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

by

B. V. Nakonechny

July 1959

Report 1338
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NOTATION

b₀.₇  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
Re   Reynolds number, \( Re = \frac{b₀.₇ \sqrt{v_a² + (0.7\pi nD)²}}{\nu} \)
s    Maximum thickness of nozzle profile
TN   Nozzle thrust
TP   Propeller thrust
va   Speed of advance of the "nozzle plus propeller" system
x    Distance along nozzle chord
y₁   Ordinates of lower surface of the nozzle profile
yᵤ   Ordinates of upper surface of the nozzle profile
x;   Angle of the nozzle profile relative to the shaft line
ν    Kinematic viscosity
ρ    Density of water
σ    Cavitation number, \( \sigma = \frac{2gH}{v_a²} \)
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,

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

Open-water tests of a low pitch three-bladed propeller series in a nozzle were conducted at Reynolds numbers from 0.70 to $1.24 \times 10^6$ 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, 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. Their works as well as extensive open-water tests of systematic series with propellers in nozzles 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 nozzle No. 7.

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 \(1.24 \times 10^6\). 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

<table>
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<th>x (percent chord)</th>
<th>( y_u ) (inches)</th>
<th>( y_l ) (inches)</th>
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<tr>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>1.25</td>
<td>0.132</td>
<td>0.070</td>
</tr>
<tr>
<td>2.5</td>
<td>0.180</td>
<td>0.097</td>
</tr>
<tr>
<td>5.0</td>
<td>0.244</td>
<td>0.122</td>
</tr>
<tr>
<td>7.5</td>
<td>0.296</td>
<td>0.134</td>
</tr>
<tr>
<td>10.0</td>
<td>0.338</td>
<td>0.140</td>
</tr>
<tr>
<td>15.0</td>
<td>0.408</td>
<td>0.142</td>
</tr>
<tr>
<td>20.0</td>
<td>0.450</td>
<td>0.136</td>
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<td>25.0</td>
<td>0.476</td>
<td>0.129</td>
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<td>30.0</td>
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<td>40.0</td>
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<td>50.0</td>
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<td>60.0</td>
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<td>70.0</td>
<td>0.314</td>
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<td>80.0</td>
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<td>90.0</td>
<td>0.123</td>
<td>0.022</td>
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<td>95.0</td>
<td>0.069</td>
<td>0.013</td>
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<tr>
<td>100.0</td>
<td>0.007</td>
<td>0.007</td>
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Leading edge radius: 0.099 inch  
Trailing edge radius: 0.006 inch

### TABLE 2
Test Ranges of \( n \) and \( v_a \)

<table>
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<tr>
<th>Propeller No.</th>
<th>Test ( n ) in rps</th>
<th>Test ( v_a ) in fps</th>
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<tr>
<td>828</td>
<td>16.5 to 27.4</td>
<td>0.9 to 8.6</td>
</tr>
<tr>
<td>829</td>
<td>15.7 to 29.6</td>
<td>0.9 to 6.7</td>
</tr>
<tr>
<td>830</td>
<td>15.1 to 29.7</td>
<td>0.9 to 4.4</td>
</tr>
<tr>
<td>935</td>
<td>15.6 to 29.6</td>
<td>0.9 to 5.6</td>
</tr>
<tr>
<td>936</td>
<td>16.5 to 29.2</td>
<td>0.9 to 7.7</td>
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### Table 3

Reynolds and Cavitation Numbers

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<th>Prop No.</th>
<th>$\sigma$</th>
<th>$Re \times 10^6$</th>
<th>$\sigma$</th>
<th>$Re \times 10^6$</th>
<th>$\sigma$</th>
<th>$Re \times 10^6$</th>
<th>$\sigma$</th>
<th>$Re \times 10^6$</th>
<th>$\sigma$</th>
<th>$Re \times 10^6$</th>
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<td>0.747</td>
<td>-</td>
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<td>-</td>
<td>0.750</td>
<td>-</td>
<td>1.052</td>
<td>-</td>
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<tr>
<td>0.05</td>
<td>1.102</td>
<td>-</td>
<td>0.918</td>
<td>-</td>
<td>0.870</td>
<td>-</td>
<td>0.756</td>
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<td>1.170</td>
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<td>0.10</td>
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<td>1.216</td>
<td>600</td>
<td>0.940</td>
<td>900</td>
<td>0.834</td>
<td>1250</td>
<td>1.200</td>
<td>615</td>
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<td>310</td>
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<td>0.40</td>
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<tr>
<td>0.45</td>
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<td>85</td>
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<td>0.720</td>
<td>55</td>
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Figure 1—Sketch of "Propeller plus Nozzle"
Open-Water Test Arrangement.
Figure 1a—Fitting Room Photographs
<table>
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<tr>
<th>Propeller No.</th>
<th>828</th>
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<th>830</th>
<th>935</th>
<th>936</th>
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</thead>
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<tr>
<td>Number of Blades</td>
<td>3</td>
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<tr>
<td>Exp. Area Ratio</td>
<td>0.618</td>
<td>0.618</td>
<td>0.618</td>
<td>0.618</td>
<td>0.618</td>
</tr>
<tr>
<td>MWR</td>
<td>0.400</td>
<td>0.400</td>
<td>0.400</td>
<td>0.400</td>
<td>0.400</td>
</tr>
<tr>
<td>BTF</td>
<td>0.050</td>
<td>0.050</td>
<td>0.050</td>
<td>0.050</td>
<td>0.050</td>
</tr>
<tr>
<td>P/D</td>
<td>0.800</td>
<td>0.616*</td>
<td>0.400</td>
<td>0.500</td>
<td>0.700</td>
</tr>
<tr>
<td>Diameter (inches)</td>
<td>8.000</td>
<td>8.000</td>
<td>8.000</td>
<td>8.000</td>
<td>8.000</td>
</tr>
<tr>
<td>Pitch (inches)</td>
<td>6.400</td>
<td>4.930*</td>
<td>3.200</td>
<td>4.000</td>
<td>5.600</td>
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<tr>
<td>Rotation</td>
<td>RH</td>
<td>RH</td>
<td>RH</td>
<td>RH</td>
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Tested for........ BUSHIPS
Designed by........ BUC&R

*Average Measured Value

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.
SYSTEM THRUST COEFFICIENT, $K_{ts}$ = $\frac{T_s}{\rho n D^2}$
TORQUE COEFFICIENT $K_p$ = $\frac{P}{\rho n D^3}$
SPEED COEFFICIENT, $J$ = $\frac{R}{V_0}$
EFFICIENCY, $\eta$ = $\frac{W_s + \frac{1}{2} \rho V_0^2}{W}$
$T_s$ = PROPELLER THRUST

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.
REFERENCES


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Prof. H. A. Schade, Director
Institute of Engineering Research
Univ. of Calif.

1

Davidson Laboratory, SIT
Attn: Dr. J. Breslin

1

Dir, Nederlandsch Scheepsbouwkundig Proefstation
Wageningen, Holland

1

Dir, Hamburg Model Basin, Hamburg 33, Germany
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</tr>
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1 Dravo Corporation, Pittsburgh 25, Pennsylvania

1 SNAME, 74 Trinity Place, New York 6, N.Y.