NAVY DEPARTMENT
THE DAVID W. TAYLOR MODEL BASIN
WASHINGTON 7, D.C.

OPEN WATER TEST SERIES OF A
CONTROLLABLE PITCH PROPELLER WITH
VARYING NUMBER OF BLADES

By
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Report No. 932
INTRODUCTION

A series of open water propeller tests was conducted with an adjustable pitch propeller with 2, 3, 4, 5 and 6 blades. The faired coefficient curves of thrust, torque, and efficiency are presented with the propeller design. An example is given in the appendix to illustrate the use of the curves in selecting the optimum propeller for a given set of conditions.

PROCEDURE AND PRESENTATION OF RESULTS

The propeller used for these tests was a model of the 4-bladed controllable pitch propeller designed for the USS GRENADE (SS525) (Figure 1 and Table 1). To obtain tests on a varying number of blades, three hubs and six identical blades were manufactured. One hub was designed for two and four blades, another for three and six blades and the third for five blades. Pitch was varied by turning the blades about their radial axes and was set by means of a template. Table 2 gives the propeller pitch ratios at 0.7 radius, for the different test conditions.

All the tests were conducted at the David Taylor Model Basin in open water on the 35 HP dynamometer, with the centerline of the shaft submerged 4 feet. Drag and torque of the dummy hub were measured so that the thrust and torque of the propeller could be corrected for the effect of the hub. The tests were run at constant RPM, for each pitch setting, and at various speeds of advance so that the Reynolds number would have a minimum of variation throughout each test. The RPM and speed were determined to give the highest Reynolds number within the limits of the dynamometer.

The values of thrust, torque, RPM and speed are put in the form of non-dimensional coefficients. The coefficients chosen are of the conventional K-J system:

\[
\begin{align*}
\text{Thrust coefficient } K_t &= \frac{T}{\rho n^2 D^4} \\
\text{Torque coefficient } K_q &= \frac{Q}{\rho n^2 D^5} \\
\text{Speed coefficient } J &= \frac{V_o}{nD} \\
\text{Propeller efficiency } e &= \frac{TV_o}{2\pi Qn} = \frac{K_t J}{2\pi K_q}
\end{align*}
\]

where:
- \( T \) = Propeller thrust
- \( Q \) = Propeller torque
\( V_o \) = Speed of advance
\( D \) = Diameter of propeller
\( n \) = Revolutions per unit time
\( \rho \) = density of water

Test results for positive pitch settings are presented in Figures 2, 3, 4, 5 and 6. These results are plotted so that all the pitch ratios for a given number of blades are on the same Figure. Negative pitch tests were run using the four bladed propeller and are shown in Figure 7.

It should be noted that since all the blades are identical, the expanded area of each propeller is dependent on the number of blades. Thus, when considering the problem of an optimum propeller, factors such as stress and cavitation, which are dependent on the area, must be considered as well as the efficiency (see the Appendix).
## TABLE 1

**MAIN DIMENSIONS OF BLADE**

<table>
<thead>
<tr>
<th>r/R</th>
<th>Chord Per cent of Dia.</th>
<th>Thickness Per cent of Dia.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>0.2150</td>
<td>0.02623</td>
</tr>
<tr>
<td>0.4</td>
<td>0.2613</td>
<td>0.02201</td>
</tr>
<tr>
<td>0.5</td>
<td>0.2932</td>
<td>0.01807</td>
</tr>
<tr>
<td>0.6</td>
<td>0.3091</td>
<td>0.01484</td>
</tr>
<tr>
<td>0.7</td>
<td>0.3115</td>
<td>0.01126</td>
</tr>
<tr>
<td>0.8</td>
<td>0.2942</td>
<td>0.00836</td>
</tr>
<tr>
<td>0.9</td>
<td>0.2456</td>
<td>0.00568</td>
</tr>
<tr>
<td>0.95</td>
<td>0.2037</td>
<td>0.00439</td>
</tr>
</tbody>
</table>

## TABLE 2

**TESTS CONDUCTED**

<table>
<thead>
<tr>
<th>Number of Blades</th>
<th>P/D (Pitch Ratio)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.452 0.742 0.807 0.871 1.065</td>
</tr>
<tr>
<td>2</td>
<td>x</td>
</tr>
<tr>
<td>3</td>
<td>x</td>
</tr>
<tr>
<td>4</td>
<td>x</td>
</tr>
<tr>
<td>5</td>
<td>x</td>
</tr>
<tr>
<td>6</td>
<td>x</td>
</tr>
</tbody>
</table>

The four bladed propeller was also tested with negative pitch ratios of 0, 0.3, 0.6, 0.9 and 1.1.
APPENDIX

In order to show how the curves presented in this report may be used, an example is given:

Assume the following design conditions:

\[ V_s = 17 \text{ knots} \]
\[ \text{ehp} = 1950 \]
\[ \text{rpm} = 360 \]
\[ \text{Thrust deduction} = t = 0.08 \]
\[ \text{Wake fraction} = w_t = 0.17 \]

Determine the diameter, pitch and number of blades to obtain the maximum efficiency.

First the thrust that must be developed by the propeller is determined and then the speed of advance.

\[ T = 316.8 \frac{\text{ehp}}{V_s (1 - t)} = 39,500 \text{ lbs.} \]
\[ V_o = \text{speed of advance} = V_s (1 - w_t)(1.689) = 23.83 \text{ fps.} \]

To find the optimum diameter the following coefficient is used:

\[ K_{tn} = K_t / J^4 = T / \rho V_o^2 = 2.305 \]

This coefficient ascertains the parabola \( K_t = 2.305 J^4 \) in the \( K_t - J \) plot, Figure 4. Each point of this parabola determines a propeller of 4 blades which satisfies the given conditions, the differences between these propellers are in efficiency, diameter, and pitch. To find the one of greatest efficiency, lines of constant efficiency are drawn on the \( K_t - J \) plot and also several parabolas, \( K_t = (\text{constant}) J^4 \). The points at which the parabolas are tangent to the lines of constant efficiency determine the curve "emax". On this curve, the maximum efficiency for any value of \( K_{tn} \) is obtained.

For the example, the parabola \( K_t = 2.305 J^4 \) crosses the curve "emax" at \( J = 0.498 \). At this point, the pitch ratio amounts to 0.765 and the efficiency to 0.605. From these values, the following optimum dimensions are obtained:
\[ D = \frac{V_0}{Jn} = 7.976 \text{ ft.} \]
\[ P = (P/D)D = 6.10 \text{ ft.} \]

The same process is carried out for each number of blades and the following table is obtained:

<table>
<thead>
<tr>
<th>Number of Blades</th>
<th>D (ft.)</th>
<th>P (ft.)</th>
<th>eff.</th>
<th>P/D</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>8.65</td>
<td>6.055</td>
<td>0.65</td>
<td>0.700</td>
</tr>
<tr>
<td>3</td>
<td>8.207</td>
<td>6.18</td>
<td>0.62</td>
<td>0.753</td>
</tr>
<tr>
<td>4</td>
<td>7.976</td>
<td>6.10</td>
<td>0.605</td>
<td>0.765</td>
</tr>
<tr>
<td>5</td>
<td>7.773</td>
<td>6.20</td>
<td>0.59</td>
<td>0.798</td>
</tr>
<tr>
<td>6</td>
<td>7.222</td>
<td>6.61</td>
<td>0.55</td>
<td>0.915</td>
</tr>
</tbody>
</table>

The two bladed propeller has the highest efficiency, but it also has the largest diameter, the greatest stress, and the smallest blade area. These facts must be taken into consideration before a final design can be selected.
2 BLADES

P/D (at 0.7R) 0.452 0.807 1.065
J 0.35 0.70 0.95
Re x 10^-6 2.46 2.00 1.90

CHARACTERISTIC CURVES
OF
PROPELLER 3227
TESTED FOR BUSHIPS
DESIGNED BY NORFOLK NAVAL SHIPYARD
BUSHIPS DRAWING SS525 - 54400-962058

NUMBER OF BLADES 2
EXP AREA RATIO 0.250
MWR 0.273
BTF VAR
P+D (at 0.7R) 0.8065 DESIGN
DIAMETER 14.553 IN
PITCH (at 0.7R) 11.742 IN DESIGN
ROTATION R.H.
TEST RPM 1200-1800
TEST V0 29 TO 15.6 KNOTS

REYNOLD'S NO. Re = \frac{V0 \times D \times \rho}{\mu}

THRUST COEFFICIENT, Kt = \frac{T}{\frac{1}{2} \rho V^2 D^2}

TORQUE COEFFICIENT, Kq = \frac{Q0}{\frac{1}{2} \rho V^2 D^2}

SPEED COEFFICIENT, J = \frac{V0}{\gamma D}

EFFICIENCY, \eta = \frac{1}{\frac{1}{2} \rho V^2 D^2} \cdot \frac{Kt \times Kq}{2} \cdot \frac{2}{2 V0}

T = THRUST
Q = TORQUE
n = REVOLUTIONS PER UNIT TIME
V0 = SPEED OF ADVANCE
\gamma = KINEMATIC VISCOSITY
D = DIAMETER
P = PITCH
\rho = DENSITY OF WATER

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FIG. 2
CHARACTERISTIC CURVES
OF
PROPELLER 3227
TESTED FOR BUSHIPS
DESIGNED BY NORFOLK NAVAL SHIPYARD
BUSHIPS DRAWING SS25-S4400-962058

NUMBER OF BLADES 3
EXP AREA RATIO 0.375
MWR 0.273
BTF VAR.
p-d (at 0.7R) 0.8065 DESIGN
DIAMETER 14.553 IN.
PITCH (at 0.7R) 11.742 IN. DESIGN
ROTATION R.H.
TEST RPM 1200-1600
TEST Vo 3.0 TO 15.5 KNOTS

REYNOLD'S NO, Re = \( \frac{\nu_{\text{eff}} L}{\nu} \)
THRUST COEFFICIENT, \( K_t = \frac{T}{p Q} \)
TORQUE COEFFICIENT, \( K_q = \frac{Q}{p} \)
SPEED COEFFICIENT, \( J = \frac{V_o}{\nu} \)
EFFICIENCY, \( e = \frac{T Q}{p - d} \)

T = THRUST
Q = TORQUE
n = REVOLUTIONS PER UNIT TIME
V_o = SPEED OF ADVANCE
\( \nu = \) KINEMATIC VISCOSITY
d = DIAMETER
p = PITCH
\( \rho = \) DENSITY OF WATER

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OF
PROPELLER 3227
TESTED FOR BUSHIPS

DESIGNED BY NORFOLK NAVAL SHIPYARD
BUSHIPS DRAWING SS525-S4400-962058

NUMBER OF BLADES 4
EXP. AREA RATIO 0.500
M W R 0.273
B T F VAR.
p-d (at 0.7 R) 0.8065 DESIGN
DIAMETER 14.553 IN.
PITCH (at 0.7 R) 11.742 IN. DESIGN
ROTATION R.H.
TEST RPM 1200-1600
TEST V_o 3.1 TO 15 KNOTS

REYNOLD'S NO. R_e = 1R_e^{2/3} + 0.7end^2

THRUST COEFFICIENT, K_t = \frac{T}{\rho d^2 n^3}
TORQUE COEFFICIENT, K_q = \frac{Q}{\rho d^2 n^3}
SPEED COEFFICIENT, J = \frac{V_o}{d^n}
EFFICIENCY, e = \frac{T V_o}{K_t K_q} = \frac{J}{\frac{V_o}{d^n}}

T = THRUST
Q = TORQUE
n = REVOLUTIONS PER UNIT TIME
V_o = SPEED OF ADVANCE
\gamma = KINEMATIC VISCOSITY
d = DIAMETER
p = PITCH
\rho = DENSITY OF WATER
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FIG. 4
CHARACTERISTIC CURVES
OF
PROPELLER 3227
TESTED FOR BUSHPIS

DESIGNED BY NORFOLK NAVAL SHIPYARD
BUSHIPS DRAWING SS525-S4400-962058

NUMBER OF BLADES 5
EXP AREA RATIO 0.625
M M R 0.273
B T F 127 VAR
P-d (at 0.7R) 0.8065 DESIGN
DIAMETER 14.553 IN.
PITCH (at 0.7R) 11.742 IN. DESIGN
ROTATION R.H.
TEST RPM 1200-1600
TEST $V_o$ 3.1 TO 15.0 KNOTS

REYNOLDS NO., $Re = \frac{d V V}{\nu}$, $\nu$ = $\nu$(0.7R)
THRU ST COEFFICIENT, $K_t = \frac{Th}{\rho V^2 p}$
TORQUE COEFFICIENT, $K_q = \frac{Q}{\rho p D^2}$
SPEED COEFFICIENT, $J = \frac{V}{V_0}$
EFFICIENCY, $e = \frac{1}{2} \frac{Th}{Q} = \frac{J}{2\pi n}$

$T =$ THRUST
$Q =$ TORQUE
$n =$ REVOLUTIONS PER UNIT TIME
$V_o =$ SPEED OF ADVANCE
$\nu =$ KINEMATIC VISCOSITY
$d =$ DIAMETER
$p =$ PITCH
$\rho =$ DENSITY OF WATER

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FIG. 5
CHARACTERISTIC CURVES OF PROPELLER 3227
TESTED FOR BUSHIPS

NUMBER OF BLADES: 6
EXP AREA RATIO: 0.750
M W R: 0.273
B T F: 0.8065 DESIGN
DIAMETER: 14.553 IN.
PITCH (at 0.7R): 11.742 IN. DESIGN
ROTATION: R.H.
TEST RPM: 1200-1600
TEST VO: 29 TO 160 KNOTS

REYNOLD'S NO, Re = \frac{d^3n}{\nu}
THRUST COEFFICIENT, \( K_t = \frac{T}{2\pi Re} \)
TORQUE COEFFICIENT, \( K_q = \frac{Q}{2\pi Re} \)
SPEED COEFFICIENT, \( J = \frac{\nu}{n} \)
EFFICIENCY, \( \eta = \frac{\frac{\nu}{n} \cdot \frac{T}{Q}}{K_t} \)

T = THRUST
Q = TORQUE
n = REVOLUTIONS PER UNIT TIME
\nu = SPEED OF ADVANCE
\nu = KINEMATIC VISCOSITY
d = DIAMETER
p = PITCH
\rho = DENSITY OF WATER
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FIG. 6
CHARACTERISTIC CURVES OF
PROPELLER 3227
TESTED FOR BUSHIPS
DESIGNED BY NORFOLK NAVAL SHIPYARD
BUSHIPS DWG. SS525-S4400-962058

NUMBER OF BLADES 4
EXP AREA RATIO 0.500
MWR 0.273
BTF VARIABLE
p+d (AT 0.7R) 0.8065 (DESIGN)
DIAMETER 14.558 INS.
PITCH (AT 0.7R) 11.742 INS. (DESIGN)
ROTATION R.H.
TEST n, see Table
TEST V, see Table

REYNOLDS NO., Re = \frac{D^2V}{v}

THrust coefficient, K = \frac{T}{D^3V^2}

TORque coefficient, K = \frac{Q}{D^2V^2}

SPEED COEFFICIENT, J = \frac{V}{D}

EFFICIENCY, \psi = \frac{1}{\sqrt{2}}\left(\frac{C_0}{C_0 + C_1}\right)

T = THRUST
Q = TORQUE
n = REVOLUTIONS PER UNIT TIME
V = SPEED OF ADVANCE
\gamma = KINEMATIC VISCOSITY
d = DIAMETER
p = PITCH
\rho = DENSITY OF WATER

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