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WIND-TUNNEL TESTS OF FOUR CURTISS PROPELLERS EMBODYING DIFFERENT BLADE SECTIONS

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MEMORANDUM REPORT

for

Army Air Corps

WIND-TUNNEL TESTS OF FOUR CURTISS PROPELLERS EMBODYING DIFFERENT BLADE SECTIONS

By W. H. GRAY

SUMMARY

Tests of four 10-foot propellers were made in the propeller-research tunnel for the Army Air Corps to check flight and static thrust test results made on several propellers embodying Clark Y and modified NACA 16-series sections. These propellers were identical as to diameter and acitvity factor and very closely identical in thickness ratio and pitch distribution. The blades embodied sections with both single- and double-cambered Clark Y, modified NACA 16-series, and a combination of Clark Y and modified NACA-16 airfoils. Tests covered a range of blade angles from 20° to 70°, and were all made at tip speeds below 280 feet per second.

Although these tests were not conclusive in themselves, owing to the conditions under which they were made, the results seem to check the flight and static tests as closely as would be expected.

INTRODUCTION

Last year (1940) the Curtiss Propeller Company built and tested three propellers which differed only in the sections employed. The purpose of these tests was to determine the relative merits of the Clark Y and a modification of NACA 16-series section for the various conditions of flight. The tests consisted of static tests conducted at Wright Field and flight tests conducted on a Hawk 75 airplane at Caldwell, New Jersey. The results from these tests, listed in Curtiss Report Number C-1123, (reference 1) indicated that the Clark Y section was 10 to 15 percent superior to the modified NACA 16-series for the take-off condition; but that the modified NACA 16-series propeller was from 0 to 3 percent more efficient at high speed.

Inasmuch as the modified NACA 16-series propellers displayed both bad and good characteristics, the Curtiss Company could not decide to use this section for production. The Army Air Corps was also interested in this matter, so an arrangement was made for the NACA to test these same propellers in the propeller-research tunnel as well as on the static whirl rig. Since the tunnel tests could be made only at low tip speeds, the object would be to furnish more complete information regarding the stalling properties of the sections, and perhaps a measure of the relative drags. The static

tests would provide information relative to compressibility effects.

The NACA 16-series propellers did not incorporate true sections, having been modified by the Curtiss Company at the leading and trailing edges in order to improve the manufacturing and serviceability qualities. As there was some question as to the effect of these modifications on the aerodynamic qualities, it was decided to test these propellers as they were, and then rework the leading edges into conformity with true NACA 16 profiles, after which additional tests would be made.

This report covers the tunnel tests of the three propellers which had been flight tested by the Curtiss Company, and an additional propeller which incorporated modified Clark Y sections. A blade-angle range from 20° to 70° was investigated.

A separate report covers the static whirl rig tests.

APPARATUS AND METHODS

Propellers. - The diameter of all four propellers tested varied only slightly from ten feet. The dip in the 101332 geometric pitch curves, as shown in figure 1, blade-form data, is due to the blade angle of the section in transition from Clark Y at the root to modified NACA-16 at the tip. The assumed chord line rather than the zero lift line has

been used as a basis of computation for the geometric pitch.

Propeller 101330 consists of a modified NACA-16 blade section throughout. The airfoil is based on data from reference 2, using the basic 16-000 airfoil.

Propeller 101332 has a modified NACA 16-series tip and a Clark Y root. The blade sections fair from one airfoil to the other between the 30 inch and 42 inch stations.

Propeller 101336 is a Clark Y section cambered on both upper and lower surfaces.

Propeller 89306-22S has a true Clark Y section throughout.

Following tests of the 101332 propeller described above, the three blades were shipped to the factory and the leading edge radius was decreased to more nearly conform to the NACA 16-series. Subsequent measurements indicated that the sections were not yet accurately formed, and must be considered to be modified NACA 16 sections.

All of the above propellers were tested in a 28-inch diameter spinner on the streamline nacelle shown in figure 5.

Driving mechanism. - The propellers were driven by two 25-horsepower electric motors arranged in tandem. (See figure 6.) The set-up was originally designed for tests of propellers in dual rotation, and for that reason the front motor was directly connected to the front propeller while the rear motor drove the rear propeller through chains and a

countershaft. For these tests the propeller shafts were locked together.

Measurements. - The net thrust or drag of the propeller-body combination was measured on a thrust balance located on the floor of the test chamber.

The torque of each motor was measured with a spring-Selsyn dynamometer. The motors rested on bearings concentric with the shaft axis, and were restrained from rotating by springs attached to the fixed frame. The amount of deflection of the motor frames was measured by Selsyn generator units and transmitted to indicating units on the floor.

Measurement of rotational speed was made with a condenser tachometer developed by the NACA. Frequent checks on the accuracy of the instrument were made by means of a tuning fork and oscillograph.

The tunnel speed ranged from 0 to about 110 miles per hour, and the maximum propeller speed was not over 520 rpm, or about 287 feet per second rotational tip speed.

RESULTS AND DISCUSSION

The measured values have been reduced to the usual coefficients or thrust, power, and propulsive efficiency.

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

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

$$\eta = \frac{C_T}{C_P}\ \frac{V}{nD}$$

where the effective thrust is the measured thrust of the propeller-body combination plus the drag of the body alone. "D" is the propeller diameter in feet and "n" is the propeller rotational speed in revolutions per second.

The results are given in the following figures:

LIST OF FIGURES

Figure	
7 to 9	Characteristic curves for 101330 (modified NACA 16 thoughout)
10 to 12	Characteristic curves for 89306-22S (Clark Y throughout)
13 to 15	Characteristic curves for 101332 (modified NACA 16 tip, Clark Y root)
16 to 18	Characteristic curves for 101336 (double-cambered Clark Y)
19	NACA 16 and Clark Y propeller characteristic comparisons

20 Characteristic comparisons for three propellers

21 Efficiency envelope comparisons

22 Efficiency comparisons for constant $C_P = 0.2$

23 Efficiency comparisons for constant $C_P = 0.4$

24 Thrust ratio comparisons

The characteristic curves (see figures 19 and 20) have been adjusted to the equivalent angle of the Clark Y blades, for three representative angles. This is necessitated by the difference in the effective blade angles based on the assumed chord lines.

Figure 19 is a comparison between the modified NACA 16 and Clark Y propellers only and indicates a higher thrust, power, and consequently efficiency, in the range of take-off $(0.3(V/nD)_{max.\ eff.})$ for the Clark Y. The same figure shows the delayed stalling characteristic of the Clark Y as compared with the early stall of the modified NACA 16.

In figure 20 the order of delayed stalling for the four propellers is indicated as follows: modified NACA 16-series, combination modified NACA-16 and Clark Y, double cambered Clark Y, and Clark Y.

Comparison of efficiency envelope curves for the high-speed condition (see figure 21) shows very little choice between propellers. The data indicates that about 2 percent higher efficiency was realized for the modified NACA

16 propeller at values of V/nD below 3.0; but at higher values of V/nD the Clark Y propeller was slightly superior. The crossover of the envelope could be accounted for by the fact that at the higher values of V/nD the modified NACA 16 profile was operating outside the range of lift coefficients for which it was designed. This is even more apparent in figures 22 and 23, which provide comparisons at constant power.

Low-speed comparisons of thrust in the range of take-off and climb, (see figure 24) indicate that the double-cambered Clark Y gives the best approach to the available thrust of the Clark Y.

The tests of the propeller which had been returned to the factory for minor reworking showed no appreciable aerodynamic difference, within the experimental accuracy, from those conducted with the original specimen.

CONCLUDING REMARKS

As these tests were made in a low speed, turbulent airstream, the results may not be indicative of the relative merits of the different propellers for high-speed operating conditions. Obviously, the delayed compressibility characteristics of the NACA 16-series sections would not be expected to be made evident by these tests. The tunnel turbulence may have limited the extent of laminar flow disproportionately for the various sections. Increased Mach number operating

conditions may have an equalizing effect on the stalling characteristics; although these tests seem to check those reported in references 1 and 3.

If it is accepted that the use of NACA 16-series sections does result in inferior take-off qualities it should be pointed out that the lower drag qualities at high speeds permit the use of larger blade areas, or operation at higher tip speeds, or the employment of sections designed for higher values of C_L, all of which will increase the take-off thrust.

This indicates that all future propellers built for experimentally checking the relative merits of the Clark Y and NACA 16-series sections should not be designed geometrically similar except for section, but should be designed for equal take-off thrust, so that they can be compared on a basis of high speed performance alone.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., August 21, 1941.

REFERENCES

1. Anon.: Comparison of Flight Test on Propellers Using Clark-Y, N.A.C.A.-16 and Combination Clark-Y and N.A.C.A.-16 Profiles. Rep. No. C-1123, Curtiss Propeller Div., Curtiss-Wright Corp., Nov. 11, 1940.

2. Stack, John: Tests of Airfoils Designed to Delay the Compressibility Burble. NACA TN No. 976, Dec. 1944. (Reprint of ACR, June 1939.)

3. Corson, Blake W., Jr., and Mastrocola, Nicholas: Static Characteristics of Curtiss Propellers Having Different Blade Sections. NACA MR, Aug. 27, 1941.

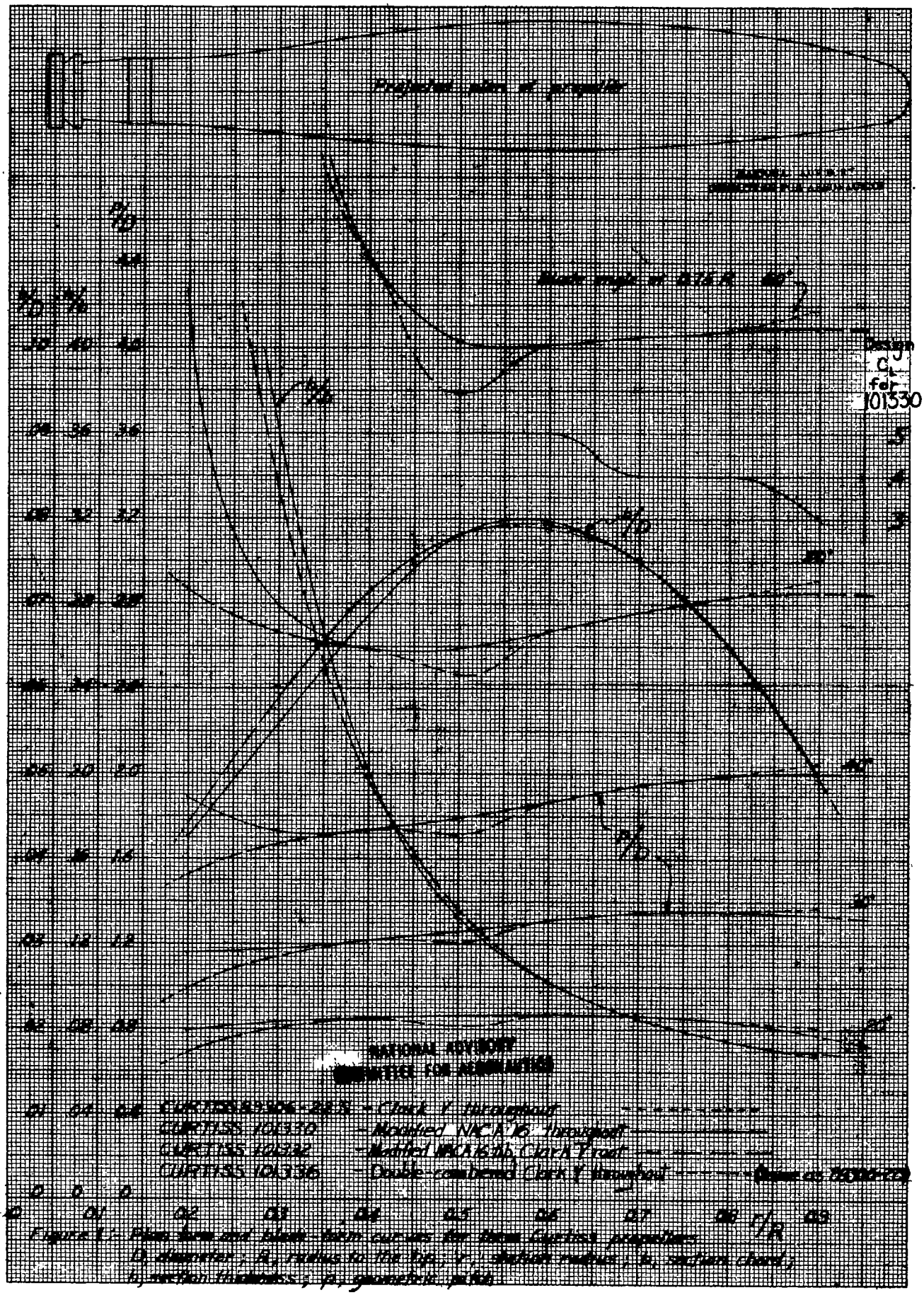
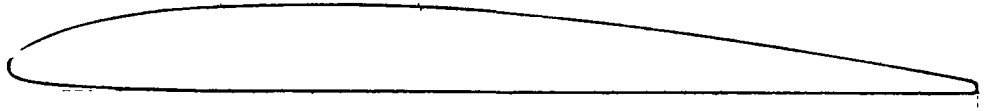


Figure 1.- Plan form and blade form curves for three Curtiss propellers. D, diameter; R, radius to the tip; r, station radius; c, section chord; t, section thickness; p, geometric pitch.



89306-22.5 Clark Y

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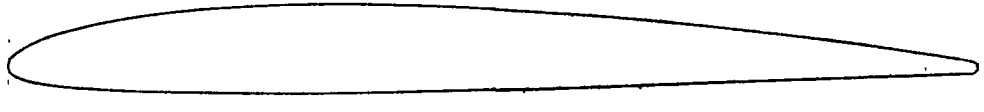

101336 Double-cambered Clark Y

101330 & 101332 NACA 16

FIGURE 2 Blade sections at 0.7R for the propellers tested.

Figure 3.- Photograph showing plan form of all the propeller blades tested.

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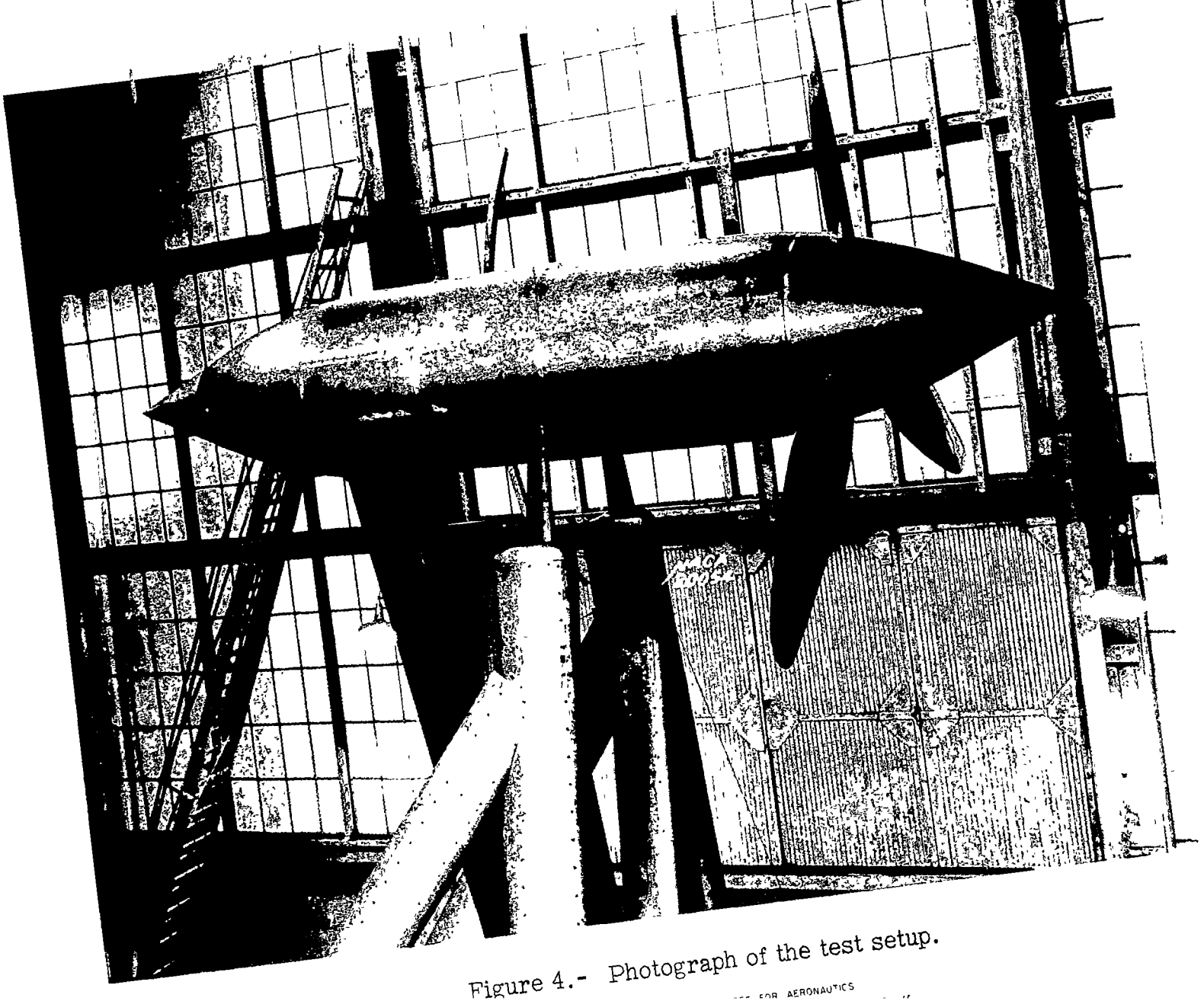


Figure 4.- Photograph of the test setup.

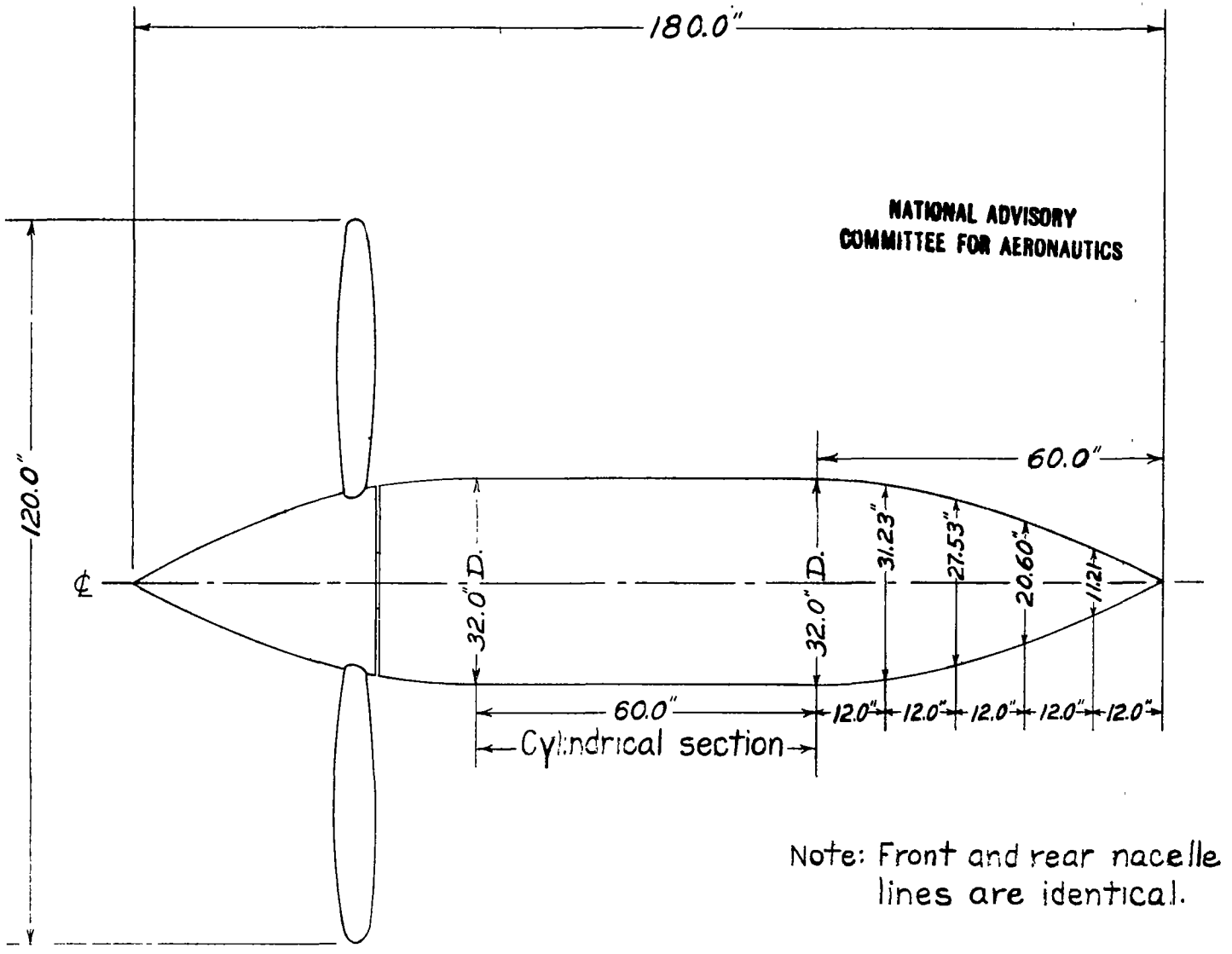


FIGURE 5. Plan view showing dimensional details of nacelle.

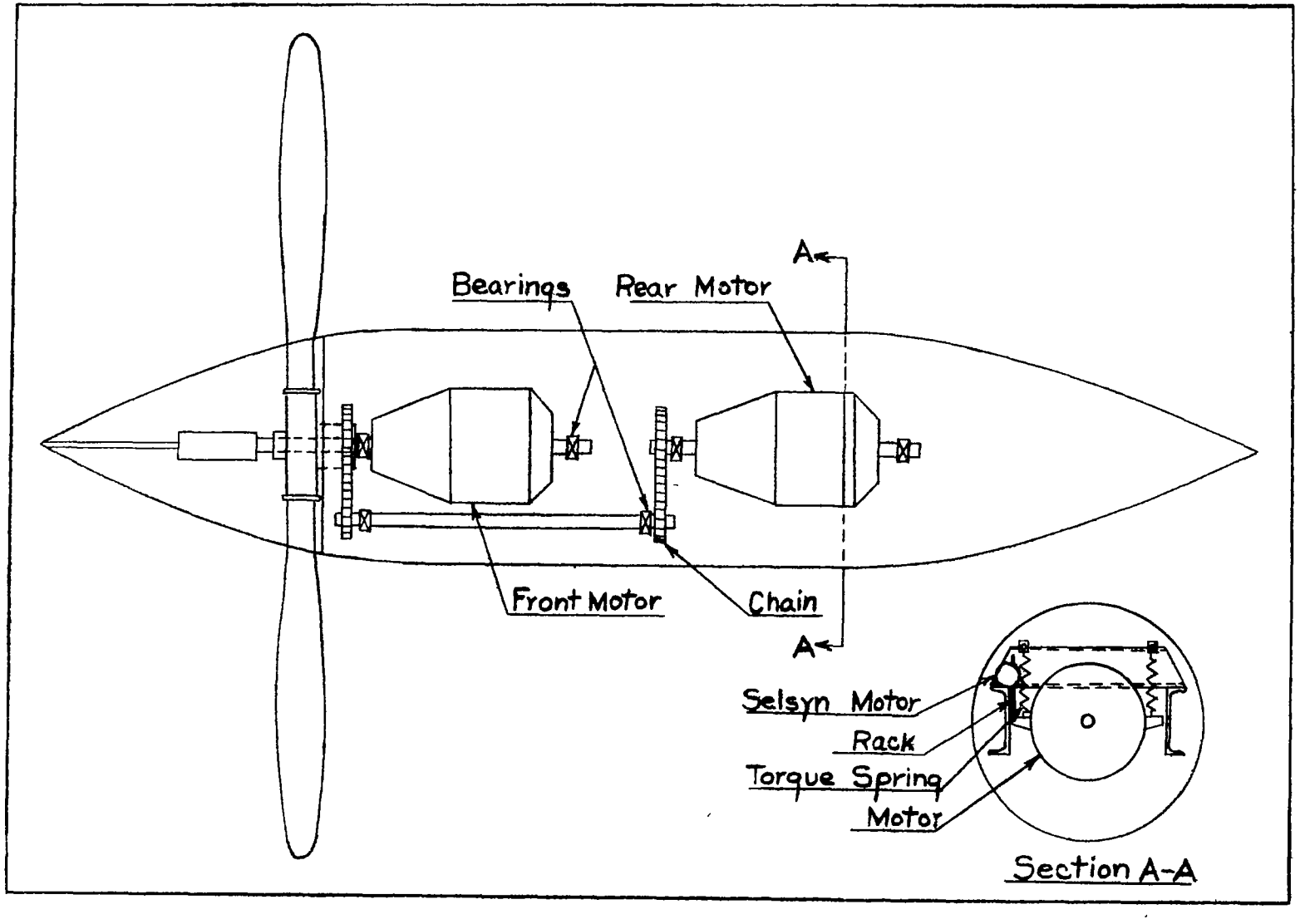


FIGURE 6. Propeller drive mechanism.

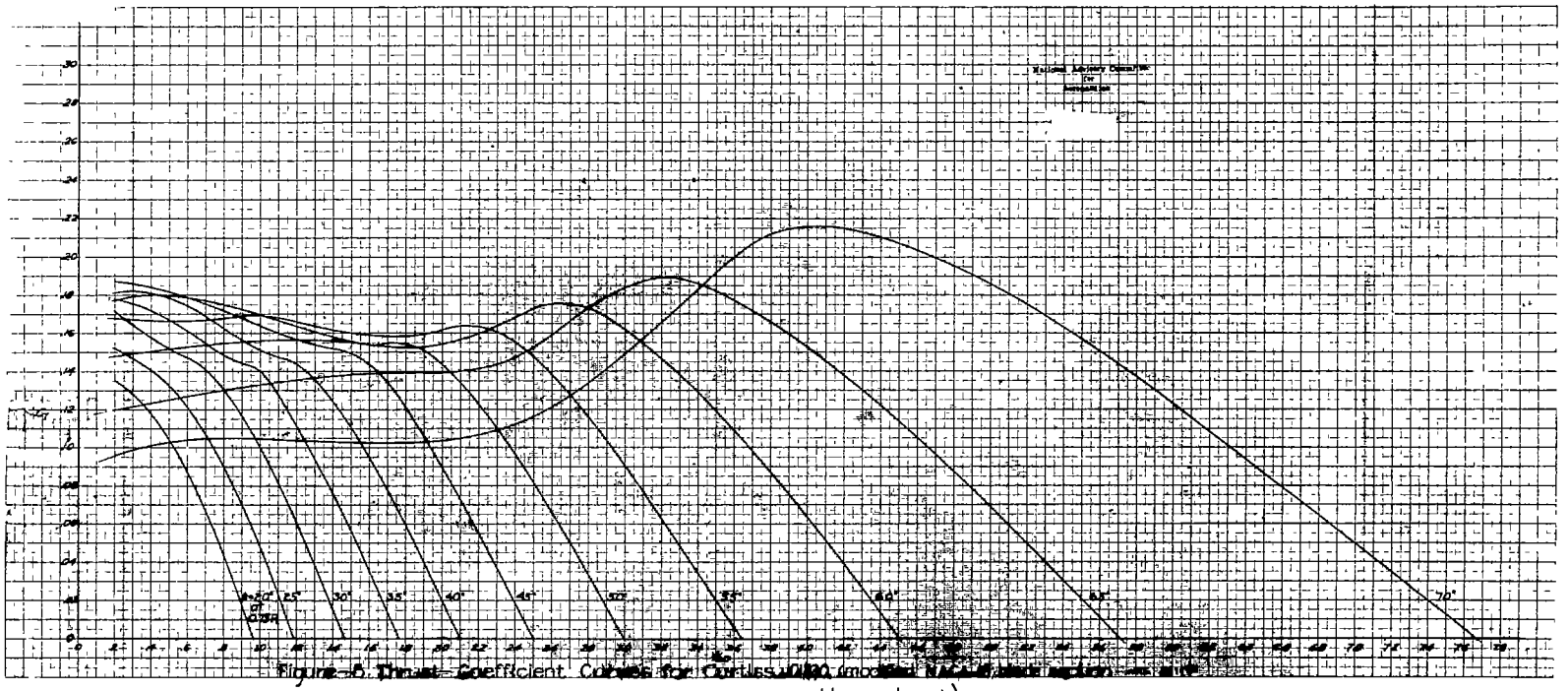


Figure 5. Thrust Coefficient Curves for Curtiss [illegible] (modified NACA [illegible] blade section [illegible] throughout)

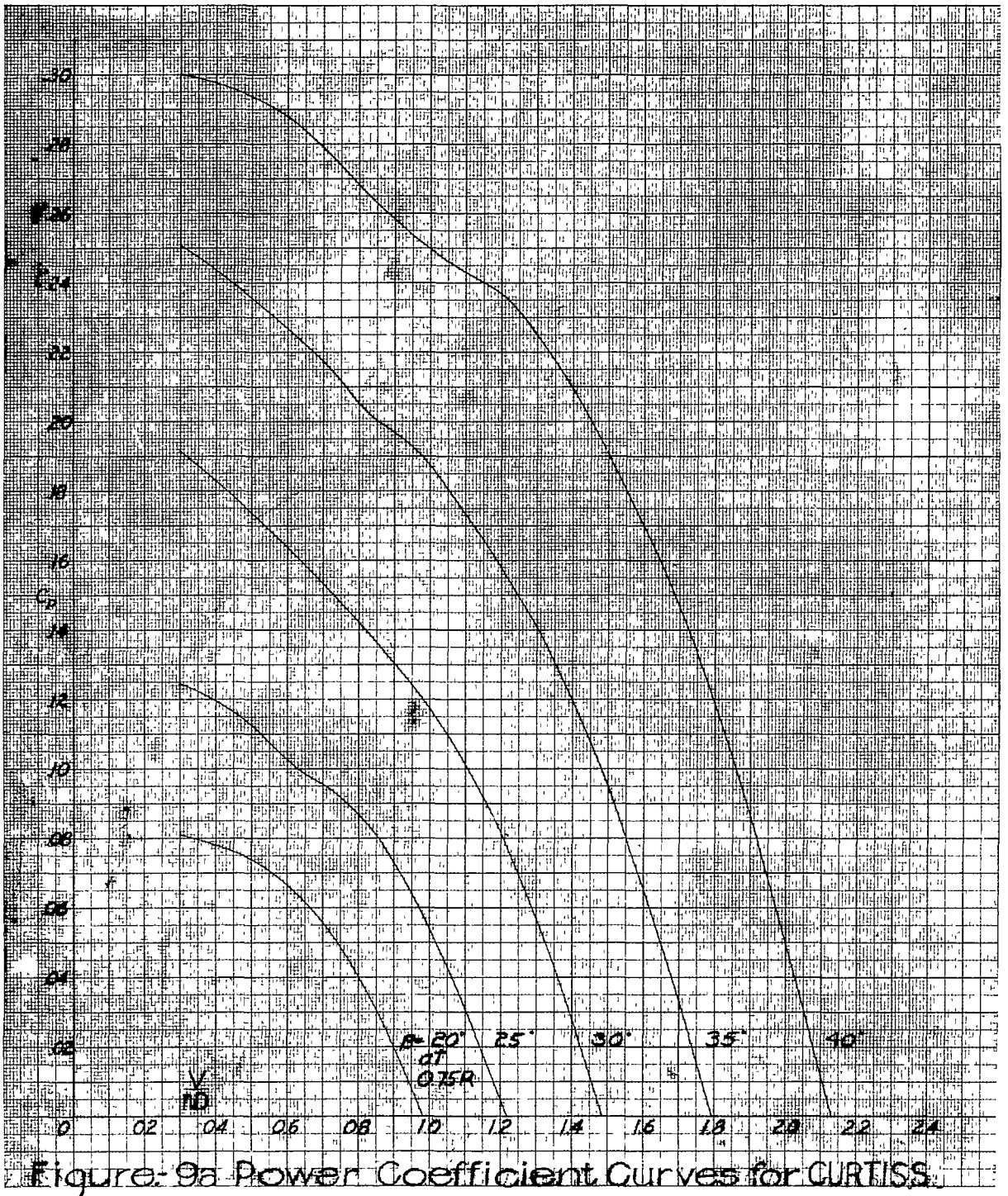


Figure:- 9a Power Coefficient Curves for CURTISS 101330, (modified NACA blade section throughout)

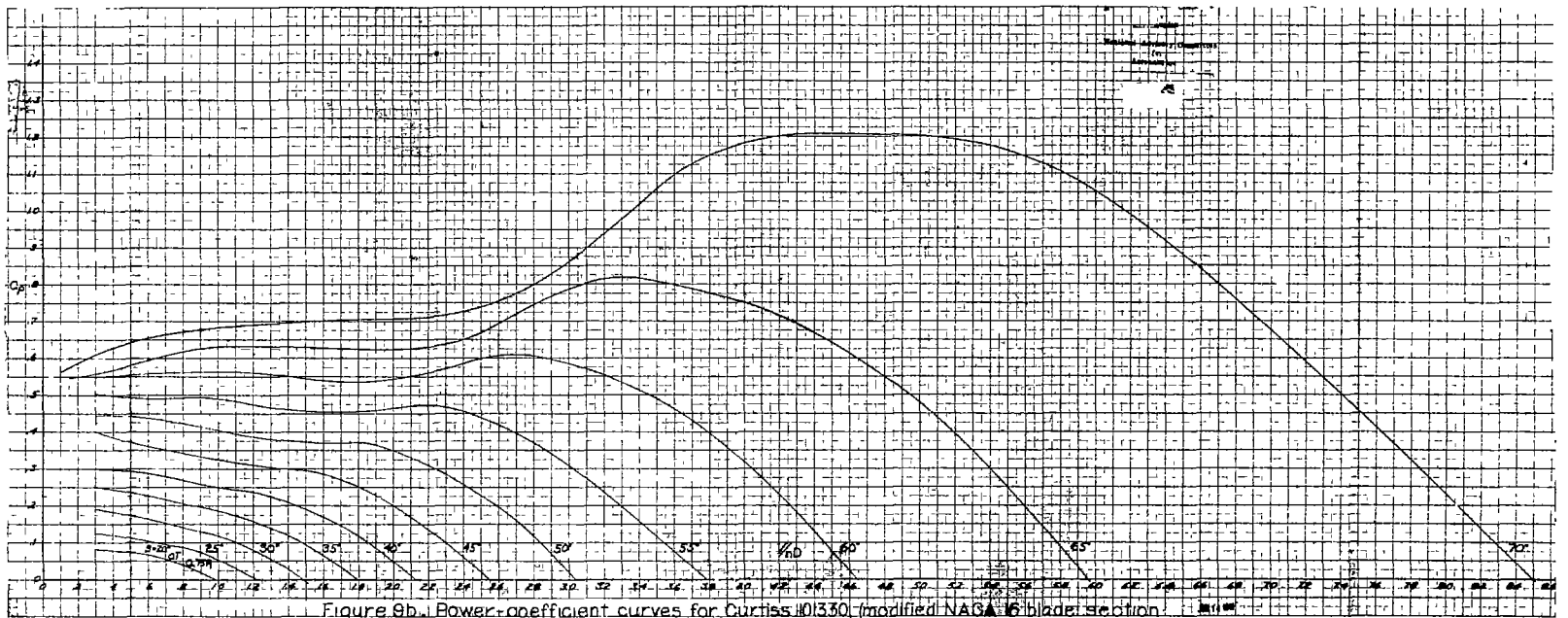


Figure 9b. Power-coefficient curves for Curtiss 10330 (modified NACA 16 blade section throughout).

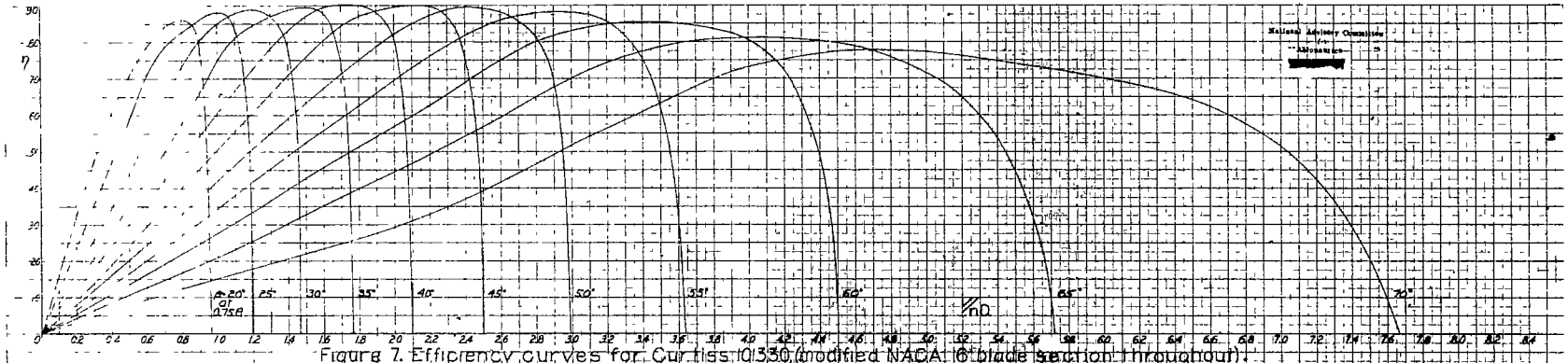


Figure 7. Efficiency curves for Curtiss 10330 (modified NACA 16 blade section throughout).

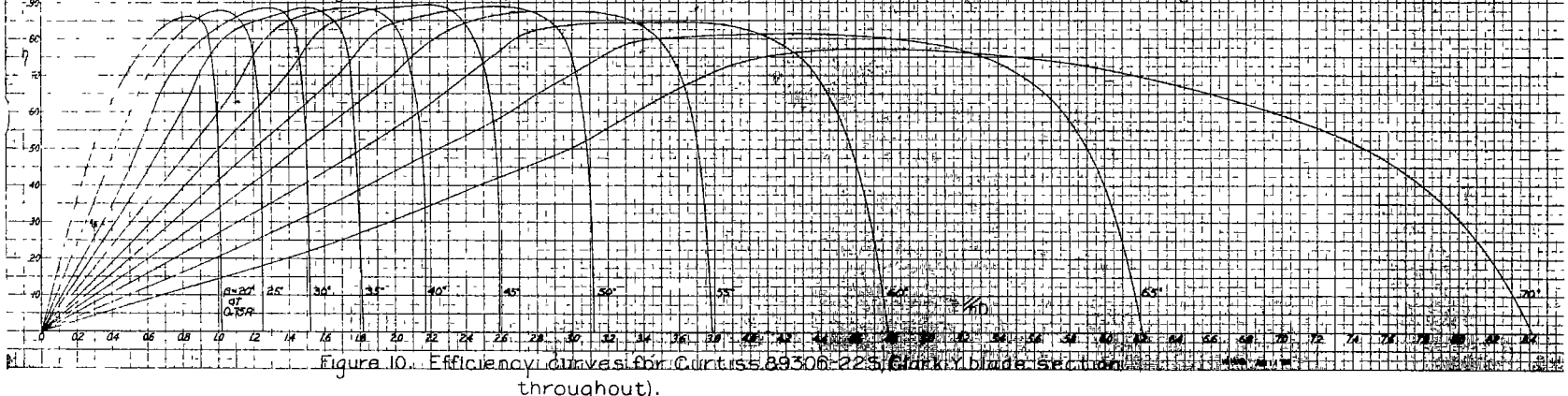


Figure 10. Efficiency curves for Curtiss 89306-22S (Clark Y blade section throughout).

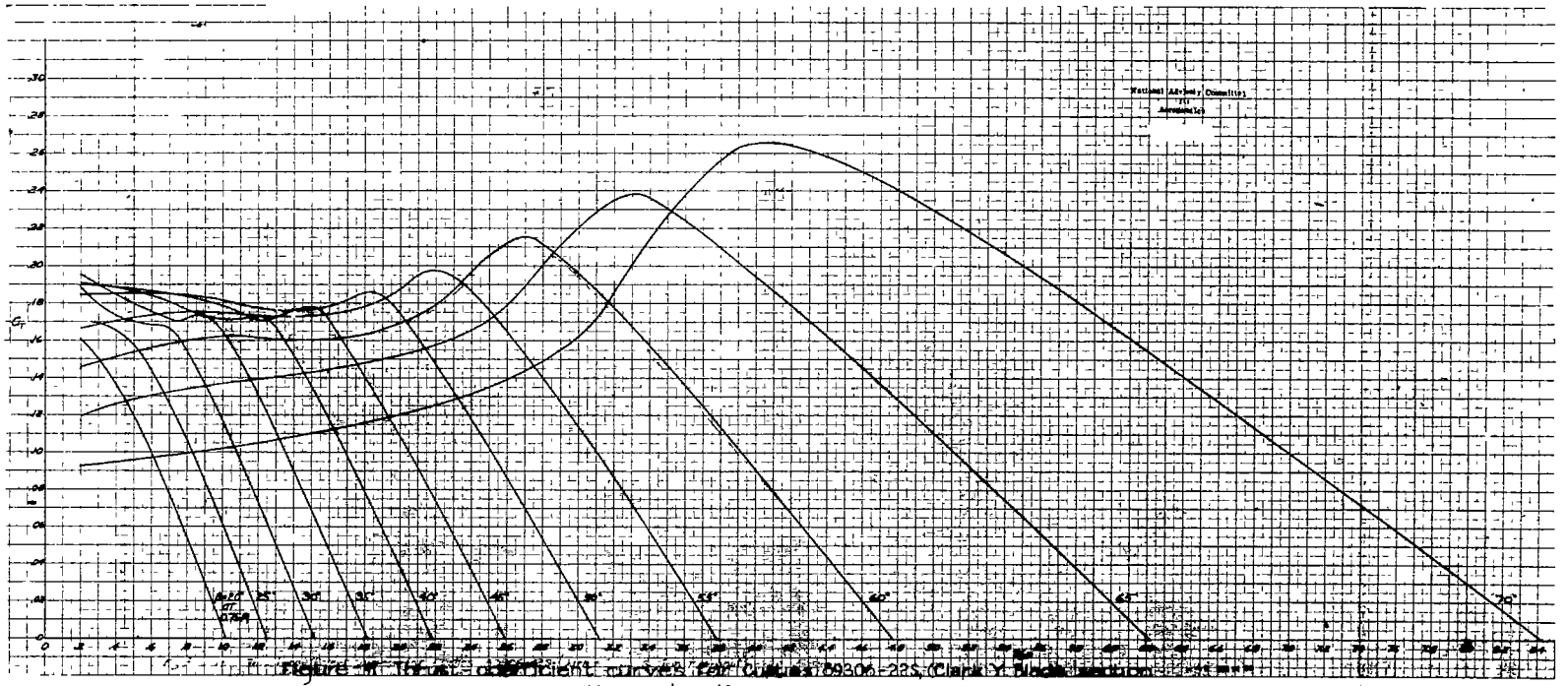


Figure 11. Thrust coefficient curves for Curtiss 89306-22S (Clark Y blade section throughout)

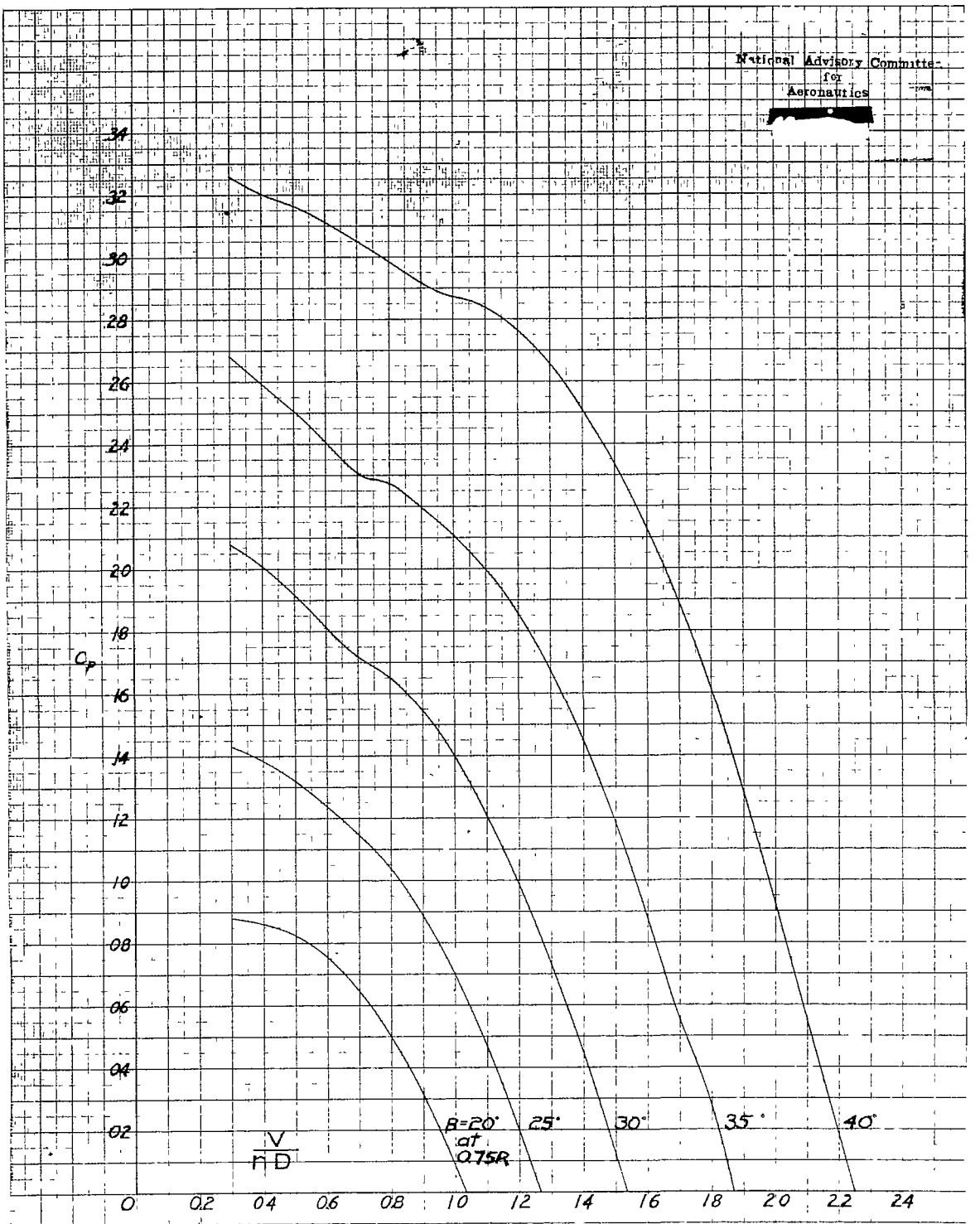


Figure-12a Power-coefficient curves CURTISS 89306-22 S
Clark Y blade section throughout

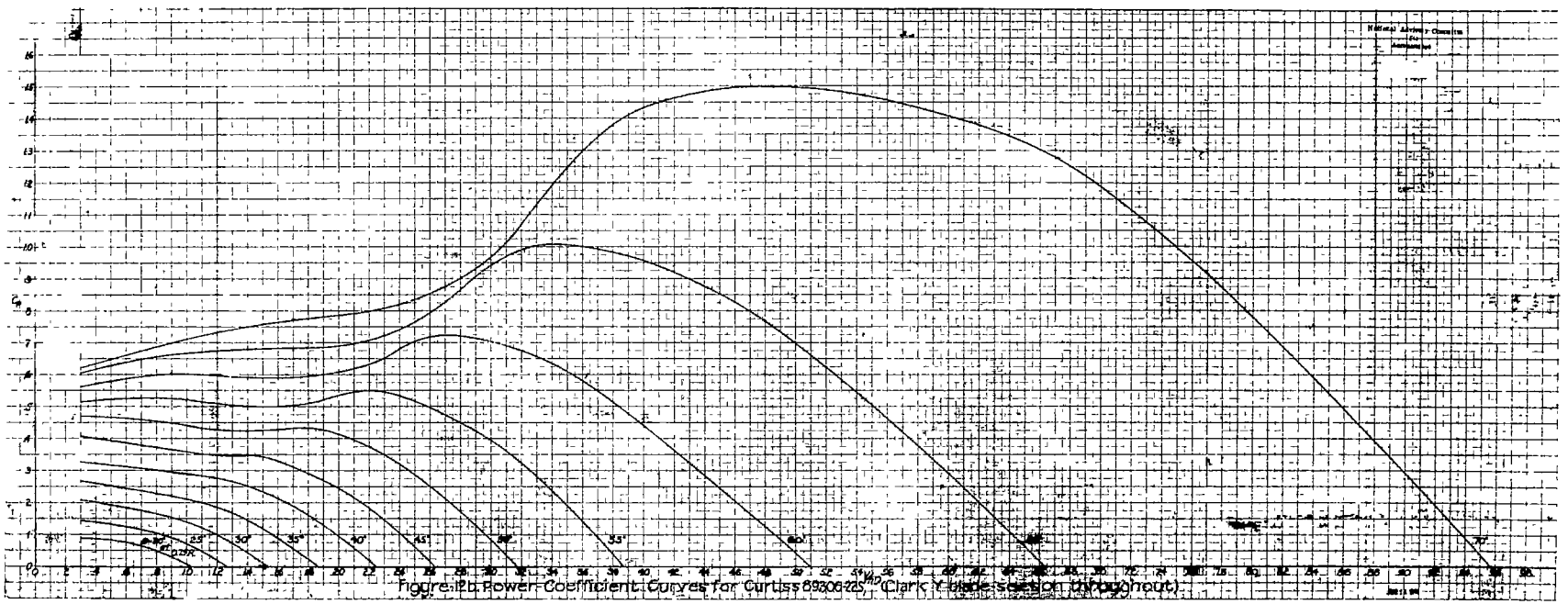


Figure 12b. Power-Coefficient Curves for Curtiss 8930-6-25. (Clark Y blade section throughout.)

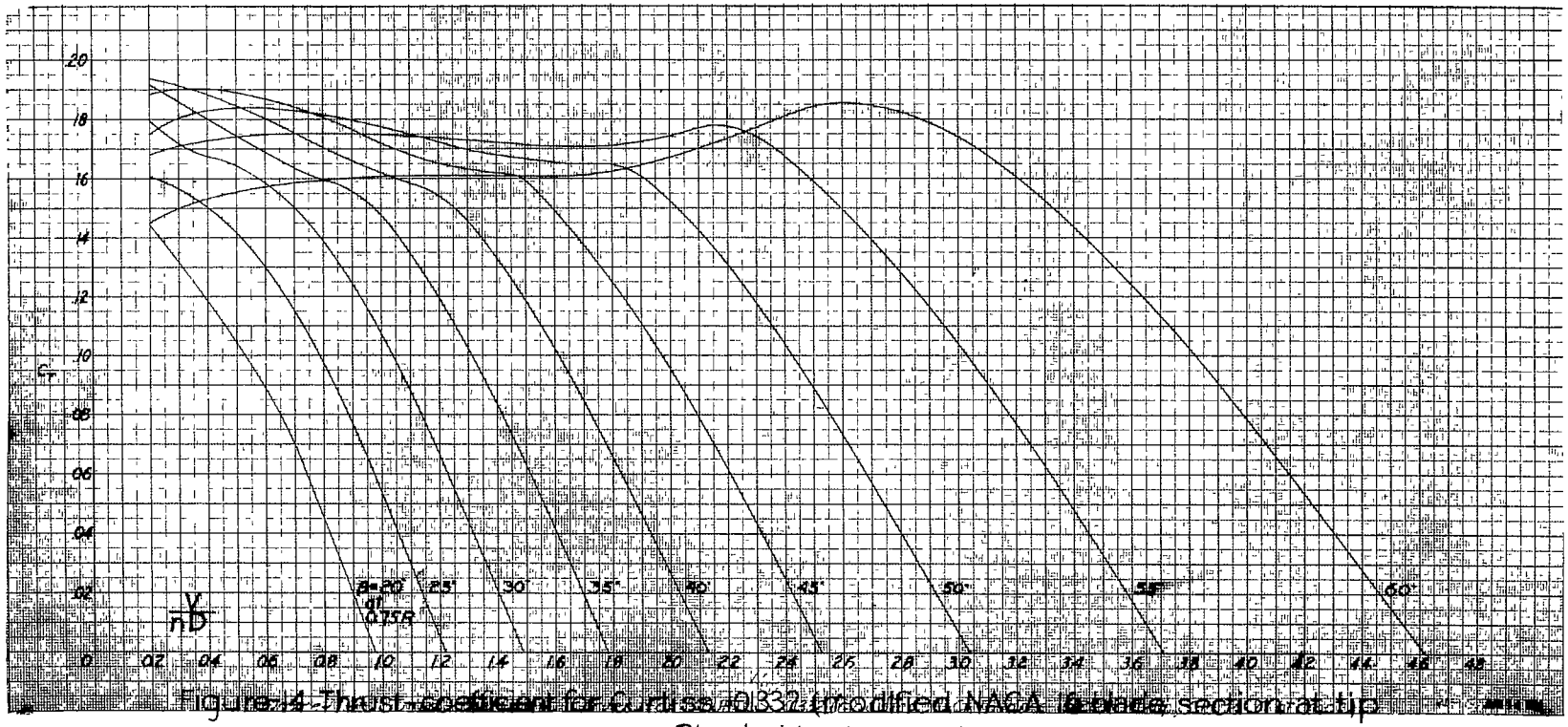


Figure 4 Thrust coefficient for Curtiss 0332 (modified NACA 16 blade section at tip Clark Y at root)

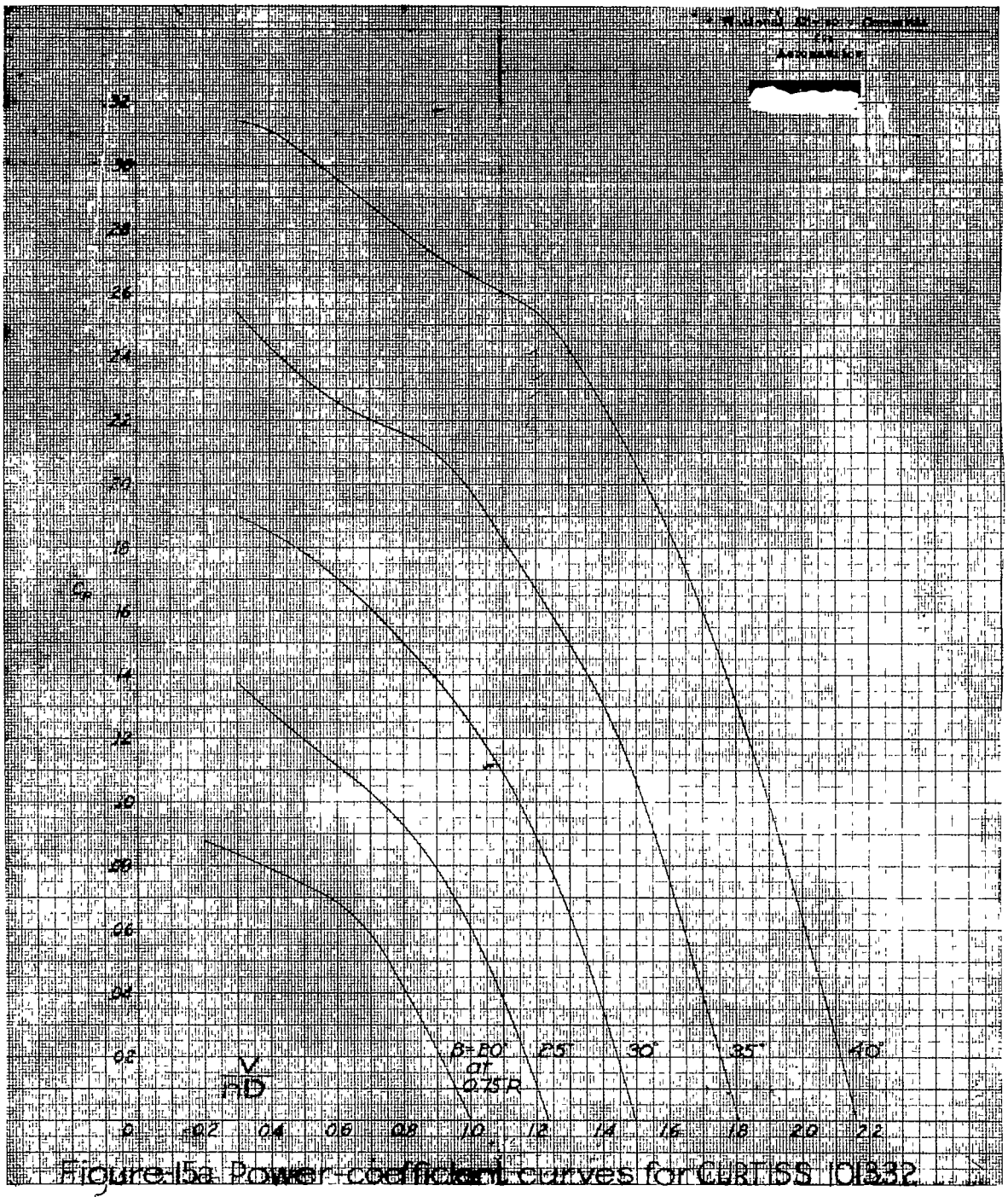


Figure 15a Power-coefficient curves for CURTISS 10B32
(modified NACA 16 blade section at tip, Clark Y at root)

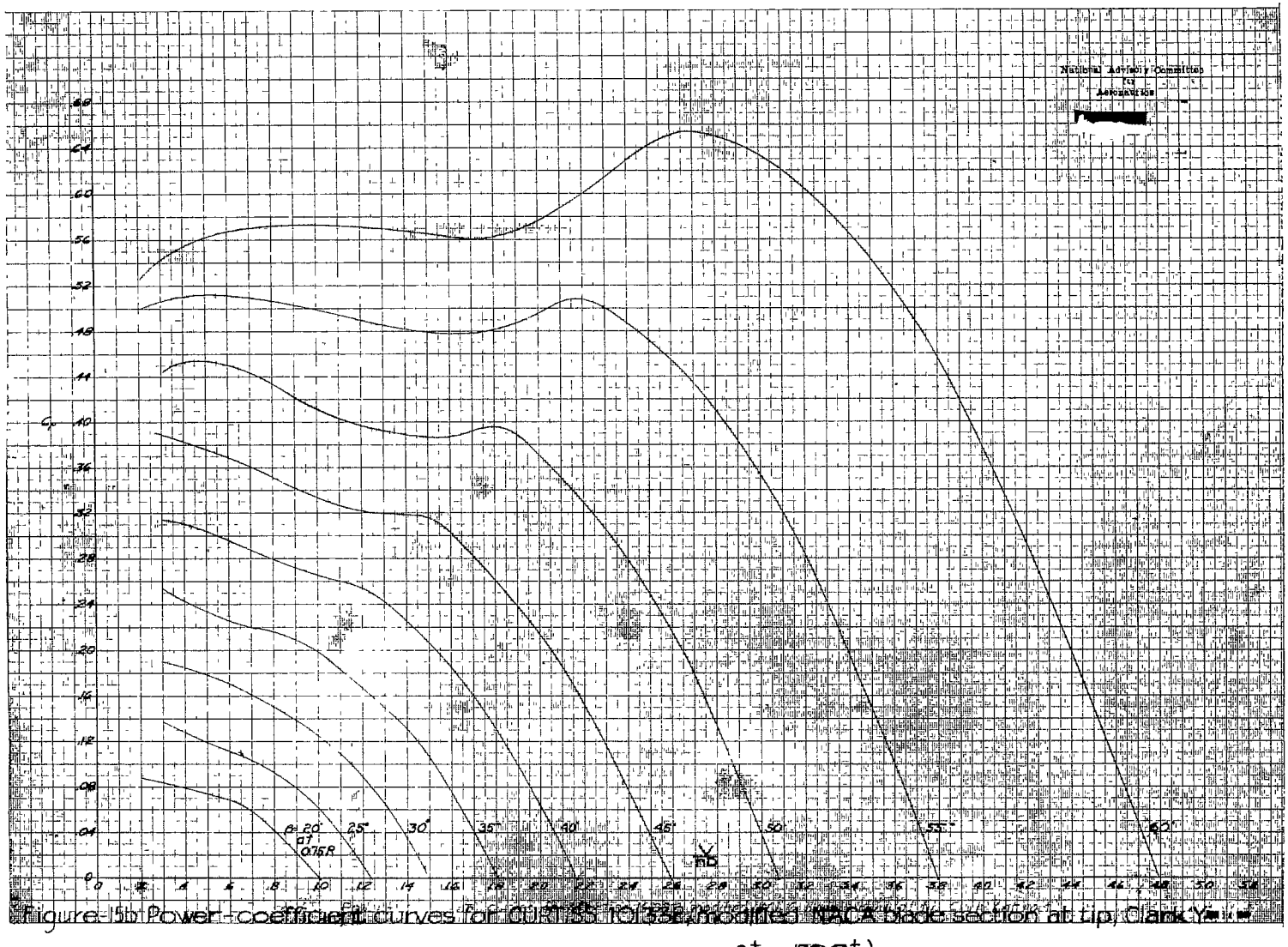


Figure 5b Power-coefficient curves for CURTISS 10133E (modified NACA blade section at tip, Clark Y at root)

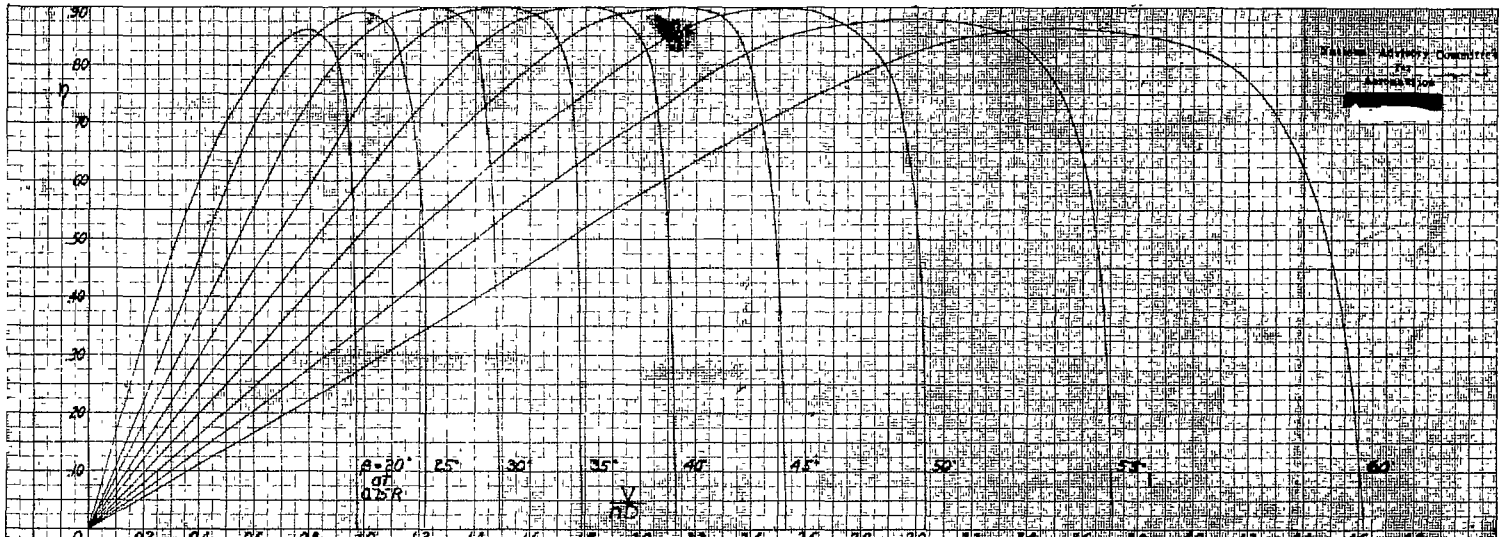


Figure-13 Efficiency Curves for Curtiss 101332, (modified NACA 16 blade section at tip, Clark Y at root)

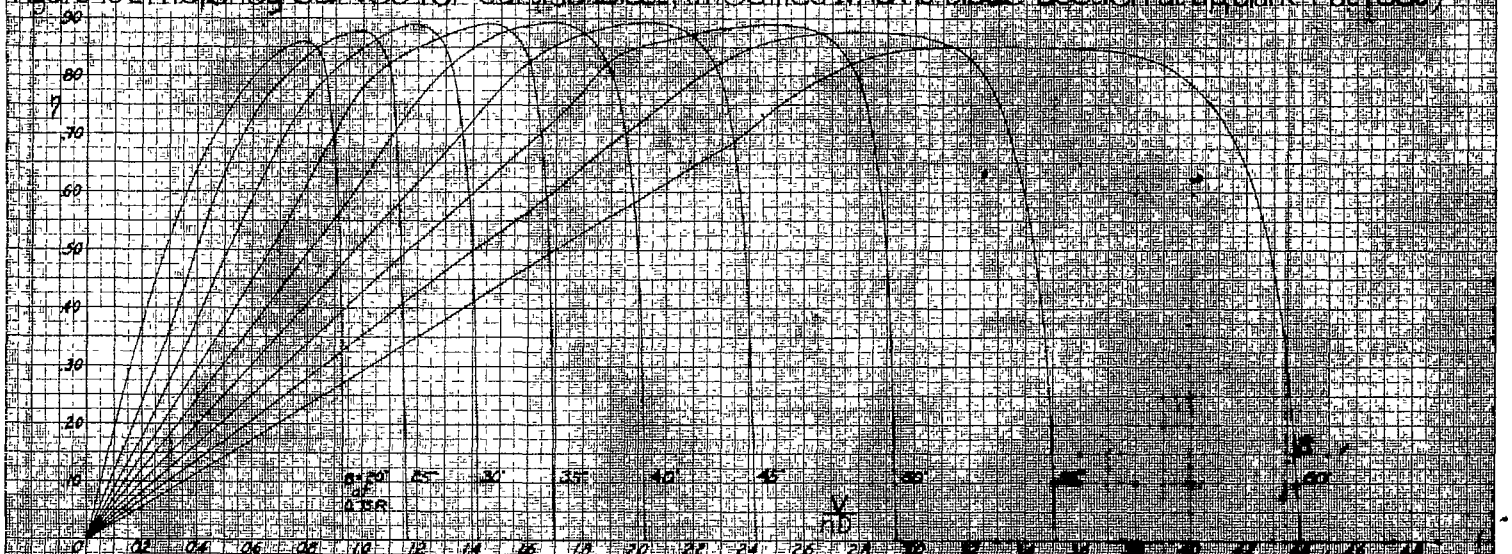


Figure-16 Efficiency Curves for Curtiss 101336, (double [redacted] Clark Y [redacted]

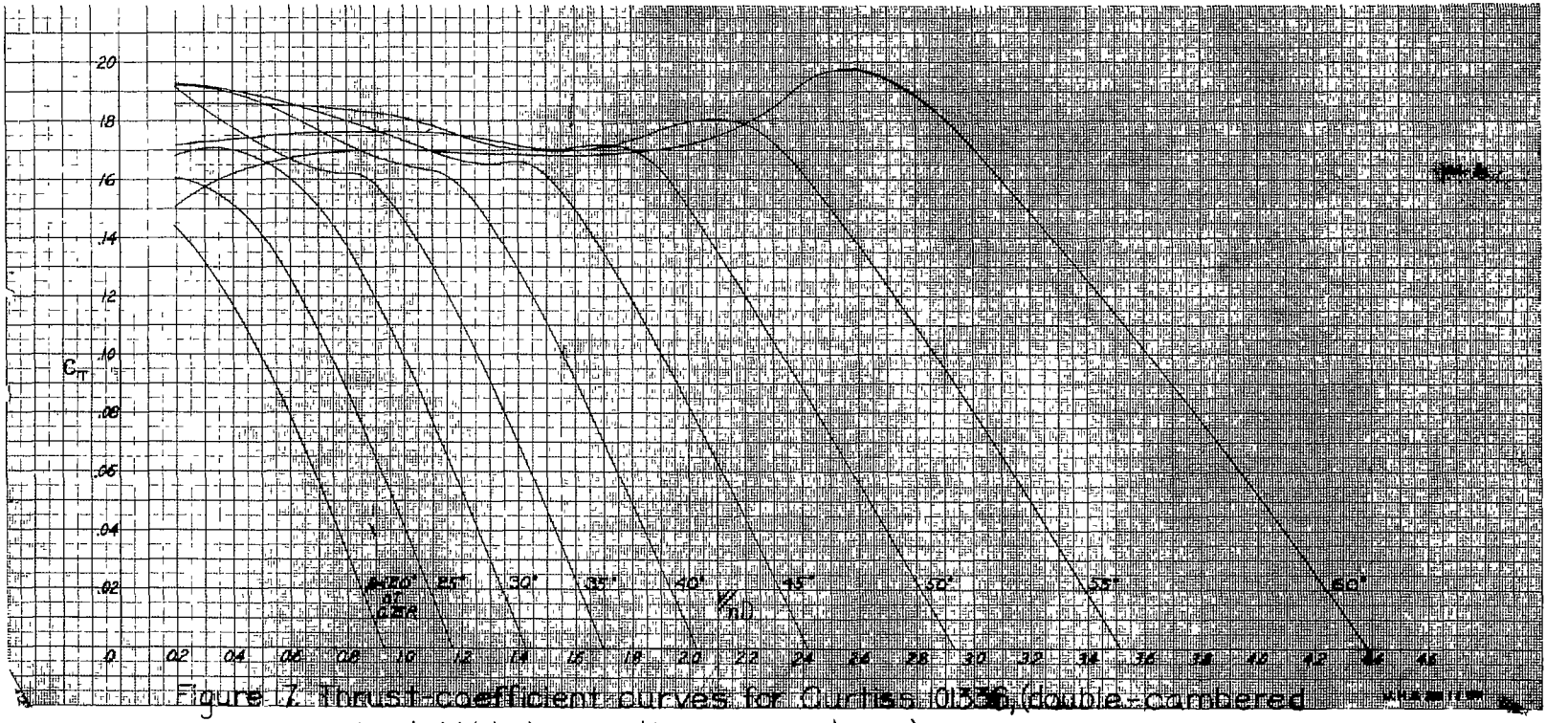


Figure 7. Thrust-coefficient curves for Curtiss 01336, (double-cambered Clark Y blade section throughout).

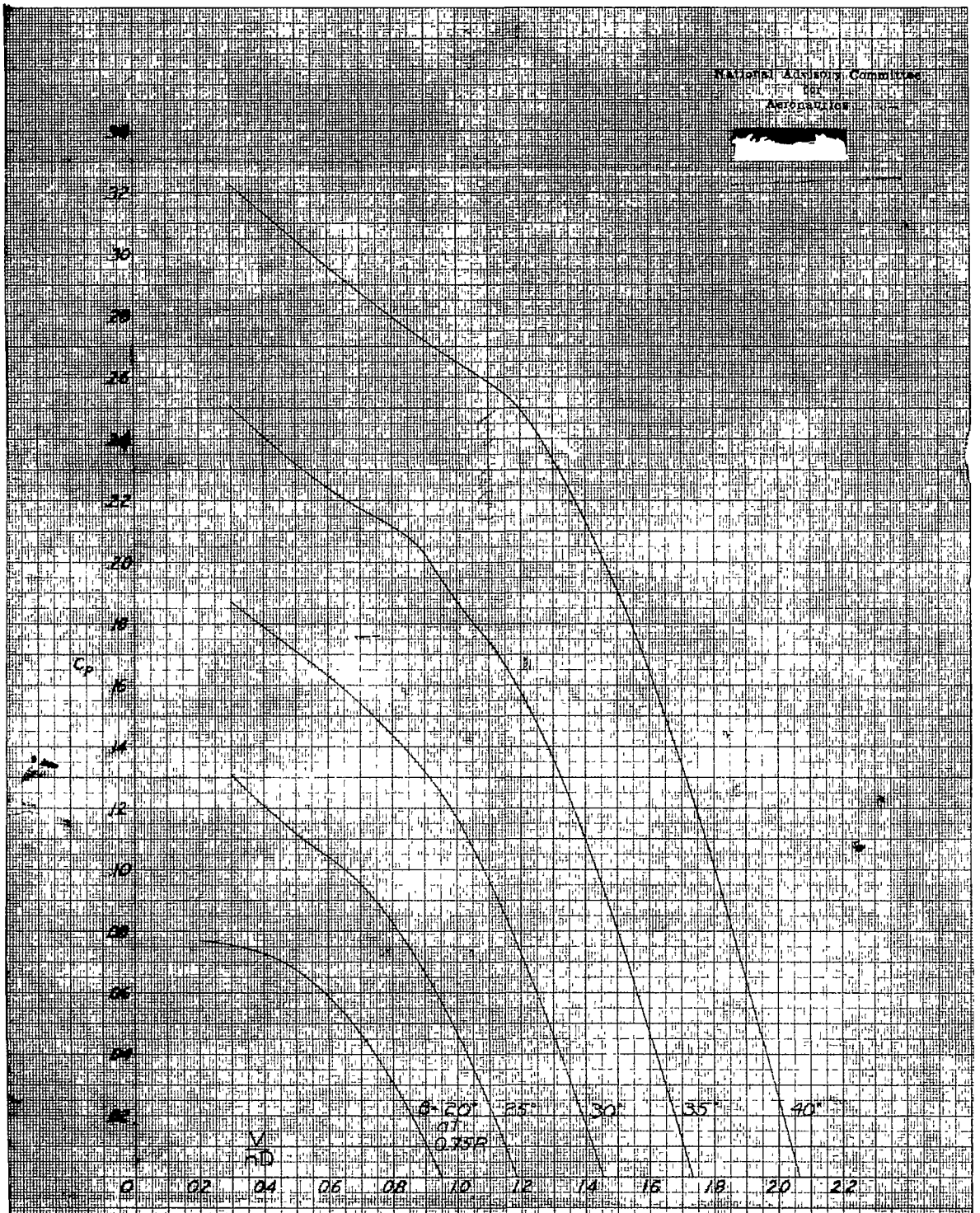


Figure 18a Power-coefficient curves for CURTISS 10[illegible]
(double-cambered Clark Y Blade Section throughout)

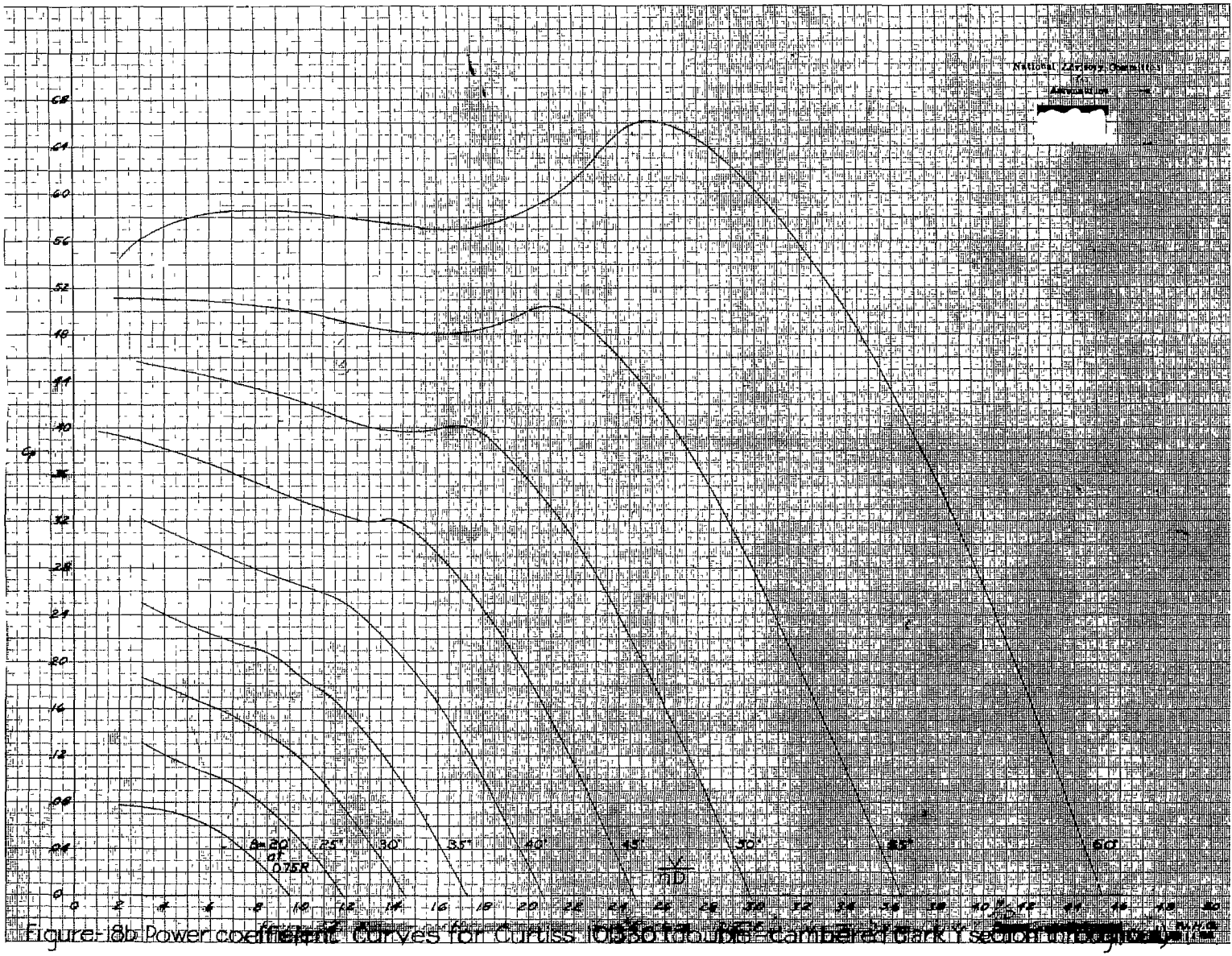
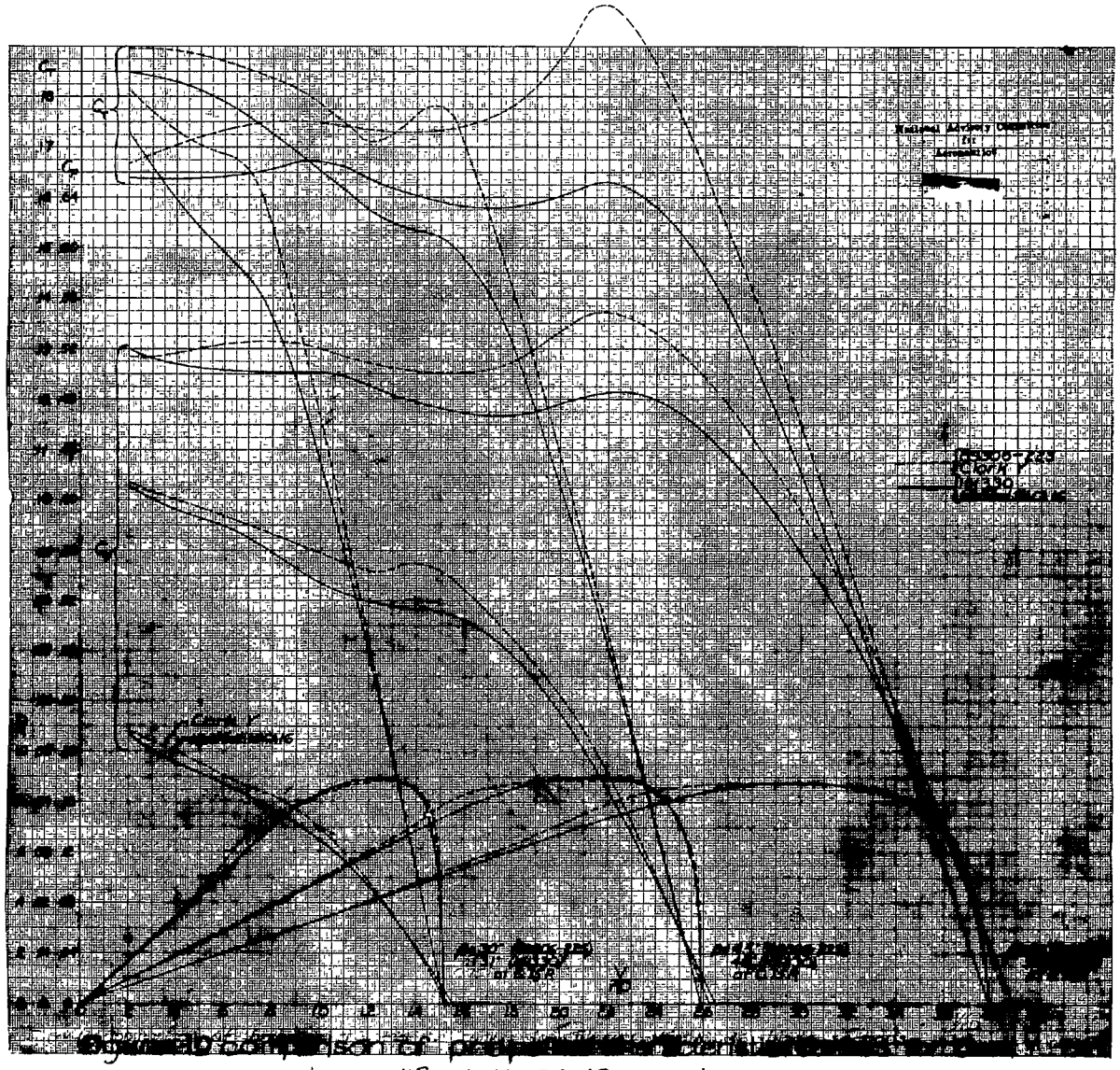


Figure-18b Power coefficient curves for Curtiss 10D30 (double-cambered Clark Y section [illegible])



and modified NACA 16 blade sections

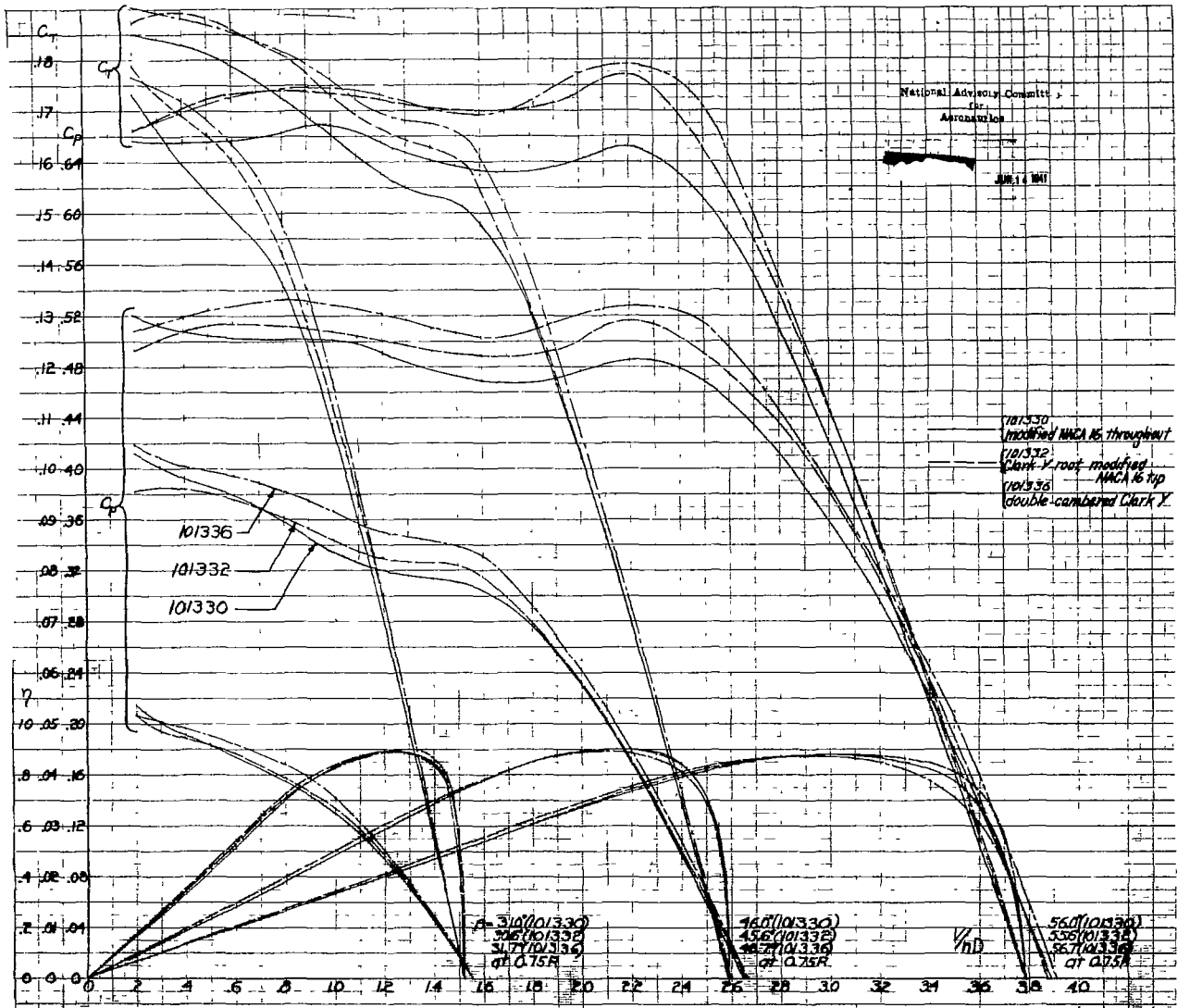


Figure 20. Comparison of propeller characteristic curves for three propellers.

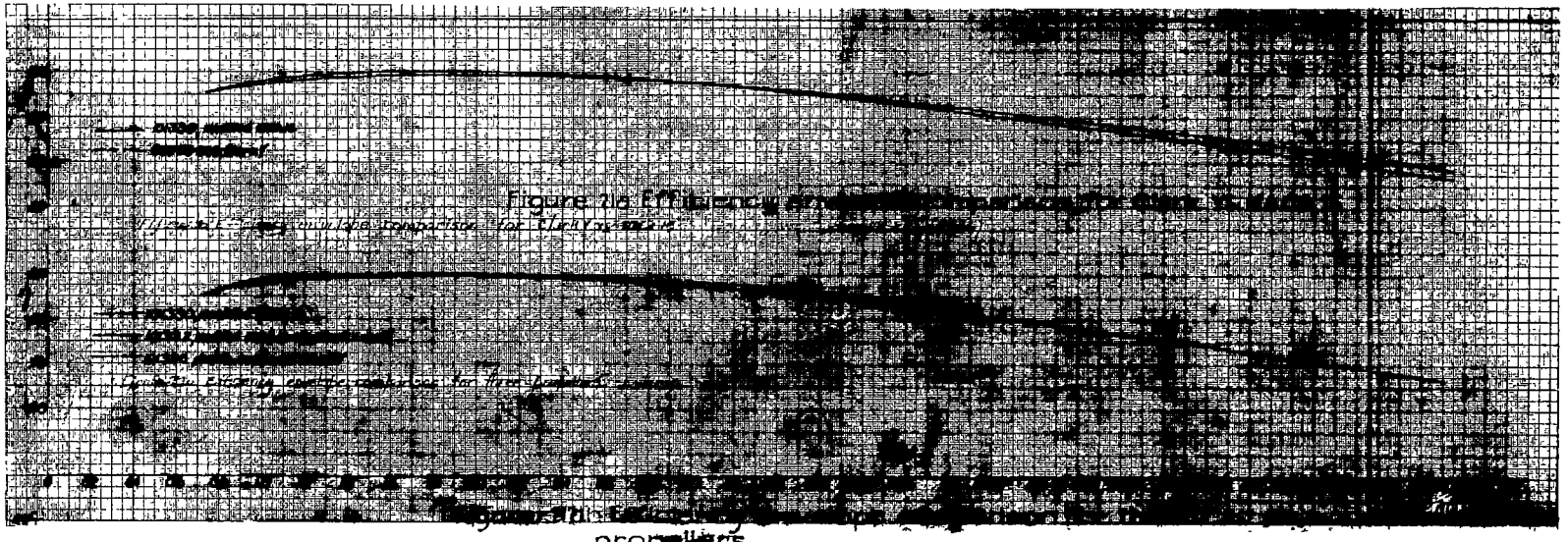


Figure 21a Efficiency [illegible]

propellers

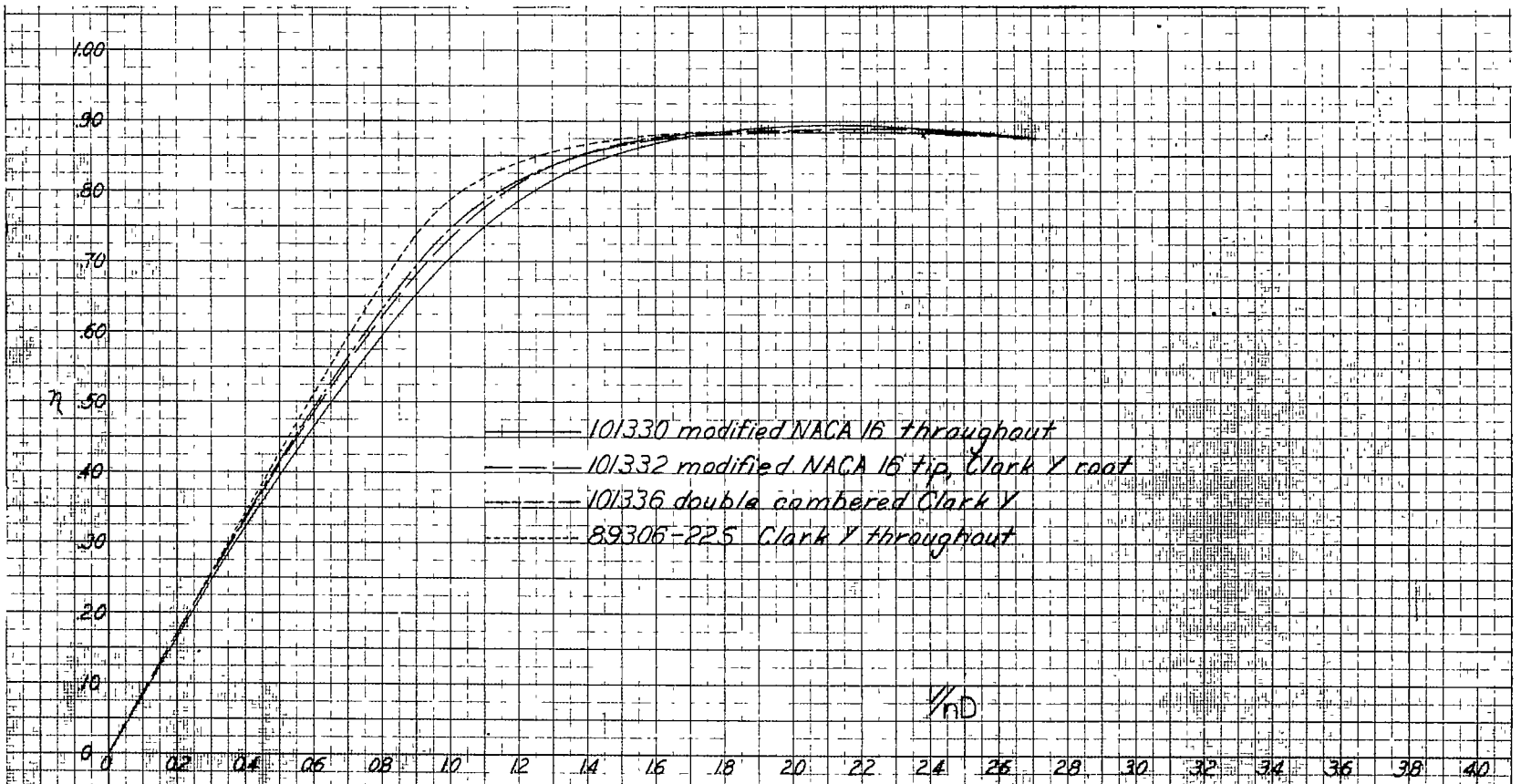


Figure 22. Efficiency Comparisons for Four Propellers at Cp = 0.2

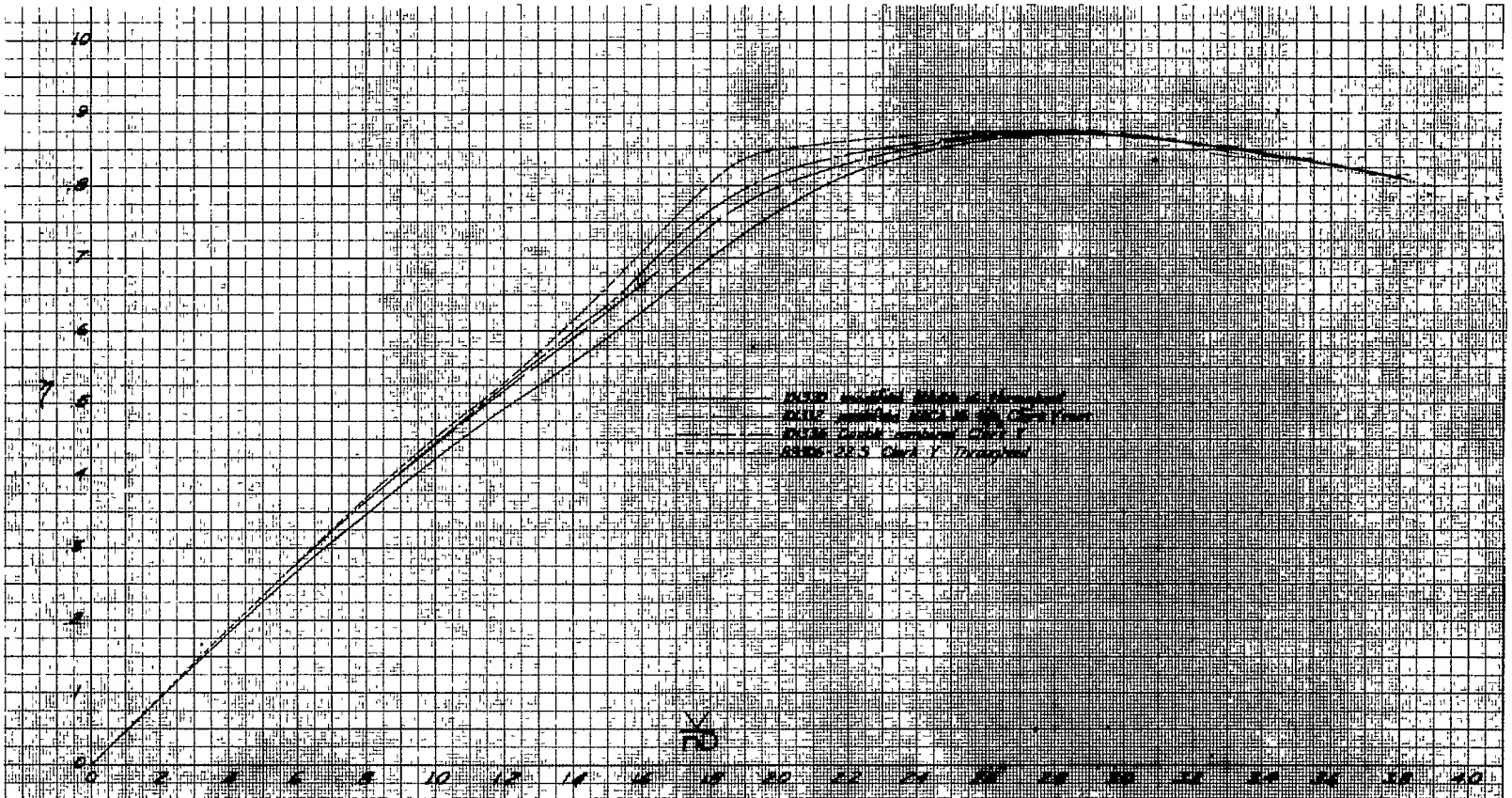


Figure-23 Efficiency Comparisons for Four Propellers at C_p=0.4

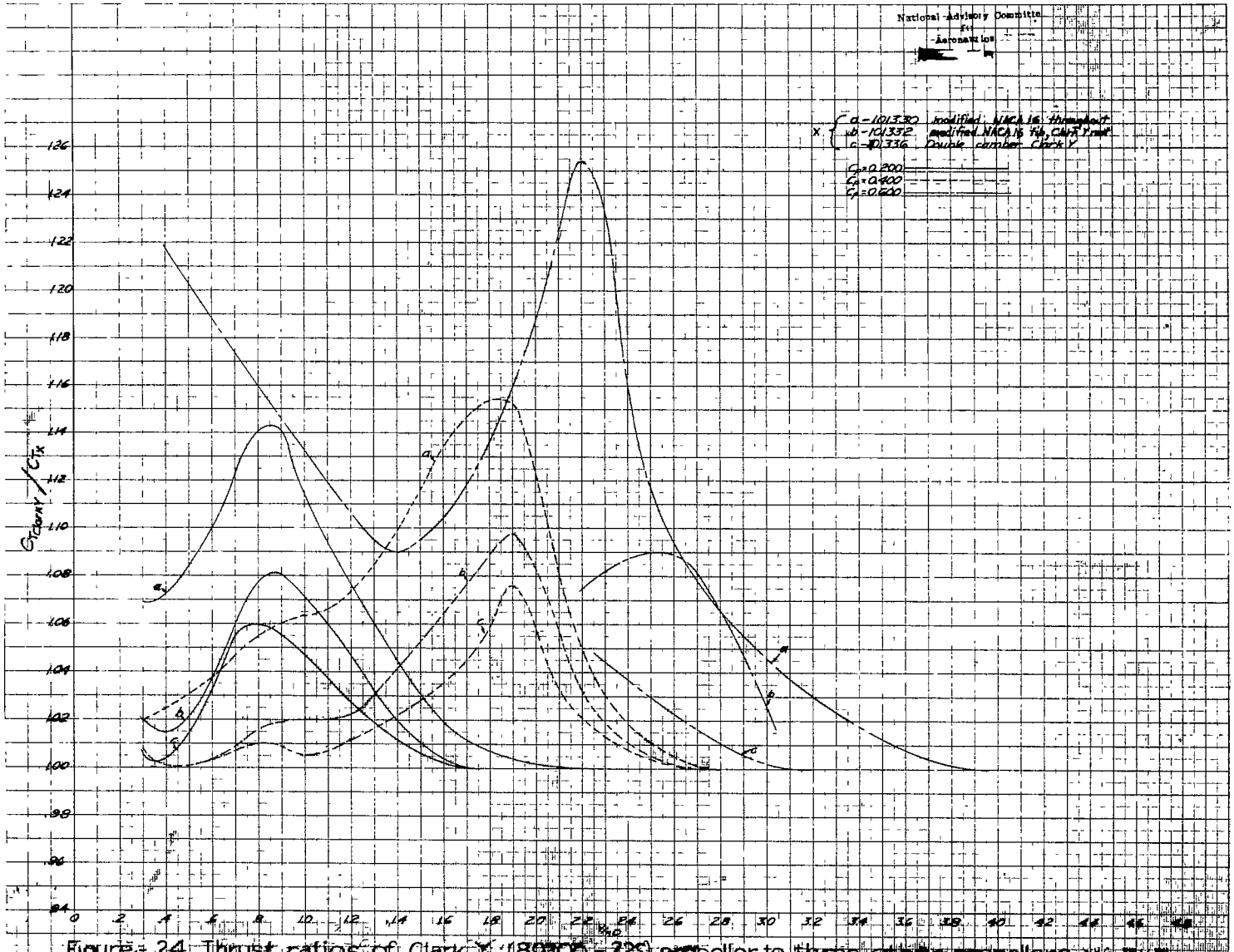


Figure 24 Thrust ratios of Clark Y (89300 - 225) propeller to three other propellers

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