TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 698

PROPELLER TESTS TO DETERMINE THE EFFECT OF NUMBER OF BLADES AT TWO TYPICAL SOLIDITIES

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SUMMARY

Propellers with equal total blade area, but with different numbers of blades, were tested at Stanford University.

The tests show generally that, for equal total blade area, propellers with the larger number of blades absorb the greater power and, provided hubs have equal drag, develop the higher efficiency.

It is shown that the differences found are in agreement, qualitatively, with what might be predicted from simple blade-element theory.

INTRODUCTION

The simple blade-element theory as developed by Drzewiecki shows that between two propellers with similar blade plan forms and blade section profiles and with equal total blade area, but with different numbers of blades, the power absorbed and the efficiency developed by the propeller with the larger number of blades should be the greater. The larger power absorption would be expected from the increased lift coefficients for blade elements of higher aspect ratio. A gain in efficiency should arise from increased L/D of blade elements.

In the practical case, unless the aerodynamic superiority of the many-blade propeller is considerable, the propeller with fewer and wider blades might be chosen, since, particularly for the controllable-pitch propeller, the mechanical features will be less complicated and the original cost no doubt smaller.

At the request and with the financial assistance of the National Advisory Committee for Aeronautics, the subsequently described experimental study was undertaken. The purpose was to determine by test the quantitative differences in aerodynamic characteristics between two- and three-blade propellers having equal total blade areas, and between three- and four-blade propellers, again having equal total blade areas but, in this case, 33-1/3 percent more area than for the two-blade -- three-blade comparison.

APPARATUS AND TESTS

Wind tunnel.- The experiments of this investigation were carried on in the wind tunnel of the Daniel Guggenheim Aeronautical Laboratory at Stanford University. The tunnel is of the Eiffel type with open throat 7-1/2 feet in diameter. The maximum wind velocity is 90 miles per hour.

Dynamometer.- The propeller dynamometer consists essentially of an electric motor carried on axially disposed, thin, steel plate knife edges. The propeller is secured to an extension of the motor shaft. The extension is free from axial constraint except that provided by a beam balance which measures the pull upon the shaft or the propeller thrust. The propeller torque is measured by the counter moment, indicated by a beam balance, required to restrain the driving motor against roll about the knife edges that support it. The propeller is placed well forward, about one and one-half diameters, of any considerable slipstream obstruction.

Model propellers.- The propellers were all 3-foot diameter, metal, adjustable-pitch models. The blade plan forms are shown in figure 1; the propeller hubs are shown in figure 2.

Blade E (fig. 1) has the plan form, blade angles and sections of propeller E in reference 1. The aspect ratio is 7.7. The nominal pitch-diameter ratio is 0.7 from 0.6 R outward to the tip. It gradually decreases from 0.6 R toward the hub to 0.42 at 0.15 R.

Blade E' is 33-1/3 percent wider and thicker than blade E. The aspect ratio is 5.77.

Blade E" is 50 percent wider and thicker than blade E. The aspect ratio is 5.13.

A two-blade propeller with E'' blades thus has the same total area as a three-blade propeller with E blades. Likewise a three-blade propeller with E' blades has the same total area as a four-blade propeller with E blades.

Distribution along the radius of geometrical pitch-diameter ratio, width-diameter ratio, and thickness-width ratio for the three blade forms is shown in figure 3.

Tests were made of all propellers for blade angles at 0.75 R of 15°, 25°, 35°, and 45°.

Following the Stanford laboratory practice, a constant angular velocity was employed for all tests at a given blade angle. Variation in the parameter V/nD was brought about through change in the wind velocity. Because of limitations in wind speed and in power and rotational speeds available in the dynamometer, the rotational speeds employed were 2,000, 1,800, 1,500, and 1,000 revolutions per minute for the 15°, 25°, 35°, and 45° blade angles, respectively. The Reynolds Number of the tests was thus from 0.11 to 0.06 that of flight, assuming full-scale propellers 9 feet in diameter turning at 2,000 revolutions per minute.

The observed quantities of the tests, thrust, torque, rotational speed, velocity of advance, and density, were converted into the usual coefficients:

Thrust coefficient,

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

Power coefficient,

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

Speed-power coefficient,

$$C_s = V\sqrt[5]{\frac{\rho}{P\ n^2}} = \frac{V}{nD}\sqrt[5]{\frac{1}{C_P}}$$

where

T is propeller thrust.

ρ, mass density of the air.

n, revolutions per unit time.

D, propeller diameter.

Q, propeller turning moment or torque.

P, power absorbed.

V, velocity.

RESULTS AND DISCUSSION

The coefficients derived from the observations of the tests are given in table I. In figures 4 to 7, C_T, C_P, and η are represented graphically as functions of V/nD.

Figures 4 and 5 show that, between two- and three-blade propellers of equal total blade area, there are appreciable differences in performance. The C_T and C_P curves for the three-blade propellers show a higher slope than corresponding curves of the two-blade propellers. From simple blade-element theory, C_T and C_P depend largely upon the lift coefficients of the blade elements. Curves of lift coefficients as functions of geometrical angle of attack will have higher slope for elements of greater aspect ratio. A higher slope in curves of C_T and C_P as functions of V/nD for the three-blade, greater aspect ratio propellers is therefore to be expected since, for a given blade setting, V/nD determines the geometrical angles of attack of the blade elements.

In the usual operating range, from V/nD for maximum efficiency to about 0.75 V/nD for maximum efficiency, the three-blade propellers develop from 2 to 8 percent more thrust and absorb a correspondingly greater power so that the differences in efficiency are barely noticeable. The differences in efficiency appear to be in favor of the three-blade propellers in some cases but in others the reverse is true.

The dynamic pitch-diameter ratio (V/nD for zero thrust) is larger in all cases for the two-blade than for the three-blade propellers. This result was believed to be evidence that the drag of the three-blade hub was considerably more than that of the two-blade hub. The blades had identical forms of section profiles. At zero thrust, the lift coefficients of the elements are too small to be significantly affected by the variation in aspect ratio. Therefore, unless the drags of the hubs were different, the V/nD for zero thrust would be the same for both propellers.

For the 25°, 35°, and 45° blade angles at 0.75 R, it may be seen that both two-blade and three-blade propellers show pronounced changes in the direction of the C_T and C_P curves at certain points, with resulting sudden increases in the slope of the efficiency curves. The values of V/nD at which the change occurs are about 0.4, 0.9, and 1.5 for the 25°, 35°, and 45° blade angles, respectively. The angle of attack for the tip section of the propellers is thus very close to 14°, which is near the burble point for sections of this type. (See reference 2.) It may be noted that the burbled tip condition, as evidenced by the sudden change in slope of the efficiency curves, occurs for the two-blade propellers at lower values of V/nD than for the three-blade propellers. The two-blade propellers thus show appreciably greater efficiency near this point. For example, the two-blade, 35° propeller shows an efficiency of 0.75 at $V/nD = 0.95$. That of the three-blade propeller for the same V/nD is 0.70. Outside of this region, however, and except at values of V/nD greater than that for maximum efficiency, neither two- nor three-blade propeller shows a consistent advantage in efficiency.

The qualitative difference in V/nD for burble of wide and narrow blade propellers may be explained, as has been the difference in slope of C_T and C_P curves, by consideration of the blades as made up of airfoil elements of different aspect ratios. The wider blades (smaller aspect ratio) have, for given geometrical angles of attack, larger induced angles of attack and thus smaller effective angles of attack.

Burble will occur at the same effective angles of attack for both wide and narrow blades and therefore at larger geometrical angles of attack (smaller V/nD) for the wider blades.

Calculation of the difference in geometrical angle of attack at burble for elliptically loaded airfoils, having the aspect ratios of the two- and the three-blade propellers of equal total blade area, gives about 1°. This value is close to what is shown by the change in V/nD for burble in the propeller tests.

It appeared that the later tip burble in the two-blade propellers might be partly explained by difference in Reynolds Number. A subsequent test of the two-blade, 35° propeller at two-thirds the angular velocity formerly employed, and thus at the same Reynolds Numbers as for the three-blade propeller, however, gave practically the identical curves for C_T, C_P, and η formerly derived.

During the tests, a pronounced change in the sound of the propellers was observed at burble. Before burble they were relatively quiet, giving off only a high-pitch hissing sound. At burble and thereafter, the sound was manyfold louder, of lower pitch, and similar to that of tearing cloth.

Comparison of figures 6 and 7 shows somewhat similar differences between three- and four-blade propellers of equal total blade area as are evident in the two-blade--three-blade comparison.

The thrust and the power coefficients are generally greater for four-blade propellers than for three-blade propellers but the difference is considerably less than shown between three-blade and two-blade propellers.

The efficiency of the four-blade propellers appears to be from zero to 2 percent greater than for the three-blade propellers.

The dynamic pitch-diameter ratio (V/nD for zero thrust) is generally somewhat less for the four-blade propellers than for the three-blade propellers. The difference is smaller and less consistent than for the two-blade--three-blade comparison.

As previously stated, the simple blade-element theory shows that, other things being equal, there should be an increase in power absorbed and in efficiency developed for the propellers with the larger number of blades.

In order to estimate the qualitative differences that might be expected the following computations were carried through.

1. The lift and the drag coefficients for the 0.75 R section (given in reference 2) were transformed to coefficients for airfoils of the aspect ratios represented in the model propeller blades.

2. Computations were made of quantities corresponding to C_P and η of the 0.75 R element of the 35° propellers at $V/nD = 1.3$ (maximum efficiency).

Assuming that the computed coefficients derived for the 0.75 R section would be relatively representative of the propeller as a whole, it was predicted that the three-blade E propeller would absorb about 7 percent more power and develop 2 percent greater peak efficiency than the two-blade E" propeller. Likewise the four-blade E propeller would absorb about 4 percent more power and develop 1.6 percent greater peak efficiency than the three-blade E' propeller.

Smaller V/nD for zero thrust, as shown by the three-blade E propeller in comparison with the two-blade E" propeller and the failure of the three-blade propeller to realize in test an increase in efficiency led to further tests. These tests were thought desirable because the predicted increase in efficiency of the four-blade E propeller over that of the three-blade E' propeller appeared to have been shown.

The drags of the two-, three-, and four-blade hubs and propeller shaft (hubs without blades being placed on the shaft and rotated at propeller speed) were measured. It was found that the drag of the three-blade hub and shaft was more than double that of the two-blade hub and shaft. The drag of the four-blade hub and shaft was about 18 percent more than that of the three-blade hub and shaft.

It was seen that the difference in drag of two- and three-blade hubs and shafts might account for the failure of the three-blade E propeller to realize the 2 percent greater peak efficiency predicted for it. In order to confirm this explanation, identical spinners were fitted over the hubs of two- and three-blade propellers (as shown in figure 8 for the two-blade propeller) and tests were made for the 35° blade angle. Observations reduced to coefficient form are given in table II and are shown graphically in figure 9. From this figure it may be seen that the 2 percent greater peak efficiency predicted for the three-blade propeller is realized and that V/nD for zero thrust of the two propellers is the same.

Comparison of the C_T curves of figure 8 with the 35° C_T curves of figures 4 and 5 and in the region of maximum efficiency (V/nD 1.1 to 1.4) reveals that the thrust realized from the propellers with spinners is appreciably greater than for those with bare hubs. The increase in thrust for the two-blade propeller is about 1-1/2 percent, while that for the three-blade propeller is about 3-1/2 percent. Since there are only insignificant differences between power coefficients, with and without spinners, the net result is that the three-blade propeller shows 2 percent greater peak efficiency than the two-blade propeller when identical spinners are fitted over the hubs, while with bare hubs there is no consequential difference between them.

The increase of efficiency of the two-blade propeller through the addition of a spinner was somewhat surprising since, at first glance, it appeared that the drag of the spinner would be at least equal to that of the two-blade hub. A drag test like that employed to measure the comparative drags of two-, three-, and four-blade hubs showed, however, that the drag of the spinner and the shaft was not more than one-third of that of the two-blade hub and shaft. The increase in efficiency found was thus easily accounted for.

It would appear that, if spinners had been fitted in the four-blade--three-blade comparison, a further addition to efficiency in favor of the four-blade propeller might have been found. As compared with what was found for the three-blade--two-blade comparison, the addition would, however, have been small because the difference in drag between three- and four-blade hubs and shafts was only one-third of that between two- and three-blade hubs and shafts.

CONCLUSION

These tests show that, for a given diameter and total blade area provided other things are equal, the propeller with the largest number of blades will absorb the greatest power and develop the highest efficiency.

Daniel Guggenheim Aeronautical Laboratory,
Stanford University, December 10, 1938.

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. T.R. No. 326, N.A.C.A., 1929.

2. Weick, Fred E.: Aircraft Propeller Design. McGraw-Hill Book Co., Inc., 1930.

TABLE I

Three-Blade E Propeller

15° at 0.75 R

V/nD	C_T	C_P	C_s	η
0.734	0.0020	0.0120	1.780	0.122
.679	.0178	.0204	1.478	.592
.631	.0292	.0266	1.304	.693
.593	.0379	.0307	1.191	.732
.548	.0483	.0355	1.069	.745
.506	.0576	.0394	.966	.739
.473	.0646	.0422	.891	.724
.425	.0748	.0452	.790	.703
.370	.0833	.0473	.681	.651
.326	.0905	.0485	.597	.607
.254	.1007	.0497	.463	.514

TABLE I - Continued

Three-Blade E Propeller

25° at 0.75 R

V/nD	C_T	C_P	C_s	η
1.166	0.0024	0.0216	2.511	0.130
1.123	.0174	.0349	2.198	.560
1.059	.0316	.0478	1.946	.700
1.007	.0457	.0598	1.770	.770
.962	.0549	.0673	1.651	.784
.912	.0638	.0732	1.540	.797
.868	.0733	.0793	1.442	.800
.817	.0819	.0846	1.339	.791
.783	.0888	.0886	1.272	.785
.738	.0962	.0921	1.190	.771
.689	.1049	.0959	1.102	.754
.628	.1155	.0997	.996	.727
.585	.1215	.1011	.925	.704
.541	.1279	.1021	.854	.677
.479	.1344	.1042	.753	.617
.419	.1375	.1038	.659	.554
.354	.1374	.1098	.551	.443

TABLE I - Continued

Three-Blade E Propeller

35° at 0.75 R

V/nD	C_T	C_P	C_s	η
1.625	0.0172	0.0613	2.840	0.457
1.586	.0300	.0778	2.642	.612
1.523	.0449	.0964	2.431	.709
1.468	.0556	.1083	2.290	.752
1.409	.0668	.1200	2.152	.784
1.361	.0760	.1278	2.053	.809
1.297	.0868	.1387	1.926	.812
1.231	.0972	.1481	1.805	.808
1.171	.1069	.1554	1.700	.805
1.111	.1168	.1624	1.598	.798
1.051	.1233	.1667	1.505	.777
.999	.1290	.1720	1.421	.749
.939	.1298	.1770	1.328	.689
.880	.1316	.1781	1.243	.650
.801	.1333	.1798	1.128	.594
.728	.1358	.1836	1.022	.538
.646	.1383	.1850	.905	.983

TABLE I - Continued

Three-Blade E Propeller

45° at 0.75 R

V/nD	C_T	C_P	C_s	η
2.247	0.0378	0.1380	3.340	0.615
2.188	.0485	.1554	3.174	.683
2.103	.0626	.1775	2.971	.742
2.025	.0753	.1962	2.802	.777
1.944	.0876	.2137	2.647	.797
1.856	.0997	.2291	2.491	.807
1.763	.1120	.2439	2.340	.810
1.681	.1221	.2557	2.210	.803
1.599	.1298	.2648	2.087	.784
1.511	.1315	.2689	1.966	.739
1.420	.1319	.2676	1.850	.700
1.335	.1328	.2674	1.739	.662
1.261	.1340	.2683	1.642	.629
1.181	.1356	.2681	1.538	.597
1.112	.1369	.2694	1.448	.566
1.043	.1385	.2706	1.356	.534
.982	.1401	.2728	1.275	.504
.874	.1425	.2775	1.121	.449
.790	.1453	.2828	1.014	.406

TABLE I - Continued

Two-Blade E" Propeller
15° at 0.75 R

V/nD	C_T	C_P	C_s	η
0.763	0.0011	0.0101	1.915	0.085
.705	.0158	.0185	1.565	.602
.655	.0271	.0246	1.375	.722
.611	.0352	.0287	1.244	.749
.565	.0443	.0331	1.118	.755
.516	.0536	.0370	.998	.748
.451	.0657	.0411	.854	.721
.416	.0722	.0436	.779	.689
.377	.0777	.0448	.702	.654
.328	.0852	.0462	.607	.605
.275	.0936	.0480	.505	.536

TABLE I - Continued

Two-Blade E" Propeller
25° at 0.75 R

V/nD	C_T	C_P	C_s	η
1.190	0.0045	0.0208	2.582	0.258
1.128	.0173	.0323	2.241	.604
1.078	.0293	.0425	2.027	.744
1.022	.0399	.0515	1.850	.792
.971	.0495	.0597	1.708	.805
.909	.0610	.0686	1.554	.808
.863	.0696	.0750	1.448	.801
.803	.0785	.0805	1.329	.782
.754	.0871	.0850	1.237	.772
.710	.0944	.0888	1.153	.755
.660	.1027	.0924	1.063	.734
.619	.1100	.0953	.991	.714
.574	.1163	.0968	.916	.689
.526	.1226	.0976	.838	.661
.475	.1305	.0990	.754	.626
.427	.1362	.0990	.678	.587
.390	.1413	.0995	.619	.554
.336	.1402	.1092	.523	.432
.249	.1428	.1135	.385	.313

TABLE I - Continued

Two-Blade E" Propeller
35° at 0.75 R

V/nD	C_T	C_P	C_s	η
1.625	0.0229	0.0625	2.830	0.596
1.570	.0344	.0764	2.625	.706
1.508	.0449	.0890	2.446	.760
1.454	.0545	.1006	2.301	.788
1.397	.0644	.1115	2.168	.807
1.318	.0767	.1244	2.000	.812
1.267	.0850	.1323	1.899	.814
1.202	.0941	.1403	1.781	.806
1.145	.1020	.1463	1.684	.799
1.114	.1066	.1502	1.627	.791
1.081	.1118	.1535	1.573	.787
1.051	.1158	.1560	1.525	.780
1.015	.1206	.1588	1.466	.771
.985	.1247	.1608	1.417	.762
.953	.1286	.1635	1.370	.750
.921	.1325	.1670	1.318	.731
.891	.1324	.1733	1.266	.681
.860	.1338	.1756	1.218	.655
.785	.1358	.1788	1.106	.596
.717	.1388	.1803	1.010	.552
.666	.1431	.1841	.935	.518
.412	.1584	.2011	.568	.325

TABLE I - Continued

Two-Blade E" Propeller
45° at 0.75 R

V/nD	C_T	C_P	C_s	η
2.243	0.0377	0.1284	3.387	0.659
2.189	.0485	.1452	3.190	.724
2.092	.0599	.1643	3.002	.763
2.022	.0700	.1793	2.850	.790
1.940	.0813	.1965	2.682	.803
1.859	.0930	.2125	2.532	.814
1.766	.1036	.2251	2.380	.812
1.688	.1133	.2371	2.250	.806
1.595	.1242	.2475	2.108	.800
1.504	.1322	.2586	1.972	.769
1.418	.1338	.2658	1.849	.714
1.343	.1343	.2667	1.750	.678
1.266	.1360	.2671	1.649	.644
1.174	.1378	.2694	1.528	.600
1.112	.1412	.2731	1.444	.575
1.031	.1434	.2766	1.334	.534
.961	.1476	.2824	1.239	.502

TABLE I - Continued

Four-Blade E Propeller

15° at 0.75 R

V/nD	C_T	C_P	C_s	η
0.744	0.0020	0.0155	1.715	0.095
.715	.0137	.0220	1.552	.445
.679	.0244	.0278	1.391	.597
.646	.0353	.0334	1.275	.684
.627	.0405	.0359	1.221	.708
.595	.0494	.0403	1.132	.730
.553	.0600	.0449	1.029	.741
.525	.0680	.0480	.964	.743
.493	.0758	.0512	.893	.731
.467	.0825	.0535	.839	.720
.445	.0861	.0548	.796	.698
.406	.0958	.0576	.719	.677
.381	.1004	.0594	.670	.646
.335	.1086	.0610	.586	.596
.300	.1148	.0624	.523	.552
.265	.1206	.0632	.457	.502
.227	.1258	.0634	.394	.451

TABLE I - Continued

Four-Blade E Propeller

25° at 0.75 R

V/nD	C_T	C_P	C_s	η
1.171	0.0062	0.0327	2.320	0.222
1.128	.0209	.0458	2.090	.515
1.078	.0381	.0594	1.897	.692
1.046	.0488	.0685	1.788	.745
.998	.0613	.0785	1.661	.779
.960	.0719	.0864	1.567	.799
.906	.0824	.0936	1.455	.798
.883	.0888	.0979	1.405	.801
.853	.0978	.1038	1.342	.803
.823	.1041	.1084	1.283	.791
.786	.1126	.1130	1.216	.783
.735	.1221	.1174	1.128	.765
.687	.1331	.1226	1.045	.746
.640	.1429	.1265	.968	.722
.585	.1545	.1300	.877	.693
.523	.1655	.1315	.785	.650
.465	.1736	.1341	.695	.603
.409	.1780	.1368	.609	.532
.333	.1753	.1411	.493	.406
.267	.1771	.1430	.394	.331

TABLE I - Continued

Four-Blade E Propeller

35° at 0.75 R

V/nD	C_T	C_P	C_s	η
1.597	0.0409	0.1032	2.515	0.632
1.544	.0545	.1189	2.364	.708
1.484	.0684	.1347	2.217	.754
1.440	.0796	.1476	2.112	.776
1.406	.0873	.1550	2.042	.790
1.374	.0956	.1641	1.972	.801
1.336	.1031	.1704	1.905	.808
1.274	.1153	.1816	1.792	.808
1.206	.1312	.1954	1.672	.810
1.138	.1451	.2065	1.561	.799
1.078	.1565	.2146	1.467	.786
1.006	.1661	.2213	1.362	.757
.938	.1669	.2268	1.263	.691
.877	.1695	.2275	1.179	.655
.820	.1700	.2265	1.104	.616
.750	.1724	.2298	1.006	.563
.670	.1757	.2352	.895	.501
.584	.1812	.2410	.776	.439
.482	.1843	.2440	.638	.364
.352	.1884	.2534	.465	.262

TABLE I - Continued

Four-Blade E Propeller

45° at 0.75 R

V/nD	C_T	C_P	C_s	η
2.184	0.0661	0.2135	2.978	0.676
2.085	.0865	.2418	2.772	.746
2.020	.0990	.2619	2.640	.764
1.930	.1160	.2856	2.480	.784
1.848	.1289	.3022	2.350	.790
1.807	.1364	.3100	2.283	.796
1.710	.1522	.3290	2.136	.791
1.626	.1635	.3447	2.013	.772
1.542	.1679	.3502	1.902	.739
1.448	.1704	.3500	1.786	.706
1.349	.1716	.3505	1.664	.661
1.258	.1722	.3502	1.552	.619
1.134	.1756	.3510	1.398	.567
1.052	.1779	.3530	1.295	.530
.958	.1815	.3571	1.177	.487
.821	.1830	.3614	1.007	.415
.660	.1876	.3725	.804	.332
.532	.1910	.3828	.644	.265

TABLE I - Continued

Three-Blade E' Propeller

15° at 0.75 R

V/nD	C_T	C_P	C_s	η
0.765	0.0011	0.0136	1.808	0.062
.715	.0176	.0228	1.524	.552
.655	.0344	.0328	1.298	.687
.606	.0474	.0391	1.159	.735
.552	.0619	.0460	1.021	.743
.506	.0733	.0508	.919	.730
.451	.0850	.0549	.806	.698
.396	.0966	.0588	.698	.650
.353	.1040	.0607	.619	.605
.296	.1147	.0629	.515	.539
.245	.1235	.0639	.425	.474

TABLE I - Continued

Three-Blade E' Propeller

25° at 0.75 R

V/nD	C_T	C_P	C_s	η
1.203	0.0081	0.0255	2.510	0.382
1.145	.0204	.0427	2.151	.547
1.085	.0372	.0582	1.916	.694
1.032	.0523	.0705	1.755	.766
.964	.0679	.0829	1.586	.790
.919	.0805	.0929	1.478	.796
.856	.0936	.1025	1.350	.781
.795	.1065	.1105	1.235	.766
.744	.1172	.1158	1.145	.753
.689	.1292	.1221	1.049	.729
.625	.1416	.1273	.944	.695
.550	.1568	.1318	.825	.654
.485	.1671	.1345	.724	.602
.425	.1725	.1398	.630	.524
.379	.1744	.1443	.558	.458
.318	.1747	.1463	.467	.380

TABLE I - Continued

Three-Blade E' Propeller

35° at 0.75 R

V/nD	C_T	C_P	C_s	η
1.625	0.0325	0.0972	2.590	0.543
1.552	.0527	.1150	2.391	.711
1.490	.0657	.1310	2.238	.747
1.465	.0719	.1377	2.179	.765
1.415	.0838	.1513	2.061	.783
1.349	.0979	.1663	1.932	.794
1.290	.1101	.1784	1.821	.796
1.255	.1171	.1852	1.760	.794
1.215	.1250	.1925	1.689	.789
1.169	.1335	.1997	1.613	.782
1.098	.1464	.2099	1.498	.765
1.041	.1557	.2173	1.413	.746
1.016	.1597	.2210	1.373	.734
.985	.1624	.2245	1.328	.712
.950	.1647	.2298	1.275	.681
.919	.1668	.2321	1.230	.660
.876	.1693	.2338	1.172	.634
.810	.1728	.2362	1.081	.592
.753	.1766	.2391	1.003	.556
.654	.1841	.2459	.839	.475
.529	.1900	.2538	.696	.396

TABLE I - Continued

Three-Blade E' Propeller

45° at 0.75 R

V/nD	C_T	C_P	C_s	η
2.277	0.0462	0.1831	3.194	0.574
2.200	.0618	.2044	3.022	.665
2.123	.0772	.2274	2.856	.721
2.042	.0919	.2510	2.691	.748
1.962	.1068	.2703	2.550	.775
1.870	.1219	.2920	2.390	.780
1.779	.1376	.3119	2.248	.785
1.689	.1504	.3281	2.110	.774
1.605	.1619	.3412	1.990	.761
1.518	.1668	.3505	1.865	.719
1.427	.1696	.3537	1.757	.684
1.348	.1720	.3551	1.658	.653
1.271	.1740	.3569	1.562	.620
1.184	.1783	.3608	1.451	.585
1.121	.1803	.3631	1.373	.556
1.051	.1841	.3672	1.285	.527
.974	.1888	.3717	1.187	.495
.885	.1936	.3774	1.075	.454
.781	.1987	.3842	.946	.404

TABLE II

Three-Blade E Propeller with Spinner

35° at 0.75 R

V/nD	C_T	C_P	C_s	η
1.652	0.0178	0.0574	2.926	0.312
1.599	.0384	.0754	2.682	.687
1.541	.0445	.0906	2.498	.757
1.479	.0598	.1073	2.312	.816
1.426	.0692	.1190	2.183	.839
1.361	.0808	.1288	2.051	.849
1.306	.0897	.1388	1.939	.844
1.245	.0999	.1470	1.824	.844
1.196	.1071	.1538	1.739	.833
1.138	.1161	.1602	1.637	.822
1.082	.1236	.1655	1.551	.807
1.030	.1296	.1701	1.468	.784
.975	.1338	.1745	1.383	.744
.932	.1398	.1765	1.319	.708
.888	.1356	.1771	1.257	.671
.839	.1341	.1784	1.185	.651
.787	.1345	.1788	1.111	.598
.736	.1367	.1810	1.066	.556

TABLE II - Continued

Two-Blade E" Propeller with Spinner

35° at 0.75 R

V/nD	C_T	C_P	C_s	η
1.685	0.0099	0.0489	3.164	0.389
1.620	.0240	.0611	2.833	.656
1.568	.0340	.0742	2.638	.718
1.516	.0448	.0870	2.470	.781
1.465	.0543	.0981	2.328	.810
1.386	.0662	.1117	2.149	.821
1.332	.0751	.1205	2.033	.831
1.268	.0866	.1318	1.893	.829
1.188	.0977	.1487	1.754	.814
1.126	.1072	.1496	1.647	.807
1.065	.1157	.1568	1.545	.791
.968	.1290	.1655	1.392	.765
.905	.1345	.1737	1.285	.701
.837	.1387	.1776	1.168	.632
.741	.1396	.1801	1.044	.574
.656	.1440	.1844	.920	.512

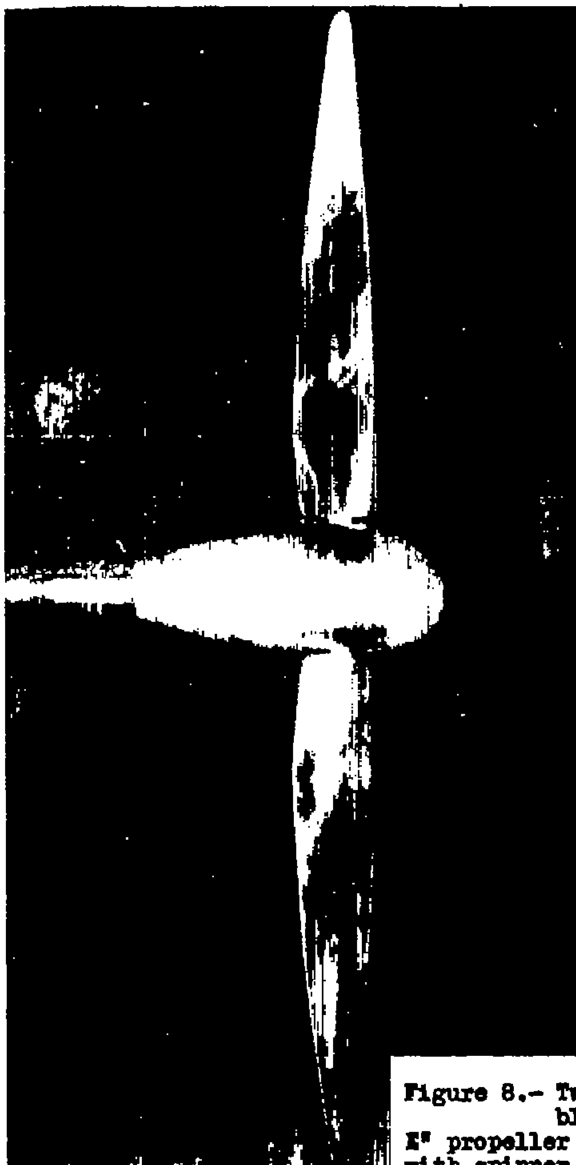

Figure 8.- Two-blade E" propeller with spinner.

Figure 1. Blade plan forms.

E E' E"

Figure 2.- Propeller hubs.

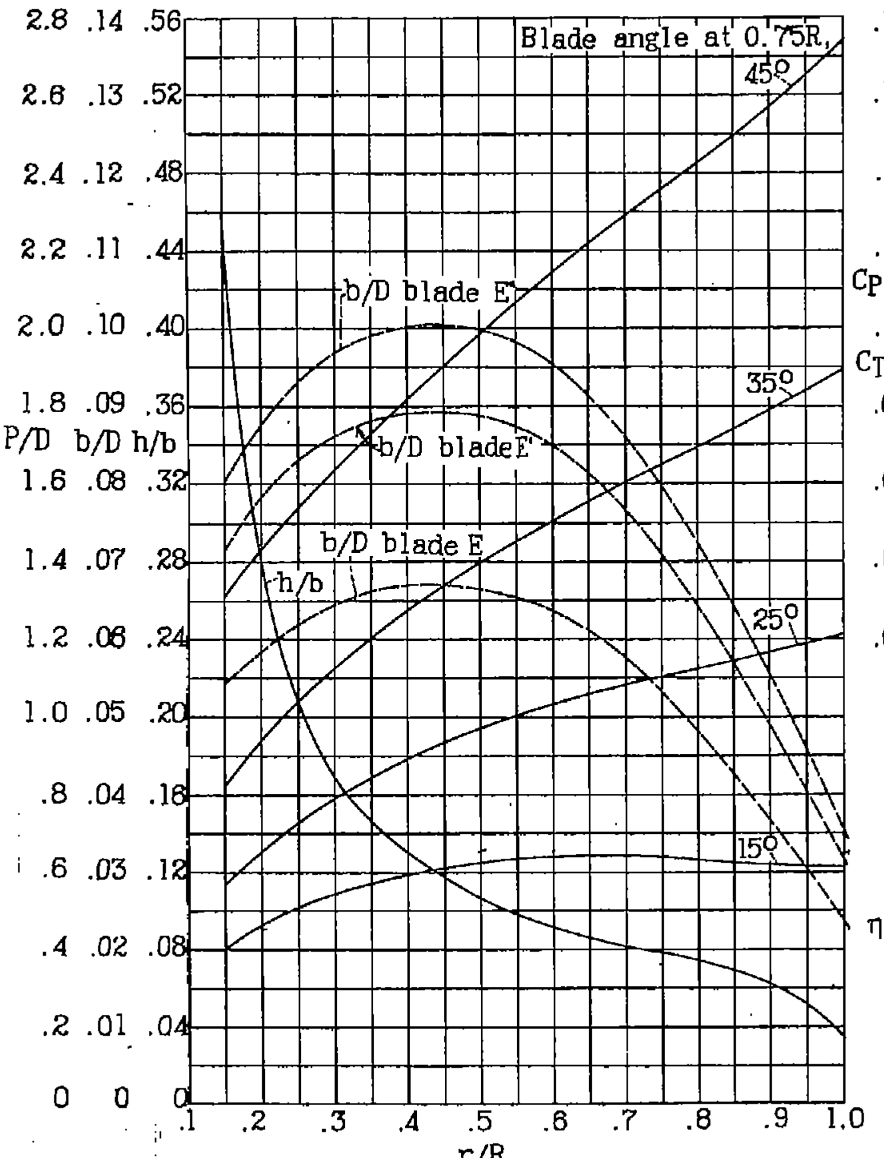

Figure 3.- Blade-form curves.

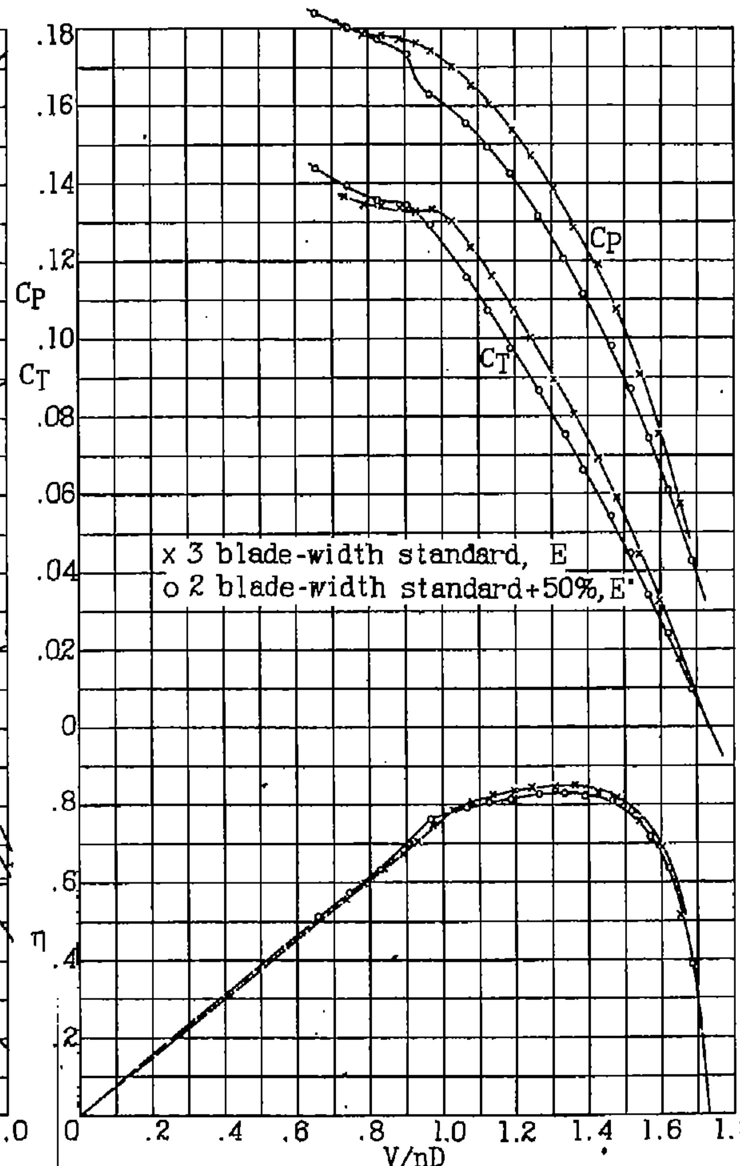

Figure 9.- Three-blade E and two-blade E" propellers with spinners. Blade angle 35°.

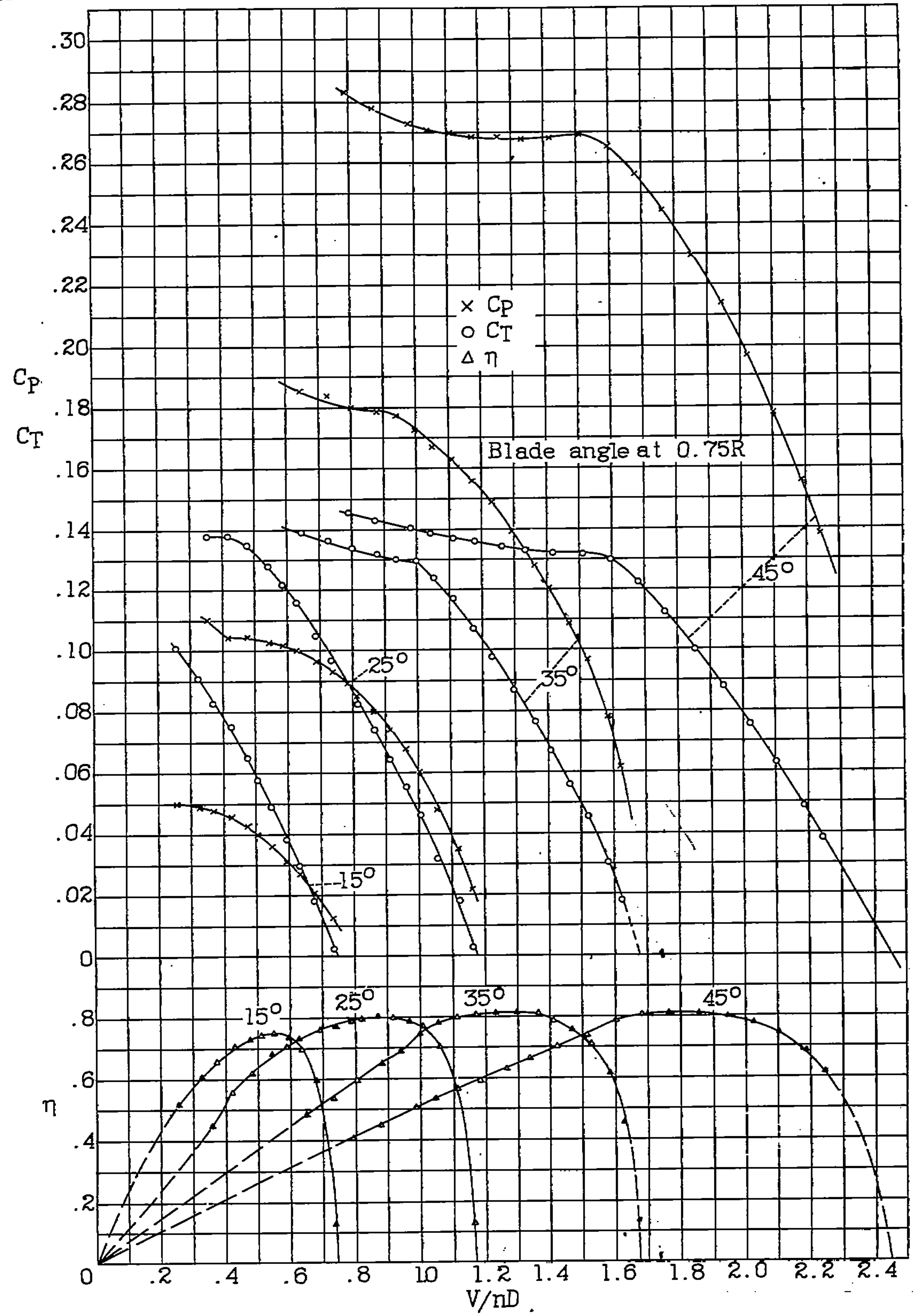

Figure 4.- Three-blade E propeller.

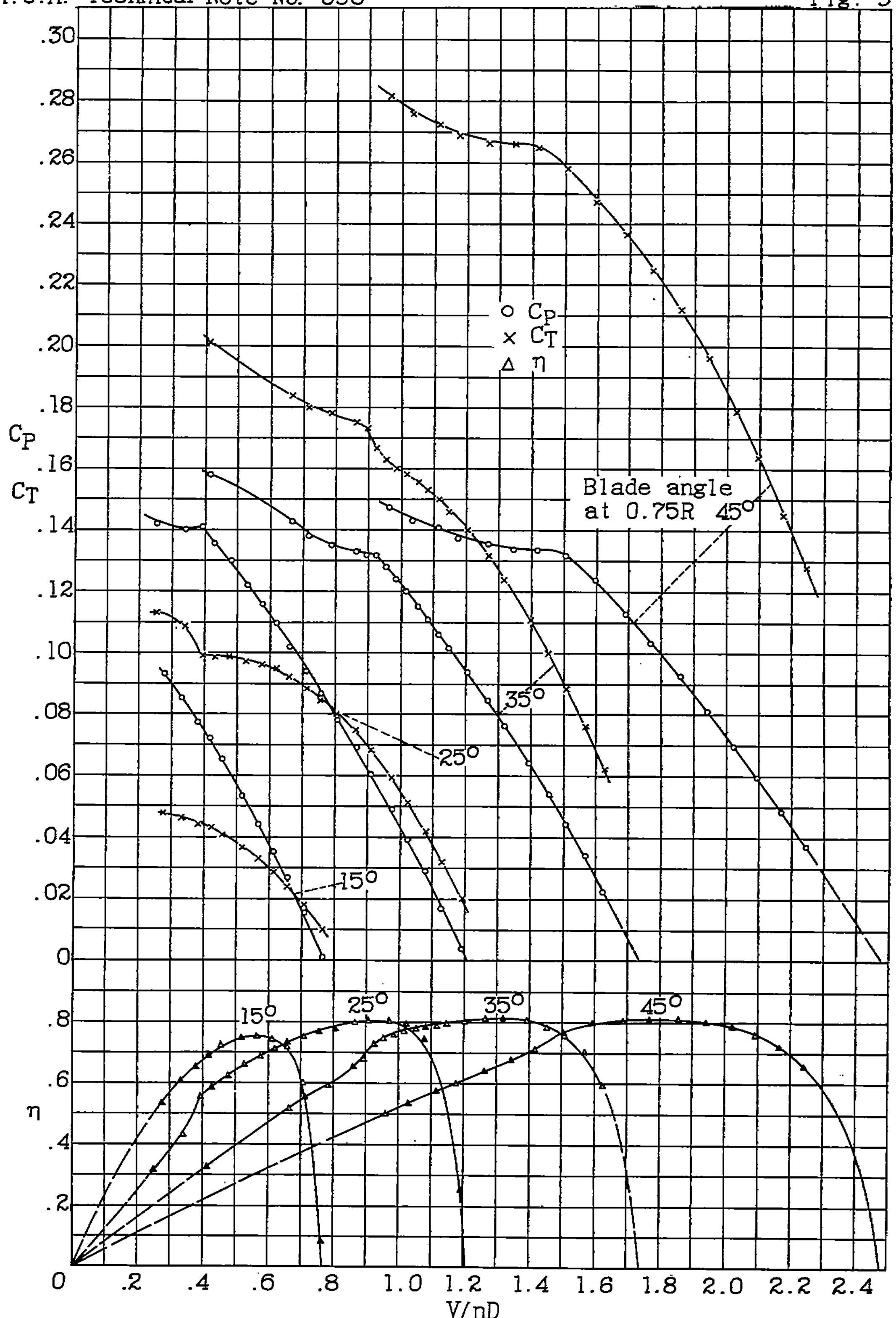

Figure 5.- Two-blade E' propeller.

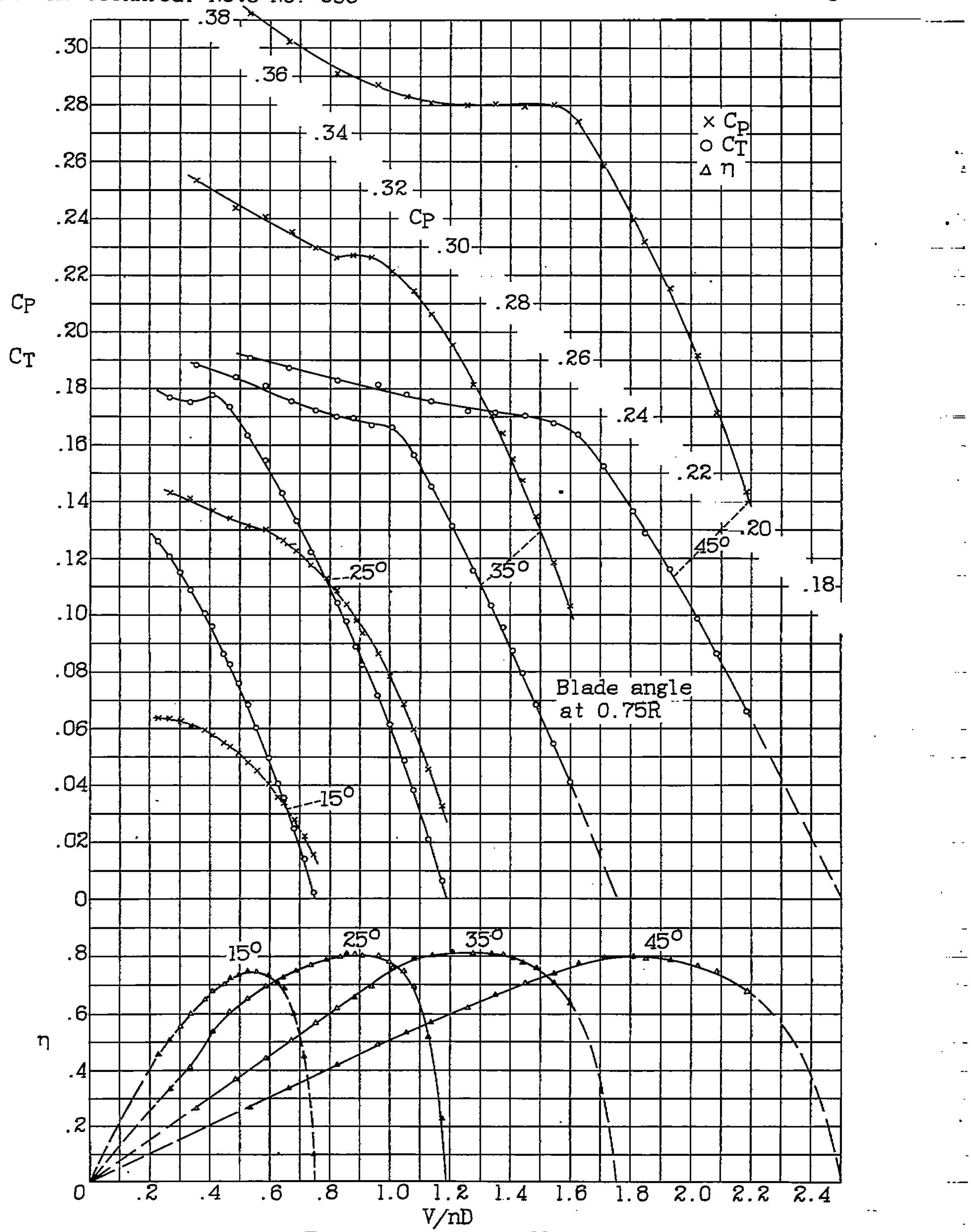

Figure 6.- Four-blade E propeller.

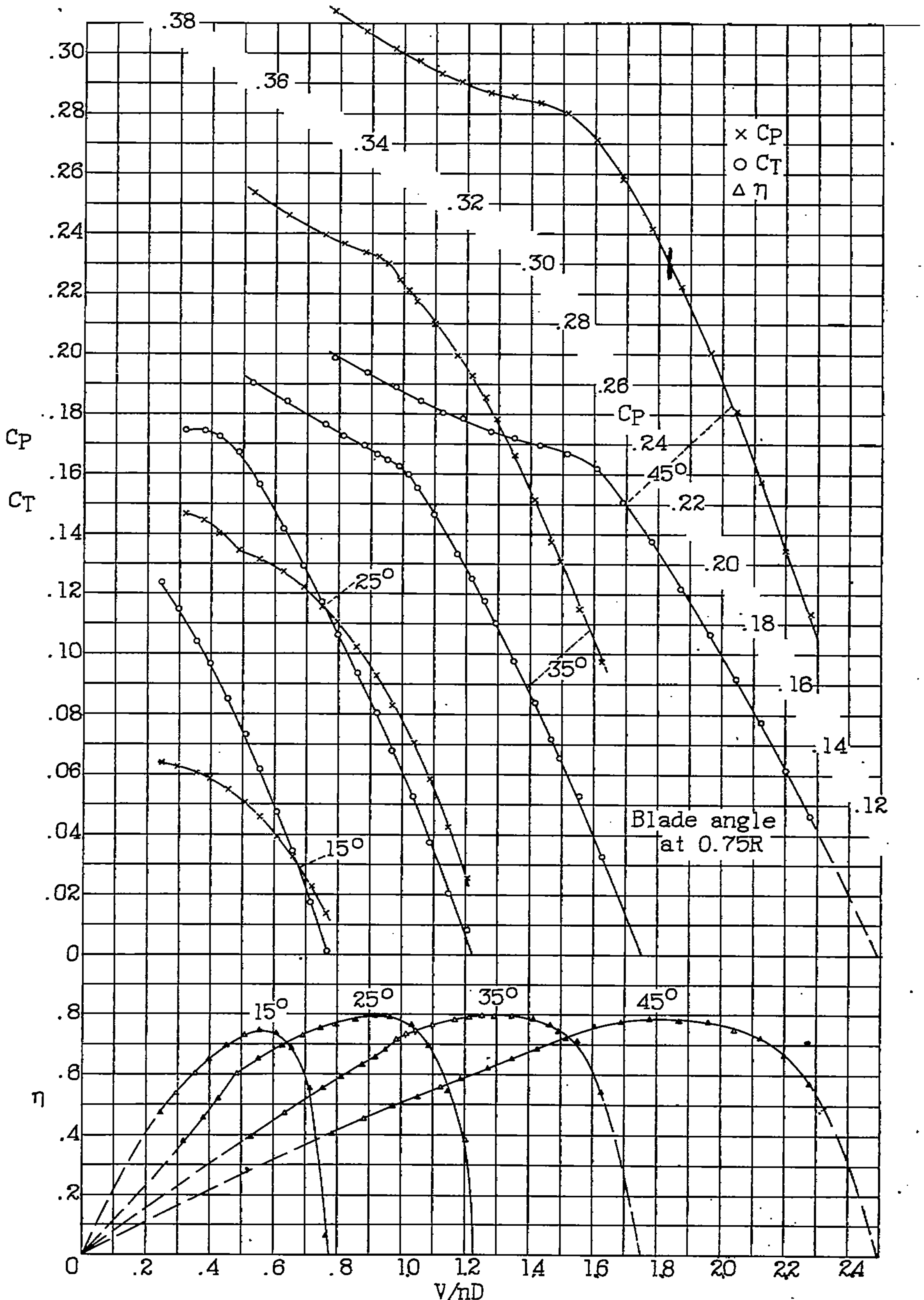

Figure 7.- Three-blade E propeller.