THE DAVID W. TAYLOR MODEL BASIN

UNITED STATES NAVY

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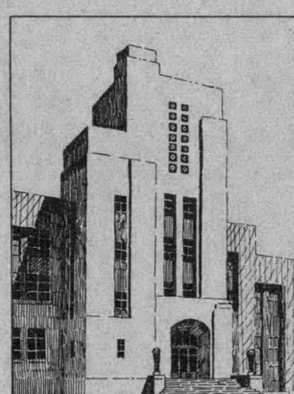
BY DR. K.E. SCHOENHERR, W. H. BOWERS
AND A. Q. AQUINO



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PERSONNEL

The report is the result of cooperative work between various members of the David W. Taylor Model Basin staff. The principal contributors were Dr. K.E. Schoenherr, W.H. Bowers, and A.Q. Aquino.

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ABSTRACT

Data for estimating the torque exerted on a non-rotating propeller moving through the water in a direction parallel to the shaft axis have been assembled from the results of tests on models of various ships and have been evaluated. The data are presented in both tabular and graphical form. Formulas are given for estimating locked torque, which are believed to be accurate within plus or minus five per cent, and which utilize only such data as are conveniently available to the designer.

INTRODUCTION

It is frequently required to know the torque exerted on a non-rotating propeller which is moving at steady speed parallel to its shaft axis. Data of this nature are required for estimating the holding torque which must be allowed for when a vessel is launched with propellers in place or for determining the torque exerted on the turning gear of an idle shaft when a multiple-screw vessel is proceeding with other shafts driving.

The purpose of this report is to present in readily usable form data on locked torque derived from self-propelled tests on models of various types of ships and from tests on model propellers run in the 12-inch variable pressure water tunnel at the David W. Taylor Model Basin.

DESCRIPTION OF THE TESTS

For the self-propulsion tests, standard 20-foot self-propelled models were used. These models were towed by the carriage at various speeds ahead while the self-propulsion dynamometers were set to turn the propellers slowly, first in the ahead direction and then in the astern direction. The torque was measured in the usual manner and was plotted against propeller RPM for each model speed. From this plot the holding torque at zero RPM was obtained by interpolation.

The tests in the water tunnel were conducted in a similar manner, by causing the propellers to move slowly ahead and astern, while the water in the test jet was moving past them.

PRESENTATION OF DATA

The data derived from the self-propulsion tests are shown in Table 1 and the corresponding data derived from the water-tunnel tests on the same propellers are shown in Table 2. Other data, derived from water-tunnel tests on miscellaneous propellers of standard type are given in Figure 1, page 4.

The principal dimensions of the ships and propellers for which the locked torque were determined are shown in Table 1. In Column 13 of this table the measured torque is given in pound-feet for the ship; in Column 15 it is expressed in terms of a coefficient K_{Q_0}.

TABLE 1

Values of Locked Torque Obtained from Tests on Various Models

Model	Type of Ship	Model Prop.	Length feet	Beam feet	Draft feet	Displ. tons	Diam. feet D	Pitch feet P	Developed Area sq. ft. HA	Ship Speed knots V	Wake Fraction w	Locked Torque lb-ft. Q_0	Slip Ratio	Locked Torque Coeff. K_{Q_0}
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
3629	Lake Cargo Vessel	1999	650	70	24	26,050	17.33	12.67	118.3	8 14	0.398 0.397	17,670 54,150	0.412 0.440	0.1304 0.1297
3632	Merchant Tanker	2163	500	68	29.94	21,900	19.5	17.5	138.1	7 10 16	0.355 0.351 0.323	23,800 56,000 130,000	0.350 0.350 0.365	0.1519 0.1725 0.1441
3420	Destroyer	1847 and 1848	341.3	35.9	12.39	2204	11.25	12.5	74.92	8.5 14.5 17.5 23.0	0.000 0.013 0.020 0.002	34,625 89,250 136,000 210,000	0.125 0.125 0.130 0.164	0.2022 0.1811 0.1615 0.1658
3625	Destroyer	2047A and 2048A	369	38.5	12.95	2700	11.375	12.229	76.78	16 20 25 31	0.062 0.056 0.032 0.002	90,000 145,000 229,000 350,000	0.170 0.172 0.192 0.215	0.1604 0.1635 0.1580 0.1467
3735	USMC P2-SE2-R1	2286 and 2287	590	75.5	28.97	22,380	18.25	19.071	125.7	15 20.7	0.120 0.120	194,000 374,000	0.190 0.204	0.1703 0.1721
3740	Escort Vessel	2324 and 2325	300	35.5	10.3	1600	8.50	7.583	28.41	12 19 24	0.043 0.027 0.012	12,000 29,800 46,700	0.175 0.184 0.225	0.1322 0.1267 0.1206

$$K_{Q_0} = \frac{Q_0}{D(HA)[v(1-w)]^2}$$

HA is the developed area in square feet
v is the ship speed ahead in feet per second
w is the wake fraction

The K_{Q_0} coefficient is the ratio of the locked torque divided by the product of the propeller diameter, the developed area of the propeller, and the square of the speed of advance; it is non-dimensional. However, like numerous similar non-dimensional coefficients used in Mechanics, K_{Q_0} is not constant but varies with several propeller characteristics, as will be discussed in a subsequent paragraph.

The torque data obtained in the variable pressure water tunnel on the same propellers as used in the self-propelled tests were also expressed in terms of K_{Q_0}, as shown in Column 7 of Table 2. Comparison of the corresponding coefficients in Tables 1 and 2 shows that the data from the self-propelled tests and from the water-tunnel tests are of the same order and are on the whole consistent, considering that the tests in the water tunnel were made without benefit of the ship form ahead of the propeller.

The test data derived from the water-tunnel tests on miscellaneous propellers were expressed as the ratio of the holding torque to the torque value in the normal ahead condition. Since the latter is a function of the slip, these torque ratios were plotted against slip as shown in Figure 1.

TABLE 2

Values of Locked Torque Obtained from Tests on Various Propeller Models in the 12-inch Water Tunnel

Towing Model	Type of Ship	Model Prop.	Ship Speed knots V	Wake Fraction w	Locked Torque lb-ft. Q_0	Locked Torque Coeff. K_{Q_0}
1	2	3	4	5	6	7
3629	Lake Cargo Vessel	1999	8 14	0.398 0.397	20,000 60,000	0.1485 0.1445
3420	Destroyer	1847 and 1848	8.5 14.5 17.5 23.0	0.000 0.013 0.020 0.002	28,700 83,600 120,300 215,000	0.1652 0.1704 0.1706 0.1700
3735	USMC P2-SE2	2286 and 2287	15 20.7	0.120 0.120	155,000 289,000	0.1358 0.1344
3740	Escort Vessel	2324 and 2325	12 19 24	0.043 0.027 0.012	12,950 31,400 54,400	0.1430 0.1332 0.1405

$$K_{Q_0} = \frac{Q_0}{D(HA)[v(1-w)]^2}$$

HA is the developed area in square feet
v is the ship speed ahead in feet per second
w is the wake fraction

DISCUSSION OF THE RESULTS

As shown in Tables 1 and 2, the vessels and propellers investigated varied greatly in type, size, and speed. The locked-torque values also varied within wide limits, but these variations diminished greatly when the locked-torque data were expressed in the form of dimensionless coefficients.

From theoretical considerations, K_{Q_0} may be expected to vary with the propeller pitch, the number of blades, the blade outline, the position of the propeller blades with respect to the hull and stern-post of the ship, and perhaps other factors. Of these, the pitch has probably the greatest influence. For this reason, the coefficients calculated in Table 1 were plotted against pitch ratio; the results are shown in Figure 2. The spots in this figure are still somewhat scattered, because of other factors not taken into consideration, but they lie within two parallel straight lines whose equations are

$$\text{Upper line, } K_{Q_0} = 0.19\, P/D$$
$$\text{Lower line, } K_{Q_0} = 0.13\, P/D$$

The equation of the mean line is

$$K_{Q_0} = 0.16\, P/D$$

Introducing the mean value for K_{Q_0} in the basic relation, it follows from the preceding discussion that the locked torque for a propeller on any normal vessel when going ahead may be determined within an accuracy of plus or minus 10 per cent by the formula

$$\text{Locked Torque } Q_0 = 0.16\, P(HA)[v(1-w)]^2 \qquad [1]$$

where

P is the propeller pitch in feet
HA is the developed area of the propeller in square feet
v is the ship speed in feet per second
w is the wake fraction.

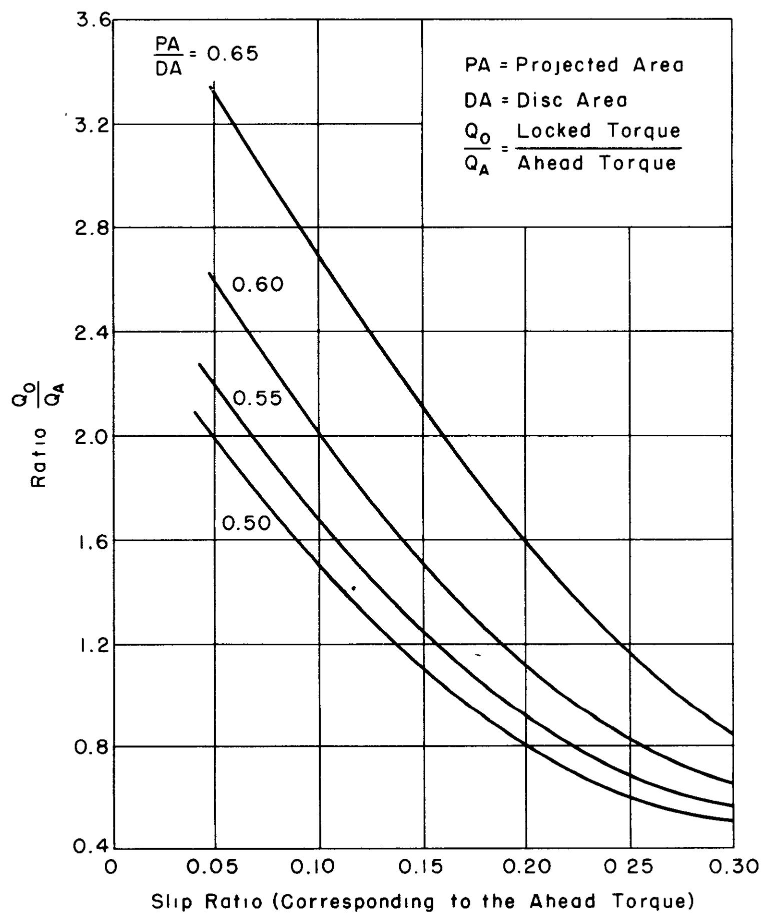

Figure 1 - Preliminary Faired Curves Giving Ratio of

$$\frac{\text{Locked Torque}}{\text{Ahead Torque}} = \frac{Q_A}{Q_0}$$

In all cases Q_A and Q_0 refer to torques at the same speed of advance.

An alternative expression for locked torque which interprets the experimental data with an accuracy of plus or minus 5 per cent is

$$K_{Q_0} = 0.233\, P/D\, [v(1 - w)]^{-\frac{1}{8}} \qquad [2]$$

or

$$\text{Locked Torque } Q_0 = 0.233\, P(HA)[v(1 - w)]^{1.875} \qquad [3]$$

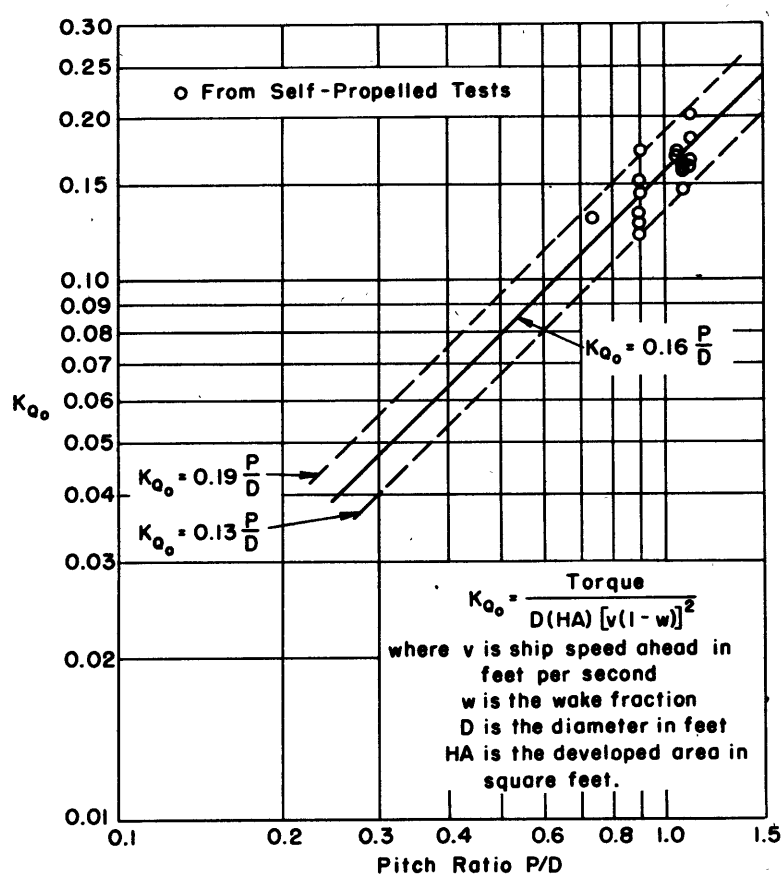

Figure 2 - Locked-Torque Coefficient Plotted against Pitch Ratio

It will be noted that Formulas [1], [2], and [3] contain only terms that are available to the designer or that may be readily estimated. Moreover, since the coefficients in these formulas were derived from tests on models of ships differing as widely as a Great Lakes ore carrier and a fast destroyer, the formulas may be expected to give results accurate within the limits stated, when applied to all ships of normal type.

When the full-power-ahead torque and the true slip are known for a propeller-vessel combination for which the locked torque is to be estimated, the data presented in Figure 1 may be used instead of the formulas just given. By entering the plot with the slip ratio as abscissa, the ratio of locked torque to ahead torque is read from the proper curve or is interpolated between the curves, whence the locked torque may be calculated directly.

Table 3 shows how the values of locked torque compare, first, as determined experimentally, second, as calculated by Formulas [1] and [3], and third, as calculated from Figure 1.

The agreement among Columns 4, 5, 6, 7, and 8 of Table 3, while not exact, is close enough for most engineering calculations.

TABLE 3

Comparison of Locked-Torque Values Determined Experimentally and by Formulas

Model	Type of Ship	Ship Speed knots	Experimental: Self-Propelled Model Test	Experimental: Water Tunnel Test	Results Using Figure 1	Values from Formula [1]	Values from Formula [3]
1	2	3	4	5	6	7	8
3629	Lake Cargo Vessel	8 14	17,670 54,150	20,000 60,000	Outside Accurate Extrapolation	15,900 48,800	17,750 50,750
3632	Merchant Tanker	7 10 16	23,800 56,000 130,000		25,800 50,900 149,000	22,500 46,700 129,600	25,400 50,000 131,000
3420	Destroyer	8.5 14.5 17.5 23.0	34,625 89,250 136,000 210,000	28,700 83,600 120,300 215,000	27,500 84,500 117,500 200,000	30,500 87,600 125,800 225,200	32,260 85,750 120,200 207,900
3625	Destroyer	16 20 25 31	90,000 145,000 229,000 350,000		73,000 114,700 190,500 303,800	96,600 151,000 250,900 410,700	98,500 150,200 229,600 364,000
3735	USMC P2-SE2-R1	15 20.7	194,000 374,000	155,000 289,000	141,000 253,000	190,600 363,300	188,300 344,200
3740	Escort Vessel	12 19 24	12,000 29,800 46,700	12,950 31,400 54,400	12,650 32,650 51,700	12,950 33,550 55,250	12,920 31,780 50,500

Formula [1]: $Q_0 = 0.16\, P\,(HA)[v(1-w)]^2$ Formula [3]: $Q_0 = 0.233\, P\,(HA)[v(1-w)]^{1.875}$

REFERENCES

(1) BuShips letter S44(3454) of 24 August 1942 to Director, David Taylor Model Basin.