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RESEARCH MEMORANDUM

INVESTIGATION OF THE NACA 4-(0)(03)-045 TWO-BLADE PROPELLER AT FORWARD MACH NUMBERS TO 0.925

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INVESTIGATION OF THE NACA 4-(0)(03)-045 TWO-BLADE PROPELLER AT FORWARD MACH NUMBERS TO 0.925

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SUMMARY

Results are presented of an investigation made of the NACA 4-(0)(03)-045 two-blade propeller in the Langley 8-foot high-speed tunnel for blade angles from 20° to 70° for forward Mach numbers up to 0.925. A comparison of this propeller with previously tested propellers is also presented.

The results show that a propeller with 3-percent-thick sections at the design station can delay the onset of adverse compressibility effects up to a forward Mach number of 0.825. With such a propeller, efficiencies as high as 73 percent are obtained at a forward Mach number of 0.925. Reductions in thickness ratio from 8 percent to 3 percent at the design station delay the onset of adverse compressibility effects by as much as 0.12 in forward Mach number. This same reduction in thickness ratio leads to an increase in efficiency of 17 percent at a forward Mach number of 0.925. When considerations of the structural difficulties and practical problems are included, it appears that the use of thinner blade sections is more advantageous than the use of sweep in propeller blades in obtaining improved propeller efficiency at high speeds.

INTRODUCTION

A partial study of the effect of thickness ratio on propeller performance was presented in reference 1. This study included basic force-test data for an NACA propeller of conventional thickness at several blade angles around its design condition, and also basic force-test data for an NACA propeller with a thickness ratio of 3 percent at its design station tested at its design blade angle ($\beta_{0.75R} = 60^\circ$). Blade failure prevented completion of the thin-propeller investigation at that time. New thin blades were made, however, and the tests were

[redacted]

completed. The results of the completed tests of the NACA 4-(0)(03)-045 propeller are presented herein. This paper is essentially a data report to expedite publication of the results obtained. Large-scale plots of the basic propeller characteristics (fig. 5) are available on request to the NACA.

SYMBOLS

b	blade width, feet
C_P	power coefficient $\left(\frac{P}{\rho n^3 D^5}\right)$
C_T	thrust coefficient $\left(\frac{T}{\rho n^2 D^4}\right)$
D	propeller diameter, feet
b/D	blade-width ratio
h	maximum thickness of blade section, feet
h/b	blade thickness ratio
J	advance ratio $\left(\frac{V_o}{nD}\right)$
M	tunnel-datum (forward) Mach number (tunnel Mach number uncorrected for tunnel-wall constraint)
M_t	helical tip Mach number $\left(M\sqrt{1 + (\pi/J)^2}\right)$
n	rotational speed, revolutions per second
P	power, foot pounds per second
R	propeller tip radius, feet
T	thrust, pounds
T_c	thrust disk loading coefficient $\left(\frac{T}{2qD^2}\right)$

V tunnel-datum velocity (tunnel-datum velocity uncorrected for tunnel-wall constraint), feet per second

V_o equivalent free-air velocity (tunnel-datum velocity corrected for tunnel-wall constraint), feet per second

β section blade angle, degrees

$\beta_{0.75R}$ section blade angle at 0.75 tip radius, degrees

η efficiency $\left(\frac{C_T}{C_P}J\right)$

η_e maximum envelope efficiency

η_{max} maximum efficiency

ρ air density, slugs per cubic foot

APPARATUS, METHODS, AND TESTS

The apparatus and methods described in reference 2 were used in this investigation which was conducted in the Langley 8-foot high-speed tunnel. A sketch of the 800-horsepower dynamometer installation in the tunnel is shown as figure 1.

The propeller used in this investigation was designed to produce minimum energy losses (profile drag assumed equal to zero) at a blade angle of 60° at the 0.7 radius and at an advance ratio of 3.36. Symmetrical NACA 16-series blade sections were used all along the blades. The propeller used for the investigation reported in reference 1 was made of a beryllium-copper alloy. This propeller, as previously mentioned, failed because of fatigue incurred by excessive flutter. For the present tests, the propeller blades were made of solid steel and, for the Mach number range tested, flutter was not evident. A photograph of the blade is shown as figure 2 and the blade-form curves are presented in figure 3.

Thrust, torque, and rotational speed were measured throughout the operating range of the propeller. For each tunnel Mach number, the propeller was operated at fixed blade angles and the rotational speed was varied. The range of blade angle covered for each forward Mach number is given in the following table:

Forward Mach number, M	Blade angle of 0.75 tip radius, $\beta_{0.75R}$ (deg)						
0.23	20	30	40				
.35		30	40				
.43		30	40				
.53			40	50			
.60				50	55	[a]60	65
.65				50	55	[a]60	
.70				50	55	[a]60	65
.75				50	55	[a]60	65
.80				50	55	[a]60	65
.85				50	55	[a]60	65
.90				50	55	[a]60	65
.925				50	55	[a]60	65

[a]Data for $\beta_{0.75R} = 60^{\circ}$ were obtained during tests reported in reference 1.

REDUCTION OF DATA

Propeller thrust.– Propeller thrust as used herein is defined as the shaft tension produced by the spinner–to–tip portion of the blades. The method used in determining thrust tares and in evaluating the propeller thrust is described in detail in reference 2.

Propeller torque.— Torque tare corrections were found to be small and dependent only on rotational speed. The indicated torque reading was corrected for the spinner tare.

Tunnel-wall corrections.— The force-test data have been corrected for the effect of tunnel-wall constraint on velocity at the propeller plane by use of the method described in reference 2. These results are presented in figure 4 where the ratio of free-air velocity to the tunnel-datum velocity is plotted as a function of thrust disk-loading coefficient and tunnel-datum Mach number.

Accuracy of results.— Analysis of the accuracy of the separate measurements required to define completely the propeller characteristics has indicated that errors in the results presented herein are probably less than 1 percent.

RESULTS AND DISCUSSION

The basic propeller characteristics are presented in figure 5. For each value of tunnel-datum Mach number, the propeller thrust and power coefficients and efficiency are plotted against advance ratio. The variation of tip Mach number with advance ratio is also included. As used herein, the tunnel-datum Mach number is not corrected for tunnel-datum constraint. The free-air Mach number, however, can be obtained by applying the tunnel-wall corrections, presented in figure 4, to the tunnel-datum Mach number. At the high Mach numbers the tunnel-wall correction is generally less than 1 percent.

Effect of forward Mach number of maximum efficiency.— The variation of maximum efficiency with forward Mach number is presented in figure 6. At relatively low speeds, the highest value of maximum efficiency was approximately 89 percent for the blade-angle of 30° to 60°. The maximum low-speed efficiency for blade angles of 20° and 65° was about 85 percent. It may be seen from the figure that the maximum efficiencies for the design blade angle ($\beta_{0.75R} = 60^{\circ}$) are at least as high as the efficiencies for any other blade angle throughout the Mach number range tested. The adverse effects of compressibility do not become evident until an operating Mach number of 0.825 is reached; beyond this Mach number the maximum efficiency falls off abruptly to an efficiency of 73 percent at a Mach number of 0.925. At blade angles other than the design blade angle the adverse effects of compressibility occur at much lower forward Mach numbers; however, for blade angles of 50° and 55° the maximum efficiencies are also about 73 percent at a Mach number of 0.925.

Effect of advance ratio and forward Mach number on maximum efficiency.— The discussion of reference 2 clearly showed that for subcritical propeller operation, relatively high advance ratios are conducive to high efficiencies, but for high supercritical propeller operation this trend is reversed, that is, to obtain the highest propeller efficiencies at supercritical speeds, low advance ratios are necessary. The curves presented in figure 7 tend to further demonstrate this phenomenon. The reversal in effect of advance ratio on maximum efficiency for this propeller did not occur until after reaching a forward Mach number of 0.90. This reversal is at a higher Mach number than that shown for the conventional propeller in reference 2; this fact indicates that the point of reversal is dependent on the critical speeds of the propeller sections and is thus delayed by use of thinner sections. Moreover, the magnitude of the trend of increased efficiency with reductions in advance ratio is considerably smaller than the trends shown in reference 2 for an 8-percent-thick propeller. The efficiency curves for these two propellers indicate that the sections of the thin propeller are operating at higher lift-to-drag ratios. It was noted in reference 2 that the gain in efficiency associated with reduction in advance ratio becomes significant only when low lift-to-drag ratios are encountered. It therefore appears that the high lift-to-drag ratios associated with the thinner propeller lead to the much smaller trend shown.

Comparison with other propellers.— Figure 8 shows the envelope efficiency for the NACA 4-(0)(03)-045 propeller plotted against forward Mach number. Superimposed on this figure are the envelope efficiencies for the NACA 4-(0)(08)-045 and 4-(4)(06)-057-45A propellers. The NACA 4-(0)(03)-045 and 4-(0)(08)-045 propellers differed only in thickness ratio, the former being 3 percent thick and the latter being 8 percent thick at the design station, X = 0.7. This figure indicates the improvement obtainable by the use of thinner sections. Not only is the onset of adverse compressibility effects delayed about 0.12 in Mach number, but the magnitude of the adverse effects is considerably reduced by the use of the thinner blade sections. As a result, the thinner propeller is 17 percent more efficient than the thicker propeller at a forward Mach number of 0.925. Thus, with blade-section thickness ratios of the order of 3 percent, propeller efficiencies of 73 percent or more can be obtained at forward Mach numbers of 0.925. Figure 8 also shows several values of efficiency calculated for the NACA 4-(0)(03)-045 propeller using section data obtained from pressure-distribution measurements on propellers, wind-tunnel force measurements, and calculations for supersonic conditions. The calculations were made by assuming an ideal load distribution and using maximum lift-to-drag ratios obtained from the Langley 16-foot high-speed-tunnel pressure-distribution studies. Despite the fact that the assumed conditions were not attained in the experiments, the agreement between the calculated and measured efficiencies is good. The method of calculation used in obtaining these points may be found in reference 3. Experimental tests of another thin propeller (reference 4) have shown efficiencies of the same order of magnitude in the high supercritical Mach number range.

For purposes of comparison, figure 8 also includes a curve representing the experimental results for the NACA 4-(4)(06)-057-45A propeller (reference 5) tested in the Langley 8-foot high-speed tunnel. This propeller is swept forward and back 45° and has a thickness ratio of 6 percent at the design station. The efficiency for this propeller falls only slightly above values which would be expected of an unswept 6-percent-thick propeller. When it is considered that the practical stress and hub problems for a swept propeller are actually more severe than those for a 3-percent-thick straight propeller, it must be concluded that the use of sweep in propellers is less advantageous than the use of very thin blade sections for maintaining good efficiencies at transonic speeds.

CONCLUSIONS

Investigation of the NACA 4-(0)(03)-045 (having 3-percent-thick symmetrical sections at the design station) two-blade propeller in the Langley 8-foot high-speed tunnel, together with comparisons of previously tested propellers, indicates the following conclusions:

1. A propeller with 3-percent-thick sections at the design station can delay the onset of adverse compressibility effects up to a forward Mach number of 0.825.

2. With such a 3-percent-thick propeller, efficiencies as high as 73 percent are obtained at a forward Mach number of 0.925.

3. Reductions in thickness ratio from 8 percent to 3 percent at the design station delay the onset of adverse compressibility effects by as much as 0.12 in forward Mach number.

4. Reductions in section thickness ratio from 8 percent to 3 percent at the design station lead to an increase in efficiency of 17 percent at a Mach number of 0.925.

5. When considerations of the structural difficulties and practical problems are included, it appears that the use of thinner blade sections is more advantageous than the use of sweep in propeller blades in obtaining improved propeller efficiency at high speeds.

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REFERENCES

1. Delano, James B., and Carmel, Melvin M.: Investigation of NACA 4-(0)(03)-045 and 4-(0)(08)-045 Two-Blade Propellers at Forward Mach Numbers to 0.925. NACA RM L9L06a, 1950.

2. Delano, James B., and Carmel, Melvin M.: Investigation of the NACA 4-(5)(08)-03 Two-Blade Propeller at Forward Mach Numbers to 0.925. NACA RM L9G06a, 1949.

3. Gilman, Jean, Jr., Crigler, John L., and McLean, F. Edward: Analytical Investigation of Propeller Efficiency at High-Subsonic Flight Speeds near Mach Number Unity. NACA RM L9L05a, 1949.

4. Smith, C. B., and Hunt, H. F.: Wind Tunnel Tests of Supersonic Propeller No. 1. Hamilton Standard Rep. No. HSP-723, U.A.C. Rep. No. R-14102-5, United Aircraft Corp. Res. Dept., Sept. 6, 1949.

5. Delano, James B., and Harrison, Daniel E.: Investigation of the NACA 4-(4)(06)-057-45A and NACA 4-(4)(06)-057-45B Two-Blade Swept Propellers at Forward Mach Numbers to 0.925. NACA RM L9L05, 1950.

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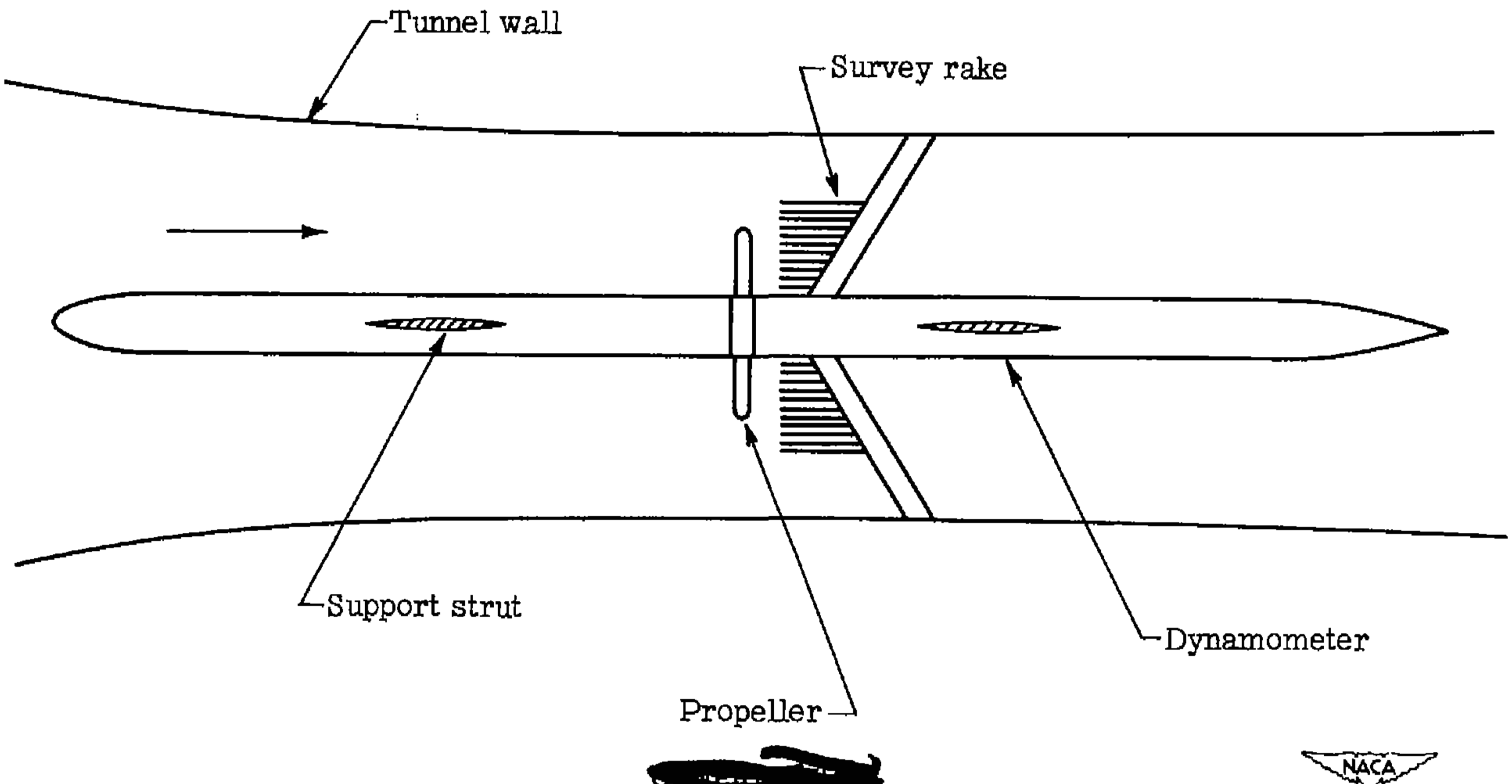

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Figure 1.- Test apparatus.

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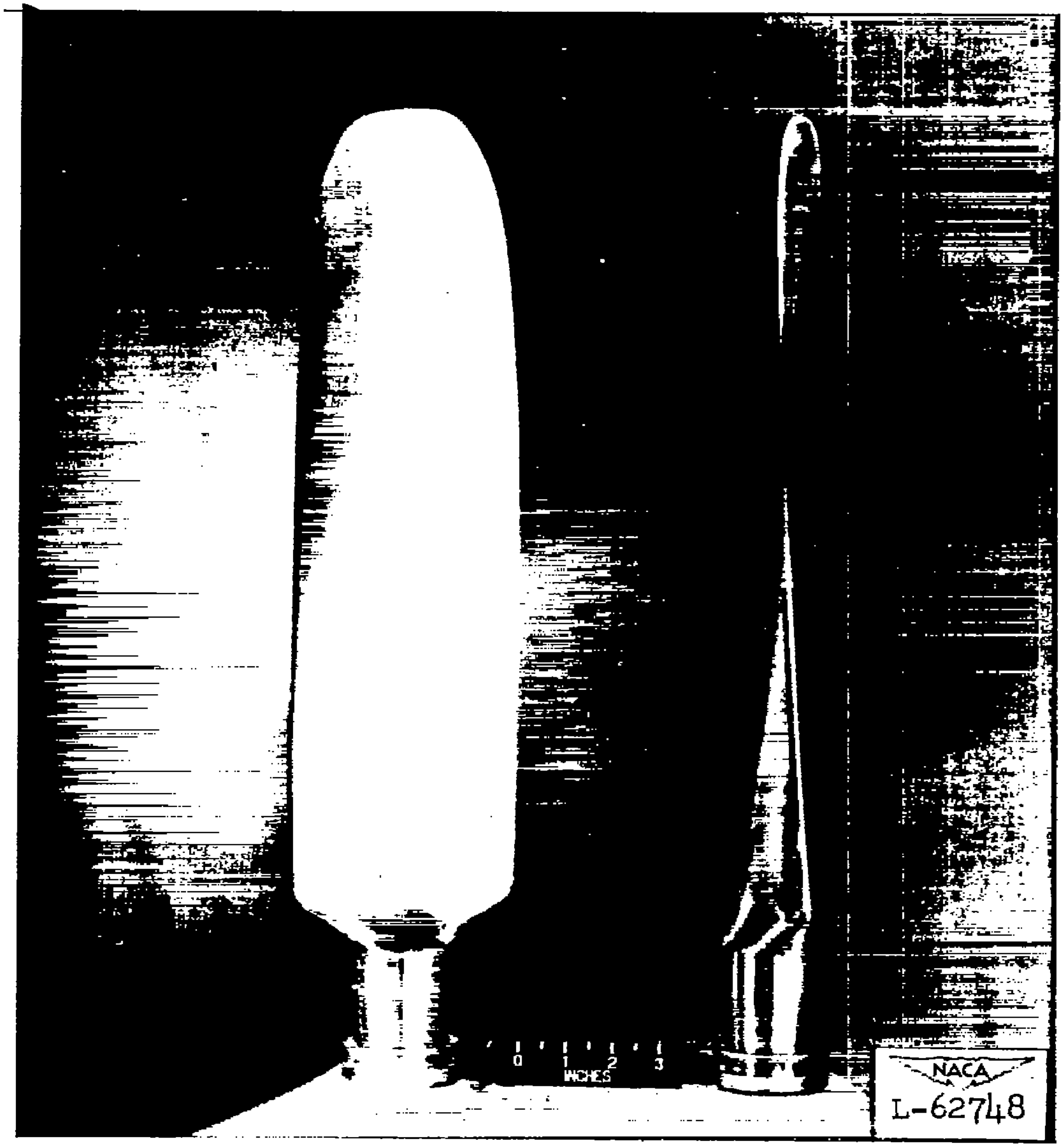

Figure 2.- NACA 4-(0)(03)-045 propeller.

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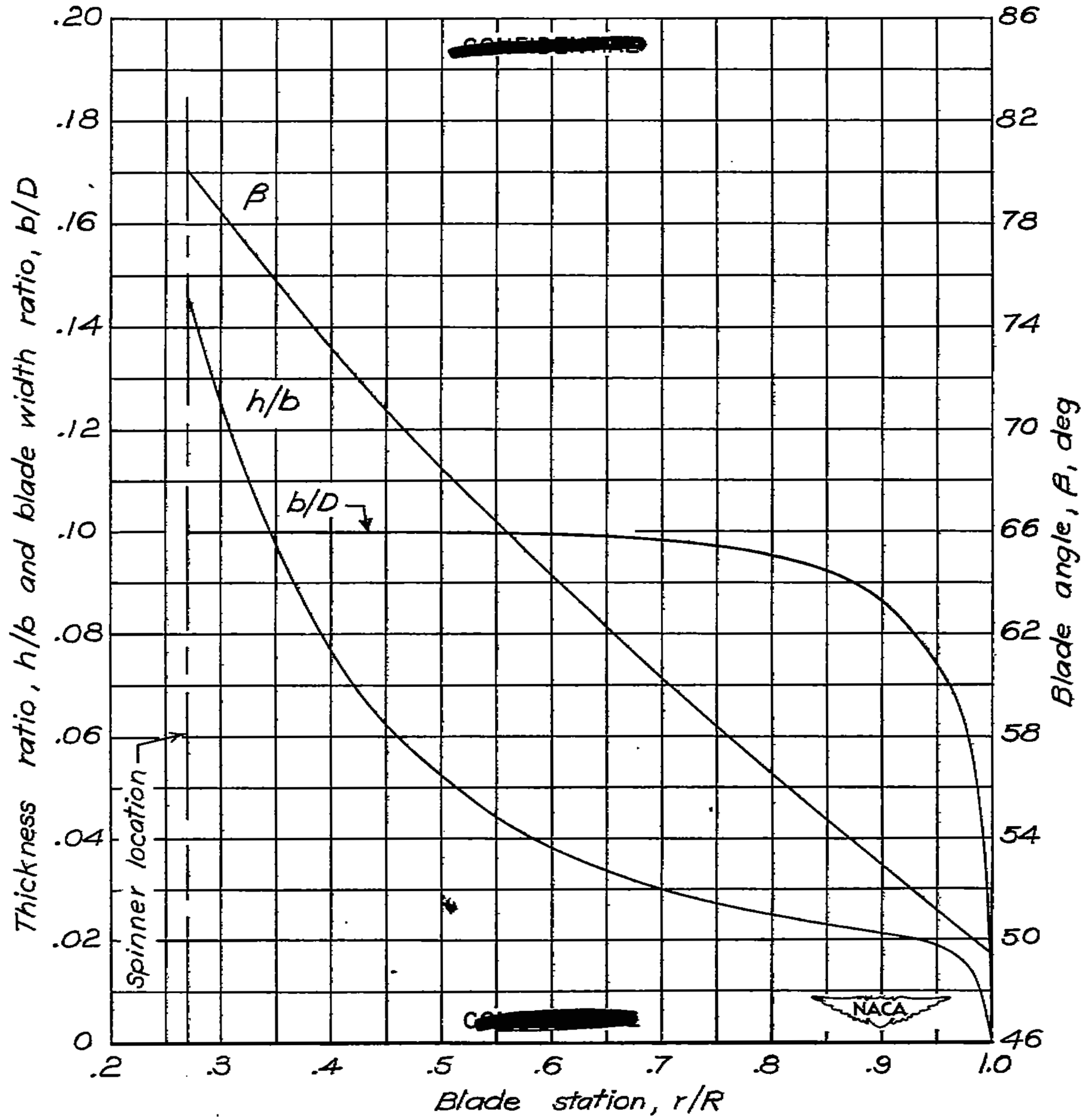


Figure 3.- Blade-form curves for NACA 4-(0)(03)-045 propeller.

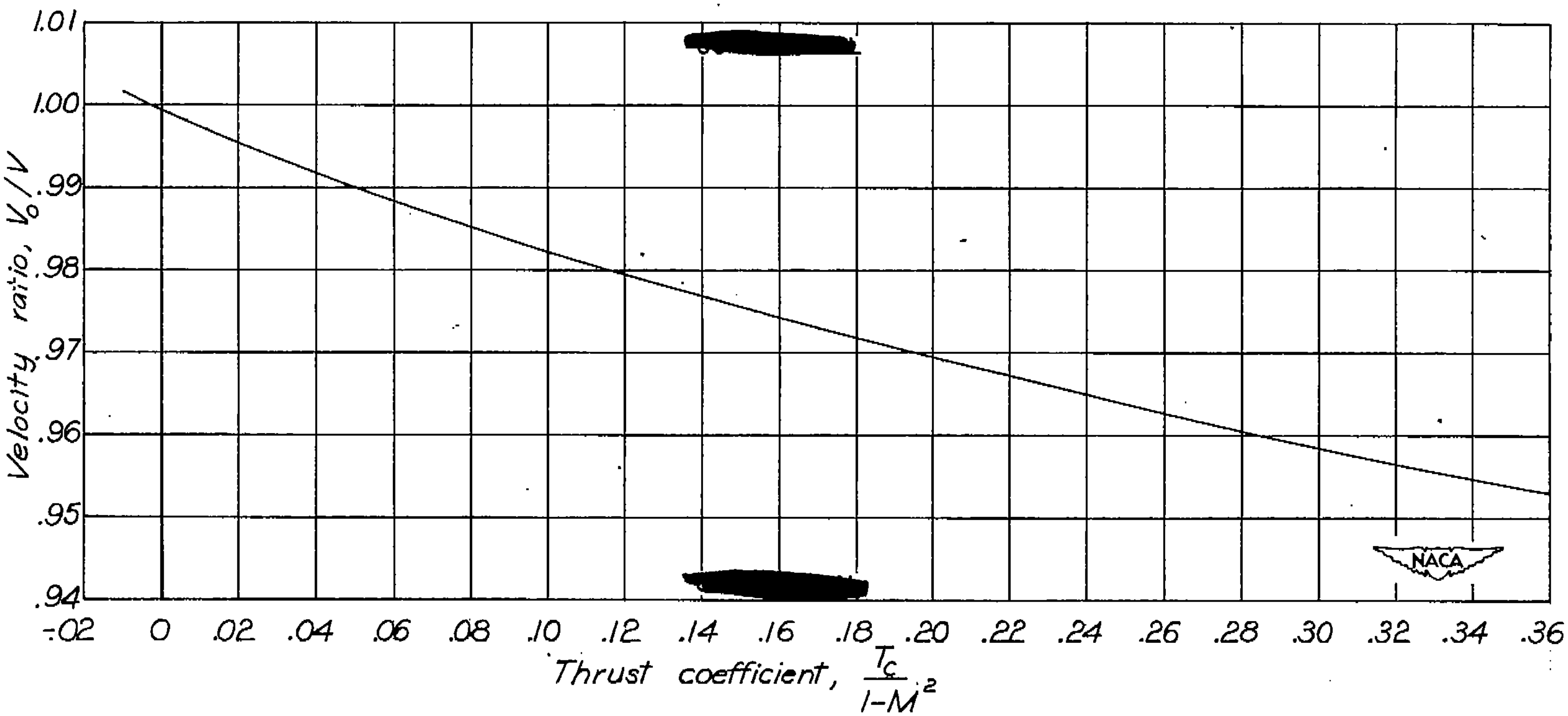
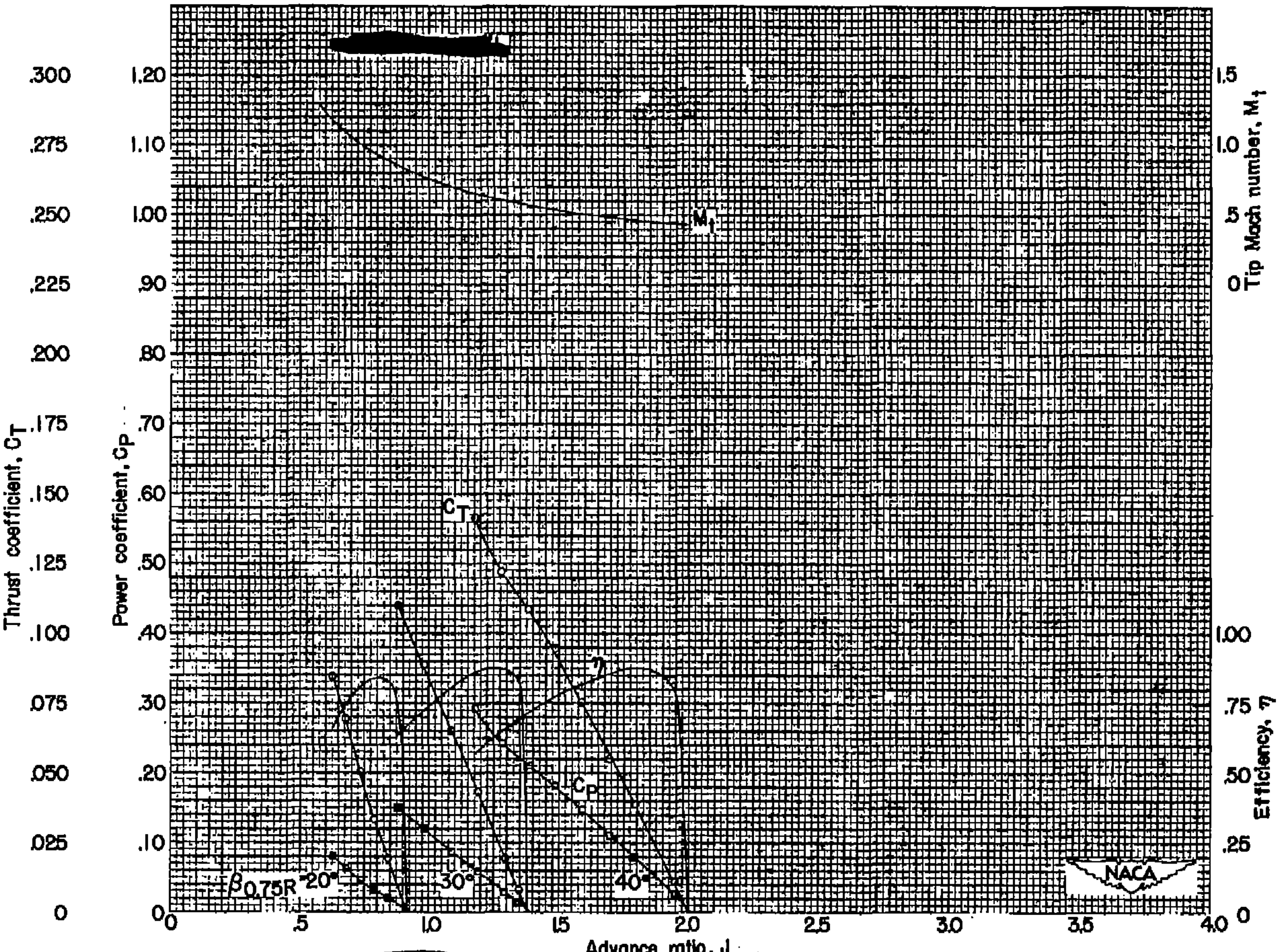


Figure 4.- Tunnel-wall-interference correction for 4-foot-diameter propeller in Langley 8-foot high-speed tunnel.



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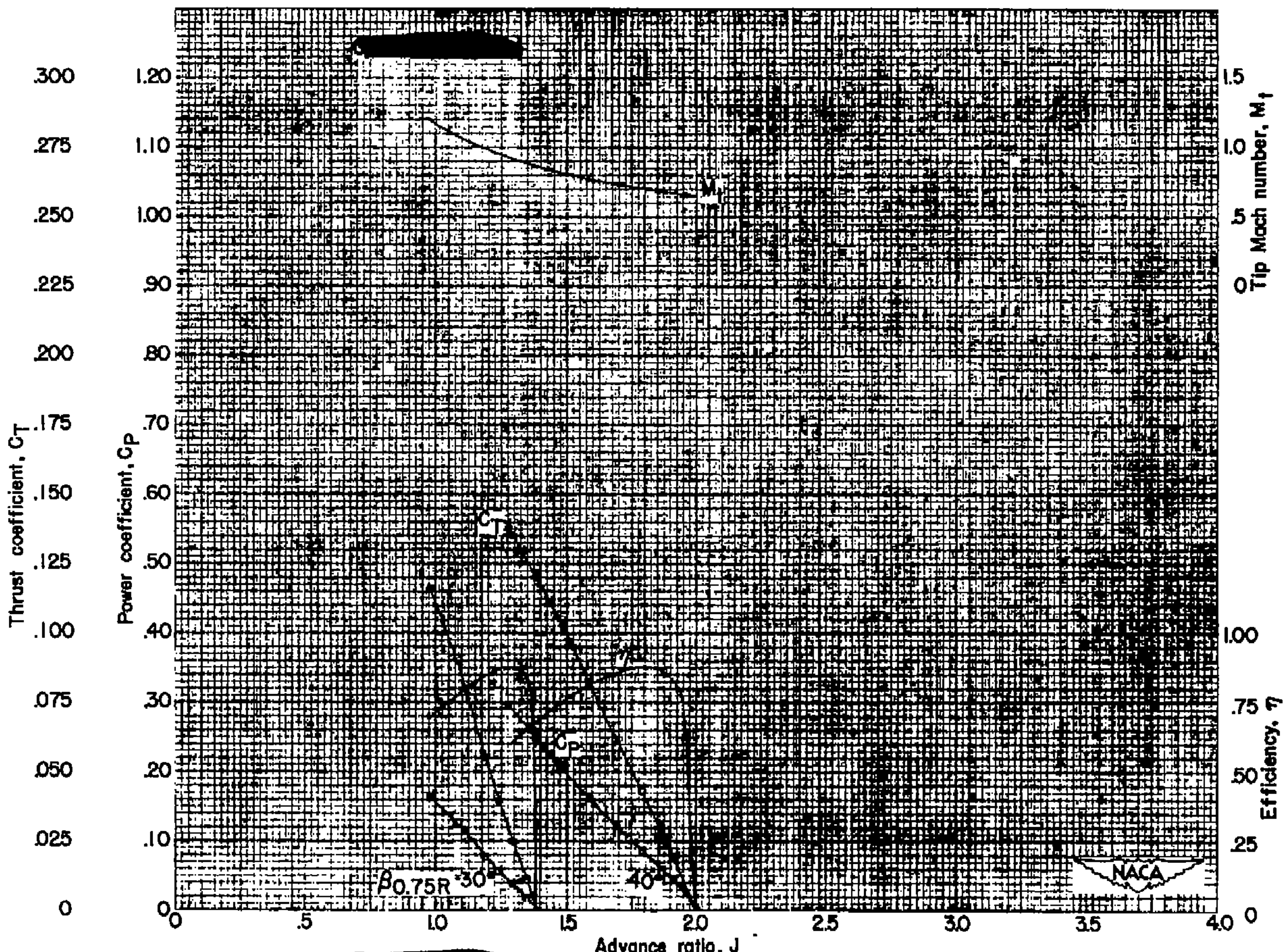
(a) M=0.23.

Figure 5 .- Characteristics of NACA 4-(0)(03)-045 propeller.



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(b) M=0.35.

Figure 5.- Continued.

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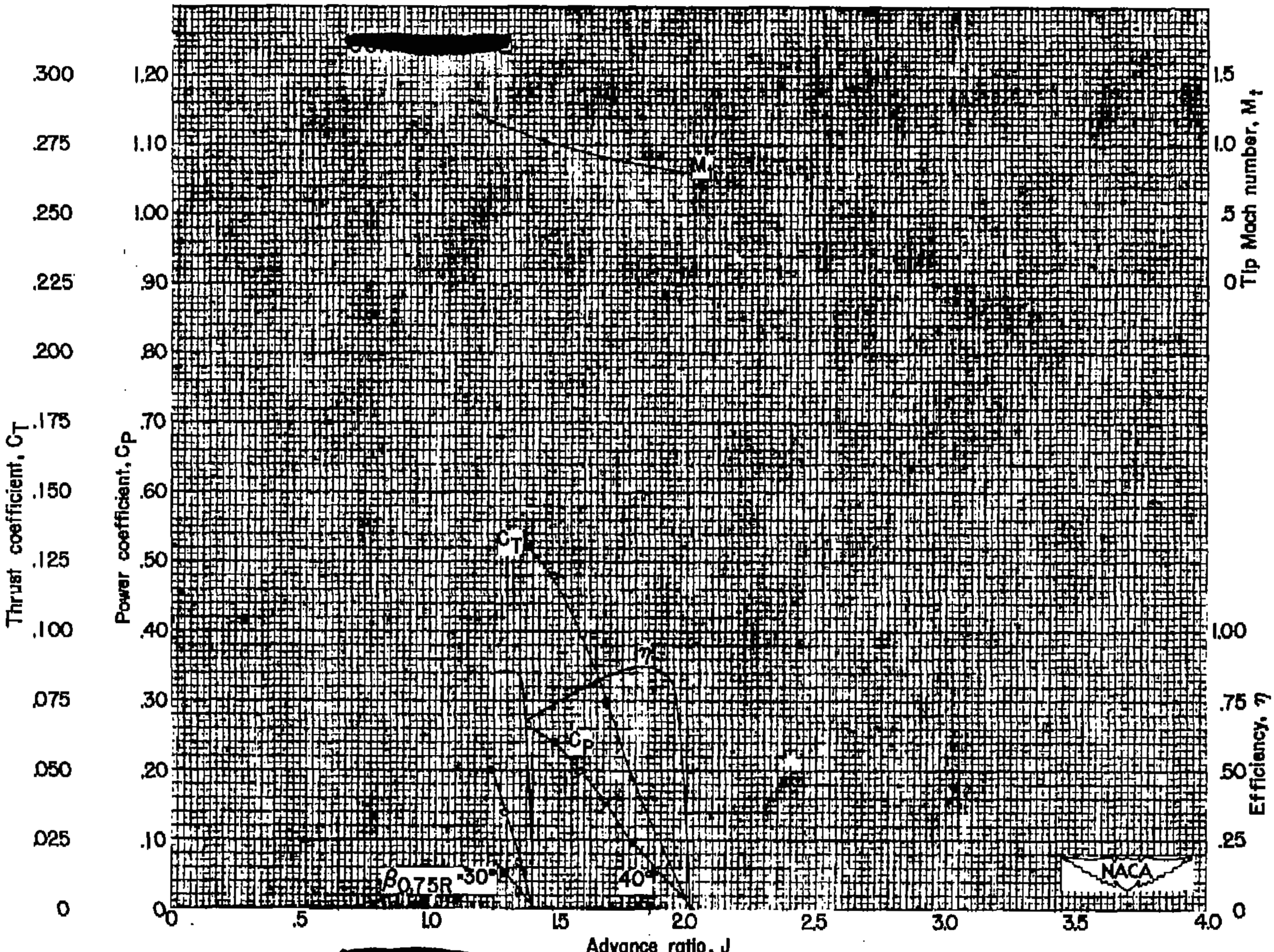

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(c) M=0.43.

Figure 5 .- Continued.

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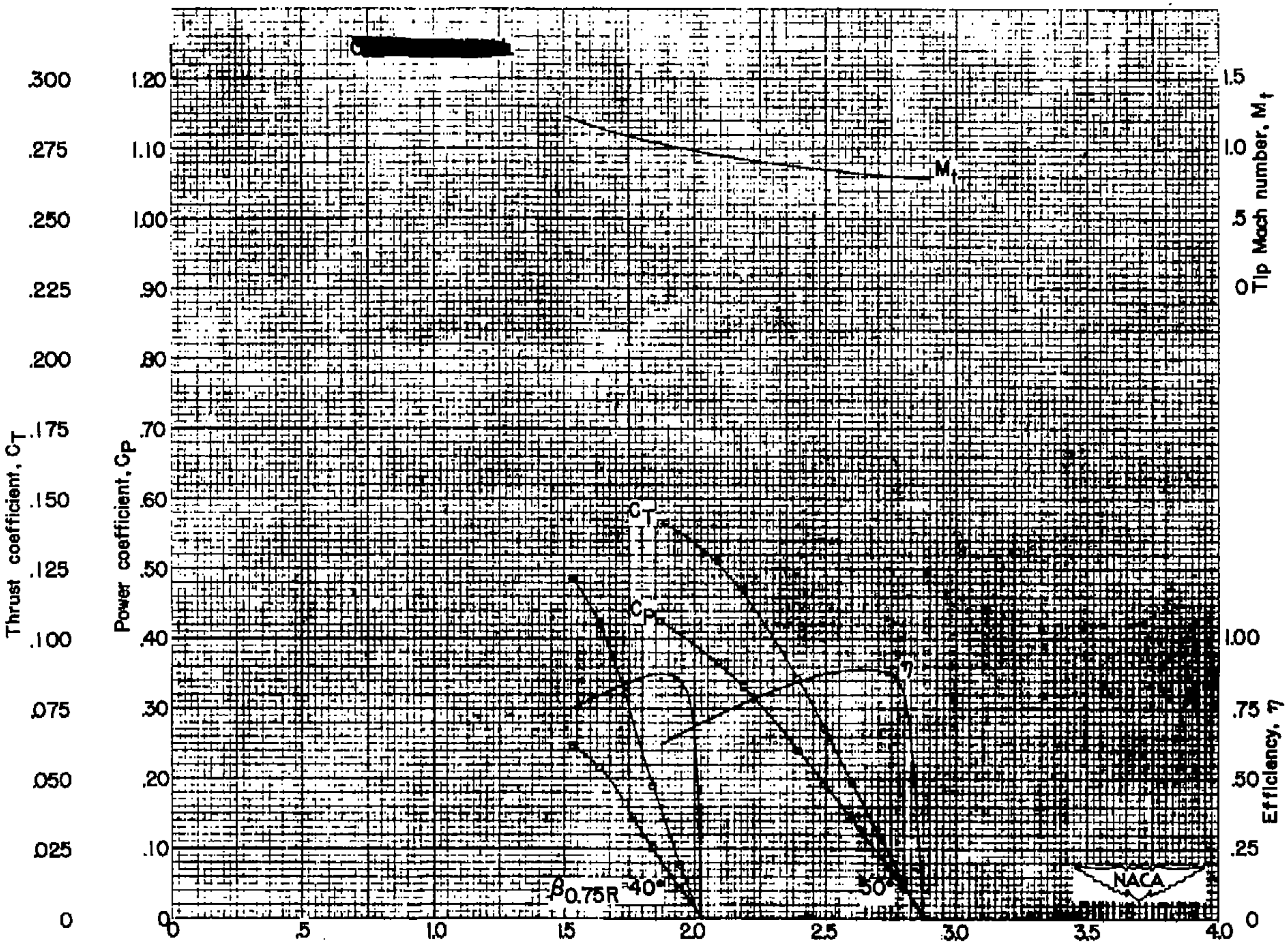

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(d) M=0.53.

Figure 5 .- Continued.

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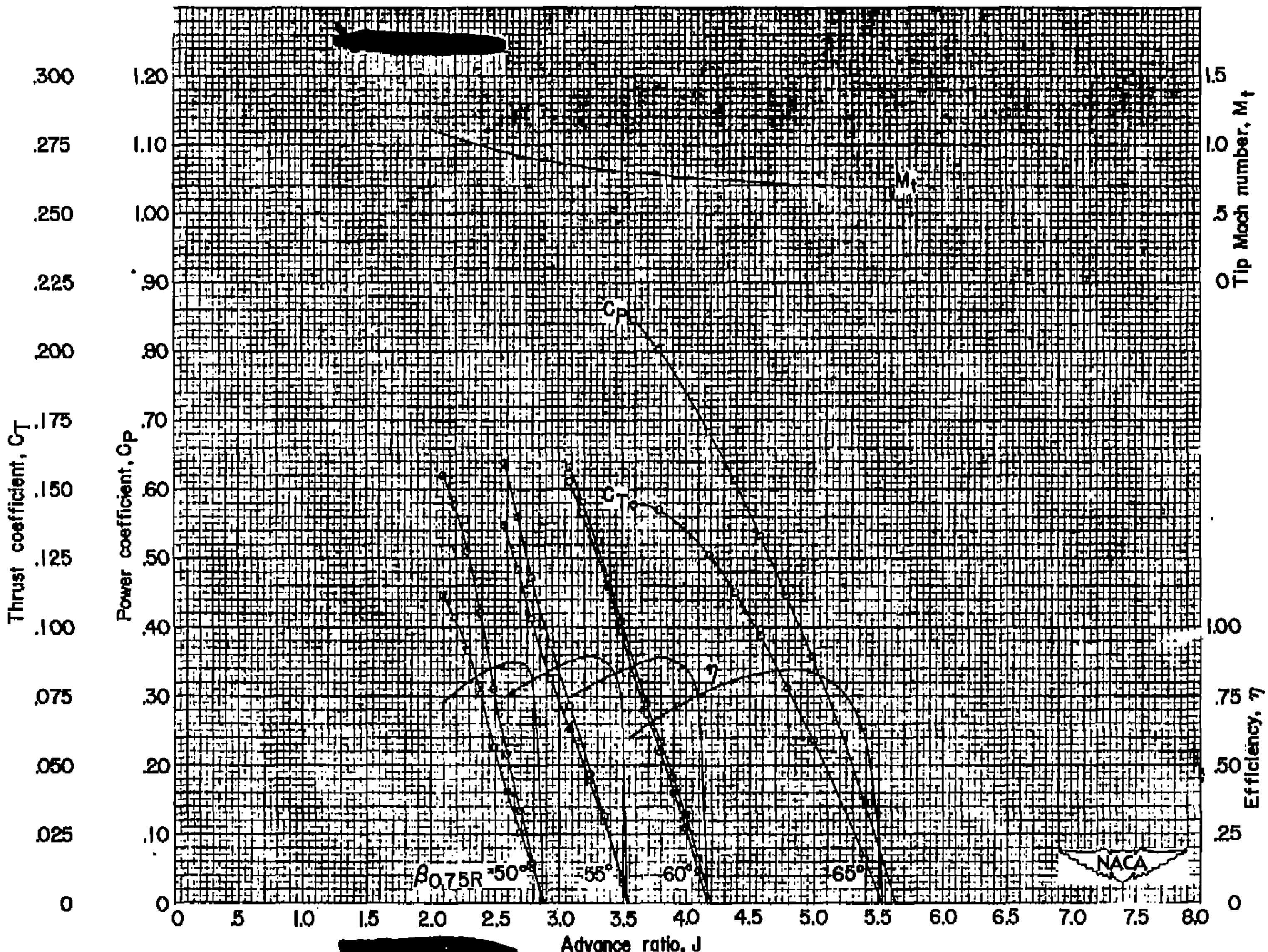

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(e) M=0.60.

Figure 5.- Continued.

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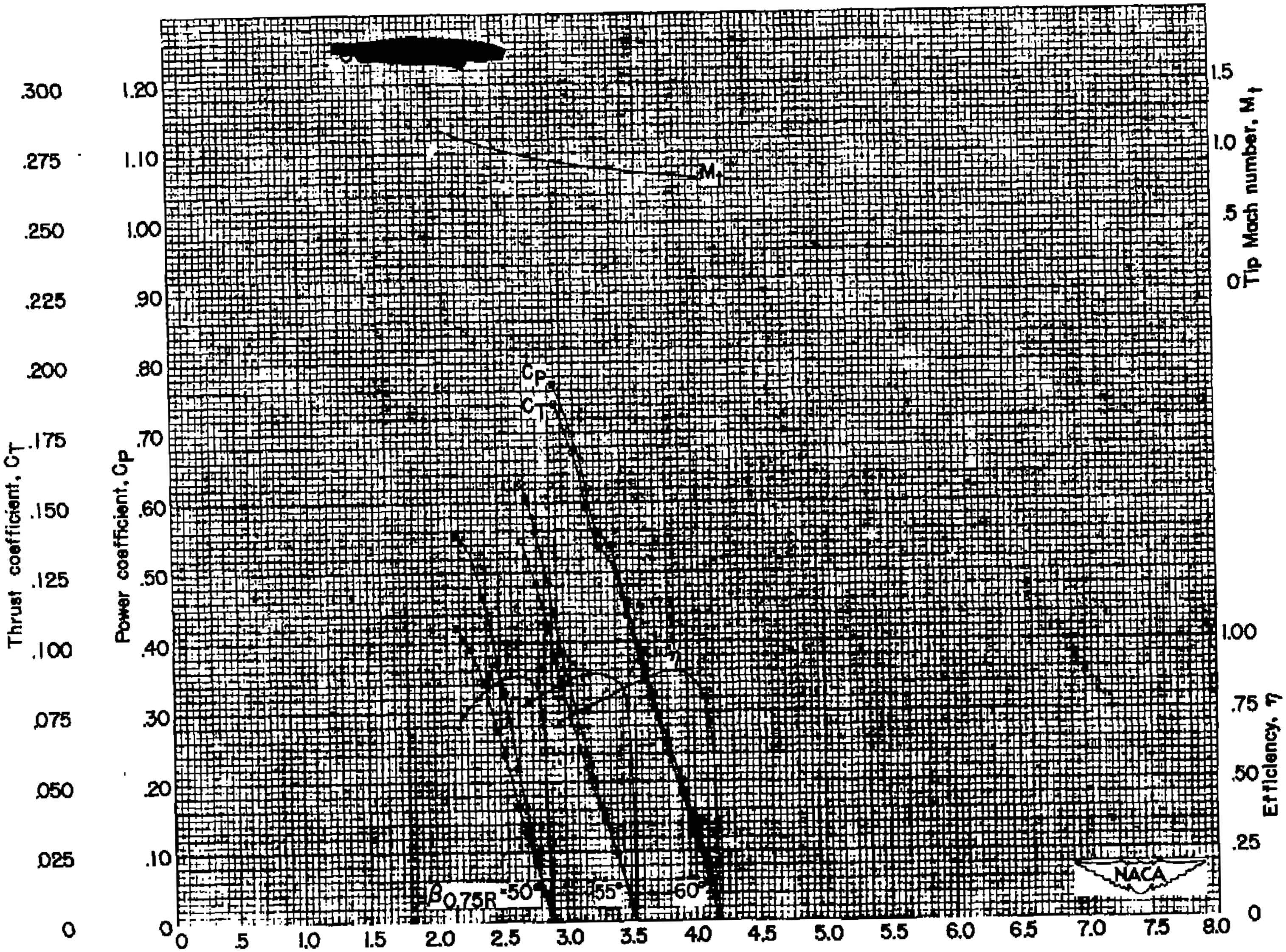

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(f) M=0.65.

Figure 5 .- Continued.

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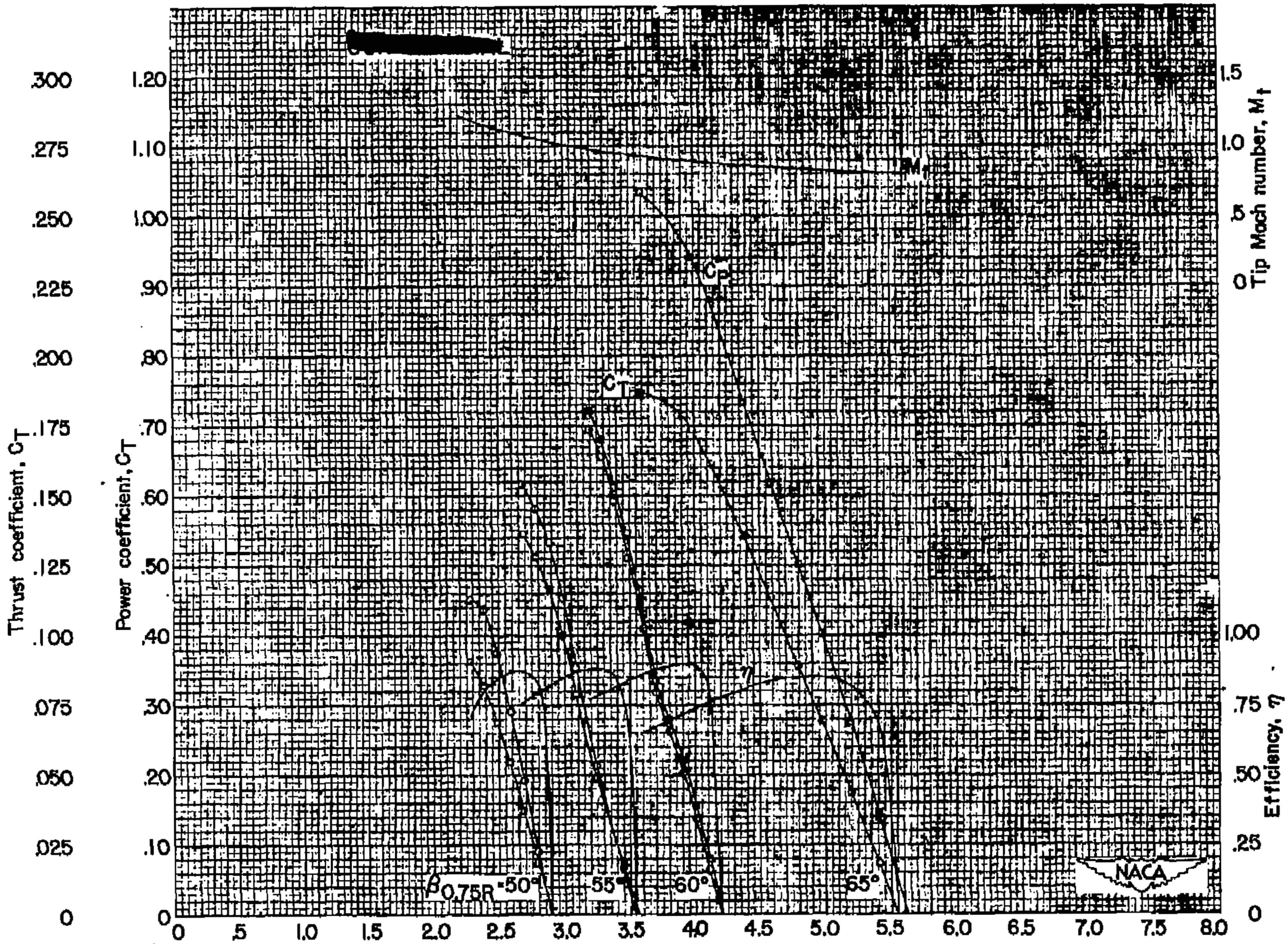

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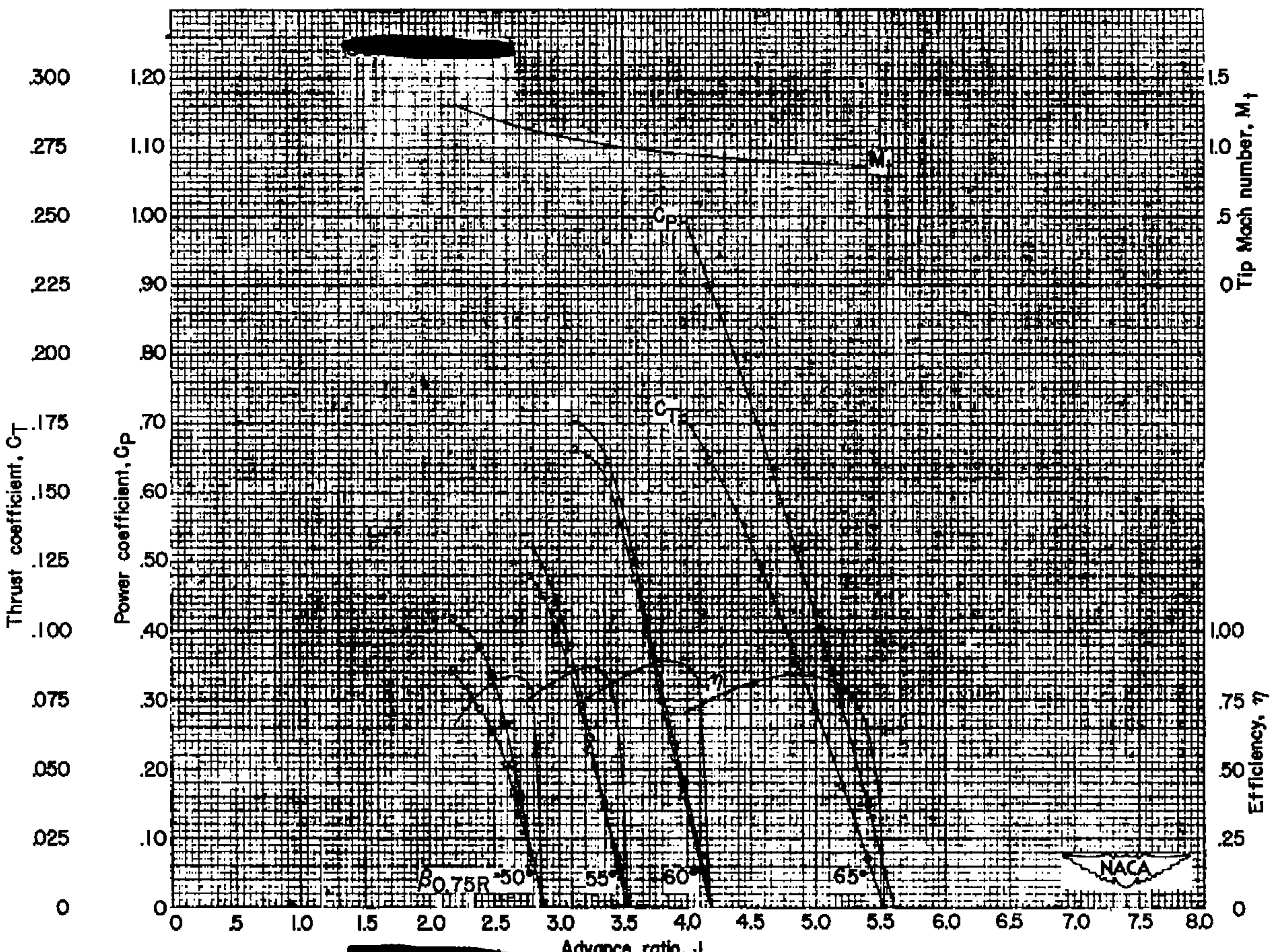
(g) M=0.70.

Figure 5.- Continued.



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(h) M=0.75.

Figure 5 .- Continued.

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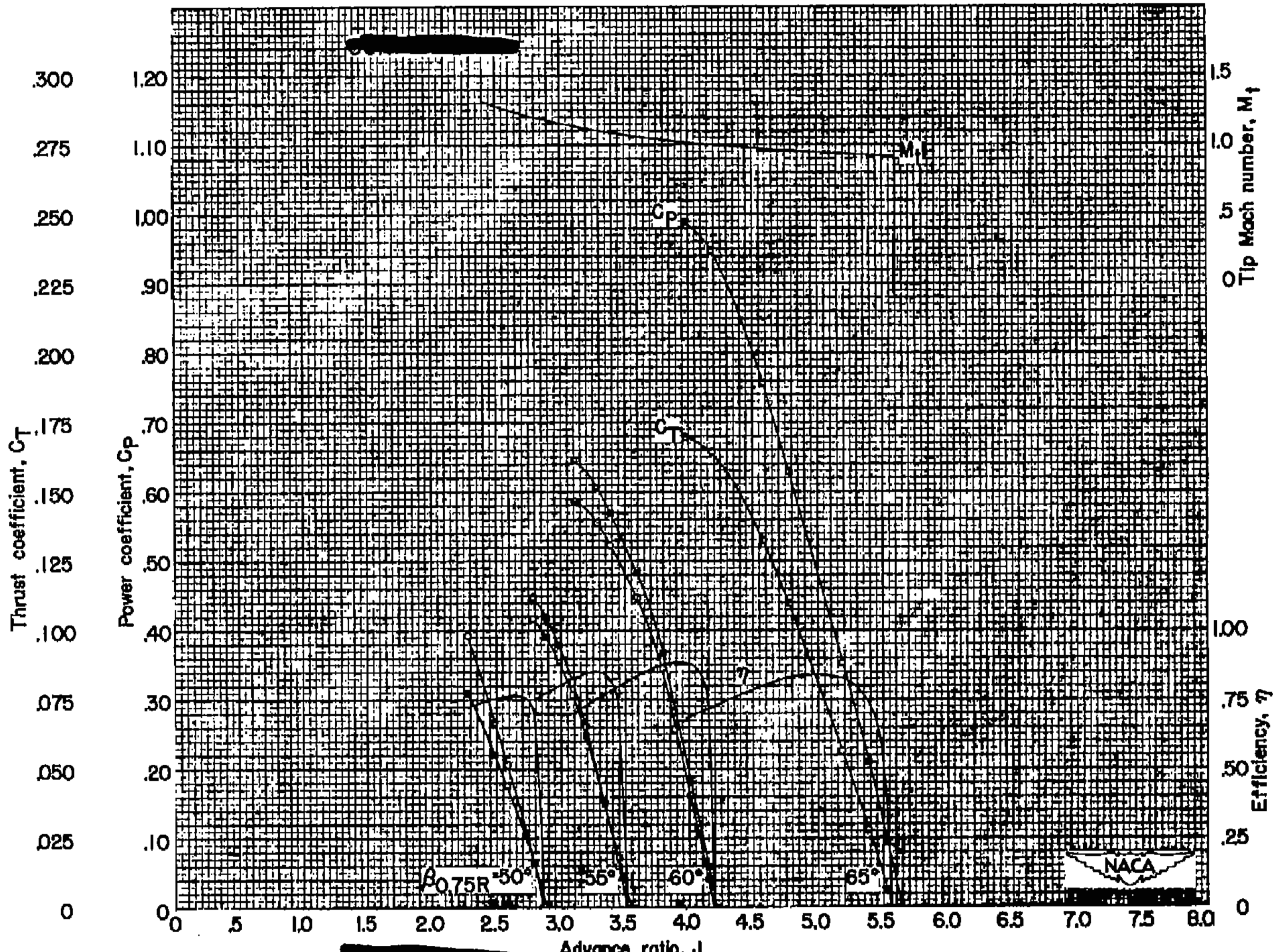

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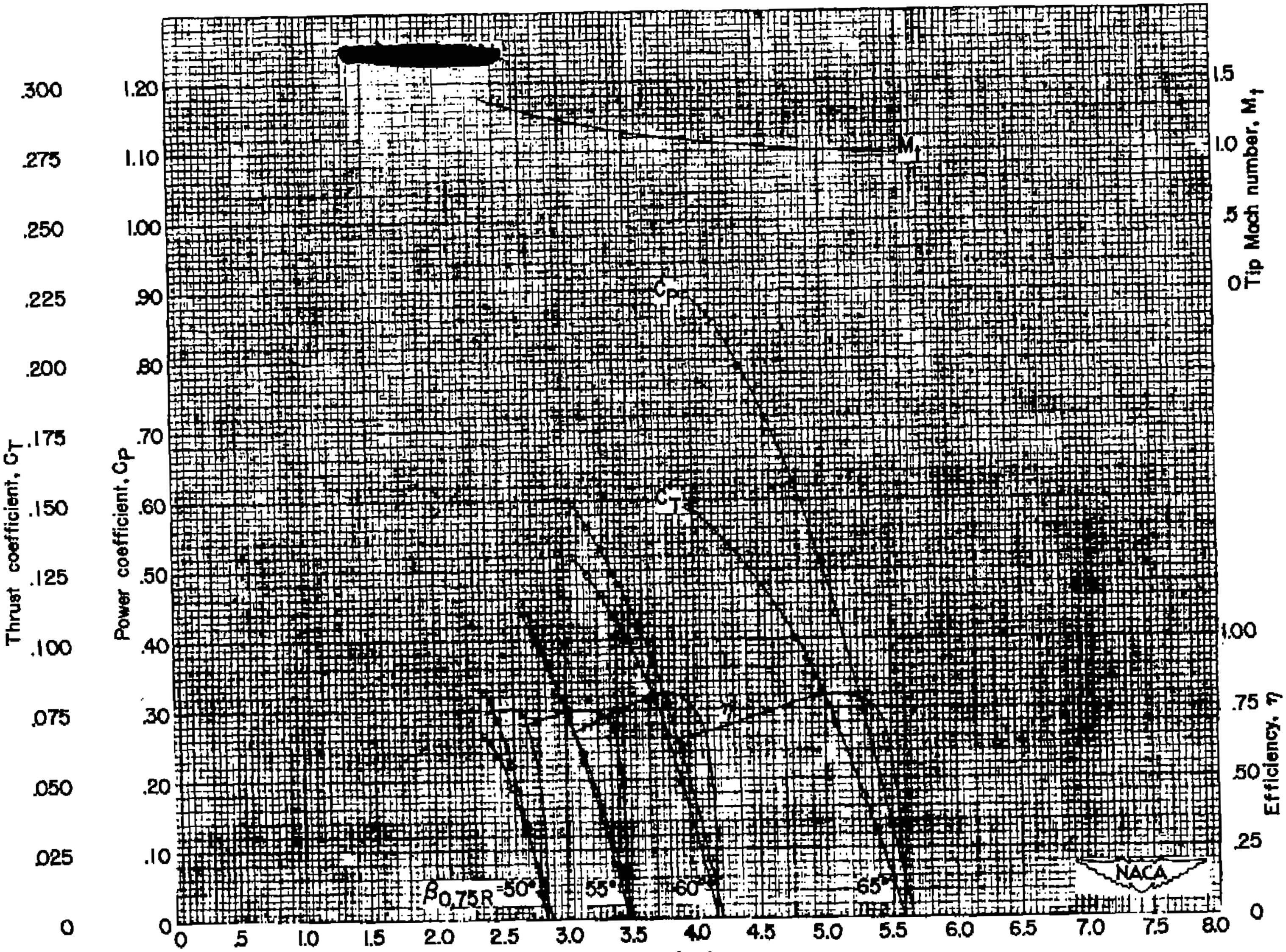
(l) M=0.80

Figure 5 - Continued.



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(j) M=0.85.

Figure 5 - Continued.

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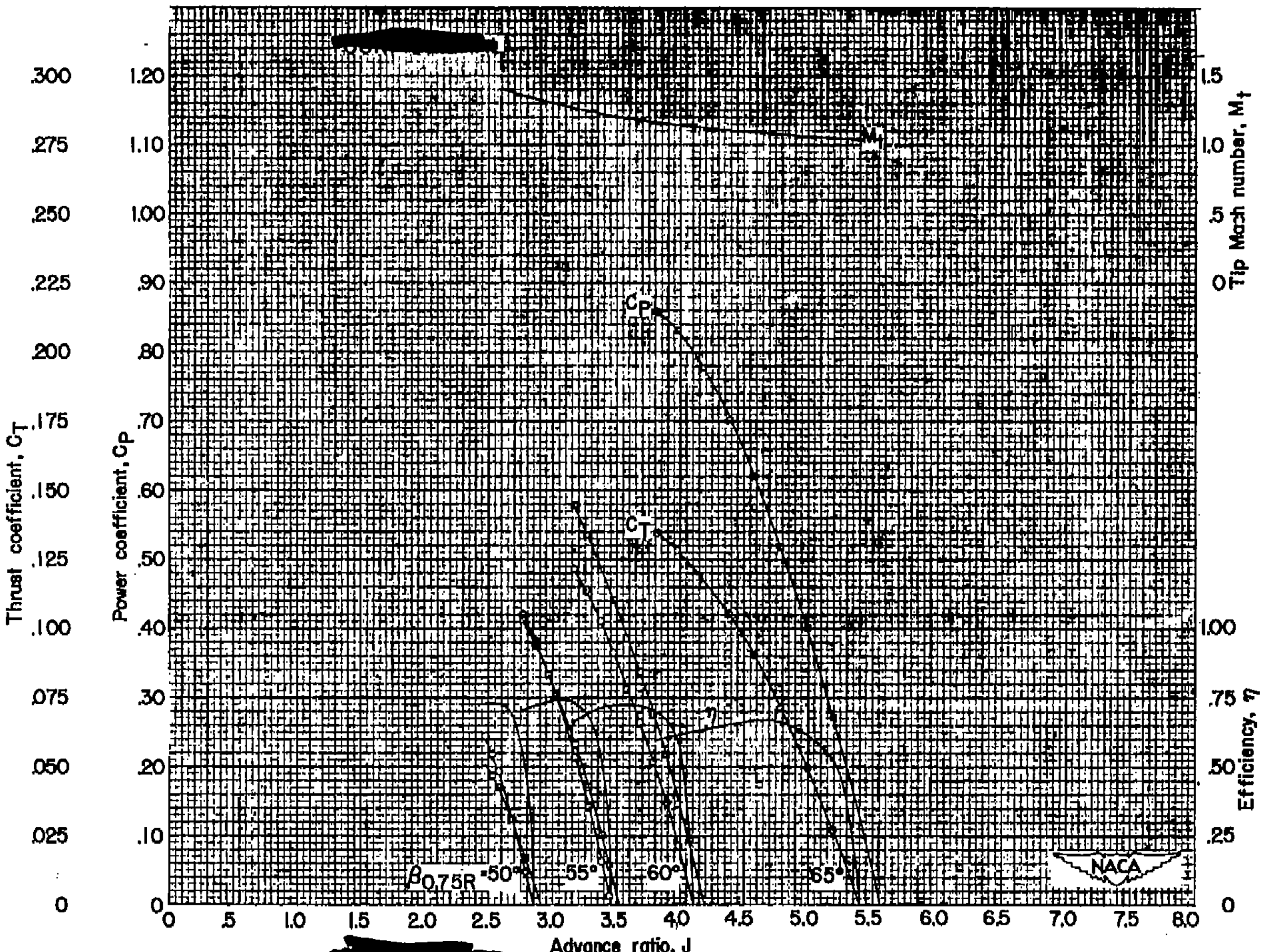

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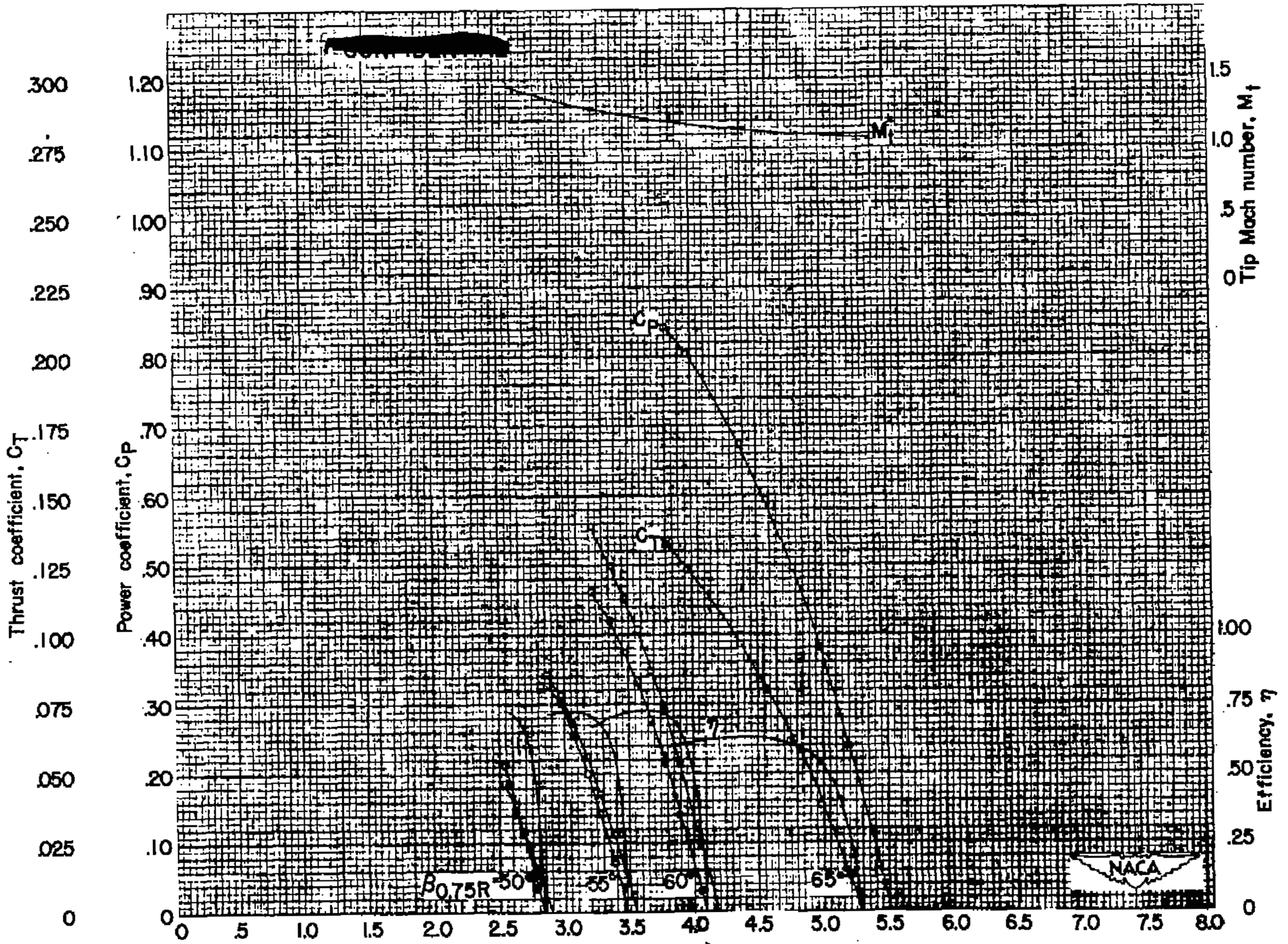
(k) M=0.90.

Figure 5.- Continued.



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(l) M=0.925.

Figure 5 - Concluded.

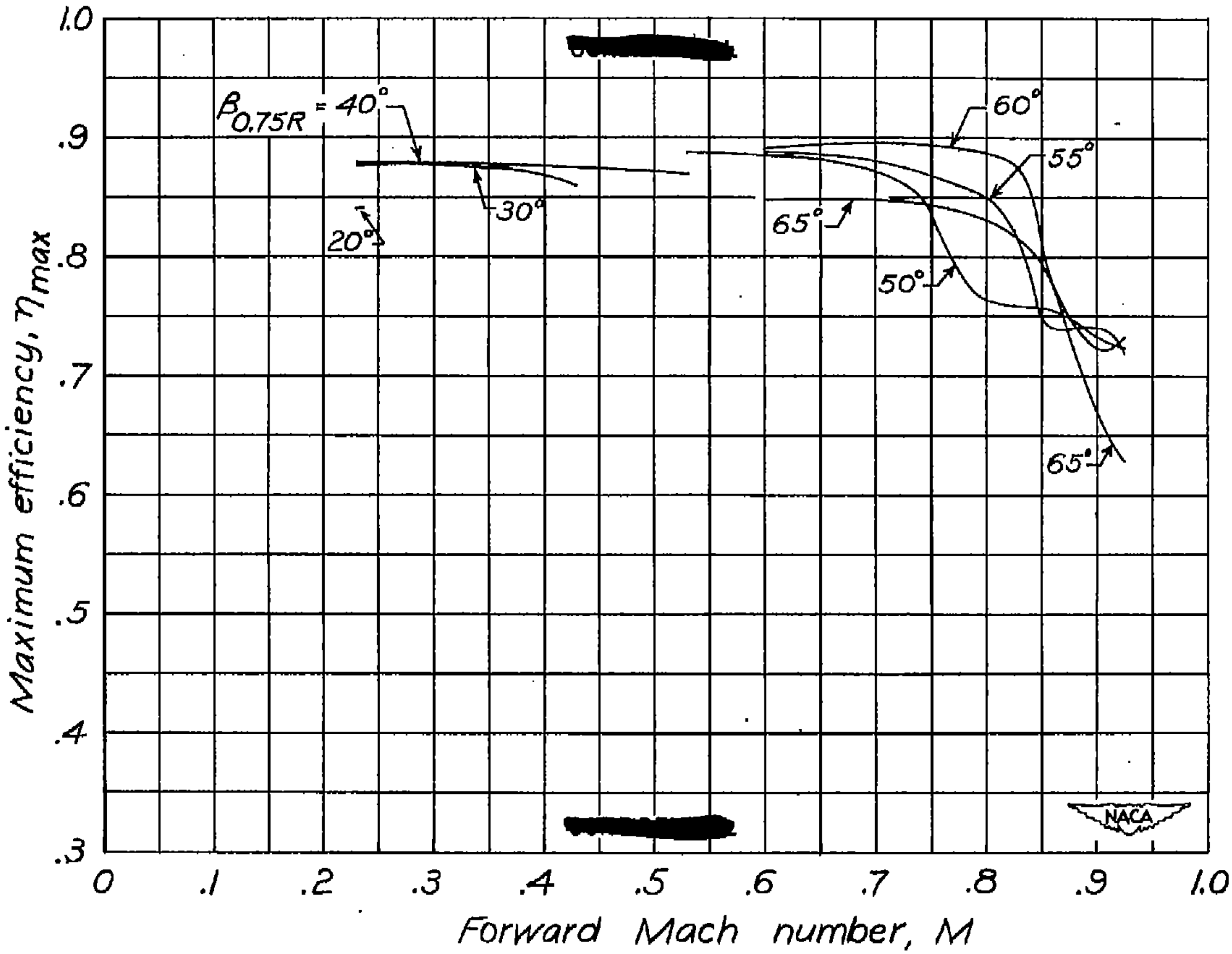

Figure 6.- Effect of forward Mach number on maximum efficiency.

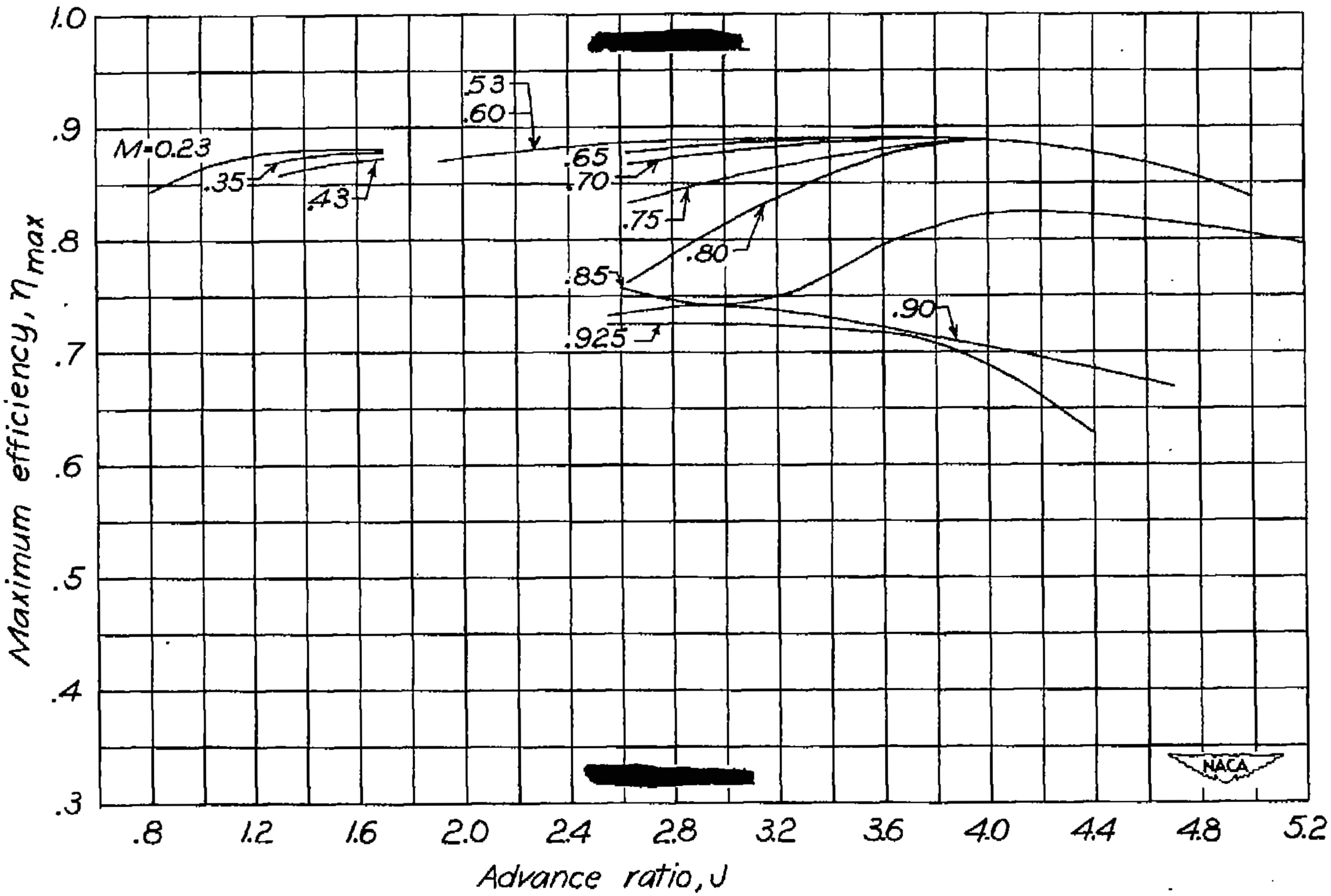

Figure 7.- Effect of compressibility and advance ratio on maximum efficiency.

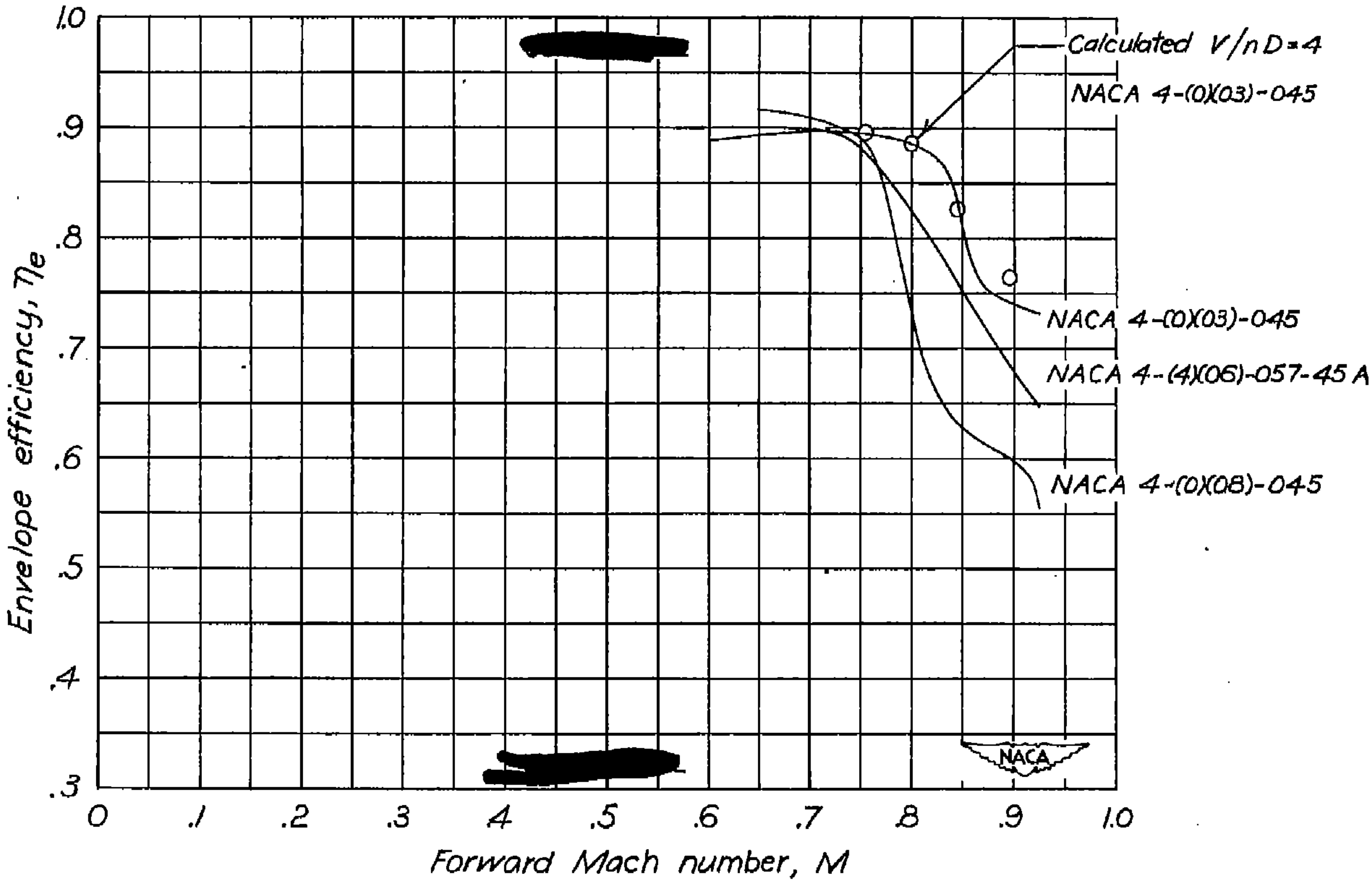

Figure 8.- Comparison of envelope efficiencies.