OPEN WATER PROPELLER TESTS IN FOUR OPERATING MODES

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LIST OF SYMBOLS

d	Propeller pitch diameter
F_L	Normal force on locked propeller blades
F_s	Normal force on stalled propeller blades
J	Advance coefficient, V_a/nd
K_Q	Torque coefficient, $Q/\rho\ n^2d^5$
K'_Q	Primed torque coefficient, $Q/\rho\ v^2d^3$
K_T	Thrust coefficient, $T/\rho\ n^2d^4$
K'_T	Primed thrust coefficient, $T/\rho\ v^2d^2$
n	Propeller revolutions per second
P_e	Effective pitch
Q	Propeller torque
T	Propeller thrust
V_a	Speed of advance
V_L	Speed of advance of a locked propeller
V_s	Speed of advance of a stalled propeller
θ	Angle between propeller plane and flat blade
π	3.1416
ρ	Fluid density

LIST OF FIGURES

INTRODUCTION

In July, 1966, a series of performance evaluation tests were run on the Project Mohole drilling rig in the model basin of the Ship Hydrodynamics Laboratory at The University of Michigan under contract with Brown and Root Incorporated, Houston, Texas.

The Mohole drilling platform is essentially a catamaran with six vertical columns tying the working platform to the two main hulls (see Figure 1). The platform has two five-bladed propellers on the main hulls to provide the main propulsive power when moving between stations and six retractable positioning units to help the main propulsion propellers in maneuvering and station keeping.

The performance tests were designed to help determine the propulsion characteristics of the Mohole platform in all operating conditions, including backing, maneuvering, and station keeping. The tests comprised two main parts: wake surveys and open water propeller tests of the main propellers, of which only the latter will be discussed in this paper as they apply to marine propellers in general.

Because the main propellers are to be used to help keep the platform on station they will be operated not only normally, with the propeller pushing the platform ahead, but in any one of three other modes: the platform moving ahead with the propeller reversed, trying to stop the platform;

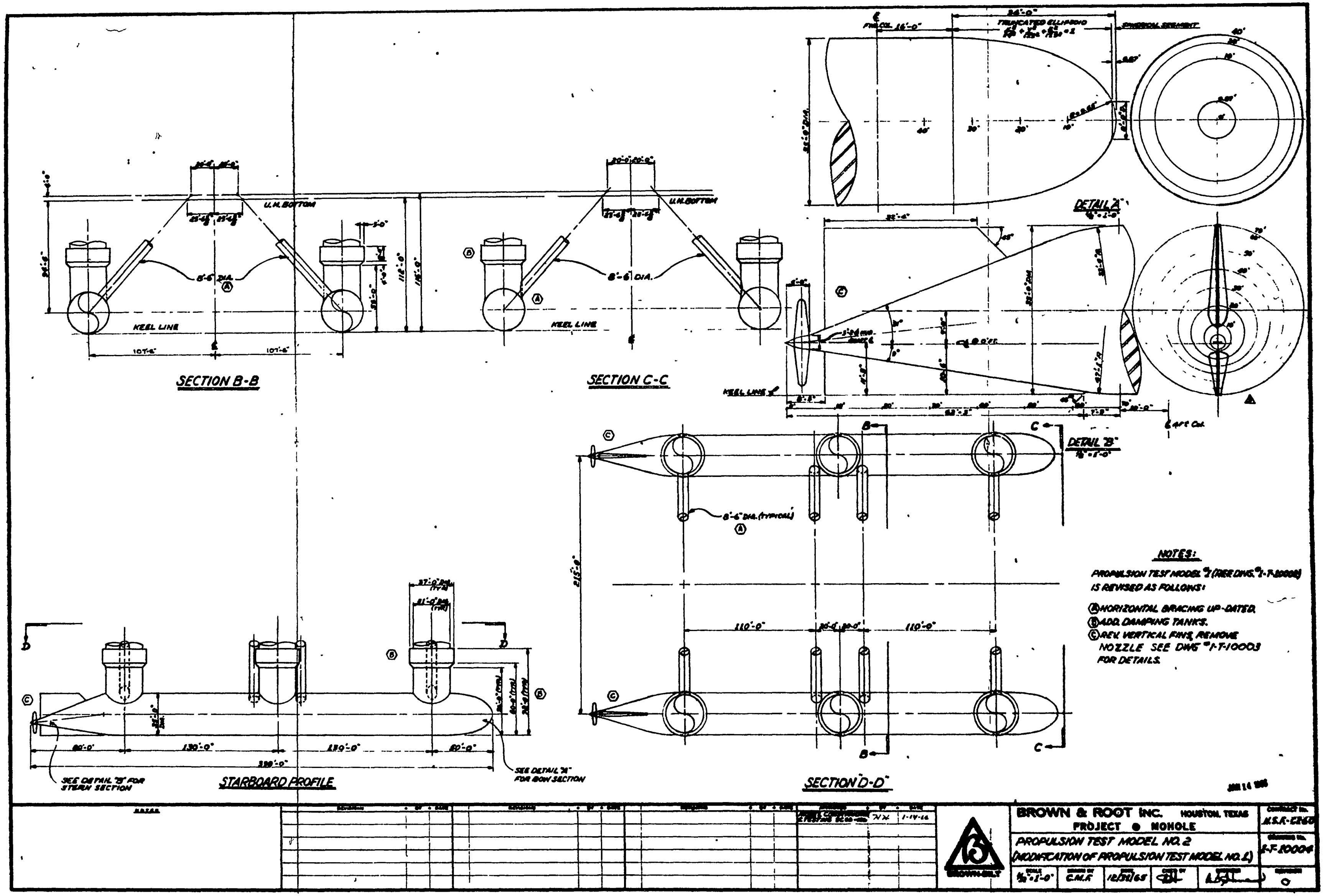


Figure 1. Project Mohole Drilling Platform

the propeller reversed, moving the platform backwards; and finally, the platform moving backwards with the propeller trying to stop its motion. These four modes of operation are summarized in Table I.

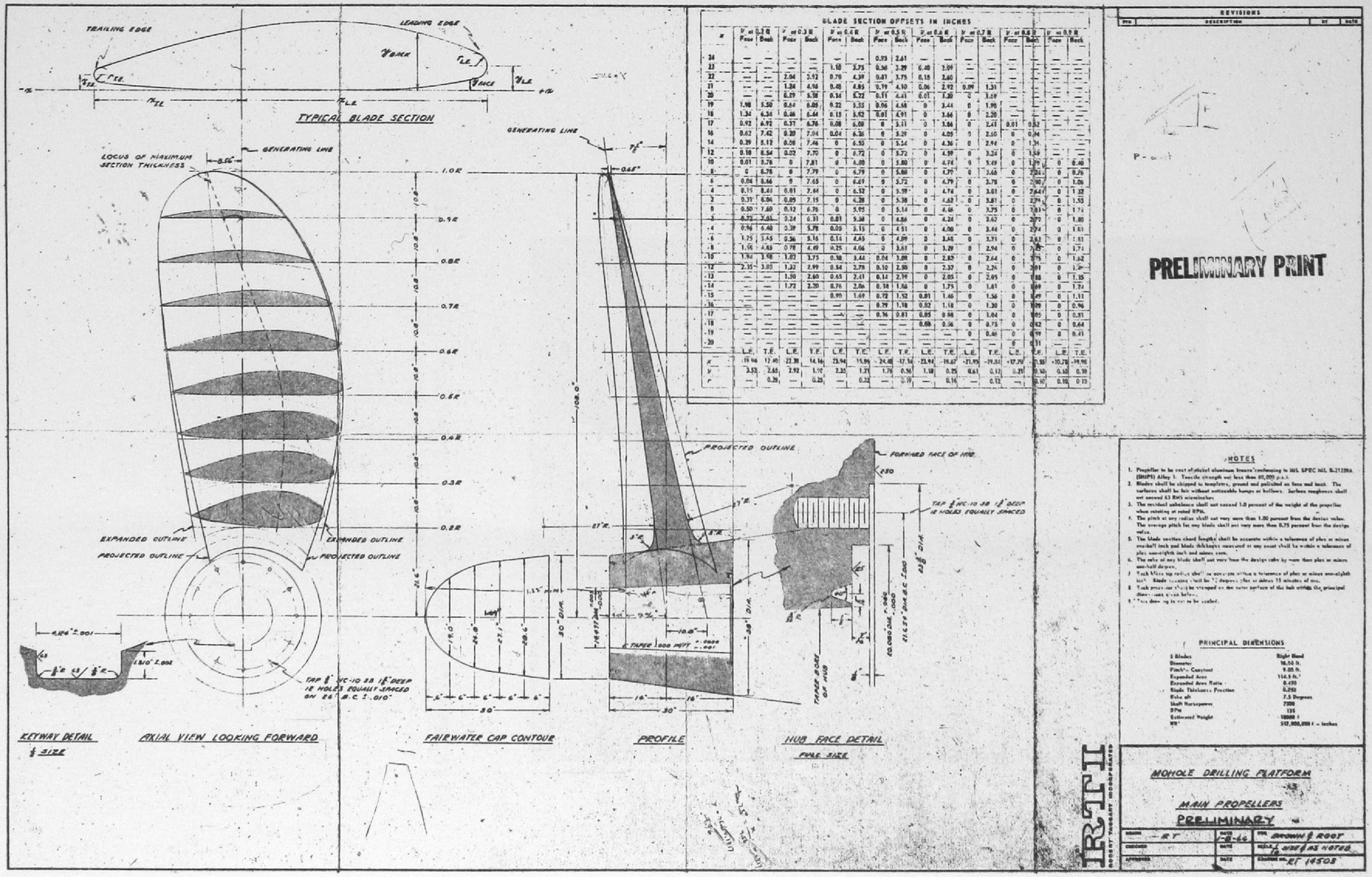
Mode	Description	RPM	Speed of Advance
1	Normal Ahead Operation	positive	positive
2	Ahead Braking	negative	positive
3	Backing	negative	negative
4	Astern Braking	positive	negative

TABLE I. Possible Modes of Propeller Operation

The original propeller drawings were redrawn to a large scale and photographically reduced to model size on metal templates. Propeller parameters are shown in Figure 2. The model propeller, 7.5 inches in diameter, was made from one piece of rolled aluminum alloy and is shown in Figure 3.

Open water propeller tests were carried out with the model propeller operating in each of the four modes. The propeller was mounted on a long shaft extending from the bow of a partially submerged streamlined structure which contained a variable speed electric motor, an RPM pickup, and an electronic thrust and torque transducer.

A constant RPM procedure was used throughout the testing program, i.e., during one set of tests runs the RPM was kept constant while the carriage speed (speed of advance) was



BLADE SECTION OFFSETS IN INCHES

x	y at 0.2R Face	y at 0.2R Back	y at 0.3R Face	y at 0.3R Back	y at 0.4R Face	y at 0.4R Back	y at 0.5R Face	y at 0.5R Back	y at 0.6R Face	y at 0.6R Back	y at 0.7R Face	y at 0.7R Back	y at 0.8R Face	y at 0.8R Back	y at 0.9R Face	y at 0.9R Back
24	—	—	—	—	—	—	0.93	2.61	—	—	—	—	—	—	—	—
23	—	—	—	—	1.10	3.75	0.56	3.29	0.40	3.09	—	—	—	—	—	—
22	—	—	2.04	3.93	0.70	4.39	0.81	3.75	0.18	2.60	—	—	—	—	—	—
21	—	—	1.24	4.96	0.48	4.85	0.19	4.10	0.06	2.92	0.09	1.31	—	—	—	—
20	—	—	0.89	5.58	0.34	5.22	0.11	4.41	0.01	3.20	0	1.69	—	—	—	—
19	1.98	5.50	0.64	6.05	0.22	5.55	0.06	4.68	0	3.44	0	1.98	—	—	—	—
18	1.34	6.34	0.46	6.44	0.13	5.92	0.01	4.91	0	3.66	0	2.20	—	—	—	—
17	0.92	6.92	0.37	6.76	0.08	6.08	0	5.11	0	3.86	0	2.41	0.01	0.52	—	—
16	0.62	7.42	0.20	7.04	0.04	6.26	0	5.29	0	4.05	0	2.60	0	0.94	—	—
14	0.29	8.12	0.06	7.46	0	6.55	0	5.54	0	4.36	0	2.94	0	1.34	—	—
12	0.10	8.54	0.02	7.70	0	6.72	0	5.72	0	4.59	0	3.24	0	1.59	—	—
10	0.01	8.76	0	7.81	0	6.80	0	5.80	0	4.74	0	3.49	0	1.79	0	0.40
8	0	8.78	0	7.79	0	6.79	0	5.80	0	4.79	0	3.66	0	2.24	0	0.76
6	0.04	8.66	0	7.65	0	6.69	0	5.72	0	4.79	0	3.78	0	2.90	0	1.06
4	0.15	8.44	0.01	7.44	0	6.52	0	5.59	0	4.74	0	3.81	0	2.64	0	1.32
2	0.31	8.04	0.05	7.15	0	6.28	0	5.38	0	4.62	0	3.81	0	2.74	0	1.55
0	0.50	7.60	0.12	6.76	0	5.95	0	5.14	0	4.46	0	3.75	0	2.81	0	1.71
-2	0.72	7.01	0.24	6.31	0.01	5.58	0	4.86	0	4.24	0	3.62	0	2.79	0	1.80
-4	0.96	6.40	0.39	5.78	0.05	5.15	0	4.51	0	4.00	0	3.44	0	2.74	0	1.61
-6	1.25	5.45	0.56	5.16	0.14	4.65	0	4.09	0	3.65	0	3.21	0	2.62	0	1.81
-8	1.55	4.65	0.78	4.49	0.25	4.06	0	3.61	0	3.29	0	2.94	0	2.45	0	1.74
-10	1.94	3.98	1.02	3.75	0.38	3.44	0.04	3.08	0	2.82	0	2.64	0	[illegible]	0	1.62
-12	2.35	3.05	1.32	2.99	0.54	2.78	0.10	2.50	0	2.37	0	2.26	0	2.01	0	[illegible]
-13	—	—	1.50	2.60	0.65	2.41	0.14	2.19	0	2.05	0	2.05	0	1.88	0	1.35
-14	—	—	1.72	2.20	0.76	2.06	0.18	1.86	0	1.75	0	1.81	0	1.69	0	1.23
-15	—	—	—	—	0.90	1.69	0.72	1.52	0.01	1.46	0	1.56	0	1.49	0	1.11
-16	—	—	—	—	—	—	0.29	1.18	0.02	1.18	0	1.30	0	1.29	0	0.96
-17	—	—	—	—	—	—	0.16	0.81	0.05	0.88	0	1.04	0	1.05	0	0.81
-18	—	—	—	—	—	—	—	—	0.08	0.56	0	0.75	0	0.82	0	0.64
-19	—	—	—	—	—	—	—	—	—	—	0	0.46	0	0.59	0	0.41
-20	—	—	—	—	—	—	—	—	—	—	—	—	0	0.31	—	—
	L.E.	T.E.	L.E.	T.E.	L.E.	T.E.	L.E.	T.E.	L.E.	T.E.	L.E.	T.E.	L.E.	T.E.	L.E.	T.E.
x	19.96	12.40	22.38	14.16	23.94	15.86	-24.40	-17.34	-23.94	-19.67	-21.95	-19.84	-17.70	[illegible]	+10.78	-19.98
y	3.52	2.65	2.92	1.92	2.35	1.21	1.76	0.56	1.18	0.25	0.61	0.12	0.21	0.10	0.10	0.10
r	—	0.28	—	0.25	—	0.22	—	0.19	—	0.16	—	0.12	—	0.10	0.10	0.10

NOTES

1. Propeller to be cast of nickel aluminum bronze conforming to MIL SPEC MIL B-21230A (SHIPS) Alloy 1. Tensile strength not less than 80,000 p.s.i.
2. Blades shall be chipped to templates, ground and polished on face and back. The surfaces shall be fair without noticeable bumps or hollows. Surface roughness shall not exceed 63 RMS microinches.
3. The residual unbalance shall not exceed 1.0 percent of the weight of the propeller when rotating at rated RPM.
4. The pitch at any radius shall not vary more than 1.00 percent from the design value. The average pitch for any blade shall not vary more than 0.75 percent from the design value.
5. The blade section chord lengths shall be accurate within a tolerance of plus or minus one-half inch and blade thickness measured at any point shall be within a tolerance of plus one-eighth inch and minus zero.
6. The rake of any blade shall not vary from the design rake by more than plus or minus one-half degree.
7. Each blade tip radius shall be accurate within a tolerance of plus or minus one-eighth inch. Blade spacing shall be 72 degrees plus or minus 15 minutes of arc.
8. Each propeller shall be stamped on the outer surface of the hub with the principal dimensions given below.
9. This drawing is not to be scaled.

PRINCIPAL DIMENSIONS

5 Blades	Right Hand
Diameter	18.00 ft.
Pitch – Constant	9.00 ft.
Expanded Area	114.5 ft.²
Expanded Area Ratio	0.450
Blade Thickness Fraction	0.050
Rake aft	7.5 Degrees
Shaft Horsepower	7500
RPM	135
Estimated Weight	18000 #
WR²	517,000,000 # – inches

MOHOLE DRILLING PLATFORM

MAIN PROPELLERS

PRELIMINARY

RT

BROWN & ROOT

RT 14503

Figure 2. Project Mohole Main Propulsion Propeller Characteristics

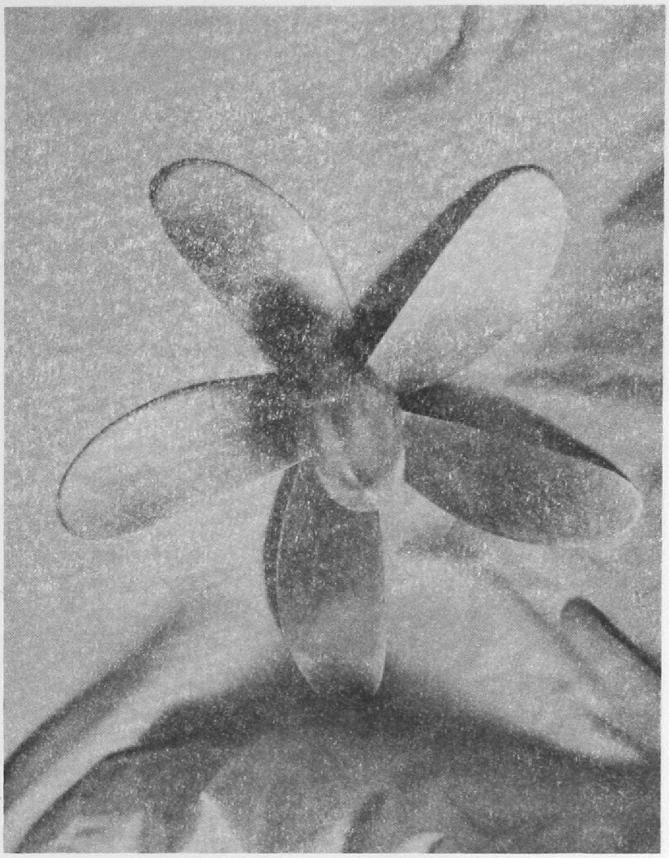


Figure 3. Project Mohole Main Propulsion Propeller Model

varied from run to run in order to cover the necessary range of advance coefficients. Before testing commenced the system friction and dummy hub torque and thrust were determined so that the measured propeller torque and thrust could be adjusted to eliminate these effects.

RESULTS AND DISCUSSION

The test results are plotted in Figures 4 through 9. Figures 4 through 7 show the conventional torque and thrust coefficient, K_Q and K_T, plotted against advance coefficient J. Figures 8 and 9 show the coefficients K_Q' and K_T' plotted against 1/J. All quantities have been plotted according to the following conventions:

The thrust coefficient is positive if the thrust vector is pointing toward the bow when the propeller is installed in its normal operating condition. The torque coefficient, on the other hand, follows the sign of the propeller rotation. To be able to extend the results to a locked propeller and to also include cases where the propeller is driving the propulsion machinery it is preferable to adopt the right-hand vector convention so that the torque is positive if the torque vector representing the torque is applied to the propeller shaft in normal operating position is directed toward the bow. Note that the advance coefficient is negative if the velocity of advance and direction of rotation are of opposite sign.

By plotting the data in this manner all four modes of operation can be plotted advantageously on one sheet. Since

FIGURE 4

KT AND 10KQ vs J

MODE NO. 1
NORMAL AHEAD OPERATION

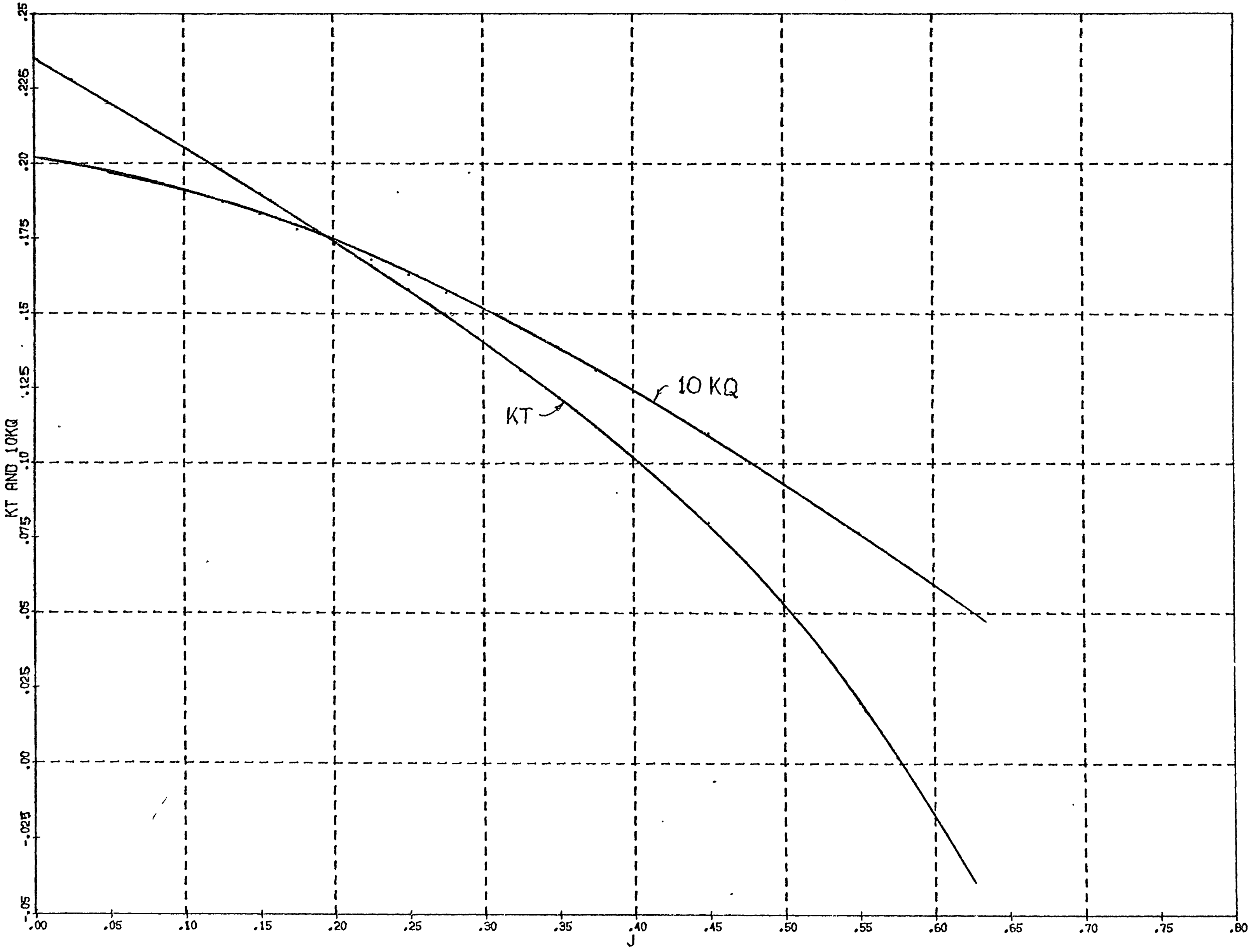


FIGURE 5

KT AND 10KQ vs J

MODE NO. 2
AHEAD BRAKING

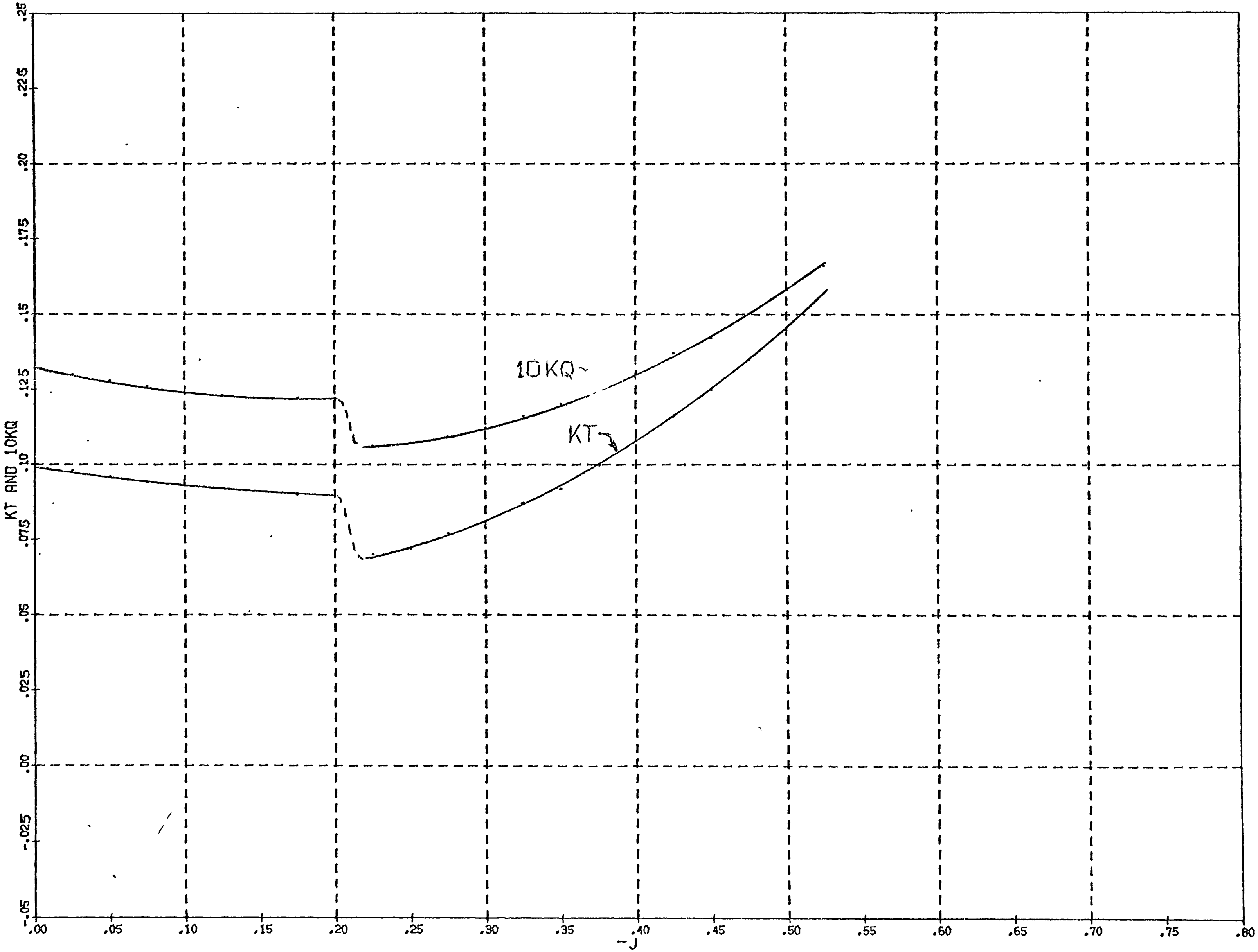


FIGURE 6

KT AND 10KQ vs J

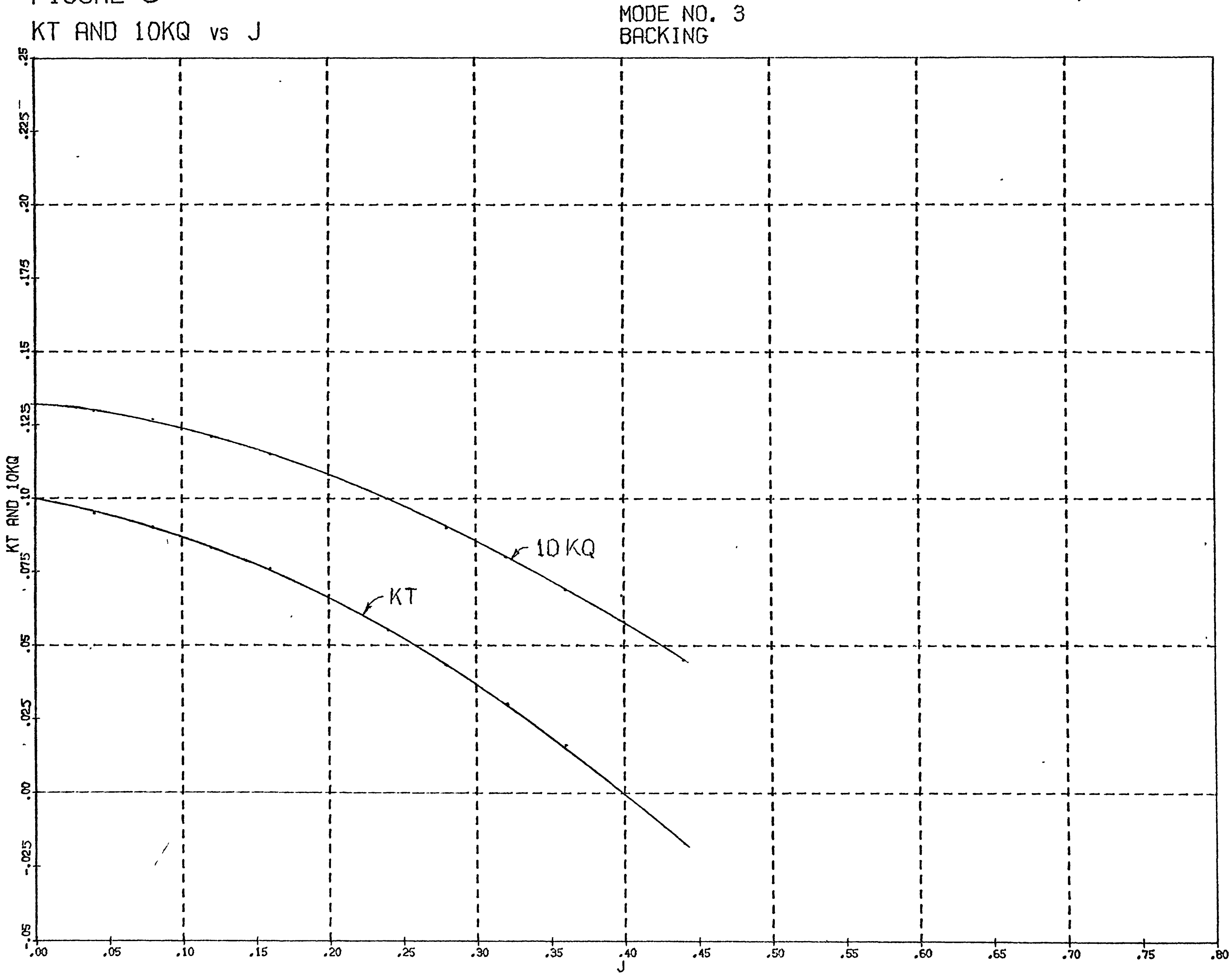
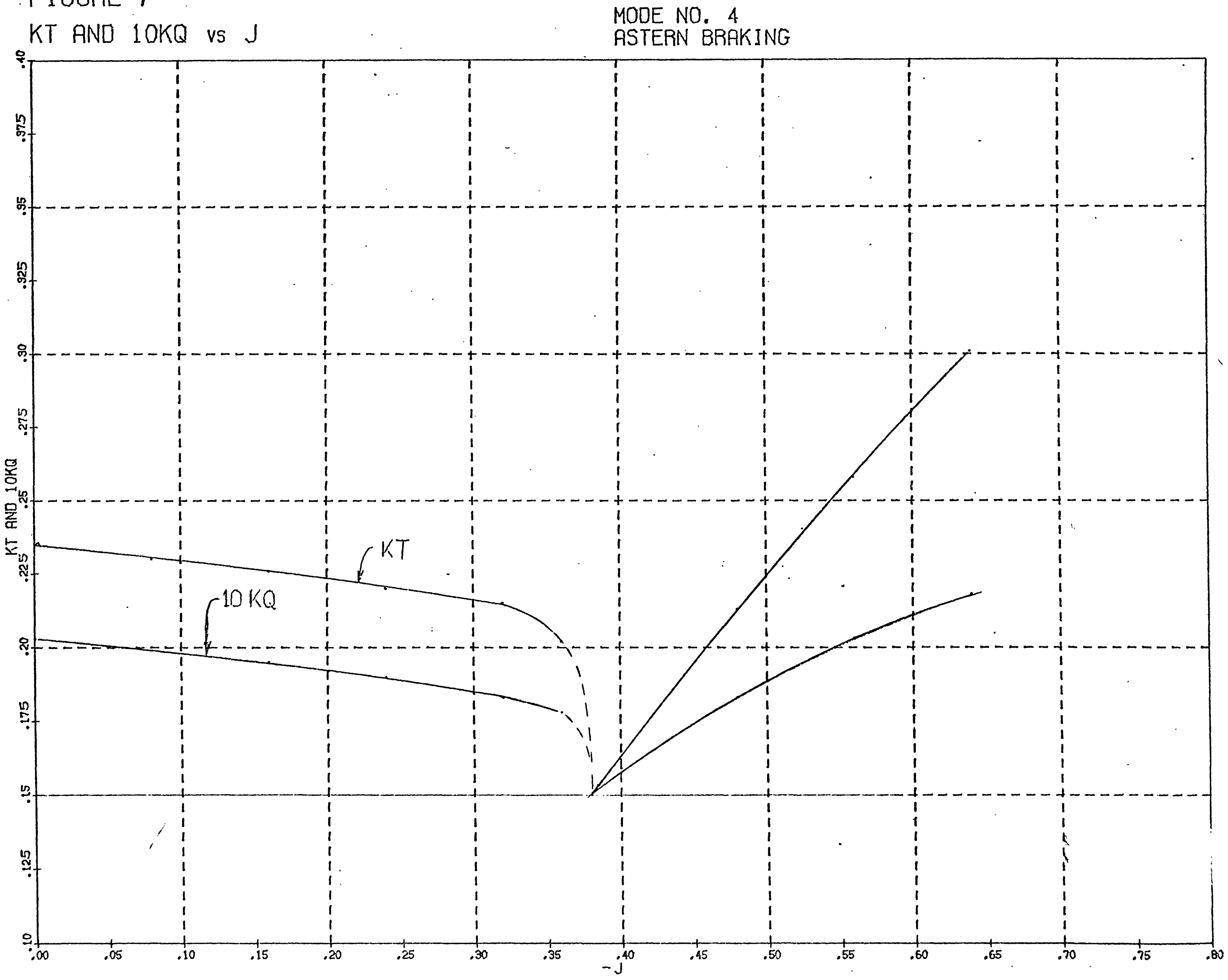


FIGURE 7
KT AND 10KQ vs J



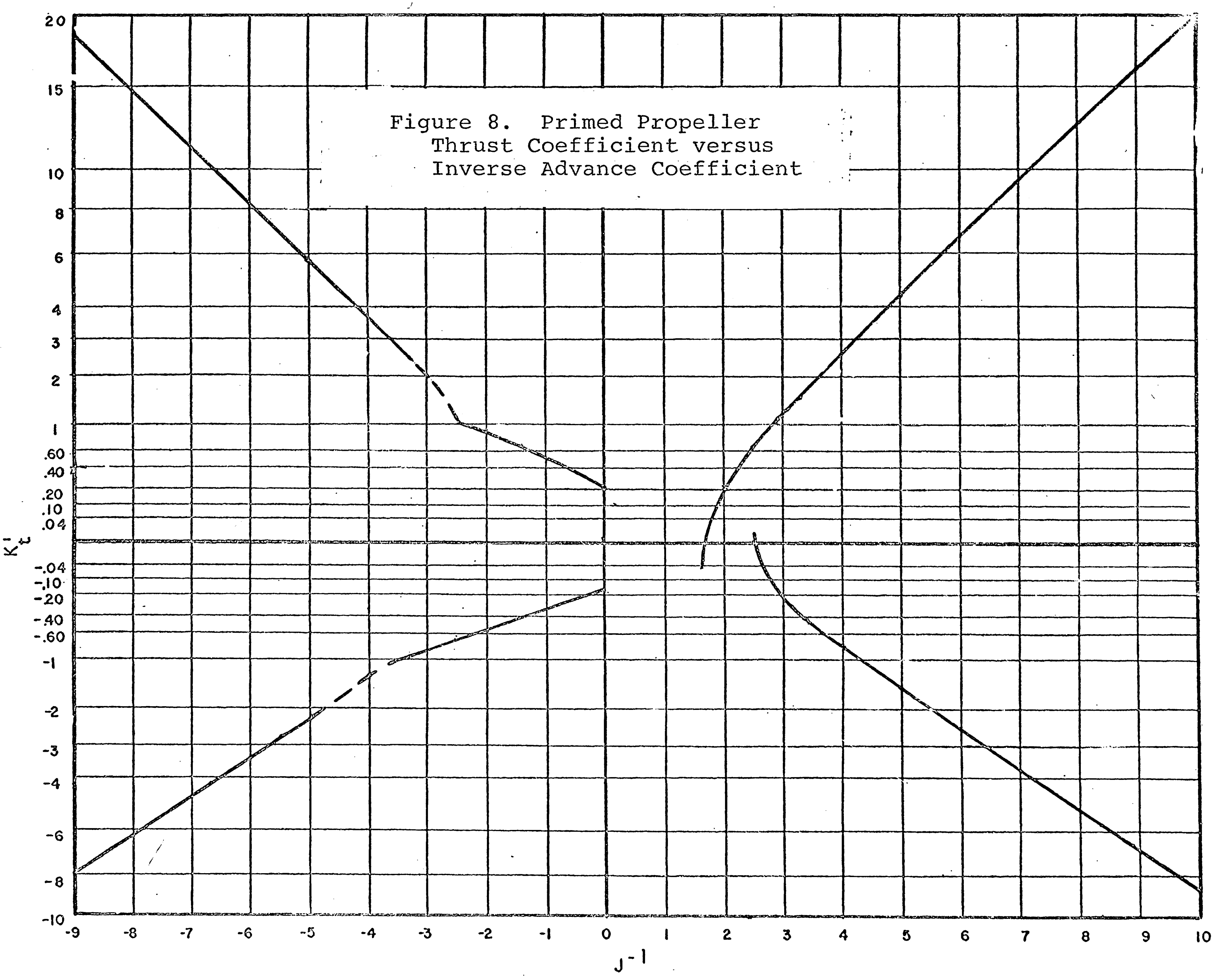


Figure 8. Primed Propeller Thrust Coefficient versus Inverse Advance Coefficient

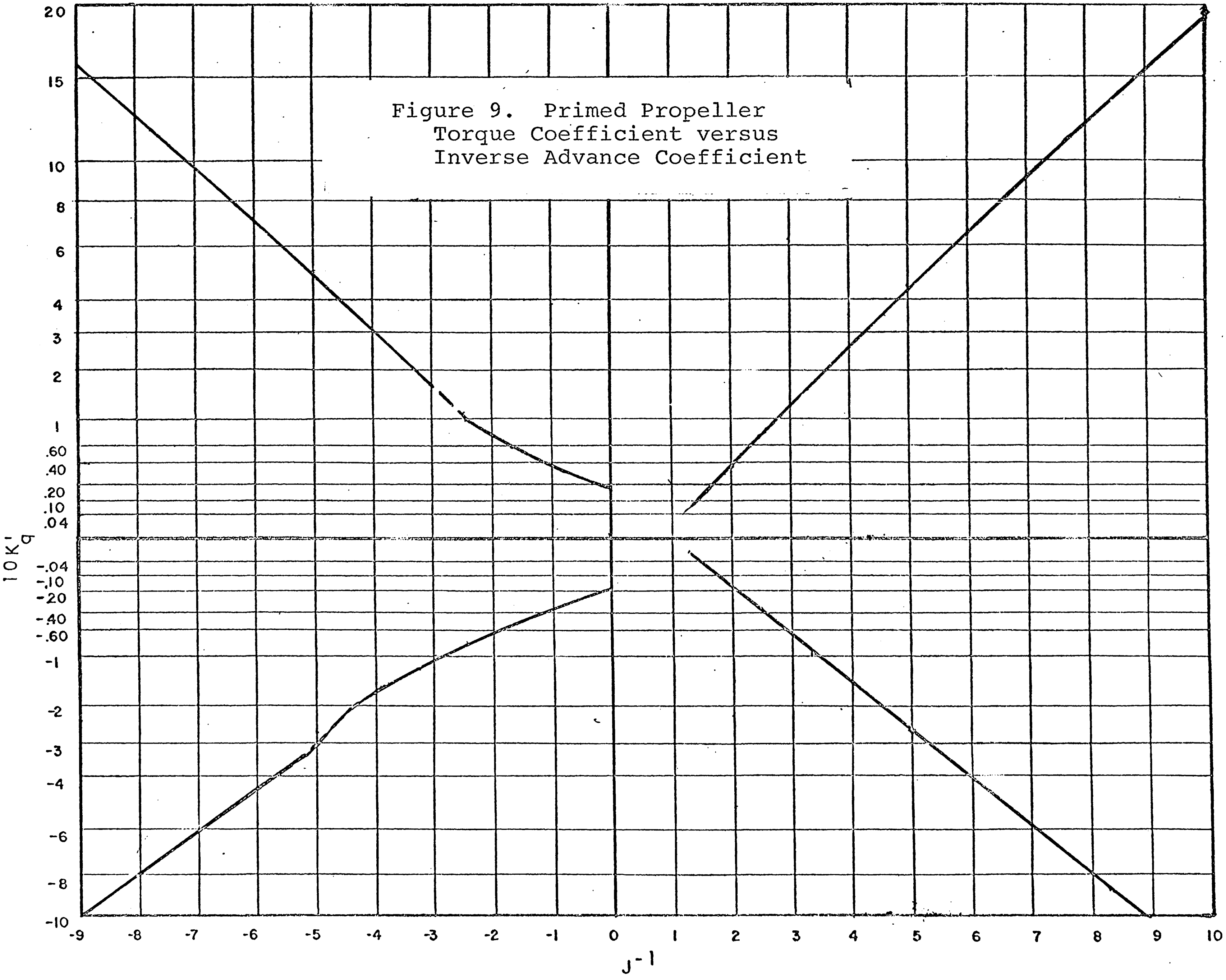


Figure 9. Primed Propeller Torque Coefficient versus Inverse Advance Coefficient

the data was found to depend on RPM only at very low values of RPM, the presented results, which were all obtained at high values of RPM (≈750), can be considered free of scale effects.

The tests where the propeller was moved against its thrust force (Figures 5 and 7) exhibit some interesting features. At low speeds of advance the torque and thrust decrease slightly with increasing J values. At a fixed value of the advance coefficient, (about .20 for negative RPM and about .33 for positive RPM) a complete stalling of the propeller blades occurs which causes a sudden drop-off in propeller force. As the speed is further increased the flow apparently separates completely from the edges of the blades and each blade behaves similar to a flat plate placed in a stream at a large angle of attack.

This separated slow at large negative J values is quite similar to the flow around a locked propeller, $1/J = 0$, at least for propellers with normal pitch diameter ratios and section shapes. That is, the flow is completely separated from the blade edges. Because of this similarity it is possible to predict the thrust and torque on the locked propeller at any given velocity using the torque and thrust coefficients at some large negative J value where separated flow is apparent. All that is necessary is to find a velocity, V_L, where the total force F_L normal to the blades in the locked condition is equal to the total force normal to the blades in the stalled condition (see Figure 10).

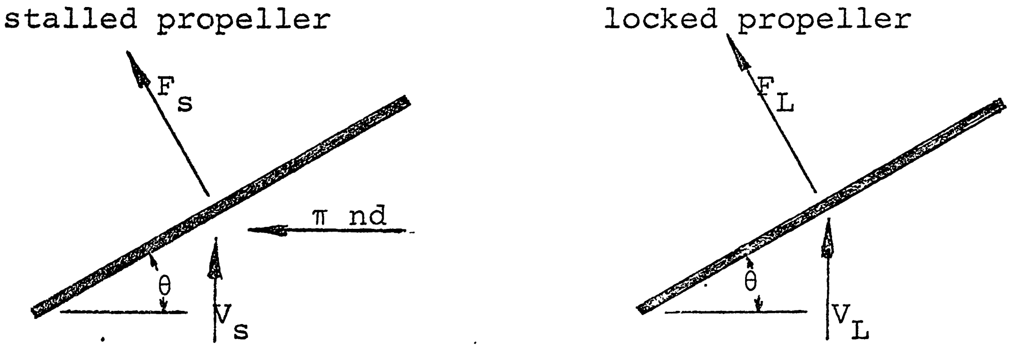


Figure 10. Separated Flow Around a Propeller Blade

Since the forces are all proportional to the normal velocity squared,

$$\sqrt{F_s} \propto \pi \, nd \sin\theta + V_s \cos\theta$$

and

$$\sqrt{F_L} \propto V_L \cos\theta$$

Therefore the condition that $F_s = F_L$ gives

$$V_L = \pi \, nd \tan\theta + V_s$$

But

$$\pi \tan\theta = P_e/d$$

Hence

$$V_L = nP_e + V_s$$

where nP is merely the zero thrust speed of advance.

In words, the speed of advance at which a locked propeller will deliver a given thrust and torque can be found by the following procedure:

1. Assume a value for n
2. Enter a propeller curve such as Figures 5 or 7 with any large negative J value and pick off K_T and K_Q
3. Calculate V_a, T and Q
4. Add the zero thrust speed of advance obtained from a normal propeller curve such as Figure 4 or 6. Use the curves representing the propeller moving ahead or astern depending on whether the locked propeller is moving ahead or astern.
5. The resulting velocity is the velocity at which the locked propeller will generate the thrust and torque calculated in Step 3.

The validity of the above procedure has been demonstrated within experimental accuracy only for the five-bladed Mohole Propellers but there is no apparent reason why it should not apply to any normal marine propeller. This procedure is one of the few ways to get reliable data when testing a locked propeller since the scale effects become very large at low RPM and extrapolation to full scale becomes impossible. The peculiar shape of the torque and thrust coefficients should also be typical of all normal propellers, and must be taken into account when designing propellers for high maneuverability applications.