[redacted]

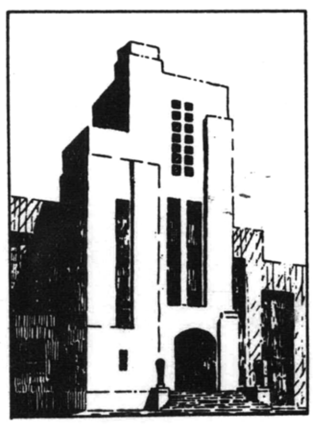
NAVY DEPARTMENT
THE DAVID W. TAYLOR MODEL BASIN
WASHINGTON 7, D.C.

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

[redacted]

By

William B. Morgan



November 1954 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 GRENADIER (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:

Thrust coefficient $K_t = T/\rho n^2 D^4$

Torque coefficient $K_q = Q/\rho n^2 D^5$

Speed coefficient $J = V_o/nD$

Propeller efficiency $e = TV_o/2\pi Qn = K_t J/2\pi K_q$

T = Propeller thrust

Q = Propeller torque

V_o = Speed of advance

D = Diameter of propeller

n = Revolutions per unit time

ρ = 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 explanded 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

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

TABLE 2

TESTS CONDUCTED

Number of Blades	P/D (Pitch Ratio) 0.452	0.742	0.807 design	0.871	1.065
2	x		x		x
3	x		x		x
4	x	x	x	x	x
5	x		x		x
6	x		x		x

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 knots

ehp = 1950

rpm = 360

Thrust deduction = t = 0.08

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.

$$T = 316.8 \, ehp/V_s(1 - t) = 39{,}500 \text{ lbs.}$$

$$V_o = \text{speed of advance} = V_s(1 - w_t)(1.689) = 23.83 \text{ fps.}$$

To find the optimum diameter the following coefficient is used:

$$K_{tn} = K_t/J^4 = Tn^2/\rho V_o^4 = 2.305$$

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 = (constant)J^4. The points at which the parabolas are tangent to the lines of constant efficiency determine the curve "e_{max}". 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 "e_{max}" 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:

$D = V_0/Jn = 7.976$ ft.

$P = (P/D)D = 6.10$ ft.

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

Number of Blades	D ft.	P ft.	eff.	P/D
2	8.65	6.055	0.65	0.700
3	8.207	6.18	0.62	0.753
4	7.976	6.10	0.605	0.765
5	7.773	6.20	0.59	0.798
6	7.222	6.61	0.55	0.915

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.

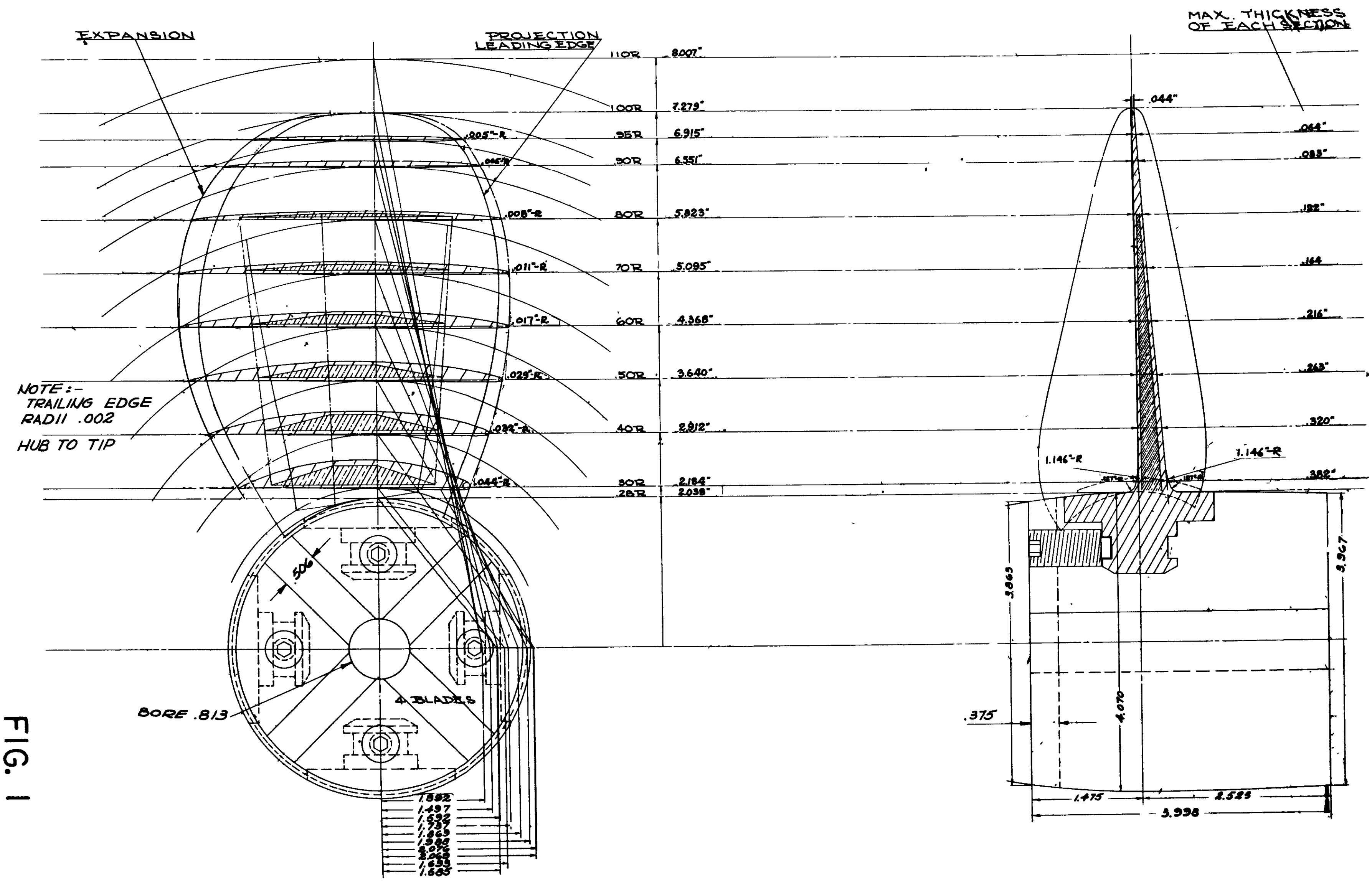
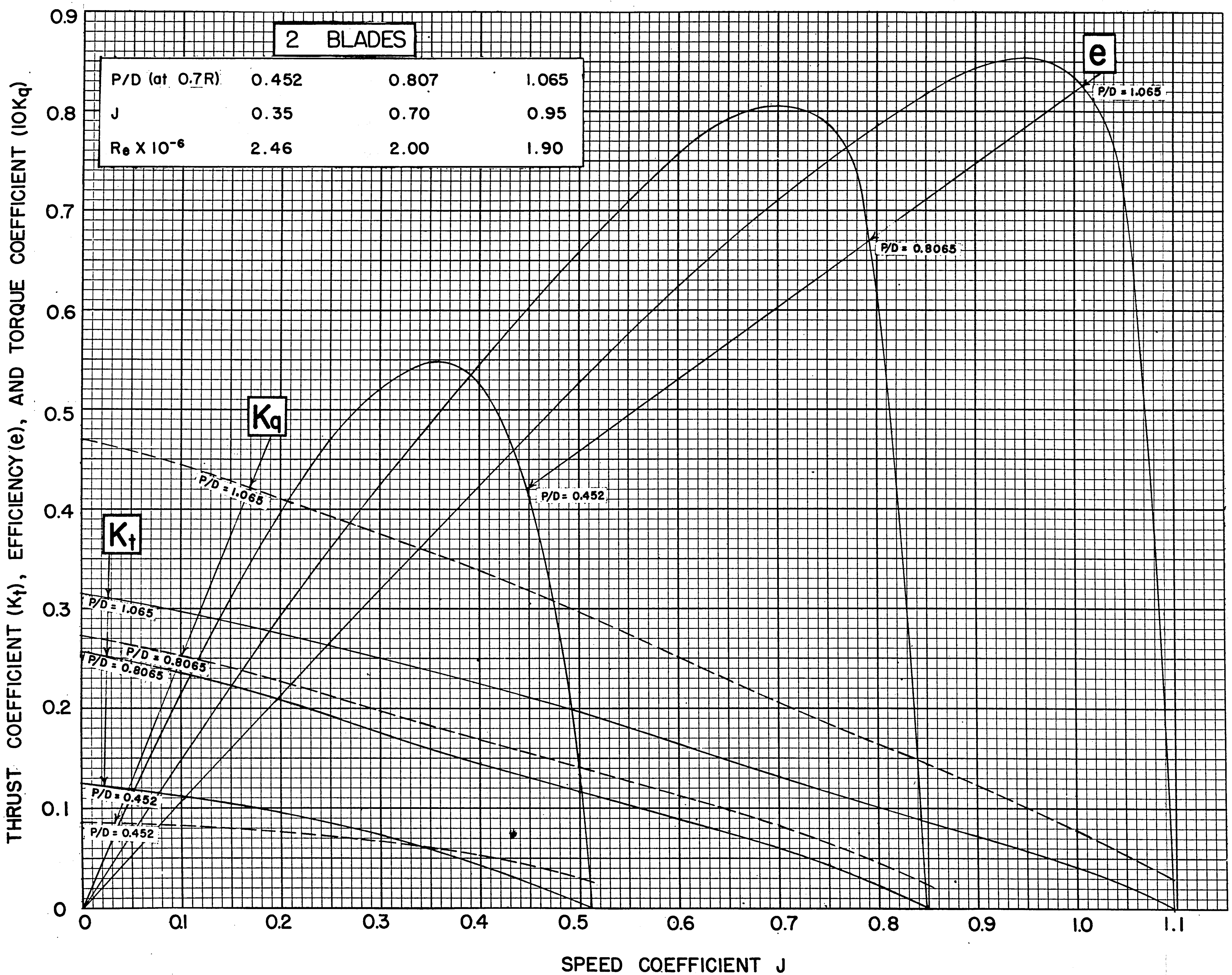

EXPANSION
PROJECTION LEADING EDGE
MAX. THICKNESS OF EACH SECTION
1.10R 8.007"
1.00R 7.279"
.95R 6.915"
.90R 6.551"
.80R 5.823"
.70R 5.095"
.60R 4.368"
.50R 3.640"
.40R 2.912"
.30R 2.184"
.28R 2.038"
.005"-R
.008"-R
.011"-R
.017"-R
.029"-R
.044"-R
.044"
.064"
.083"
.132"
.164
.216"
.263"
.320"
.382"
1.146"-R
1.146"-R
NOTE:-
TRAILING EDGE
RADII .002
HUB TO TIP
.506
BORE .813
4 BLADES
1.882
1.497
1.632
1.737
1.869
1.988
2.076
2.068
1.695
1.565
3.863
3.967
4.070
.375
1.475
2.523
3.998

FIG. 1



CHARACTERISTIC CURVES
OF
PROPELLER 3227
TESTED FOR BUSHIPS
DESIGNED BY NORFOLK NAVAL SHIPYARD
BUSHIPS DRAWING SS525 - S4400-962058

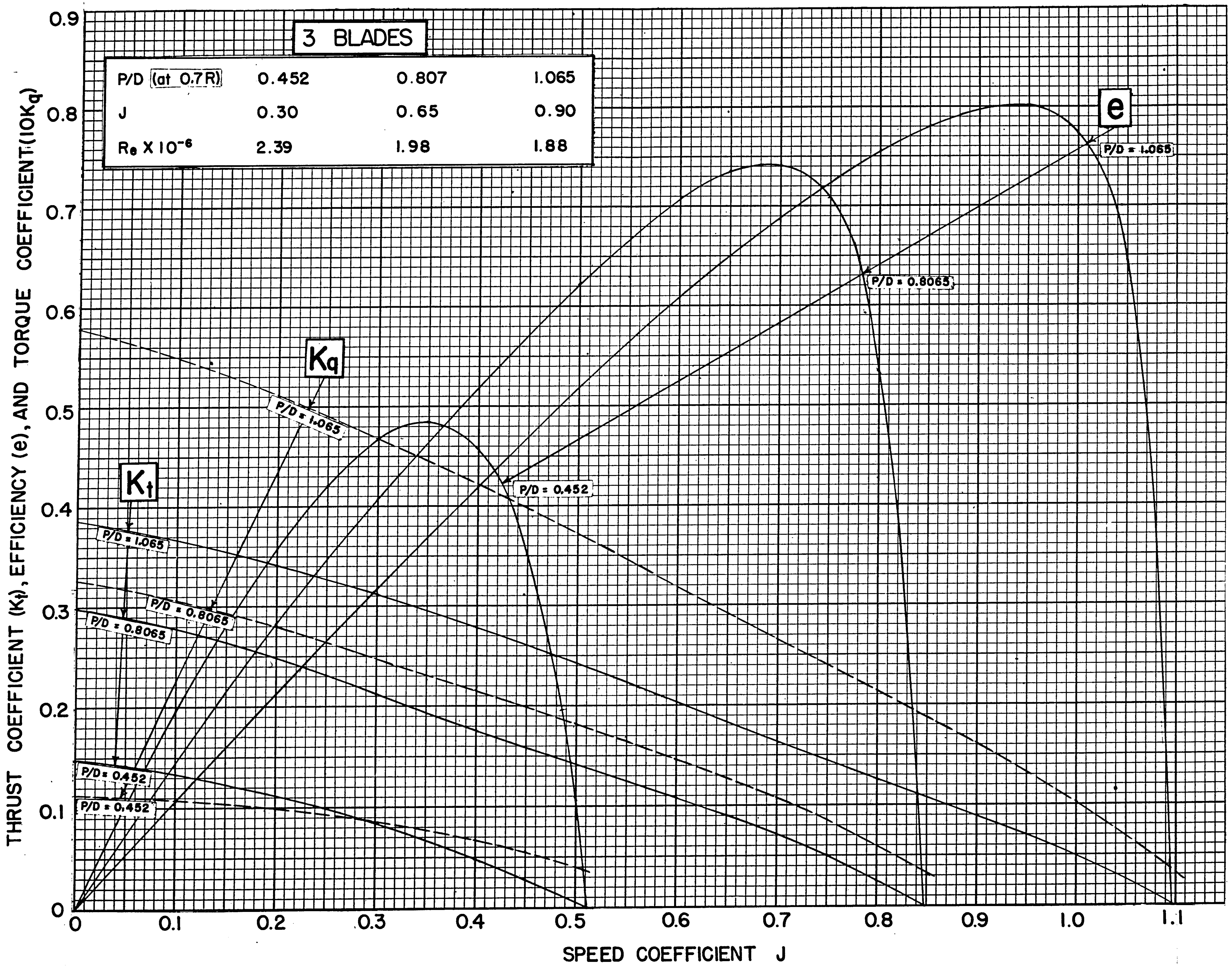
NUMBER OF BLADES	2
EXP. AREA RATIO	0.250
MWR	0.273
BTF	VAR.
p÷d (at 0.7R)	0.8065 DESIGN
DIAMETER	14.553 IN.
PITCH (at 0.7R)	11.742 IN. DESIGN
ROTATION	R.H.
TEST RPM	1200-1600
TEST V_o	2.9 TO 15.6 KNOTS

REYNOLD'S NO., $R_e = \frac{b_{0.7}\sqrt{V_o^2+(0.7\pi nd)^2}}{\gamma}$
THRUST COEFFICIENT, $K_t = \frac{T}{\rho n^2 d^4}$
TORQUE COEFFICIENT, $K_q = \frac{Q}{\rho n^2 d^5}$
SPEED COEFFICIENT, $J = \frac{V_o}{nd}$
EFFICIENCY, $e = \frac{TV_o}{2\pi Qn} = \frac{K_t}{K_q} \times \frac{J}{2\pi}$

T = THRUST
Q = TORQUE
n = REVOLUTIONS PER UNIT TIME
V_o = SPEED OF ADVANCE
γ = KINEMATIC VISCOSITY
d = DIAMETER
p = PITCH
ρ = DENSITY OF WATER

29 MAY 1953
DAVID W. TAYLOR MODEL BASIN
WASHINGTON, D.C

FIG. 2



CHARACTERISTIC CURVES
OF
PROPELLER 3227
TESTED FOR BUSHIPS

DESIGNED BY NORFOLK NAVAL SHIPYARD

BUSHIPS DRAWING SS525-S4400-962058

NUMBER OF BLADES	3
EXP. AREA RATIO	0.375
M W R	0.273
B T F	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	3.0 TO 15.5 KNOTS

REYNOLD'S NO., $R_e = \frac{b_{0.7}\sqrt{V_o^2+(0.7\pi nd)^2}}{\gamma}$

THRUST COEFFICIENT, $K_t = \frac{T}{\rho n^2 d^4}$

TORQUE COEFFICIENT, $K_q = \frac{Q}{\rho n^2 d^5}$

SPEED COEFFICIENT, $J = \frac{V_o}{nd}$

EFFICIENCY, $e = \frac{TV_o}{2\pi Q n} = \frac{K_t}{K_q} \times \frac{J}{2\pi}$

T = THRUST
Q = TORQUE
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V_o = SPEED OF ADVANCE
γ = KINEMATIC VISCOSITY
d = DIAMETER
p = PITCH
ρ = DENSITY OF WATER

28 JANUARY 1953

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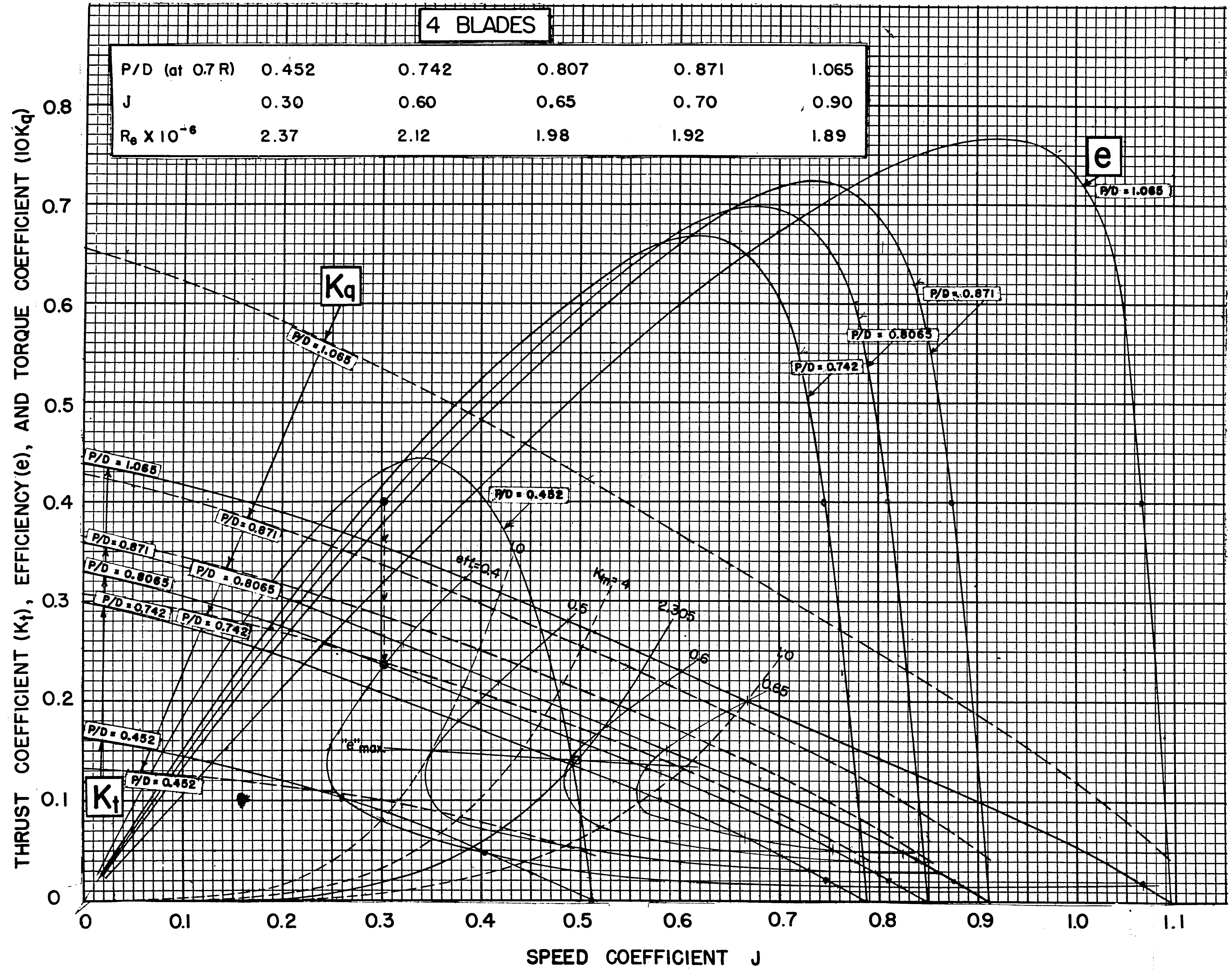
FIG. 3



CHARACTERISTIC CURVES 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 0.7R)	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 KNOTS

REYNOLD'S NO., $R_e = \frac{b_{0.7}\sqrt{V_o^2+(0.7\pi nd)^2}}{\gamma}$

THRUST COEFFICIENT, $K_t = \frac{T}{\rho n^2 d^4}$

TORQUE COEFFICIENT, $K_q = \frac{Q}{\rho n^2 d^5}$

SPEED COEFFICIENT, $J = \frac{V_o}{nd}$

EFFICIENCY, $e = \frac{TV_o}{2\pi Qn} = \frac{K_t}{K_q} \times \frac{J}{2\pi}$

T = THRUST
Q = TORQUE
n = REVOLUTIONS PER UNIT TIME
V_o = SPEED OF ADVANCE
γ = KINEMATIC VISCOSITY
d = DIAMETER
p = PITCH
ρ = DENSITY OF WATER

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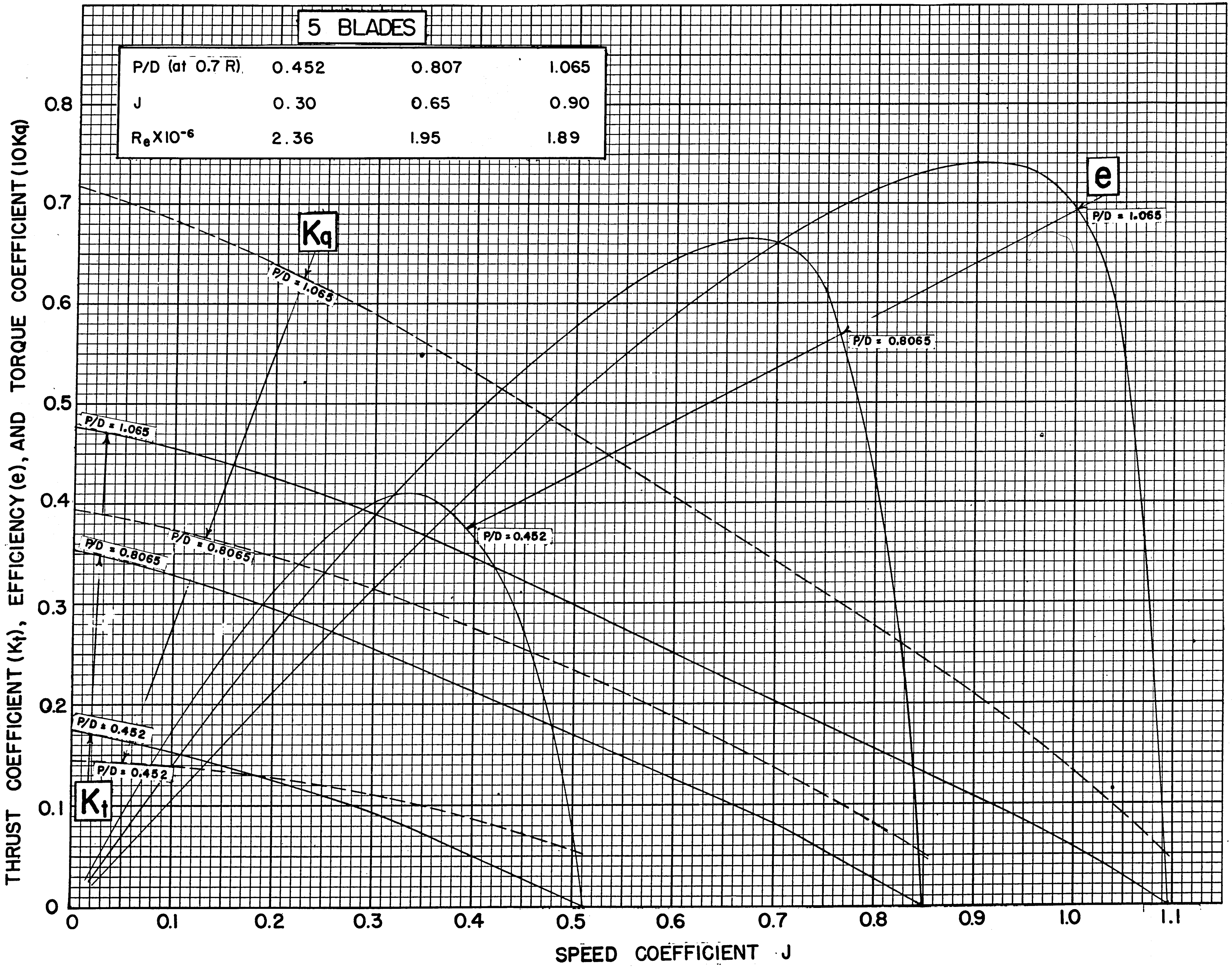
FIG. 4



CHARACTERISTIC CURVES
OF
PROPELLER 3227
TESTED FOR BUSHIPS

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

NUMBER OF BLADES	5
EXP. AREA RATIO	0.625
M W R	0.273
B T F	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

REYNOLD'S NO., $R_e = \frac{b_{0.7}\sqrt{V_o^2+(0.7\pi nd)^2}}{\gamma}$
THRUST COEFFICIENT, $K_t = \frac{T}{\rho n^2 d^4}$
TORQUE COEFFICIENT, $K_q = \frac{Q}{\rho n^2 d^5}$
SPEED COEFFICIENT, $J = \frac{V_o}{nd}$
EFFICIENCY, $e = \frac{TV_o}{2\pi Qn} = \frac{K_t}{K_q} \times \frac{J}{2\pi}$

T = THRUST
Q = TORQUE
n = REVOLUTIONS PER UNIT TIME
V_o = SPEED OF ADVANCE
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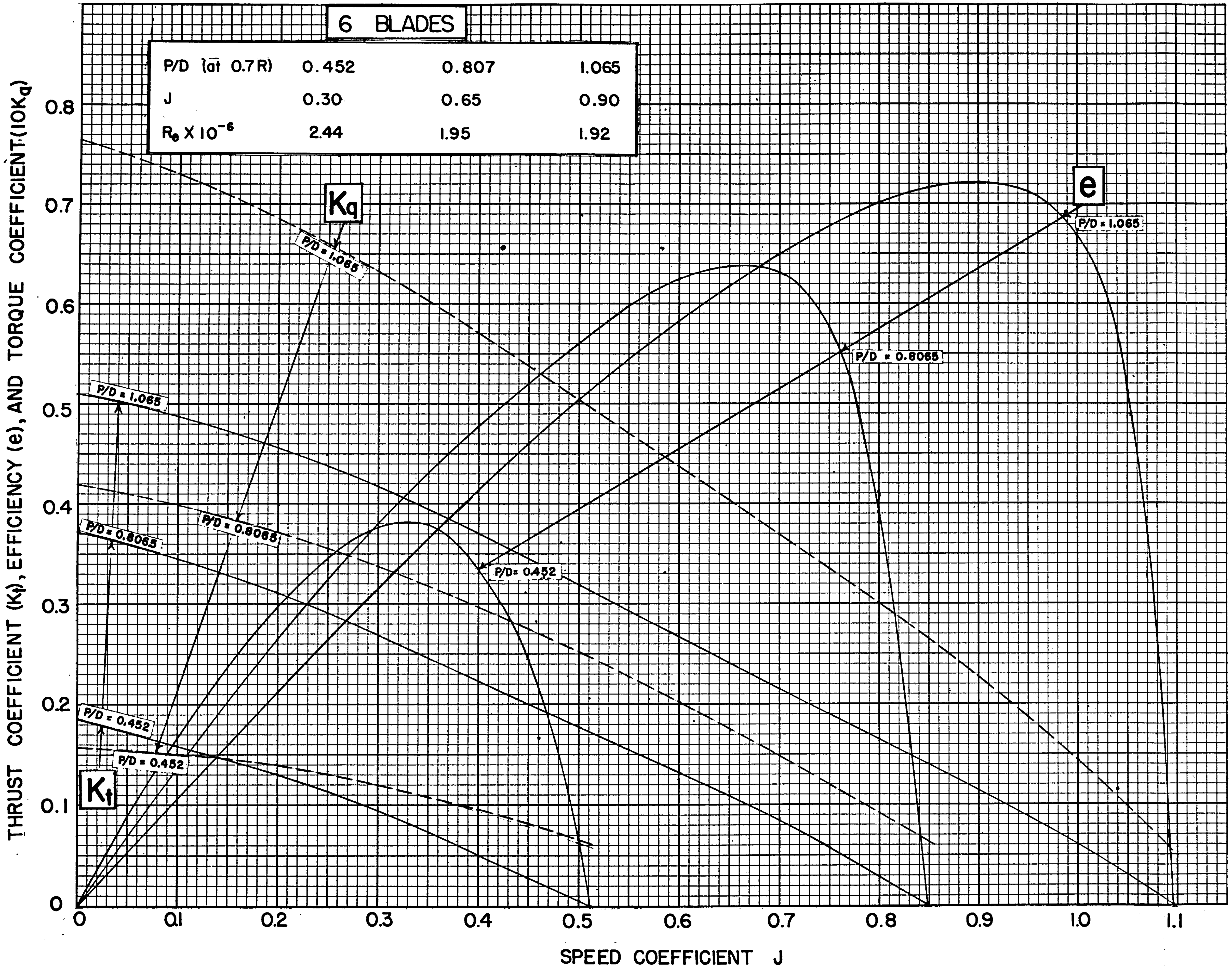
FIG. 5



CHARACTERISTIC CURVES
OF
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TESTED FOR BUSHIPS

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

NUMBER OF BLADES	6
EXP. AREA RATIO	0.750
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	2.9 TO 16.0 KNOTS

REYNOLD'S NO., $R_e = \frac{b_{0.7}\sqrt{V_o^2+(0.7\pi nd)^2}}{\gamma}$

THRUST COEFFICIENT, $K_t = \frac{T}{\rho n^2 d^4}$

TORQUE COEFFICIENT, $K_q = \frac{Q}{\rho n^2 d^5}$

SPEED COEFFICIENT, $J = \frac{V_o}{nd}$

EFFICIENCY, $e = \frac{TV_o}{2\pi Qn} = \frac{K_t}{K_q} \times \frac{J}{2\pi}$

T = THRUST
Q = TORQUE
n = REVOLUTIONS PER UNIT TIME
V_o = SPEED OF ADVANCE
γ = KINEMATIC VISCOSITY
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p = PITCH
ρ = DENSITY OF WATER

1 JUNE 1953

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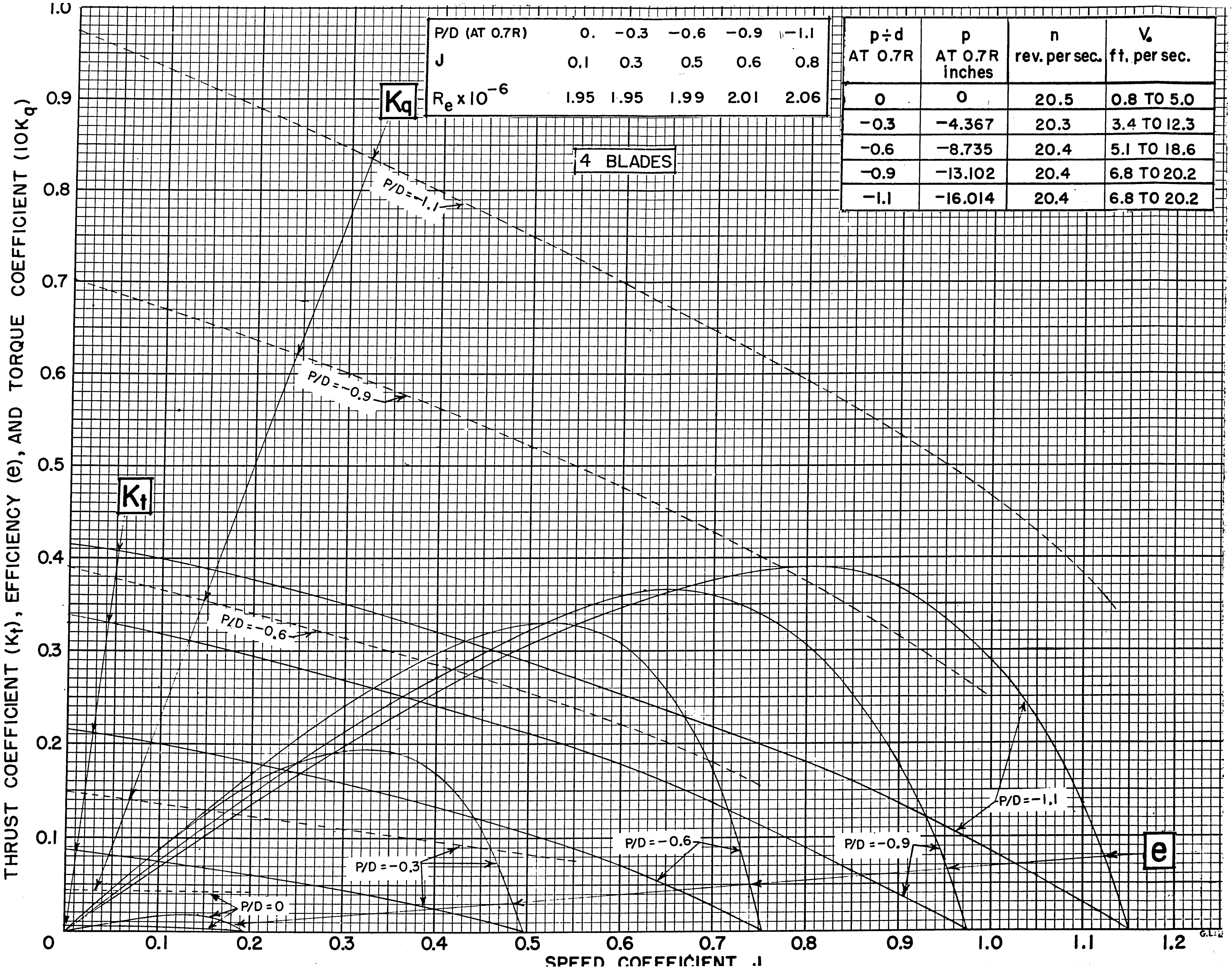
FIG. 6



P/D (AT 0.7R)	0.	−0.3	−0.6	−0.9	−1.1
J	0.1	0.3	0.5	0.6	0.8
$R_e \times 10^{-6}$	1.95	1.95	1.99	2.01	2.06

p÷d AT 0.7R	p AT 0.7R inches	n rev. per sec.	V_o ft. per sec.
0	0	20.5	0.8 TO 5.0
−0.3	−4.367	20.3	3.4 TO 12.3
−0.6	−8.735	20.4	5.1 TO 18.6
−0.9	−13.102	20.4	6.8 TO 20.2
−1.1	−16.014	20.4	6.8 TO 20.2

BACK DRIVING

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_o, SEE TABLE

REYNOLD'S NO., $R_e = \frac{b_{0.7}\sqrt{V_o^2+(0.7\pi nd)^2}}{\gamma}$
THRUST COEFFICIENT, $K_t = \frac{T}{\rho n^2 d^4}$
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FIG. 7

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UNCLASSIFIED

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I. Morgan, William B.

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