REPORT No. 447

STATIC THRUST OF AIRPLANE PROPELLERS

By Walter S. Diehl

SUMMARY

Static thrust data from more than 100 airplane propeller tests are collected from various sources and combined in working charts, from which the static thrust coefficient K_{T_0} in the equation

$$T_0 = \frac{K_{T_0} \times \text{b. hp}}{\text{r. p. m.} \times \text{diam.}}$$

may be readily determined. The available data cover practically all types of propellers and are in good agreement. For extreme pitch ratios, or for very low and for very high blade settings, the values of K_{T_0} are shown to deviate considerably from the generally used linear relations based on data at moderate pitch ratios.

INTRODUCTION

The static thrust of a propeller was formerly of interest only in connection with proposed helicopter designs, but the advent of very high powers and corresponding high performance in recent airplane designs have made in necessary to consider the static thrust as a design factor. At present the chief applications of accurate static thrust data are in the calculation of nosing-over moments and the estimation of take-off runs.

The available methods of calculating static thrust are based on constants derived from Durand and Lesley's tests on wooden propellers. (Reference 4.) It is the purpose of this report to revise the constants and to extend the methods to include recent data on adjustable metal propellers.

Warner shows in reference 1 that the thrust per horsepower is obtained by division, from the coefficients

$$C_T = \frac{T}{\rho n^2 D^4} \tag{1}$$

and

$$C_P = \frac{P}{\rho n^3 D^5} \tag{2}$$

giving

$$\frac{T}{P} = \frac{C_T}{C_P} \frac{1}{nD}$$

or

$$T = \frac{C_T}{C_P} \frac{P}{nD} \tag{3}$$

In Chapter XIV of reference 2, Mr. Warner states: "It can be shown from propeller theory that the static thrust per horsepower for a propeller is equal to a constant divided by the product of the r. p. m. of the propeller and its diameter, and experiments by Durand have shown that the average value of the constant ranges from 49,000 for propellers designed to work normally at a value of V/nD of 1.1 up to 79,000 when V/nD for maximum efficiency is 0.5 - - - -. The variation of the coefficient is approximately linear between the points given."

In reference 3 the author gives the static thrust formula

$$T_0 = 6{,}000\left(18.7 - 9.5\frac{p}{D}\right)\frac{\text{b. hp}}{(\text{r. p. m.}) \times D} \tag{4}$$

Where T_0 is the static thrust in pounds, p/D is the nominal pitch/diameter ratio and D is the diameter in feet. The value of the constant in equation (4) was based on Durand and Lesley's data and is substantially identical with Warner's values as quoted above.

It will be shown that the static thrust coefficient K_{T_0} in the equation

$$T_0 = \frac{K_{T_0} \times \text{b. hp}}{(\text{r. p. m.}) \times D} \tag{5}$$

can be determined with fair accuracy for any propeller from data usually available or readily obtained.

DURAND AND LESLEY'S TESTS

In Table V of reference 4, Durand and Lesley give the "standing thrust and power" for 67 propellers. these include a number of variations in blade section and blade form that are of academic interest only, since practically all propellers now in use are in the S_1 F_2 class. Table I lists the essential data including the static thrust coefficient K_{T_0} for all of the S_1 F_2 propellers. K_{T_0} is found from the relation

$$K_{T_0} = 33{,}000\frac{C_T'}{C_P'}$$

the conversion factor 33,000 being required for the units of b. hp and r. p. m. in equation (5).

The values of K_{T_0} are plotted against p/D on Figure 1. The dashed line on this figure corresponds to equation (4) and may be represented by

$$K_{T_0}=112{,}400-57{,}000\frac{p}{D} \tag{6}$$

or

$$K_{T_0}=57{,}000\left(1.97-\frac{p}{D}\right) \tag{6a}$$

both of which are identical with equation (4).

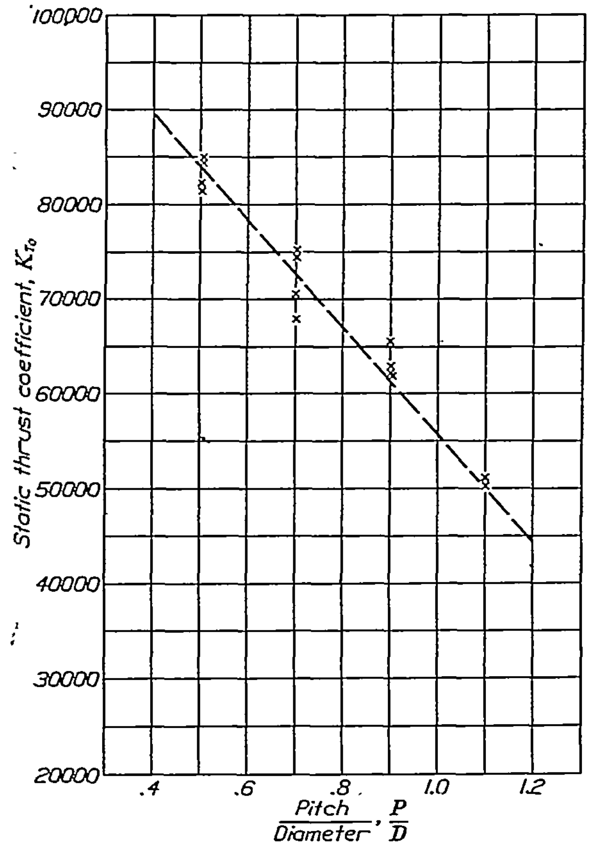

FIGURE 1.—Static thrust coefficients for 2-blade wooden propellers. Durand and Lesley's tests. N. A. C. A. Technical Report No. 30

N. A. C. A. TESTS

Three series of systematic tests on adjustable blade metal propellers have been made by the National Advisory Committee for Aeronautics in the propeller research tunnel at Langley Field. (References 5, 6, and 7.) Static thrust data from these reports are given in Tables II to V, inclusive, and the values of K_{T_0} are plotted against blade setting at 0.75 R in Figure 2. There is a considerable scattering of the points probably due to fuselage interference effects and to the method of obtaining the static values of C_T and C_P by extrapolation but the trend of the variation is well defined. It is of considerable interest to note the reduction in static thrust at high pitch angles for propellers with the Clark Y section. This characteristic, which may be due to an early stalling of the blade sections, has been observed in flight tests to such an extent that a separate curve is apparently required for these propellers. As shown by the data from Technical Report No. 351 (reference 6), given in Table III, cutting off the tips to reduce the diameter does not appreciably affect the static thrust coefficient.

BRITISH TESTS

A very complete investigation of propeller characteristics is covered by Reports and Memoranda No. 829 of the British Aeronautical Research Committee. (Reference 8.) Static thrust data from this report are given in Tables VI and VII. The former covers propellers having constant pitch along the blade, while the latter have the variable pitch distribution obtained with the usual blade adjustment. Values of K_{T_0} are plotted against blade angle at 0.75 R on Figure 3. The data are usually consistent due to care exercised in eliminating interference and fall very close to the three curves, the one for two blades being identical with that given on Figure 2.

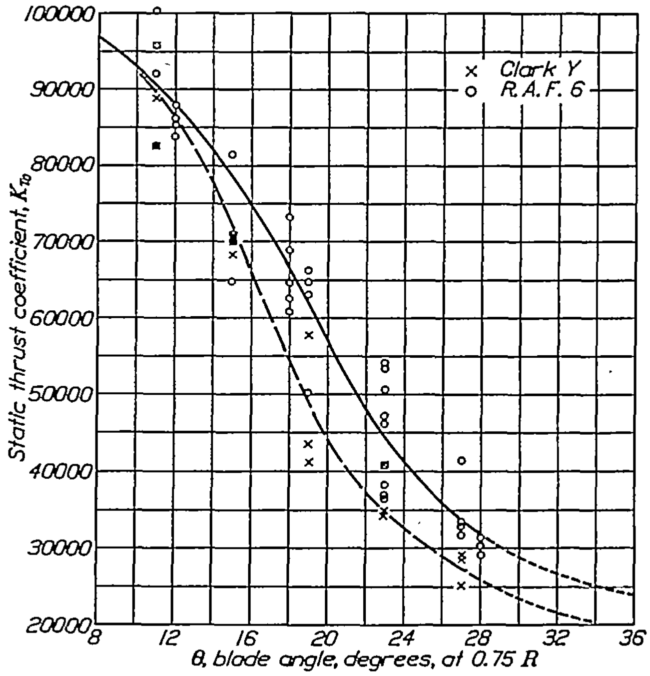

FIGURE 2.—Static thrust coefficients for adjustable blade metal propellers

THE CALCULATION OF STATIC THRUST

For any given set of design conditions the static thrust may be calculated from equation (5):

$$T_0=\frac{K_{T_0}\times(\text{b.hp})}{(\text{r.p.m.})\times(\text{diam.})} \tag{5}$$

the proper value of K_T being obtained from Figures 1, 2, or 3. In the case of adjustable blade metal propellers it is common practice to specify the blade setting in terms of the blade angle at the 42-inch radius. Figure 4 has been prepared for obtaining blade angles at 0.75 R from the values at the 42-inch radius, for conventional pitch distributions. This curve gives the correction $\Delta\theta$ to be added to or subtracted from the blade angle at the 42-inch radius to obtain the blade angle at the 0.75 R.

In design studies it is more convenient to work with the V/nD for maximum efficiency than with the blade angle. Figure 5 is a plot of K_{T_0} against V/nD for maximum efficiency, using the data from Tables I to VII. The points appear to fall nearer to regular curves than when p/D or θ is used as the base.

In using equation (5), the full rated b.hp and r.p.m. may be used without appreciable error since the ratio b.hp/r.p.m. is substantially constant for full-throttle operation.

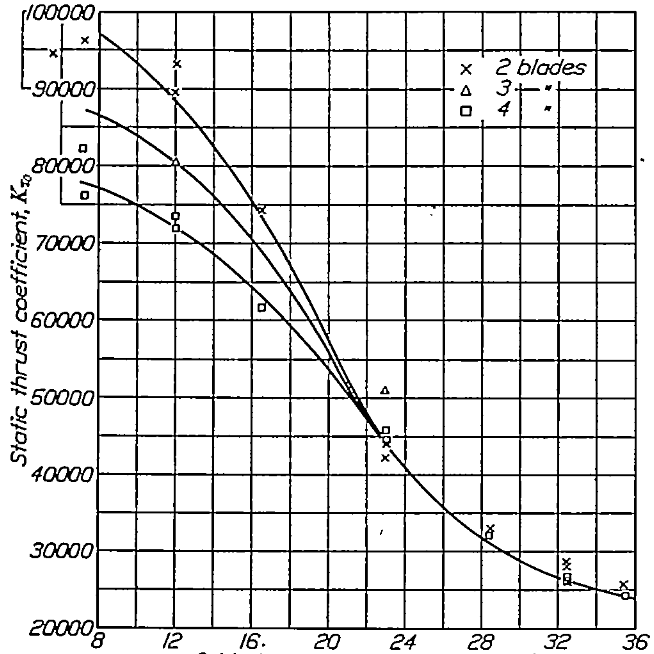

FIGURE 3.—Static thrust coefficients for metal propellers. British tests, R. & M. No. 829

CONCLUSIONS

A study of the collected data leads to the following conclusions:

1. In general, narrow blades give a higher static thrust coefficient than wide blades.
2. Thin blades appear to give a higher static thrust coefficient for low pitch setting and less static thrust at high pitch settings than thick blades.
3. Blade section may be very important in determining the static thrust coefficient at high pitch settings.
4. There is a decrease in the static thrust coefficient due to the use of 3 or 4 blades at low pitch settings but the curves converge into one curve at and above a blade setting of 23° at 0.75 R.
5. The effect of gearing an engine is to reduce the propeller r. p. m., to increase the diameter, and to increase the pitch or blade angle required. With large reduction ratios the effect of the increased diameter and the reduction in K_{T0} corresponding to the increased pitch may more than offset the effect of the change in r. p. m., and thus reduce the static thrust.

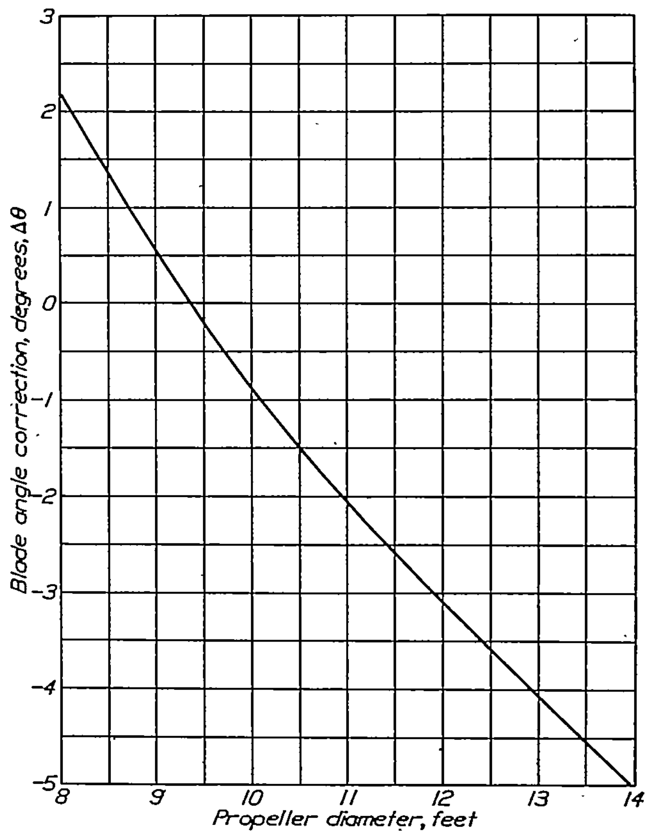

FIGURE 4.—Correction for obtaining blade angle at 0.75 radius from blade setting at 42″ station. Positive (+) values of $\Delta\theta$ to be added to setting at 42″ station, negative (−) values to be subtracted to get blade angle at 0.75 radius. Example: For 10 ft. dia. Prop. $\Delta\theta = -.9°$. $\theta_{0.75R} = \theta_{42''} - .9°$

6. The variable pitch propeller will give a large increase in static thrust coefficient when the available blade setting change is sufficient to attain blade angles of 12° or less.

BUREAU OF AERONAUTICS,
NAVY DEPARTMENT,
WASHINGTON, D. C. *Sept., 1932.*

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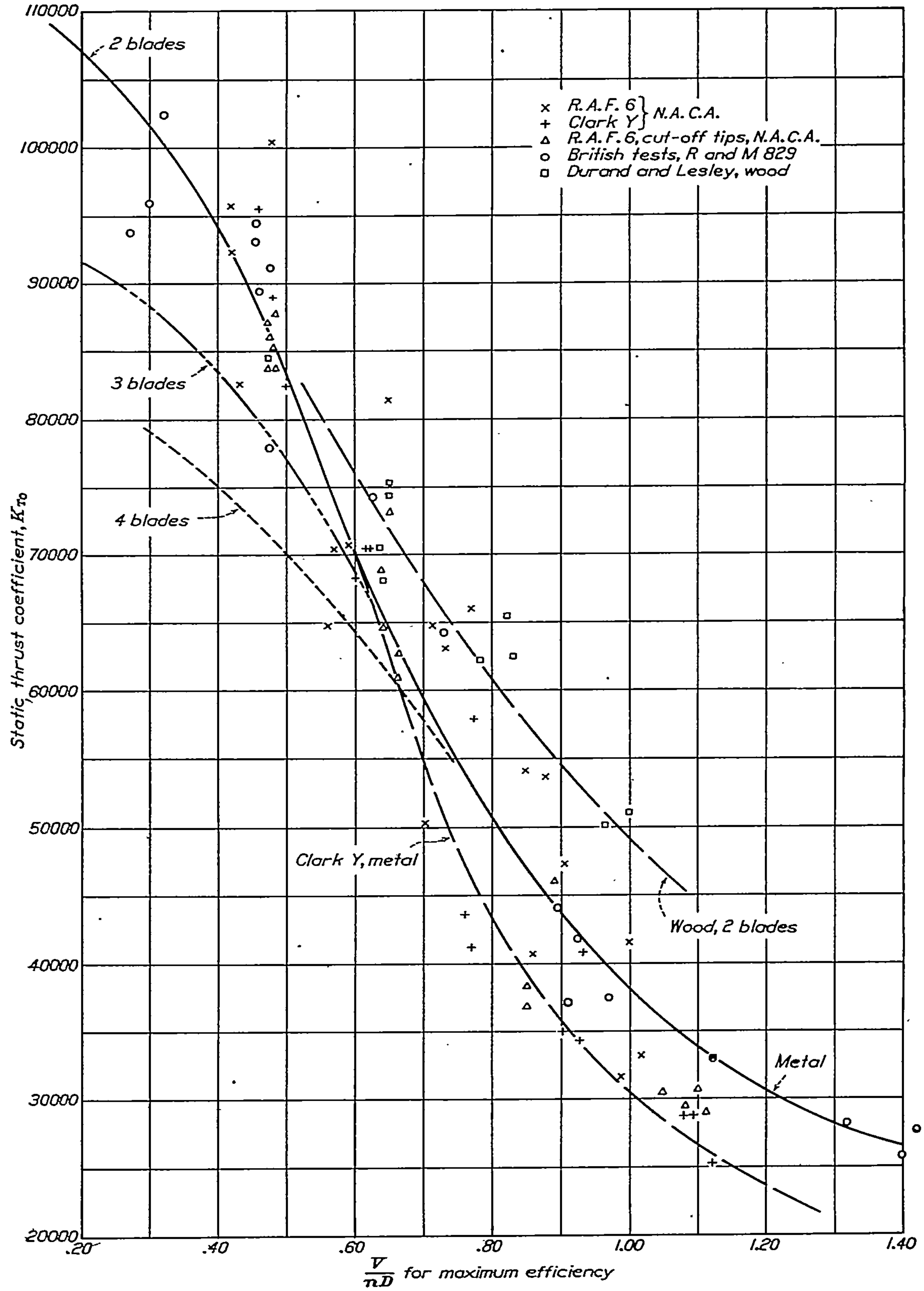
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2 blades
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4 blades
Clark Y, metal
Wood, 2 blades
Metal
× R.A.F. 6 } N.A.C.A.
+ Clark Y }
△ R.A.F. 6, cut-off tips, N.A.C.A.
○ British tests, R and M 829
□ Durand and Lesley, wood
Static thrust coefficient, K_{T_0}
$\frac{V}{nD}$ for maximum efficiency

FIGURE 5.

TABLE I

STATIC THRUST COEFFICIENTS FOR WOODEN PROPELLERS—DATA FROM DURAND AND LESLEY'S TESTS, TABLE V, N. A. C. A. TECHNICAL REPORT NO. 30

Prop. No.	$\frac{b}{D}$	$\frac{p}{D}$	Maximum efficiency		Thrust coefficient $C_T'=\frac{T_0}{g\rho n^2D^4}$	Power coefficient $C_P'=\frac{P_0}{g\rho n^3D^5}$	Static thrust coefficient $K_{T_0}=33000\frac{C_T'}{C_P'}$
			η_m	V/nD for η_m			
3	0.075	0.9	0.810	0.83	0.0160	0.00340	62800
4	.100	.9	.793	.78	.0195	.01035	62200
7	.075	.7	.778	.65	.0149	.00662	74300
8	.100	.7	.759	.63	.0164	.00769	70400
11	.075	.5	.703	.49	.0120	.00470	84300
12	.100	.5	.670	.47	.0123	.00490	82100
15	.075	.9	.804	.82	.0168	.00348	65400
16	.100	.9	.803	.80	.0188	.01000	61900
19	.075	.7	.781	.65	.0137	.00601	75100
20	.100	.7	.772	.64	.0164	.00300	67700
23	.075	.5	.699	.48	.0112	.00435	84800
24	.100	.5	.690	.47	.0121	.00491	81400
82	.075	1.1	.834	1.00	.0158	.01021	51000
83	.100	1.1	.818	.96	.0189	.01248	50000

TABLE II

STATIC THRUST COEFFICIENTS FOR METAL PROPELLERS N. A. C. A. TESTS, TECHNICAL REPORT NO. 306

Blade setting at 0.75R θ	Static thrust coefficient C_{T_0}	Static torque coefficient C_{P_0}	$\frac{V}{nD}$ for η_m	Static thrust coefficient K_{T_0}
11°	0.079	0.026	0.48	100300
15°	.094	.038	.65	81400
19°	.101	.050	.77	66200
23°	.096	.067	.91	47200
27°	.099	.098	1.13	33000

TABLE III

STATIC THRUST COEFFICIENTS FOR ADJUSTABLE METAL PROPELLERS WITH CUT-OFF TIPS N. A. C. A. TESTS, TECHNICAL REPORT NO. 351

Diameter D feet	Blade angle at 0.75R θ	Static values		Maximum efficiency		Static thrust coefficient K_{T_0}	$\frac{b}{D}$
		C_{T_0}	C_{P_0}	η_m	V/nD for η_m		
	°						
10.0	12	0.066	0.026	0.733	0.48	83700	0.0803
	17	.091	.041	.790	.05	73200	
	23	.080	.072	.819	.85	36700	
	28	.089	.101	.836	1.08	29000	
9.5	12	.080	.031	.714	.48	85200	.0845
	17	.096	.046	.771	.63	68900	
	23	.096	.083	.808	.85	38200	
	28	.108	.118	.822	1.05	30200	
9.0	12	.093	.035	.705	.48	87700	.0892
	17	.102	.052	.759	.64	64600	
	23	.110	.100	.791	.87	36300	
	28	.114	.125	.810	1.05	30100	
8.5	12	.098	.037	.689	.47	87400	.0945
	17	.116	.063	.756	.66	60700	
	23	.126	.090	.785	.89	46100	
	28	.134	.153	.800	1.11	28900	
8.0	12	.099	.038	.675	.47	86000	.1005
	17	.127	.067	.740	.66	62500	
	23	.149	.097	.772	.92	50600	
	28	.148	.159	.780	1.10	30700	

TABLE IV

STATIC THRUST COEFFICIENTS FOR ADJUSTABLE PITCH PROPELLERS WITH NAVY STANDARD SECTION (MODIFIED R. A. F.-6) N. A. C. A. TESTS, TECHNICAL REPORT NO. 378

Camber ratio	Blade setting at 0.75R θ	C_{T_0}	C_{P_0}	Maximum efficiency		Static thrust coefficient K_{T_0}
				η_m	V/nD for η_m	
	°					
0.06	11	0.081	0.028	0.700	0.42	95600
	15	.083	.039	.753	.57	70400
	19	.102	.067	.795	.70	50100
	23	.113	.092	.810	.86	40500
	27	.111	.112	.820	1.02	33300
.08	11	.081	.029	.690	.42	92000
	15	.080	.041	.740	.56	64700
	19	.098	.050	.780	.71	64700
	23	.102	.062	.805	.85	54100
	27	.115	.120	.820	.99	31600
.10	11	.075	.030	.660	.43	82400
	15	.088	.041	.732	.59	70900
	19	.101	.053	.782	.73	63000
	23	.106	.065	.802	.88	53600
	27	.116	.092	.805	1.00	41600

TABLE V

STATIC THRUST COEFFICIENTS FOR ADJUSTABLE PITCH PROPELLERS WITH CLARK Y SECTION N. A. C. A. TESTS, TECHNICAL REPORT NO. 378

Camber ratio	Blade setting at 0.75R θ	C_{T_0}	C_{P_0}	Maximum efficiency		Static thrust coefficient K_{T_0}
				η_m	V/nD for η_m	
	°					
0.06	11	0.081	0.028	0.725	0.46	95600
	15	.081	.039	.777	.60	68200
	19	.106	.085	.802	.77	41100
	23	.114	.108	.815	.90	34800
	27	.097	.110	.820	1.03	28800
.08	11	.078	.029	.750	.48	88800
	15	.083	.039	.795	.62	70400
	19	.074	.056	.810	.76	43500
	23	.088	.085	.820	.93	34100
	27	.105	.120	.826	1.09	28800
.10	11	.075	.030	.746	.50	82400
	15	.085	.040	.778	.62	70400
	19	.091	.052	.802	.77	57800
	23	.098	.079	.813	.93	40900
	27	.086	.113	.828	1.12	25100

TABLE VI

STATIC THRUST COEFFICIENTS FOR METAL PROPELLERS DATA FROM BRITISH A. R. C. R. & M. NO. 829

Data from Table No.	Blades				Pitch diam.	Maximum efficiency		Static data		Static thrust coefficient K_{T_0}
	No.	Width diam. $\frac{b}{D}$	Blade angle at 0.75R θ (°)	(′)	$\frac{P}{D}$	η_m	V/nD for η_m	Thrust coefficient K_{T_0}'	Torque coefficient K_{Q_0}	
6(1)	2	0.082	7	15	0.3	0.545	0.300	0.0622	0.00341	95900
6(2)	4	.082	7	15	.3	.446	.288	.0928	.00638	76400
6(3)	2	.082	12	0	.5	.734	.456	.0910	.00514	93000
6(4)	4	.082	12	0	.5	.630	.480	.1400	.01003	73300
6(5)	2	.082	16	30	.7	.780	.624	.1145	.00811	74200
6(6)	4	.082	16	30	.7	.725	.623	.1860	.0159	61500
6(7)	2	.082	23	0	1.0	.85	.928	.1200	.0151	41700
6(8)	4	.082	23	0	1.0	.84	.945	.2180	.0257	44500
6(9)	2	.082	32	30	1.5	.867	1.400	.1330	.0269	25900
6(10)	4	.082	32	30	1.5	.865	1.370	.2440	.0469	26200
6(11)	3	.082	12	0	.5	.664	.465	.1210	.0792	80200
6(12)	3	.082	23	0	1.0	.852	.955	.1827	.01888	50800
6(13)	2	.123	23	0	1.0	.842	.967	.1953	.01835	55800
6(14)	2	.0615	23	0	1.0	.875	.970	.0881	.01210	37400
6(15)	4	.0615	23	0	1.0	.837	.920	.1550	.0214	38000
6(16)	2	.041	23	0	1.0	.832	.910	.0536	.00760	37000
6(17)	3	.041	23	0	1.0	.865	.933	.0780	.01130	36200
6(18)	4	.041	23	0	1.0	.855	.950	.1000	.01490	35200
6(19)	6	.041	23	0	1.0	.807	.893	.1395	.02113	34700
6(20)	2	.123	12	0	.5	.663	.475	.1140	.00769	77900
6(21)	2	.0615	12	0	.5	.738	.456	.0727	.00415	94700
6(22)	4	.0615	12	0	.5	.653	.465	.1224	.00816	78900
6(23)	2	.041	12	0	.5	.758	.477	.0500	.00288	91200
6(24)	3	.041	12	0	.5	.684	.455	.0692	.00423	85900
6(25)	4	.041	12	0	.5	.665	.455	.0867	.00561	81200
6(26)	6	.041	12	0	.5	.613	.434	.1135	.00313	73500

TABLE VII

STATIC THRUST COEFFICIENTS FOR ADJUSTABLE PITCH METAL PROPELLERS—DATA FROM BRITISH A. R. C. R. & M. NO. 829

Data from Table No.	Blades				Pitch diam.	Maximum efficiency		Static data		Static thrust coefficient K_{T_0}
	No.	Width diam. $\frac{b}{D}$	Blade angle at 0.75R θ (°)	(′)	$\frac{P}{D}$	η_m	V/nD for η_m	Thrust coefficient K_{T_0}'	Torque coefficient K_{Q_0}	
7 (1)	2	0.082	7	15	0.33	0.551	0.320	0.0659	0.00338	102500
7 (2)	2	.082	12	0	.51	.715	.460	.0950	.00568	89100
6 (5)	2	.082	16	30	.70	.780	.624	.1145	.00811	74200
7 (3)	2	.082	23	0	1.00	.853	.896	.1235	.01475	44000
7 (4)	2	.082	28	30	1.25	.886	1.127	.1332	.02096	33300
7 (5)	2	.082	32	30	1.45	.896	1.424	.1383	.0255	28400
7 (6)	2	.082	35	30	1.64	.885	1.583	.1445	.0293	25900
7 (7)	2	.082	34	15	1.52	.837	1.320	.1458	.0271	28200
6 (1)	2	.082	7	15	.30	.545	.300	.0622	.00341	95900
7 (8)	2	.082	5	30	.28	.445	.272	.0556	.00328	93900
6 (9)	2	.082	32	30	1.40	.867	1.400	.1330	.0269	25900
7 (9)	4	.082	7	15	.33	.480	.312	.0987	.00631	82200
7(10)	4	.082	12	0	.51	.637	.480	.1393	.01022	71600
6 (6)	4	.082	16	30	.70	.725	.623	.1860	.0159	61400
7(11)	4	.082	23	0	1.00	.805	.896	.2245	.02585	45600
7(12)	4	.082	28	30	1.25	.847	1.136	.2330	.0379	32300
7(13)	4	.082	32	30	1.45	.855	1.236	.2395	.0471	26700
7(14)	4	.082	35	30	1.64	.882	1.560	.2170	.0534	24300