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TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 246

TEST OF A MODEL PROPELLER WITH SYMMETRICAL BLADE SECTIONS

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Washington
September, 1926

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Summary

This report, prepared at the request of the National Advisory Committee for Aeronautics, gives the results of tests on a model propeller having blade sections with form of Göttingen airfoil No. 409. The model is shown to have a dynamic pitch practically equal to the nominal or geometrical pitch, and a somewhat higher efficiency but lower power coefficient than would be expected of a propeller of more conventional sections.

Test Propeller

The form of the test propeller is shown in the accompanying Fig. 1. As may be seen, the plan form is that of the Stanford University Laboratory series designated as A_1F_2 (Reference 1). The elevation is symmetrical, and the sections, except for the 4" and 7" radii, are Göttingen airfoil No. 409, (Fig. 2). The sections are thus practically symmetrical about the chord; the lower camber, driving face of the propeller, being slightly the flatter.

In order that the model propeller might be strong and rigid enough for testing purposes, the sections at the 4" and 7" radii were made thicker than the Göttingen airfoil. For the 4" radius section, it was at first planned to add 100% to the ordinates of the airfoil, and for the 7" radius section, 20%. However, in order to produce a fair and smooth form, gradually changing from the Göttingen airfoil, at the 10" radius, to the hub, modifications of the original plan to the dimensions shown in Fig. 1 were adopted.

The model was made by carving from a stick of sugar pine, built up of laminations 1" thick, hot glued together. The laminations were placed in planes parallel to the axis of the propeller and were thus at right angles to the usual position. This arrangement has been found to give greater freedom from warping than if the models are carved from a single stick, or if the laminations are placed as usual, parallel to the plane of rotation.

The model was given several coats of orange shellac, each coat being rubbed down with fine sand paper, and a final coat of prepared wax. The surface was thus smooth and polished.

Tests

The usual tests were conducted. With a wind velocity of from 53 to 57 feet per second, the model propeller was driven at suitable angular velocities to develop a series of thrusts from zero to 33 pounds. To secure data for greater slip than obtainable under these conditions, the wind velocity was reduced.

The observed and computed data for the tests are given in Table I. In this table, as well as in Tables II and III, the following notation is used:

$\rho V^2/2$ = Dynamic pressure of wind stream - lb. per sq.ft.

ρ = Mass density of air - pound, foot, second, units.

V = Velocity - feet per second.

n = Revolutions per second.

T = Thrust - pounds.

Q = Torque moment - pound - feet.

D = Diameter - feet.

C_t = Thrust coefficient $= \dfrac{T}{\rho n^2 D^4}$

C_p = Power coefficient $= \dfrac{P}{\rho n^3 D^5}$ where P is power absorbed in foot pounds per second.

η = Efficiency $= \dfrac{TV}{P} = \dfrac{C_t}{C_p} \dfrac{V}{nD}$

The values of C_t (thrust coefficient), C_p (power coefficient), and η (efficiency) are plotted in Fig. 3. Consistent curves are drawn representing what appear to be the most probable laws of variation of these coefficients with V/nD, under the conditions of the tests.

Since it was desired to compare the results of these tests with those for propellers No. 3 and No. 27 of the Stanford Laboratory series, data from tests conducted in 1917 and 1918 are given in Tables II and III. These models were not available for retest at the time tests were conducted on the symmetrical section model No. 3, having been badly damaged in an accident and No. 27 lost. However, recent tests of other models give practically the same results as tests in 1917 and 1918, and it is therefore assumed that the early tests on No. 3 and No. 27 are sufficient for the comparison with the symmetrical section model. The coefficients C_p, C_t, and η for these tests are shown graphically in Figs. 4 and 5.

Discussion

As would be expected from the aerodynamic characteristics of the section, the symmetrical section propeller has a dynamic pitch practically equal to the nominal or geometrical pitch. The efficiency seems unusually high for a propeller with a dynamic pitch ratio of .89. From tests of models of the U.S. Navy Standard plan form, it appears that a maximum efficiency of about 78% may be expected, for a dynamic pitch ratio of .9, with propellers having more conventional sections (Reference 2). On the other hand, the power coefficients (C_p) for the symmetrical section model are considerably smaller than those for propellers of more usual form and of the same dynamic pitch.

Compared to propellers 3 and 27, it may be seen that the symmetrical section propeller shows considerably higher efficiency over the usual working range of V/nD. A difference of this nature would be expected, however, between two propellers having the same sections but different dynamic pitch.

The power coefficients for the symmetrical section propeller are much smaller than those for propellers No. 3 and No. 27. But here, as with efficiency, the difference may be mainly charged to difference in dynamic pitch.

For the symmetrical section propeller, it may be noted that at the small values of V/nD there is a marked increase in the value of the power coefficient. The result is that the efficiency curve at this point is concave upward and the efficiency is somewhat less than for either propeller No. 3 or No. 27. The rise in the value of C_p at extreme slip is believed to be due either to increased pitch, from warping under load, or to flutter, or to both. A decided increase in noise made was noted at the extreme slip.

As a matter of interest, values of C_p, C_t, and η were computed for this propeller from the simple airfoil theory. They are as follows:

V/nD	C_p	C_t	η
.4	.0484	.0749	.619
.5	.0451	.0675	.748
.6	.0388	.0524	.810
.7	.0281	.0336	.838
.8	.0169	.0173	.817

On comparison with Fig. 3, it will be seen that the coefficients C_p and C_t as computed are considerably less (5 to 15%) than those derived from test. The observed and computed efficiencies are generally close, the maximum difference being about 3%.

Table I

Model Propeller 187
Free Wind Stream
Observed Data

$\rho V^2/2$	ρ	V	n	T	Q	V/nD	C_t	C_p	η
			April 5, 1926						
3.231	.002285	53.18	19.88	.00	.137	.892	.0000	.0039	.000
3.339	.002285	54.06	22.03	1.32	.702	.818	.0147	.0164	.733
3.339	.002285	54.06	23.91	2.98	1.309	.754	.0281	.0259	.819
3.438	.002276	54.96	26.58	5.29	2.155	.689	.0406	.0347	.807
3.483	.002275	55.34	29.28	8.27	3.117	.630	.0523	.0413	.798
3.618	.002270	56.46	32.52	11.90	4.224	.579	.0612	.0455	.779
3.654	.002269	56.75	35.76	16.21	5.446	.529	.0689	.0485	.752
3.645	.002269	56.68	39.29	21.17	6.791	.481	.0746	.0501	.716
3.672	.002269	56.89	42.82	26.79	8.296	.443	.0795	.0516	.683
3.744	.002266	57.48	46.24	33.07	10.010	.414	.0843	.0534	.653
1.827	.002271	40.11	43.70	33.07	9.099	.306	.0941	.0542	.531
1.422	.002271	35.39	43.37	33.07	9.207	.272	.0956	.0557	.467
.360	.002271	17.80	42.33	33.07	9.996	.140	.1003	.0635	.221
			April 14, 1926						
3.330	.002289	53.94	24.07	2.98	1.324	.747	.0277	.0258	.802
3.771	.002273	57.60	46.28	33.07	9.916	.415	.0839	.0527	.660
3.132	.002273	52.49	45.30	33.07	9.555	.386	.0875	.0530	.637

Table II

Model Propeller 3
Free Wind Stream
Observed Data

$\rho V^2/2$	ρ	V	n	T	Q	V/nD	C_t	C_p	η
3.240	.002267	53.46	15.69	.58	.650	1.136	.0128	.0301	.484
3.450	.002266	55.18	19.64	3.47	2.010	.937	.0490	.0595	.772
3.420	.002266	54.94	19.64	3.68	1.990	.933	.0520	.0589	.823
3.790	.002261	57.90	27.93	12.67	5.460	.691	.0887	.0800	.766
4.010	.002261	59.56	31.94	18.44	7.460	.622	.0987	.0836	.734
4.140	.002261	60.51	35.87	25.48	9.590	.562	.1082	.0852	.713
4.310	.002255	61.74	40.00	33.26	11.950	.515	.1138	.0856	.685
4.560	.002255	63.51	44.30	42.30	14.620	.478	.1180	.0854	.661
3.900	.002273	58.58	17.85	1.30	1.064	1.094	.0222	.0380	.638
3.974	.002273	59.16	20.48	3.49	2.070	.963	.0452	.0561	.776
3.956	.002273	59.00	23.23	6.60	3.270	.847	.0664	.0689	.817
4.025	.002273	59.51	26.74	10.90	4.880	.742	.0828	.0776	.792
4.150	.002273	60.43	30.50	16.55	6.800	.660	.0966	.0831	.768
–	.002335	–	17.00	8.54	2.070	.000	.1562	.0793	.000

Table III

Model Propeller 27
Free Wind Stream
Observed Data

$\rho V^2/2$	ρ	V	n	T	Q	V/nD	C_t	C_p	η
3.24	.002244	53.74	15.85	.43	.940	1.130	.0094	.0431	.247
3.39	.002244	54.97	19.30	3.41	2.240	.950	.0504	.0693	.690
3.72	.002244	57.58	23.50	7.87	4.050	.817	.0784	.0845	.758
3.91	.002285	58.50	18.50	1.76	1.738	1.054	.0278	.0575	.509
3.93	.002282	58.60	18.60	1.81	1.635	1.050	.0283	.0535	.556
3.97	.002282	58.98	20.30	3.76	2.504	.968	.0494	.0689	.694
4.00	.002279	59.25	22.40	6.32	3.520	.882	.0682	.0796	.756
4.07	.002279	59.76	25.20	10.37	5.080	.730	.0885	.0908	.770
4.09	.002335	59.18	28.30	15.63	7.000	.697	.1032	.0968	.743
4.27	.002335	60.47	31.60	21.61	9.060	.638	.1144	.1004	.727
4.44	.002335	61.67	35.00	28.36	11.310	.587	.1224	.1022	.703
4.61	.002335	62.84	38.70	36.30	13.930	.541	.1282	.1030	.673
2.06	.002328	42.08	29.00	21.62	7.780	.484	.1363	.1027	.642
2.24	.002328	43.87	32.80	28.77	10.050	.446	.1418	.1037	.610
2.44	.002327	45.80	36.60	36.65	12.510	.417	.1451	.1037	.584
2.66	.002327	47.82	40.20	45.64	15.130	.397	.1498	.1040	.572
--	.002220	--	24.20	18.50	4.698	.000	.1757	.0934	.000

References

1. Durand, W. F. and Lesley, E. P. : Experimental Research on Air Propellers - V. N.A.C.A. Technical Report No. 141 - 1925.

2. Durand, W. F. and Lesley, E. P. : Comparison of Tests on Air Propellers in Flight with Wind Tunnel Model Tests on Similar Forms. N.A.C.A. Technical Report No. 220 - 1926.

Appendix

Comparison of the Symmetrical Section Propeller Characteristics with Those of a Standard Durand Model.

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In comparing the symmetrical section propeller with other propellers of about the same dynamic pitch, the efficiency of the symmetrical propeller has been found to be considerably higher over the working range of V/nD, especially at low slips. The power coefficients, however, have been found to be lower, indicating that a propeller of this type would have a somewhat larger diameter than one with common flat faced blade sections.

From the above comparison, it might be assumed that the propeller with symmetrical sections would show a better performance on an airplane, especially around maximum speed. This, however, is not necessarily true. If the symmetrical propeller had the same dynamic pitch in feet, it would require a larger diameter to absorb the same power. Thus it would have a lower dynamic pitch-diameter ratio, and would be working at a lower value of V/nD, where its efficiency would be somewhat lower. By this comparison, the relative effectiveness of the propellers is but vaguely and indefinitely shown.

A better method of comparison is one taken from the point of view of the performance required of a propeller on an airplane. A propeller must absorb a given power at a certain forward velocity and at a definite number of revolutions per unit time. A nondimensional coefficient conveniently involving these factors is

$$\sqrt{\frac{\rho V^5}{Pn^2}}$$

where V = velocity of airplane in ft. per sec.

n = revolutions per sec. of propeller.

P = power absorbed in ft. lb. per sec.

ρ = mass density of air in slugs per cu.ft.

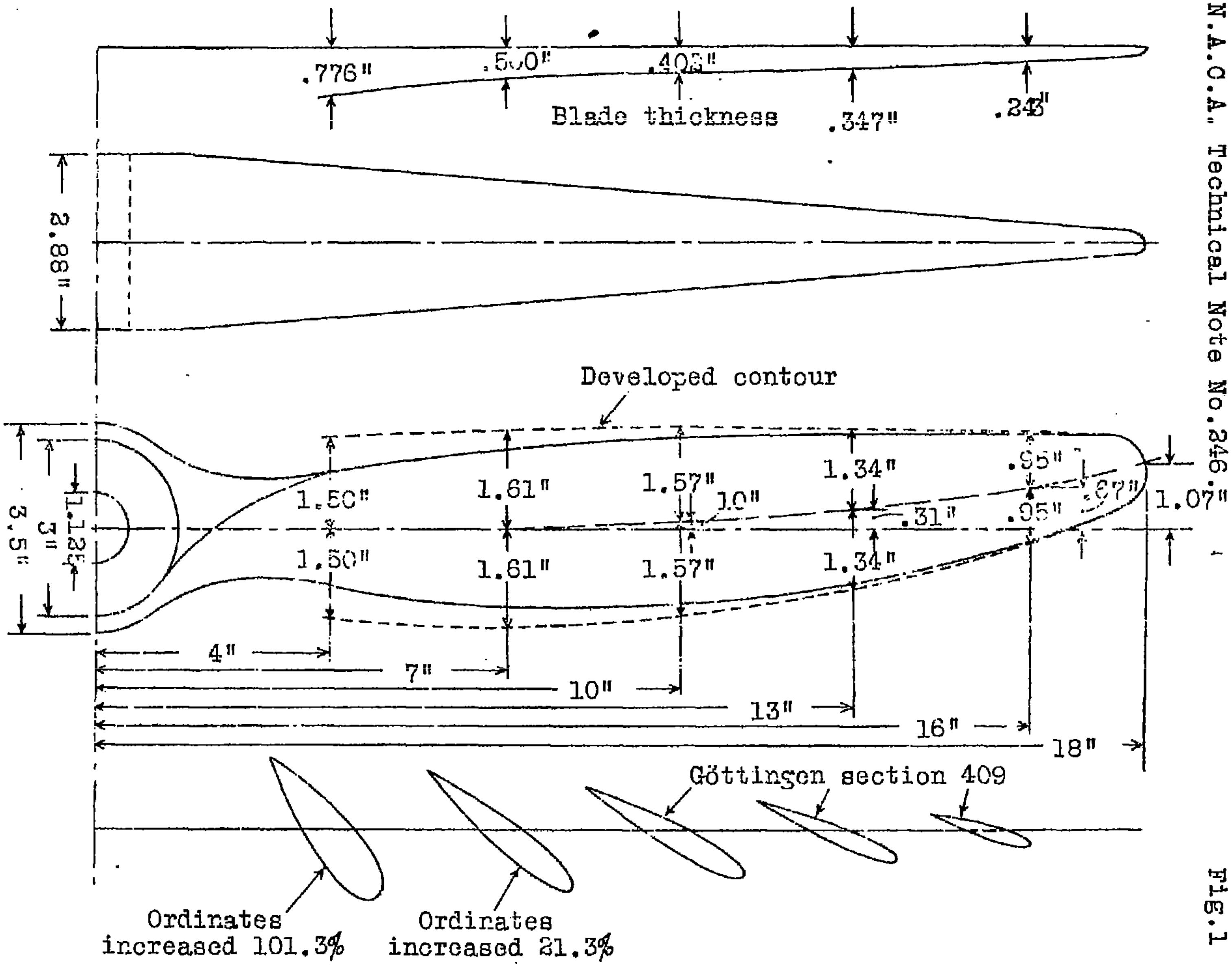
The efficiencies of different propellers operating at the same value of $\sqrt{\frac{\rho V^5}{Pn^2}}$ give a direct comparison of their effectiveness under the same operating conditions. In order to compare the effectiveness of two propellers of similar plan form but with different sections, their efficiency curves should both be maximum at the same value of the performance coefficient $\sqrt{\frac{\rho V^5}{Pn^2}}$. Then the efficiencies plotted against $\sqrt{\frac{\rho V^5}{Pn^2}}$ will afford a direct comparison of the effectiveness of the propellers at all operating conditions.

It is desirable to compare the efficiency of the symmetrical section propeller with that of one of the standard Durand propellers having the same plan form. The maximum efficiency of the symmetrical propeller occurs at a value of the performance coefficient of

$$\sqrt{\frac{\rho V^5}{Pn^2}} = \sqrt{\frac{\left(\frac{V}{nD}\right)^5}{C_p}} = \sqrt{\frac{(.72)^5}{.0306}} = 2.51.$$

Durand propeller No. 3 also has its maximum efficiency at approximately the same value of $\sqrt{\frac{\rho V^5}{Pn^2}}$. In Fig. 6 the efficiencies of both propellers are plotted against values of $\sqrt{\frac{\rho V^5}{Pn^2}}$. It will be noticed that the maximum efficiencies are practically the same for both propellers, indicating that their effectiveness is about equal at high speed. At the lower values of $\sqrt{\frac{\rho V^5}{Pn^2}}$ corresponding to climbing speeds, the symmetrical section propeller is slightly better, but throughout the whole working range the curves follow each other within the limits of experimental error.

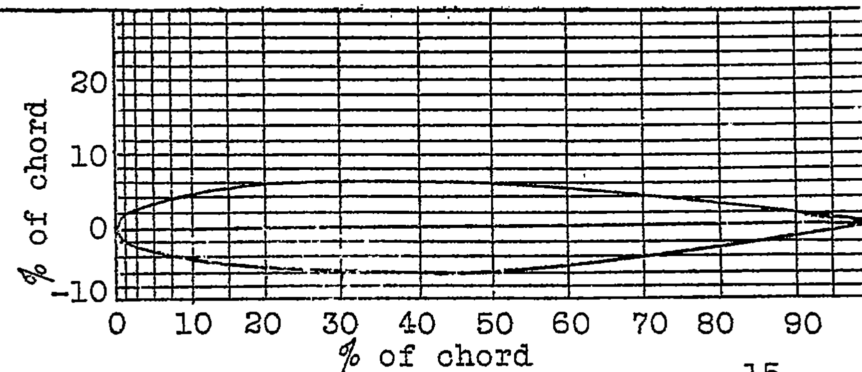
From the point of view of operating efficiency on an airplane, therefore, there is little to choose between the two forms of propellers.

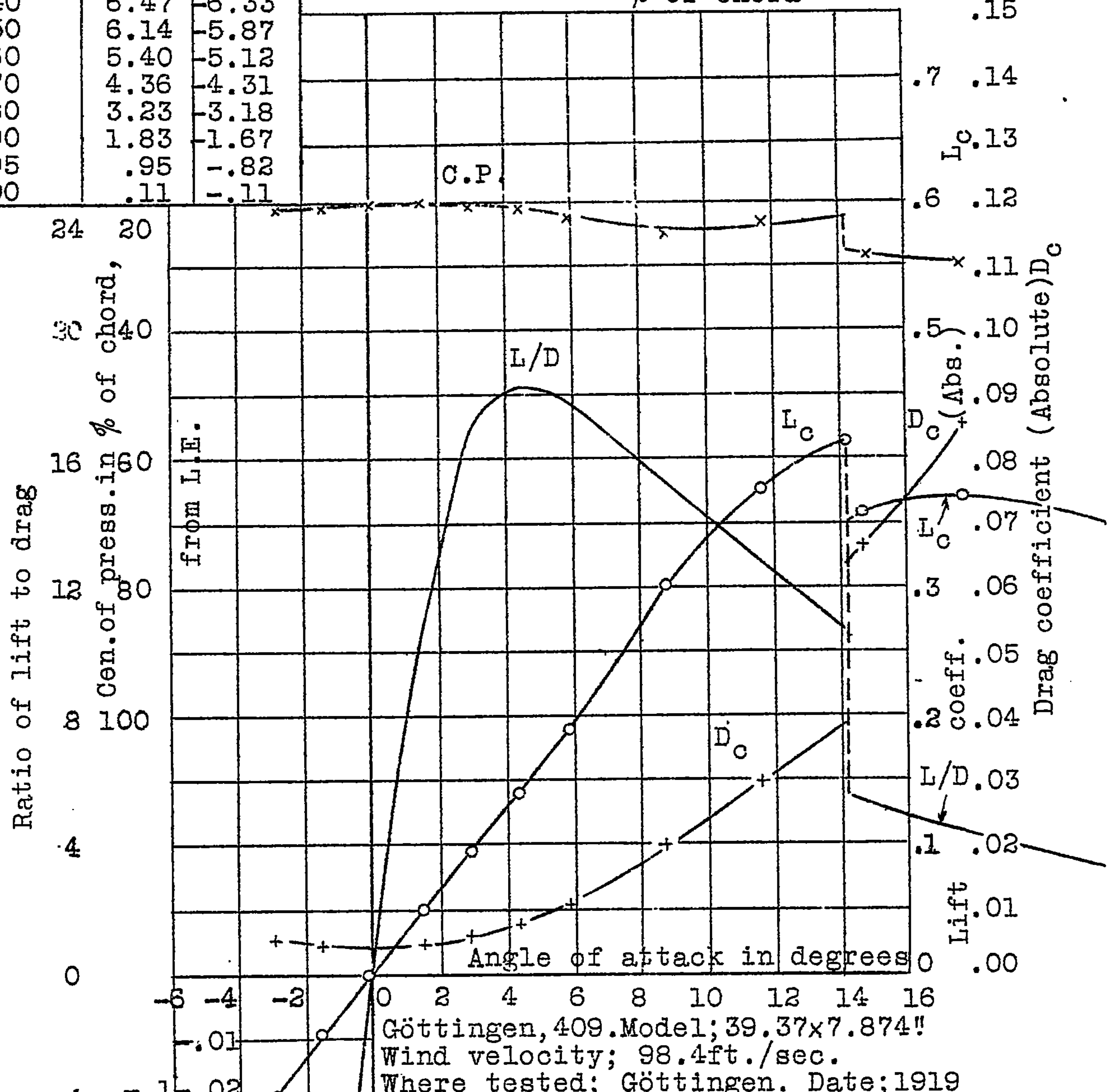


Modified Göttingen section 409.

Fig.1 Model propeller No.187. Geometric pitch 2.7ft.

%	Up'r	Lw'r
0	0.00	000
1.125	2.10	-1.75
2.500	2.85	-2.48
5.00	3.68	-3.34
7.50	4.31	-4.04
10	4.85	-4.58
15	5.55	-5.28
20	6.03	-5.71
30	6.47	-6.34
40	6.47	-6.33
50	6.14	-5.87
60	5.40	-5.12
70	4.36	-4.31
80	3.23	-3.18
90	1.83	-1.67
95	.95	-.82
100	.11	-.11





Göttingen, 409. Model; 39.37x7.874"
Wind velocity; 98.4ft./sec.
Where tested; Göttingen. Date; 1919

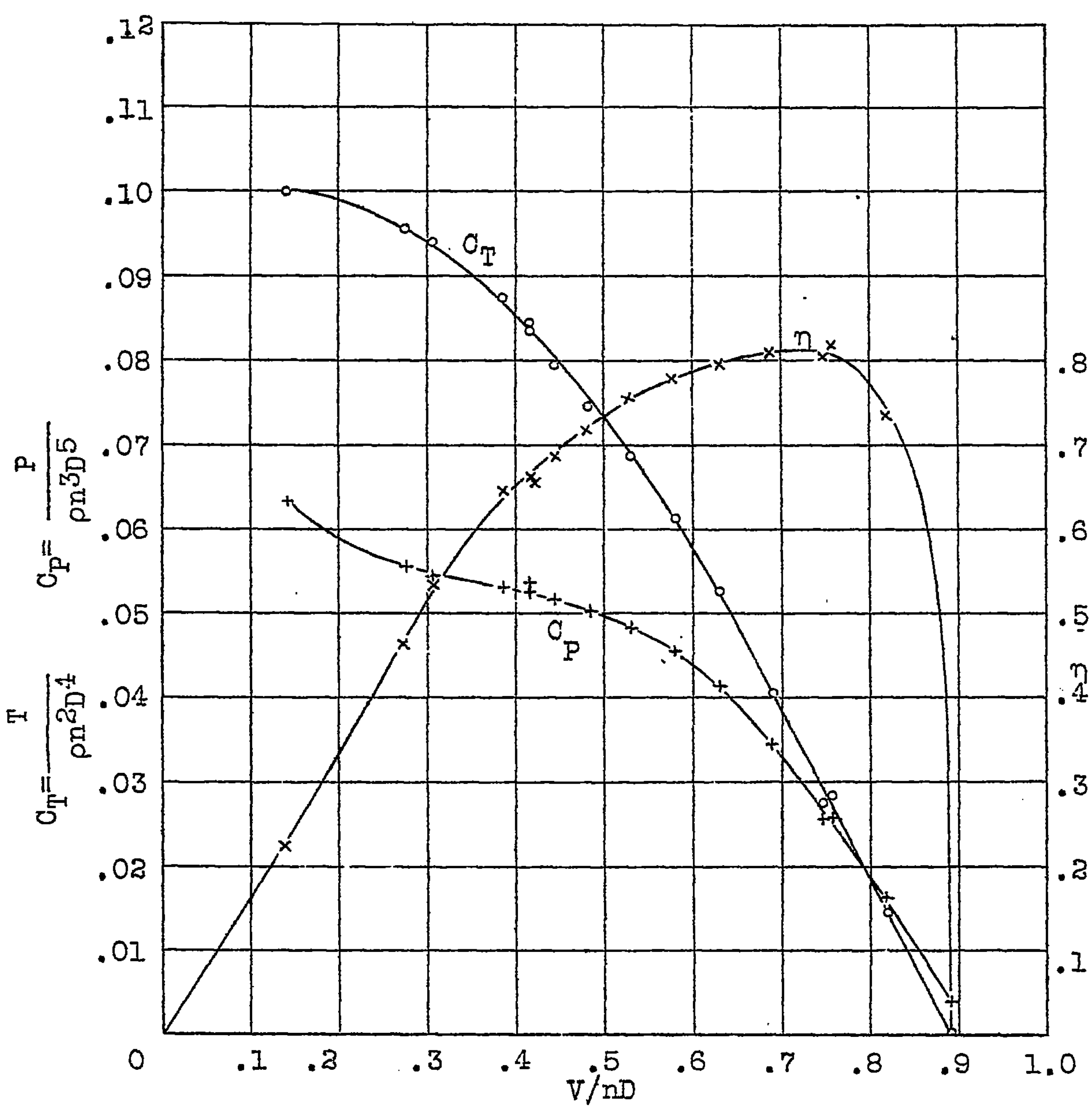


Fig. 3 Symmetrical blade section, model propeller No.187.

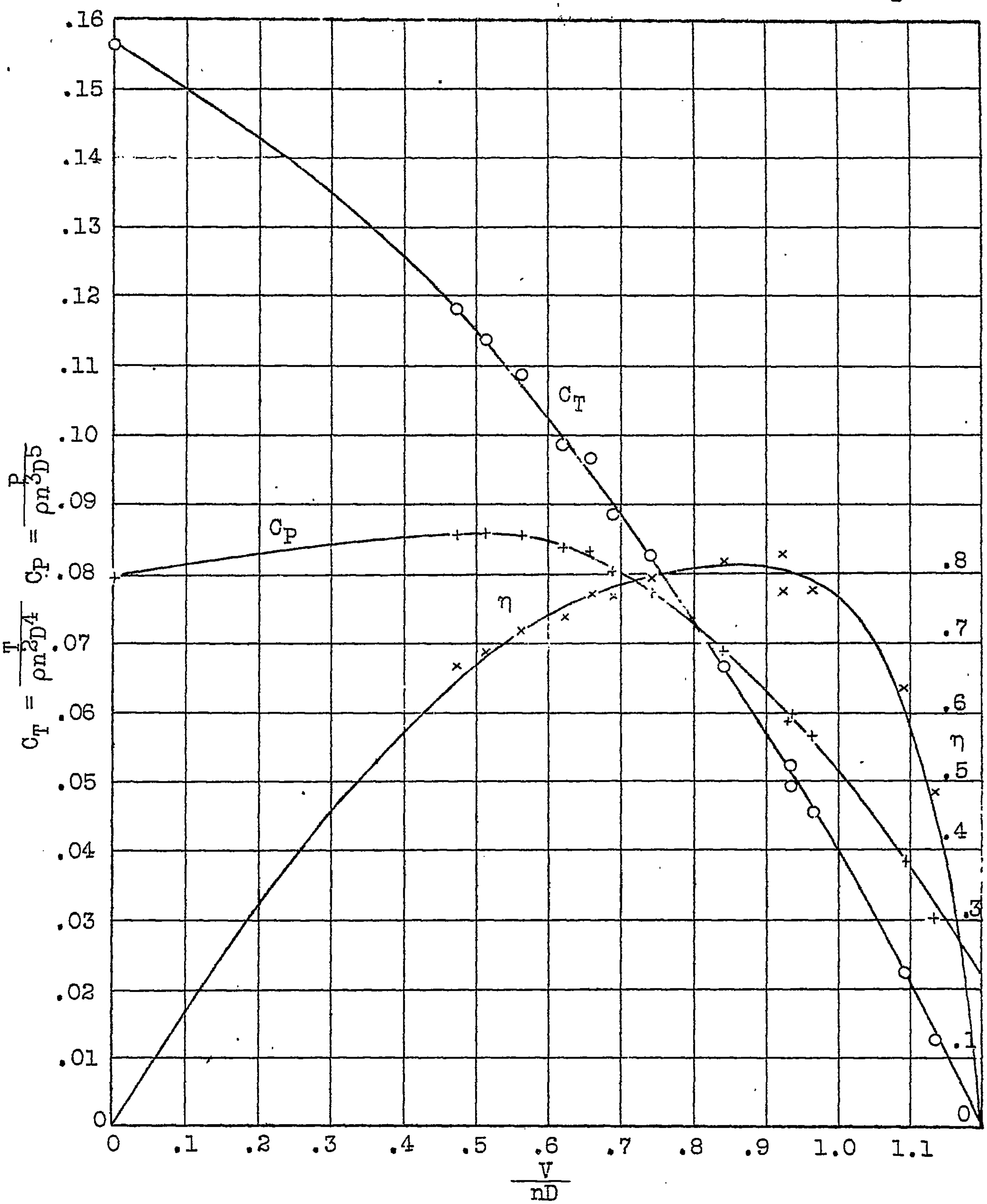


Fig.4 Model propeller No.3

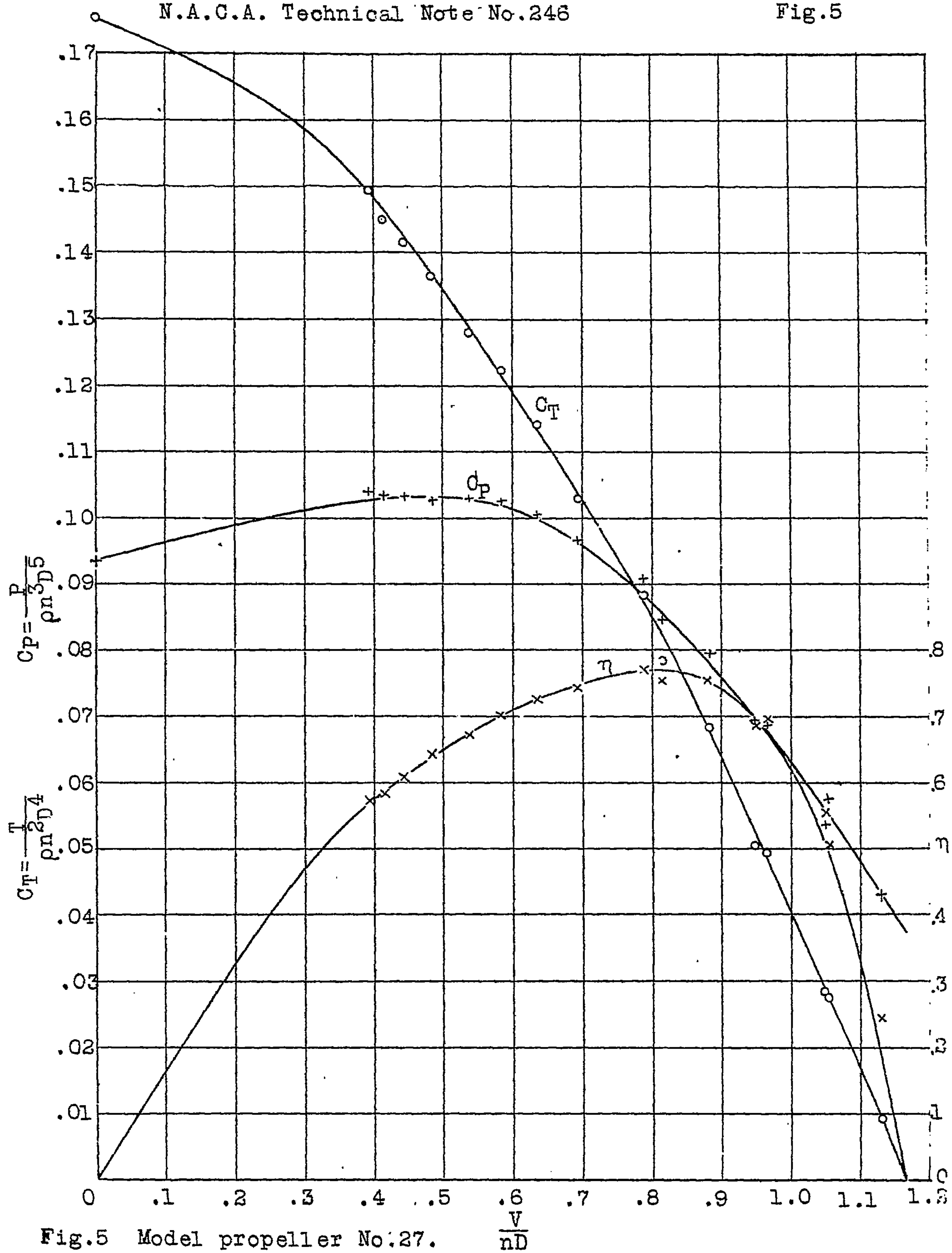


Fig.5 Model propeller No.27.

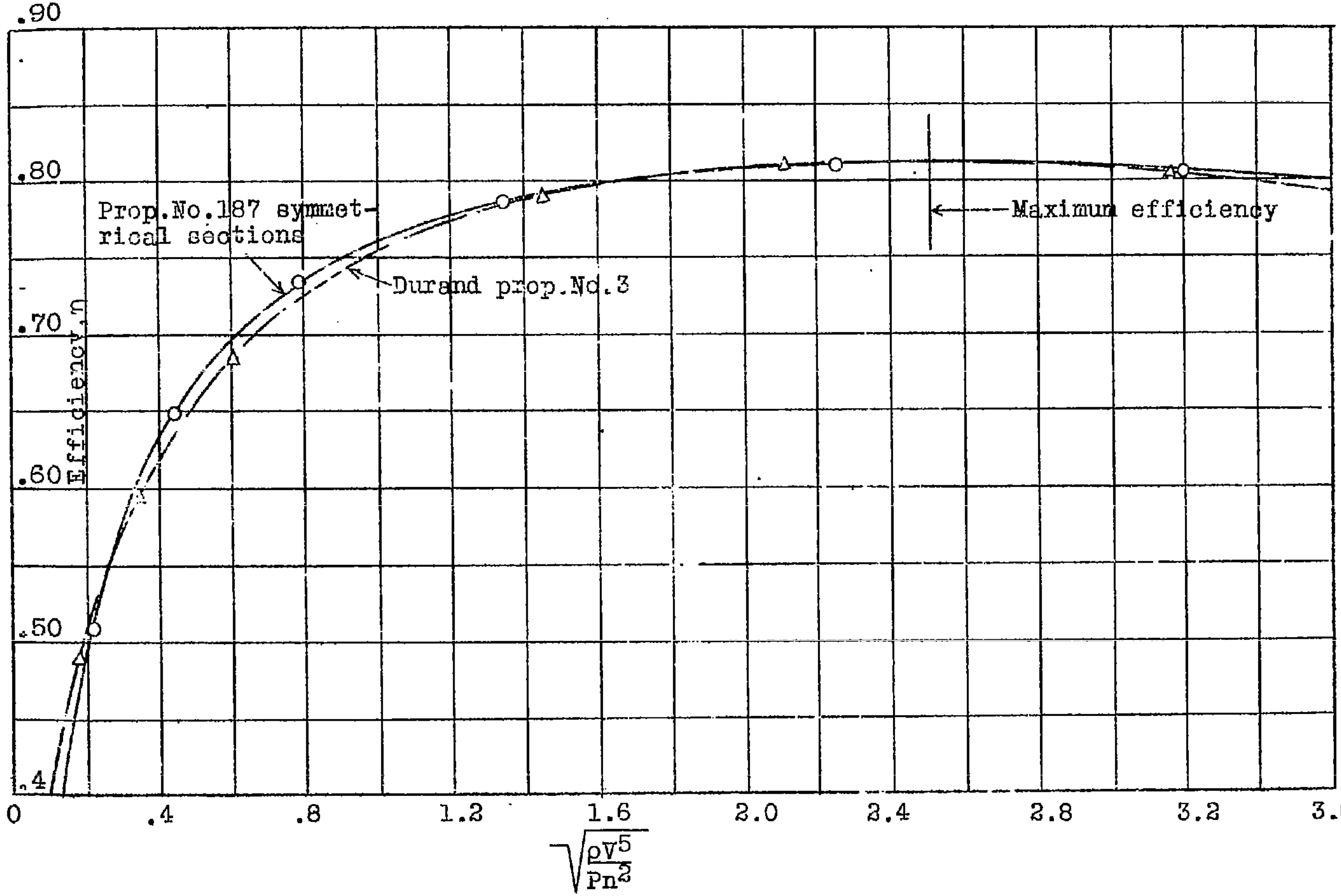


Fig.6 Comparison of efficiencies of symmetrical section propeller and Durand propeller No.3.