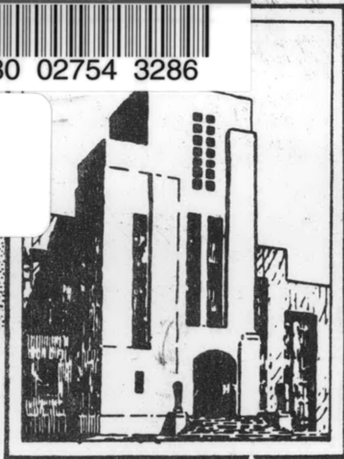

NAVY DEPARTMENT

DAVID TAYLOR MODEL BASIN

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HYDROMECHANICS

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OPEN-WATER TESTS OF A LOW PITCH THREE-BLADED PROPELLER SERIES IN A NOZZLE

by

B. V. Nakonechny

HYDROMECHANICS LABORATORY
RESEARCH AND DEVELOPMENT REPORT

July 1959 Report 1338

PRNC-TMB-648a (11-57)

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NOTATION

$b_{0.7}$	Blade section length of a propeller at 0.7 radius
D	Diameter of propeller
f	Camber of nozzle profile
g	Acceleration due to gravity
H	Static head at centerline of propeller minus vapor pressure
l	Length of nozzle profile chord
n	Revolutions per unit time
Q	Propeller torque
R_e	Reynolds number, $R_e = \frac{b_{0.7} \sqrt{v_a^2+(0.7\pi nD)^2}}{\nu}$
s	Maximum thickness of nozzle profile
T_N	Nozzle thrust
T_P	Propeller thrust
v_a	Speed of advance of the "nozzle plus propeller" system
x	Distance along nozzle chord
y_l	Ordinates of lower surface of the nozzle profile
y_u	Ordinates of upper surface of the nozzle profile
α_i	Angle of the nozzle profile relative to the shaft line
ν	Kinematic viscosity
ρ	Density of water
σ	Cavitation number, $\sigma = \frac{2gH}{v_a^2}$
J	Speed coefficient, $J = \frac{v_a}{nD}$

K_q Torque coefficient, $K_q = \frac{Q}{\rho n^2 D^5}$

K_{tS} Thrust coefficient of the "nozzle plus propeller" system

$$K_{tS} = \frac{T_P + T_N}{\rho n^2 D^4}$$

e Efficiency of the "nozzle plus propeller" system,

$$e = \frac{(T_P + T_N)\, v_a}{2\pi Q n} = \frac{K_{tS}}{K_q} \times \frac{J}{2\pi}$$

ABSTRACT

Open-water tests of a low pitch three-bladed propeller series in a nozzle were conducted at Reynolds numbers from 0.70 to 1.24×10^6 for a range of speeds from zero to the speed for zero thrust. The results of the tests are presented in the form of series diagrams for the "propeller plus nozzle" system.

INTRODUCTION

The "Kort nozzle" propulsion system, invented by Kort in the early 1930's,[1] was originally applied to heavily loaded propellers only and its design was based primarily on momentum theory and on experience. Subsequently, scientists were attracted by the problem and investigated the "propeller plus nozzle" combination theoretically by means of the circulation theory.[2,3,4,6,7] Their works as well as extensive open-water tests of systematic series with propellers in nozzles[5,8,9] form the basis of the present design methods which can be used for practical application of this propulsive device.

This report presents results of tests of a low pitch three-bladed propeller series operating in a nozzle. The tests were carried out at the David Taylor Model Basin and cover a range of low J values.

The nozzle used in these investigations had a built-up profile "NACA-5415" and was similar to Van Manen's[5] nozzle No. 7.

[1] References are listed on page 13.

The selected stock propellers for the open-water tests were 8 inches in diameter with pitch ratio variations ranging from 0.4 to 0.8. The Reynolds numbers of the tests based on speed of advance of "propeller plus nozzle" system extended from 0.70 to 1.24×10^6. In reality they were slightly higher because of higher inflow velocities at the propeller plane, caused by the presence of the nozzle.

PROCEDURE

The open-water test arrangement used for investigation of the "propeller plus nozzle" combination is shown in Figures 1 and 1a. As can be seen from the sketch and photographs, the nozzle was rigidly attached to a solid strut which in turn was mounted to a drag dynamometer. In order to eliminate the drag of this strut and to measure the axial forces of the nozzle only, a special streamlined hollow strut (outside shell) was placed around the solid strut and attached to the girder. In this manner the axial forces acting on the nozzle only were measured by the drag dynamometer.

For the tests TMB three-bladed stock propellers (numbers 828, 829, 830, 935 and 936) were used. These propellers have a diameter of 8 inches, mean width ratio (MWR) of 0.4 and blade thickness fraction (BTF) of 0.05. The pitch ratio of this series varied from 0.4 to 0.8 (Figure 2). The general characteristics of the nozzle, which was constructed from Fiberglas, are shown in Figure 3 and Table 1.

In order to examine the scale effect on the nozzle, a one-half inch wide sand strip was glued on each side of the nozzle in the vicinity of the leading edge. One of the strips can be seen on the lower photograph of Figure 1a. All tests were conducted in open water with and without these sand strips. The model propeller was located 1.951 inches from the leading edge of the nozzle (Figures 1 and 3). The centerline of the shaft was submerged 13 inches below the water surface and the clearance between blade tips and nozzle was kept at 0.04 inch. "No loads" were run before and after the test of each propeller so that the thrust and the torque of the propeller could be corrected for the effect of the hub and shaft friction. Thrust, torque, and rps of each propeller in the nozzle, as well as speed of advance of the "propeller plus nozzle" combination and axial forces on the nozzle, were recorded during the tests. Speed of advance and rps were kept in the ranges indicated in Table 2. The Reynolds and cavitation numbers at which all the tests were run are given in Table 3.

TEST RESULTS

The values of torque and rps of each propeller and thrust of the nozzle, as well as speed of advance and the total thrust of the "propeller plus nozzle" combination, are presented in the form of nondimensional coefficients of the conventional K-J system. Figures 4a and 4b present the results of this series cross-faired on the basis of even pitch ratios. It should be noted that Propeller 829 has an average measured pitch value of 4.930 inches which was taken into consideration when fairing. In addition, a design chart of the tested series is given in Figure 5. The chart was constructed for the "propeller plus nozzle" combination and encompasses the range of low J values. The principle of establishing this design chart is similar to one presented in Reference 10.

The data presented in this report are only for the nozzle with the sandstrips. The comparison of the test results with and without the sandstrips indicated only negligible differences which are within the limits of accuracy of the experiments.

TABLE 1

Stations and Ordinates of the Nozzle Profile

x (percent chord)	y_u (inches)	y_l (inches)
0	0	0
1.25	0.132	0.070
2.5	0.180	0.097
5.0	0.244	0.122
7.5	0.296	0.134
10.0	0.338	0.140
15.0	0.408	0.142
20.0	0.450	0.136
25.0	0.476	0.129
30.0	0.492	0.119
40.0	0.495	0.101
50.0	0.460	0.086
60.0	0.395	0.070
70.0	0.314	0.054
80.0	0.225	0.038
90.0	0.123	0.022
95.0	0.069	0.013
100.0	0.007	0.007
Leading edge radius: 0.099 inch Trailing edge radius: 0.006 inch		

TABLE 2

Test Ranges of n and v_a

Propeller No.	Test n in rps	Test v_a in fps
828	16.5 to 27.4	0.9 to 8.6
829	15.7 to 29.6	0.9 to 6.7
830	15.1 to 29.7	0.9 to 4.4
935	15.6 to 29.6	0.9 to 5.6
936	16.5 to 29.2	0.9 to 7.7

TABLE 3

Reynolds and Cavitation Numbers

Prop No.	828		829		830		935		936	
J	$R_e \times 10^6$	σ	$R_e \times 10^6$	σ	$R_e \times 10^6$	σ	$R_e \times 10^6$	σ	$R_e \times 10^6$	σ
0	1.092	-	0.747	-	0.855	-	0.750	-	1.052	-
0.05	1.102	-	0.918	-	0.870	-	0.756	-	1.170	-
0.10	1.115	670	1.216	600	0.940	900	0.834	1250	1.200	615
0.15	1.127	310	1.225	250	1.218	250	1.110	320	1.212	265
0.20	1.142	160	1.236	145	1.220	165	1.238	145	1.223	145
0.25	0.970	145	0.980	145	0.976	145	0.975	145	0.976	145
0.30	0.820	145	0.808	145	0.850	145	0.815	145	0.805	145
0.35	0.702	140	0.707	135	0.742	145	0.705	145	0.705	145
0.40	0.705	110	0.715	110			0.715	115	0.705	115
0.45	0.710	90	0.715	85					0.707	90
0.50	0.714	75	0.716	70					0.712	70
0.55	0.716	60							0.715	55
0.60	0.720	55								
0.65	0.725	40								

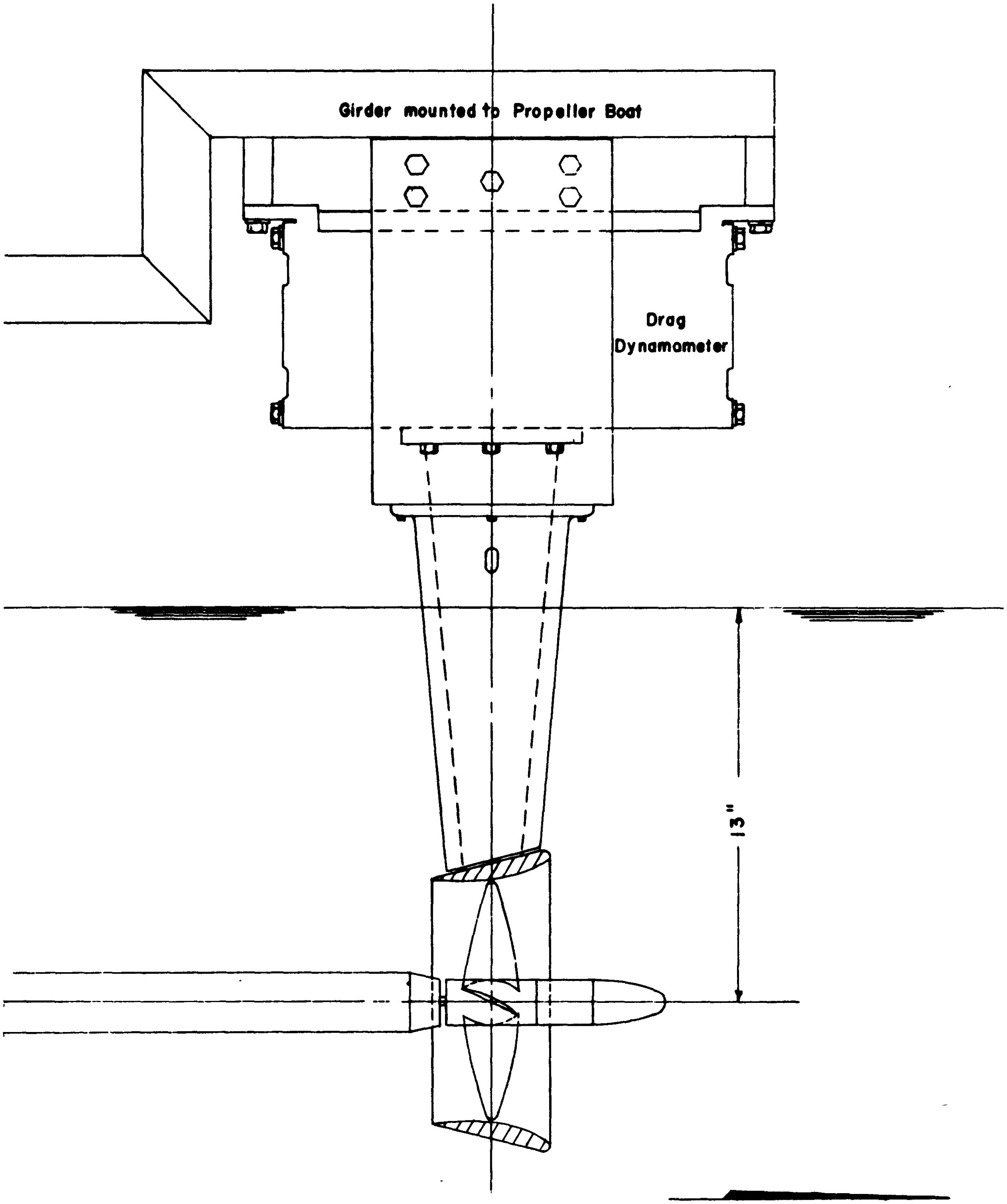

Figure 1—Sketch of "Propeller plus Nozzle" Open-Water Test Arrangement.

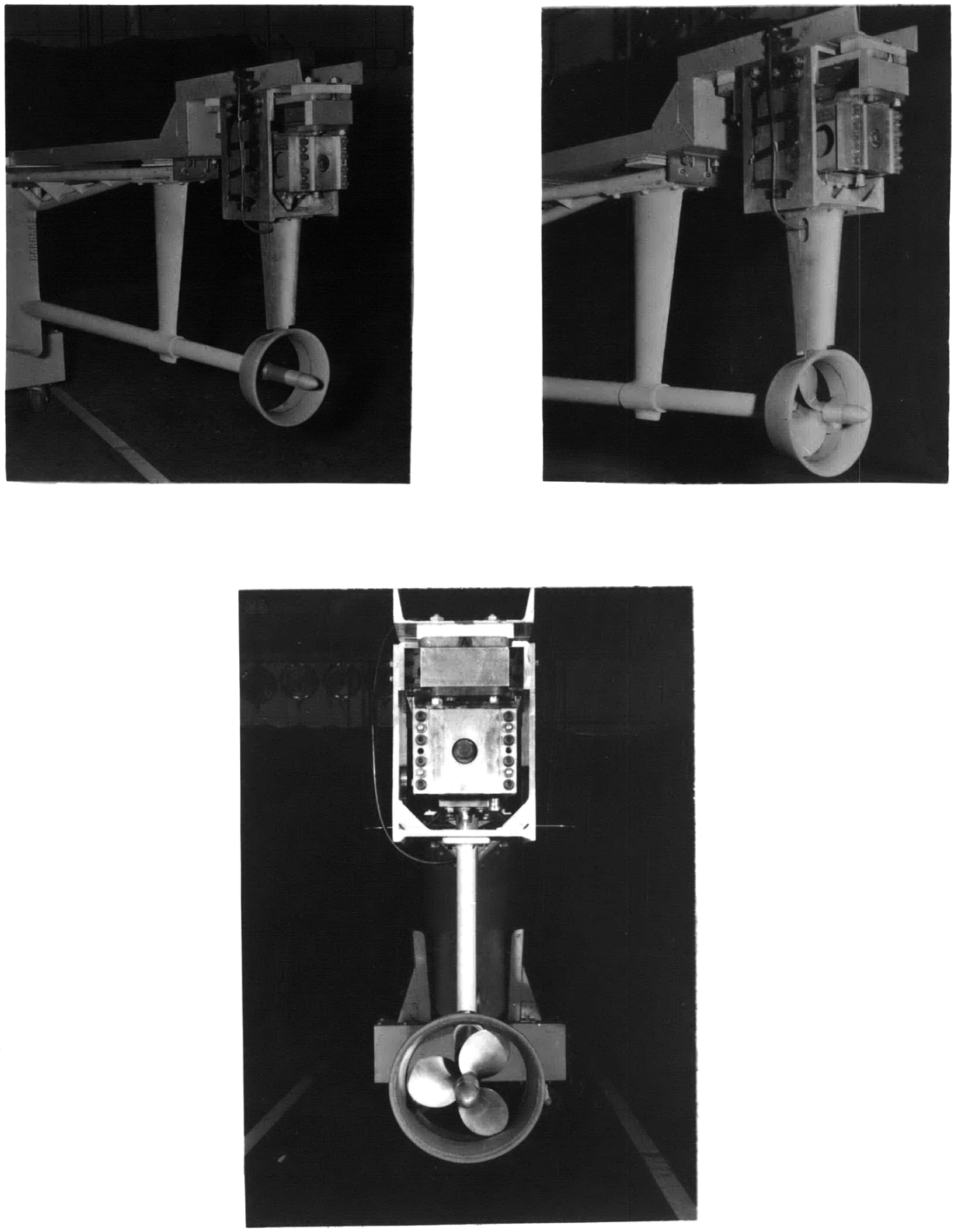

Figure 1a — Fitting Room Photographs

PROPELLER NO.	828	829	830	935	936
NUMBER OF BLADES	3	3	3	3	3
EXP.AREA RATIO	0.618	0.618	0.618	0.618	0.618
MWR	0.400	0.400	0.400	0.400	0.400
BTF	0.050	0.050	0.050	0.050	0.050
P/D	0.800	0.616*	0.400	0.500	0.700
DIAMETER (inches)	8.000	8.000	8.000	8.000	8.000
PITCH (inches)	6.400	4.930*	3.200	4.000	5.600
ROTATION	RH	RH	RH	RH	RH

* AVERAGE MEASURED VALUE

TESTED FOR.......BUSHIPS
DESIGNED BY......BUC&R

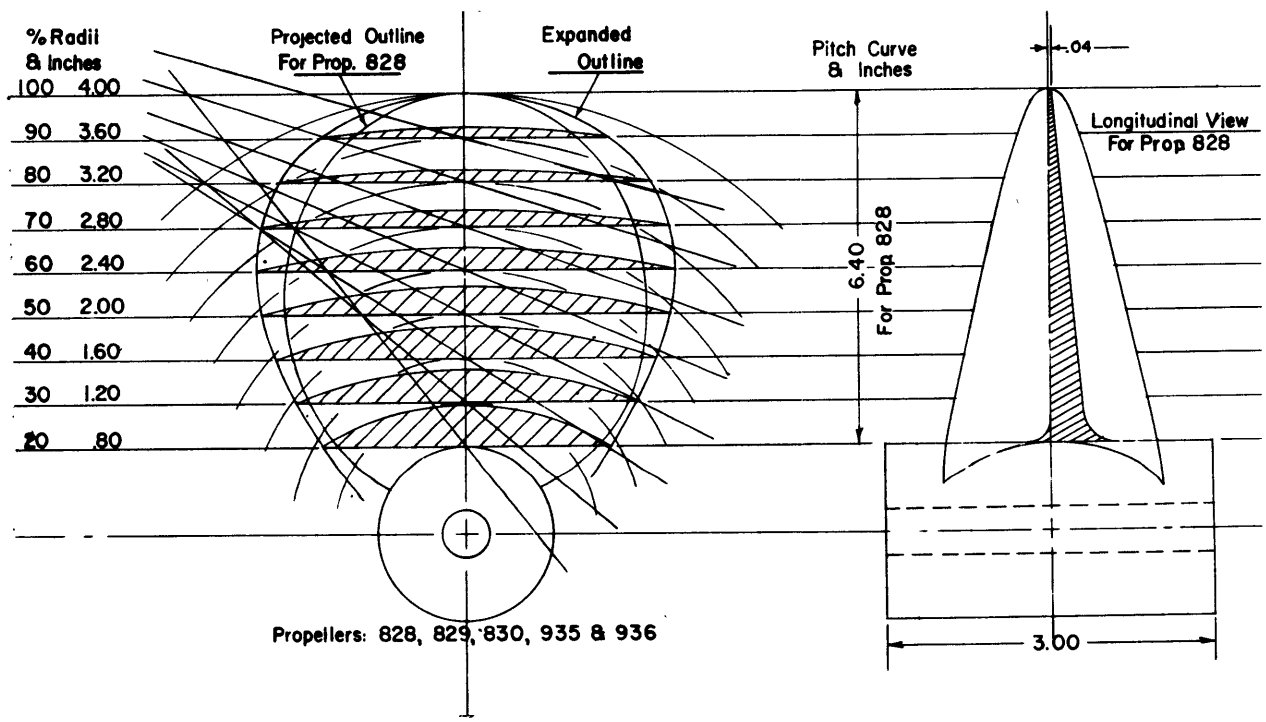

Figure 2—Propeller Drawing.

NOZZLE PROFILE ....BUILT-UP "NACA 5415"
CHORD LENGTH..............................4.0 ins.
MAXIMUM THICKNESS.........................0.6 ins.
MAXIMUM CAMBER............................0.2 ins.
ANGLE OF THE NOZZLE PROFILE
RELATIVE TO THE SHAFT LINE.........12.7 deg.

TESTED FOR........BUSHIPS

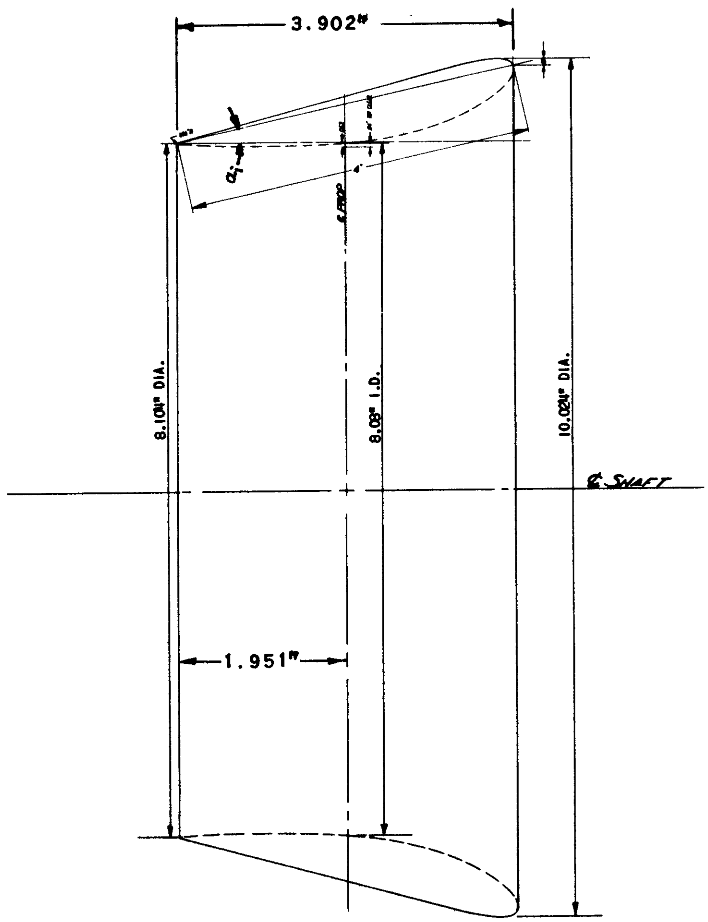

Figure 3—Nozzle.

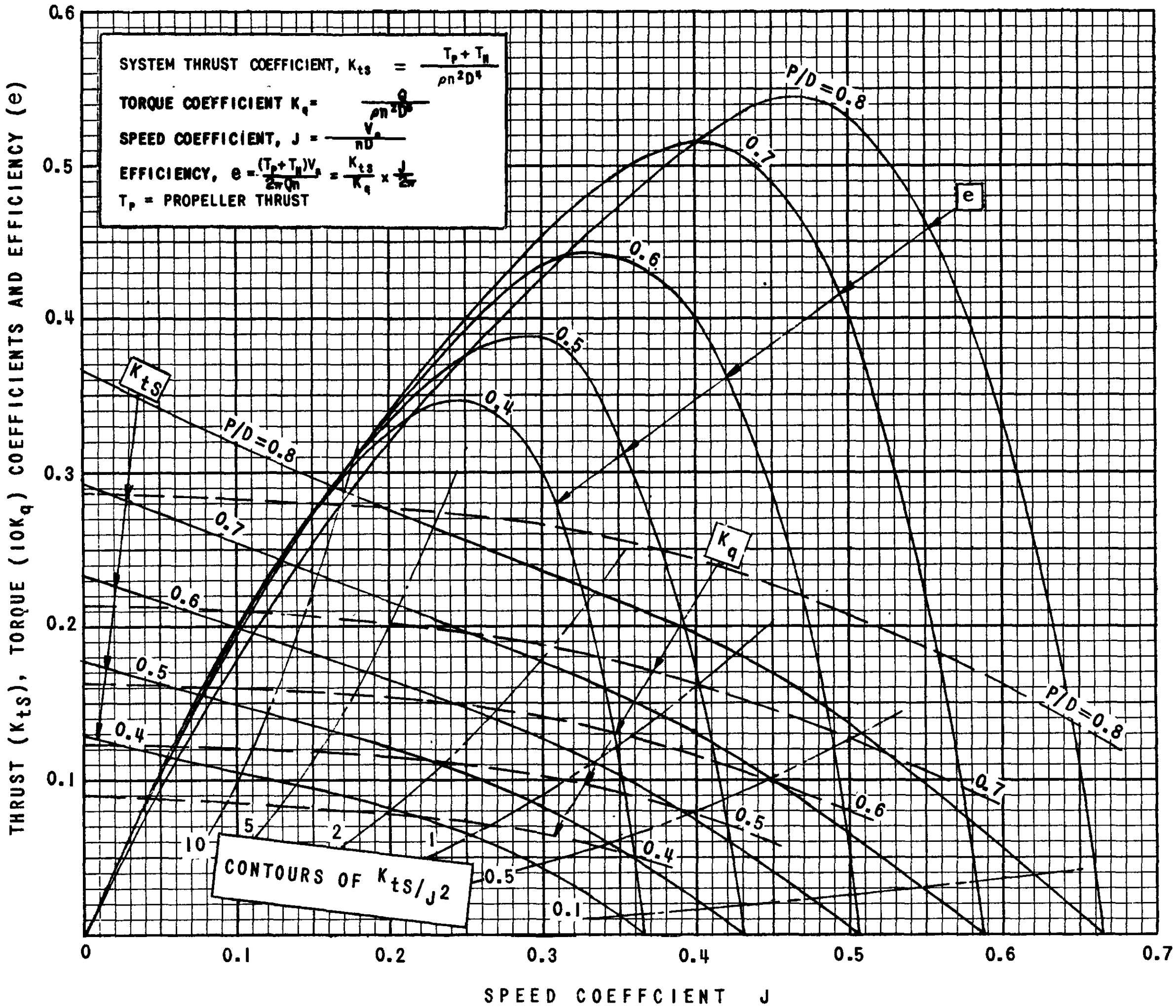

Figure 4a—Open-Water Test Results of Low Pitch Propeller Series in Nozzle.

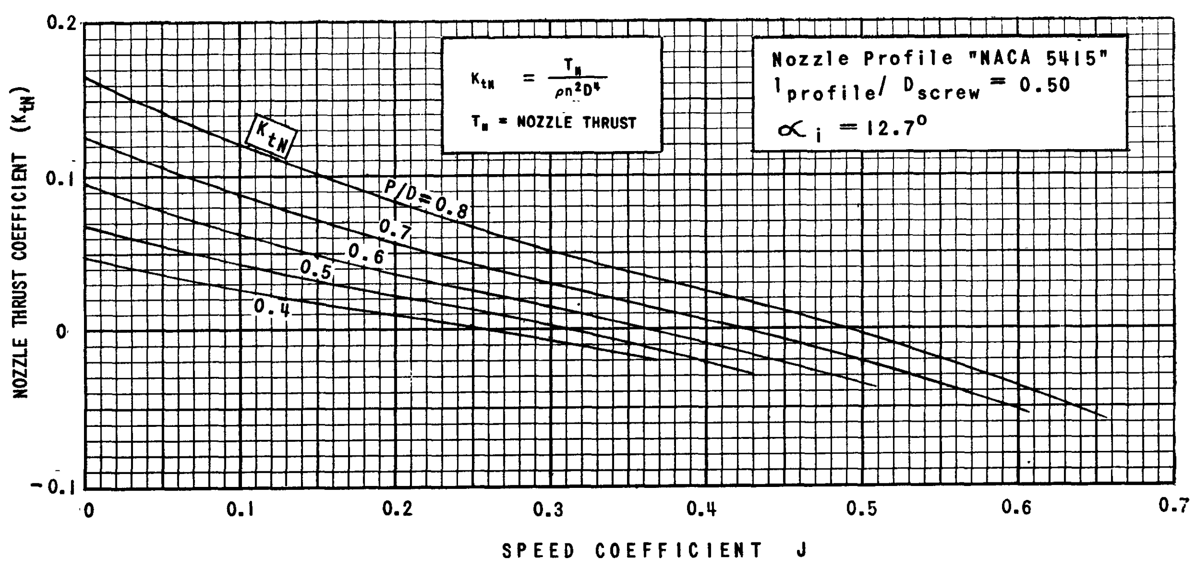

Figure 4b—Axial Forces Acting on Nozzle.

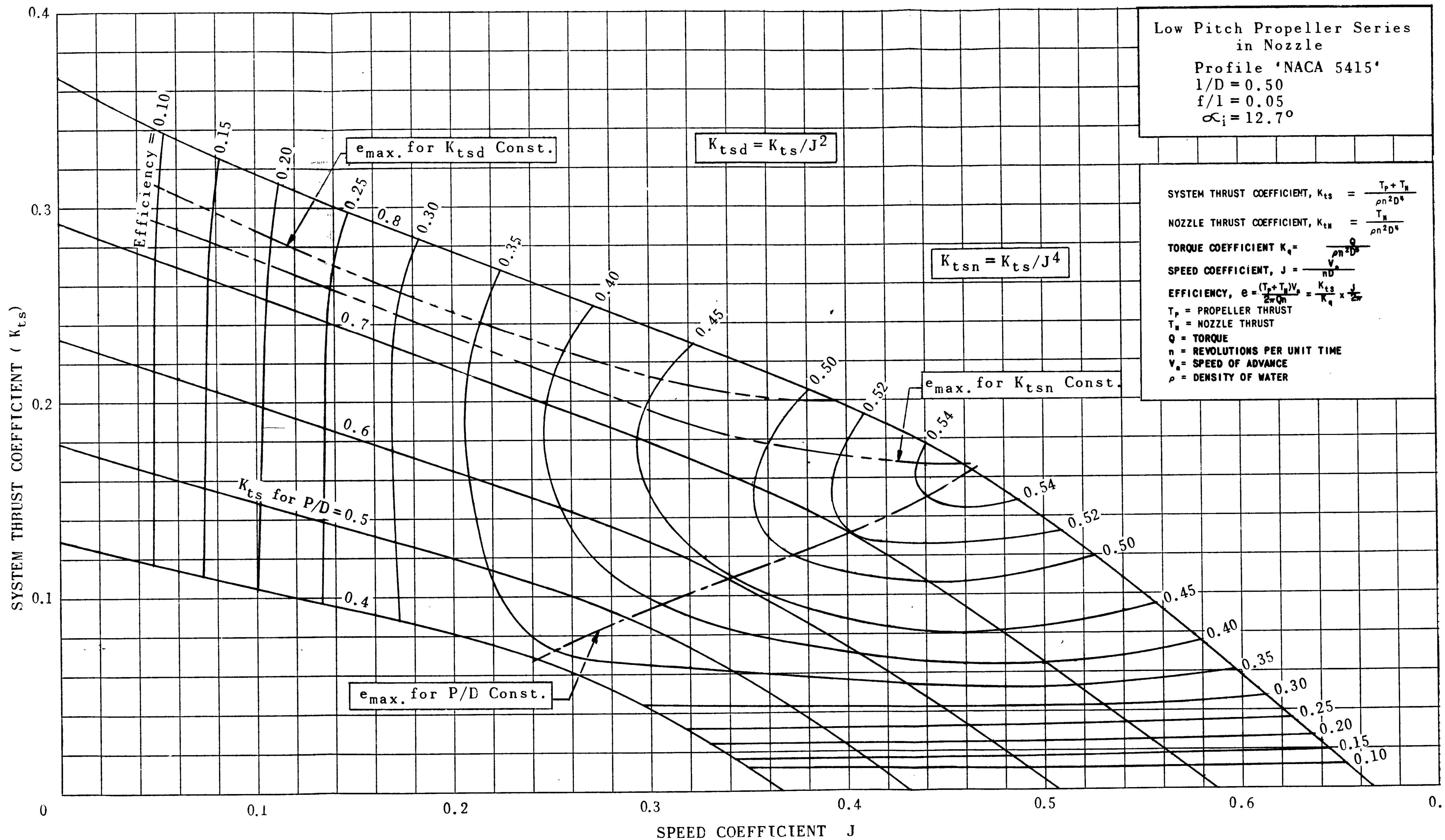

Figure 5 — Design Chart for Low Pitch Three-Bladed Propeller Series in Nozzle.

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