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RESEARCH MEMORANDUM

FLIGHT TESTS OF A CURTISS NO. 838-1C2-18 THREE-BLADE PROPELLER HAVING TRAILING-EDGE EXTENSIONS

By

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

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FLIGHT TESTS OF A CURTISS NO. 838-1C2-18 THREE-BLADE PROPELLER HAVING TRAILING-EDGE EXTENSIONS

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SUMMARY

Flight tests to determine propeller performance have been made of a Curtiss No. 838-1C2-18 three-blade propeller having trailing-edge extensions on a Republic P-47D-28 airplane in climb and high speed. These tests are a part of a general propeller flight-test program at the Langley Laboratory of the National Advisory Committee for Aeronautics.

Results of climb tests indicate that when power is changed from approximately 1475 horsepower at 2550 rpm (roughly normal power) to 2400 horsepower at 2700 rpm (approximately military power) there is a loss in propeller efficiency of 3 percent at an altitude of 7000 feet, and 4 percent at 21,000 feet. At an airplane Mach number of 0.7 there is a gain of 9 percent in propeller efficiency when the power coefficient per blade is increased from 0.06 to 0.09. Optimum power coefficient per blade at this Mach number is estimated to be approximately 0.12.

An analysis to determine the effect of the addition of extensions on the performance of the basic propeller blades indicates that climb performance was increased but high-speed performance was reduced. Both effects, however, were small.

INTRODUCTION

During the last few years the power output of airplane engines advanced more rapidly than the power absorption abilities of propellers available for use with these engines. It became apparent during this period that propellers of greater solidity were needed if the increase in power available was to be absorbed efficiently in take-off and climb conditions. However, the time needed to design higher solidity propellers and retool plants to produce them would have seriously impaired the production of blade designs then in urgent demand. A method was finally decided upon to increase the solidity of blade designs already in production, without seriously impairing this production. This method involved the addition of trailing-edge extensions to the blades. These trailing-edge extensions were added to the blades either by welding a strip to the trailing edge, or extending the upper surface of blades of hollow-steel-type construction. By the proper selection of extension length and angle setting, the design characteristics of the modified blade sections could be made to approximate those of the basic blade section.

In the present paper the results of climb and high-speed tests of a propeller having trailing-edge extensions are presented. The extensions of the propeller, a three-blade Curtiss design No. 838-1C2-18, are uncambered, average 20 percent of the basic blade chord, and are set at approximately 6.0° to the chord line. In addition to the presentation of the test data, an analysis is made of the effects of the trailing-edge extensions on the propeller performance in both the climb and high-speed conditions.

Data were obtained in climb tests at an indicated airspeed of 165 miles per hour at power conditions corresponding roughly to normal, military, and war emergency power operation. Additional data were obtained for constant power coefficient per blade conditions of 0.060, 0.082, 0.085, 0.092, and 0.102 through the airplane Mach number range from 0.25 to 0.725.

SYMBOLS

V true airspeed

n propeller rotational speed, revolutions per second

D propeller diameter

J advance ratio (V/nD)

β section blade angle at 0.75R

θ blade angle at any section

R propeller-tip radius

r propeller-section radius

$x = r/R$

b blade-section chord

h blade-section maximum thickness

r_s radial distance from thrust axis to survey point

$x_s = r_s/R$

C_T propeller thrust coefficient

C_P propeller power coefficient

η propeller efficiency

σ ratio of density of free air to density of standard air at sea level

c_l blade-section lift coefficient

M airplane Mach number

M_t propeller-tip Mach number

M_x propeller-section Mach number

PROPELLER AND TEST EQUIPMENT

General specifications of propeller and power plant are as follows:

Number of blades	Three
Blade design	Curtiss No. 838-1C2-18
Average design lift coefficient	0.5
Propeller diameter	12 feet 10 inches
Propeller-gear ratio	2:1
Engine	Pratt & Whitney R-2800-59

Normal power rating:

Engine speed, rpm	2550
Manifold pressure, inches of mercury	42
Brake horsepower	1625
Airplane critical altitude (climb), feet (approx.)	32,000

Military power rating:

Engine speed, rpm	2700
Manifold pressure, inches of mercury	52
Brake horsepower	2000
Airplane critical altitude (climb), foot (approx.)	29,000

War emergency power rating:

Engine speed, rpm	2700
Manifold pressure, inches of mercury	64
Brake horsepower	2600
Airplane critical altitude (climb), feet (approx.)	23,000

Blade-form curves of the test propeller are presented in figure 1. In figure 2 is shown a closeup view and in figure 3, a flight view of the test propeller and survey rake installed on a Republic P-47D-28 airplane.

Test equipment, test procedure, and method of data reduction are similar to those described in reference 1.

RESULTS AND DISCUSSION

Thrust was measured by the slipstream survey method, and the values given are uncorrected for slipstream rotation. Thus the reported values of thrust and efficiency are high by an estimated 1.5 to 4.0 percent, depending on the condition of operation. The correction for slipstream rotation increases with increasing power or decreasing advance ratio and is also a function of the distribution or torque along the propeller blades. Corrections were not applied to the data because of lack of torque distribution measurements and because estimates indicate that, relatively, efficiencies are not appreciably affected and comparisons between different conditions can be made with little error. For example, either at a given advance ratio and over the test range of power coefficients or at a given power coefficient and over the test range of advance ratios, efficiencies are changed relatively, a maximum of only about 1.0 percent. Neglect of the effect of slipstream rotation tends to underemphasize the effects at high advance ratios. A discussion of the effect of slipstream rotation on survey measurements is given in reference 2.

<u>Climb tests</u>.- In tables I and II are presented the data of the normal, military, and war emergency power climb tests. In figures 4, 5, and 6 these data have been plotted to show the variation of advance-ratio, power and thrust coefficients, efficiency, and airplane and propeller-tip Mach numbers with

density altitude. From the efficiency curves of figures 4 and 6 it will be noted that a change from normal to war emergency power in a 165-mile-per-hour (indicated) climb results in a loss in efficiency of 3 percent at an altitude of 7000 feet and 4 percent at 21,000 feet.

A comparison of the climb tests results on the basis of the same advance-ratio condition is made in figure 7 to show the effect of power loading on climb efficiency. From these curves it will be noted that the efficiency loss in changing from normal to war emergency power is between 3 and 4 percent. The increase in axial loss with increased power disk loading, estimated by means of the simple momentum theory, causes a loss in efficiency of approximately 2 percent at an advance-ratio of 1.0 and 1.5 percent at an advance-ratio of 1.2. The remainder of the efficiency loss is attributed to increased rotational and profile losses.

In figure 8 are presented thrust-grading curves obtained in war emergency power climb condition. There is no evidence in these surveys of loss in thrust near the tip usually associated with high-tip Mach numbers. It should be noted at this point that the large thrust difference between left and right surveys and the lateral shift in the surveys near the tip station $(x_s^2 = 1.0)$ are the result of pitched and yawed conditions, respectively, of the thrust axis and are not to be associated with the effects of compressibility. The effects of pitch and yaw are described more completely in reference 3.

It is interesting to examine the thrust distributions of figure 8 at the inboard stations near the fuselage side. On both right and left surveys a "leveling off" in the distribution is noted near the fuselage station. This station is in a region of mixing, that is, air from in front of the cowling passing over the cuff sections and not admitted to the engine is flowing around the cowling and mixing with air from propeller stations forward of the inboard rake stations. What is happening here is, therefore, considerably confused by this mixing. However, it will be noted that the more highly loaded right survey is holding up fairly well at a value of $x_s^2 = 0.15$ in figure 8, run 32 to 4, but falls off at a rapid rate in succeeding runs 32 to 5 and 32 to 6. This could very well be an indication of cuff stalling when the cuff is in the highly loaded right survey position. In the climb condition the engine-cowling exit flaps were closed and the inlet velocity ratio of the engine cooling air was less than 0.2. As the major portion of the air flowing over the cuff sections was, therefore, flowing around the cowling, any abrupt changes in the pressure rise across the cuff sections would be noted in the survey distributions.

Effect of extensions in climb.- For a given power-absorption requirement, increasing propeller solidity, in this instance by addition of trailing-edge extension, reduces the operating lift coefficients of the blade sections. Since it is generally known that blade sections operate at high-lift coefficients in the climb condition, any reduction in operating section lift coefficient has a beneficial effect on propeller efficiency from two standpoints. First, the sections operate nearer their optimum-lift coefficients for maximum L/D ratios. Second, operating at lower-lift coefficients raises section critical speeds, thus delaying the onset of compressibility effects.

In reference 4, it is shown that at an advance-ratio of 1.0 and for operation at maximum efficiency, the power absorption of a propeller is increased by an amount equal to the percent extension added to the propeller. Reference 4 also indicates that the maximum efficiency of a propeller is reduced 0.5 to 1 percent at an advance-ratio of 1.0 by the addition of trailing-edge extensions (it can be shown that this reduction in efficiency is due almost entirely to the increase in axial-energy loss associated with the increase in power loading and that, consequently, other propellor losses are not changod appreciably).

Although the test propeller is not operating at maximum efficiency, it appears to be operating near enough to maximum efficiency so that the data of reference 4 may be used in this analysis.

If the assumption is made that the rate of change of efficiency with power indicated in figure 7 for the propeller with extensions is also applicable to the propeller without extensions, the effect on efficiency of an increase of 20 percent in power absorption of the propeller without extensions can be estimated. For example, figure 7 shows that at an advance-ratio of 1.0 increasing the propeller power coefficient from 0.13 to 0.156 (a 20-percent increase) decreases the efficiency by about 2 percent. This indicates that, in addition to the increase in axial-energy loss, other losses have also been increased by a small amount.

It is now possible to estimate the amount by which the extensions increased the propeller climb efficiency. If the increase in power is absorbed without a change in solidity, the efficiency loss, as above, is about 2 percent. If trailing-edge extensions equivalent to the percent increase in power are added, then only the added axial-energy loss of 0.5 to 1 percent is incurred. Therefore, the net result is an improvement in efficiency of 1 to 1.5 percent attributable to the addition of extensions.

Constant power tests over speed range.- In table III are presented the data of the constant-power-coefficient tests made at 2700 engine rpm over the airplane Mach number range from 0.25 to 0.725. The data are plotted in figures 9 to 13 to show the variation in efficiency with airplane Mach number at constant power coefficient. Also included in these figures are curves of tip Mach number, advance-ratio, thrust and power coefficients. Points obtained from the faired climb curves of figures 4, 5, and 6 have been spotted in figures 9 to 11.

The curves of advance-ratio, tip Mach number, and efficiency of figures 9 to 13 are combined in figure 14 to facilitate comparison of the results. The tip Mach number and advance-ratio curves in figure 14 are essentially the same for all tests except that at the lowest power coefficient per blade. While, in this respect, the data at a blade loading of 0.06 are not strictly comparable to the data at the other blade loadings, the effect of the differences in tip Mach number and advance ratio on efficiency is actually small. The maximum effect on efficiency that might be expected is estimated to be less than 1 percent.

Examination of the efficiency curves of figure 14 indicates a gradual drop in efficiency at the lower speeds as the power coefficient is raised. This is in agreement with the trend in the climb tests of figure 7. At the higher speeds, a reverse trend is observed. An increase in power coefficient results in an increase in efficiency. From figure 14 it is noted that at an airplane Mach number of 0.7 increasing the power coefficient per blade from 0.06 to 0.082 results in a gain in efficiency of approximately 7 percent. A further increase to 0.092 results in an additional efficiency gain of 2 percent.

Figure 15 has been prepared to give a picture of what is happening to the loading distribution at this high Mach number as the power coefficient per blade is increased. In this figure the thrust values have been multiplied by the factor J/C_P which, in effect, converts these values into a measure of section efficiency. It will be noted in this figure that increase in loading increases the ordinates fairly evenly over almost the entire blade, showing that the load distribution has not been changed and indicating that the efficiency of almost all sections is increased as the power is increased. Blade section data presented later will further show this.

Analysis of section operating characteristics at high speeds.- The operating lift coefficients for several radial stations of the blade have been calculated using simple blade element theory and the thrust distributions obtained in these tests. Values of lift coefficients obtained are approximate as the method by which they were obtained is admittedly approximate itself. However, they are considered sufficiently accurate for the purposes of this analysis. Section lift coefficients have been calculated using the following relationship for that can easily be derived from the simple blade-element theory:

$$c_l = \frac{dC_T}{d(x_s{}^2)} \frac{8 \cos \phi}{\sigma\pi^3 x^2} \frac{1}{1 - \tan \phi \tan \gamma}$$

where

$$\phi = \tan^{-1} \frac{J}{\pi x}$$

$$\sigma = \frac{B\frac{b}{D}}{\pi x}$$

$$x = \frac{r}{R}$$

$$\gamma = \tan^{-1} \frac{c_d}{c_l}$$

and

B number of blades

c_d section drag coefficient

In using the thrust distributions, it was assumed that values of x and x_s for $x_s \geq 0.5$ were the same and the average of left and right survey $\frac{dC_T}{d(x_s{}^2)}$ values represented a true average. A value of γ was assumed corresponding to a lift-drag ratio of 10.

The results of the calculations of section lift coefficients are presented in figure 16. In this figure, the variation in operating section lift coefficients for several radial stations of the blade with changes in power coefficient and airplane Mach number are shown. The high-speed portion of these curves are of particular interest. It will be noted that at an airplane Mach number of 0.7 and a power coefficient per blade of 0.082 the average operating section lift coefficient in the range from $x_s = 0.5$ to 0.9 is approximately 0.4. These sections are therefore operating below their design C_L condition of 0.5, and an increase in loading should increase the propeller performance. This has been indicated previously in discussions of the high-speed trend of the efficiency curves of figure 14 and the high-speed loading distributions of figure 15. Referring further to figure 16, it will be noted that if the lift coefficient curves for the power coefficient per blade condition of 0.102 are extrapolated to an airplane Mach number of 0.7, the average operating section lift coefficient at that Mach number would be approximately 0.5. It might then be concluded that this power coefficient is optimum for an airplane Mach number of 0.7. Figure 17 shows that this conclusion can not readily be drawn. In this figure, curves showing the variation of efficiency with power coefficient for airplane Mach numbers of 0.6 and 0.7 are shown. A reasonable extrapolation of the curve for 0.7 Mach number would indicate the optimum loading is very likely beyond a power coefficient per blade of 0.102, possibly as high as 0.12. The average optimum operating lift coefficient for maximum lift-drag ratio would then be approximately 0.6 at 0.7 Mach number. The same analysis applied to the data at a Mach number of 0.6 again indicates that the optimum operating lift coefficient is about 0.6. It appears, therefore, that best efficiency is obtained when the propeller sections are working at lift coefficients slightly above the design values.

Effect of extensions at high speed.- It has been mentioned in the discussion of figures 15 and 16 that at an airplane Mach number of 0.7 the operating section lift coefficients are below optimum values. The use of extensions is therefore having a detrimental effect on the efficiency at high speeds since their use reduces blade-section operating lift coefficients for a given power-absorption requirement. The magnitude of this adverse effect on the efficiency cannot readily be determined because of lack of high-speed data on blade extensions. However, if the extensions were only half as effective at high speed as they are in climb, absorbing at maximum efficiency a power increase equal to half the percent extension added, (reference 4 indicates that their effectiveness falls off at higher advance ratios) by an analysis similar to that made for the climb condition, the high-speed efficiency would be decreased about 2 percent. Expressed as a loss in top speed of the aircraft, this would be 3 to 4 miles per hour.

The analysis of the climb and high-speed tests have indicated that the extensions improved climb efficiency at the expense of high-speed efficiency. For the normal loading condition of a Republic P-47D-28 airplane (approximately 13,000 pounds) it is estimated the resulting increase in rate-of-climb is of the order of 100 feet per minute. The decrease in top speed is difficult to accurately determine but it is likely that it is not more than 4 miles per hour. In addition, these tests have demonstrated that the propeller is considerably underloaded at high speeds. This condition could be corrected by increasing the power available, reducing blade solidity, or changing the propeller-engine gear ratio, but all of these methods would result in reduced climb efficiencies. However, a two-speed propeller-engine gear system would permit efficient propeller operation at both climb and high-speed conditions. The need for such a system will become more evident as the gap between the maximum speed and climbing speeds of aircraft further widens.

CONCLUSIONS

Flight tests of a Curtiss No. 838-1C2-18 three-blade propeller on a Republic P-47D airplane indicate the following:

1. A change from normal to war emergency power in a climb at an indicated airspeed of 165 miles per hour results in a 3-percent loss in propeller efficiency at an altitude of 7000 feet and 4 percent at an altitude of 21,000 feet.

2. At an airplane Mach number of 0.7 increasing the power coefficient per blade from 0.06 to 0.08 results in a 7 percent efficiency gain, a further increase to 0.09 results in an additional efficiency gain of 2 percent.

3. For airplane Mach numbers of 0.6 to 0.7, peak efficiency will be reached at a power coefficient per blade of approximately 0.12.

4. The only apparent effect of using the extensions on the propeller has been to increase solidity. As a result, a small

improvement in climb performance and a small reduction in high-speed performance has been observed.

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TABLE I

FLIGHT DATA OBTAINED FROM NORMAL POWER CLIMB

TESTS OF CURTISS NO. 838-102-18 THREE-BLADE

PROPELLER ON REPUBLIC P-47D-28 AIRPLANE

Figure	Run	J	C_P	C_T	η	n (rps)	M	M_t	σ
4	25 to 1	0.972	0.119	0.1007	0.823	21.48	0.244	0.825	0.845
4	25 to 2	.983	.126	.1043	.813	21.48	.247	.826	.803
4	25 to 3	.996	.134	.1095	.814	21.45	.251	.829	.769
4	25 to 4	1.020	.140	.1135	.827	21.40	.258	.835	.737
4	25 to 5	1.050	.148	.1144	.811	21.45	.268	.845	.702
4	25 to 6	1.092	.157	.1200	.834	21.42	.280	.852	.669
4	25 to 7	1.101	.163	.1232	.832	21.45	.284	.857	.638
4	25 to 8	1.129	.172	.1263	.829	21.42	.291	.860	.607
4	25 to 9	1.138	.180	.1307	.826	21.45	.296	.868	.579
4	25 to 10	1.178	.187	.1308	.824	21.45	.307	.875	.555
4	25 to 11	1.194	.195	.1353	.828	21.45	.314	.883	.530
4	25 to 12	1.222	.204	.1401	.839	21.47	.323	.890	.507
4	25 to 13	1.255	.213	.1433	.844	21.45	.333	.898	.486
4	25 to 14	1.273	.222	.1448	.830	21.47	.340	.906	.463
4	25 to 15	1.291	.229	.1458	.822	21.45	.347	.912	.445
4	25 to 16	1.328	.237	.1486	.832	21.47	.359	.921	.431
4	25 to 17	1.338	.244	.1507	.826	21.47	.362	.924	.420
4	25 to 18	1.356	.256	.1542	.817	21.47	.369	.932	.400
4	25 to 19	1.385	.261	.1559	.827	21.47	.380	.941	.389
4	25 to 20	1.415	.269	.1562	.822	21.47	.390	.951	.377
4	25 to 21	1.421	.274	.1599	.829	21.48	.394	.956	.364
4	25 to 22	1.467	.284	.1594	.823	21.32	.405	.958	.355
4	25 to 23	1.495	.293	.1599	.816	21.27	.414	.963	.344
4	25 to 24	1.486	.295	.1618	.815	21.38	.415	.970	.334

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TABLE II

FLIGHT DATA OBTAINED FROM MILITARY POWER AND WAR

EMERGENCY POWER CLIMB TESTS OF CURTISS NO. 838-1C2-18

THREE-BLADE PROPELLER ON REPUBLIC P-47D-28 AIRPLANE

Figure	Run	J	C_P	C_T	η	n (rps)	M	M_t	σ
5	22 to 1	0.887	0.120	0.1068	0.789	22.62	0.231	0.851	0.923
5	22 to 2	.911	.128	.1132	.805	22.62	.240	.863	.872
5	22 to 3	.972	.142	.1163	.795	22.65	.257	.868	.798
5	22 to 4	.980	.150	.1217	.795	22.52	.259	.870	.749
5	22 to 5	1.002	.162	.1277	.790	22.48	.267	.877	.702
5	22 to 6	1.031	.172	.1319	.791	22.63	.278	.892	.651
5	22 to 7	1.075	.185	.1365	.793	22.52	.291	.898	.605
5	22 to 8	1.117	.194	.1381	.795	22.48	.303	.905	.572
5	22 to 9	1.157	.207	.1431	.800	22.52	.317	.917	.535
5	22 to 10	1.186	.220	.1500	.809	22.53	.328	.927	.501
5	22 to 11	1.226	.229	.1497	.801	22.52	.342	.939	.475
5	22 to 12	1.260	.241	.1562	.817	22.58	.355	.954	.446
5	22 to 13	1.272	.250	.1595	.812	22.53	.360	.959	.423
5	22 to 14	1.296	.262	.1602	.792	22.47	.368	.964	.402
6, 8(a)	32 to 1	.971	.177	.1421	.780	22.55	.252	.855	.805
6, 8(b)	32 to 2	1.005	.191	.1482	.780	22.58	.263	.864	.731
6, 8(c)	32 to 3	1.055	.209	.1554	.784	22.53	.278	.872	.664
6, 8(d)	32 to 4	1.080	.226	.1641	.784	22.57	.287	.884	.610
6, 8(e)	32 to 5	1.135	.243	.1693	.791	22.53	.304	.896	.561
6, 8(f)	32 to 6	1.183	.265	.1781	.795	22.50	.320	.907	.513
6	33 to 1	.979	.178	.1408	.774	22.48	.251	.844	.800
6	33 to 2	1.008	.191	.1482	.782	22.55	.262	.857	.735
6	33 to 3	1.032	.212	.1573	.766	22.55	.272	.869	.665
6	33 to 4	1.093	.228	.1626	.779	22.57	.290	.884	.617
6	33 to 5	1.134	.245	.1694	.784	22.55	.303	.894	.563
6	33 to 6	1.202	.264	.1727	.786	22.57	.325	.908	.519

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TABLE III

FLIGHT DATA OBTAINED FROM LOW-HIGH SPEED 2700 ENGINE RPM TESTS OF CURTISS NO. 838-1C2-18 THREE-BLADE PROPELLER ON REPUBLIC P-47D-28 AIRPLANE

Figure	Run	J	C_P	C_T	η	n (rps)	M	M_t	σ
9	20 to 1	0.913	0.181	0.1495	0.754	22.42	0.252	0.901	0.630
9	20 to 2	1.149	.180	.1268	.809	22.55	.319	.929	.629
9	20 to 3	1.405	.177	.1043	.828	22.63	.390	.956	.636
9	20 to 4	1.646	.180	.0920	.841	22.55	.458	.987	.631
9	20 to 5	1.918	.176	.0730	.795	22.63	.530	1.018	.640
9	20 to 6	2.174	.181	.0623	.748	22.43	.598	1.050	.638
9	20 to 7	2.391	.173	.0484	.669	22.48	.658	1.086	.656
9	20 to 8	2.620	.178	.0415	.611	22.62	.725	1.132	.641
10	23 to 25	2.456	.245	.0716	.718	22.50	.694	1.127	.440
10	23 to 26	2.186	.248	.0893	.787	22.28	.611	1.068	.444
10	23 to 27	1.887	.244	.1044	.807	22.65	.537	1.043	.433
10	23 to 28	1.656	.241	.1197	.822	22.65	.471	1.010	.437
10	23 to 29	1.386	.236	.1389	.816	22.67	.394	.977	.436
10	23 to 30	1.117	.237	.1632	.770	22.67	.318	.950	.433
9	24 to 7	2.622	.176	.0414	.617	22.27	.711	1.110	.654
9	24 to 8	2.469	.180	.0482	.661	22.67	.671	1.086	.606
9	24 to 9	2.252	.180	.0610	.762	22.64	.610	1.044	.610
9	24 to 10	1.950	.183	.0762	.812	22.63	.528	1.001	.617
9	24 to 11	1.709	.188	.0923	.839	22.68	.465	.973	.594
9	24 to 12	1.455	.188	.1065	.824	22.58	.393	.936	.606
9	24 to 13	1.184	.185	.1241	.794	22.50	.319	.905	.614
9	24 to 14	.935	.181	.1429	.738	22.67	.254	.891	.617
11	34 to 12	1.416	.269	.1506	.793	22.72	.400	.973	.412
11	34 to 13	2.344	.256	.0820	.751	22.67	.659	1.103	.410
11	34 to 14	2.113	.257	.0982	.808	22.60	.595	1.066	.412
11	34 to 15	1.942	.255	.1072	.816	22.60	.547	1.040	.412
11	34 to 16	1.699	.251	.1224	.829	22.67	.479	1.007	.412
11	34 to 17	1.454	.247	.1385	.815	22.60	.409	.973	.412
11	34 to 18	1.211	.260	.1666	.776	22.67	.341	.949	.410
12	35 to 1	2.522	.263	.0746	.715	22.53	.698	1.115	.496
12	35 to 2	2.453	.283	.0850	.737	22.48	.684	1.111	.464
12	35 to 3	2.221	.286	.0992	.770	22.50	.620	1.073	.467
12	35 to 4	1.965	.280	.1134	.796	22.53	.550	1.038	.468
12	35 to 5	1.707	.276	.1322	.818	22.55	.478	1.001	.468
12	35 to 6	1.427	.282	.1556	.787	22.42	.397	.961	.464
12	35 to 7	1.213	.282	.1815	.781	22.37	.337	.936	.466

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

TABLE III - Concluded

FLIGHT DATA OBTAINED FROM LOW-HIGH SPEED 2700 ENGINE RPM

TESTS OF CURTISS NO. 838-1C2-18 THREE-BLADE PROPELLER

ON REPUBLIC P-47D-28 AIRPLANE - Concluded

Figure	Run	J	C_P	C_T	η	n (rps)	M	M_t	σ
10	35 to 8	1.175	0.246	0.1654	0.790	22.53	0.332	0.948	0.433
10	35 to 9	1.427	.245	.1390	.810	22.52	.403	.975	.439
10	35 to 10	1.687	.246	.1194	.819	22.55	.477	1.009	.438
10	35 to 11	1.917	.251	.1048	.800	22.48	.540	1.037	.434
10	35 to 12	2.229	.246	.0848	.768	22.37	.624	1.079	.442
10	35 to 13	2.490	.249	.0715	.715	22.48	.700	1.127	.441
10	35 to 14	2.620	.256	.0656	.672	22.43	.734	1.142	.432
12	36 to 1	1.225	.270	.1747	.793	22.63	.339	.933	.455
12	36 to 2	2.507	.278	.0834	.752	22.70	.700	1.121	.455
12	36 to 3	2.153	.270	.0991	.790	22.72	.602	1.065	.459
12	36 to 4	2.071	.283	.1106	.810	22.60	.574	1.042	.454
12	36 to 5	2.539	.277	.0796	.730	22.80	.711	1.130	.460
12	36 to 6	2.083	.277	.1071	.805	22.65	.581	1.050	.458
12	36 to 7	1.423	.273	.1541	.803	22.58	.395	.958	.457
12	36 to 8	1.714	.278	.1331	.820	22.67	.477	.997	.457
10	36 to 9	2.513	.245	.0700	.718	22.78	.710	1.136	.430
10	36 to 10	2.534	.246	.0689	.710	22.67	.711	1.133	.437
10	36 to 11	2.287	.239	.0781	.747	22.67	.651	1.107	.436
10	36 to 12	1.985	.247	.0996	.800	22.65	.560	1.049	.431
10	36 to 13	1.428	.244	.1401	.820	22.67	.402	.971	.429
10	36 to 14	1.702	.247	.1204	.830	22.63	.479	1.006	.430
10	36 to 15	2.069	.267	.1024	.794	22.68	.592	1.076	.480
13	22 to 15	2.200	.304	.1118	.809	22.48	.618	1.090	.426
13	22 to 16	1.940	.310	.1293	.809	22.48	.548	1.042	.417
13	22 to 17	1.724	.307	.1487	.835	22.47	.486	1.011	.418
13	22 to 18	1.431	.303	.1651	.780	22.53	.404	.975	.418

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

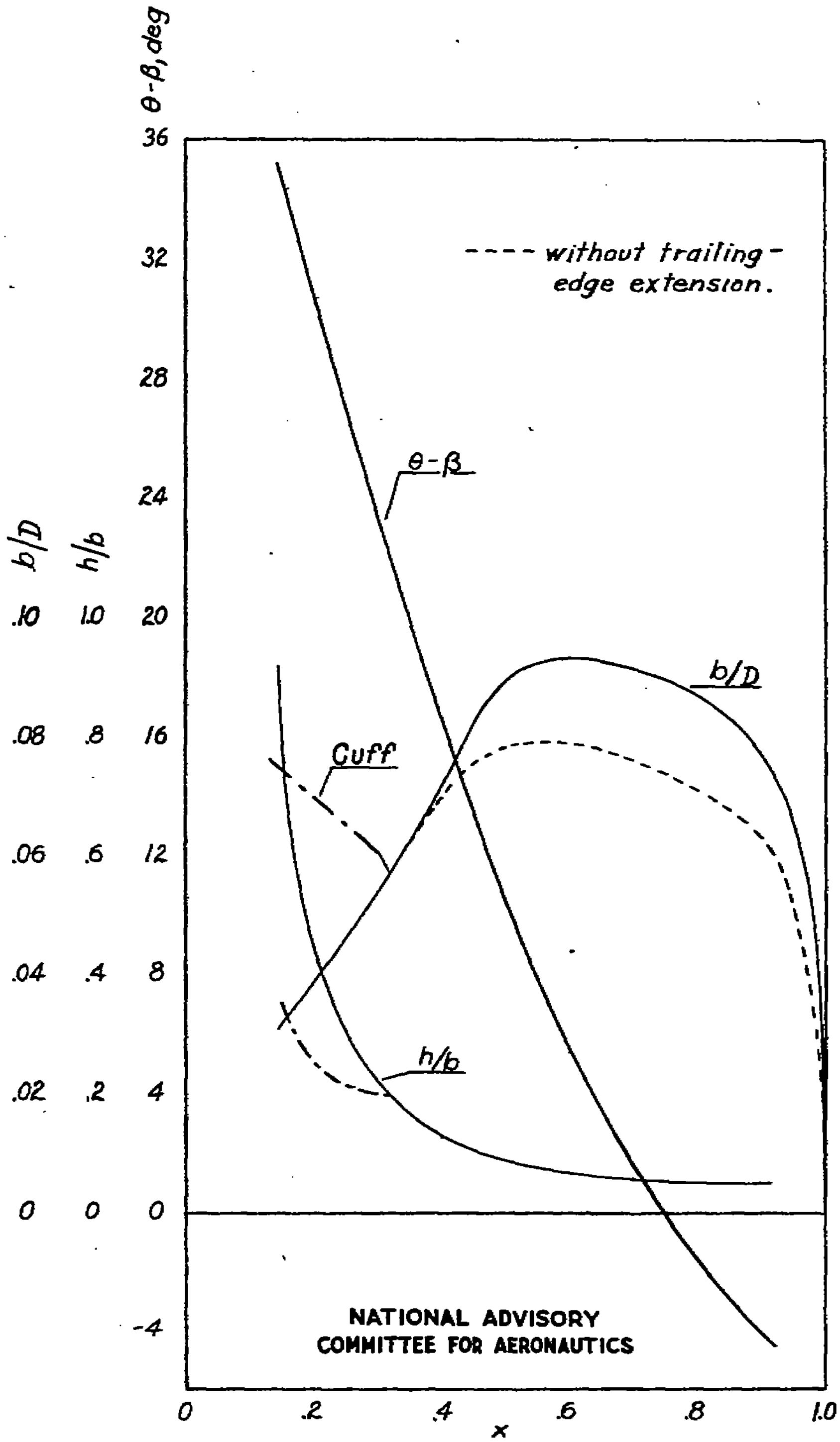


Figure 1.- Blade-form curves for the Curtiss No. 838-1C2-18 three-blade propeller.

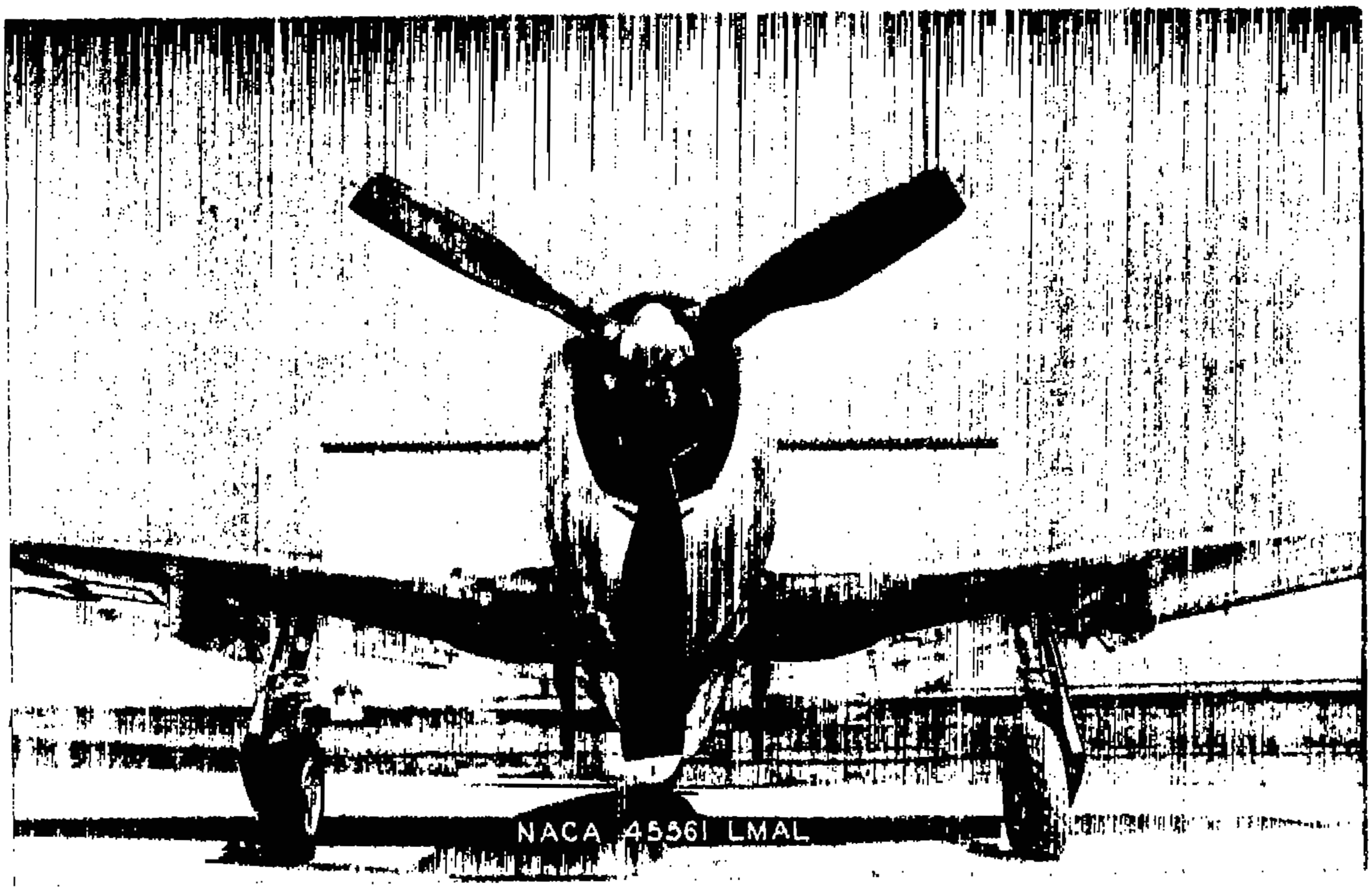


Figure 2.- Republic P-47D-28 airplane equipped with a Curtiss No. 838-1C2-18 three-blade propeller and survey rakes.

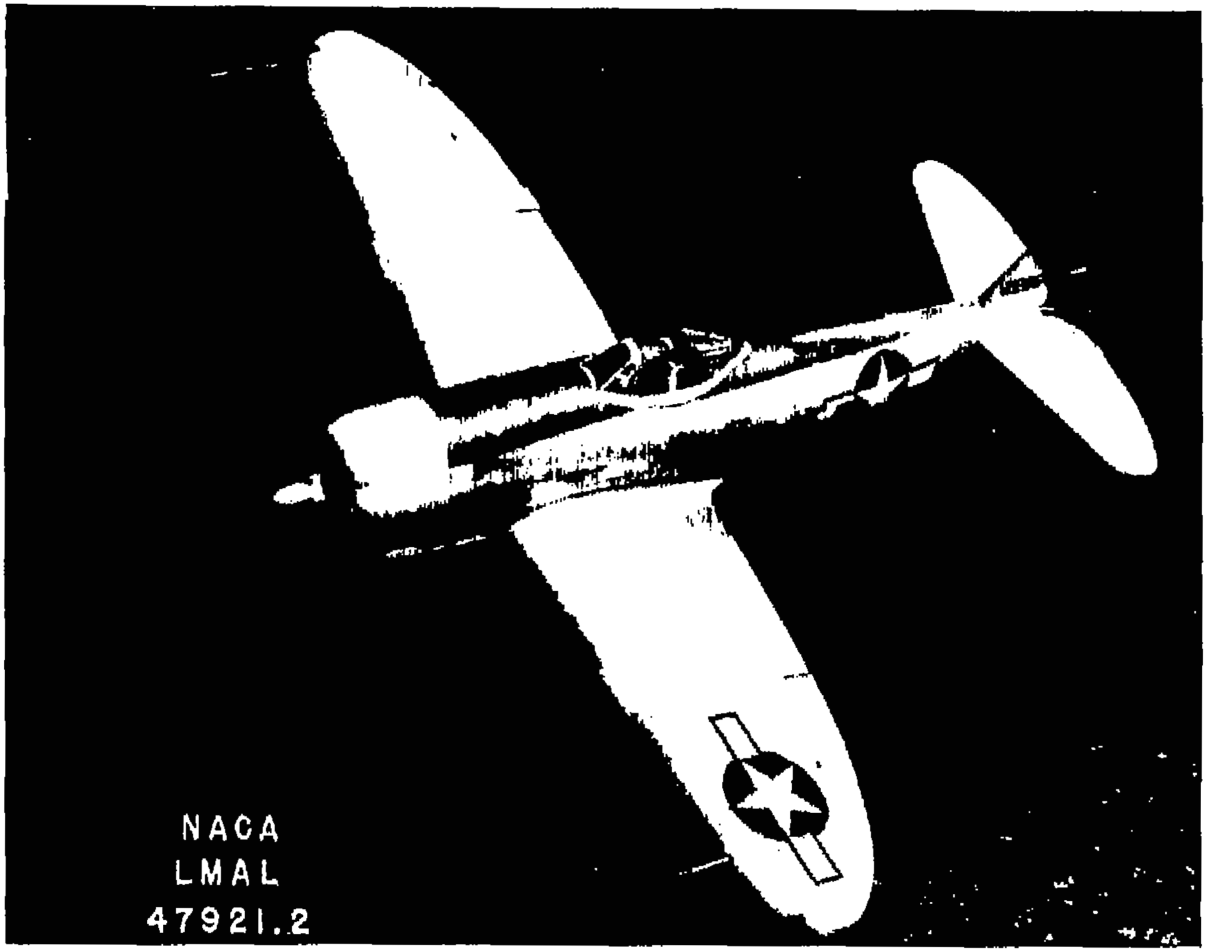


Figure 3.- Flight view of Republic P-47D-28 airplane equipped with a Curtiss No. 838-1C2-18 three-blade propeller and survey rakes.

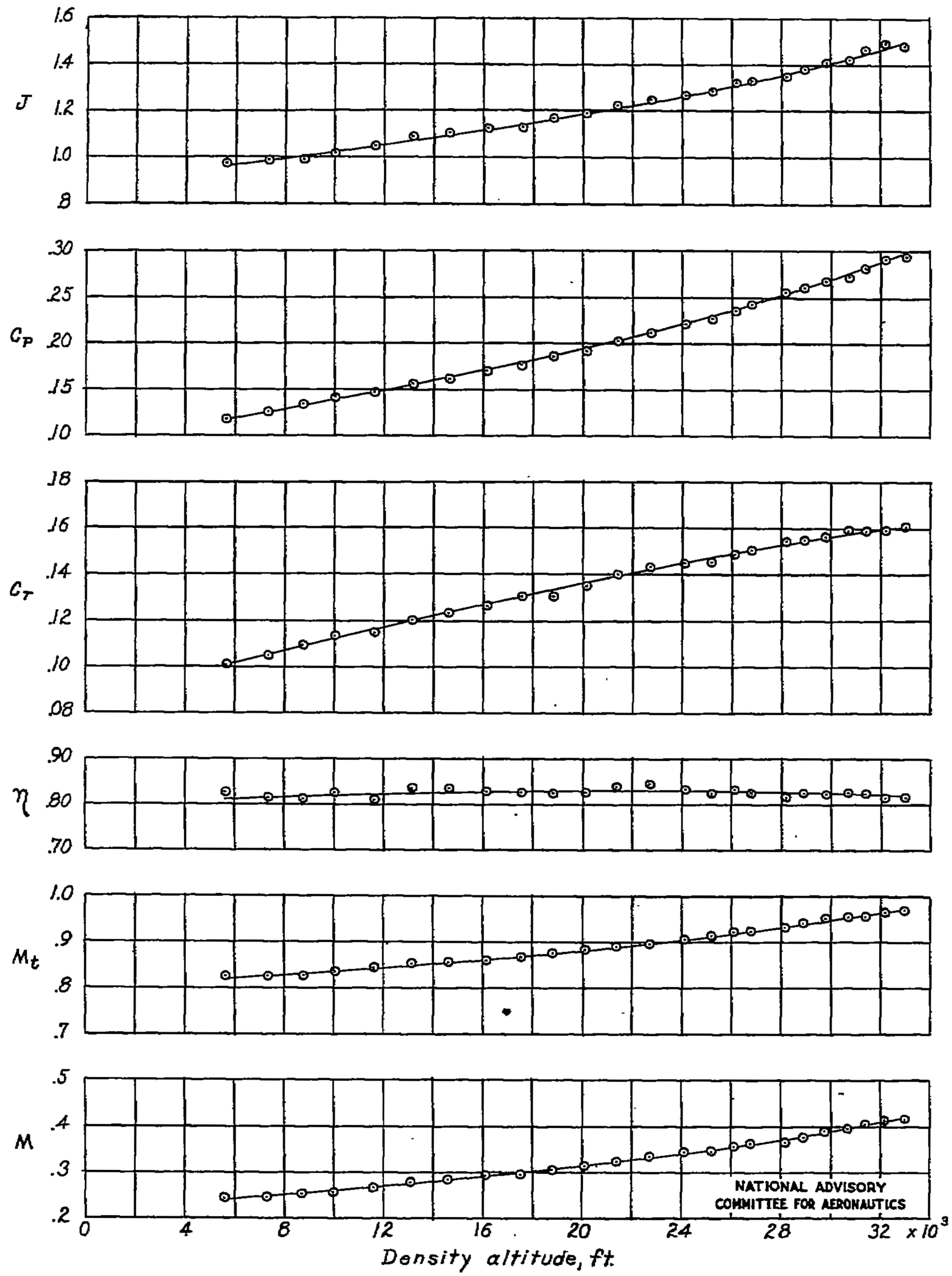


Figure 4.- Normal power climb at an indicated airspeed of 165 miles per hour. Curtiss No. 838-102-18 three-blade propeller on Republic P-47D-28 airplane.

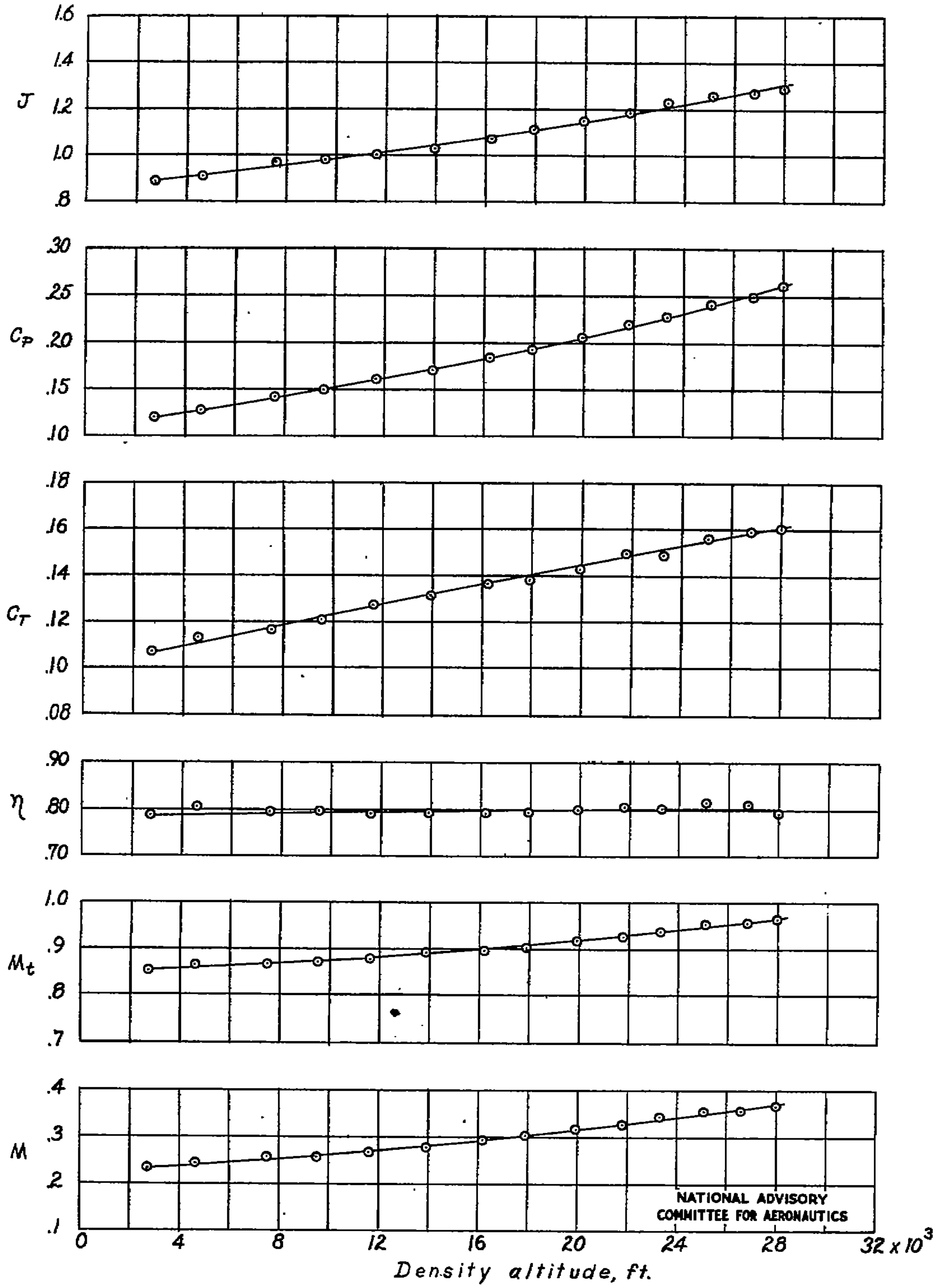


Figure 5.- Military power climb at an indicated airspeed of 165 miles per hour. Curtiss No. 836-102-18 three-blade propeller on Republic P-47D-28 airplane.

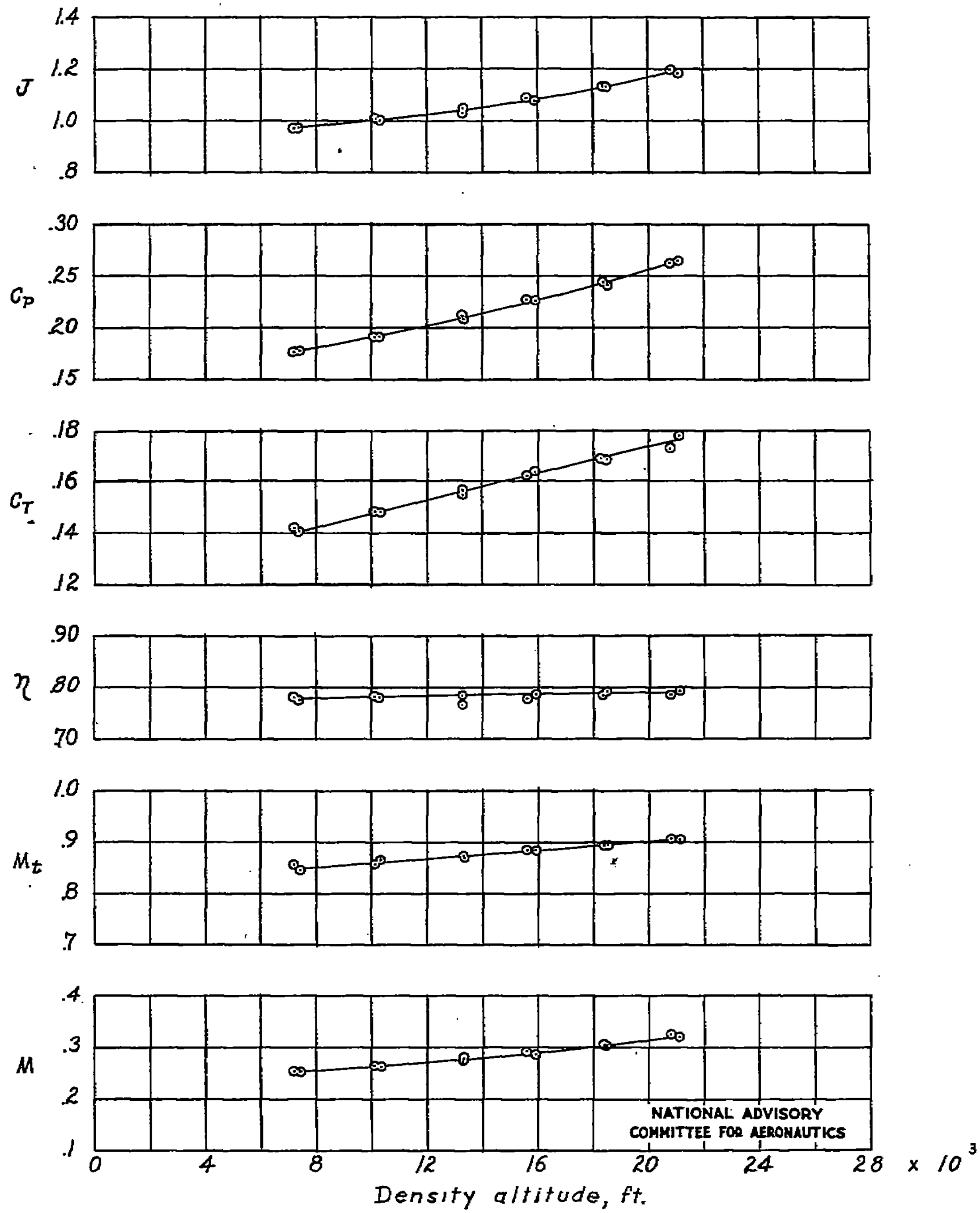
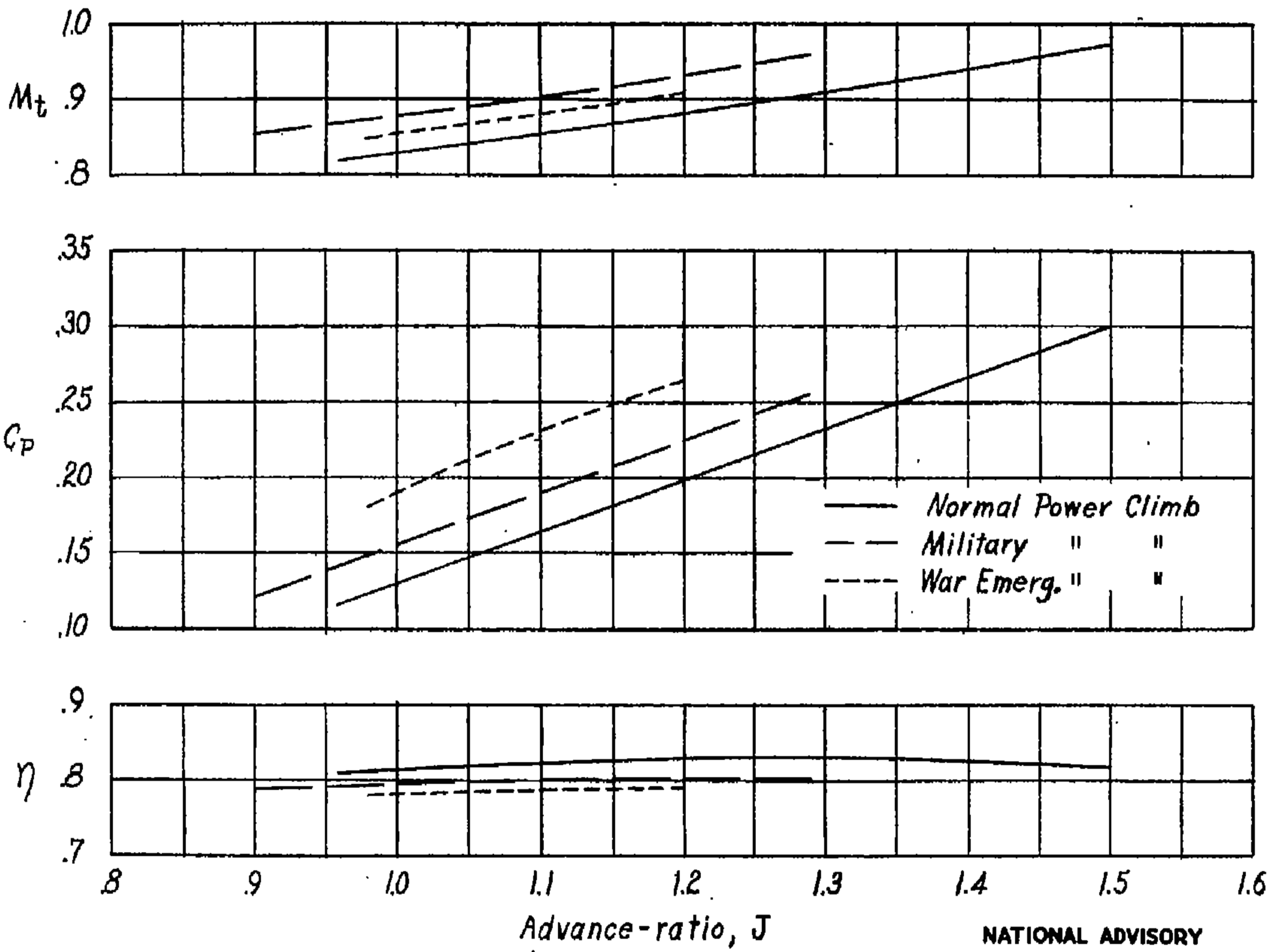
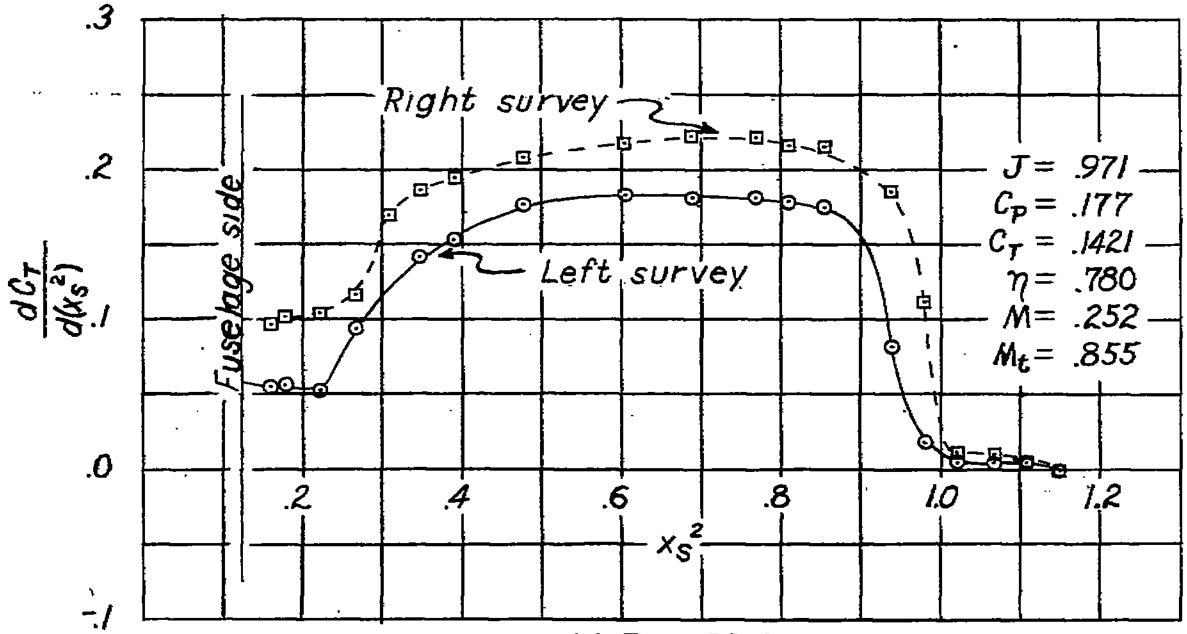


Figure 6.- War emergency power climb at an indicated airspeed of 165 miles per hour. Curtiss No. 838-102-18 three-blade propeller on Republic P-47D-23 airplane.

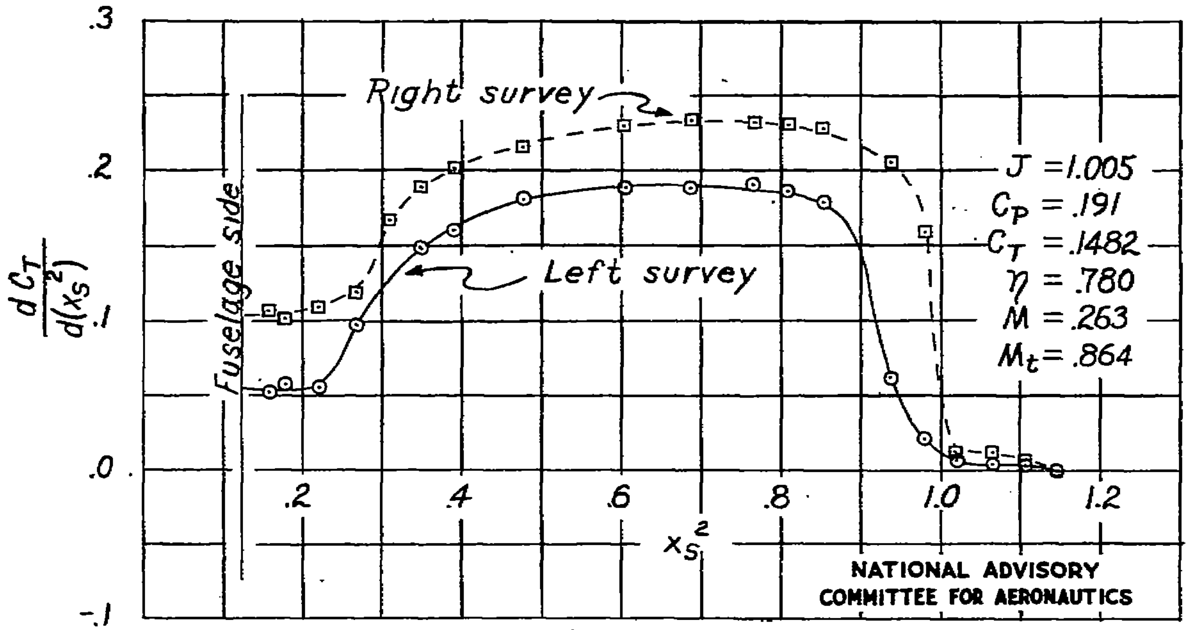


NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

Figure 7.- Effect of power loading on efficiency in the climb condition. Curtiss No. 838-1C2-18 three-blade propeller on Republic P-47D-28 airplane.

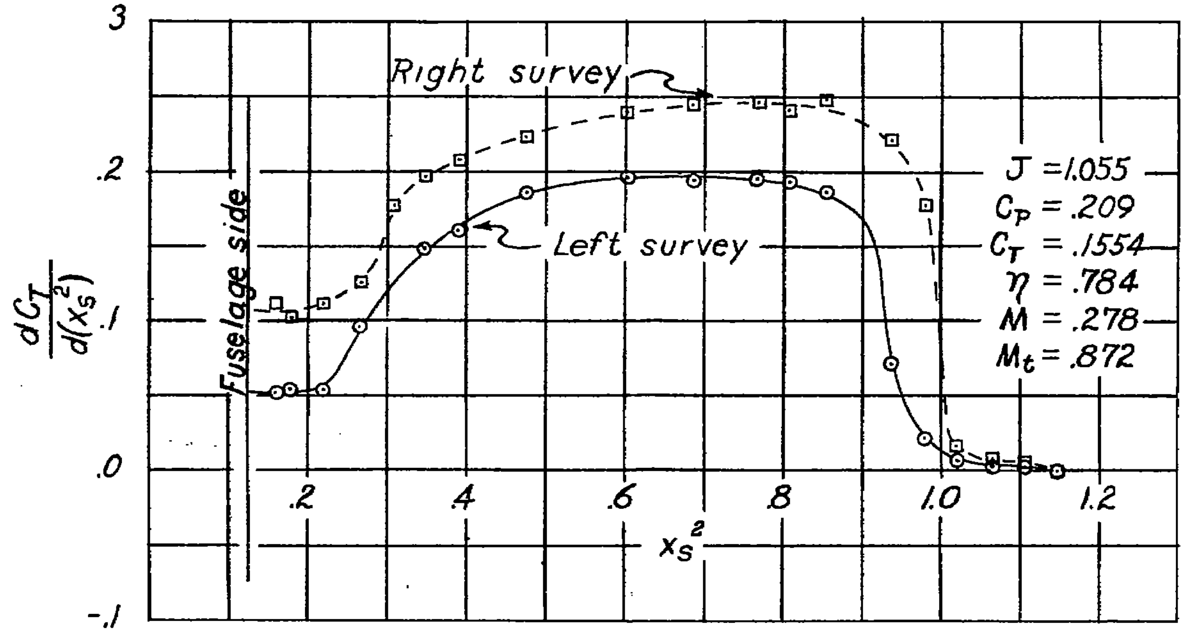


(a) Run 32-1

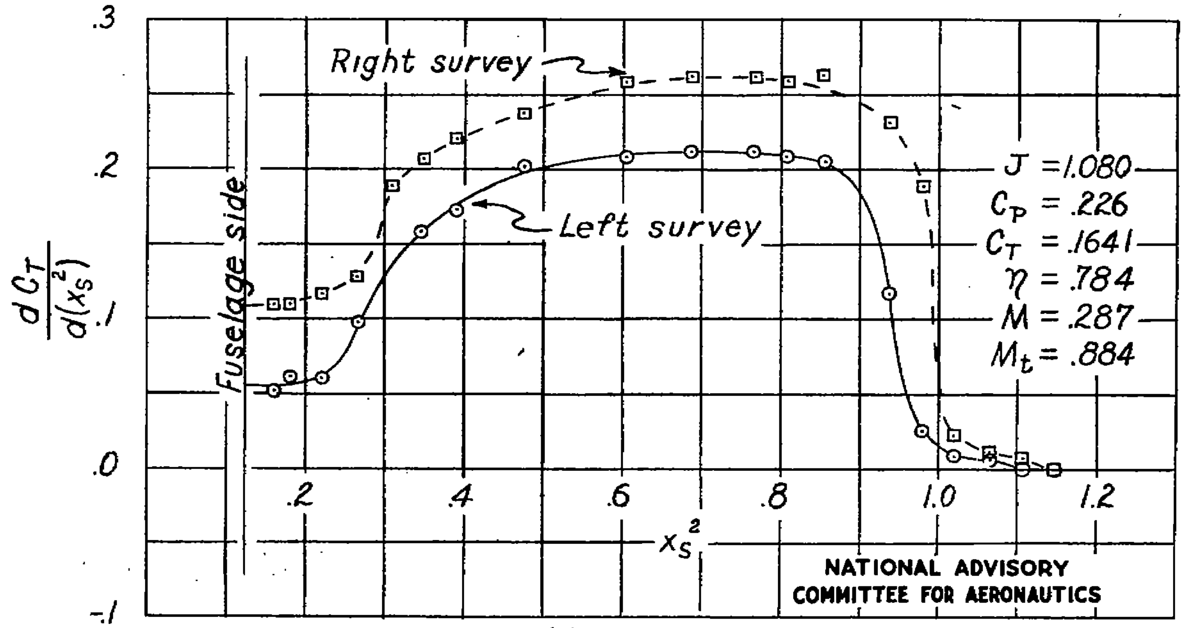


(b) Run 32-2

Figure 8.- Thrust-grading curves for climb at war emergency power. Indicated airspeed, 165 miles per hour. Curtiss No. 838-1C2-18 three-blade propeller on Republic P-47D-28 airplane.

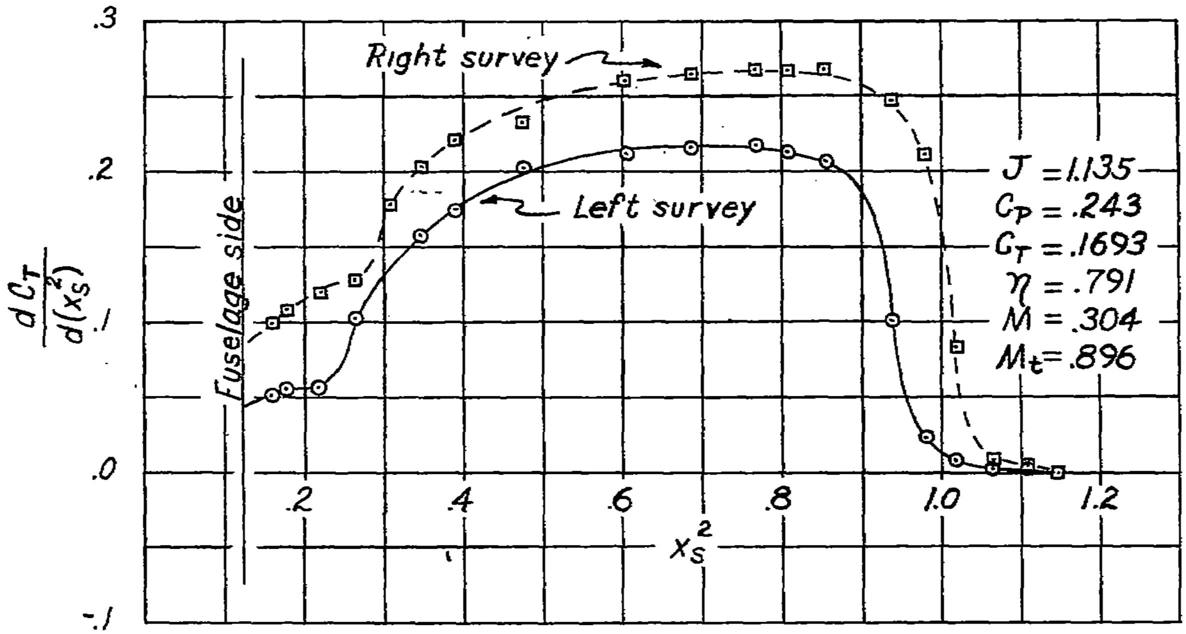


(c) Run 32-3

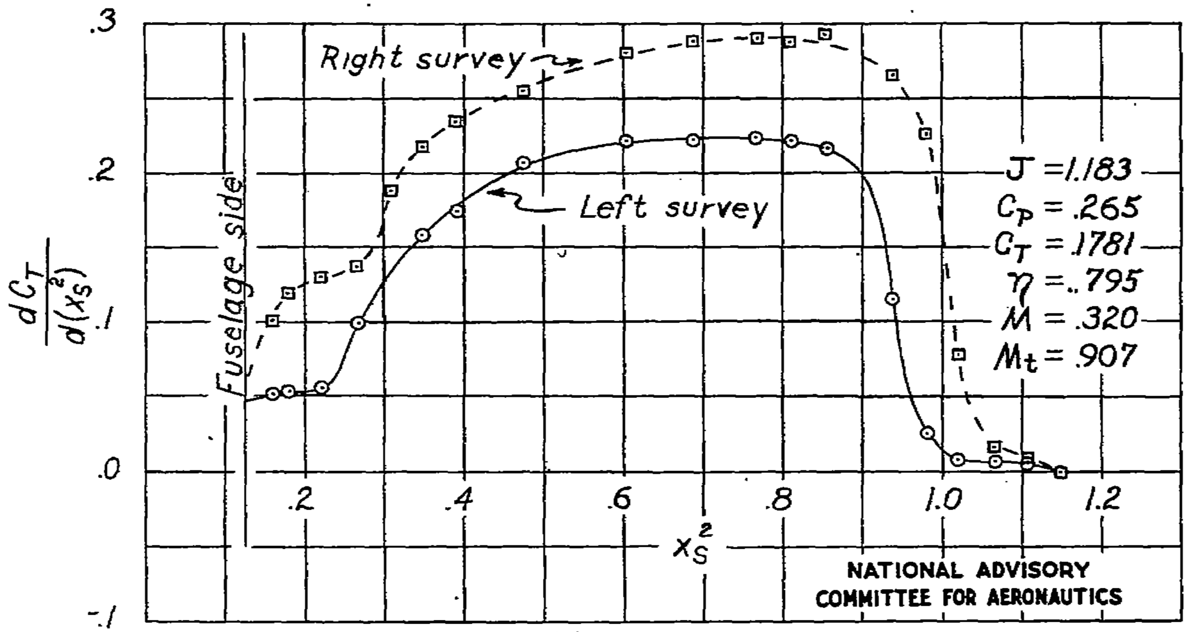


(d) Run 32-4

Figure 8.- Continued.



(e) Run 32-5



(f) Run 32-6

Figure 8.- Concluded.

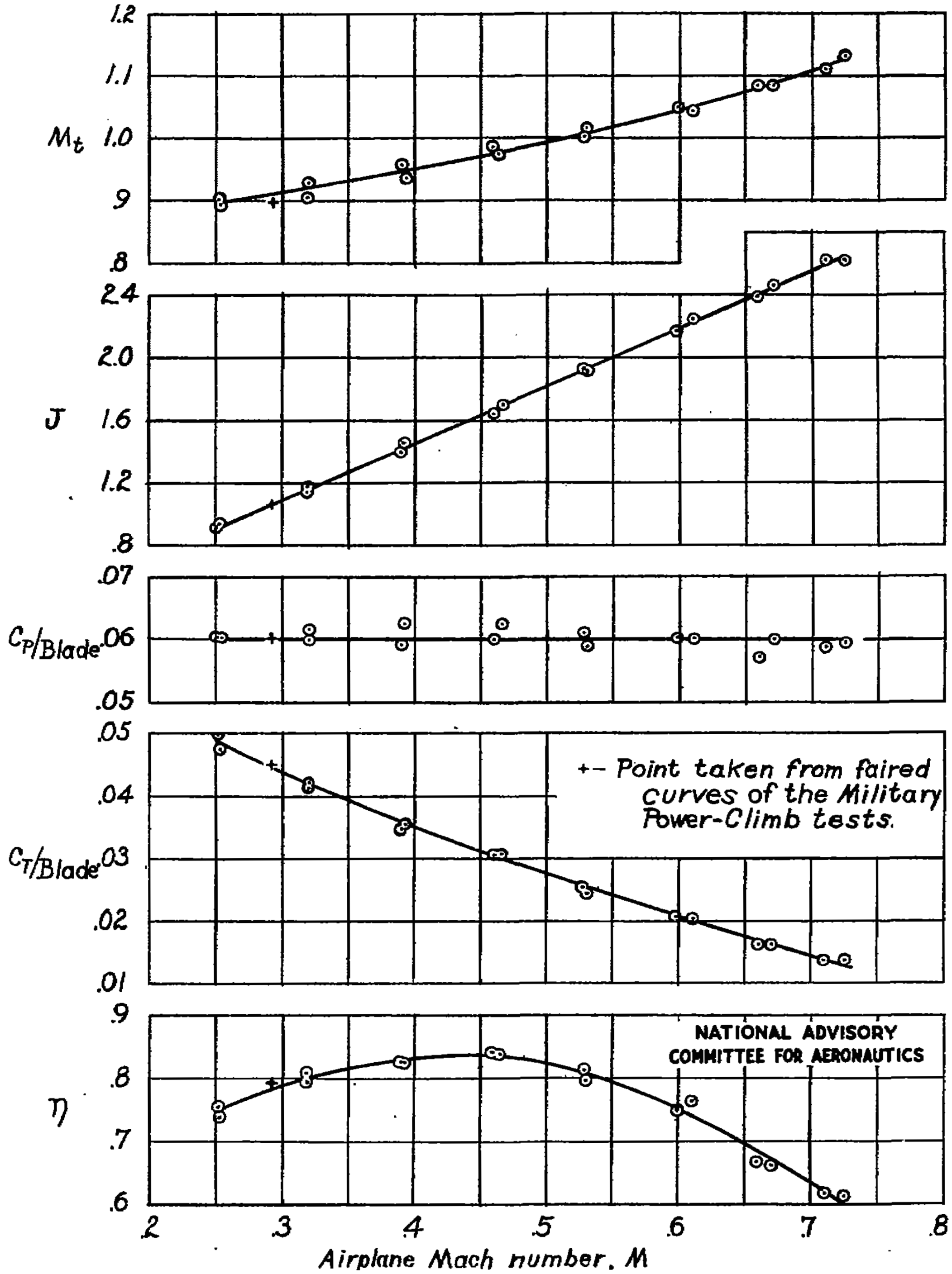


Figure 9.- Variation in propeller efficiency with airplane Mach number at constant blade-loading condition. Power coefficient per blade approximately .06; 2700 engine rpm. Curtiss No. 838-102-18 three-blade propeller on Republic P-47D-28 airplane.

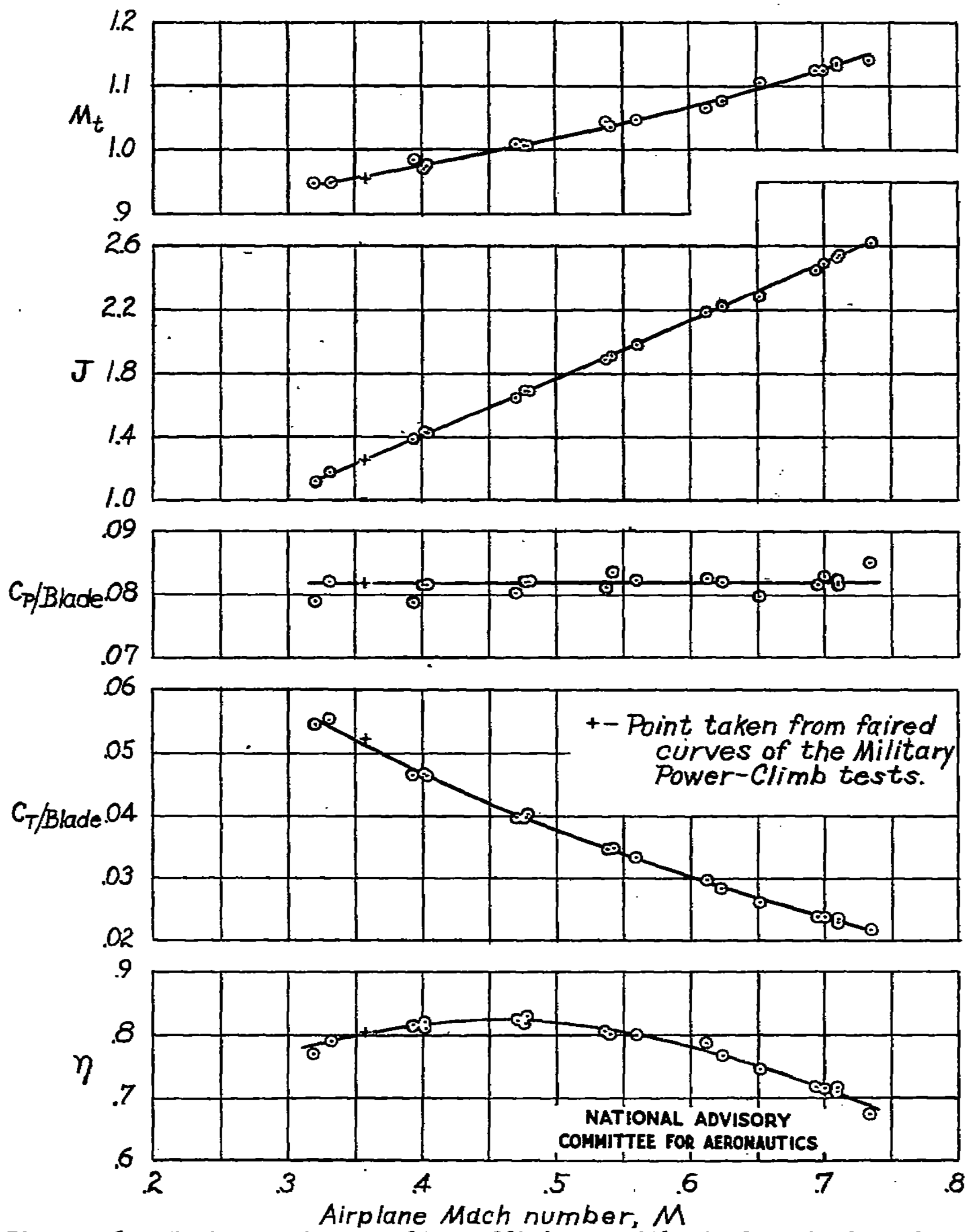


Figure 10.- Variation in propeller efficiency with airplane Mach number at constant blade-loading condition. Power coefficient per blade approximately, .082; 2700 engine rpm. Curtiss No. 838-102-18 three-blade propeller on Republic P-47D-28 airplane.

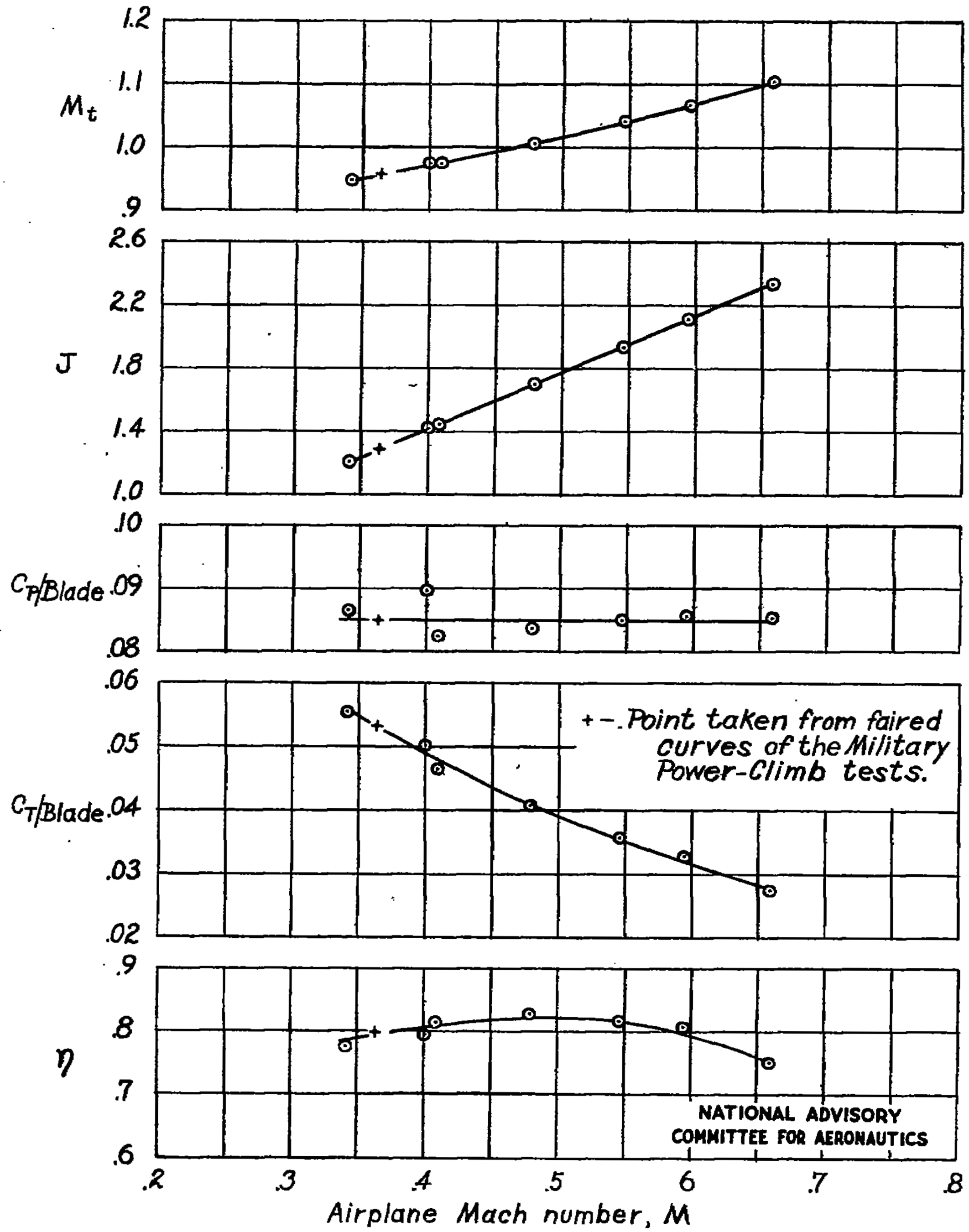


Figure 11.- Variation in propeller efficiency with airplane Mach number at constant blade-loading condition. Power coefficient per blade approximately .085; 2700 engine rpm. Curtiss No. 838-1C2-18 three-blade propeller on Republic P-47D-28 airplane.

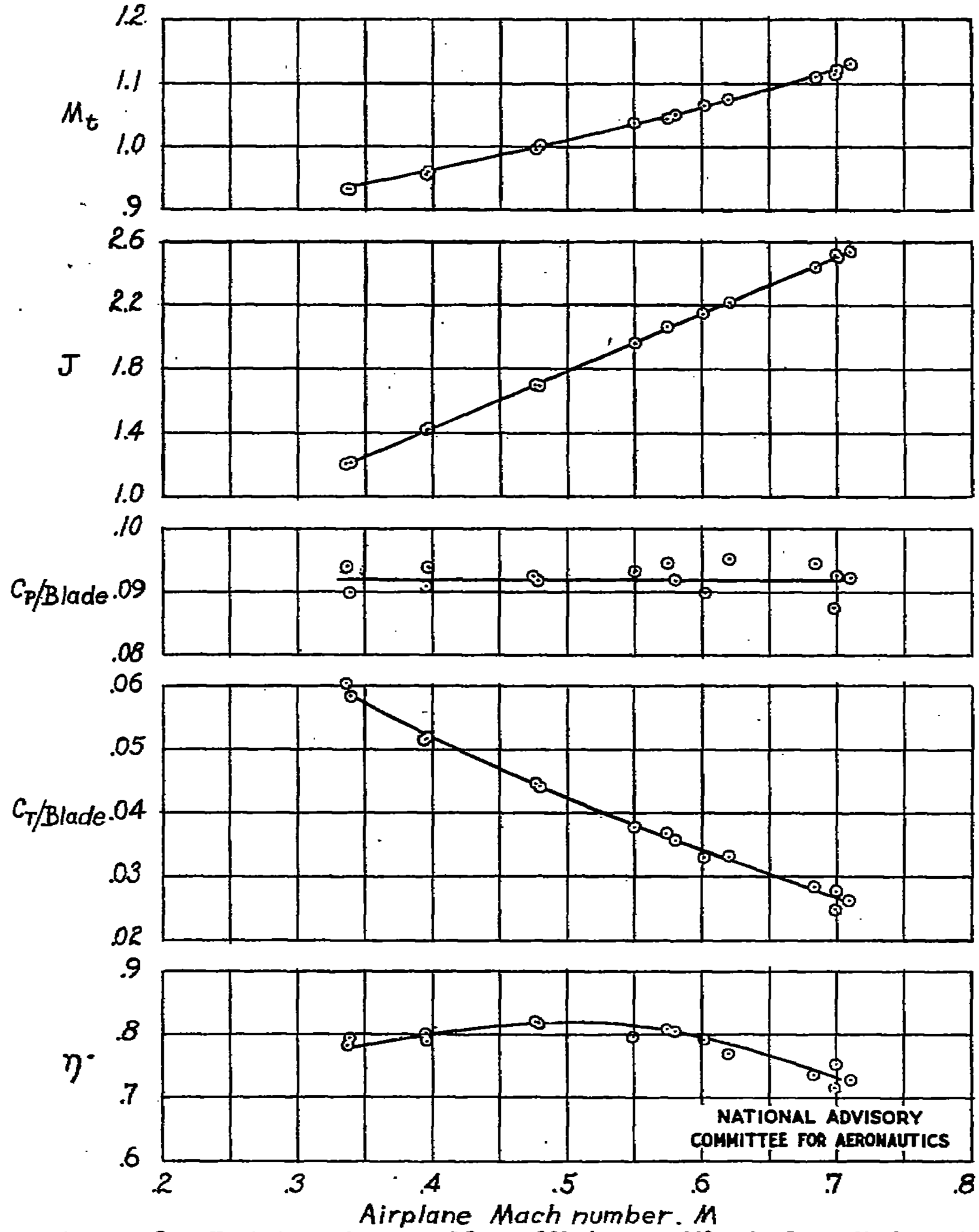


Figure 12.- Variation in propeller efficiency with airplane Mach number at constant blade-loading condition. Power coefficient per blade approximately, .092; 2700 engine rpm. Curtiss No. 838-102-18 three-blade propeller on Republic P-47D-28 airplane.

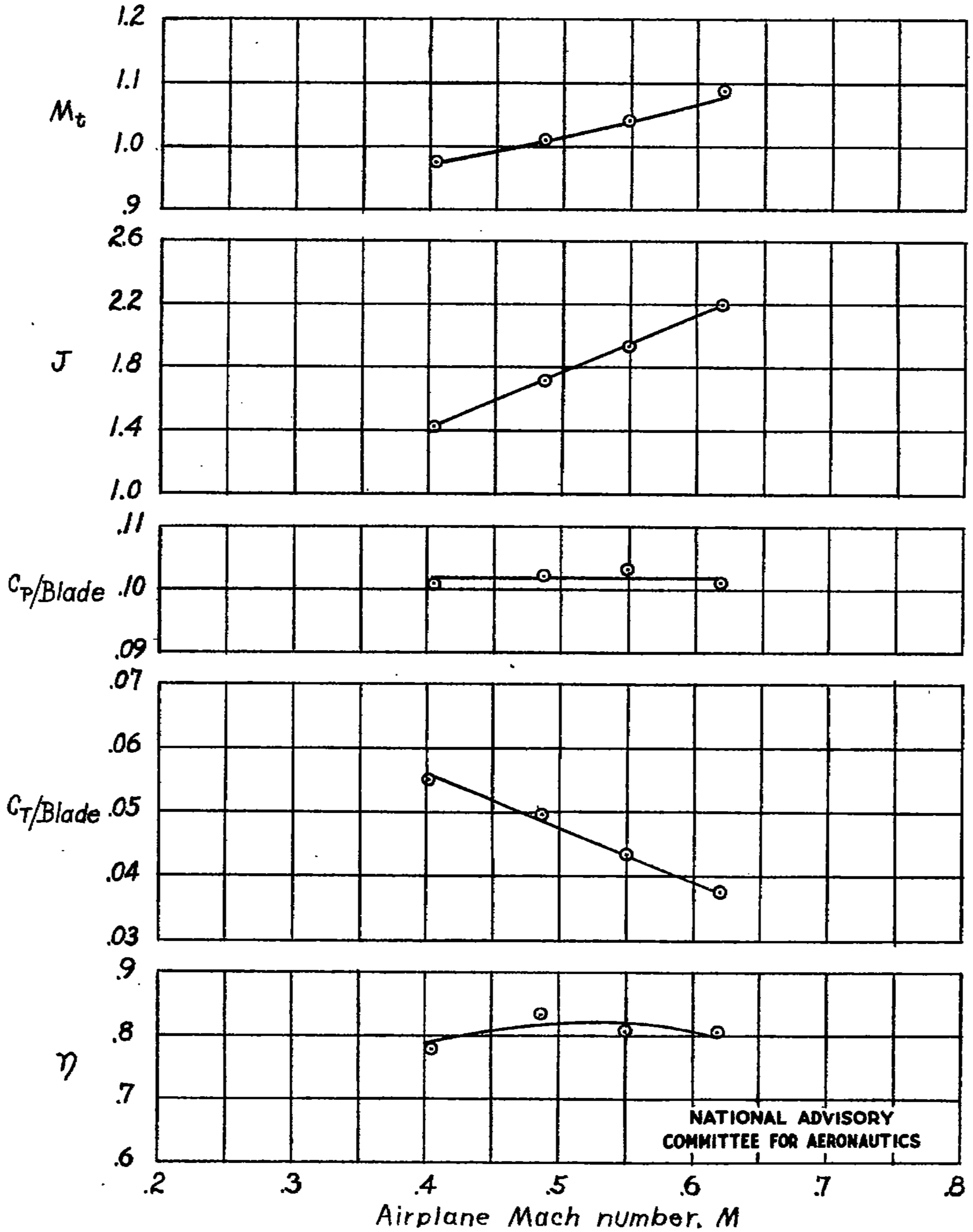


Figure 13.- Variation in propeller efficiency with airplane Mach number at constant blade-loading condition. Power coefficient per blade, approximately, .102; 2700 engine rpm. Curtiss No. 838-102-18 three-blade propeller on Republic P-47D-28 airplane.

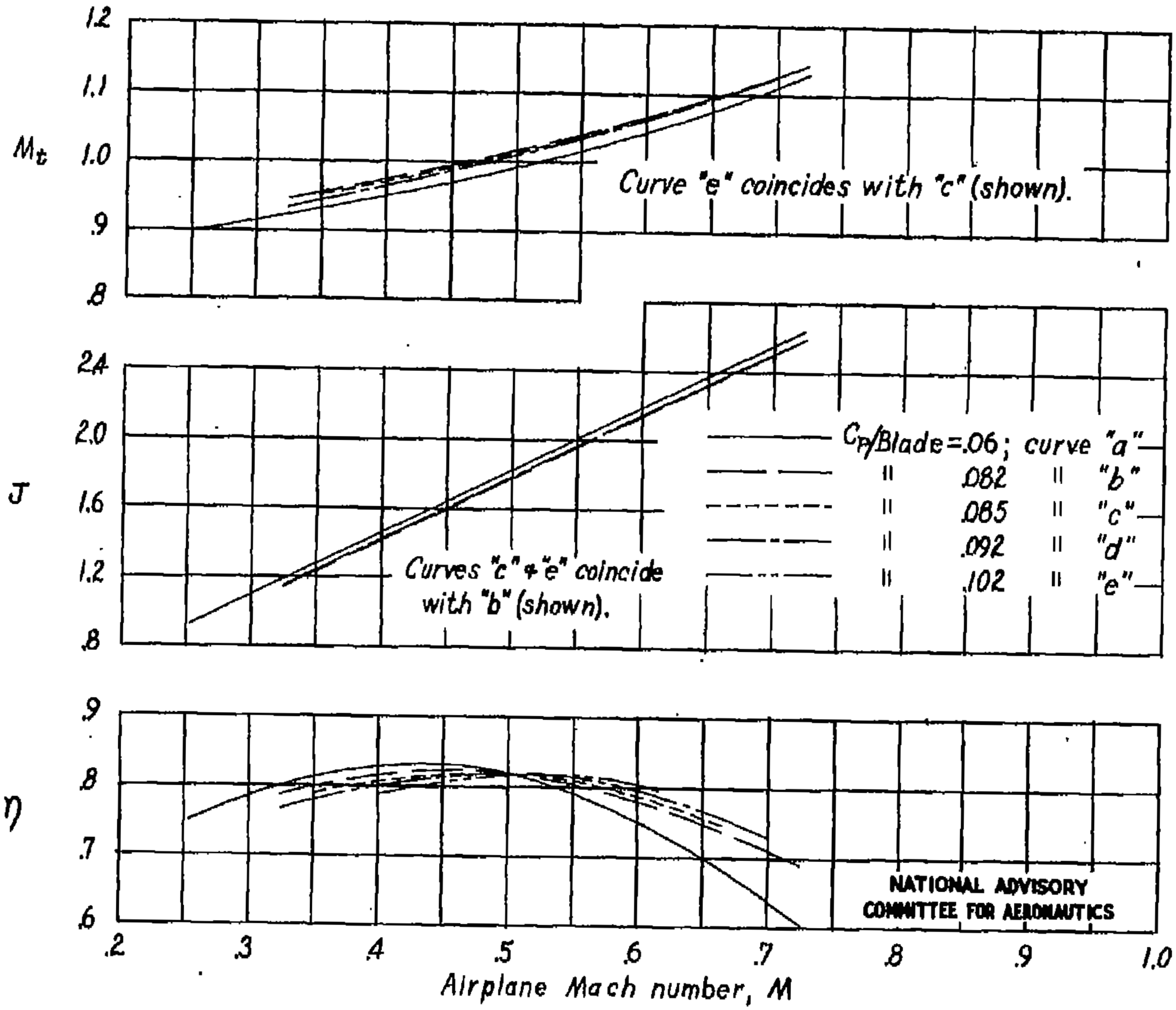


Figure 14.- Effect of blade loading on propeller efficiency. Airplane Mach number range, M = .25 to M = .725; 2700 engine rpm. Curtiss No. 838-102-18 three-blade propeller on Republic P-47D-28 airplane.

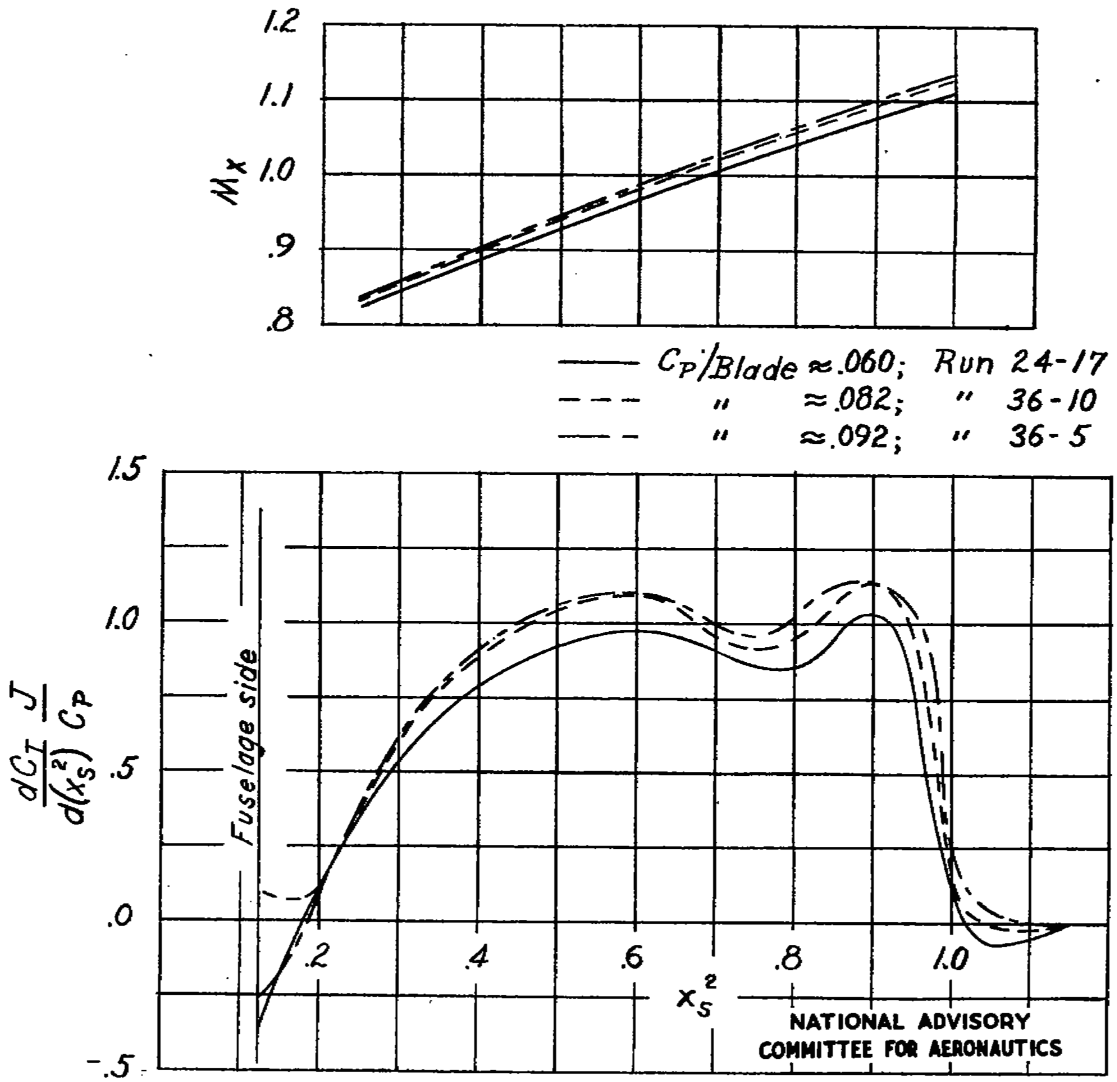


Figure 15.- Comparative thrust-grading curves for several blade loading conditions. Advance-ratio approximately 2.5, airplane Mach number approximately 0.7. Curtiss No. 838-102-18 three-blade propeller on Republic P-47D airplane.

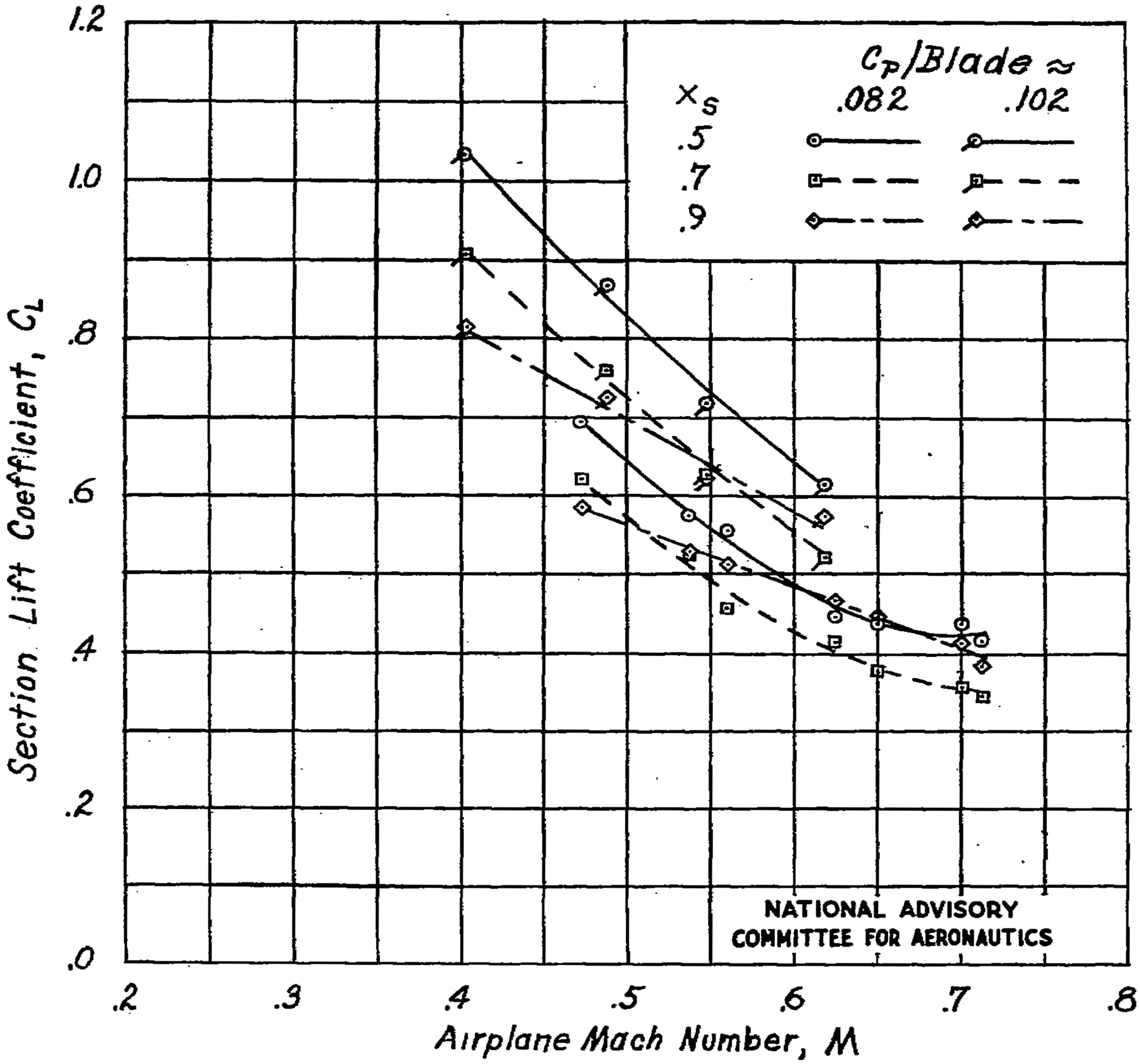


Figure 16.- Section lift coefficient for Curtiss No. 838-102-18 three-blade propeller on Republic P-47D airplane for military and war emergency powers at altitude.

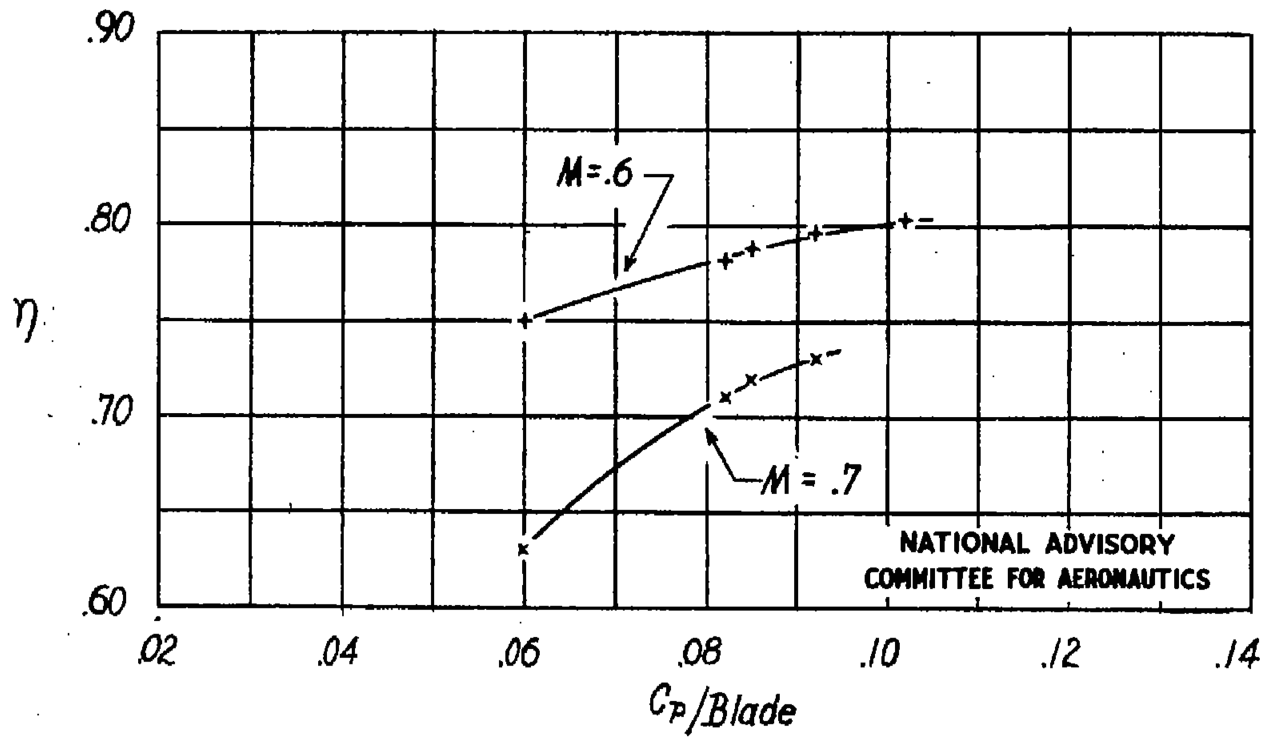


Figure 17.- Effect of blade loading on efficiency at airplane Mach numbers of 0.6 and 0.7; 2700 engine rpm. Curtiss No. 838-1C2-18 three-blade propeller on Republic P-47D-28 airplane.