NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 301 c. 4

FULL SCALE TESTS OF WOOD PROPELLERS ON A VE-7 AIRPLANE IN THE PROPELLER RESEARCH TUNNEL

By FRED E. WEICK

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AERONAUTICAL SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Symbol	Unit	Symbol
Length	l	meter	m	foot (or mile)	ft. (or mi.)
Time	t	second	sec	second (or hour)	sec. (or hr.)
Force	F	weight of one kilogram	kg	weight of one pound	lb.
Power	P	kg/m/sec		horsepower	HP.
Speed		{km/hr		mi./hr	M. P. H.
		{m/sec		ft./sec	f. p. s.

2. GENERAL SYMBOLS, ETC.

W, Weight, $=mg$

g, Standard acceleration of gravity $=9.80665$ m/sec.$^2=32.1740$ ft./sec.^{2}

m, Mass, $=\frac{W}{g}$

ρ, Density (mass per unit volume).

Standard density of dry air, 0.12497 (kg-m^{-4} sec.^{2}) at 15° C and 760 mm $=0.002378$ (lb.-ft.$^{-4}$ sec.^{2}).

Specific weight of "standard" air, 1.2255 kg/m$^3=0.07651$ lb./ft.^{3}

mk^2, Moment of inertia (indicate axis of the radius of gyration, k, by proper subscript).

S, Area.

S_w, Wing area, etc.

G, Gap.

b, Span.

c, Chord length.

b/c, Aspect ratio.

f, Distance from c. g. to elevator hinge.

μ, Coefficient of viscosity.

3. AERODYNAMICAL SYMBOLS

V, True air speed.

q, Dynamic (or impact) pressure $=\frac{1}{2}\rho V^2$

L, Lift, absolute coefficient $C_L=\frac{L}{qS}$

D, Drag, absolute coefficient $C_D=\frac{D}{qS}$

C, Cross-wind force, absolute coefficient $C_C=\frac{C}{qS}$

R, Resultant force. (Note that these coefficients are twice as large as the old coefficients L_C, D_C.)

i_w Angle of setting of wings (relative to thrust line).

i_t, Angle of stabilizer setting with reference to thrust line.

γ, Dihedral angle.

$\rho\frac{Vl}{\mu}$, Reynolds Number, where l is a linear dimension.

e. g., for a model airfoil 3 in. chord, 100 mi./hr. normal pressure, 0° C: 255,000 and at 15° C., 230,000;

or for a model of 10 cm chord 40 m/sec, corresponding numbers are 299,000 and 270,000.

C_p, Center of pressure coefficient (ratio of distance of $C. P.$ from leading edge to chord length).

β, Angle of stabilizer setting with reference to lower wing, $=(i_t-i_w)$.

α, Angle of attack.

ϵ, Angle of downwash.

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6722—29——1

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

NAVY BUILDING, WASHINGTON, D. C.

(An independent Government establishment, created by act of Congress approved March 3, 1915, for the supervision and direction of the scientific study of the problems of flight. It consists of 12 members who are appointed by the President, all of whom serve as such without compensation.)

REPORT No. 301

FULL SCALE TESTS OF WOOD PROPELLERS ON A VE-7 AIRPLANE IN THE PROPELLER RESEARCH TUNNEL

By Fred E. Weick

SUMMARY

The investigation described in this report was made primarily to afford a comparison between propeller tests in the new Propeller Research Tunnel and flight tests and small model tests on propellers. Three wood propellers which had been previously tested in flight on a VE-7 airplane, and of which models had also been tested in a wind tunnel, were tested again on a VE-7 airplane in the Propeller Research Tunnel. The results of these tests are in fair agreement with those of the flight and model tests.

Tests were also made with the tail surfaces removed, and with both the wings and tail surfaces removed. It was found that the effect of the tail surfaces on the propeller characteristics was negligible, but that the wings reduced the maximum propulsive efficiency about 5 per cent.

INTRODUCTION

Heretofore aerodynamic tests on propellers have been made either in flight or on small models in a wind tunnel. Full scale tests are highly desirable, but flight tests to obtain the aerodynamic characteristics of propellers are difficult to make and have not been sufficiently accurate to be useful in bringing out small differences in propellers.

The tests reported in this paper are the first wind-tunnel investigations on full-size propellers. They were made in the 20-foot Propeller Research Tunnel of the National Advisory Committee for Aeronautics, which is described in detail in Reference 1. Three wood propellers of standard Navy form were tested on a Vought VE-7 airplane with a Wright 180 HP. E-2 engine. These particular propellers were selected for this investigation because they had been previously tested on a VE-7 airplane in flight (References 2 and 3) and models of the propellers had also been tested with a model VE-7 airplane in the Stanford University wind tunnel; thus, a direct comparison of the full-scale wind tunnel results with the results of the flight and the model tests was afforded.

In addition to the aerodynamic characteristics of the three propellers on the complete airplane, the effects of the wings and tail surfaces on the characteristics of one propeller were measured at one angle of attack. Also, the angle of twist of one section of each propeller was measured in operation.

METHODS AND APPARATUS

The Propeller Research Wind Tunnel is of the open jet type with an airstream 20 feet in diameter, in which velocities up to 110 M. P. H., can be obtained. A complete description of the tunnel, balances, and other measuring apparatus is given in Reference 1.

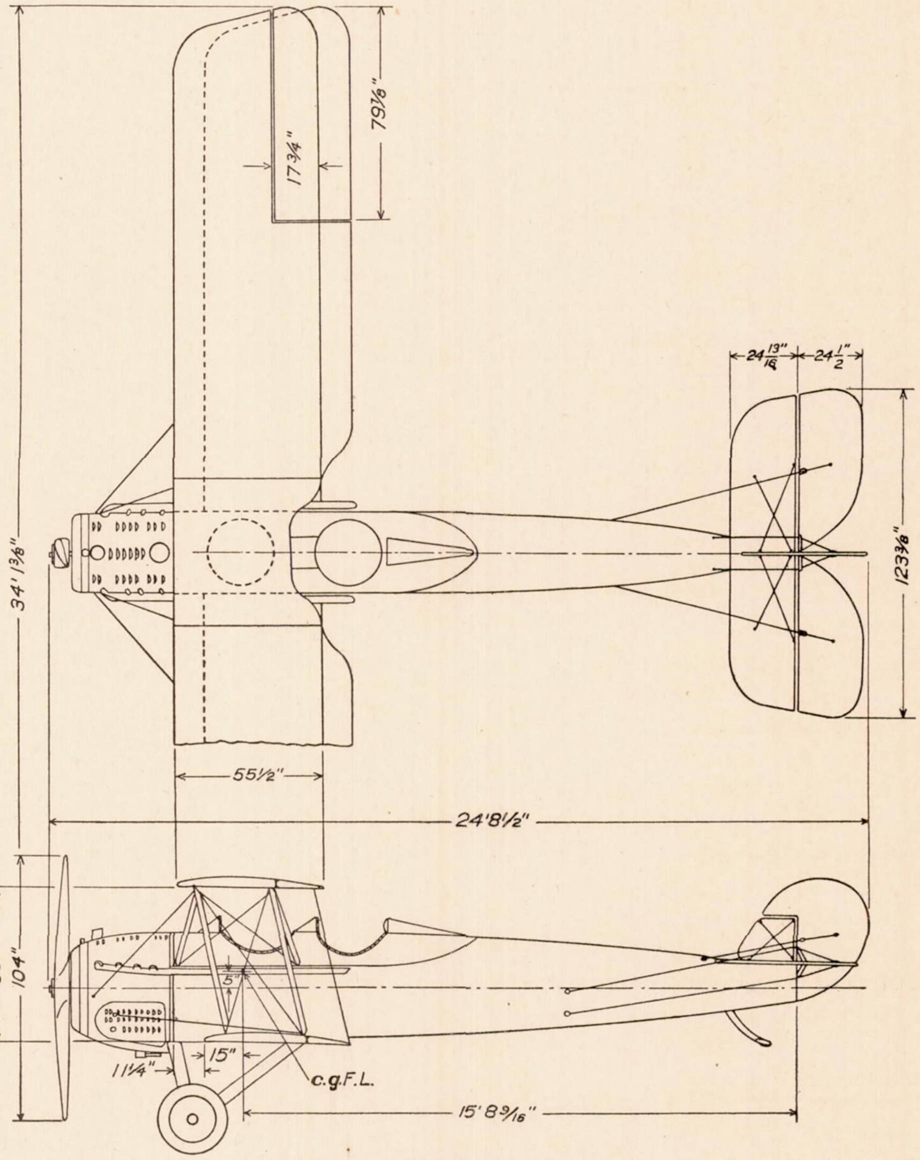
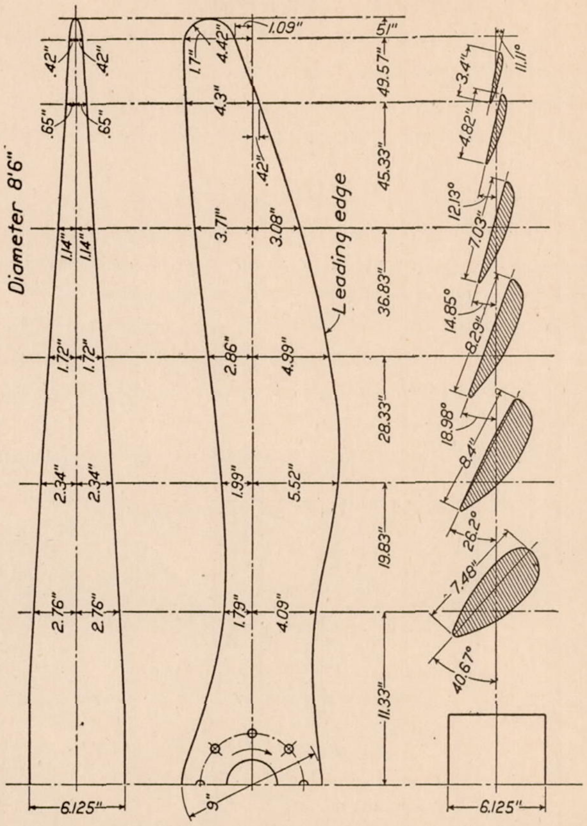
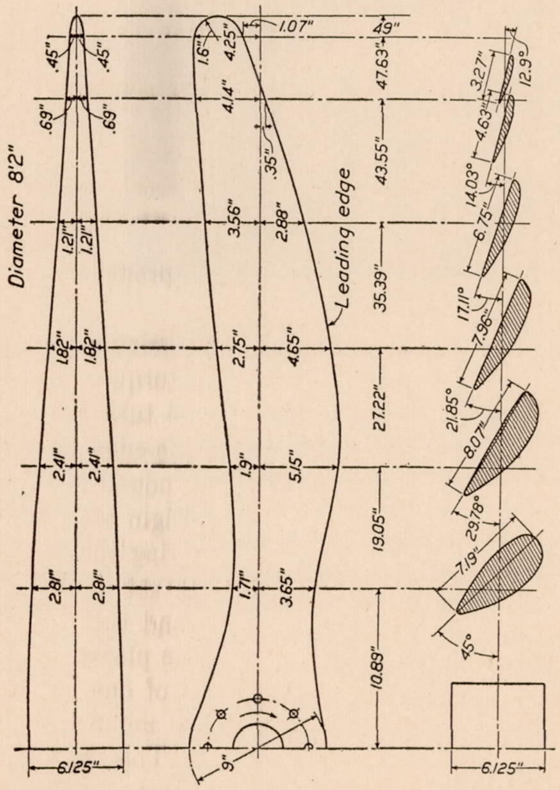


FIG. 1.—The VE-7 airplane



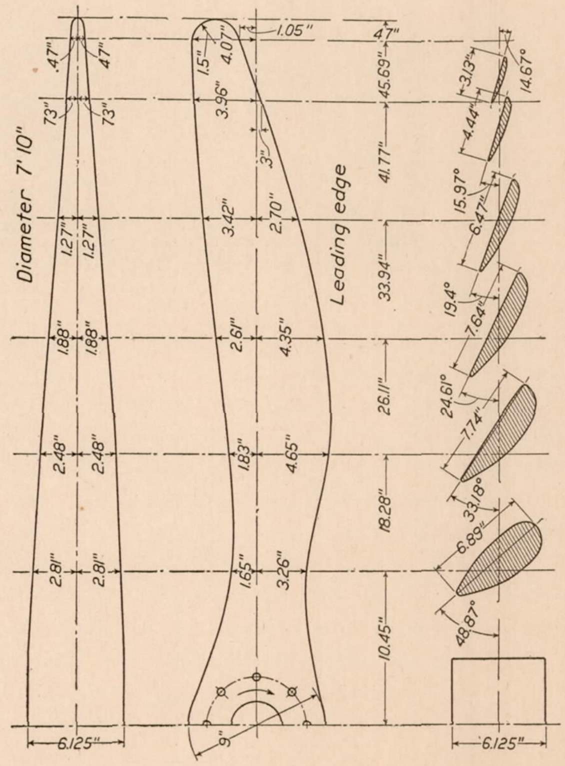
Pitch: 5′ 1.2″. Pitch ratio: 0.6. Aspect ratio: 6. Camber ratio: Minimum +20 per cent. Rotation: Right hand.

FIG. 3.—Experimental propeller B′ for VE-7 airplane



Pitch: 5′ 8.6″. Pitch ratio: 0.7. Aspect ratio: 6. Camber ratio: Minimum +20 per cent. Rotation: Right hand.

FIG. 4.—Experimental propeller I for VE-7 airplane



Pitch: 6′ 3.2″. Pitch ratio: 0.8. Aspect ratio: 6. Camber ratio: Minimum +20 per cent. Rotation: Right hand.

FIG. 5.—Experimental propeller D′ for VE-7 airplane

The VE-7 airplane (fig. 1) had a span of 34 feet. When mounted in the center of the air stream the wings projected approximately 7 feet outside the air stream. Figure 2 is a photograph of the airplane mounted in the experiment chamber. It is considered that a sufficient portion of the wing structure was in the air stream to include all parts which would react on or be influenced by the propeller.

The general dimensions of the three propellers tested are given in Figures 3, 4, and 5, and the ordinates of the various sections shown in the drawings are given in Table I. The propellers, which are of standard Navy wood type, form a series varying in pitch ratio. Propeller I, the central one of the series, has a ratio of pitch to diameter of 0.7, and the other two propellers, B′ and D′, have pitch ratios of 0.6 and 0.8, respectively. The blade width, thickness, and angle were measured for each section of each propeller after the tests were completed. In nearly all cases the measured blade widths and thickness were about $\frac{1}{16}$ inch greater than those shown on the drawings, probably due to the fabric with which the propellers were covered. The measured blade angles over the working section or outer portion of the blade averaged

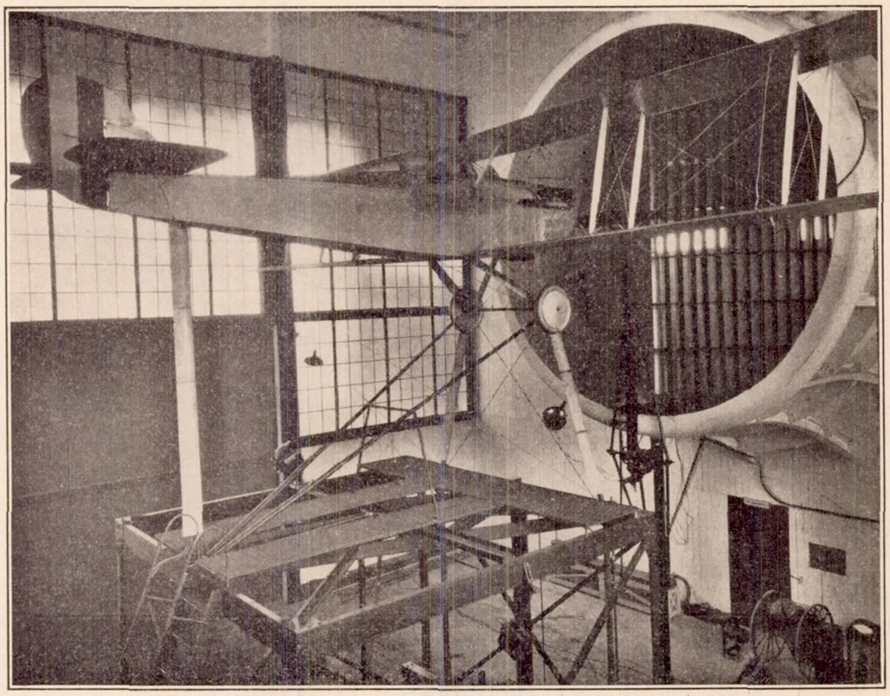


FIG. 2.—The VE-7 airplane mounted on balance of Propeller Research Tunnel

0.3° less than the drawing for propeller B′, 0.5° greater than the drawing for propeller I, and the same as the drawing for propeller D′.

The VE-7, as mounted in the tunnel, had inclosed within it a special steel skeleton fuselage with a built-in dynamometer scale to measure the engine and propeller torque directly. (Reference 1.) The engine was mounted in such a manner that it was free to turn about its own axis, but was restrained by means of a torque arm and system of knife-edge linkages leading to a Toledo scale dial, upon which the torque was indicated directly in pound-feet.

The revolution speed of the engine was measured by means of a special Elgin tachometer which, according to calibration, is accurate within ±2 R. P. M., although during the present tests it was not possible to read it within less than 5 R. P. M. An observer sat in the rear cockpit throughout the tests to operate the engine and read the torque scale and the tachometer. The velocity of the air stream was obtained by means of calibrated static plates.

In order to know the pitch of the propellers in operation, the deflection of one blade of each propeller was measured at the 36-inch radius, by means of a telescope mounted on a graduated base and sighted on first the leading and then the trailing edge. This was done while the propeller was standing still and then was repeated for each test point while the propeller was running.

The resultant horizontal force of the propeller-body combination, which may be either a thrust or a drag, was measured on the regular thrust balance (also described in Reference 1).

This resultant horizontal force R may be thought of as composed of three horizontal components, such that

$$R = T - D - \Delta D,$$

where

T = the thrust of the propeller while operating in front of the body (the tension in the crank shaft).

D = the drag of the airplane alone (without propeller) at the same air velocity and density.

ΔD = the increase in drag of the airplane with propeller, due to the slip stream.

In order to obtain the propulsive efficiency, which includes the propeller-body interference, an effective thrust is used which is defined as

$$\text{Effective thrust} = T - \Delta D = R + D.$$

The propulsive efficiency is the ratio of the useful power to the input power, or

$$\text{Propulsive efficiency} = \frac{\text{Effective thrust} \times \text{Velocity of advance.}}{\text{Input power}}$$

RESULTS

The results of the tests are given in Figures 6 to 10, inclusive, and in Tables II and III. They are reduced to the usual thrust and power coefficients and plotted against $\frac{V}{nD}$ for convenience in comparing them with the results of flight and model tests. These coefficients are:

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

$$C_P = \frac{\text{Power}}{\rho n^3 D^5}$$

$$\eta = \text{Propulsive efficiency}$$

$$= \frac{\text{Effective thrust} \times \text{Velocity}}{\text{Power}}$$

where D = propeller diameter and n = revolutions per unit time. Any homogeneous system of units may be used with these coefficients. The propeller characteristics are also given in terms of two other coefficients (sometimes called speed-power coefficients) in Table III.

The points in Figures 6 to 10 have been calculated directly from the observed data. Their dispersion, which it will be noticed is small, is in a general way a measure of the accuracy of the observations.

The angular deflections of one blade of each propeller are plotted against $\frac{V}{nD}$ in Figures 6, 7, and 8. In general, the deflections of all of the propellers were small. Throughout the working range of $\frac{V}{nD}$, propeller B′ had an average increase of blade angle of about 0.4° which, with its initial set of −0.3°, brought the angles in operation very close to the drawing values. The average curve through the points for propeller I shows practically no twist in operation, leaving the blade angles as they were measured, 0.5° too high. Propeller D′ checked the drawing without load, and averaged about 0.2° less in operation. The accuracy of the individual deflection measurements is apparently ±0.5°, and the faired curves are probably correct to within ±0.2°.

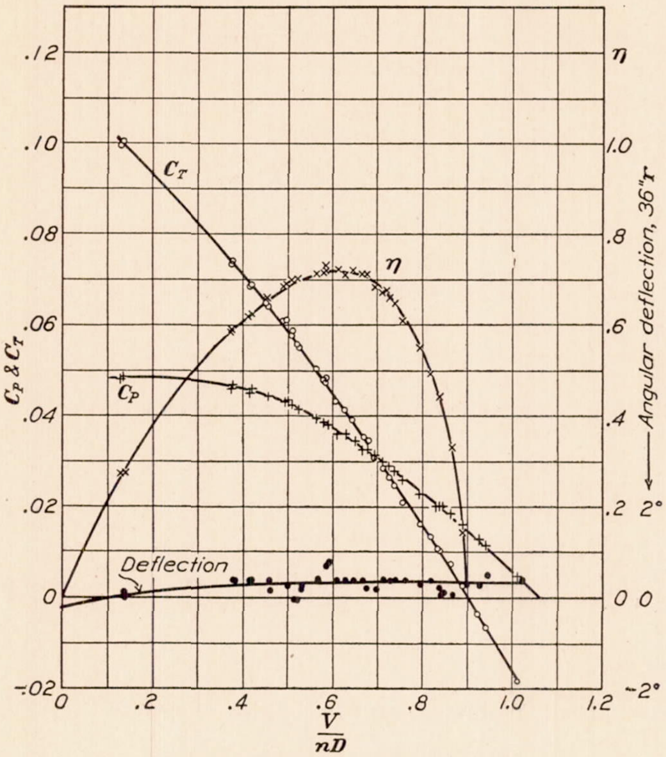


FIG. 6.—Propeller B′ with VE-7 airplane

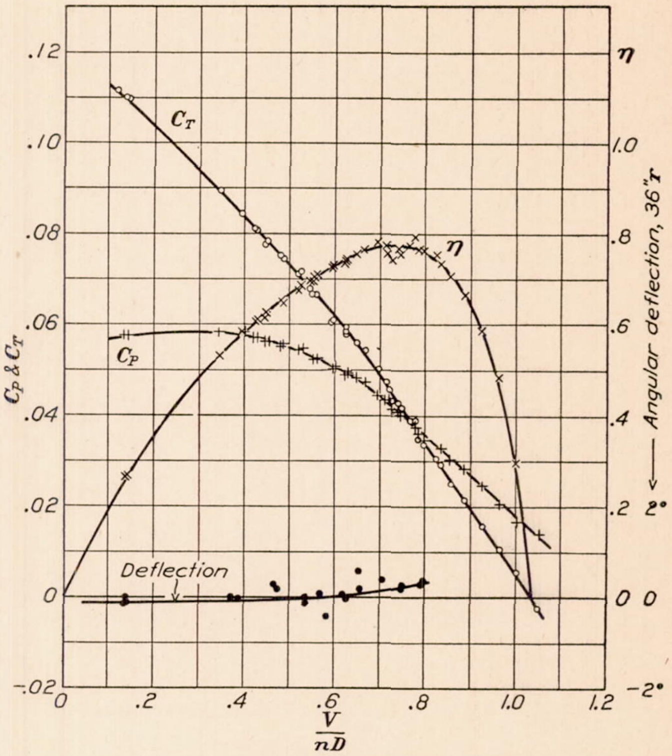


FIG. 7.—Propeller I (3714) with VE-7 airplane

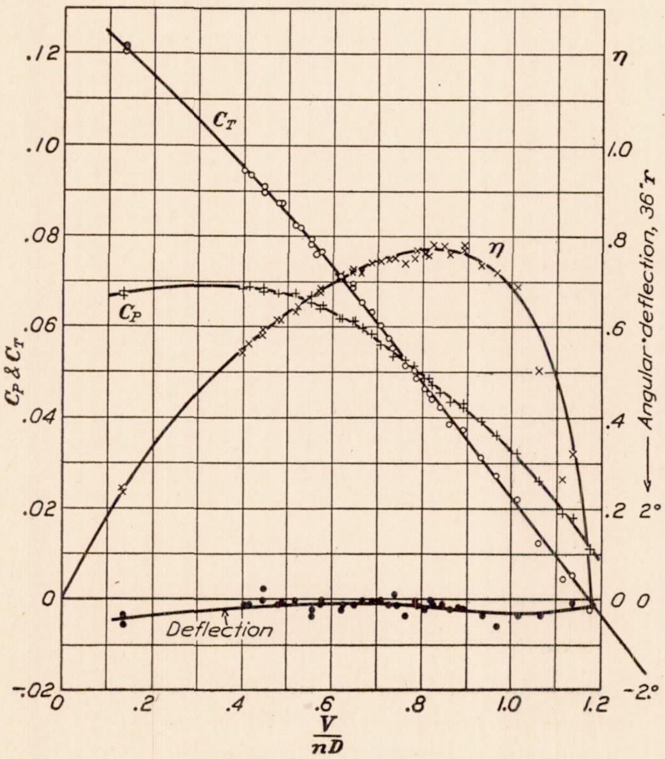


FIG. 8.—Propeller D′ with VE-7 airplane

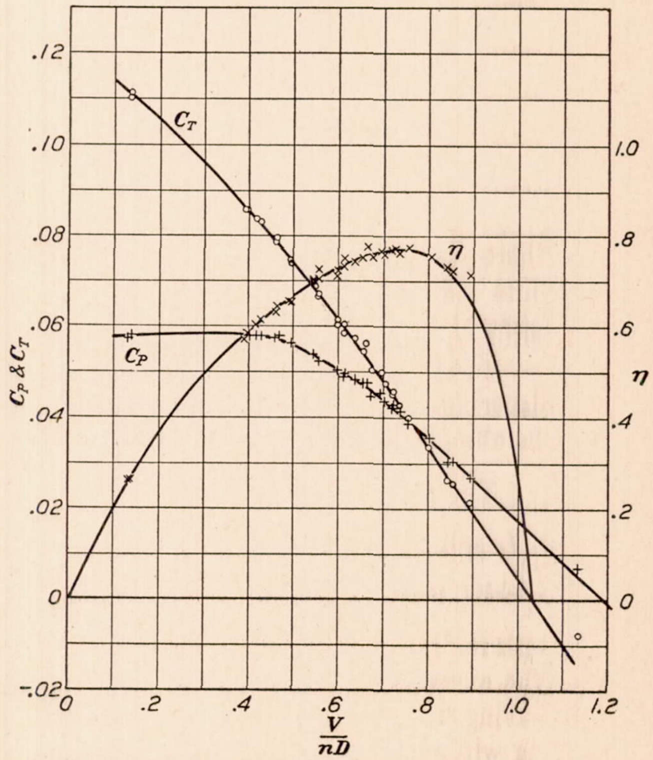


FIG. 9.—Propeller I (3714) with VE-7 airplane, without tail surfaces

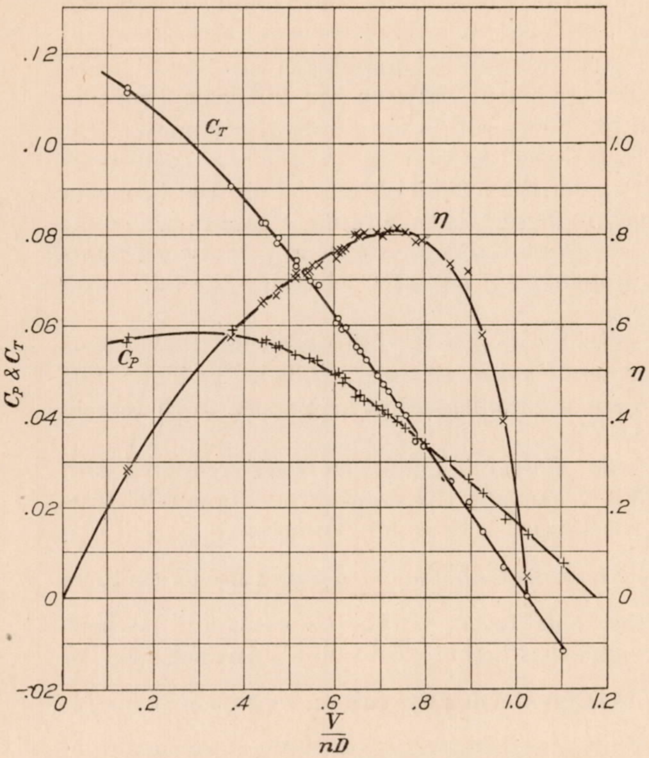


FIG. 10.—Propeller I (3714) with VE-7 airplane, without wings or tail surface

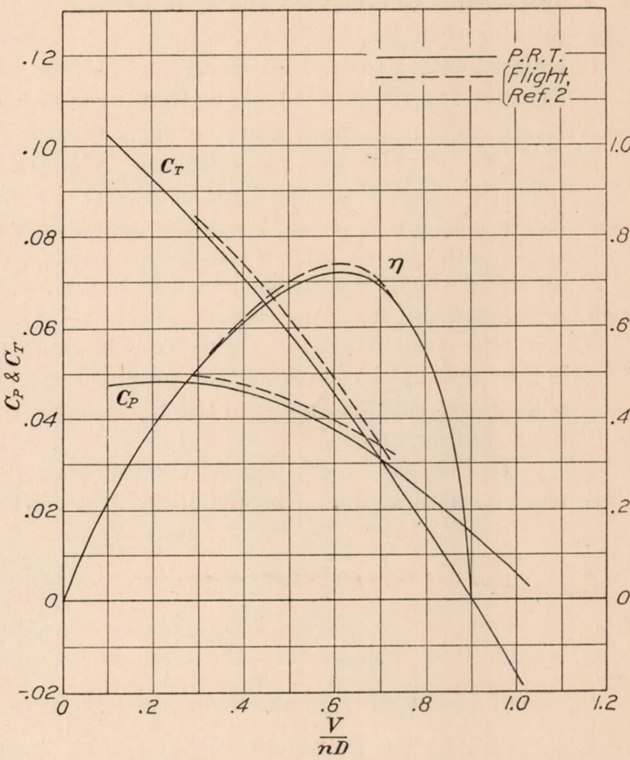


FIG. 11.—Comparison of propeller research tunnel and flight tests on Propeller B′

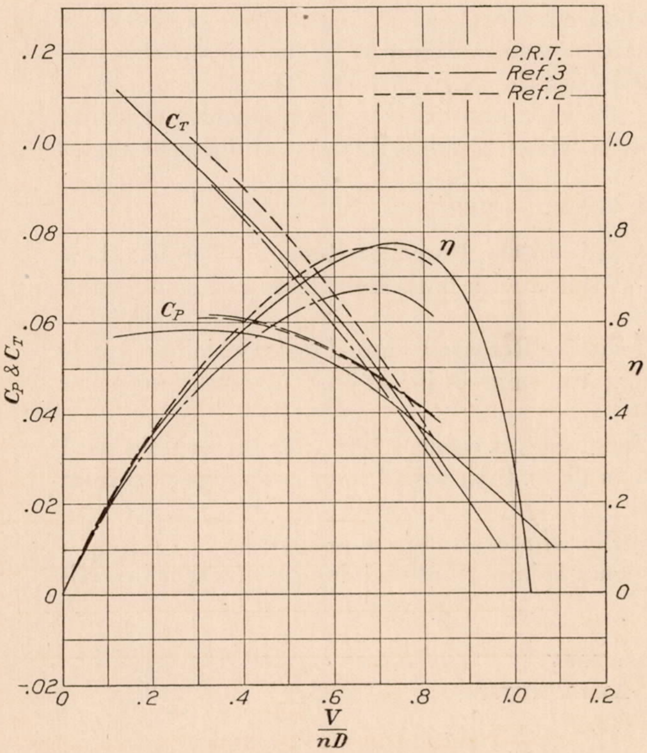


FIG. 12.—Comparison of propeller research tunnel and flight tests on Propeller I (3714)

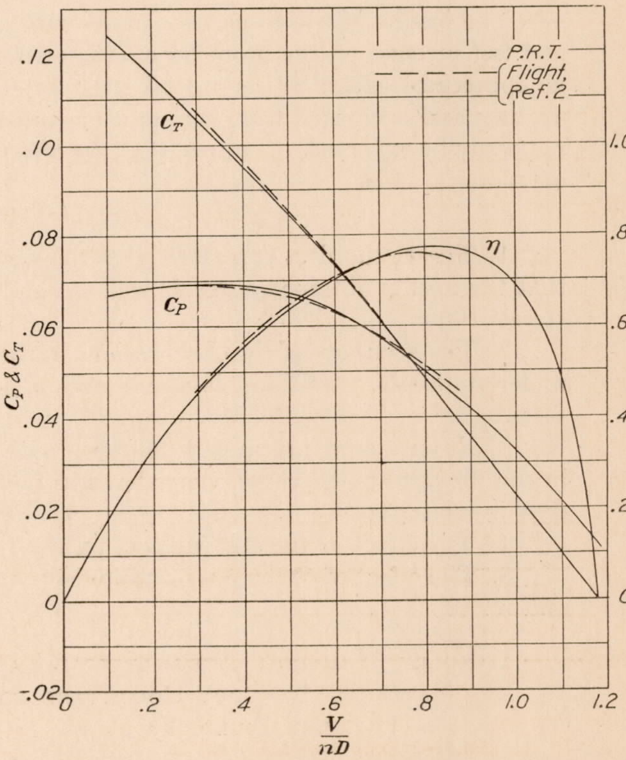


FIG. 13.—Comparison of propeller research tunnel and flight tests on Propeller D′

The present tests on the above three propellers are compared with flight tests on the same propellers (References 2 and 3) in Figures 11, 12, and 13. Propellers B′ and D′ are the identical ones used in the tests of Reference 2. Propeller I (3714), which is of the same design as I of Reference 2, was used in the tests of Reference 3 (and called 3714) and also in the present tests. Figures 11, 12, and 13 show that in general the agreement between the full-scale Propeller Research Tunnel tests and the flight tests is fair, probably within the limits of accuracy of the flight tests which are quite difficult to make. In three of the four tests the power coefficients from the flight tests are 3 per cent to 5 per cent higher than those obtained from the Propeller Research Tunnel tests. Since the power developed in flight was taken from a calibration of the engine made with an electric dynamometer on the ground, this difference in power coefficients indicates that the engines, when in flight, were probably not actually delivering the full power developed on the dynamometer.

One possible cause for difference between the flight tests and the full-scale wind tunnel tests is the fact that in the latter the propeller axis was kept level at all times, while in the flight tests it assumed various angles to the flight path from about zero degrees at high speed to 10 degrees near stalling speed.

In Figures 14, 15, and 16 the full-scale Propeller Research Tunnel tests are compared with tests on similar model propellers with a model VE–7 airplane (Reference 2). The model tests agree better than the flight tests with those of the Propeller Research Tunnel.

For the full-scale tests the maximum efficiency occurs at a higher $\frac{V}{nD}$, and in two of the three cases reaches a noticeably higher value than for the model tests. (In this connection it has been learned that later tests on the same models give somewhat higher efficiencies.) In each case the rate of advance $\left(\frac{V}{nD}\right)$ at which zero thrust occurs is greater for the full-scale propellers, apparently indicating that the effect of scale is more pronounced in the region of the lower angles of attack of the blade elements. In general, also, the full-scale tests give higher values of the thrust and power coefficients at the lower rates of advance.

The results of the three tests made with propeller I (3714) to obtain the effect of the wings and tail surfaces on the propeller characteristics are plotted in Figure 17. The tail surfaces had no appreciable effect on the propeller characteristics, but the wings increased the power absorbed slightly and decreased the maximum propulsive efficiency approximately 5 per cent. It would naturally be expected, of course, that the effect of the wings would be different at different angles of attack.

CONCLUSIONS

1. These, the first complete propeller tests made in the Propeller Research Tunnel, show that the results obtained agree as well as can be expected with both flight tests and model wind tunnel tests.

2. The accuracy of the observations in the Propeller Research Tunnel tests, which are made under full-scale conditions, is apparently of about the same order as that of model propeller tests.

3. From a comparison of these tests with flight tests, it seems likely that the engines used in the flight tests delivered somewhat less power in flight than would have been expected from dynamometer tests.

4. The effect of the tail surfaces on the propeller characteristics is negligible.

5. The effect of the wings on propulsive efficiency is important and deserves further investigation.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., *June 18, 1928.*

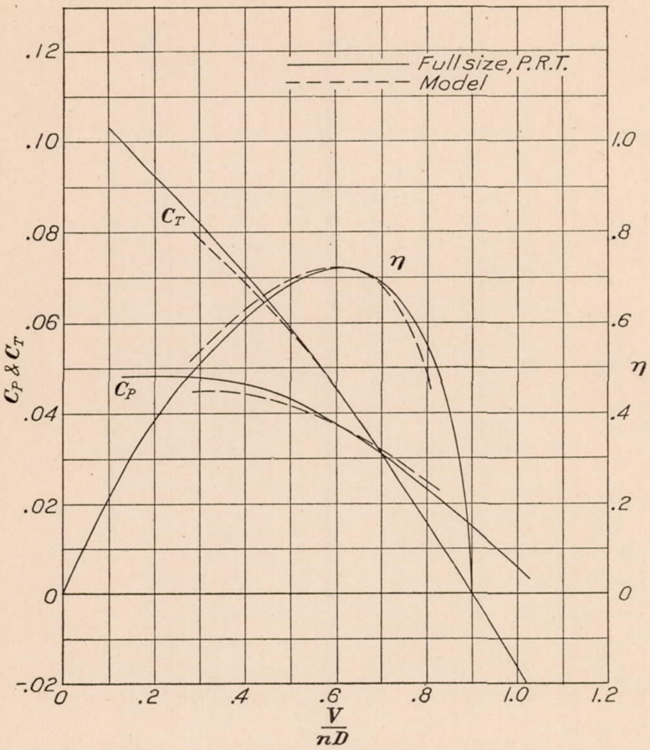


FIG. 14.—Comparison of model and full-size Propeller Research Tunnel tests on Propeller B′

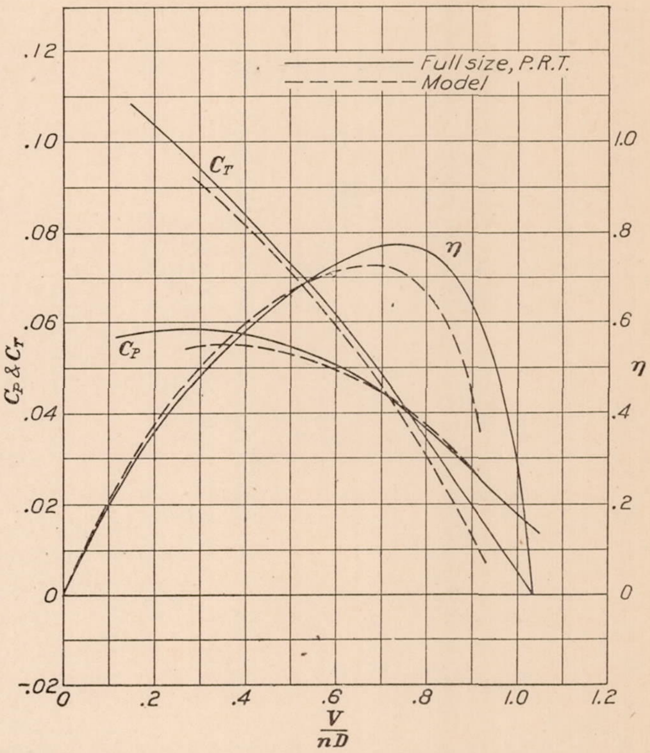


FIG. 15.—Comparison of model and full-size Propeller Research Tunnel tests on Propeller I (3714)

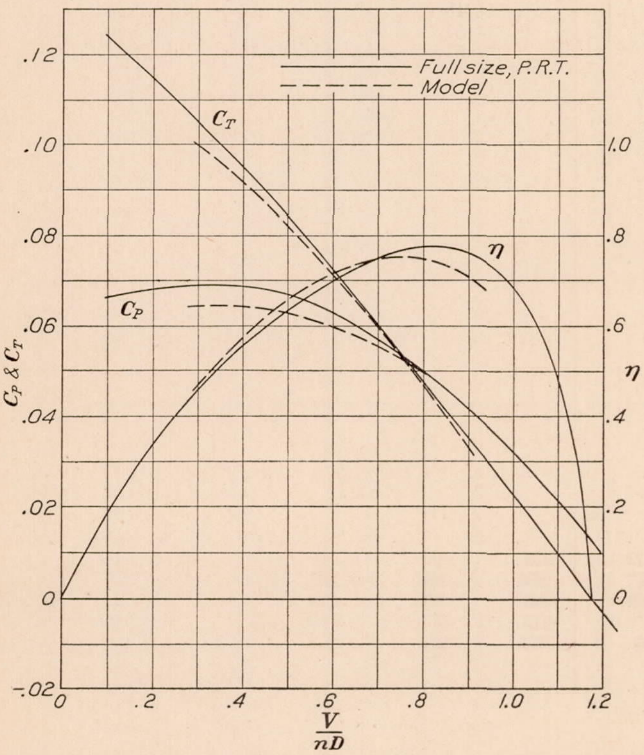


FIG. 16.—Comparison of model and full-size Propeller Research Tunnel tests on Propeller D′

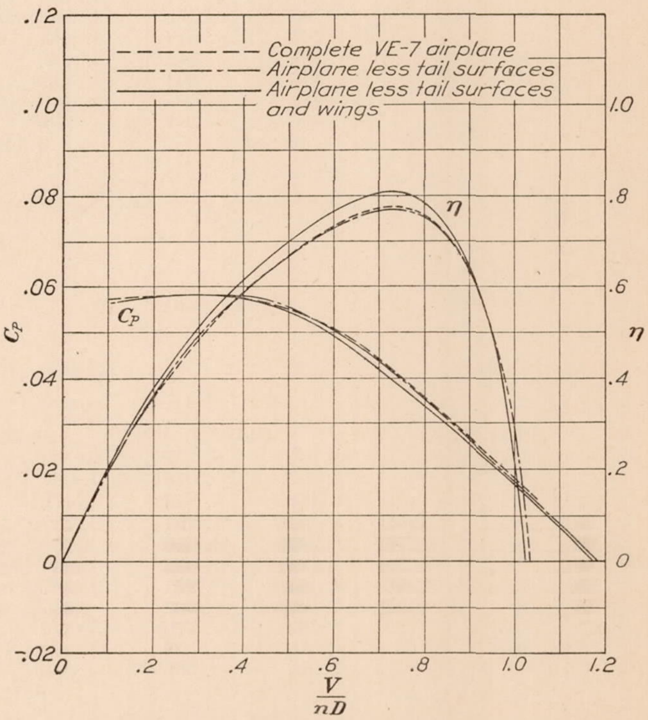


FIG. 17.—Effect of wings and tail surfaces on the performance of Propeller I on VE-7 airplane (Propeller Research Tunnel tests)

TABLE I

ORDINATES FOR SECTIONS OF PROPELLER D′ (see fig. 5)

Radius	10. 45″		18. 28″		26. 11″	33. 94″	41. 77″	45. 69″
Camber	Upper	Lower	Upper	Lower	Upper	Upper	Upper	Upper
Rad. L. E.	0. 877″		0. 282″		0. 128″	0. 083″	0. 047″	0. 031″
2.5	0. 686	0. 410	0. 730	0. 047	. 526	. 338	. 194	. 128
5	. 987	. 589	1. 053	. 066	. 758	. 489	. 279	. 185
10	1. 322	. 790	1. 410	. 088	1. 015	. 655	. 373	. 247
20	1. 588	. 949	1. 692	. 106	1. 222	. 786	. 448	. 298
30	1. 664	. 996	1. 777	. 113	1. 285	. 830	. 473	. 313
40	1. 654	. 990	1. 764	. 113	1. 275	. 821	. 470	. 310
50	1. 588	. 949	1. 692	. 106	1. 222	. 786	. 448	. 298
60	1. 454	. 868	1. 551	. 097	1. 118	. 720	. 410	. 272
70	1. 238	. 739	1. 319	. 085	. 952	. 614	. 351	. 232
80	. 937	. 558	. 996	. 063	. 720	. 464	. 266	. 175
90	. 586	. 351	. 623	. 041	. 451	. 291	. 166	. 110
Rad. T. E.	0. 26″		0. 125″		. 098″	. 064″	. 036″	. 024″

All ordinates in inches. Station in per cent of chord.

ORDINATES FOR SECTIONS OF PROPELLER B′ (see fig. 3)

Radius	11. 33″		19. 83″		28. 33″	36. 83″	45. 33″	49. 57″
Camber	Upper	Lower	Upper	Lower	Upper	Upper	Upper	Upper
Rad. L. E.	0. 952″		0. 306″		0. 139″	0. 090″	0. 051″	0. 034″
2.5	0. 745	0. 445	0. 792	0. 051	. 571	. 367	. 211	. 139
5	1. 071	. 639	1. 142	. 071	. 823	. 530	. 303	. 201
10	1. 435	. 857	1. 530	. 095	1. 102	. 710	. 405	. 269
20	1. 724	1. 030	1. 836	. 115	1. 326	. 854	. 486	. 323
30	1. 806	1. 081	1. 928	. 122	1. 394	. 901	. 513	. 340
40	1. 795	1. 075	1. 915	. 122	1. 384	. 891	. 510	. 337
50	1. 724	1. 030	1. 836	. 115	1. 326	. 854	. 486	. 323
60	1. 578	. 942	1. 683	. 105	1. 214	. 782	. 445	. 296
70	1. 343	. 802	1. 432	. 092	1. 034	. 667	. 381	. 252
80	1. 017	. 605	1. 081	. 068	. 782	. 503	. 289	. 190
90	. 636	. 381	. 676	. 044	. 490	. 316	. 180	. 119
Rad. T. E.	0. 280″		0. 115″		. 106″	. 071″	. 039″	. 026″

All ordinates in inches. Stations in per cent of chord.

ORDINATES FOR SECTIONS OF PROPELLER I (see fig. 4)

Radius	10. 89″		19. 05″		27. 22″	35. 39″	43. 55″	47. 63″
Camber	Upper	Lower	Upper	Lower	Upper	Upper	Upper	Upper
Rad. L. E.	0. 844″		0. 272″		0. 133″	0. 087″	0. 049″	0. 033″
2.5	0. 719	0. 427	0. 762	0. 049	. 550	. 357	. 204	. 133
5	1. 032	. 615	1. 097	. 068	. 789	. 512	. 291	. 193
10	1. 380	. 822	1. 470	. 092	1. 056	. 686	. 392	. 259
20	1. 661	. 991	1. 767	. 112	1. 271	. 825	. 471	. 310
30	1. 742	1. 040	1. 856	. 117	1. 337	. 866	. 495	. 327
40	1. 729	1. 032	1. 840	. 117	1. 326	. 860	. 490	. 324
50	1. 661	. 991	1. 767	. 112	1. 271	. 825	. 471	. 310
60	1. 522	. 906	1. 617	. 109	1. 165	. 757	. 430	. 283
70	1. 293	. 770	1. 377	. 087	. 991	. 642	. 367	. 242
80	. 980	. 582	1. 042	. 065	. 748	. 487	. 278	. 182
90	. 612	. 365	. 650	. 041	. 468	. 305	. 174	. 114
Rad. T. E.	0. 245″		0. 120″		. 103″	. 068″	. 038″	. 024″

All ordinates in inches. Stations in per cent of chord.

TABLE II

TEST DATA

PROPELLER B′, $\frac{p}{D}=0.6$

VE-7 AIRPLANE, COMPLETE

ρ	V M. P. H.	N R. P. M.	Q lb. ft.	T lb.	C_T	C_P	$\frac{V}{nD}$	η
0. 002289	83. 6	1, 700	556	561	0. 0588	0. 0428	0. 510	0. 700
. 002289	83. 6	1, 705	557	557. 5	. 0579	. 0427	. 509	. 689
. 002289	86. 6	1, 715	552	545	. 0559	. 0417	. 522	. 700
. 002289	86. 7	1, 715	552	541	. 0554	. 0418	. 523	. 695
. 002279	95. 7	1, 755	547	512. 5	. 0505	. 0399	. 564	. 715
. 002279	95. 7	1, 755	547	514. 5	. 0505	. 0399	. 564	. 715
. 002275	100. 6	1, 775	540	490	. 0474	. 0385	. 587	. 722
. 002275	100. 8	1, 780	540	499	. 0479	. 0382	. 585	. 734
. 002279	98. 0	1, 080	62	−27	−. 00676	. 0119	. 939	−. 555
. 002279	97. 7	1, 000	22	−61	−. 0185	. 00493	1. 010	−. 380
. 002279	99. 6	1, 120	73	−15. 5	−. 00374	. 01305	. 921	−. 264
. 002275	99. 7	1, 160	97	11. 5	. 00260	. 0162	. 889	. 1422
. 002275	99. 7	1, 200	120	34. 5	. 00728	. 0188	. 861	. 3335
. 002275	100. 2	1, 245	142	56	. 01095	. 0205	. 834	. 445
. 002275	100. 4	1, 235	137	51. 5	. 01030	. 0202	. 841	. 430
. 002275	99. 8	1, 270	160	72	. 01358	. 0223	. 814	. 496
. 002275	99. 7	1, 300	175	90	. 01615	. 0232	. 792	. 551
. 002275								
. 002275	99. 9	1, 365	215	131	. 02110	. 0260	. 756	. 613
. 002275	99. 9	1, 405	247	162. 5	. 0249	. 0281	. 735	. 651
. 002275	99. 9	1, 460	287	202. 5	. 0285	. 0302	. 709	. 675
. 002270	99. 7	1, 430	263	179. 5	. 0267	. 0292	. 724	. 662
. 002270	99. 7	1, 500	312	229. 5	. 0310	. 0312	. 690	. 685
. 002270	99. 3	1, 550	353	280. 5	. 0356	. 0330	. 664	. 716
. 002265	99. 1	1, 525	339	267	. 0349	. 0329	. 673	. 713
. 002265	99. 5	1, 600	396	329. 5	. 0392	. 0348	. 643	. 723
. 002265	99. 3	1, 645	436	369. 5	. 0416	. 0364	. 624	. 712
. 002265	99. 3	1, 695	467	407. 5	. 0435	. 0365	. 606	. 722
. 002265	99. 5	1, 775	540	496. 5	. 0480	. 0387	. 580	. 720
. 002260	80. 0	1, 690	552	570. 5	. 0610	. 0437	. 491	. 686
. 002260	80. 0	1, 685	550	570	. 0612	. 0438	. 493	. 689
. 002279	72. 9	1, 660	547	583. 5	. 0642	. 0446	. 455	. 654
. 002279	72. 9	1, 665	552	591. 5	. 0651	. 0447	. 453	. 660
. 002279	66. 3	1, 660	562	621. 5	. 0685	. 0457	. 413	. 619
. 002279	66. 7	1, 655	565	622	. 0688	. 0461	. 417	. 622
. 002282	59. 7	1, 645	566	661. 5	. 0740	. 0468	. 375	. 593
. 002282	59. 7	1, 650	565	660	. 0734	. 0467	. 374	. 587
. 002292	20. 8	1, 615	567	867	. 1004	. 0484	. 1332	. 2765
. 002292	20. 8	1, 620	567	866	. 0996	. 0482	. 1328	. 2745

TABLE II—Continued

PROPELLER I (3714), $\frac{p}{D}=0.7$

VE-7 AIRPLANE, COMPLETE

ρ	V M. P. H.	N R. P. M.	Q lb. ft.	T lb.	C_T	C_P	$\frac{V}{nD}$	η
0. 002325	85. 2	1, 665	545	526. 5	0. 0663	0. 0527	0. 550	0. 692
. 002325	84. 3	1, 665	550	535. 5	. 0678	. 0532	. 545	. 694
. 002324	86. 7	1, 675	552	531. 5	. 0665	. 0526	. 567	. 703
. 002324	86. 5	1, 675	552	530	. 0662	. 0526	. 559	. 707
. 002324	96. 6	1, 705	552	506. 5	. 0609	. 0509	. 609	. 729
. 002320	96. 1	1, 705	549	503. 5	. 0607	. 0504	. 605	. 729
. 002318	99. 5	1, 720	547	499	. 0592	. 0497	. 623	. 742
. 002318	99. 5	1, 720	545	497	. 0589	. 0496	. 623	. 741
. 002318	100. 2	1, 720	542	489. 5	. 0581	. 0493	. 627	. 739
. 002318	99. 7	1, 720	542	487. 5	. 0578	. 0493	. 624	. 737
. 002305	100. 1	1, 665	495	441	. 0560	. 0482	. 647	. 754
. 002305	99. 5	1, 610	455	399	. 0543	. 0475	. 665	. 766
. 002305	100. 1	1, 550	397	342. 5	. 0503	. 0447	. 694	. 780
. 002300	100. 2	1, 520	372	308. 5	. 0471	. 0434	. 711	. 770
. 002305	99. 0	1, 465	332	260	. 0426	. 0418	. 729	. 743
. 002305	99. 5	1, 495	359	289	. 0458	. 0434	. 717	. 757
. 002300	99. 3	1, 435	312	243	. 0416	. 0412	. 745	. 753
. 002300	99. 4	1, 445	317	252. 5	. 0427	. 0411	. 740	. 769
. 002300	99. 3	1, 395	277	213. 5	. 0388	. 0385	. 766	. 771
. 002300	98. 8	1, 365	257	200. 5	. 0380	. 0374	. 779	. 791
. 002300	98. 9	1, 355	245	184	. 0353	. 0362	. 785	. 765
. 002300	98. 8	1, 335	230	168	. 0333	. 0348	. 796	. 761
. 002300	98. 6	1, 290	203	143. 5	. 0304	. 0332	. 823	. 752
. 002300	98. 6	1, 275	197	133. 5	. 0290	. 0328	. 832	. 736
. 002300	98. 4	1, 240	172	109	. 0250	. 0304	. 854	. 703
. 002300	98. 5	1, 200	152	87. 5	. 0214	. 0286	. 885	. 664
. 002300	98. 2	1, 145	119	58	. 0156	. 0246	. 924	. 586
. 002300	97. 9	1, 095	92	36	. 0106	. 0209	. 962	. 487
. 002300	97. 6	1, 050	70	16	. 00511	. 0172	1. 001	. 298
. 002300	97. 8	1, 000	50	−7. 5	−. 002657	. 0140	1. 053	−. 200
. 002305	80. 5	1, 665	559	558	. 071	. 0545	. 520	. 678
. 002305	80. 5	1, 655	557	557	. 0716	. 0547	. 523	. 686
. 002305	73. 8	1, 655	563	582. 5	. 0750	. 0553	. 480	. 652
. 002305	74. 3	1, 655	565	581. 5	. 0747	. 0557	. 483	. 649
. 002318	68. 4	1, 645	567	598. 5	. 0775	. 0564	. 447	. 615
. 002318	68. 7	1, 645	567	603. 5	. 0781	. 0564	. 450	. 623
. 002318	65. 0	1, 635	567	616. 5	. 0805	. 0572	. 428	. 603
. 002318	64. 9	1, 635	567	616. 5	. 0805	. 0572	. 427	. 602
. 002318	59. 7	1, 630	569	641. 5	. 0845	. 0575	. 394	. 579
. 002318	52. 4	1, 620	571	672. 5	. 0896	. 0585	. 348	. 533
. 002320	21. 05	1, 625	567	828. 5	. 110	. 0577	. 139	. 263
. 002320	21. 05	1, 625	567	826. 5	. 110	. 0577	. 139	. 263

TABLE II—Continued

PROPELLER D′, $\frac{p}{D}=0.8$

VE-7 AIRPLANE, COMPLETE

ρ	V M. P. H.	N R. P. M.	Q lb. ft.	T lb.	C_T	C_P	$\frac{V}{nD}$	η
------	0	0	------	------	------	------	------	------
0. 002305	82. 4	1, 685	555	535	0. 0783	0. 0653	0. 549	0. 658
. 002305	82. 1	1, 675	549	535. 5	. 0795	. 0652	. 550	. 671
. 00230	86. 4	1, 690	550	525	. 0767	. 0645	. 574	. 681
. 00230	86. 4	1, 695	552	525	. 0762	. 0642	. 572	. 679
. 002295	95. 1	1, 725	549	509. 5	. 0715	. 0619	. 619	. 716
. 002295	94. 8	1, 725	550	507	. 0711	. 0619	. 617	. 710
. 002290	99. 5	1, 740	552	499	. 0689	. 0613	. 643	. 723
. 002290	99. 5	1, 735	550	499. 5	. 0693	. 0613	. 645	. 729
. 002295	96. 7	960	50	11. 5	. 00523	. 01815	1. 137	. 327
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. 002290	99. 0	940	30	−5	−. 00237	. 0114	1. 175	−. 244
. 002290	99. 0	1, 050	86	33	. 0125	. 0261	1. 060	. 508
. 002285	99. 1	1, 000	57	11	. 00461	. 01915	1. 115	. 269
. 002285	99. 5	1, 105	117	65	. 0222	. 0324	1. 010	. 692
. 002285	99. 5	1, 160	145	88	. 0272	. 0362	. 964	. 724
. 002285	99. 9	1, 205	169	109	. 0312	. 0394	. 930	. 738
. 002285	99. 1	1, 250	201	138	. 0373	. 0431	. 890	. 772
. 002280	99. 5	1, 255	199	140	. 0373	. 0426	. 890	. 781
. 002280	99. 2	1, 295	217	155	. 0388	. 0438	. 861	. 763
. 002280	99. 7	1, 335	242	181	. 0427	. 0459	. 839	. 780
. 002280	99. 7	1, 365	262	196	. 0442	. 0473	. 821	. 784
. 002280	99. 7	1, 375	272	204	. 0453	. 0486	. 815	. 760
. 002280	99. 7	1, 395	282	215	. 0465	. 0489	. 803	. 764
. 002280	99. 9	1, 440	319	248	. 0502	. 0519	. 780	. 756
. 002280	99. 8	1, 425	301	236	. 0488	. 0499	. 787	. 771
. 002275	99. 1	1, 465	335	264	. 0518	. 0530	. 760	. 743
. 002275	99. 5	1, 570	366	300	. 0554	. 0544	. 739	. 753
. 002275	100. 1	1, 525	369	305	. 0554	. 0538	. 736	. 757
. 002275	100. 1	1, 550	392	328	. 0574	. 0552	. 724	. 754
. 002275	100. 2	1, 590	424	361	. 0601	. 0567	. 706	. 750
. 002275	99. 8	1, 640	462	402	. 0631	. 0583	. 685	. 742
. 002270	100. 2	1, 700	507	452	. 0656	. 0598	. 662	. 726
. 002280	77. 0	1, 655	537	535	. 0819	. 0665	. 522	. 644
. 002280	76. 1	1, 655	545	539	. 0825	. 0672	. 516	. 635
. 002280	70. 7	1, 645	543	564	. 0876	. 0676	. 484	. 620
. 002280	69. 8	1, 640	546	565	. 0885	. 0685	. 479	. 618
. 002285	65. 9	1, 640	547	575	. 0898	. 0684	. 445	. 584
. 002285	64. 6	1, 635	542	580	. 0910	. 0682	. 445	. 594
. 002285	60. 0	1, 635	546	599	. 0939	. 0688	. 412	. 562
. 002285	58. 0	1, 635	547	602	. 0944	. 0688	. 400	. 547
. 00230	19. 7	1, 655	556	801	. 1215	. 0678	. 134	. 240
. 00230	19. 7	1, 665	556	801	. 1205	. 0671	. 134	. 240
. 00230	19. 7	1, 660	552	798	. 1210	. 0668	. 134	. 243

TABLE II—Continued

PROPELLER I (3714), $\frac{p}{D}=0.7$

VE-7 WITH WINGS, WITHOUT TAIL

ρ	V M. P. H.	N R. P. M.	Q lb. ft.	T lb.	C_T	C_P	$\frac{V}{nD}$	η
0. 00240	83. 4	1, 660	572	565. 5	0. 0694	0. 0540	0. 542	0. 695
. 00240	83. 4	1, 660	572	567. 5	. 0699	. 0540	. 542	. 701
. 002396	86. 3	1, 660	560	534	. 0669	. 0529	. 557	. 702
. 002396	86. 3	1, 660	557	537	. 0690	. 0526	. 557	. 728
. 002390	95. 0	1, 705	567	525. 5	. 0614	. 0506	. 600	. 722
. 002390	94. 8	1, 705	567	520. 5	. 0607	. 0506	. 599	. 713
. 002381	98. 8	1, 730	567	517. 5	. 0605	. 0495	. 615	. 753
. 002381	98. 9	1, 735	567	520. 5	. 0586	. 0492	. 614	. 732
. 002378	99. 1	1, 675	525	471	. 0575	. 0491	. 637	. 747
. 002378	98. 7	1, 625	477	421. 5	. 0545	. 0473	. 654	. 754
. 002378	98. 7	1, 603	470	422	. 0564	. 0479	. 662	. 780
. 002378	99. 9	1, 595	435	374. 5	. 0504	. 0448	. 673	. 757
. 002375	99. 7	1, 545	415	348	. 0500	. 0455	. 695	. 764
. 002375	99. 3	1, 525	387	322. 5	. 0474	. 0437	. 701	. 760
. 002375	99. 1	1, 480	357	294	. 0459	. 0428	. 721	. 772
. 002375	98. 8	1, 475	352	288	. 0454	. 0424	. 721	. 772
. 002370	98. 8	1, 440	325	259	. 0428	. 0413	. 738	. 766
. 002370	98. 8	1, 395	287	223. 5	. 0394	. 0386	. 763	. 778
. 002370	98. 5	1, 325	237	174. 5	. 0339	. 0360	. 801	. 755
. 002370	98. 1	1, 250	182	120. 5	. 0266	. 0306	. 844	. 735
. 002370	98. 0	1, 235	177	115. 5	. 0260	. 0306	. 855	. 727
. 002370	98. 0	1, 180	143	88. 5	. 0217	. 0270	. 894	. 716
. 002370	98. 0	940	25	−22. 5	−. 00875	. 00746	1. 137	----------
. 002378	75. 5	1, 640	575	586	. 0745	. 0560	. 495	. 657
. 002378	75. 4	1, 640	575	589	. 0746	. 0560	. 494	. 658
. 002378	69. 7	1, 620	573	612. 5	. 0797	. 0574	. 465	. 644
. 002378	69. 4	1, 625	573	610. 5	. 0790	. 0571	. 461	. 637
. 002381	62. 6	1, 610	575	636. 5	. 0837	. 0580	. 418	. 603
. 002381	64. 4	1, 615	575	634. 5	. 0830	. 0578	. 429	. 617
. 00239	59. 0	1, 620	582	664	. 0858	. 0578	. 392	. 581
. 00239	59. 2	1, 620	582	660. 5	. 0854	. 0580	. 393	. 579
. 002396	20. 8	1, 625	582	860. 5	. 1105	. 0575	. 136	. 261
. 002396	20. 8	1, 620	583	861. 5	. 1114	. 0578	. 138	. 266

TABLE II—Continued

PROPELLER I (3714), $\frac{p}{D}=0.7$

VE-7, WITHOUT WINGS OR TAIL

ρ	V M. P. H.	N R. P. M.	Q lb. ft.	T lb.	C_T	C_P	$\frac{V}{nD}$	η
0. 002381	83. 7	1, 660	557	564	0. 0698	0. 0528	0. 543	0. 717
. 002381	84. 1	1, 660	557	564. 5	. 0698	. 0528	. 545	. 720
. 002378	87. 3	1, 670	557	556. 6	. 0679	. 0524	. 565	. 732
. 002370	96. 4	1, 720	552	257. 8	. 0610	. 0491	. 603	. 749
. 002370	96. 5	1, 710	550	528	. 0618	. 0494	. 609	. 761
. 002368	100. 4	1, 735	553	524. 6	. 0596	. 0483	. 622	. 768
. 002368	100. 2	1, 745	552	527	. 0591	. 0477	. 619	. 766
. 002368	100. 2	1, 665	472	445. 4	. 0551	. 0447	. 649	. 800
. 002368	100. 0	1, 640	457	429	. 0545	. 0448	. 657	. 798
. 002368	99. 8	1, 615	432	404	. 0529	. 0438	. 665	. 803
. 002363	99. 8	1, 555	387	347. 5	. 0492	. 0423	. 691	. 802
. 002363	99. 8	1, 525	367	320. 5	. 0472	. 0416	. 705	. 799
. 002363	99. 8	1, 495	347	299. 5	. 0459	. 0409	. 719	. 806
. 002363	99. 7	1, 455	312	265. 1	. 0428	. 0388	. 738	. 815
. 002363	99. 3	1, 415	287	234. 2	. 0402	. 0376	. 755	. 806
. 002363	99. 0	1, 370	242	187. 6	. 0342	. 0341	. 780	. 782
. 00236	99. 1	1, 340	232	175. 6	. 0335	. 0340	. 796	. 785
. 00236	98. 8	1, 245	177	116. 3	. 0258	. 0301	. 854	. 731
. 00236	98. 7	1, 190	142	88. 5	. 0214	. 0266	. 894	. 718
. 00236	98. 6	1, 145	117	56	. 0147	. 0236	. 927	. 577
. 00236	98. 3	1, 090	77	23. 7	. 00685	. 0171	. 971	. 390
. 00236	98. 2	1, 030	56	2	. 00065	. 0140	1. 026	. 0476
. 00236	100. 1	980	27	−32	−. 0115	. 00743	1. 102	----------
. 002368	76. 4	1, 590	517	547	. 0741	. 0537	. 517	. 713
. 002368	76. 4	1, 600	520	547	. 0731	. 0534	. 515	. 705
. 00237	70. 5	1, 610	545	592	. 0783	. 0553	. 471	. 666
. 00237	70. 5	1, 600	543	592	. 0793	. 0555	. 476	. 680
. 00237	65. 2	1, 595	545	616. 2	. 0829	. 0562	. 440	. 649
. 00237	65. 8	1, 595	547	614	. 0828	. 0565	. 445	. 652
. 002378	54. 6	1, 585	557	663. 5	. 0903	. 0583	. 371	. 575
. 002381	20. 7	1, 565	527	804. 8	. 1113	. 0563	. 1428	. 282
. 002381	20. 7	1, 555	527	798. 8	. 1124	. 0572	. 1438	. 282

TABLE III

FINAL ADJUSTED COEFFICIENTS

PROPELLER B′, $\frac{p}{D}=0.6$

VE-7 AIRPLANE, COMPLETE

$\frac{V}{nD}$	C_T	C_P	η	$\sqrt{\frac{\rho V^5}{Pn^2}}$	$\sqrt[5]{\frac{\rho V^5}{Pn^2}}$
0. 15	0. 0982	0. 0485	0. 304	0. 0396	----------
. 20	. 0933	. 0485	. 384	. 0814	0. 368
. 25	. 0881	. 0483	. 456	. 1423	. 458
. 30	. 0828	. 0479	. 519	. 2260	. 551
. 35	. 0771	. 0470	. 574	. 3345	. 645
. 40	. 0712	. 0462	. 616	. 4720	. 741
. 45	. 0650	. 0450	. 650	. 6420	. 8375
. 50	. 0586	. 0430	. 681	. 8540	. 9390
. 55	. 0521	. 0405	. 708	1. 1140	1. 044
. 60	. 0451	. 0378	. 715	1. 4350	1. 155
. 65	. 0377	. 0343	. 715	1. 8430	1. 278
. 70	. 0305	. 0310	. 689	2. 3300	1. 402
. 75	. 0234	. 0272	. 645	2. 9600	1. 544
. 80	. 0160	. 0232	. 552	3. 7600	1. 698
. 85	. 0082	. 0190	. 389	4. 8400	1. 880
. 90	. 0000	. 0148	. 000	6. 3200	2. 090

TABLE III—Continued

PROPELLER I (3714), $\frac{p}{D}=0.7$

VE-7 AIRPLANE, COMPLETE

$\frac{V}{nD}$	C_T	C_P	η	$\sqrt{\frac{\rho V^5}{Pn^2}}$	$\sqrt[5]{\frac{\rho V^5}{Pn^2}}$
0. 10	----------	----------	----------	----------	----------
. 15	0. 1085	0. 0576	0. 282	0. 0364	----------
. 20	. 1037	. 0580	. 357	. 0745	0. 354
. 25	. 0989	. 0583	. 424	. 1292	. 440
. 30	. 0940	. 0584	. 483	. 204	. 529
. 35	. 0890	. 0583	. 534	. 3002	. 616
. 40	. 0839	. 0578	. 581	. 421	. 707
. 45	. 0785	. 0566	. 624	. 572	. 800
. 50	. 0731	. 0550	. 665	. 755	. 894
. 55	. 0678	. 0530	. 705	. 975	. 988
. 60	. 0620	. 0507	. 735	1. 240	1. 0898
. 65	. 0558	. 0479	. 758	1. 559	1. 194
. 70	. 0486	. 0442	. 770	1. 95	1. 306
. 75	. 0412	. 0400	. 773	2. 44	1. 428
. 80	. 0340	. 0358	. 759	3. 02	1. 555
. 85	. 0264	. 0312	. 719	3. 78	1. 700
. 90	. 0192	. 0268	. 645	4. 70	1. 86
. 95	. 0120	. 0222	. 513	5. 90	2. 04
1. 00	. 0048	. 0179	. 268	7. 46	2. 235

TABLE III—Continued

PROPELLER D', $\frac{p}{D}$=0.8

VE-7 AIRPLANE, COMPLETE

$\frac{V}{nD}$	C_T	C_P	η	$\sqrt{\frac{\rho V^5}{Pn^2}}$	$\sqrt[5]{\frac{\rho V^5}{Pn^2}}$
0. 10	0. 1243	0. 0668	0. 186	----------	----------
. 15	. 1197	. 0677	. 265	0. 0336	----------
. 20	. 1149	. 0683	. 336	. 0685	0. 341
. 25	. 110	. 0689	. 399	. 119	. 426
. 30	. 1051	. 0690	. 457	. 1878	. 512
. 35	. 1002	. 0690	. 508	. 276	. 599
. 40	. 0951	. 0689	. 554	. 386	. 684
. 45	. 0900	. 0682	. 594	. 521	. 771
. 50	. 0847	. 0671	. 631	. 682	. 858
. 55	. 0789	. 0654	. 664	. 876	. 948
. 60	. 0730	. 0631	. 694	1. 11	1. 0426
. 65	. 0671	. 0603	. 724	1. 39	1. 141
. 70	. 0608	. 0570	. 745	1. 72	1. 242
. 75	. 0544	. 0534	. 765	2. 11	1. 348
. 80	. 0478	. 0497	. 770	2. 565	1. 457
. 85	. 0418	. 0457	. 775	3. 12	1. 575
. 90	. 0351	. 0416	. 759	3. 77	1. 70
. 95	. 0288	. 0372	. 735	4. 56	1. 836
1. 00	. 0224	. 0325	. 689	5. 55	1. 982
1. 05	. 0160	. 0272	. 618	6. 85	2. 16
1. 10	. 0096	. 0216	. 489	8. 65	2. 37

TABLE III—Continued

PROPELLER I (3714), $\frac{p}{D}=0.7$

VE-7, WITH WINGS, WITHOUT TAIL

$\frac{V}{nD}$	C_T	C_P	η	$\sqrt{\frac{\rho V^5}{Pn^2}}$	$\sqrt[5]{\frac{\rho V^5}{Pn^2}}$
0. 15	0. 1099	0. 0578	0. 285	0. 0362	----------
. 20	. 1054	. 0580	. 364	. 0745	0. 354
. 25	. 1010	. 0581	. 434	. 1298	. 440
. 30	. 09590	. 0582	. 494	. 204	. 530
. 35	. 0908	. 0581	. 546	. 301	. 619
. 40	. 0852	. 0580	. 588	. 421	. 708
. 45	. 0799	. 0574	. 626	. 568	. 798
. 50	. 0740	. 0558	. 664	. 750	. 892
. 55	. 0679	. 0532	. 702	. 974	. 987
. 60	. 0616	. 0506	. 730	1. 240	1. 090
. 65	. 0550	. 0475	. 754	1. 565	1. 196
. 70	. 0482	. 0441	. 765	1. 950	1. 306
. 75	. 0411	. 0400	. 770	2. 44	1. 429
. 80	. 0339	. 0358	. 757	3. 02	1. 556
. 85	. 0264	. 0311	. 720	3. 78	1. 700
. 90	. 0191	. 0266	. 645	4. 71	1. 86
. 95	. 0121	. 0221	. 520	5. 91	2. 04
1. 00	. 0048	. 0175	. 274	7. 62	2. 25

TABLE III—Continued

PROPELLER I (3714), $\frac{p}{D}=0.7$

VE-7, WITHOUT WINGS OR TAIL

$\frac{V}{nD}$	C_T	C_P	η	$\sqrt{\frac{\rho V^5}{Pn^2}}$	$\sqrt[5]{\frac{\rho V^5}{Pn^2}}$
0.15	0.1118	0.0571	0.293	0.03645	----------
.20	.1079	.0579	.372	.0745	0.357
.25	.1038	.0582	.445	.1396	.453
.30	.0989	.0585	.507	.204	.529
.35	.0939	.0581	.565	.301	.620
.40	.0881	.0576	.612	.419	.705
.45	.0822	.0563	.656	.574	.800
.50	.0758	.0546	.694	.758	.896
.55	.0690	.0522	.730	.984	.993
.60	.0623	.0491	.761	1.26	1.097
.65	.0554	.0458	.786	1.59	1.204
.70	.0482	.0420	.803	2.00	1.319
.75	.0409	.0380	.807	2.50	1.442
.80	.0333	.0340	.784	3.105	1.574
.85	.0260	.0298	.740	3.86	1.715
.90	.0185	.0256	.650	4.81	1.872
.95	.0110	.0210	.497	6.07	2.058
1.00	.0037	.0166	.223	7.76	2.27

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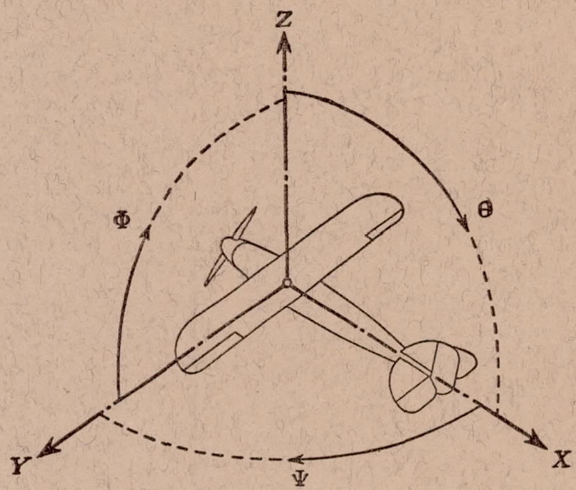

Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Symbol		Designation	Symbol	Positive direction	Designation	Symbol	Linear (component along axis)	Angular
Longitudinal	X	X	rolling	L	$Y \longrightarrow Z$	roll	Φ	u	p
Lateral	Y	Y	pitching	M	$Z \longrightarrow X$	pitch	Θ	v	q
Normal	Z	Z	yawing	N	$X \longrightarrow Y$	yaw	Ψ	w	r

Absolute coefficients of moment

$$C_L=\frac{L}{qbS}\ C_M=\frac{M}{qcS}\ C_N=\frac{N}{qfS}$$

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

D, Diameter.
p_e, Effective pitch
p_g, Mean geometric pitch.
p_s, Standard pitch.
p_v, Zero thrust.
p_a, Zero torque.
p/D, Pitch ratio.
V', Inflow velocity.
V_s, Slip stream velocity.

T, Thrust.
Q, Torque.
P, Power.
(If "coefficients" are introduced all units used must be consistent.)
η, Efficiency $= T\,V/P$.
n, Revolutions per sec., r. p. s.
N, Revolutions per minute., R. P. M.
Φ, Effective helix angle $=\tan^{-1}\left(\frac{V}{2\pi rn}\right)$

5. NUMERICAL RELATIONS

1 HP = 76.04 kg/m/sec. = 550 lb./ft./sec.
1 kg/m/sec. = 0.01315 HP.
1 mi./hr. = 0.44704 m/sec.
1 m/sec. = 2.23693 mi./hr.

1 lb. = 0.4535924277 kg.
1 kg = 2.2046224 lb.
1 mi. = 1609.35 m = 5280 ft.
1 m = 3.2808333 ft.