TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 333

TEST OF AN ADJUSTABLE PITCH MODEL PROPELLER
AT FOUR BLADE SETTINGS

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Washington
February, 1930

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Summary

This note describes tests of an adjustable blade metal model propeller, both in a free wind stream and in combination with a model fuselage, at four settings of the blades. The model propeller is designed for a uniform nominal pitch/diameter ratio of .7 and the blade settings used correspond to nominal pitch/diameter ratios of .5, .7, .9, and 1.1 at the .6 radius.

The tests show that propellers of this type may be considerably changed in setting from the designed pitch angles and yet give excellent performance.

The efficiency realized and power absorbed when blades are set at other than the designed angle, are little different than would be obtained from a propeller with uniform pitch equal to the mean pitch of the propeller under test.

Introduction

The adjustable blade metal propeller is usually designed to have the blades set at such an angle as will provide a somewhat uniform pitch along the radius. It has been shown that (Reference 1), in a free wind stream, while such a propeller gives the greatest efficiency there may be considerable variation in pitch as distributed along the radius without serious efficiency loss. It has also been shown that (Reference 1), in combination with a slipstream obstruction, a propeller with a radial pitch distribution similar to the radial distribution of velocity through the propeller plane, gives superior results. The present tests give some further confirmation of the above conclusions.

T e s t s

The model propeller chosen for these tests was propeller A of Reference 1. The blade form is shown in Figure 1. The model has a uniform nominal pitch/diameter ratio of .7 when set at the angles shown. For a nominal pitch/diameter ratio (at .6 radius) of .5, the blade angles are decreased 5.6°. For a pitch/diameter ratio of .9 they are increased 5.1°. For a pitch/diameter ratio of 1.1 they are increased 9.9°.

Table I shows the radial distribution of nominal pitch-diameter ratio for the settings employed.

TABLE I

Pitch-Diameter Ratio - Propeller A

Angle at 60% Radius 10.8	Radius - % of tip radius						
	15	30	45	60	75	90	100
14.8°	.57	.56	.53	.50	.46	.41	.39
20.4	.7	.7	.7	.7	.7	.7	.7
25.5	.86	.84	.87	.90	.94	.97	1.01
30.3	1.05	1.00	1.04	1.10	1.17	1.25	1.31

It is seen from the above that the 14.8° setting provides a propeller of radially decreasing pitch, the 20.4° setting, a propeller of uniform pitch, and the other settings propellers of radially increasing pitch.

The tests were conducted in the Guggenheim Aeronautic Laboratory at Stanford University and in the usual manner - described in detail in Reference 1.

The observed data and computed coefficients are given in Tables II to IX. The coefficients

$$C_P = \frac{hp \times 550}{\rho \; n^3 \; D^5}$$

$$C_T = \frac{thrust}{\rho \; n^2 \; D^4}$$

and $$\eta = \text{efficiency},$$

with V/nD as argument, are shown in Figures 2 to 9.

R e m a r k s

The free wind stream tests of this model reveal no startling results. As may be seen from tests of other propellers (Reference 2) the power absorbed and efficiency developed are about what would be expected.

Reference 2 gives the results of tests, in a free wind stream, of adjustable blade metal model propellers with five uniform nominal pitch ratios. Each propeller is tested at six blade angles, thus providing thirty propellers with a considerable range of mean pitch and a wide variety of radial pitch distribution. These models are similar in plan form and section to model A of the present tests.

Figure 10 shows the maximum efficiency points for the tests of Reference 2, and for the free stream tests of propeller A. It may be seen from this figure that, while in a free wind stream, the uniform pitch propeller of this form generally attains the higher efficiency, the departure from uniform pitch, in settings of model A used, is insufficient to cause an appreciable difference between realized efficiency and highest efficiency to be expected.

The three spots of Figure 10 that are more than 5% below a line drawn through the higher maxima are for propellers having pitch at the tip twice that at the 30% radius, which is three times the maximum radial variation encountered in propeller A.

With respect to power it may be seen that for propellers of given plan form and sections the power coefficient $C_P = \frac{550\ hp}{\rho\ n^3\ D^5}$ at maximum efficiency depends mainly upon the dynamic pitch. Figure 11 shows C_P for maximum efficiency for all tests of Reference 2, and the free stream tests of propeller A plotted against dynamic pitch ratio, or V/nD for zero thrust. While there is some lack of an exact correlation of C_P at maximum efficiency and V/nD for zero thrust, the general relation is evident. Further, since, near the peak of the efficiency curve, efficiency changes hardly at all and the power coefficient considerably with a small change in. V/nD , particularly with propellers of large pitch ratio, the spots of Figure 11 can be brought into a linear relation with no departure from the observations beyond the probable experimental error.

The model fuselage used in these tests was the same as that of Reference 1 - a VE-7 with stub wings. It appears from the tests of propeller A in combination with the model fuselage that for the 14.8° setting there is a decrease in peak efficiency of 2.5% from that of the free stream test. For the 20.4° setting the decrease is 5%, for the 25.5° setting it is zero, and for the 30.3° setting there appears to be a slight gain. If the efficiencies are compared at the power coefficient of maximum efficiency for the free stream tests, however, it will be seen that at all settings the propeller is less efficient in the presence of the model fuselage, and that there is the smallest loss - about 1% - with the 25.5° and 30.3° settings.

A survey at the propeller plane in front of the model fuselage shows velocity varying from zero at the hub to free stream velocity at the blade tip (Reference 1). A smaller loss in peak efficiency for the 25.5° and 30.3° settings seems therefore not unreasonable since the pitch distribution for these settings is of the same nature as the velocity distribution. On the other hand, the small loss in peak efficiency for the 14.8° setting seems contrary to the natural expectation.

It should be noted that, with the wind speeds employed in these tests, the absolute values of thrust amd torque at maximum efficiency are small, particularly with the high pitch settings, and that therefore a small absolute error in observation of thrust or torque is relatively large. The probable errors in thrust and torque observations are believed to be about ±.02 lb. and ±.01 lb. ft., respectively, corresponding to about $\pm\frac{1}{2}$% of the observed values for maximum efficiency at the 30.3° setting. Individual determinations of efficiency near the maximum may be, therefore, +1% in error.

TABLE II

Propeller A – Free Wind Stream – 10.8" Radius at 14.8°

$\frac{1}{2}\rho V^2$	ρ	V ft./sec.	n r.p.s.	thrust lb.	torque lb.-ft.
4.91	.00232	65.0	34.5	0	0.84
4.95	.00232	65.4	35.7	0.76	1.07
5.15	.00232	66.6	37.4	2.03	1.35
5.22	.00232	67.2	39.0	3.05	1.67
5.25	.00231	67.5	40.3	4.57	2.05
5.36	.00231	68.1	42.7	6.61	2.53
5.30	.00231	67.7	45.1	9.15	3.13
5.38	.00231	68.3	47.7	12.22	3.81
5.53	.00231	69.2	50.8	15.25	4.51
5.74	.00231	70.5	56.7	22.37	6.01
5.97	.00231	72.0	62.5	30.50	7.75
3.15	.00231	52.3	56.7	30.50	6.79
1.42	.00231	35.0	52.1	30.50	5.98
0.19	.00231	12.9	47.7	30.50	4.91

TABLE II (Cont.)

Propeller A – Free Wind Stream – 10.8" Radius at 14.8°

$\frac{1}{2}\rho V^2$	V/nD	$C_T = \frac{\text{thrust}}{\rho n^2 D^4}$	$C_P = \frac{\text{power}}{\rho n^3 D^5}$	η efficiency
4.91	.628	0	.0079	0
4.95	.611	.0032	.0094	.207
5.15	.594	.0077	.0108	.426
5.22	.574	.0107	.0122	.501
5.25	.558	.0151	.0141	.595
5.36	.532	.0194	.0155	.864
5.30	.501	.0241	.0172	.700
5.38	.477	.0288	.0188	.731
5.53	.453	.0315	.0195	.733
5.74	.415	.0373	.0210	.738
5.97	.384	.0419	.0223	.722
3.15	.307	.0508	.0237	.660
1.42	.224	.0601	.0247	.546
0.19	.091	.0717	.0242	.269

TABLE III

Propeller A - Free Wind Stream - 10.8" Radius at 20.4°

$\frac{1}{2}\rho V^2$	ρ	V ft./sec.	n r.p.s.	thrust lb.	torque lb.-ft.
4.76	.00226	64.8	25.8	0	0.46
4.86	.00226	65.5	27.0	.76	0.74
5.00	.00224	66.8	28.7	2.03	1.19
5.01	.00223	67.0	29.8	3.04	1.53
4.94	.00223	66.4	31.2	4.56	2.00
4.99	.00223	66.9	33.3	6.58	2.63
5.10	.00223	67.6	35.8	9.11	3.37
5.14	.00223	67.9	38.5	12.15	4.21
5.24	.00223	68.5	41.9	16.20	5.32
5.37	.00223	69.4	46.6	22.27	6.86
5.54	.00223	70.4	51.8	30.37	8.86
3.19	.00224	53.4	48.2	30.37	8.01
1.35	.00224	34.8	44.8	30.37	6.96
.25	.00224	15.0	42.7	20.37	6.16

TABLE III (Cont.)

Propeller A - Free Wind Stream - 10.8" Radius at 20.4°

$\frac{1}{2}\rho V^2$	V/nD	$C_T = \frac{\text{thrust}}{\rho n^2 D^4}$	$C_P = \frac{\text{power}}{\rho n^3 D^5}$	η efficiency
4.76	.837	0	.0078	0
4.86	.809	.0057	.0117	.394
5.00	.775	.0135	.0167	.628
5.01	.749	.0189	.0199	.703
4.94	.710	.0259	.0238	.774
4.99	.670	.0328	.0274	.801
5.10	.629	.0393	.0304	.812
5.14	.588	.0453	.0329	.810
5.24	.545	.0510	.0351	.793
5.37	.496	.0567	.0365	.769
5.54	.453	.0626	.0382	.742
3.19	.369	.0721	.0398	.668
1.35	.258	.0830	.0398	.539
.25	.117	.0917	.0390	.275

TABLE IV

Propeller A - Free Wind Stream - 10.8" Radius at 25.5°

$\frac{1}{2}\rho V^2$	ρ	V ft./sec.	n r.p. s.	thrust lb.	torque lb.-ft.
5.29	.00232	67.6	21.5	0	0.44
5.35	.00231	68.1	22.5	0.76	0.83
5.43	.00231	68.6	23.6	2.03	1.35
5.45	.00231	68.7	24.8	3.05	1.75
5.47	.00231	68.9	26.2	4.58	2.34
5.54	.00231	69.3	28.3	6.61	3.10
5.44	.00231	68.7	30.4	9.15	3.97
5.55	.00231	69.3	33.1	12.20	4.97
5.69	.00231	70.2	36.2	16.27	6.33
5.94	.00231	71.7	40.5	22.37	8.22
6.13	.00231	72.8	45.3	30.51	10.63
3.21	.00231	52.7	42.2	30.51	9.32
1.28	.00232	33.2	40.6	30.51	8.74
0.27	.00232	15.3	40.7	30.51	9.06

TABLE IV (Cont.)

Propeller A - Free Wind Stream - 10.8" Radius at 25.5°

$\frac{1}{2}\rho V^2$	V/nD	$C_T = \frac{\text{thrust}}{\rho n^2 D^4}$	$C_P = \frac{\text{power}}{\rho n^3 D^5}$	η efficiency
5.29	1.049	0	.0107	0
5.35	1.011	.0081	.0185	.441
5.43	.967	.0195	.0270	.698
5.45	.925	.0265	.0319	.771
5.47	.875	.0356	.0381	.817
5.54	.817	.0441	.0434	.831
5.44	.753	.0530	.0482	.829
5.55	.699	.0596	.0509	.818
5.69	.647	.0665	.0542	.794
5.94	.590	.0728	.0561	.765
6.13	.637	.0796	.0582	.734
3.21	.417	.0917	.0587	.650
1.28	.273	.0983	.0590	.454
0.27	.125	.0990	.0608	.203

TABLE V

Propeller A - Free Wind Stream - 10.8" Radius at 30.3°

$\frac{1}{2}\rho V^2$	ρ	V ft./sec.	n r.p.s.	thrust lb.	torque lb.-ft.
5.17	.00231	66.9	17.8	0	0.34
5.15	.00232	66.8	18.4	0.76	0.80
5.23	.00232	67.2	19.8	2.03	1.45
5.43	.00231	68.5	21.1	3.05	1.92
5.49	.00231	68.9	22.9	4.58	2.62
5.63	.00231	69.8	25.0	6.61	3.50
5.42	.00232	68.4	26.9	9.15	4.52
5.71	.00231	70.3	29.7	12.20	5.72
5.74	.00232	70.4	31.1	14.24	6.46
5.86	.00232	71.2	36.5	22.37	9.26
6.06	.00232	72.3	41.0	30.51	12.07
3.33	.00232	53.6	40.7	30.51	11.81
1.51	.00233	36.1	40.2	30.51	11.50
0.30	.00233	16.1	39.8	30.51	12.44

TABLE V (Cont.)

Propeller A - Free Wind Stream - 10.8" Radius at 30.3°

$\frac{1}{2}\rho V^2$	V/nD	$C_T = \frac{\text{thrust}}{\rho\, n^2 D^4}$	$C_P = \frac{\text{power}}{\rho\, n^3 D^5}$	$\frac{1}{C_p}$		η efficiency
5.17	1.253	0	.0120	[illegible]	2.03	0
5.15	1.211	.0120	.0264	37.90	2.51	.552
5.23	1.131	.0276	.0413	24.22	2.14	.754
5.43	1.082	.0364	.0483	[illegible]	[illegible]	.816
5.49	1.004	.0466	.0560	17.85	[illegible]	.836
5.63	.930	.0564	.0625	16.00	1.62	.838
5.42	.847	.0673	.0696	14.36	1.45	.819
5.71	.788	.0738	.0724	13.82	1.32	.803
5.74	.753	.0782	.0743	13.45	1.27	.792
5.86	.651	.0896	.0778	12.85	1.08	.749
6.06	.587	.0965	.0799	12.52	.97	.709
3.33	.439	.0980	.0796	12.56	.73	.540
1.51	.299	.1003	.0792	12.63	.50	.379
0.30	.134	.1021	.0873	11.46	.22	.157

TABLE VI

Propeller A with VE-7 Fuselage - 10.8" Radius at 14.8°

$\frac{1}{2}\rho V^2$	ρ	V ft./sec.	n r.p.s.	thrust lb.	torque lb.-ft.
4.80	.00230	64.5	33.2	-0.01	0.77
4.85	.00230	65.0	34.7	+0.79	1.02
4.87	.00229	65.1	36.1	2.07	1.35
4.86	.00229	65.1	37.2	3.08	1.65
4.84	.00229	65.0	38.9	4.57	2.02
4.51	.00229	62.7	40.4	6.56	2.44
4.63	.00229	63.6	46.5	12.25	3.75
4.79	.00229	64.7	50.7	16.43	4.73
5.16	.00229	67.2	56.6	22.83	6.17
5.24	.00228	67.8	62.8	31.00	7.90
2.60	.00228	47.7	56.8	29.97	6.76
1.27	.00228	33.4	54.0	30.36	6.21
0.17	.00229	12.3	50.6	30.35	5.37

TABLE VI (Cont.)

Propeller A with VE-7 Fuselage - 10.8" Radius at 14.8°

$\frac{1}{2}\rho V^2$	V/nD	$C_T = \frac{\text{thrust}}{\rho n^2 D^4}$	$C_P = \frac{\text{power}}{\rho n^3 D^5}$	η efficiency
4.80	.647	-.0001	.0078	-.004
4.85	.624	+.0035	.0095	+.231
4.87	.601	.0085	.0117	.440
4.86	.583	.0120	.0134	.519
4.84	.557	.0163	.0151	.603
4.51	.518	.0217	.0169	.666
4.63	.456	.0305	.0196	.711
4.79	.425	.0345	.0208	.705
5.16	.396	.0385	.0218	.699
5.24	.360	.0426	.0227	.674
2.60	.280	.0502	.0237	.593
1.27	.206	.0563	.0241	.481
0.17	.081	.0642	.0238	.219

TABLE VII

Propeller A with VE-7 Fuselage - 10.8" Radius at 20.4°

$\frac{1}{2}\rho V^2$	ρ	V ft./sec.	n r.p.s.	thrust lb.	torque lb.-ft.
4.76	.00227	64.8	24.4	-0.06	0.38
4.80	.00227	65.1	25.6	+0.75	0.71
4.85	.00227	65.4	27.4	2.05	1.18
4.88	.00226	65.7	28.7	3.09	1.59
4.94	.00226	66.1	30.5	4.66	2.15
4.48	.00226	62.9	31.8	6.53	2.70
4.53	.00226	63.3	34.6	9.11	3.48
4.64	.00226	64.1	37.8	12.27	4.41
4.82	.00226	65.3	41.7	16.46	5.59
5.11	.00226	67.3	46.7	22.66	7.33
5.42	.00226	69.3	52.5	30.78	9.54
3.12	.00227	52.5	49.4	30.54	8.56
1.38	.00227	35.0	46.9	30.17	7.68
0.20	.00227	13.2	44.7	30.37	6.90

TABLE VII (Cont.)

Propeller A with VE-7 Fuselage - 10.8" Radius at 20.4°

$\frac{1}{2}\rho V^2$	V/nD	$C_T = \frac{\text{thrust}}{\rho n^2 D^4}$	$C_P = \frac{\text{power}}{\rho n^3 D^5}$	η efficiency
4.76	.885	-.0005	.0073	-.062
4.80	.846	+.0062	.0123	.429
4.85	.797	.0149	.0130	.662
4.88	.762	.0205	.0220	.709
4.94	.721	.0273	.0263	.747
4.48	.659	.0352	.0305	.761
4.53	.610	.0416	.0332	.764
4.64	.565	.0468	.0351	.753
4.82	.523	.0517	.0368	.734
5.11	.480	.0568	.0385	.709
5.42	.440	.0610	.0396	.677
3.12	.354	.0683	.0401	.603
1.38	.249	.0748	.0399	.466
0.20	.099	.0828	.0394	.207

TABLE VIII

Propeller A with VE-7 Fuselage - 10.8" Radius at 25.5°

$\frac{1}{2}\rho V^2$	ρ	V ft./sec.	n r.p.s.	thrust lb.	torque lb.-ft.
4.95	.00228	65.9	20.0	0.13	0.33
5.01	.00228	66.3	21.2	0.93	0.77
4.99	.00227	66.2	22.5	2.19	1.30
5.02	.00227	66.4	23.7	3.22	1.75
5.15	.00227	67.3	25.8	4.85	2.44
4.72	.00227	64.5	27.5	6.75	3.13
4.74	.00227	64.6	30.0	9.29	4.03
4.84	.00227	65.3	32.9	12.42	5.08
5.08	.00227	66.9	36.5	16.68	6.47
5.33	.00227	68.5	41.2	22.93	8.42
5.59	.00227	70.2	46.6	31.30	10.97
3.01	.00227	51.5	44.4	30.92	9.96
1.29	.00227	33.7	43.3	30.38	9.92
0.19	.00227	12.8	42.8	30.37	9.25

TABLE VIII (Cont.)

Propeller A with VE-7 Fuselage - 10.8" Radius at 25.5°

$\frac{1}{2}\rho V^2$	V/nD	$C_T = \frac{\text{thrust}}{\rho n^2 D^4}$	$C_P = \frac{\text{power}}{\rho n^3 D^5}$	η efficiency
4.95	1.098	.0017	.0095	.180
5.01	1.042	.0112	.0194	.605
4.99	.982	.0235	.0294	.786
5.02	.932	.0310	.0352	.820
5.15	.869	.0395	.0416	.826
4.72	.782	.0486	.0473	.805
4.74	.717	.0559	.0508	.789
4.84	.661	.0623	.0533	.773
5.08	.612	.0682	.0554	.752
5.33	.554	.0734	.0565	.721
5.59	.502	.0785	.0576	.684
3.01	.387	.0855	.0576	.774
1.29	.259	.0880	.0602	.378
0.19	.100	.0902	.0575	.156

TABLE IX

Propeller A with VE-7 Fuselage - 10.8" Radius at 30.3°

$\frac{1}{2}\rho V^2$	ρ	V ft./sec.	n r.p.s.	thrust lb.	torque lb.-ft.
4.76	.00226	65.0	16.1	-.05	0.19
4.80	.00225	65.2	17.3	+.75	0.67
4.87	.00225	65.8	19.1	2.09	1.37
4.94	.00225	66.2	20.4	3.15	1.91
4.99	.00225	66.5	22.5	4.71	2.66
4.55	.00225	63.5	24.2	6.55	3.45
4.56	.00226	63.5	26.5	9.14	4.46
4.77	.00226	64.9	29.6	12.36	5.67
4.96	.00226	66.3	33.1	16.59	7.24
5.14	.00226	67.4	37.6	22.80	9.58
5.53	.00226	69.9	43.9	31.24	13.38
3.06	.00227	51.9	42.7	30.40	12.37
1.25	.00227	33.2	42.3	30.34	12.48
0.22	.00227	14.1	42.2	30.42	13.54

TABLE IX (Cont.)

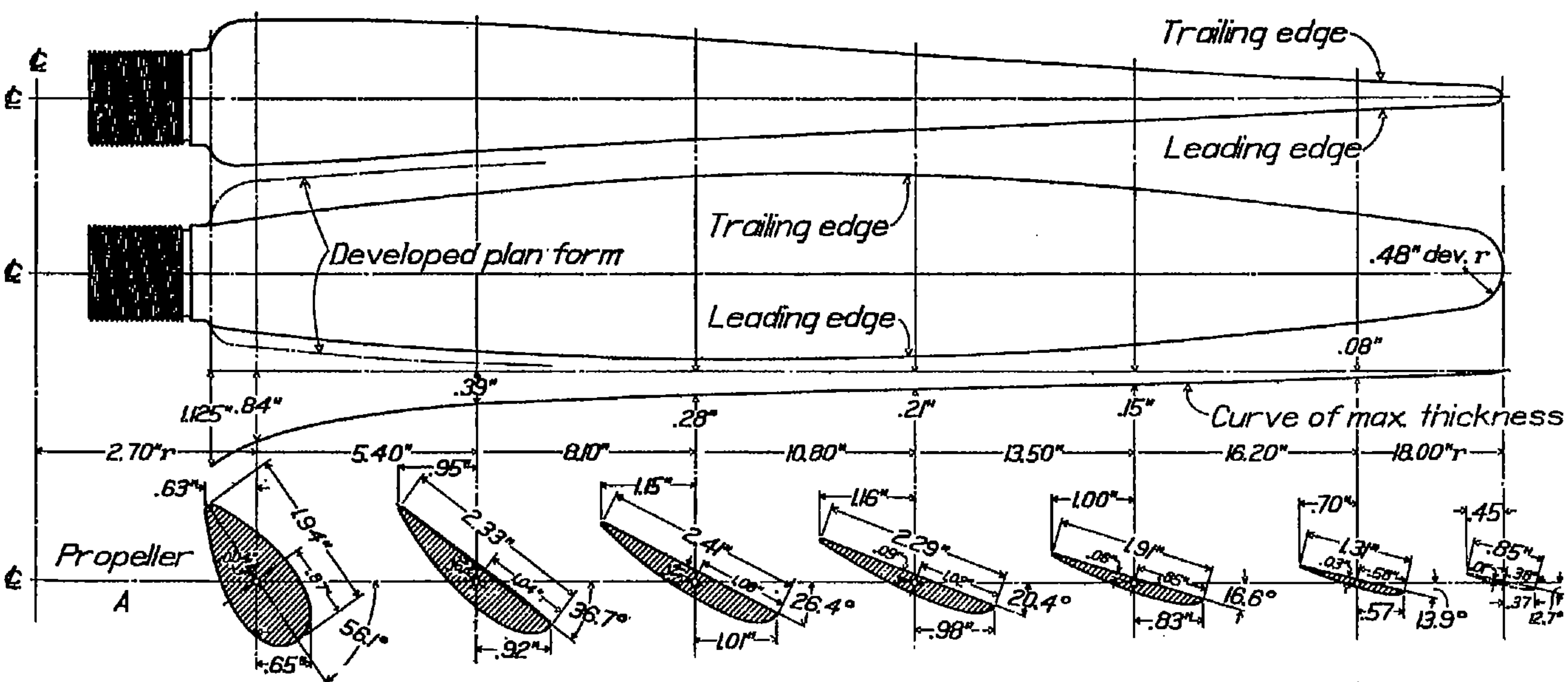
Propeller A with VE-7 Fuselage - 10.8" Radius at 30.3°

$\frac{1}{2}\rho V^2$	V/nD	$C_T = \frac{\text{thrust}}{\rho n^2 D^4}$	$C_P = \frac{\text{power}}{\rho n^3 D^5}$	η efficiency
4.76	1.342	-.0011	.0083	-.172
4.80	1.256	+.0137	.0255	+.674
4.87	1.151	.0314	.0434	.834
4.94	1.083	.0415	.0527	.851
4.99	.998	.0511	.0606	.834
4.55	.876	.0614	.0678	.793
4.56	.797	.0709	.0723	.782
4.77	.732	.0771	.0742	.761
4.96	.667	.0826	.0755	.730
5.14	.597	.0879	.0773	.679
5.53	.531	.0885	.0794	.592
3.06	.406	.0910	.0776	.476
1.25	.262	.0926	.0797	.304
0.22	.111	.0930	.0867	.119

References

1. Lesley, E. P. and Reid, Elliott G. : Tests of Five Metal Model Propellers with Various Pitch Distributions in a Free Wind Stream and in Combination with a Model VE-7 Fuselage. N.A.C.A. Technical Report No. 326, 1929.

2. Materiel Division, Air Corps : Comparison of Wind Tunnel Tests with Flight Tests on a Number of Detachable Blade Propellers Made from the Same Plan Form. Air Corps Information Circular No. 632, Volume VII, 1928.



Sections taken looking from hub to tip

Fig.1

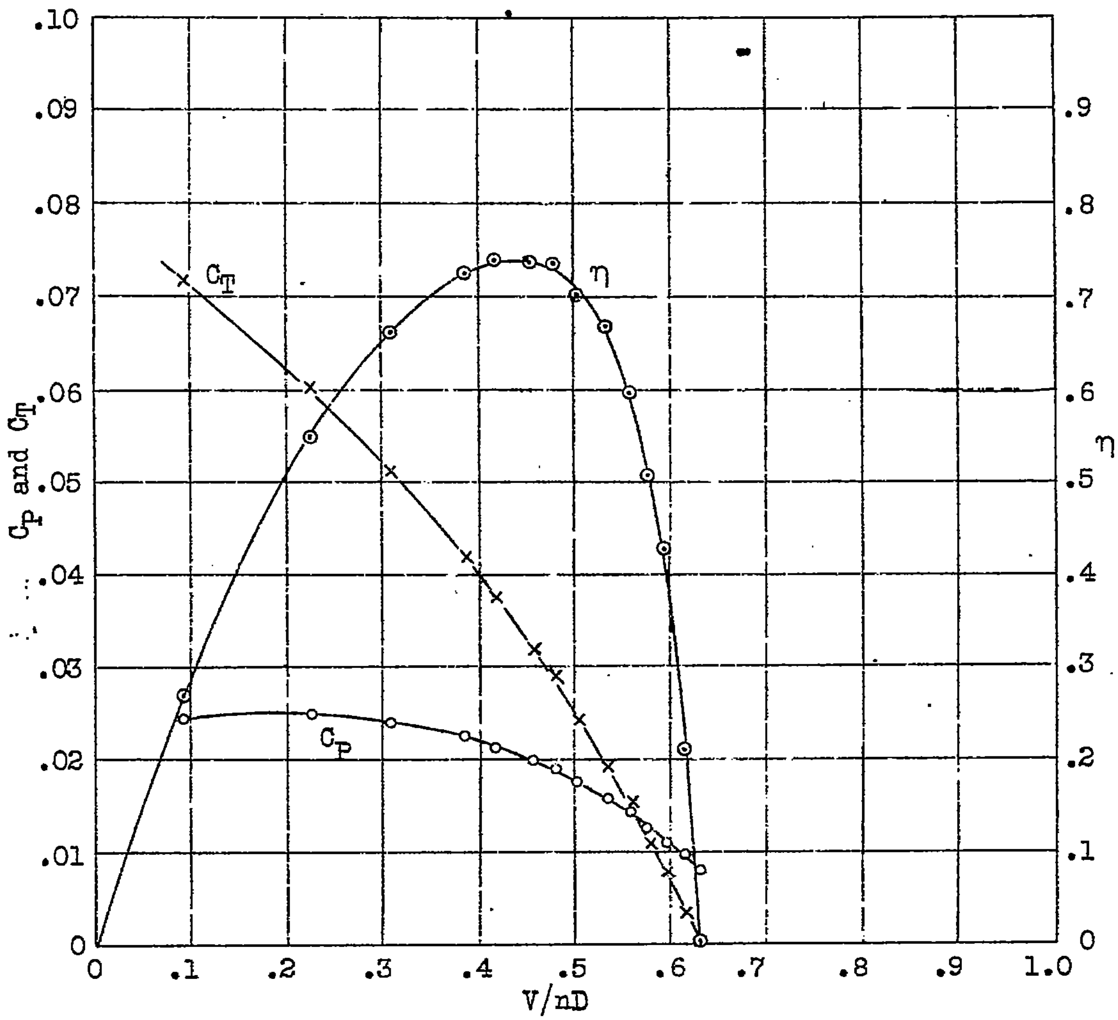


Fig.2 Propeller A in free wind stream, 10.8" radius at 14.8°

3.8
11.0°

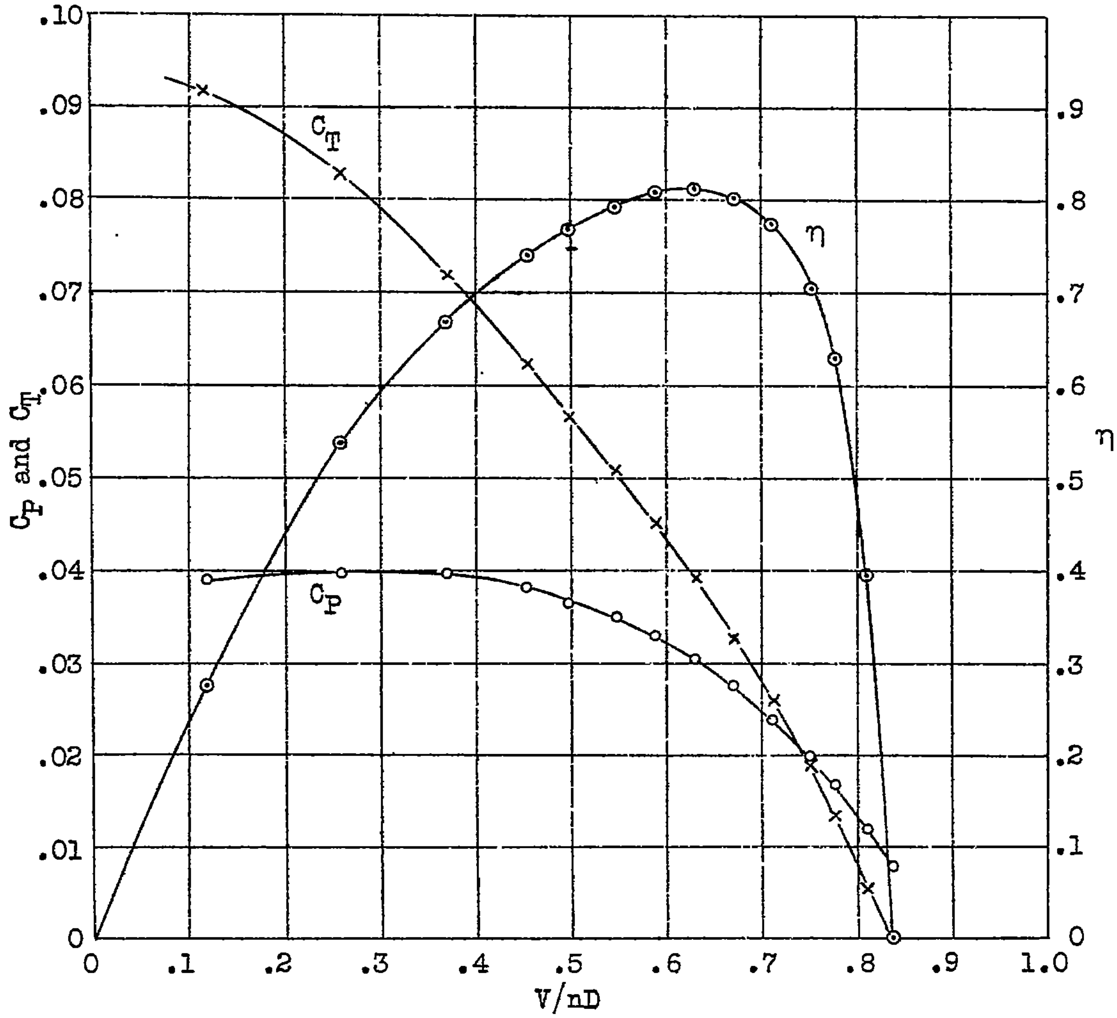


Fig.3 Propeller A in free wind stream, 10.8" radius at 20.4°
3.8°
16.6°

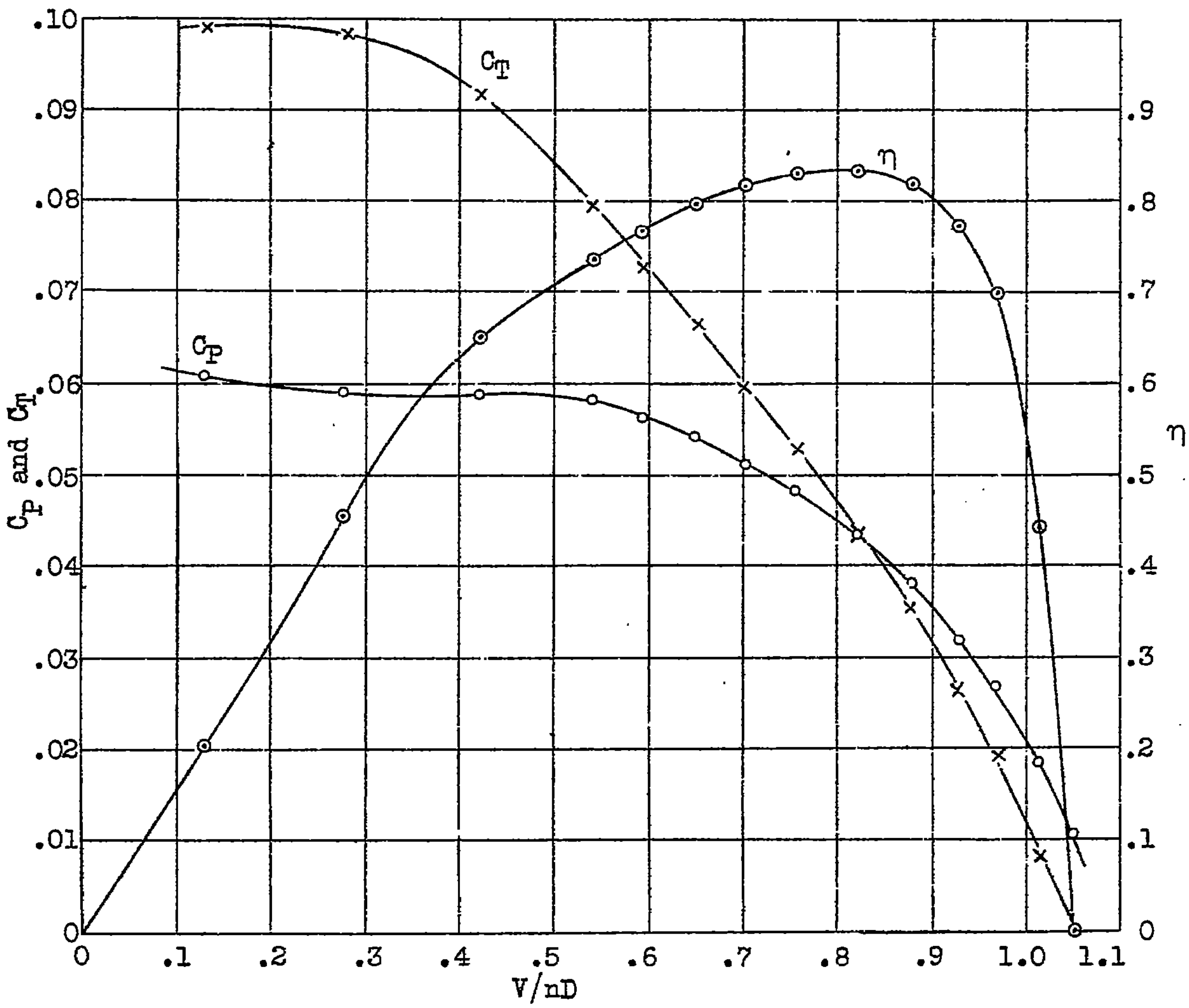


Fig.4 Propeller A in free wind stream, 10.8" radius at 25.5°
3.8
21.7°

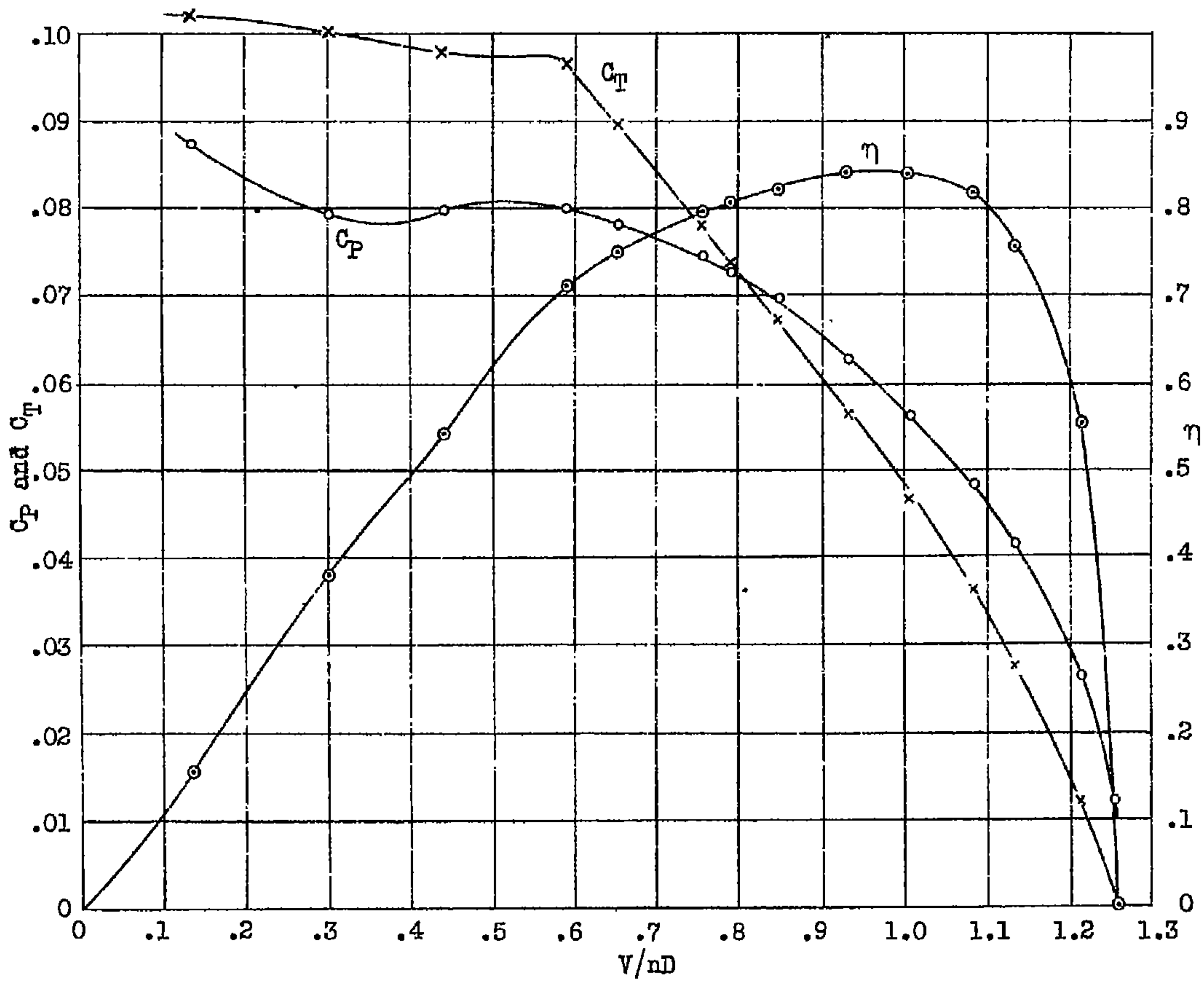


Fig.5 Propeller A in free wind stream, 10.8" radius at 30.3°

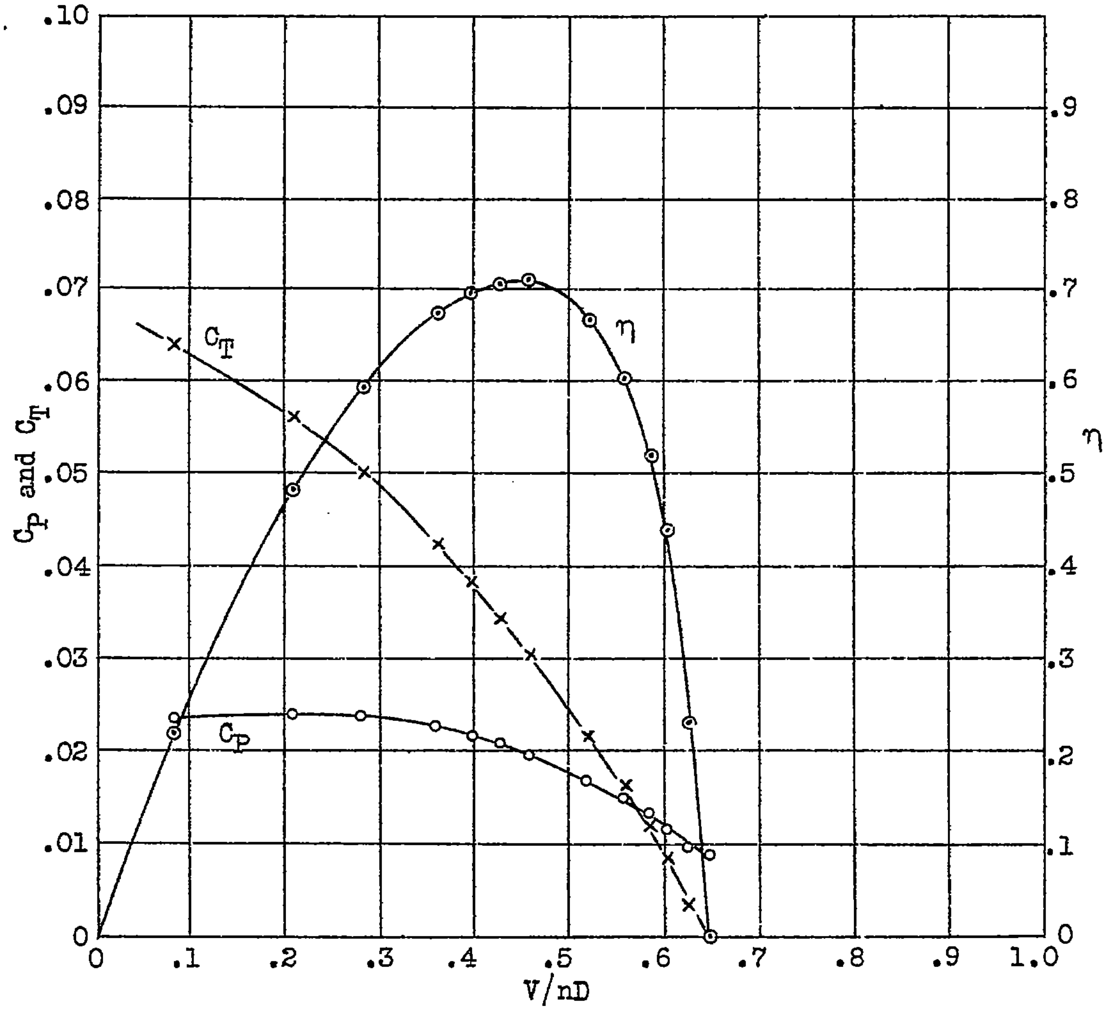


Fig.6 Propeller A with model fuselage, 10.8" radius at 14.8°

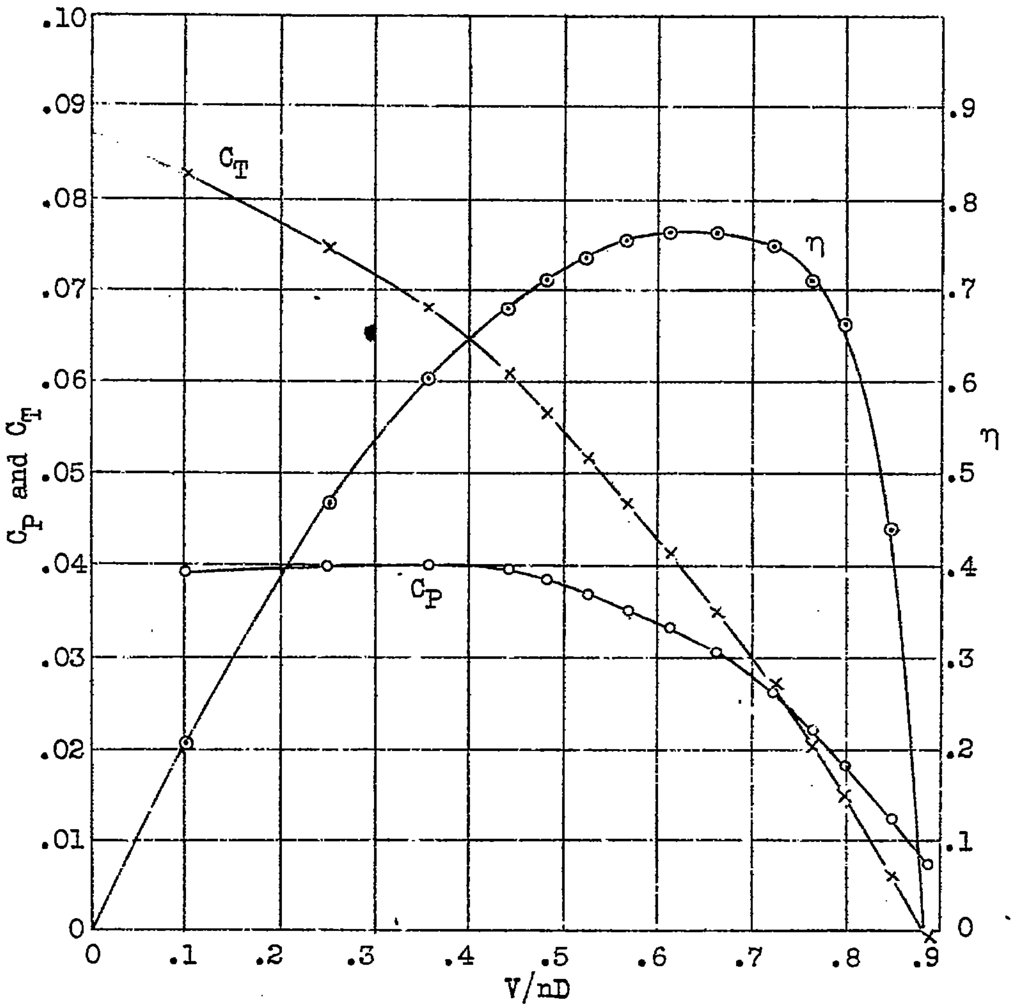


Fig.7 Propeller A with model fuselage, 10.8" radius at 20.4°

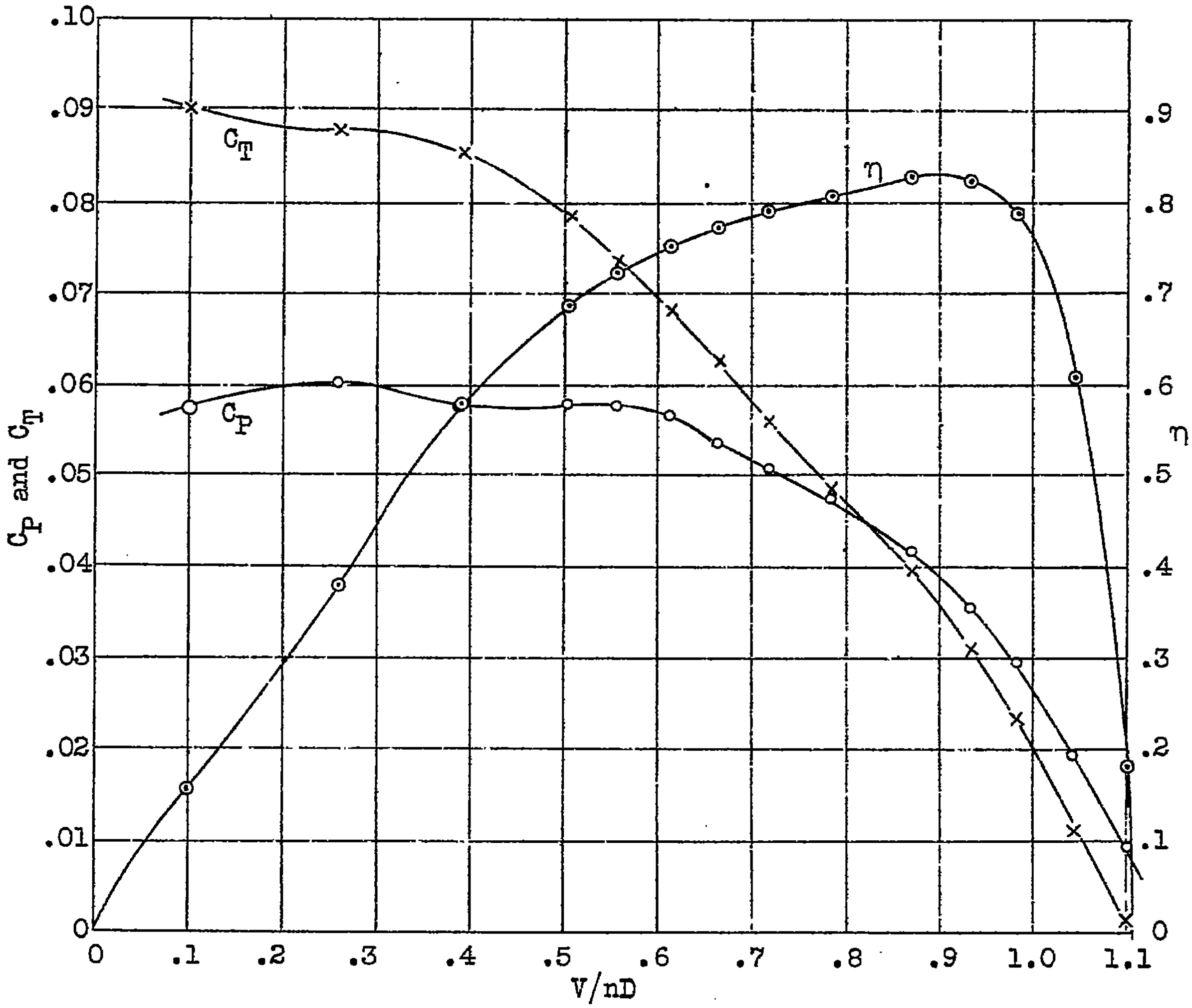


Fig.8 Propeller A with model fuselage, 10.8" radius at 25.5°

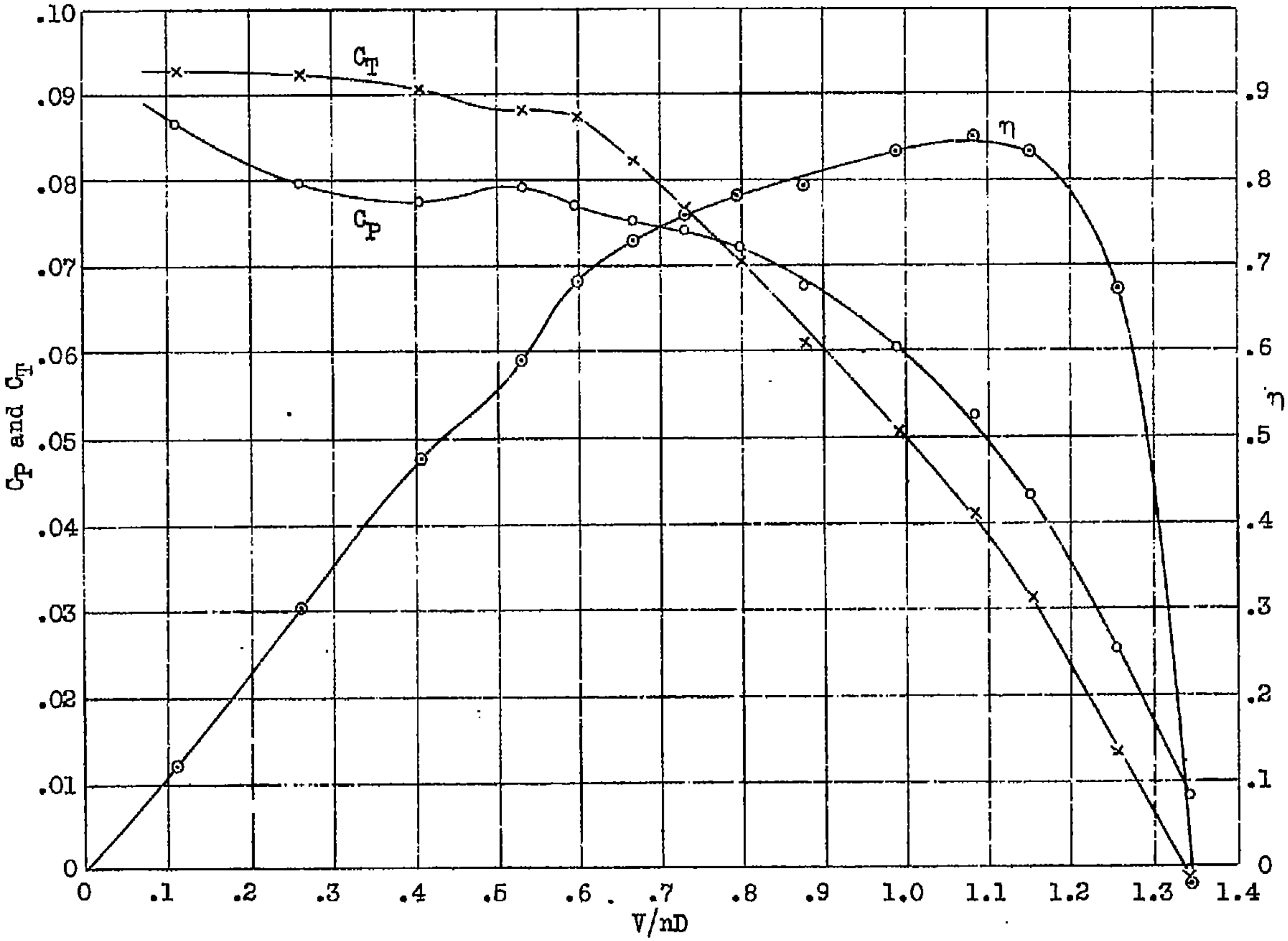
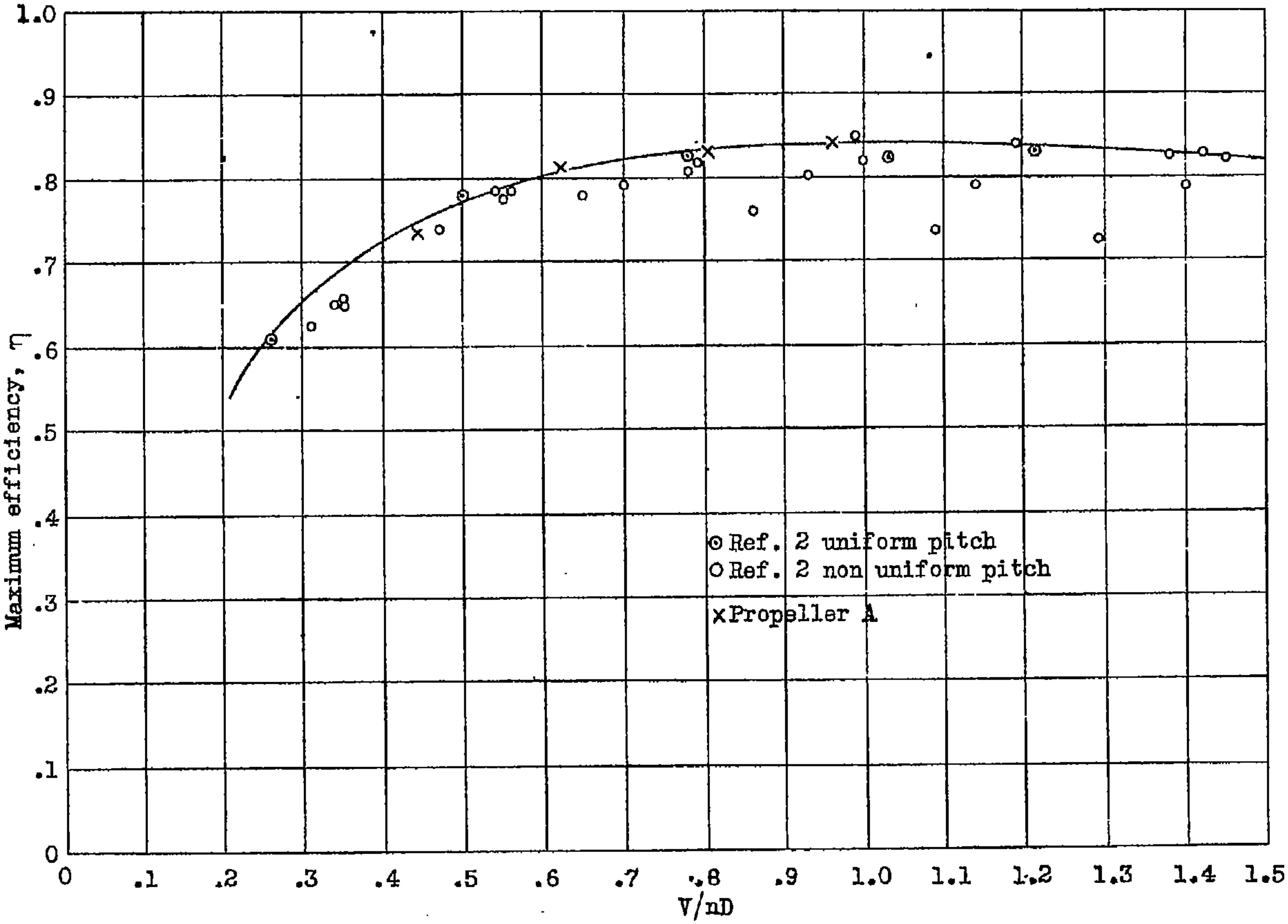


Fig.9 Propeller A with model fuselage, 10.8" radius at 30.3°



Maximum efficiency, η
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
1.5
V/nD
⊙ Ref. 2 uniform pitch
○ Ref. 2 non uniform pitch
× Propeller A

Fig.10

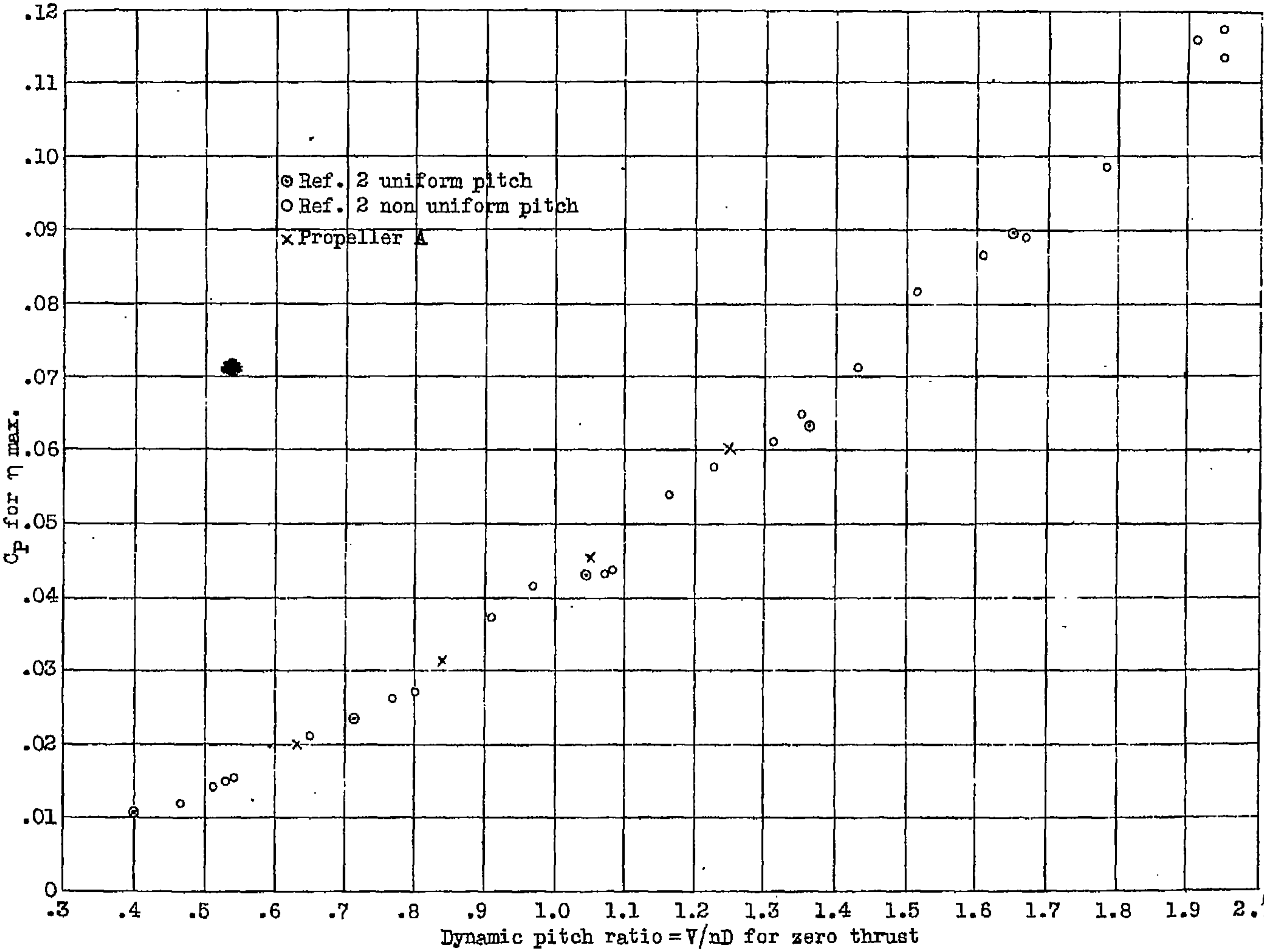

⊙ Ref. 2 uniform pitch
○ Ref. 2 non uniform pitch
× Propeller A
C_P for η max.
.12
.11
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
0
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
Dynamic pitch ratio = V/nD for zero thrust

Fig.11