead of the propeller depending on the orientation of the free streamlines.

Thrust Deduction Experiments

Experiments to determine thrust deduction for a foil ahead of the propeller were conducted with Propeller 3768 in the 24-inch variable pressure water tunnel. Figure 1 gives the open-water characteristic curves for Propeller 3768 at a cavitation index $\sigma_o = 0.60$, and Figure 2 shows Propeller 3768 operating behind TMB Hydrofoil H-54 (Tulin 2-term section) at $\sigma_o = 0.60$ and a speed coefficient $J_a = 0.52$. The interaction or thrust deduction tests included measurements of propeller thrust, torque, revolutions, and hydrofoil drag with and without the propeller. The foil trailing edge was located at z = 0.72 ahead of the reference line of the propeller.

Figure 3 shows the variation of the thrust deduction coefficient t as a function of propeller speed coefficient and foil angle of attack α. It can be seen from the curves of Figure 3 that within the fully cavitating range, $J < 0.75$, the thrust deduction is small and approaches zero as the cavity becomes thicker and the flow angle decreases.

CONCLUSIONS

1. Calculations showed that the total induced velocity field ahead of a fully cavitating propeller is profoundly affected by blade-cavity thickness.

2. For the fully cavitating propeller considered, thickness effects caused the total induced velocity to be negative at field points ahead of the propeller. It should not be construed, however, that ahead of a fully cavitating propeller the induced velocities are always negative since if the cavity is thin enough the load effect may be greater than the thickness effect.

3. Negative total induced velocity ahead of a fully cavitating propeller infers that the thrust deduction must be equal to or less than zero. This result is substantiated by the experiments where the force measurements from tests of a fully cavitating propeller and hydrofoil system showed essentially zero thrust deduction in the fully cavitating condition.

REFERENCES

1. Bavin, V.F., and Miniovich, I.J., "Experimental Investigations of Interaction Between Hull and Cavitating Propeller," Tenth International Towing Tank Conference (1963).

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3. Kerwin, J.E., "Linearized Theory for Propellers in Steady Flow," MIT, Dept. of Naval Architecture and Marine Engineering (Jul 1963).

4. Tachmindji, A.J., Morgan, W.B., et al, "The Design and Performance of Supercavitating Propellers," David Taylor Model Basin Report C-807 (Feb 1957).

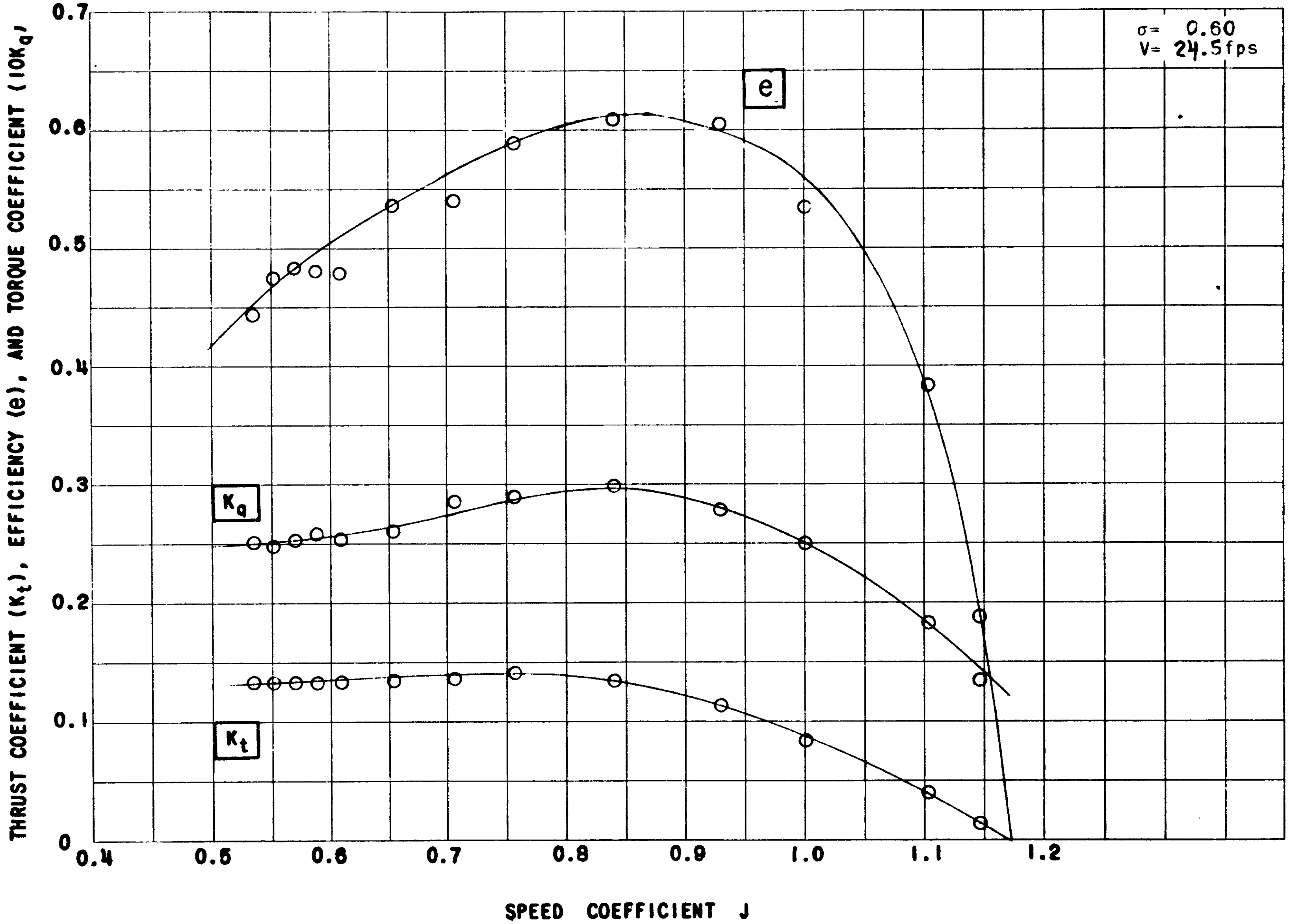
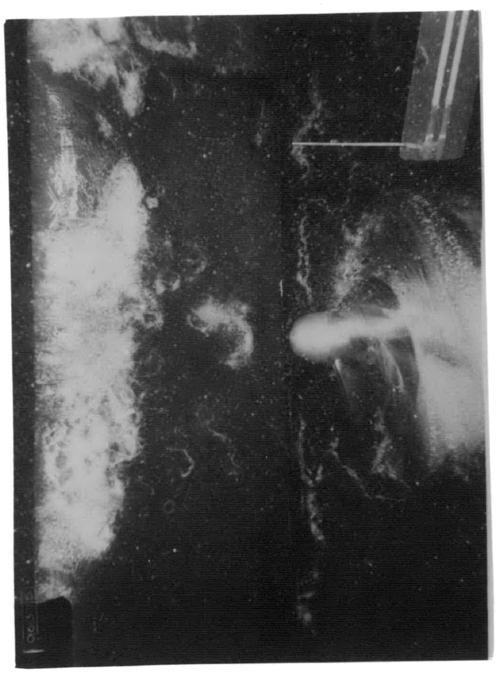


Figure 1 - Open-Water Characteristic Curves for Propeller 3768

Angle of Attack of Hydrofoil
is 8 Degrees

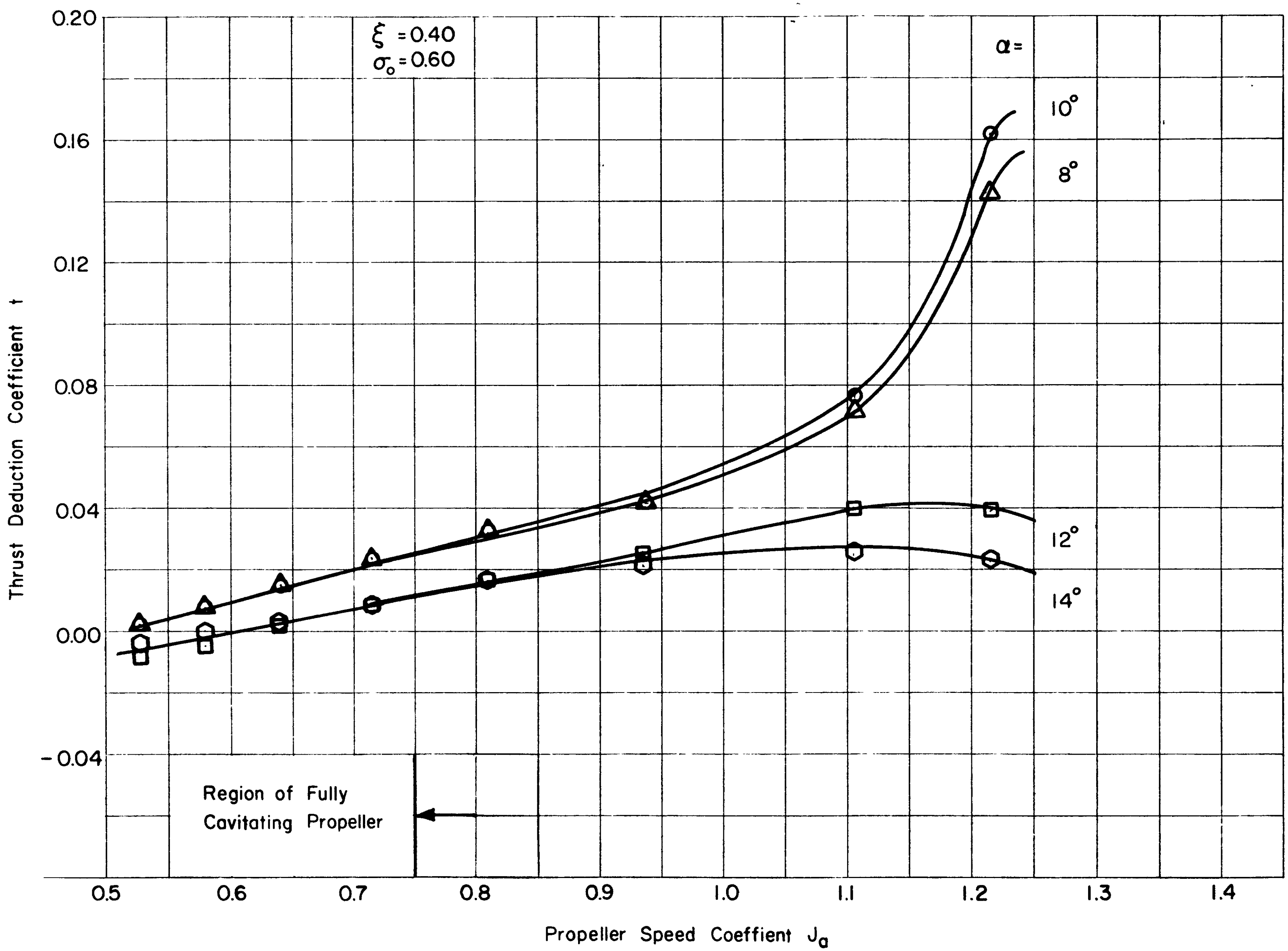
Angle of Attack of Hydrofoil
is 10 Degrees



Angle of Attack of Hydrofoil
is 12 Degrees

Angle of Attack of Hydrofoil
is 14 Degrees

Figure 2 - Hydrofoil and Fully Cavitating Propeller in 24-Inch Water Tunnel
(Cavitation Index σ_o = 0.60, Propeller Speed Coefficient J_a = 0.52)



0.20
0.16
0.12
0.08
0.04
0.00
- 0.04
ξ = 0.40
σ_o = 0.60
α =
10°
8°
12°
14°
Region of Fully Cavitating Propeller
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
Thrust Deduction Coefficient t
Propeller Speed Coeffient J_a

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