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RESEARCH MEMORANDUM

PRELIMINARY INVESTIGATION OF TWO FULL-SCALE PROPELLERS TO DETERMINE THE EFFECT OF SWEPT-BACK BLADE TIPS ON PROPELLER AERODYNAMIC CHARACTERISTICS

By

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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RESEARCH MEMORANDUM

PRELIMINARY INVESTIGATION OF TWO FULL-SCALE PROPELLERS TO DETERMINE THE EFFECT OF SWEPT-BACK BLADE TIPS ON PROPELLER AERODYNAMIC CHARACTERISTICS

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SUMMARY

A preliminary investigation of two 10-foot-diameter three-blade propellers has been made to determine the effect of swept-back blade tips on propeller aerodynamic characteristics. The blade tips of one propeller were composed of Clark Y sections, the quarter-chord points of which were on a straight radial line; the other propeller had blade tips composed of the same sections, but the locus of the quarter-chord points formed a swept-back curved line. The design parameters chosen for the swept-back blade tip were as follows: propeller advance ratio of 1.2, helical tip Mach number of 1.0, and section critical Mach number of 0.80.

The value of helical tip Mach number at which the peak envelope efficiency began to decrease was increased from 0.80 for the propeller with straight blade tips to about 0.92 for the propeller with swept-back blade tips, and at values of helical tip Mach number above 0.92 the propeller with swept-back blade tips was found to have a 2-percent increase in peak envelope efficiency. Based on equal power absorption and constant rotational speed, the propeller with swept-back blade tips showed an improvement in efficiency at high rotational speeds and at correspondingly high helical tip Mach numbers; at low rotational speeds, however, the propeller with straight blade tips showed a higher efficiency.

The results of the tests indicated that the efficiency of a propeller may be increased for values of helical tip Mach number above the critical by utilizing sweepback in the blade design.

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INTRODUCTION

Work of the National Advisory Committee for Aeronautics (see reference 1) and recently available German work (reference 2) have shown that the critical Mach number of a wing can be materially increased by the utilization of sweepback or sweepforward. According to German reports a conventional wing having sections with a critical Mach number in the neighborhood of 0.80 may have its critical Mach number increased to 1.10 by sweeping back the wing 45° from the normal to the stream axis. German tests of propellers (reference 3) incorporating swept-back blades show an increase in efficiency of about 3 to 4 percent over propellers with conventional blade design. The available German data, however, is very limited and the present tests have been undertaken to determine rapidly the feasibility of using sweepback in propeller blade designs.

A series of comparative tests of a propeller with swept-back blade tips and a propeller with the same blade-form characteristics but no sweepback of the tips has been made in the Langley 16-foot high-speed tunnel. The propeller blades as tested are modified conventional blades of Curtiss 89324 design. The swept-back propeller, therefore, does not have truly swept-back blades, but rather a modified swept-back tip. The blades were tested as three-blade propellers in a Curtiss electric hub.

SYMBOLS

C_P	power coefficient	$\left(P/\rho n^3 D^5\right)$
C_T	thrust coefficient	$\left(T/\rho n^2 D^4\right)$
D	propeller diameter, feet	
J	propeller advance ratio	(V/nD)
M	air-stream Mach number	
M_{cr}	section critical Mach number	
M_t	helical tip Mach number	$\left(M\sqrt{1+\left(\frac{\pi}{J}\right)^2}\right)$
P	power absorbed by propeller, foot-pounds per second	
R	radius to tip	

T propeller thrust, pounds

V airspeed, feet per second

b blade width, feet

h blade section maximum thickness, feet

n propeller rotational speed, revolutions per second

r radius to any blade element

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

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

ρ mass density of air, slugs per cubic foot

APPARATUS

Propeller Dynamometer

A 2000-horsepower propeller dynamometer was used to test the propellers in the Langley 16-foot high-speed tunnel. Figure 1 is a photograph of the propeller with swept-back blade tips mounted on the dynamometer. In order to expedite the tests, no spinners were used; as a consequence, the hub was left exposed to the air stream.

Propeller Blades

Both the straight tip blades and the swept-back tip blades used in these tests were modified from standard duralumin blades of the Curtiss 89324 design incorporating Clark Y sections (fig. 2). The diameter of the original standard blade was reduced from 13 feet to 10 feet by cutting off the tips. New tips were formed on the reduced-diameter blades beginning at the 45-inch-radius section; in one case the locus of the section quarter-chord points was maintained as a straight radial line, and in the case of the swept-back blade tips the locus of the section quarter-chord points was swept back as a curved line. It should be noted that the taper ratio for these propeller blades is higher than normally employed.

Tests of swept-back wings have shown that the critical Mach number of a conventional wing can be increased by sweeping back the

wing and that the increase in critical Mach number is a function of the cosine of the angle of sweepback. Based on this conclusion, the equation of the curve of sweepback for the present design was derived by using the following design parameters: section critical Mach number of the blade, propeller rotational speed, and advance ratio at which the swept-back propeller is intended to operate. The curve starts at the radial station where the section speed just reaches the critical value; from that station out to the blade tip, the locus of the section quarter-chord points is swept back so that at each radial station the excess section speed above the critical is compensated by the local sweepback. The design parameters chosen for the blades used in the tests were as follows: $J = 1.2$, $M_t = 1.0$, and $M_{cr} = 0.80$. These design conditions were not chosen to represent any design flight condition. Since the maximum amount of sweepback was desired, the width of the blades determined the radial station at which the curve of sweepback started and indirectly influenced the choice of the design parameters.

The sections of the blades with swept-back tips and the sections of the blades with straight tips were the same within manufacturing tolerances. The blade-pitch distribution was the same for both propellers and was measured in a plane perpendicular to the radial center line of the blades. (See fig. 2.) Figures 3 and 4 are photographs of the blades.

TESTS

The test results are presented in the usual propeller coefficient form as plots of thrust coefficient, power coefficient, and efficiency against advance ratio.

Propeller thrust as used herein is defined as the increase in shaft tension caused by the hub-to-tip part of the propeller blades. The indicated propeller thrust has been corrected by the amount of the tare thrust found by operating the dynamometer with the propeller hub installed without propeller blades at the same values of airspeed as were used in the propeller tests. The effect of rotational speed on the tare thrust was negligible, the error being within the experimental accuracy of the tests.

Thrust, torque, and rotational speed were measured for each of the two propellers at blade angles of 20°, 25°, 30°, 35°, 40°, and 45° at the three-quarter (45-in.) radius. A constant rotational speed was used for each test, and a range of advance ratio $\left(J = \frac{V}{nD}\right)$ was covered by changing the tunnel airspeed, which was varied from about 60 miles per hour to 425 miles per hour.

In order to cover a range of tip Mach number, the tests were run at rotational speeds of 1350, 1600, 1800, 2000, 2100, and 2160 revolutions per minute. Because of the limited torque available, however, high rotational speeds were not run at high blade angles. At 2000, 2100, and 2160 revolutions per minute the blade angles were set at 20°, 25°, and 30°; at 1600 and 1800 revolutions per minute the blade angles were set at 20°, 25°, 30°, and 35°; and at 1350 revolutions per minute the blade angles were set at 20°, 25°, 30°, 35°, 40°, and 45°. The range of tip Mach number varied from 0.67 to 1.13.

The Glauert tunnel-wall correction (reference 4) was applied to the data obtained in the tests and amounted to less than 2 percent in the range of peak efficiency.

RESULTS AND DISCUSSION

Faired curves of thrust coefficient, power coefficient, propeller efficiency, air-stream Mach number, and helical tip Mach number plotted against advance ratio are presented in figures 5 to 16 for the two propellers. Test points shown in the figures are given for thrust and power coefficients. Repeated runs on former propeller tests made in the Langley 16-foot high-speed tunnel have shown data, acquired with the equipment used, to be accurate within 1.0 percent. Comparative data, therefore, are presented as being accurate within 1.0 percent for the present tests.

Effect of Swept-Back Tips on Maximum Efficiency

A comparison of the envelope curves of propeller efficiency, as shown in figure 17, indicates an increase in efficiency over most of the range for the propeller with swept-back blade tips at high rotational speeds - and consequently at high tip Mach numbers - and a loss in efficiency over most of the range at low rotational speeds - and consequently at low tip Mach numbers. The peak envelope efficiencies at 1350 and 1600 revolutions per minute, however, are the same for both propellers.

The improvement in efficiency caused by sweeping back the propeller blade tips is also illustrated in figure 18, in which the envelopes of the efficiency curves are plotted against tip Mach number. An envelope has been made over the peaks of these curves and affords a comparison of the peak efficiencies for the two propellers as the tip Mach number is varied. The efficiency of the propeller with straight blade tips starts to decrease with increasing tip Mach number at a value of tip Mach number of approximately 0.80, whereas the

efficiency of the propeller with swept-back blade tips maintains a constant value until a tip Mach number of 0.92 is reached and then decreases from this point at the same rate as the propeller with straight blade tips. At values of tip Mach number below 0.80, no appreciable difference was noted in the peak envelope efficiencies of the two propellers; but at helical tip Mach numbers above 0.92, the propeller with swept-back blade tips is approximately 2 percent more efficient.

Constant-Power Propeller Operation

At the same values of blade angle, rotational speed, and advance ratio the propeller with swept-back tips absorbed more power and developed more thrust than the propeller with straight tips. This difference is most pronounced at the high rotational speeds. Although small changes in the blade-angle setting could cause the small differences that occur at the low rotational speeds, the consistently higher thrust and torque for the propeller with swept-back tips is believed to be caused by a greater upwash at the tip sections and also by a delay in adverse compressibility effects at the high tip Mach numbers.

Although propeller theory is based on the assumption of independent operation of propeller blade elements, mutual interference of the blade elements does exist and the operation of each element is affected by the net induced flow created by all the blade elements. The flow field of the inboard blade elements tends to produce an upwash in the vicinity of the blade tip that effectively increases the angle of attack and the operating lift coefficient of the tip sections. This upwash, normally manifest as a tip vortex, becomes stronger with increasing distance downstream and attains nearly its full strength a few chords behind the lifting line; hence the tip sections of the propeller with swept-back tips operate in a stronger upwash and, consequently, at higher lift coefficients than those of the propeller with straight tips. Since a large part of the air load is concentrated near the tip sections, a small increase in upwash at the tip produces a noticeable change in the lift and, hence, in the thrust and torque. Wind-tunnel tests of wings with sweepback have shown a similar increase in lift at the outboard sections.

The thrust and torque for the propeller with swept-back tips are further increased at high tip Mach numbers. The effect of sweepback is to increase the Mach number at which there is a loss in lift and a rapid increase in drag. At speeds above the critical value of the airfoil sections, the swept-back tip sections will maintain their lift whereas the unswept tip sections will experience a loss in lift and an increase in drag. As a consequence of the higher lift at the tip

sections, the propeller with swept-back tips will absorb more power and develop a greater thrust than the propeller with straight tips at the same operating conditions.

The efficiencies of the two propellers at constant power coefficient are compared in figure 19. Over most of the range of advance ratio covered in the tests, the propeller with swept-back tips shows a lower efficiency at the low rotational speeds, the difference in efficiency being greater for the low values of power coefficient. As rotational speed is increased, and consequently tip Mach number, the differences in efficiency become less. At rotational speeds above 1800 revolutions per minute the propeller with swept-back tips shows a distinct advantage.

CONCLUSIONS

As a preliminary step in the development of a swept-back propeller blade, comparative tests were made of two full-scale three-blade propellers to determine the effect of sweeping back the blade tips. The results of the tests led to the following conclusions:

1. The value of helical tip Mach number at which peak envelope efficiency began to decrease was increased from 0.80 for the propeller with straight blade tips to about 0.92 for the propeller with swept-back blade tips.

2. Based on equal power absorption and constant rotational speed, the propeller with swept-back blade tips showed an increase in efficiency over the propeller with straight blade tips at high values of helical tip Mach number and a loss of efficiency at low values of helical tip Mach number.

3. In the range of helical tip Mach number above the critical value of 0.92, the efficiency of the propeller with swept-back blade tips was about 2 percent greater than that of the propeller with straight blade tips.

4. These preliminary tests indicate that significant gains in the propeller operation may be had by employing sweepback in the blade design.

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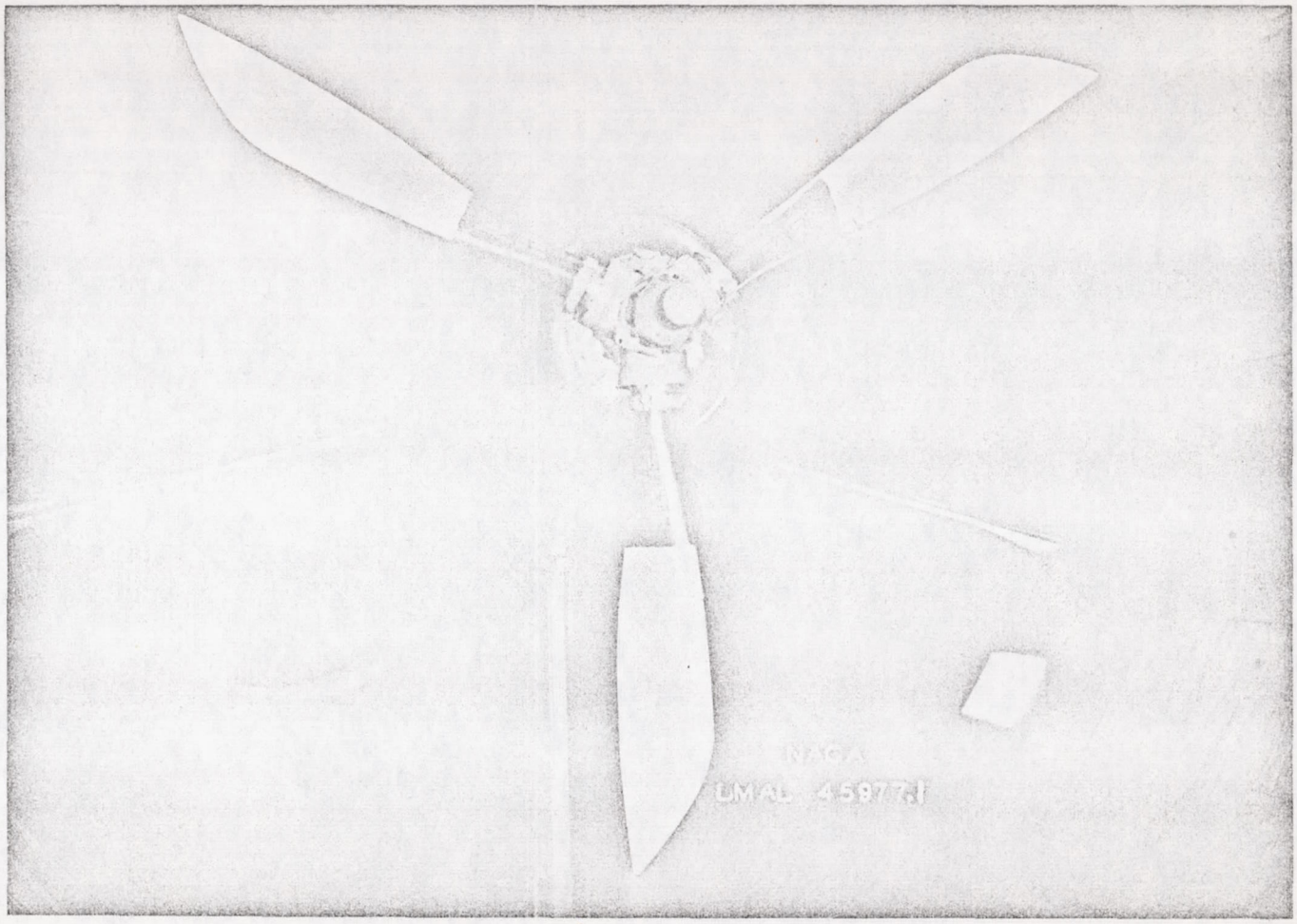

Figure 1.- Propeller with swept-back blade tips mounted on dynamometer in test section of Langley 16-foot high-speed tunnel.

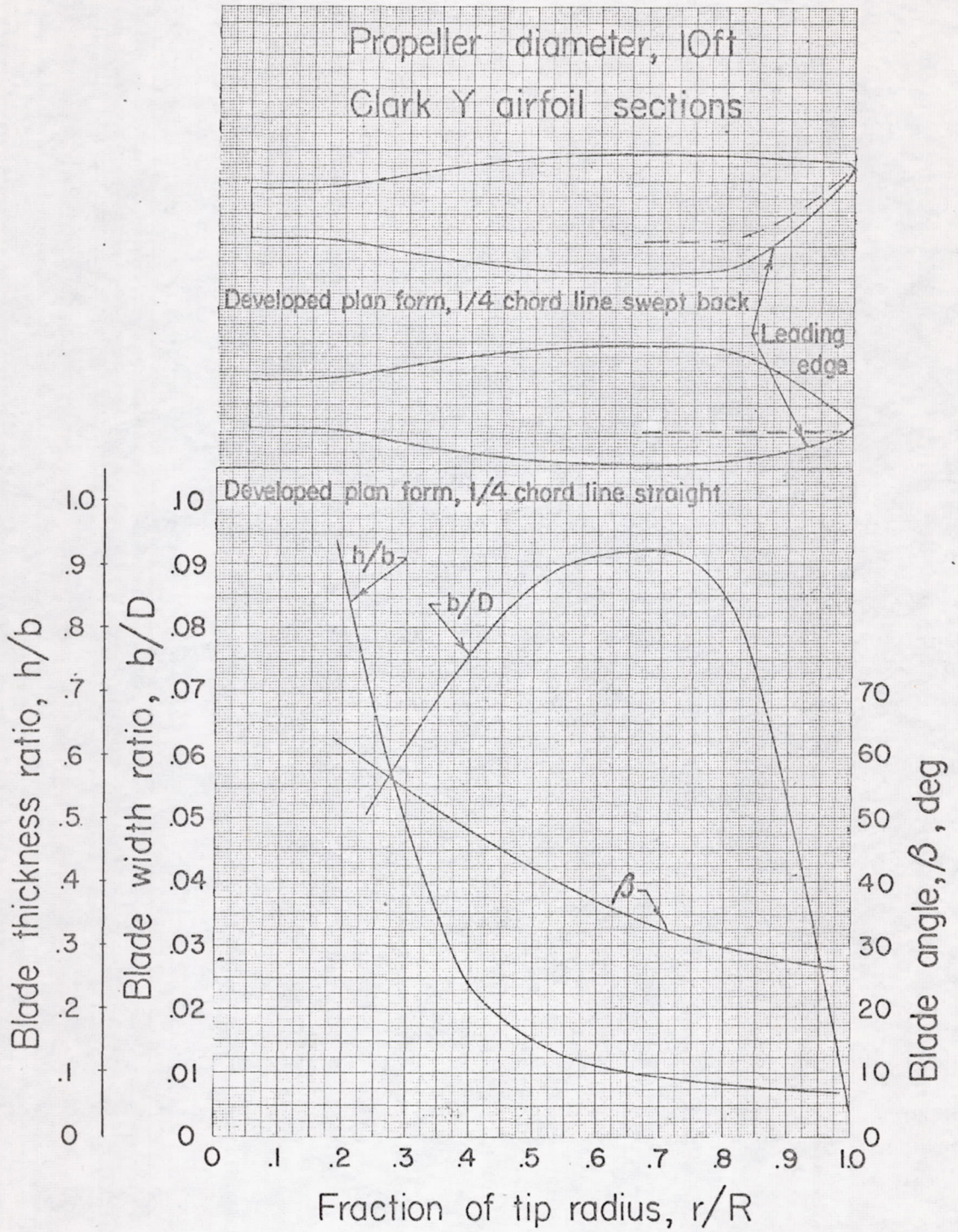

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Figure 2.—Blade-form characteristic curves for propeller blades with straight and swept-back tips.

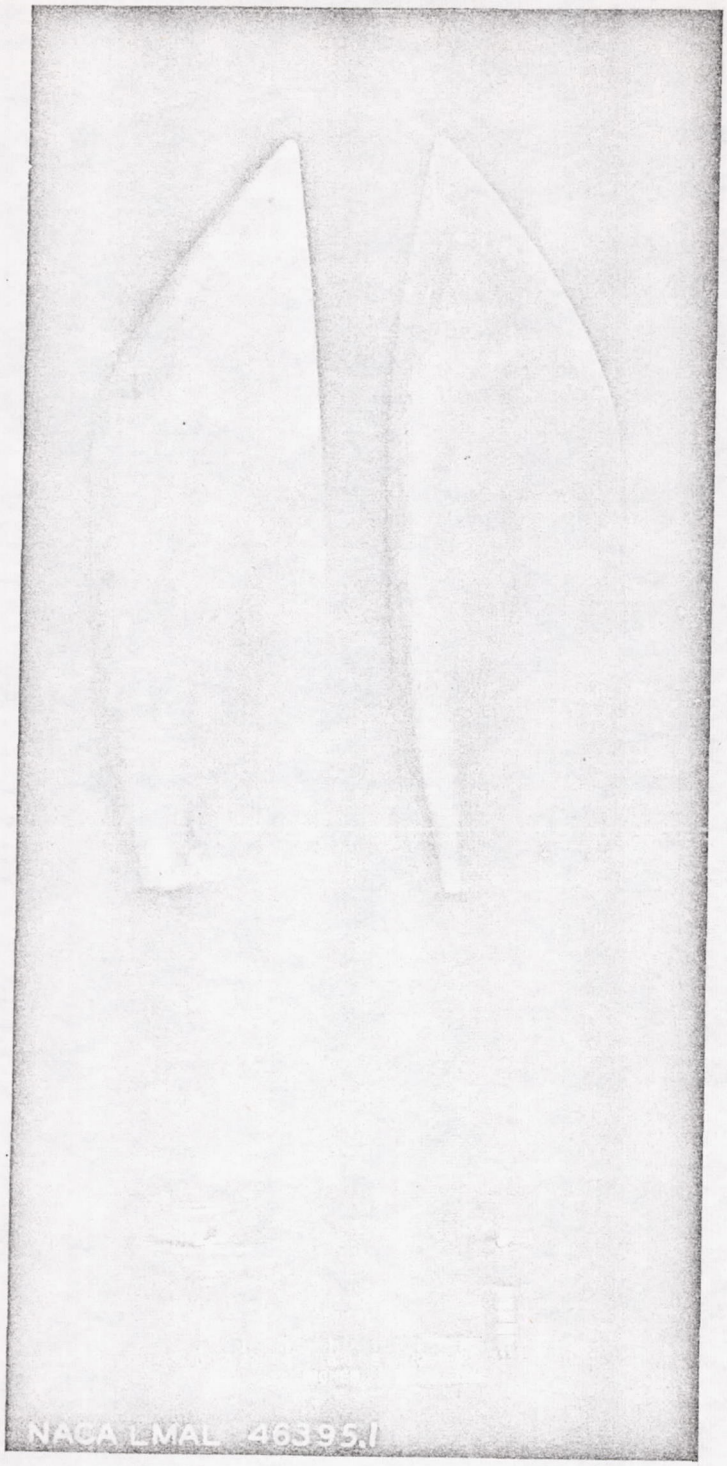


Figure 3.- Propeller blade with swept-back tip (left) and straight tip (right). Cambered surface.

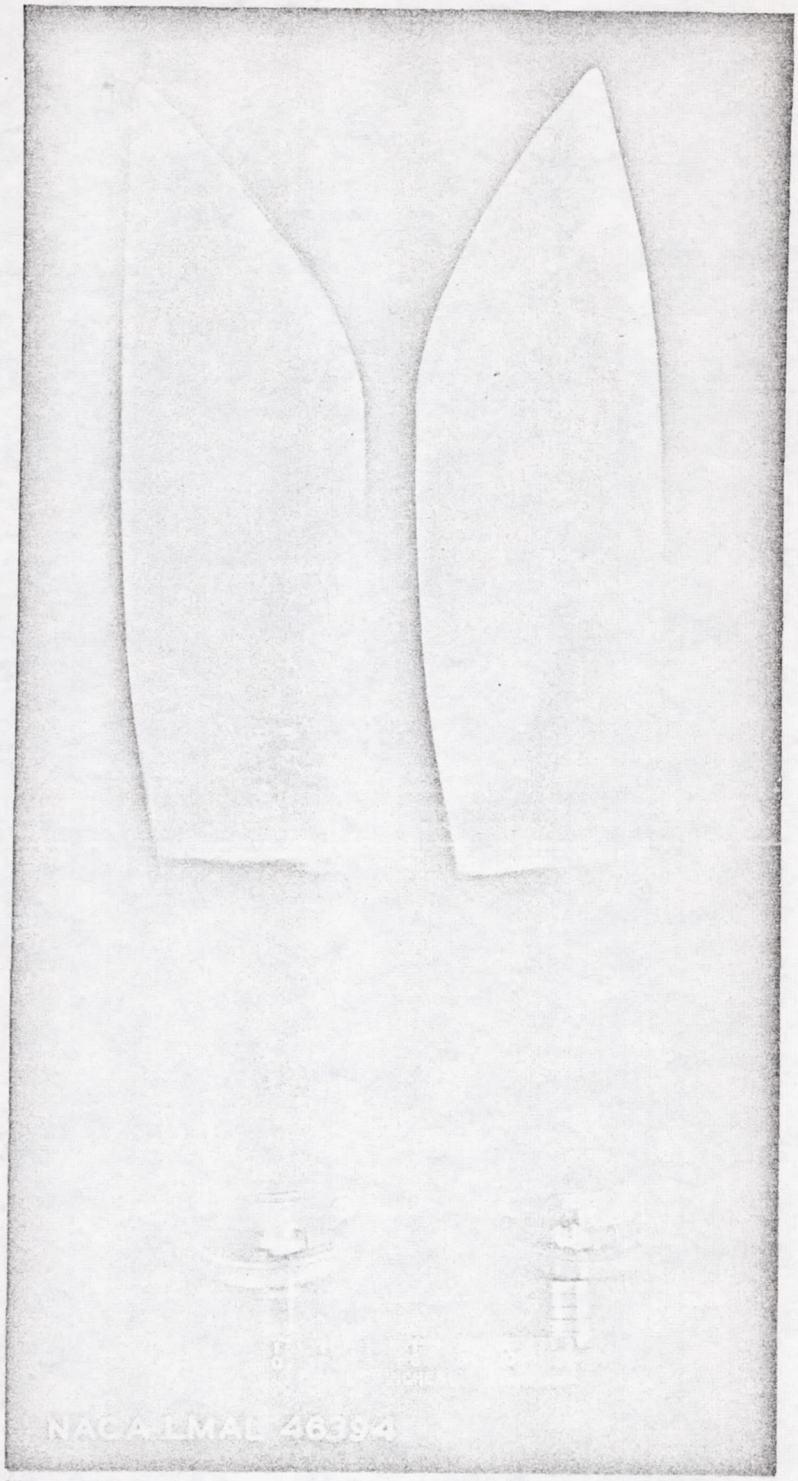
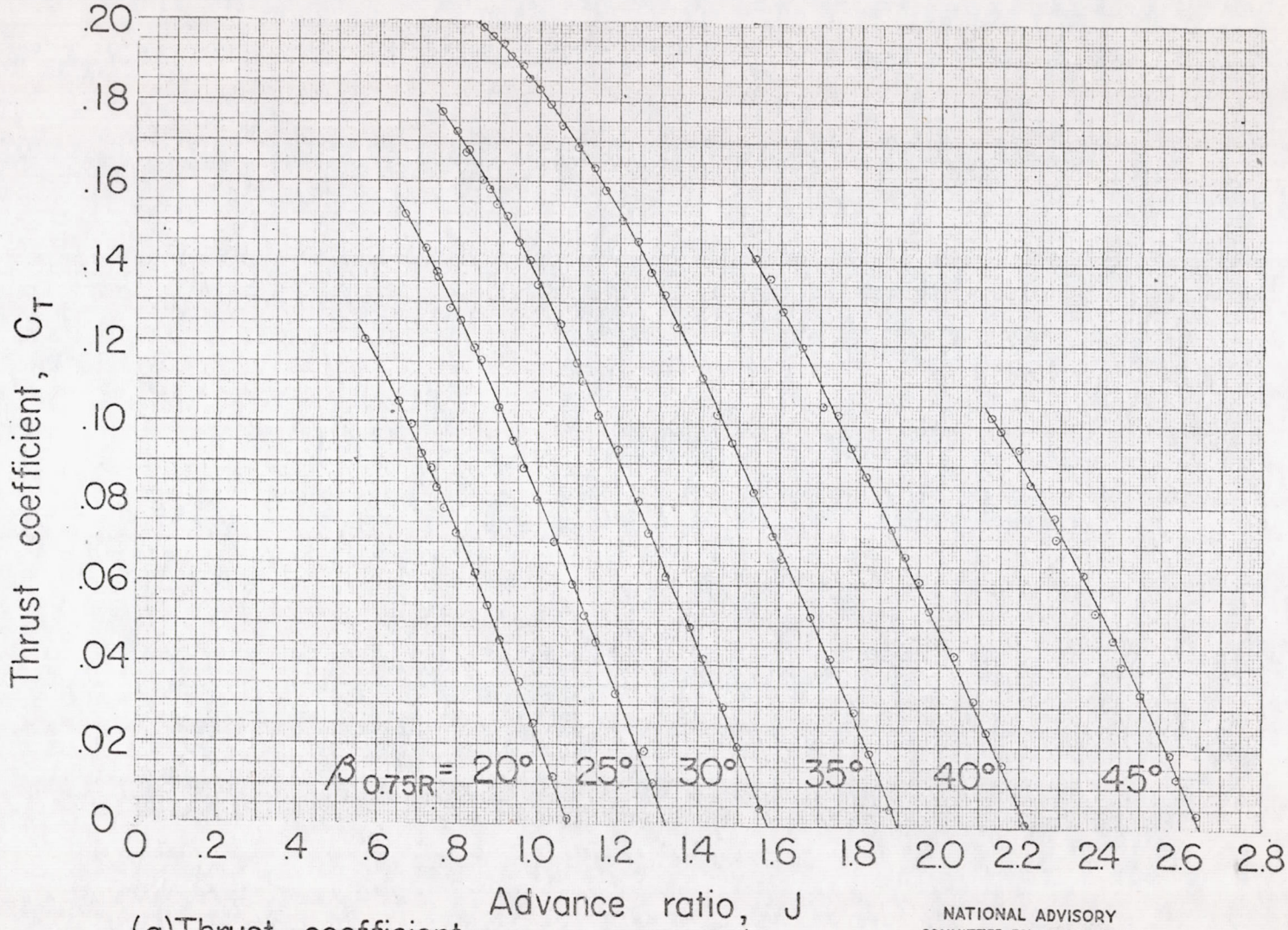


Figure 4.- Propeller blade with swept-back tip (left) and straight tip (right). Thrust surface.



(a)Thrust coefficient.

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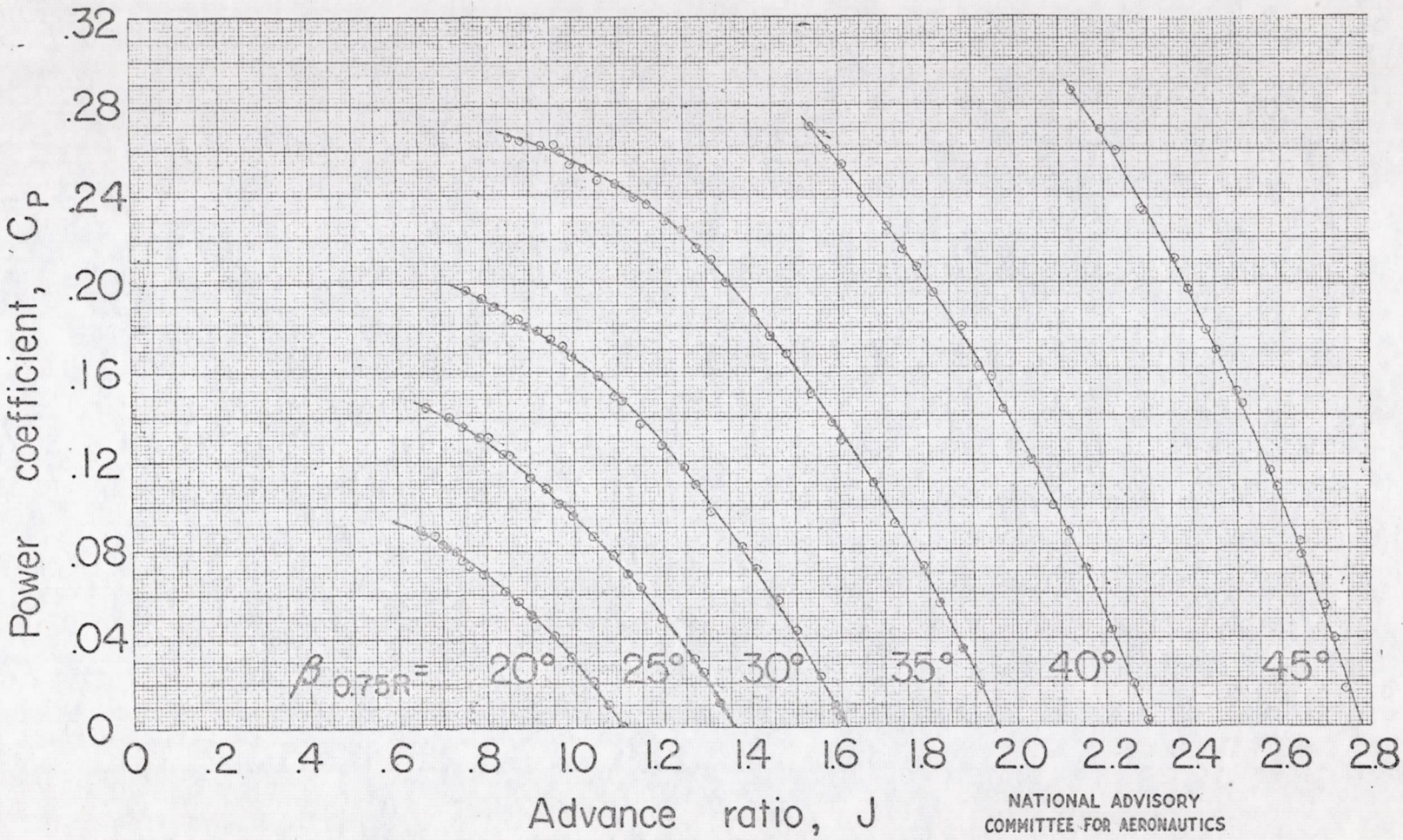
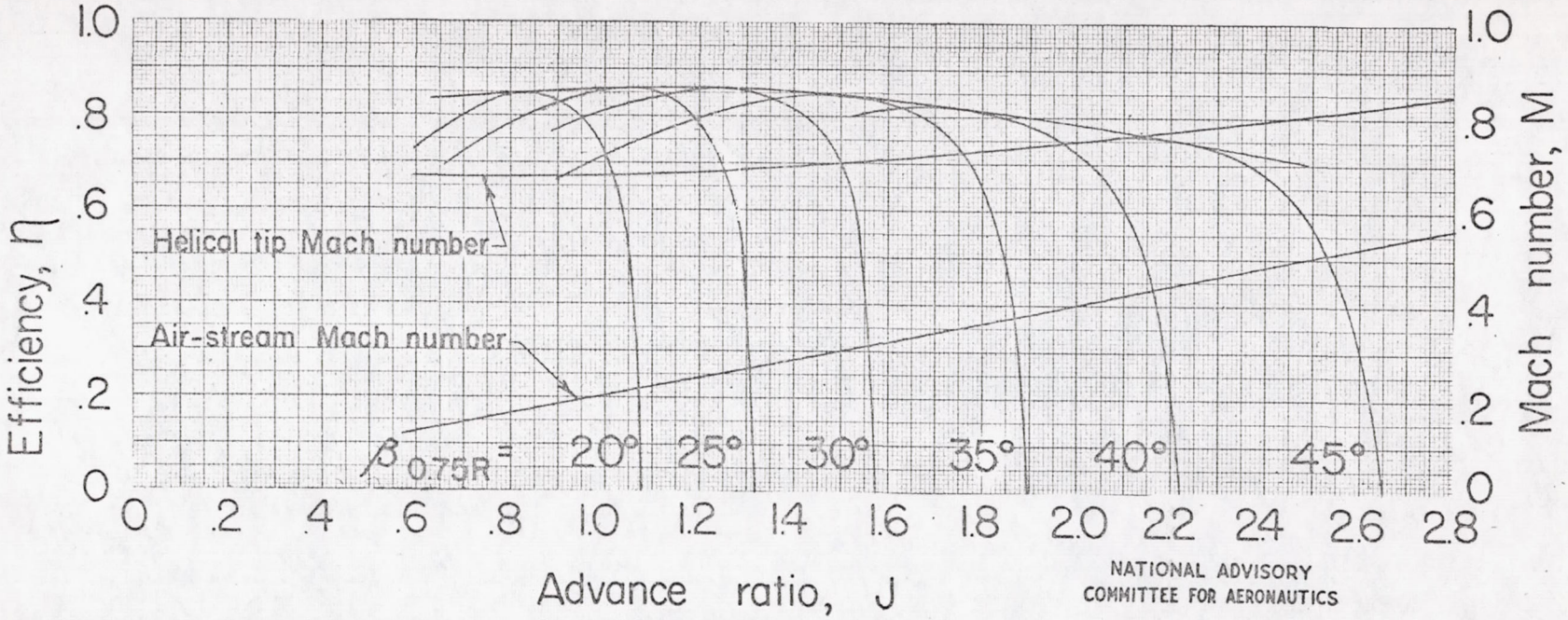
Figure 5.—Characteristics of propeller with swept-back blade tips at 1350 rpm.



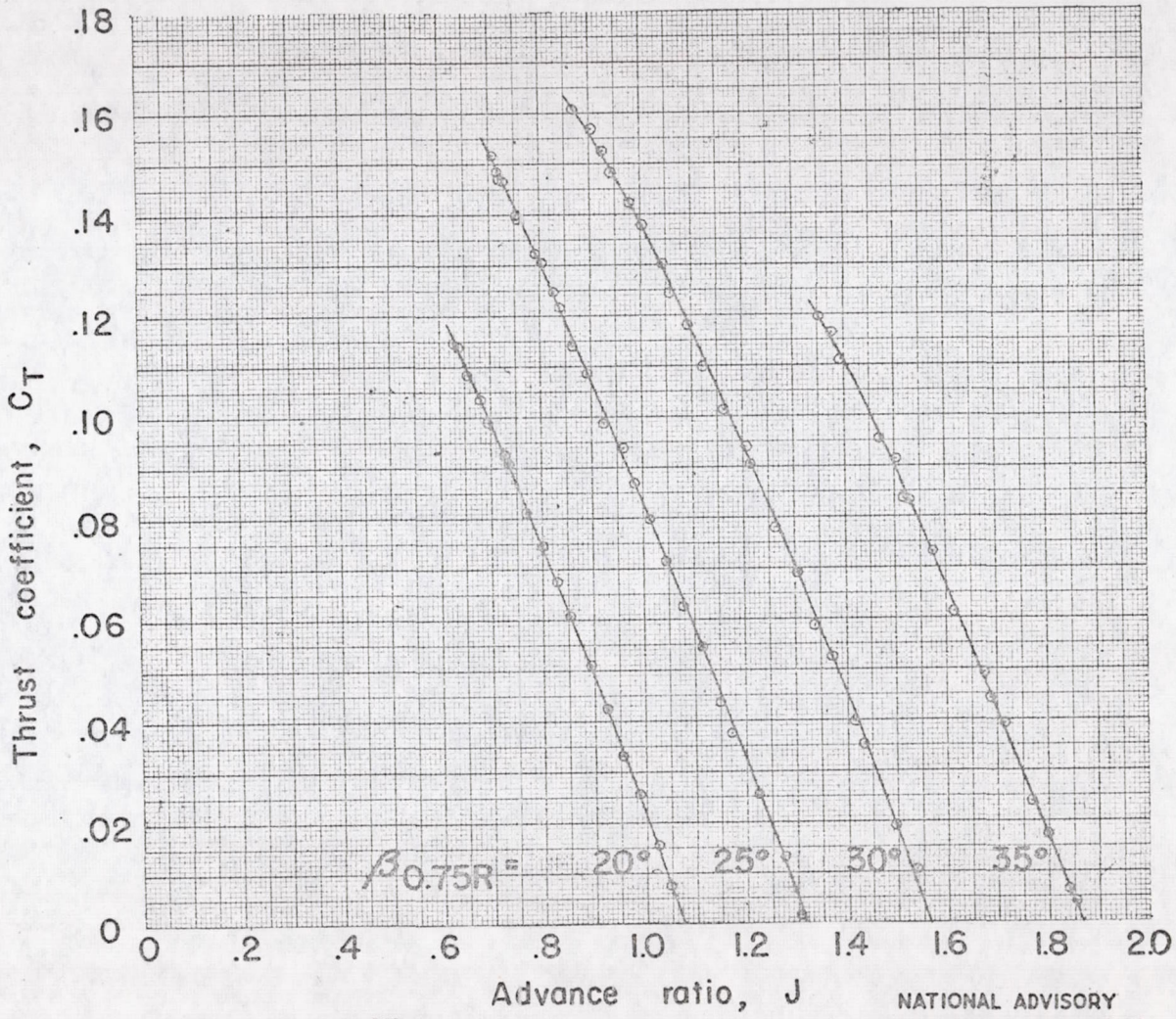
(b) Power coefficient.

Figure 5 .— Continued.



(c) Efficiency.

Figure 5.—Concluded.



(a) Thrust coefficient.

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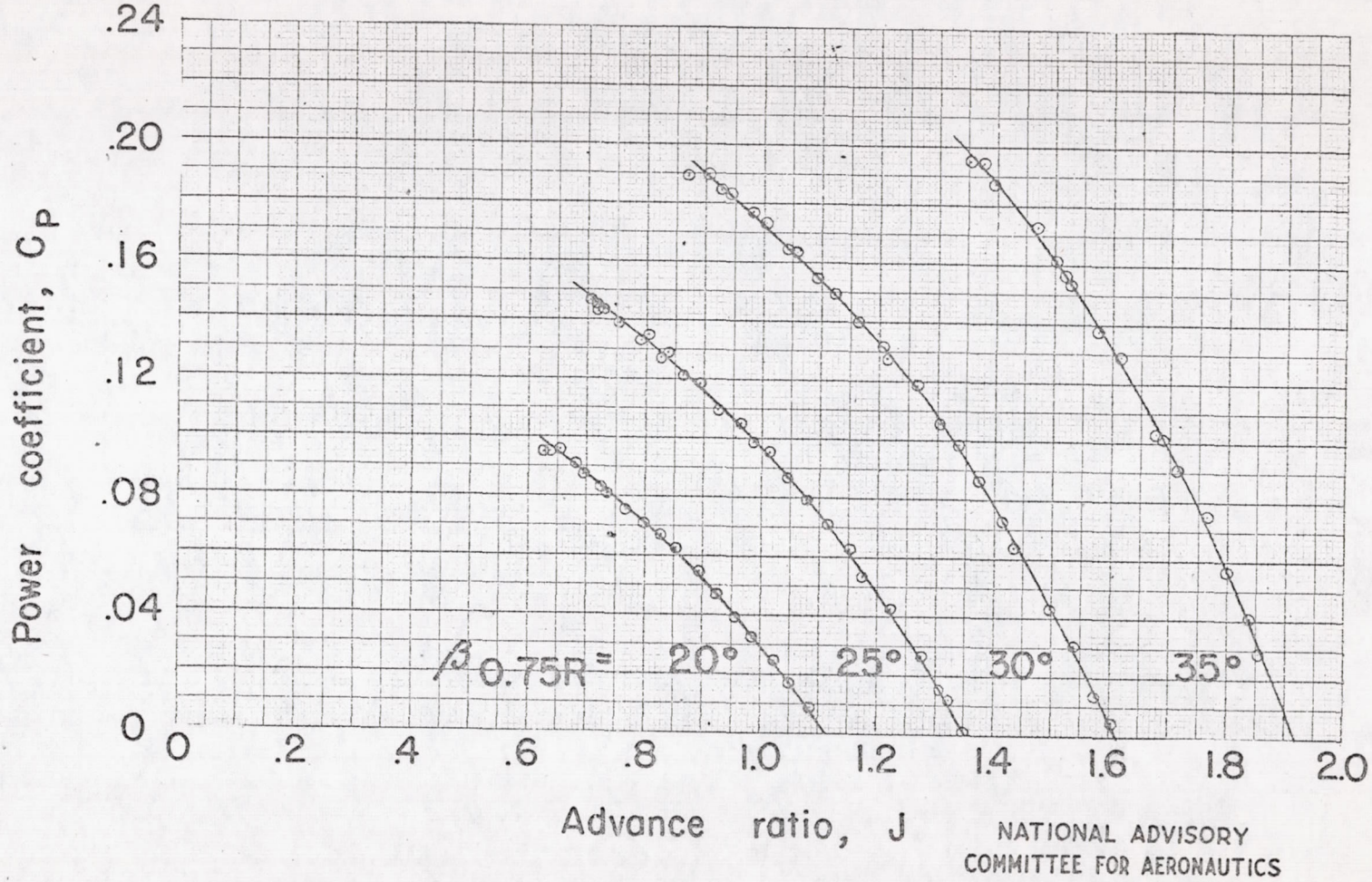
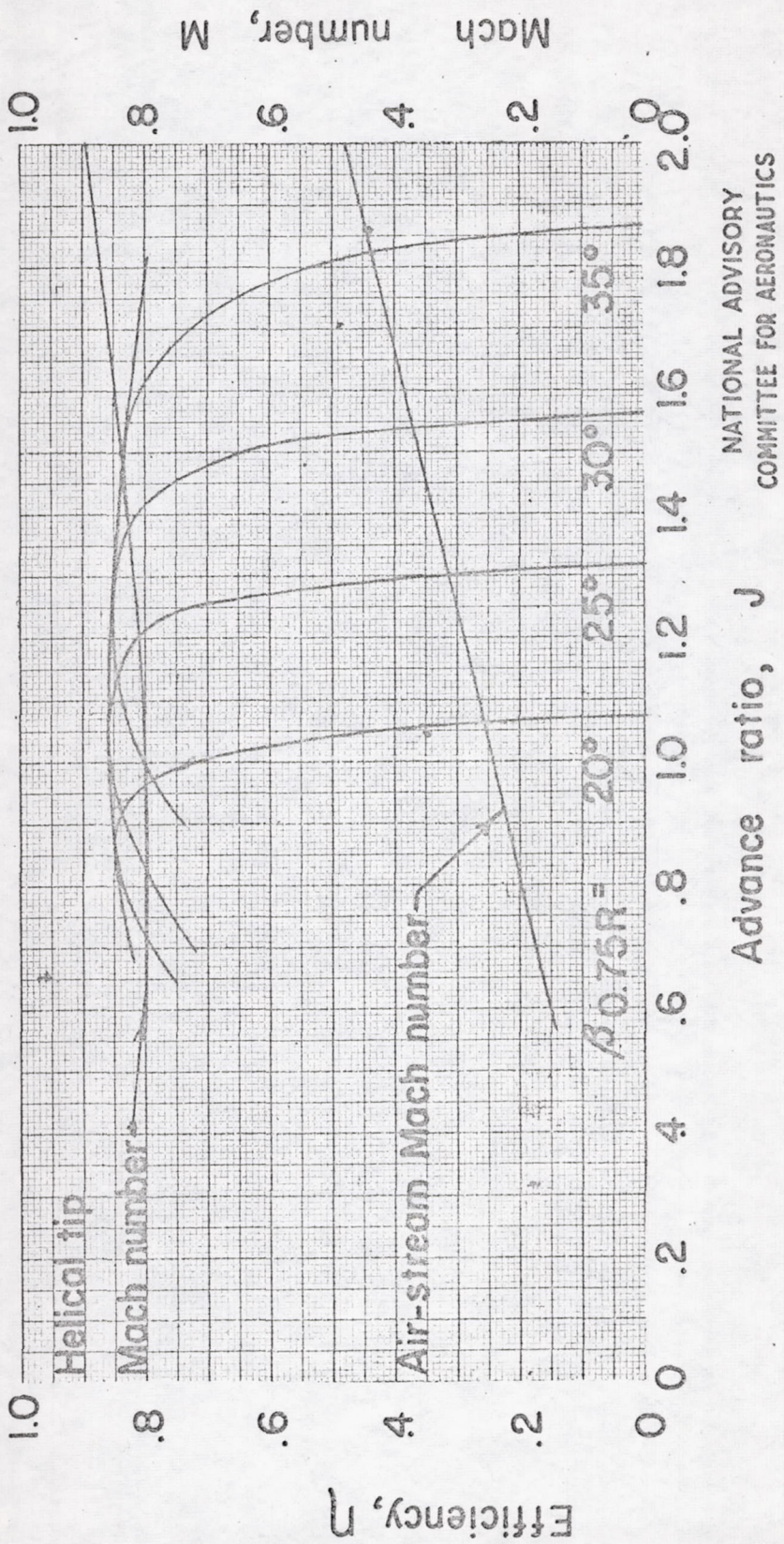
Figure 6.—Characteristics of propeller with swept-back blade tips at 1600 rpm.



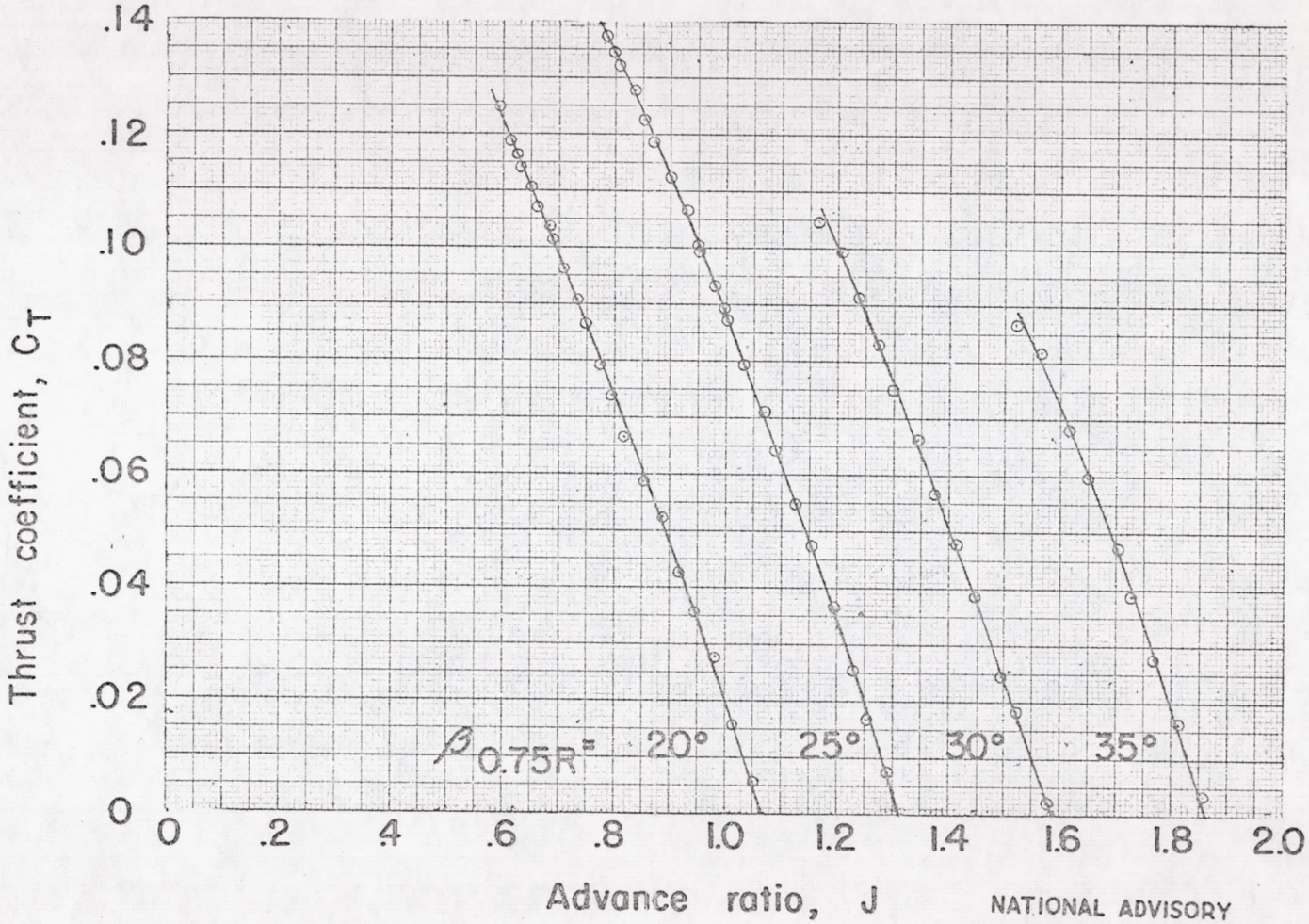
(b) Power coefficient.

Figure 6 .—Continued.



(c) Efficiency.

Figure 6 .— Concluded.



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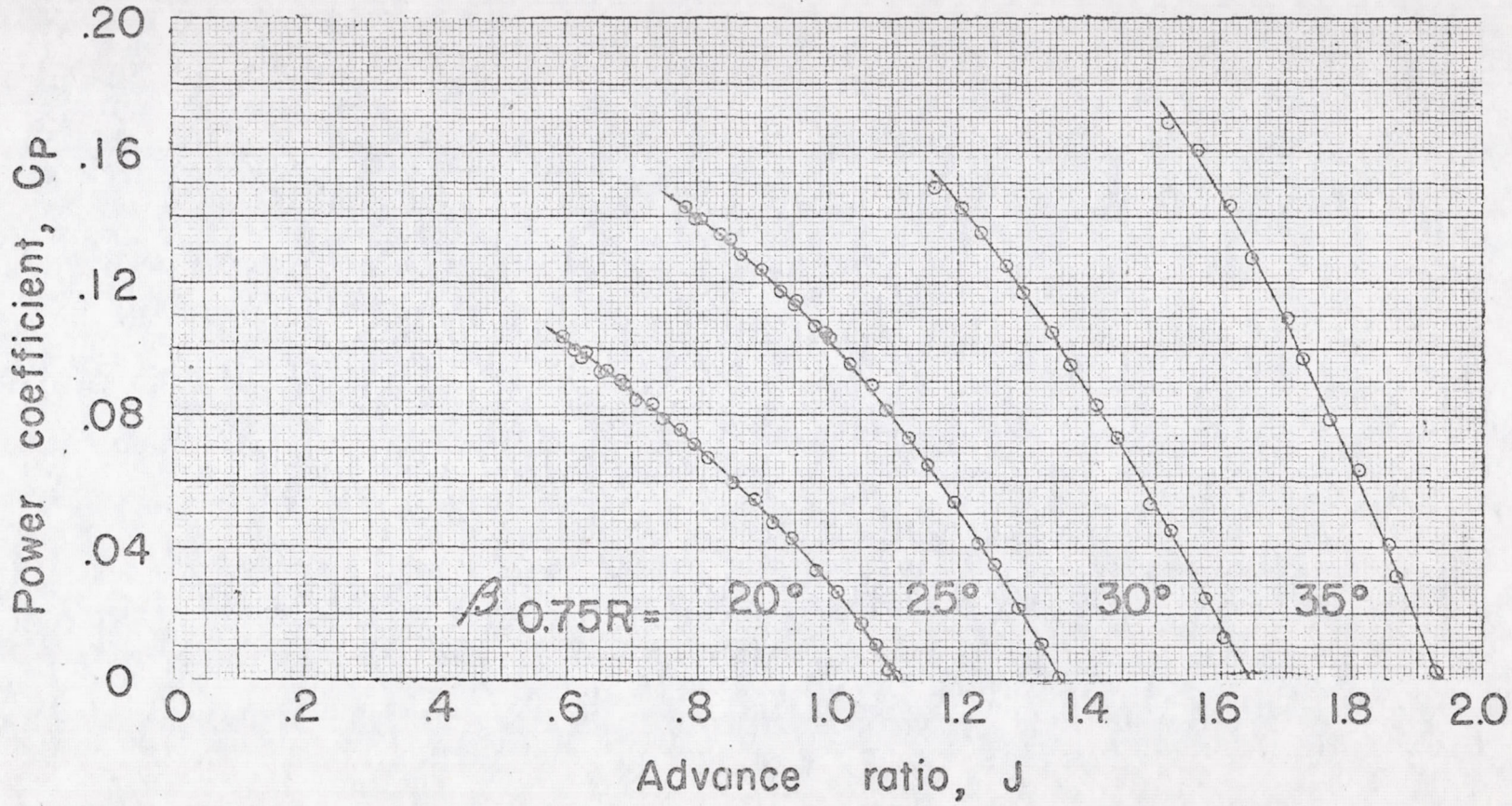
(a) Thrust coefficient.

Figure 7.—Characteristics of propeller with swept-back blade tips at 1800rpm.



(b) Power coefficient.

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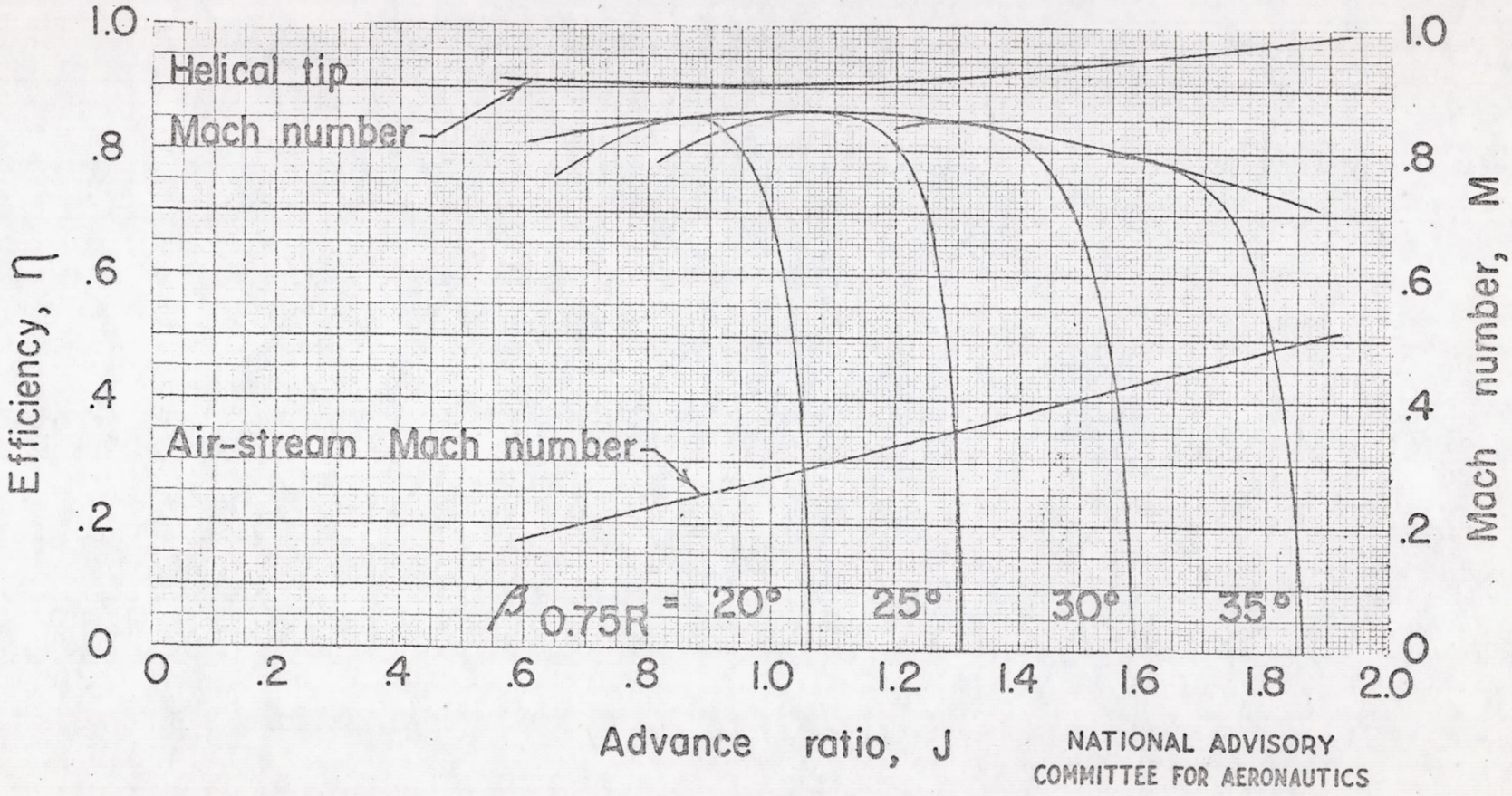
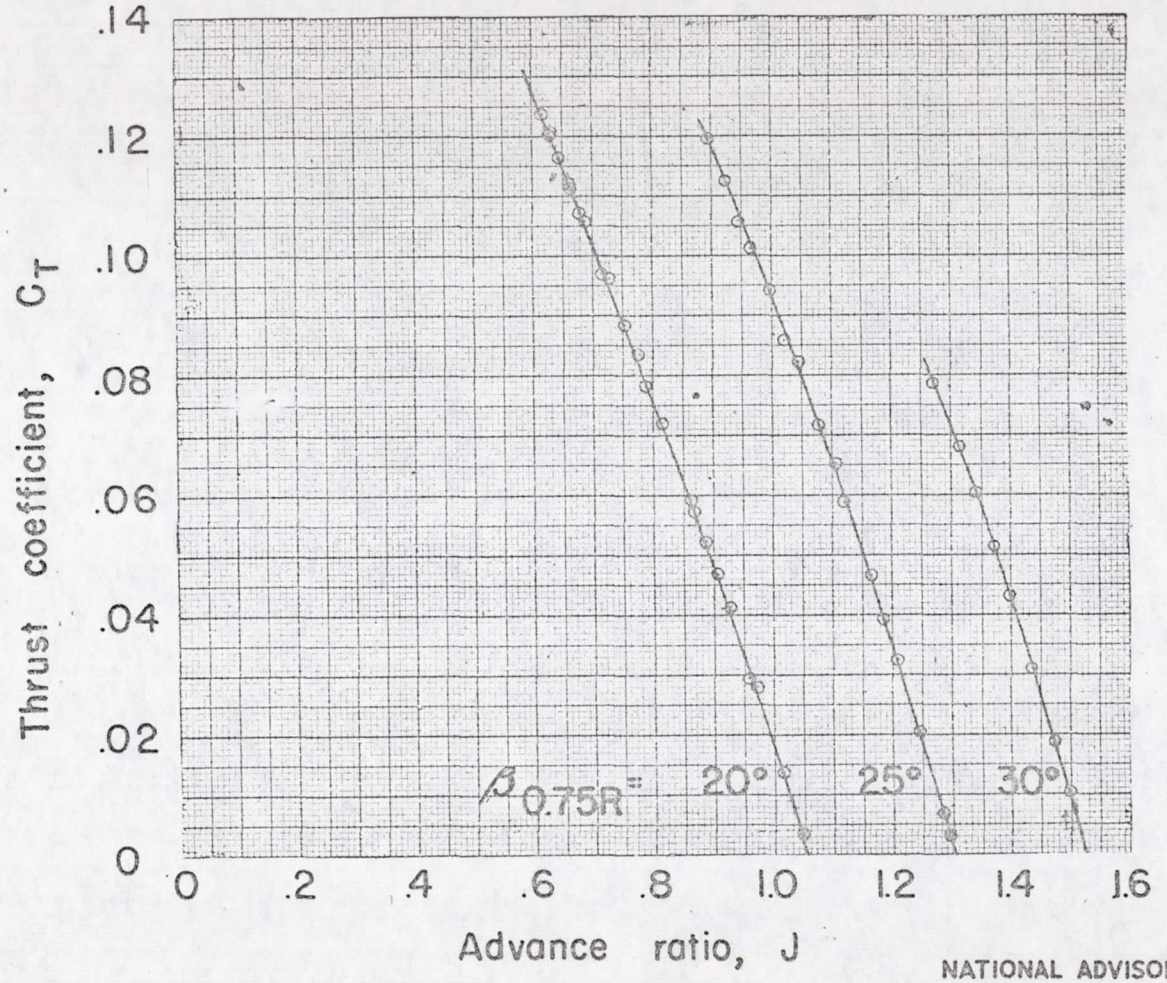
Figure 7 .—Continued.



(c) Efficiency.

Figure 7 .— Concluded.



(a) Thrust coefficient.

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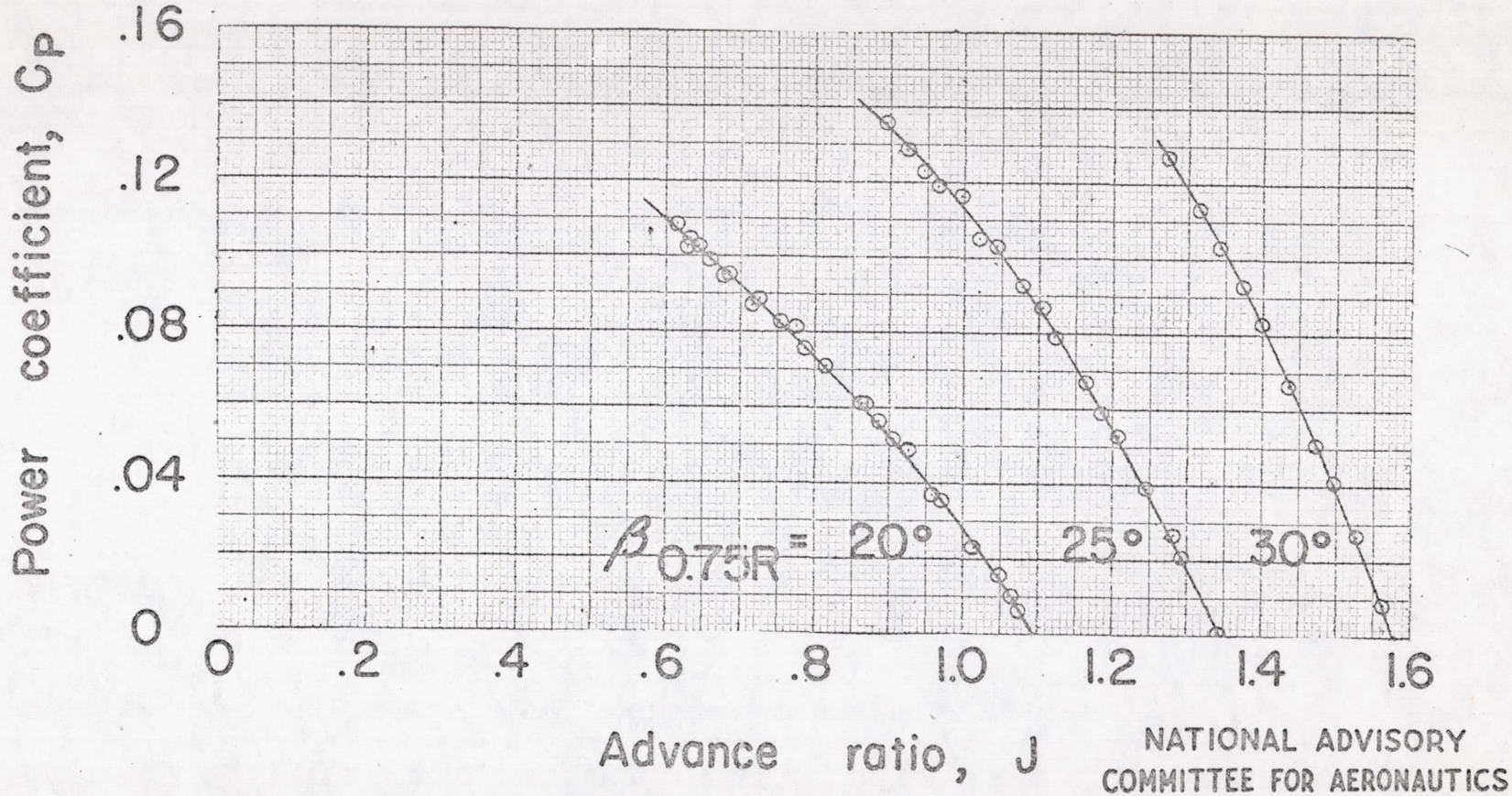
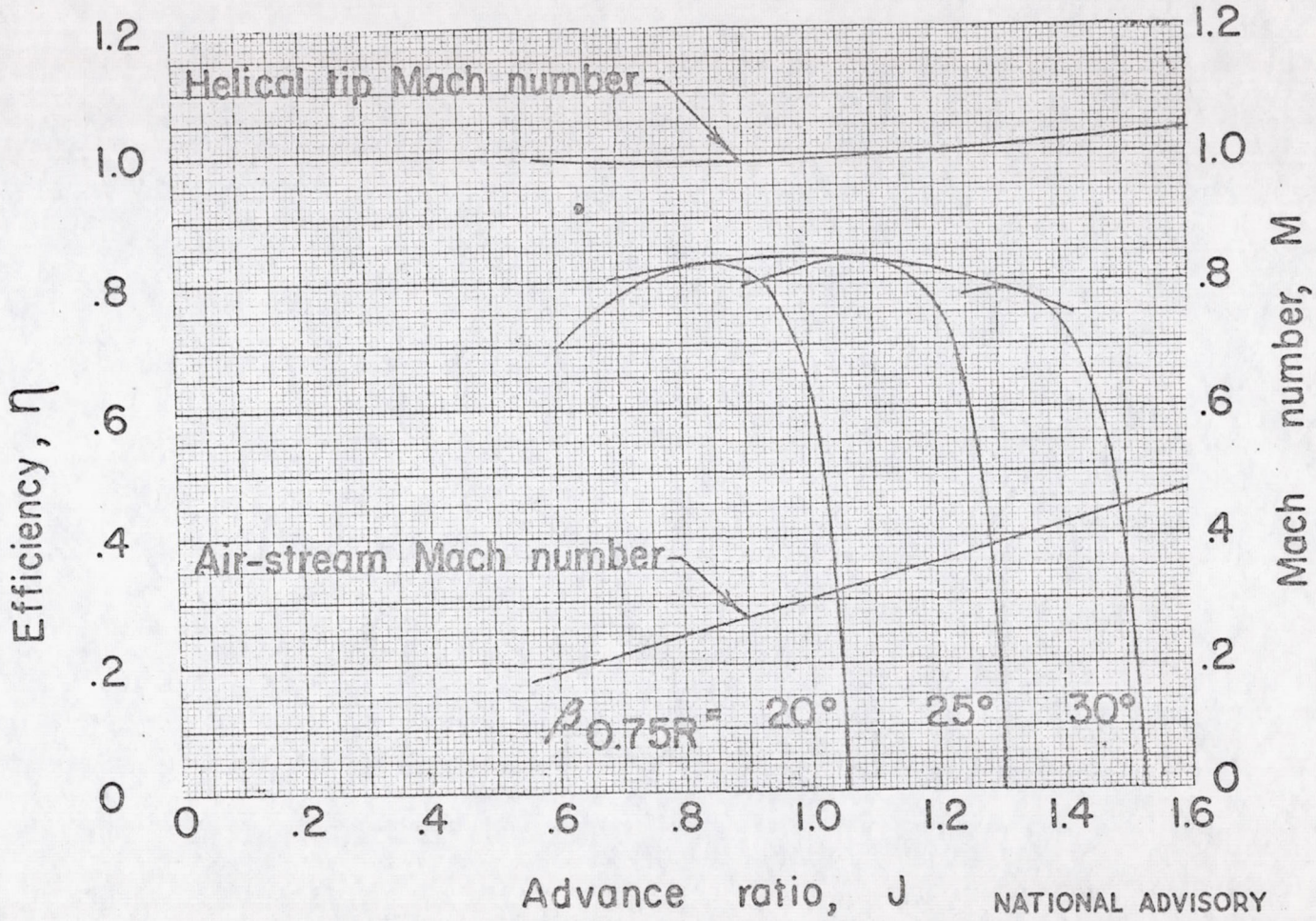
Figure 8 .—Characteristics of propeller with swept-back blade tips at 2000rpm.



(b) Power coefficient.

Figure 8 .— Continued.



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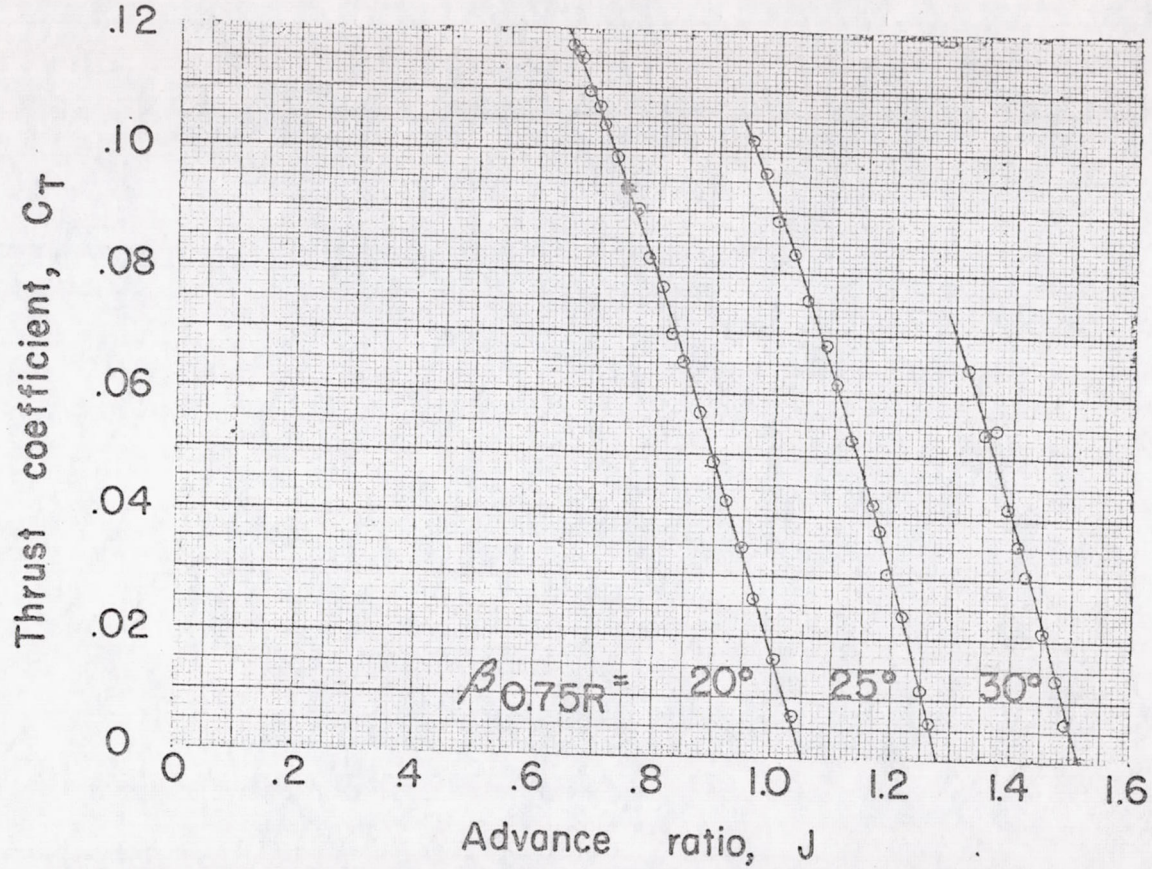
(c) Efficiency.

Figure 8.—Concluded.



(a) Thrust coefficient.

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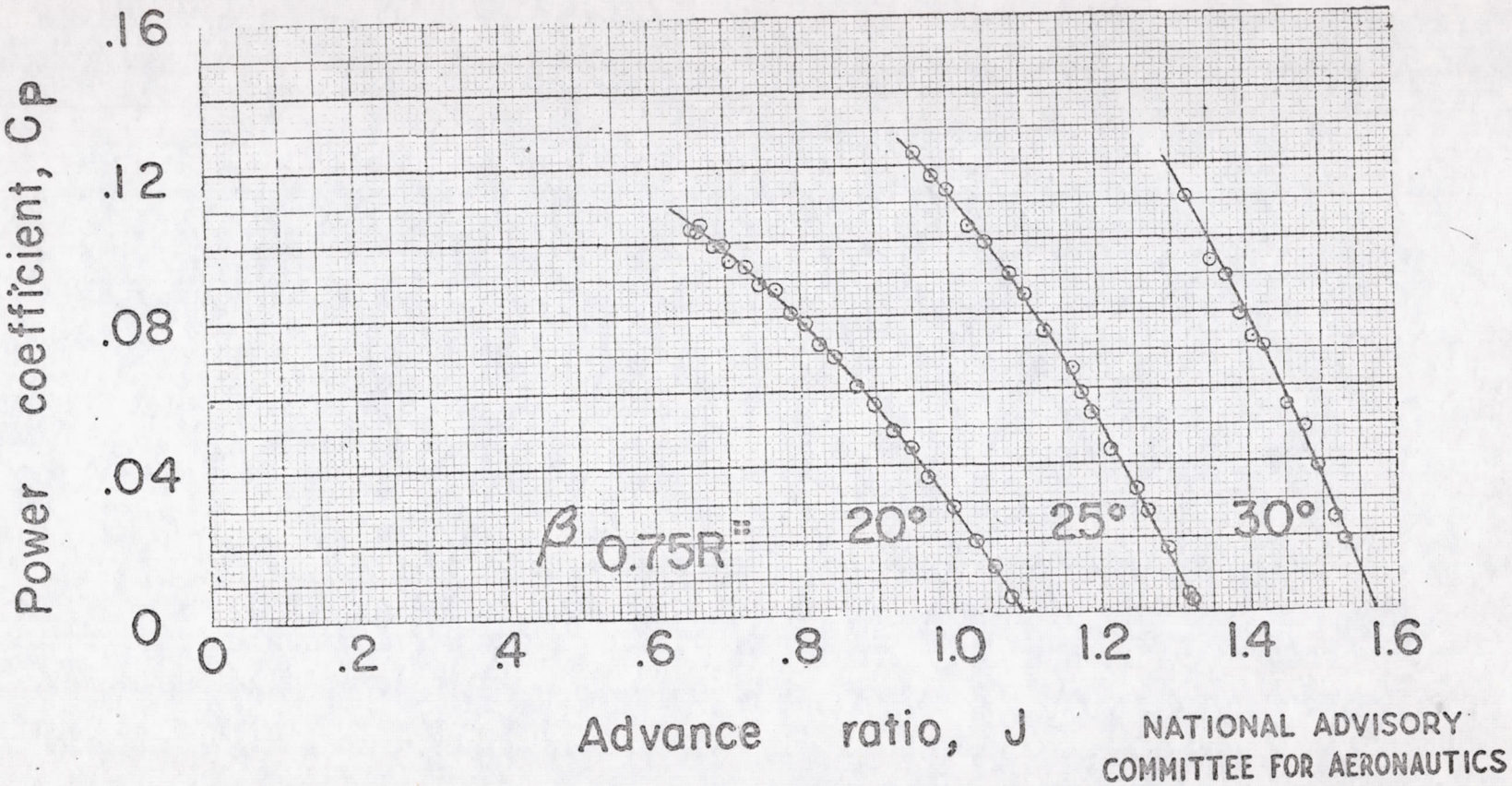
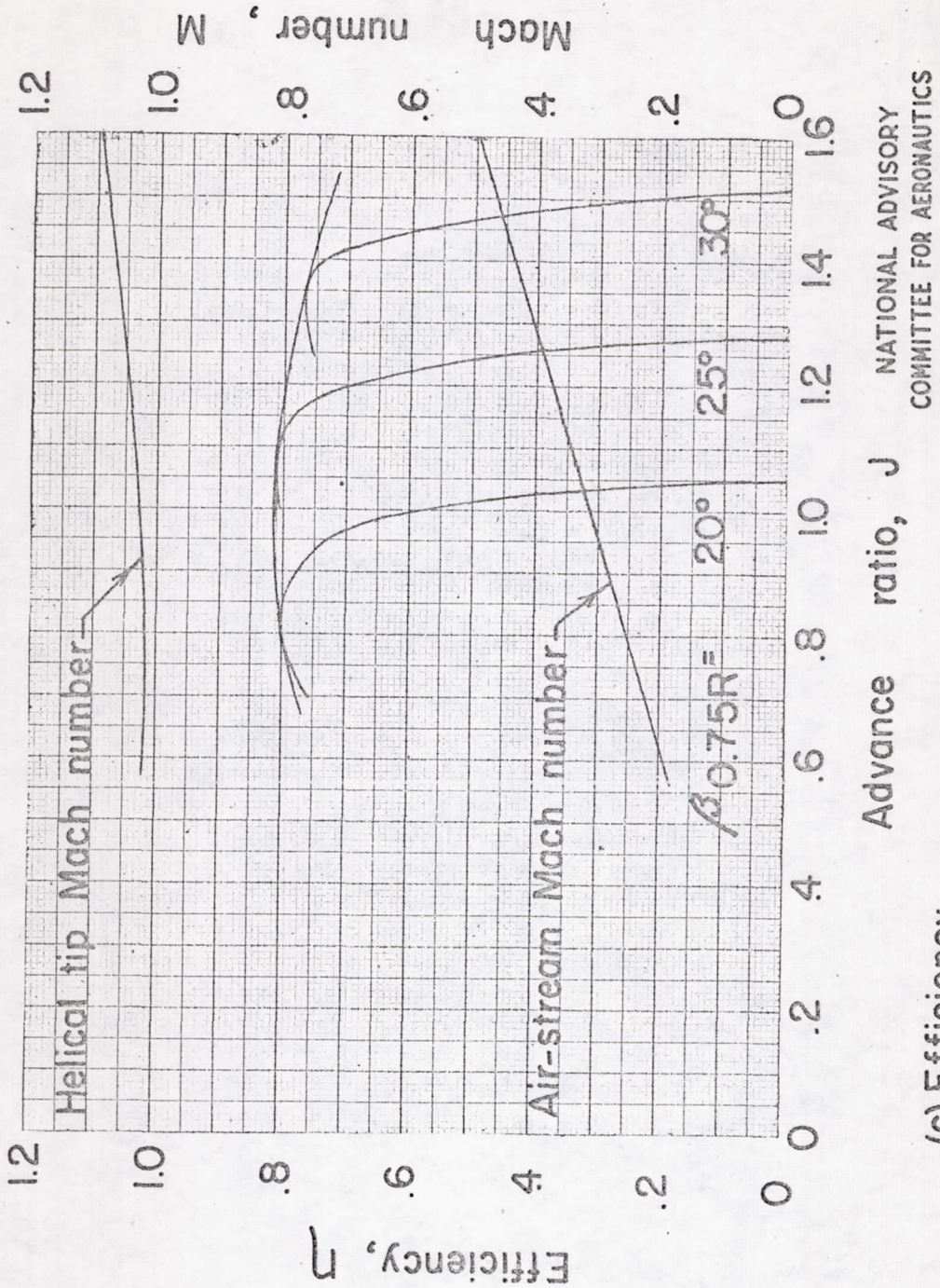
Figure 9 .— Characteristics of propeller with swept-back blade tips at 2100 rpm.



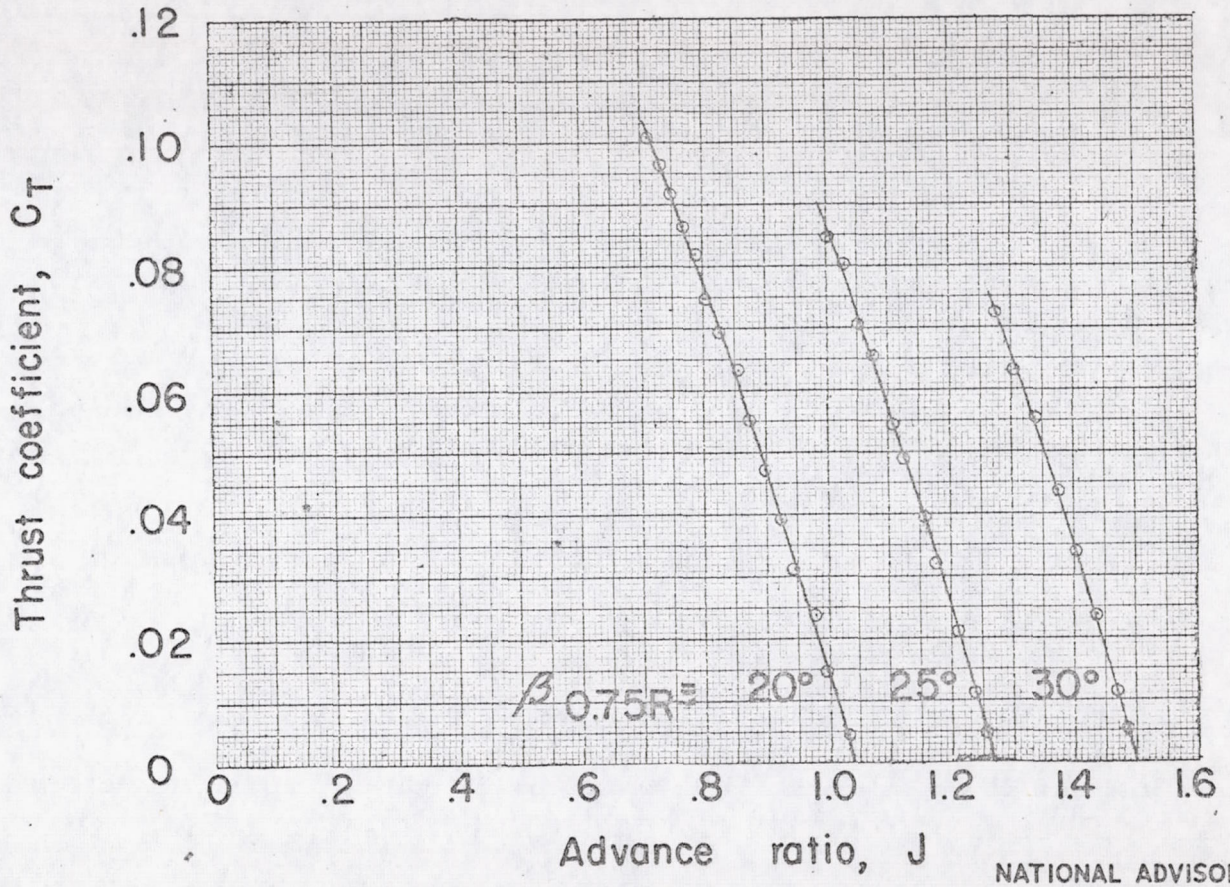
(b) Power coefficient.

Figure 9 .—Continued.



(c) Efficiency.

Figure 9.—Concluded.



(a) Thrust coefficient.

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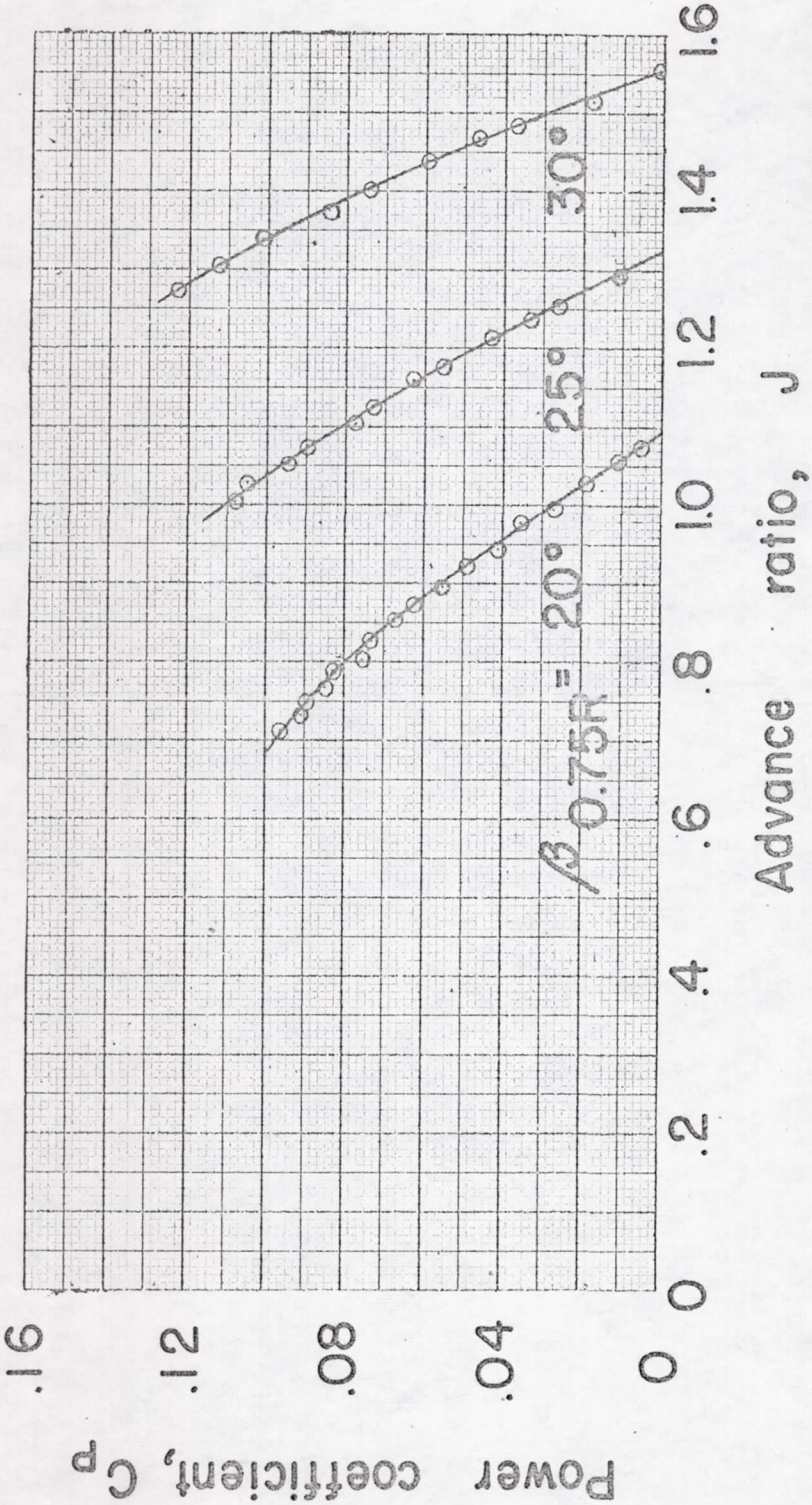
Figure 10.—Characteristics of propeller with swept-back blade tips at 2160 rpm.



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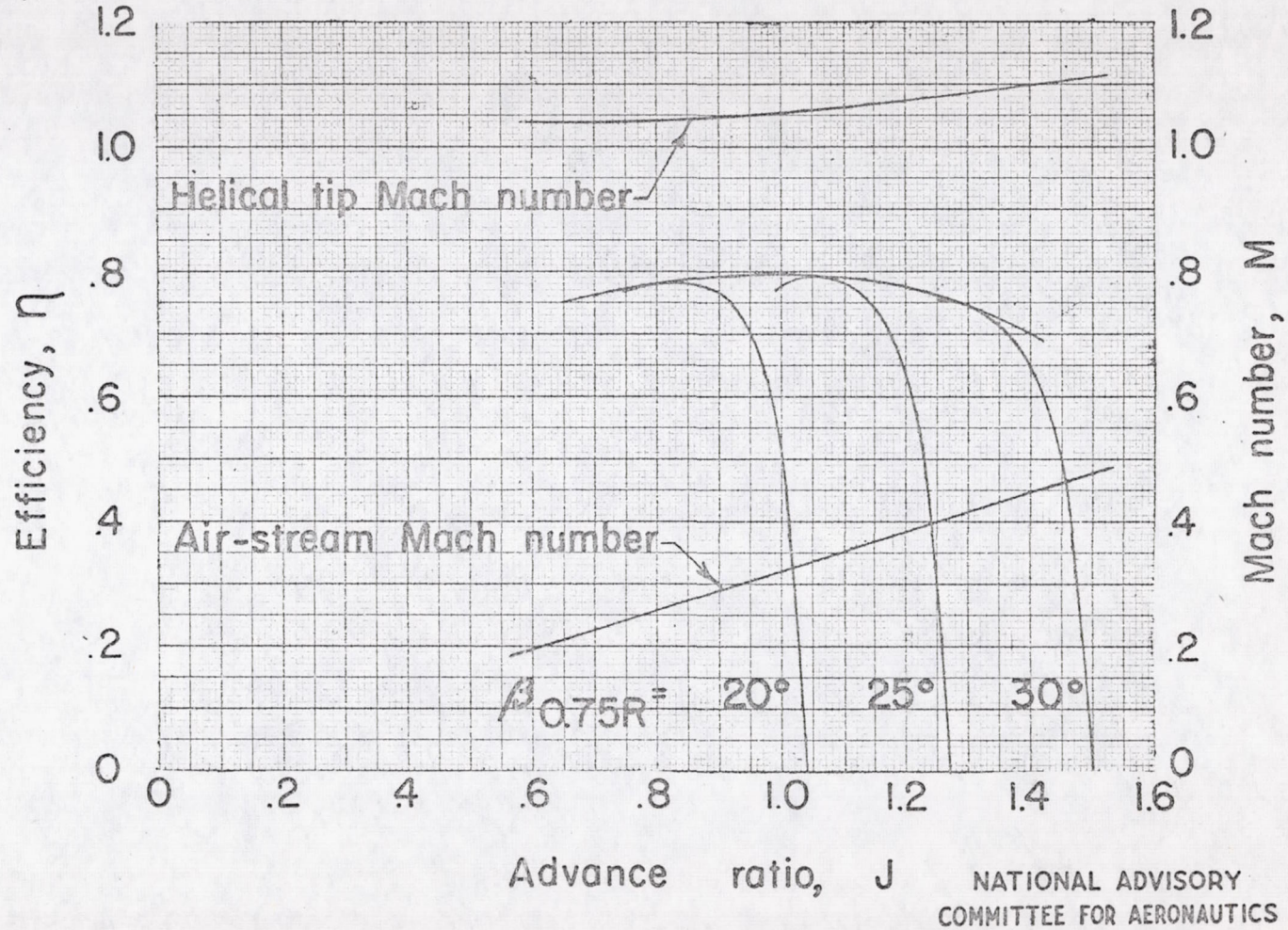
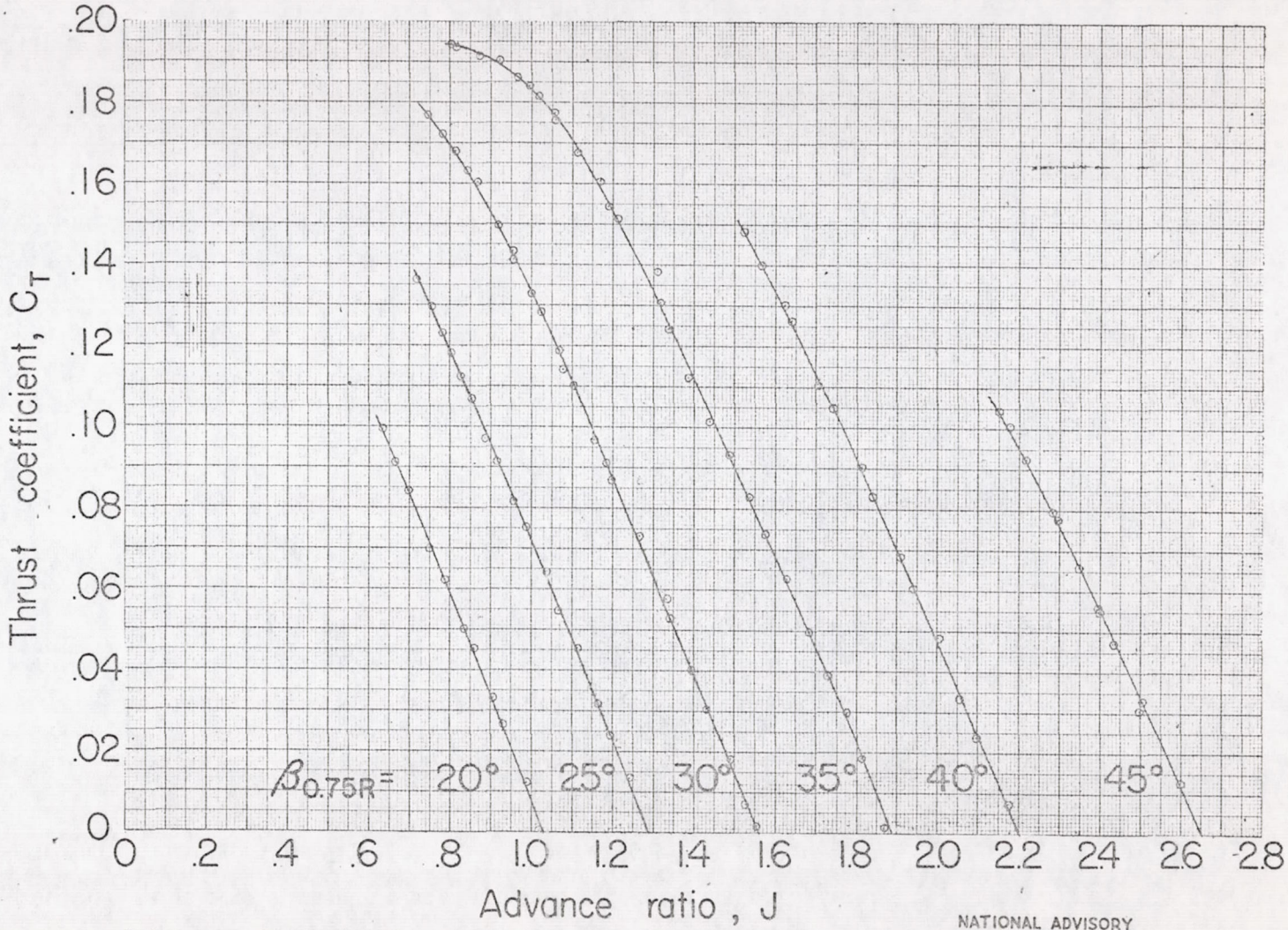
(b) Power coefficient.

Figure 10 .— Continued.



(c) Efficiency.

Figure 10 . — Concluded.



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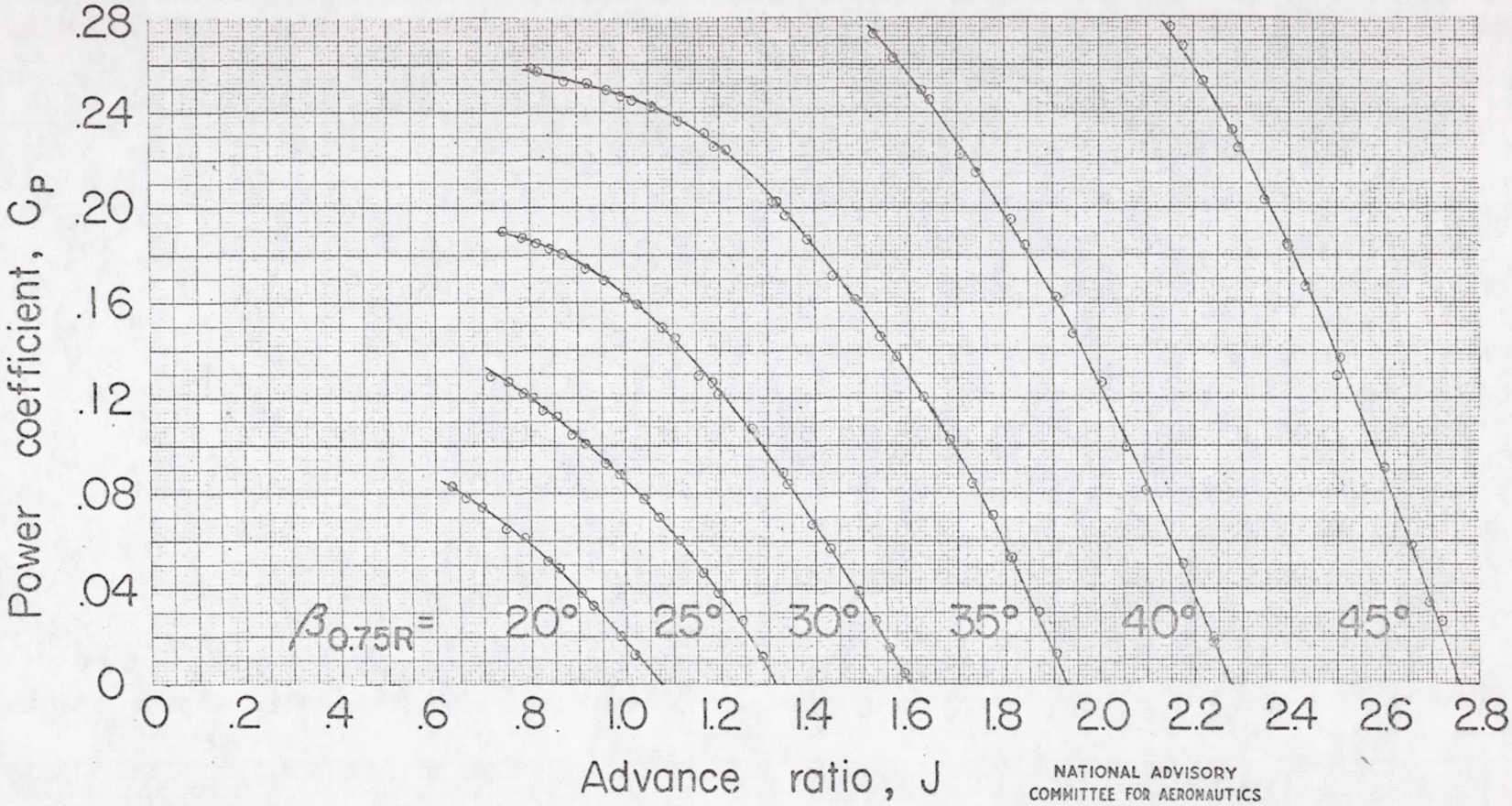
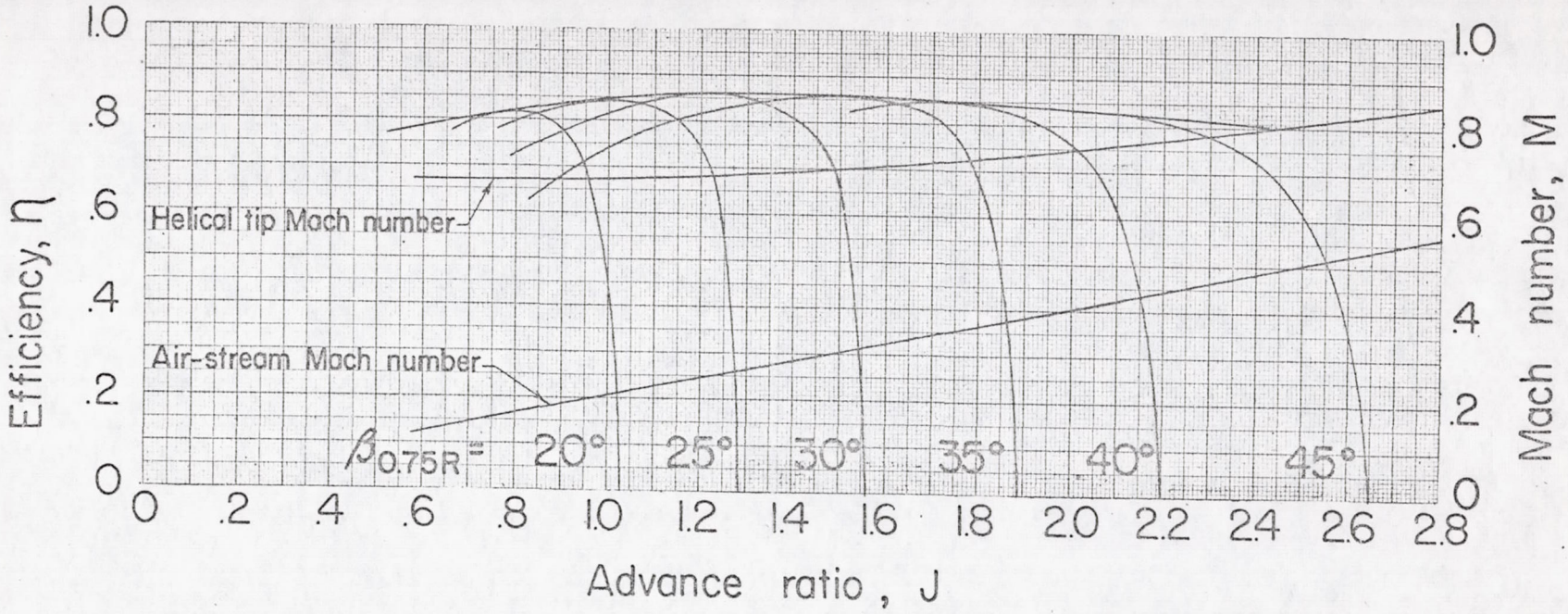
(a) Thrust coefficient.

Figure 11.—Characteristics of propeller with straight blade tips at 1350 rpm.



(b) Power coefficient.

Figure 11 .—Continued.



(c) Efficiency.

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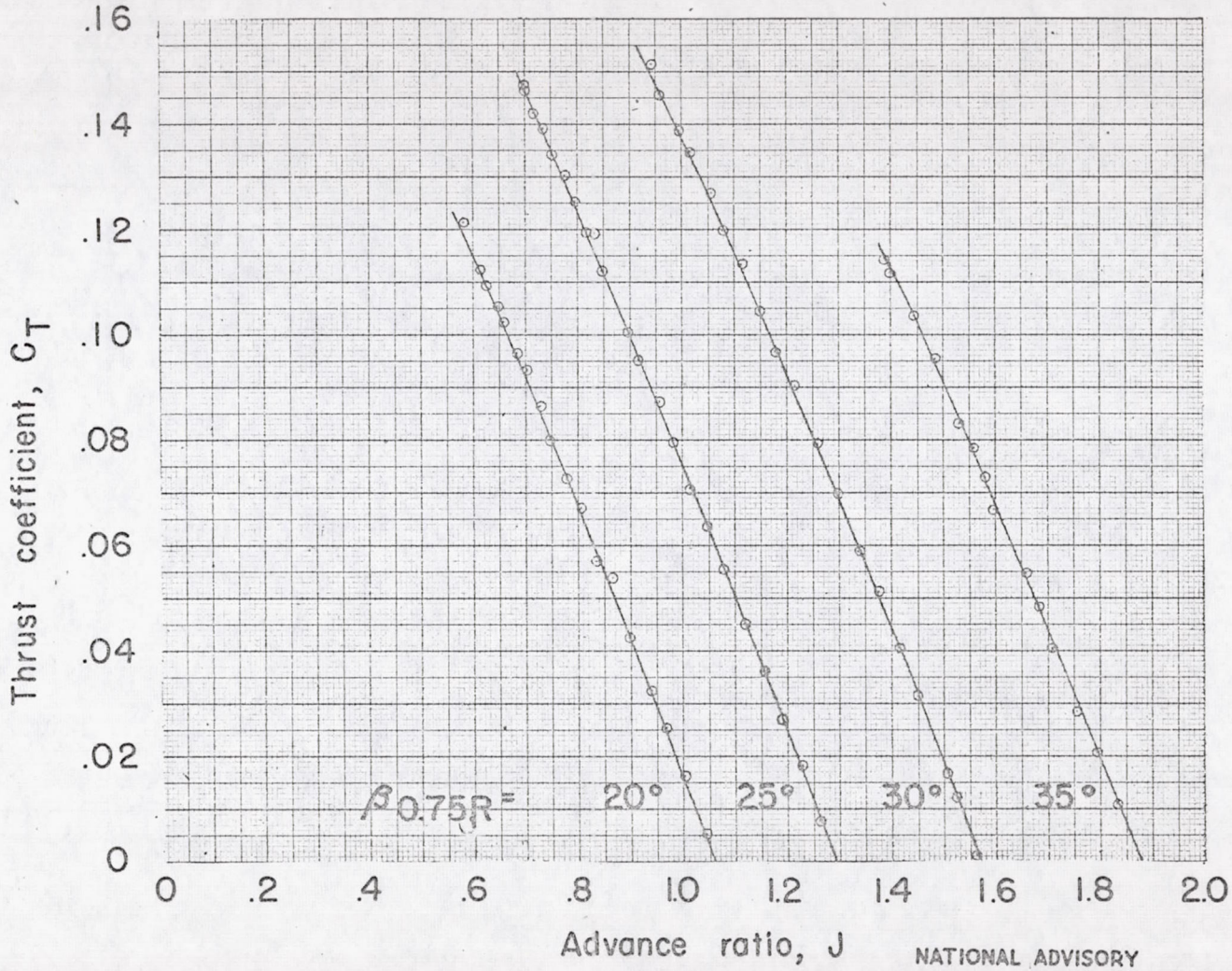
Figure 11.—Concluded.



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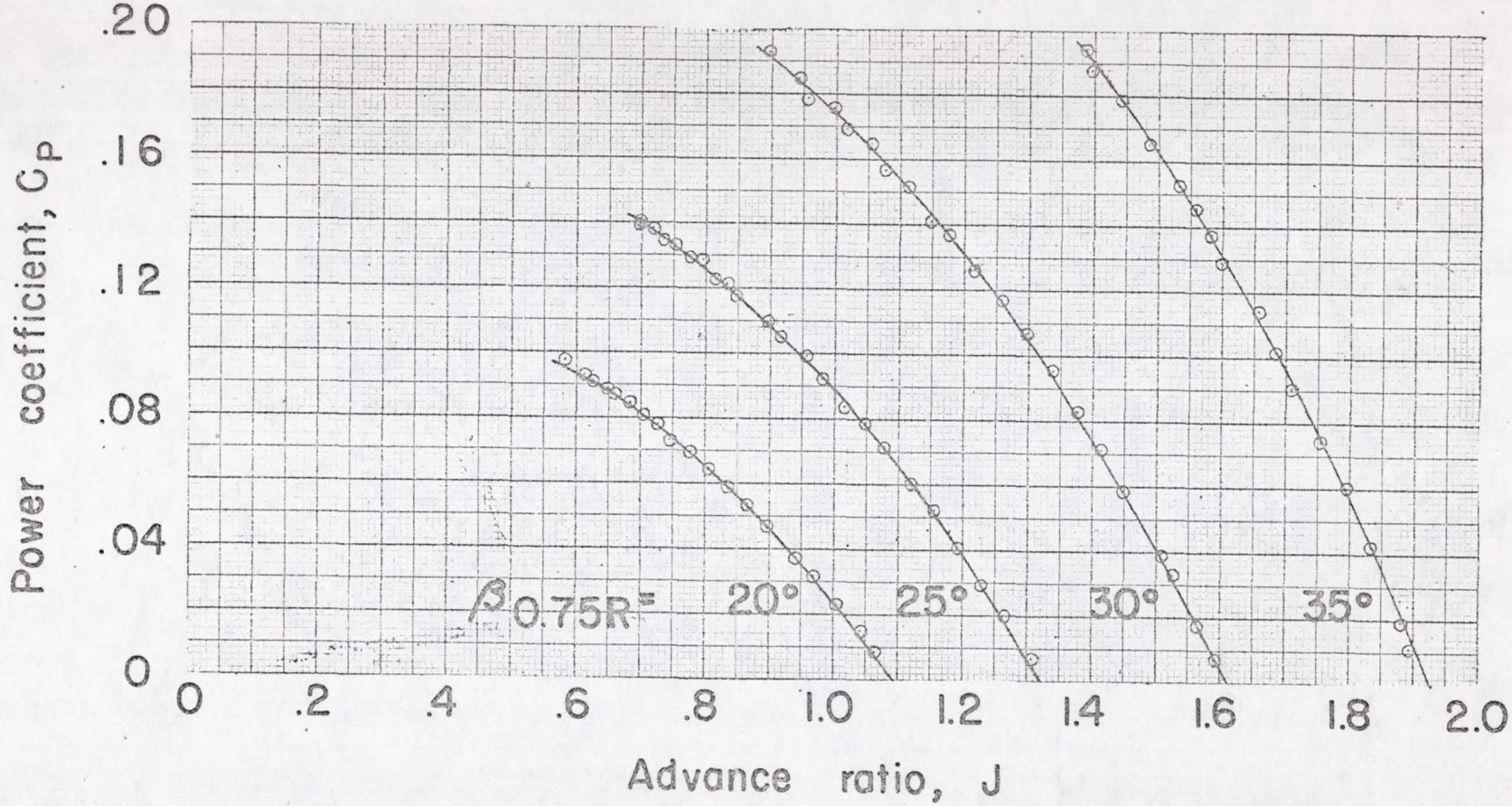
(a) Thrust coefficient.

Figure 12.—Characteristics of propeller with straight blade tips at 1600rpm.



(b) Power coefficient.

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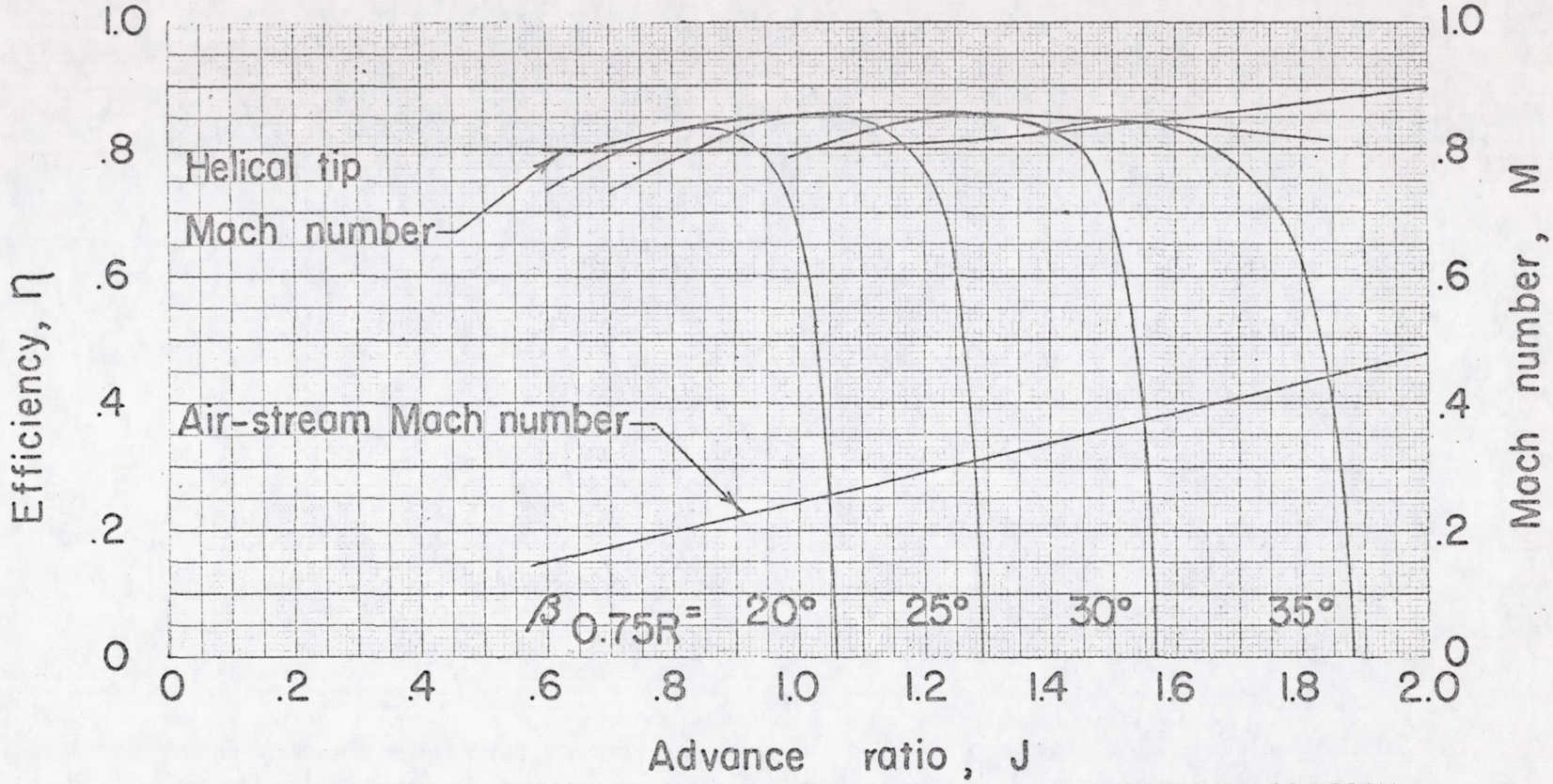
Figure 12 . —— Continued.



(c) Efficiency.

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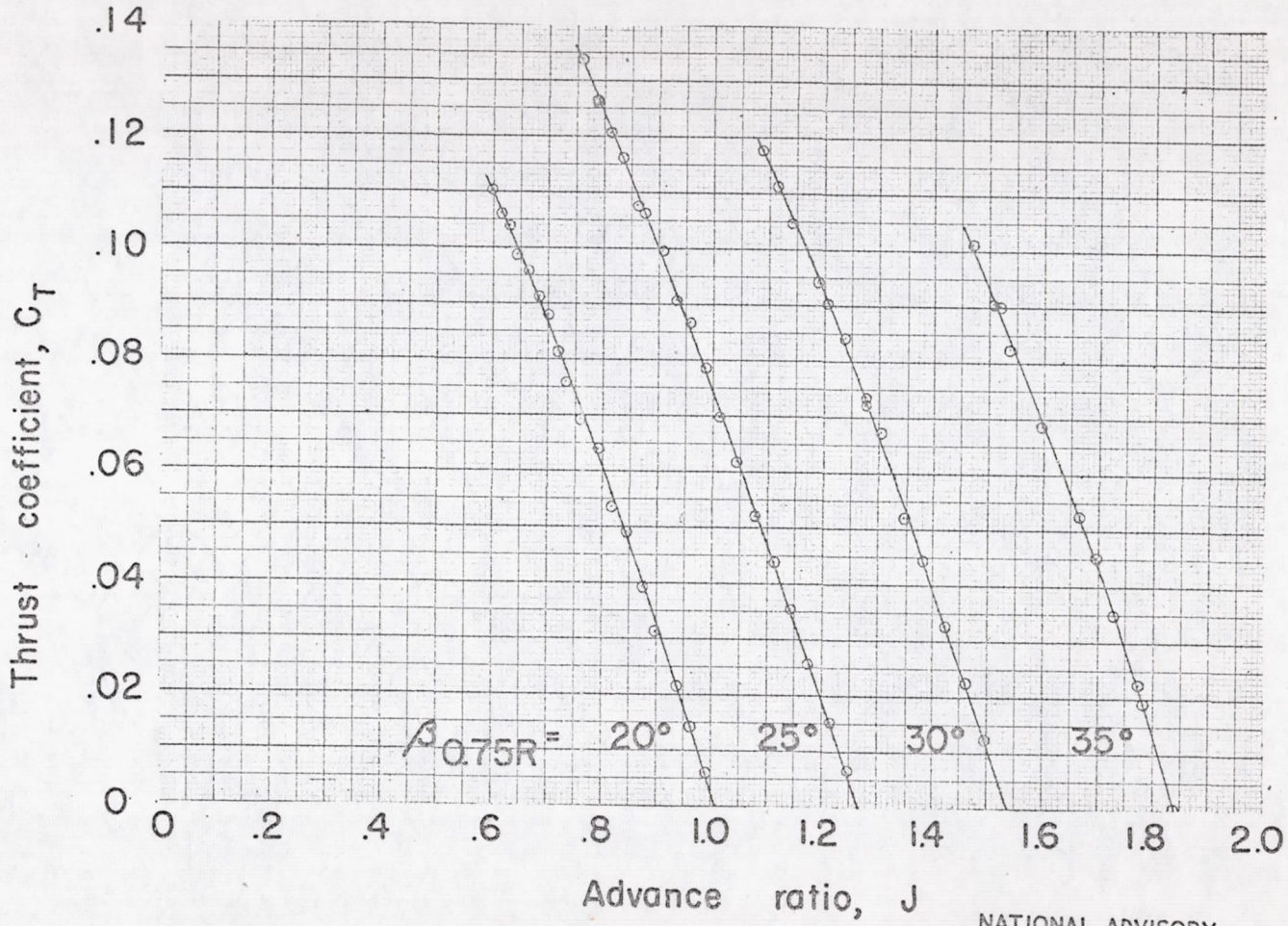
Figure 12 .—— Concluded.



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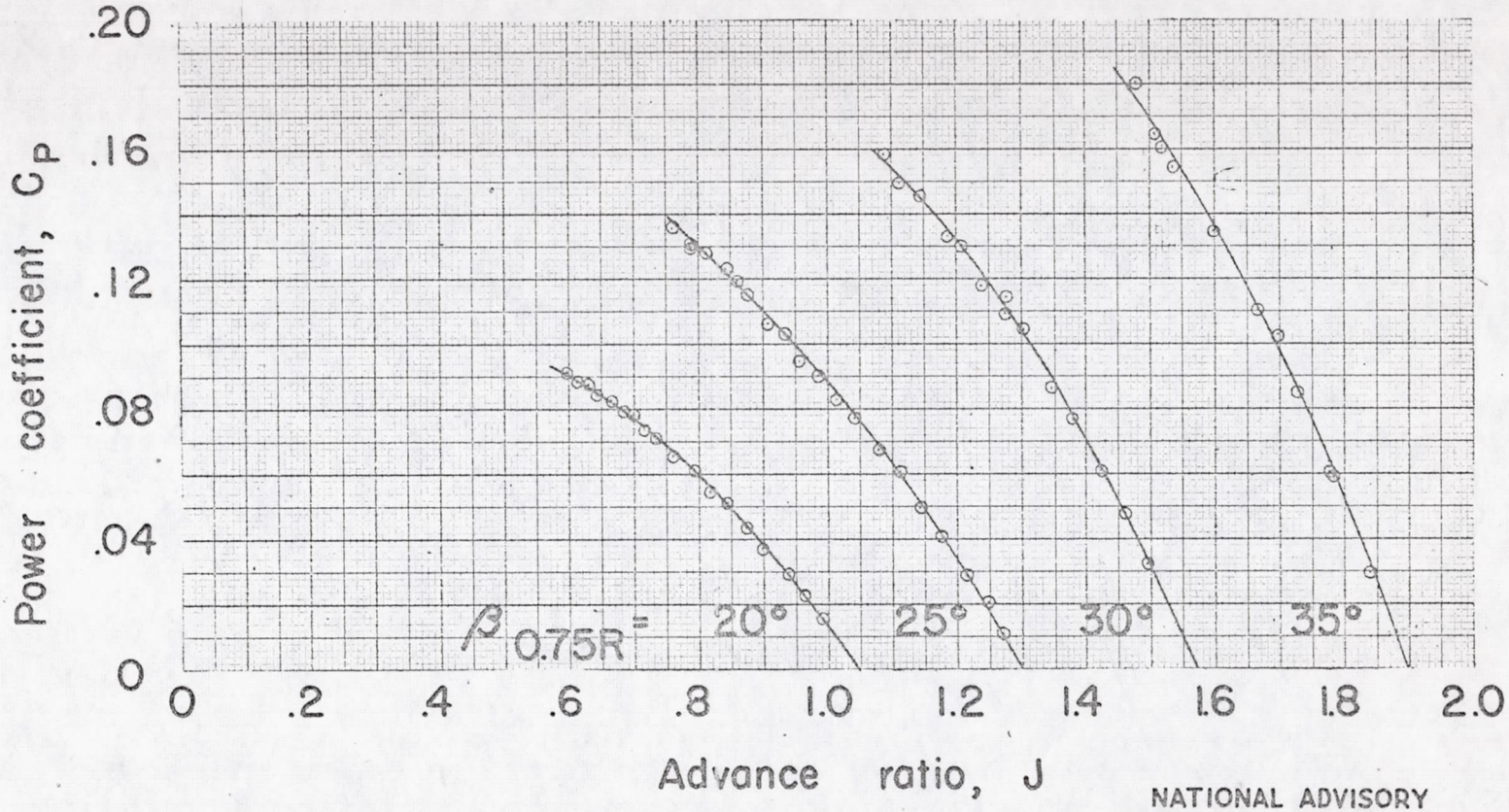
(a) Thrust coefficient.

Figure 13 .—Characteristics of propeller with straight blade tips at 1800rpm.



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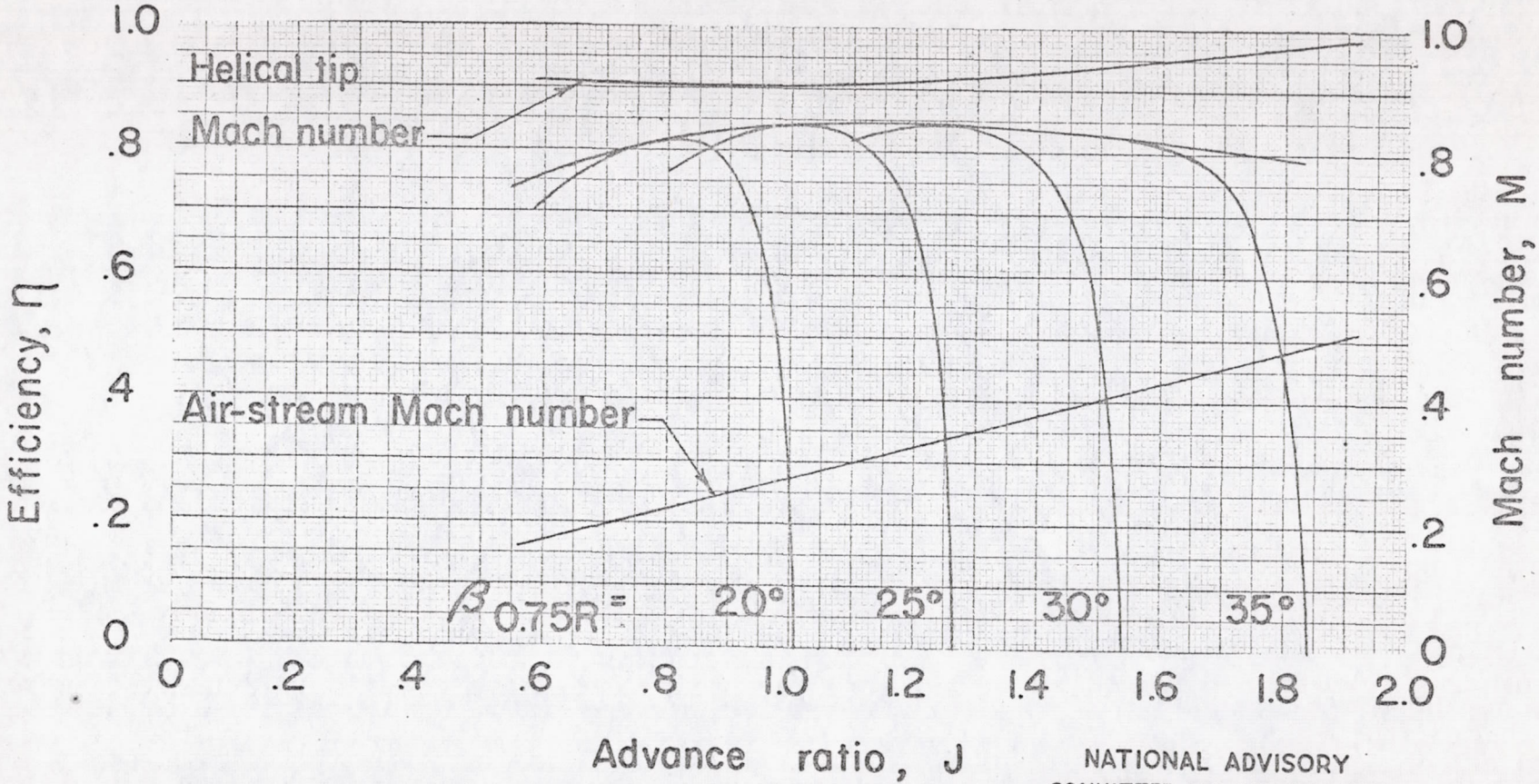
(b) Power coefficient.

Figure 13 .—Continued.



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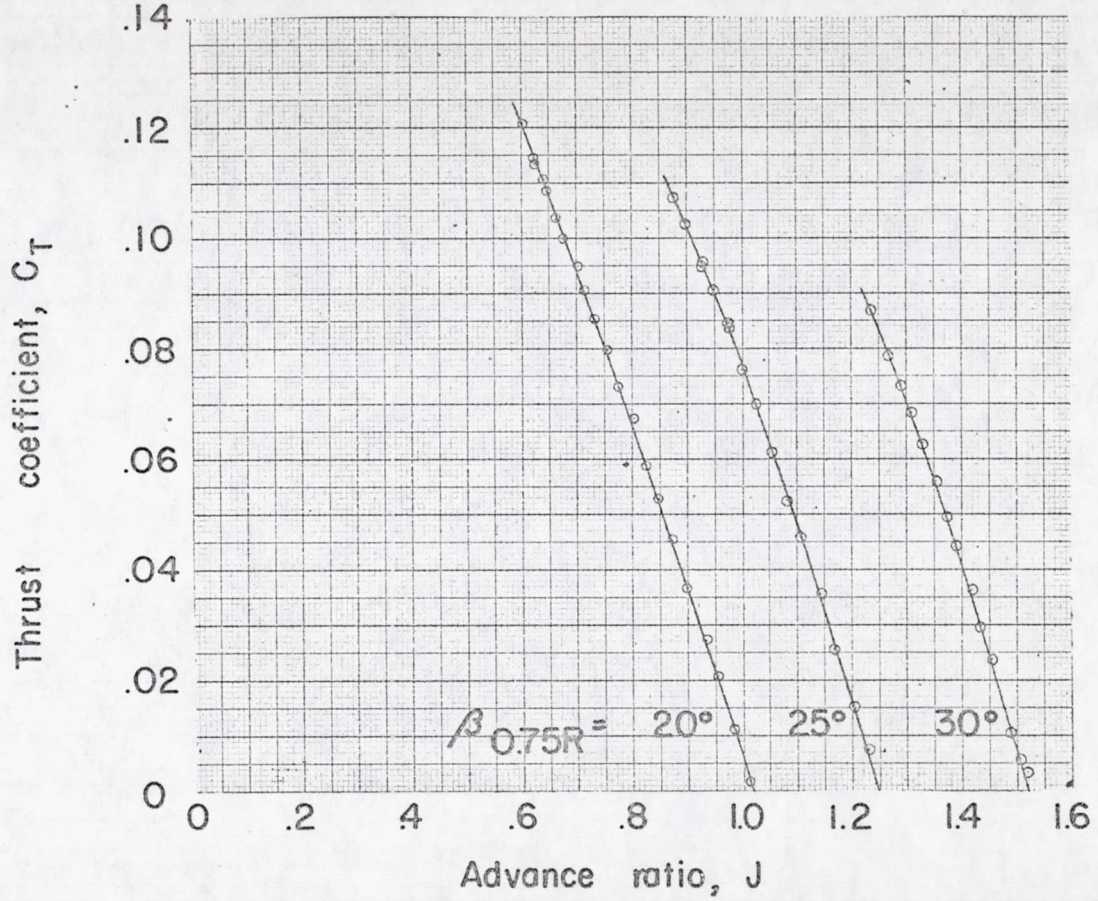
(c) Efficiency.

Figure 13.— Concluded.



(a)Thrust coefficient.

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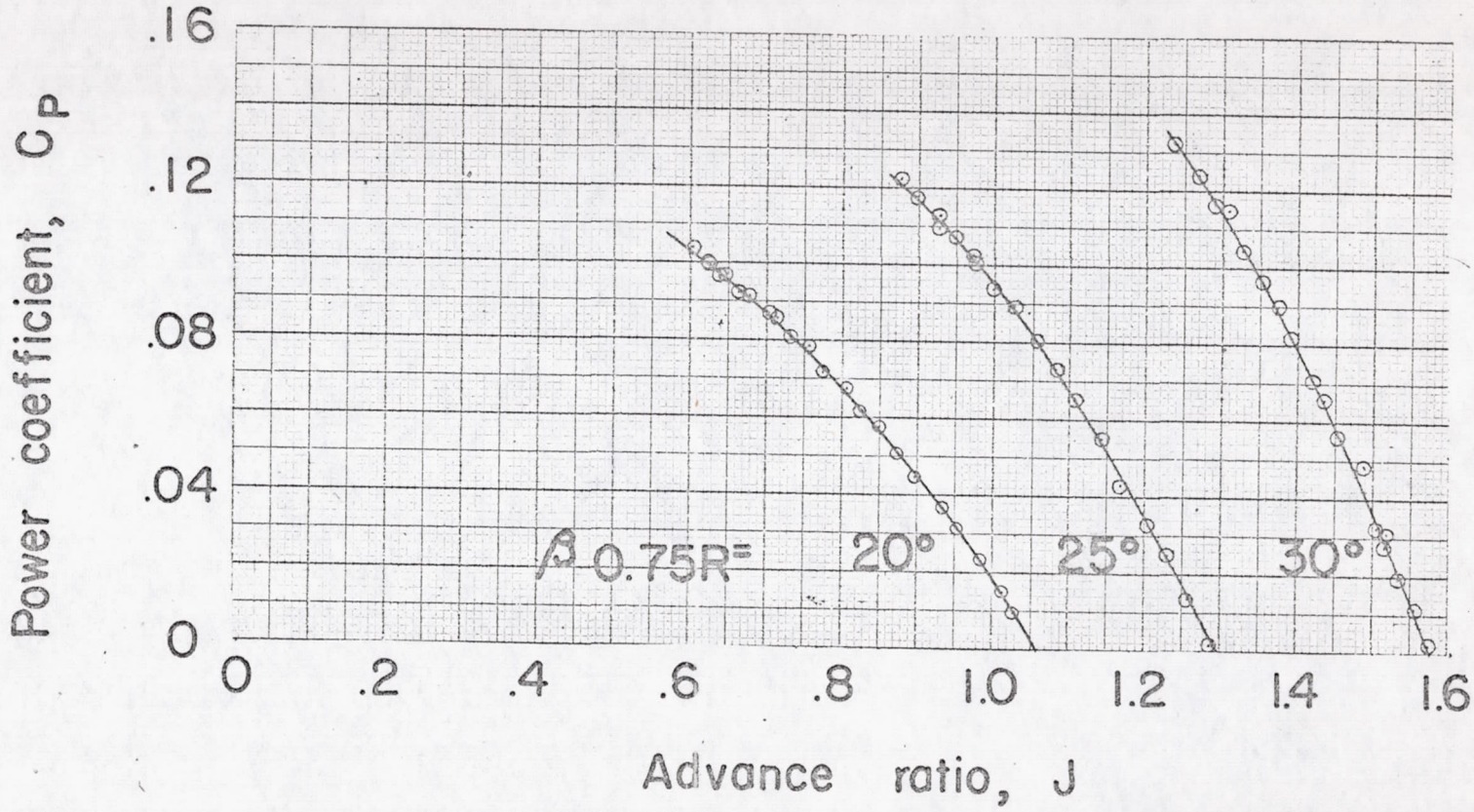
Figure 14.—Characteristics of propeller with straight blade tips at 2000 rpm.



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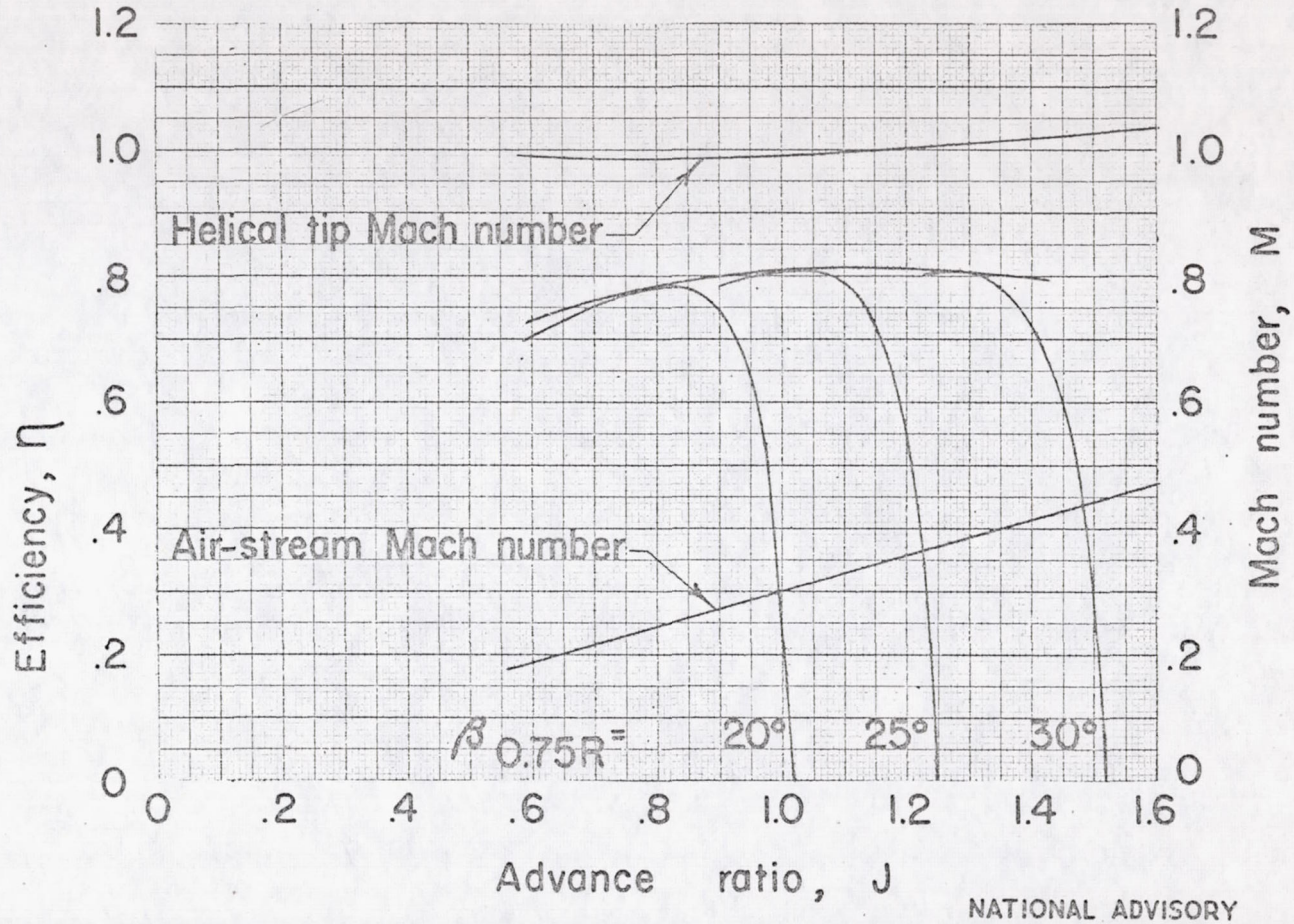
(b) Power coefficient.

Figure 14 .— Continued.



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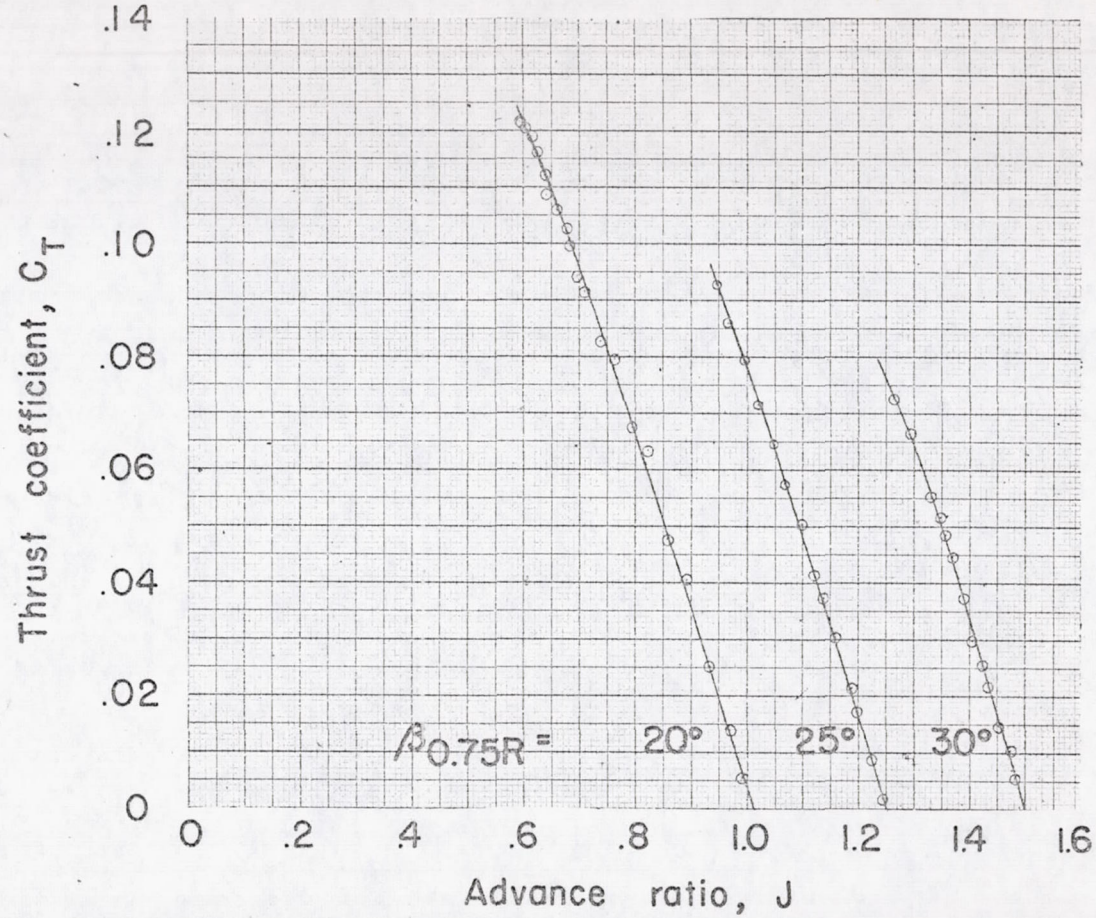
(c) Efficiency.

Figure 14.— Concluded.



(a) Thrust coefficient.

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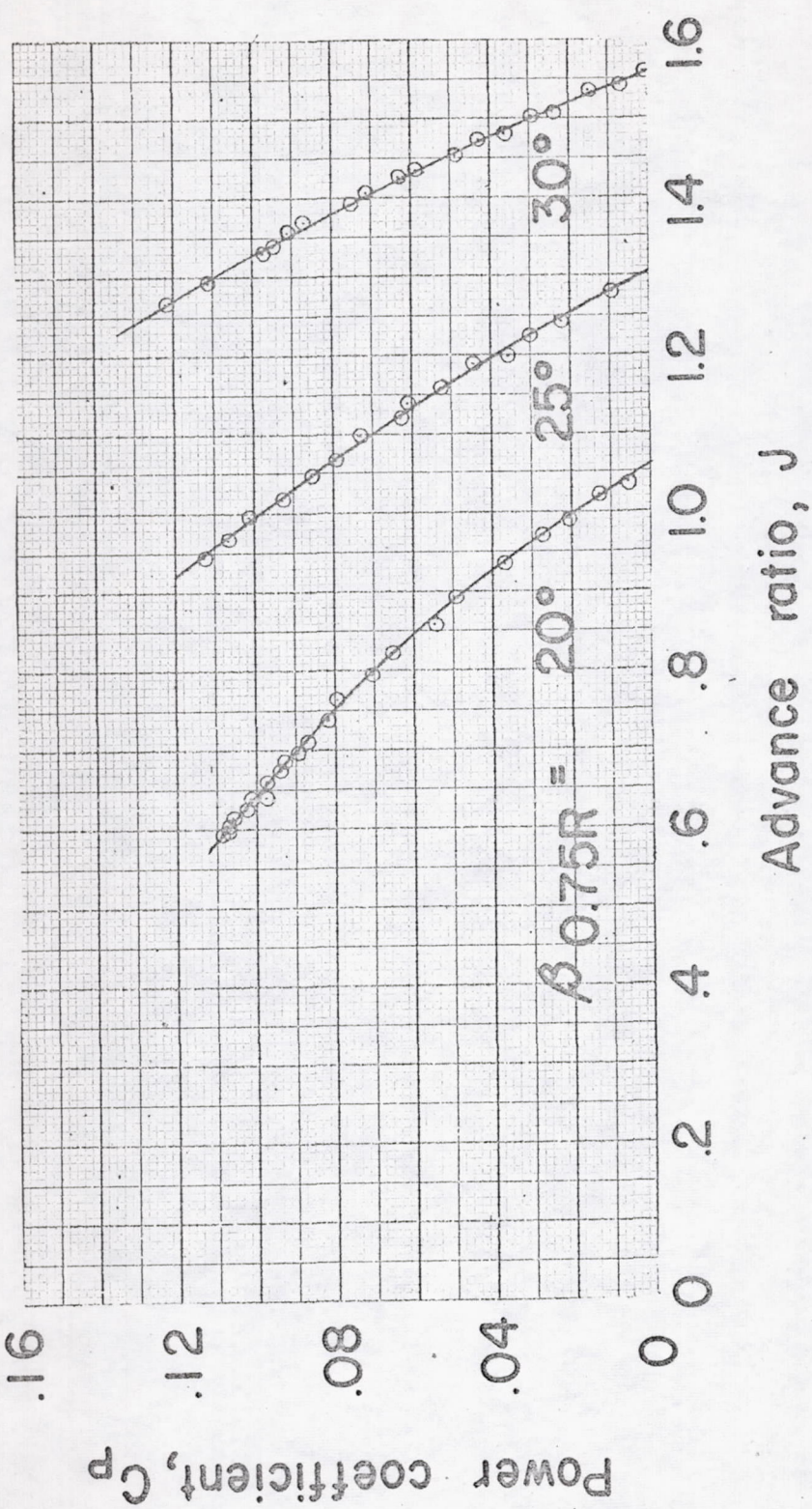
Figure 15 .— Characteristics of propeller with straight blade tips at 2100 rpm.



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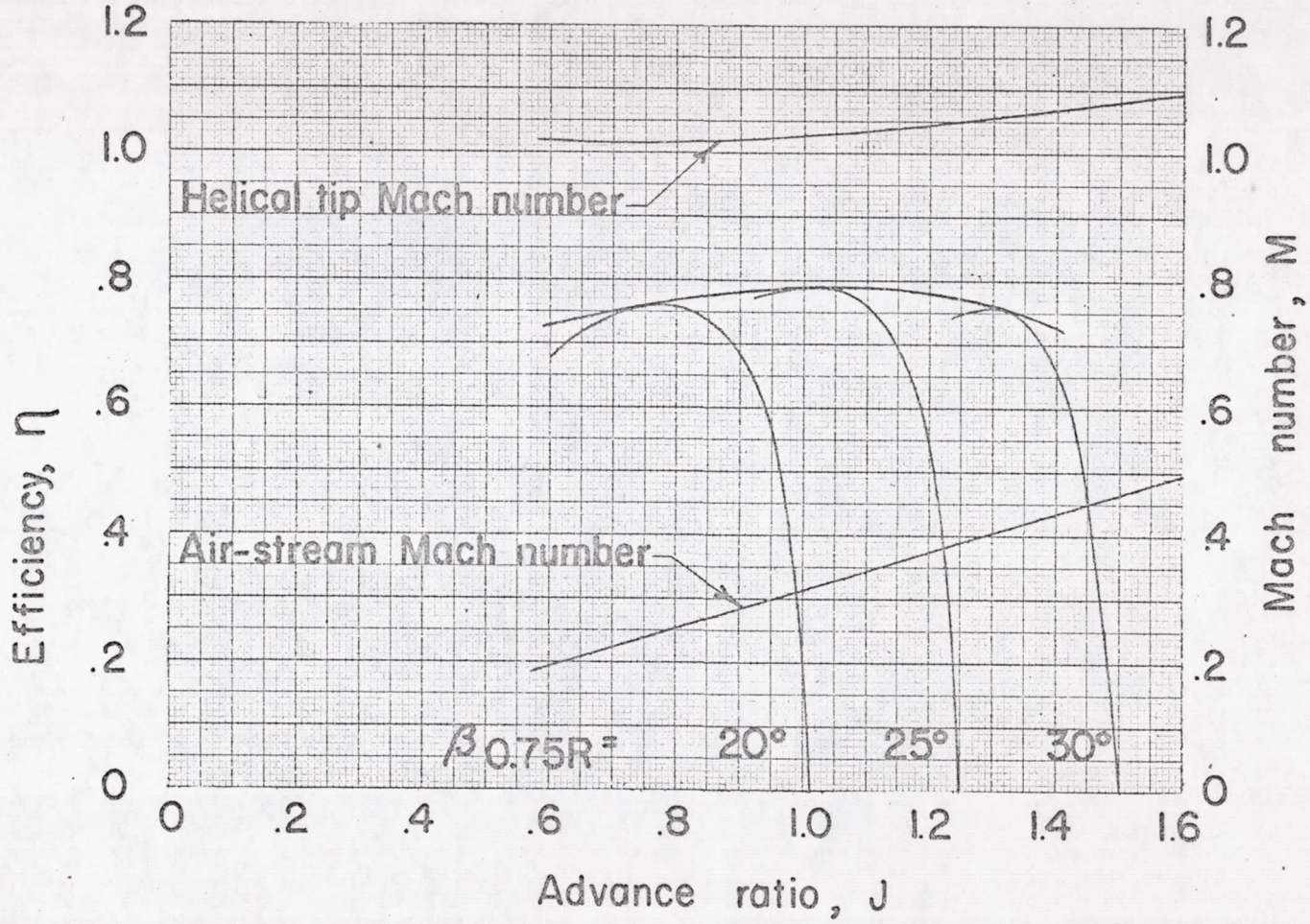
(b) Power coefficient.

Figure 15.—Continued.



(c) Efficiency.

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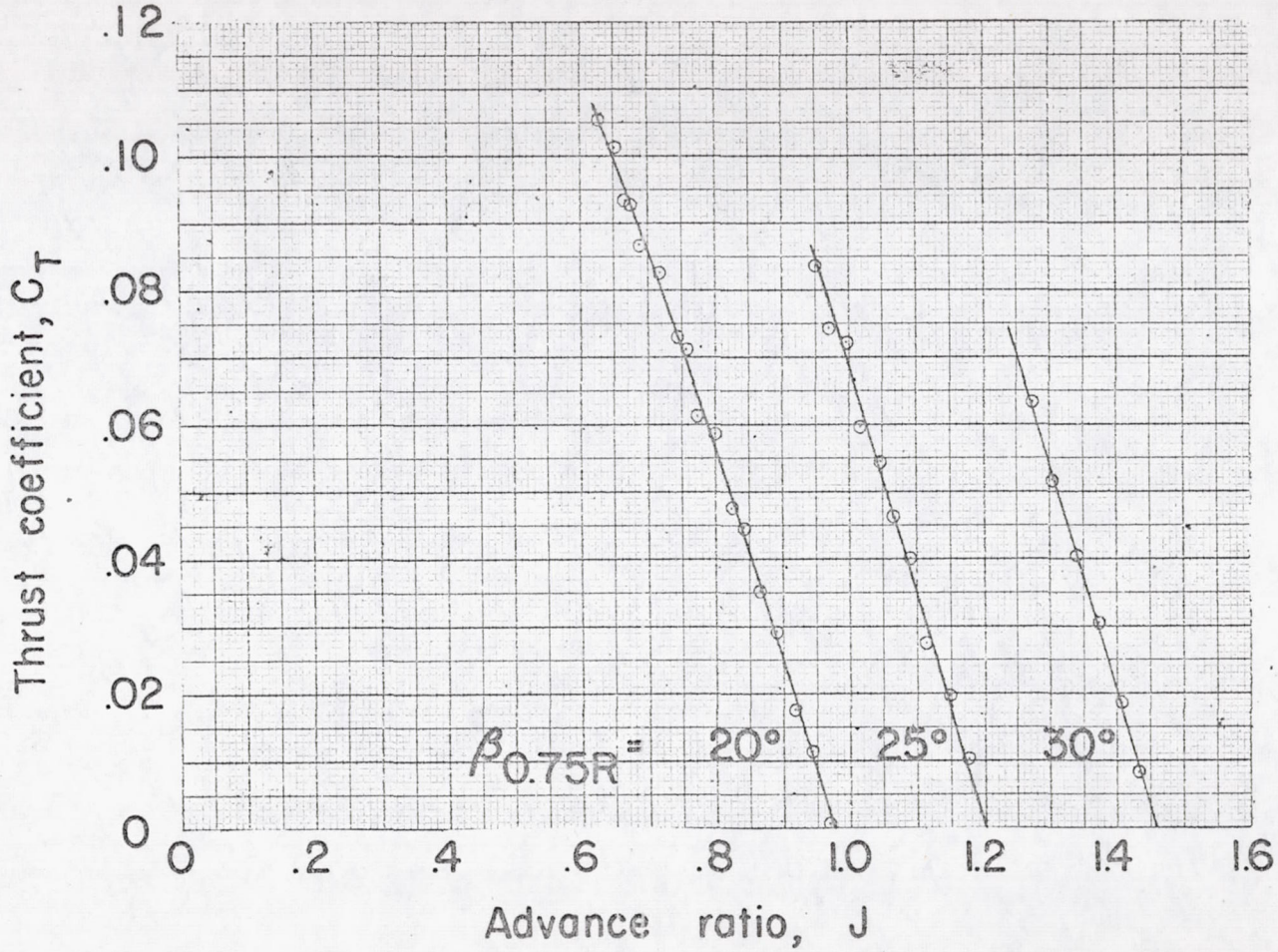
Figure 15.——Concluded.



(a) Thrust coefficient.

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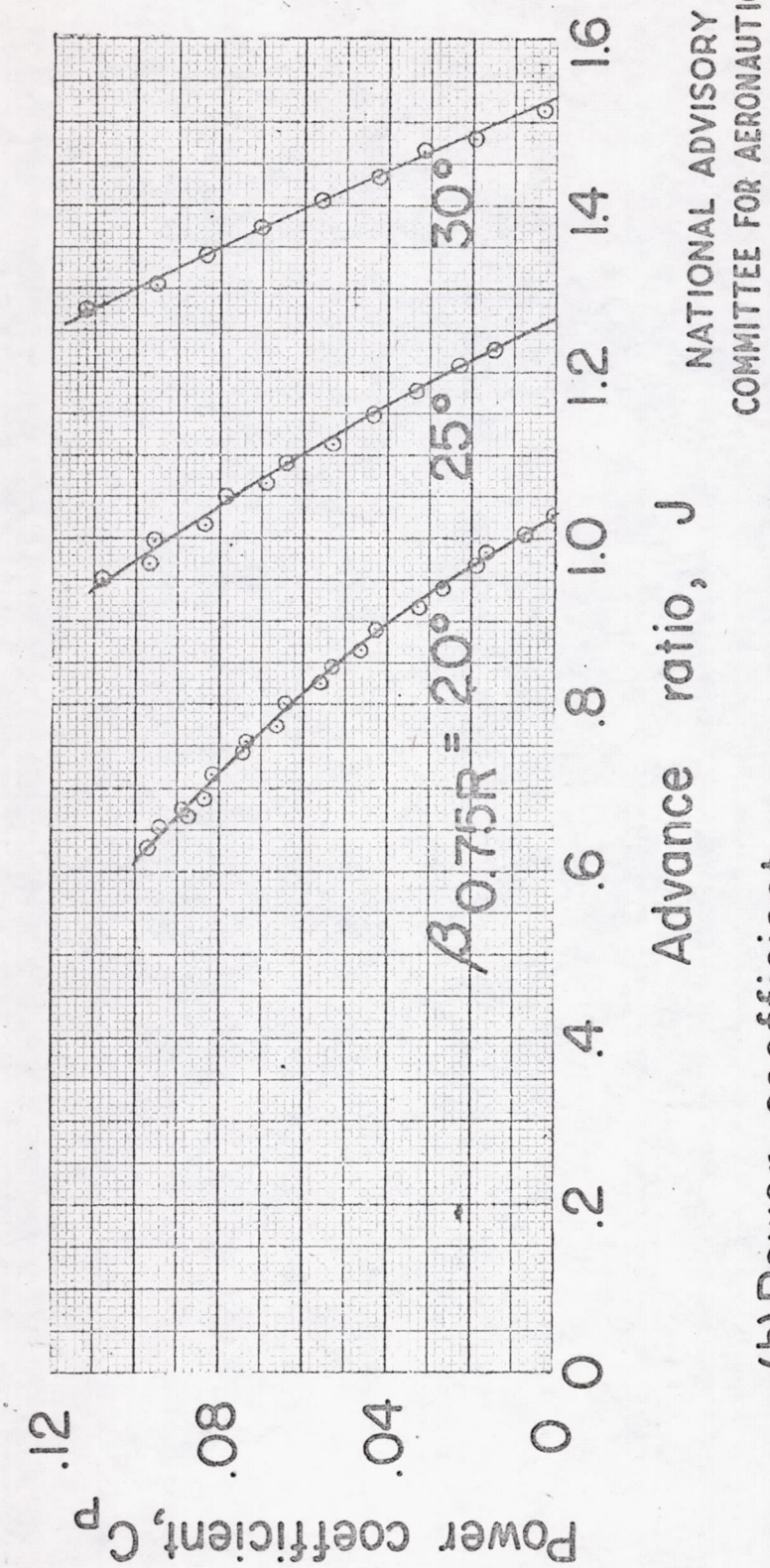
Figure 16.—Characteristics of propeller with straight blade tips at 2160 rpm.



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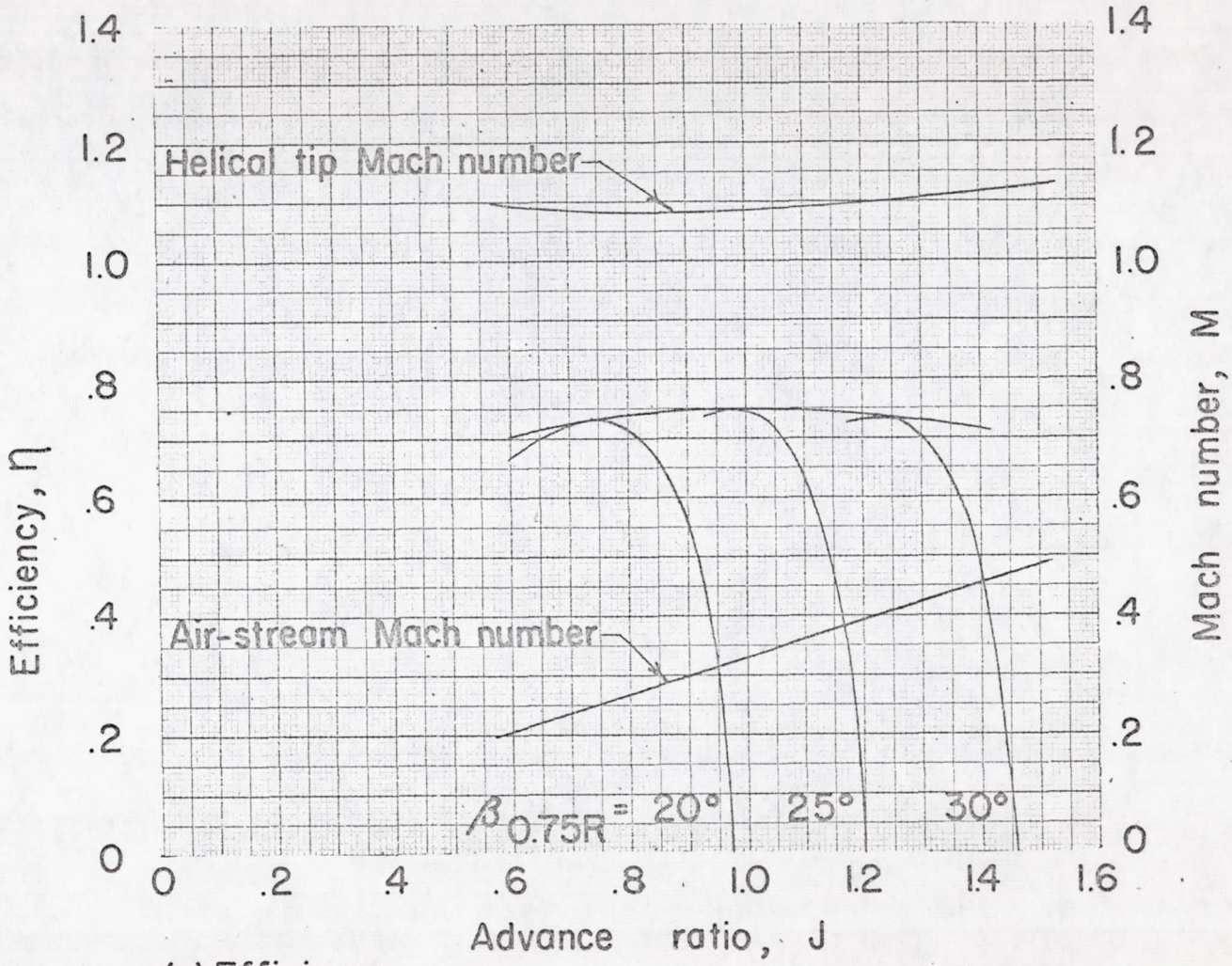
(b) Power coefficient.

Figure 16. — Continued.



(c) Efficiency.

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Figure 16.——Concluded.

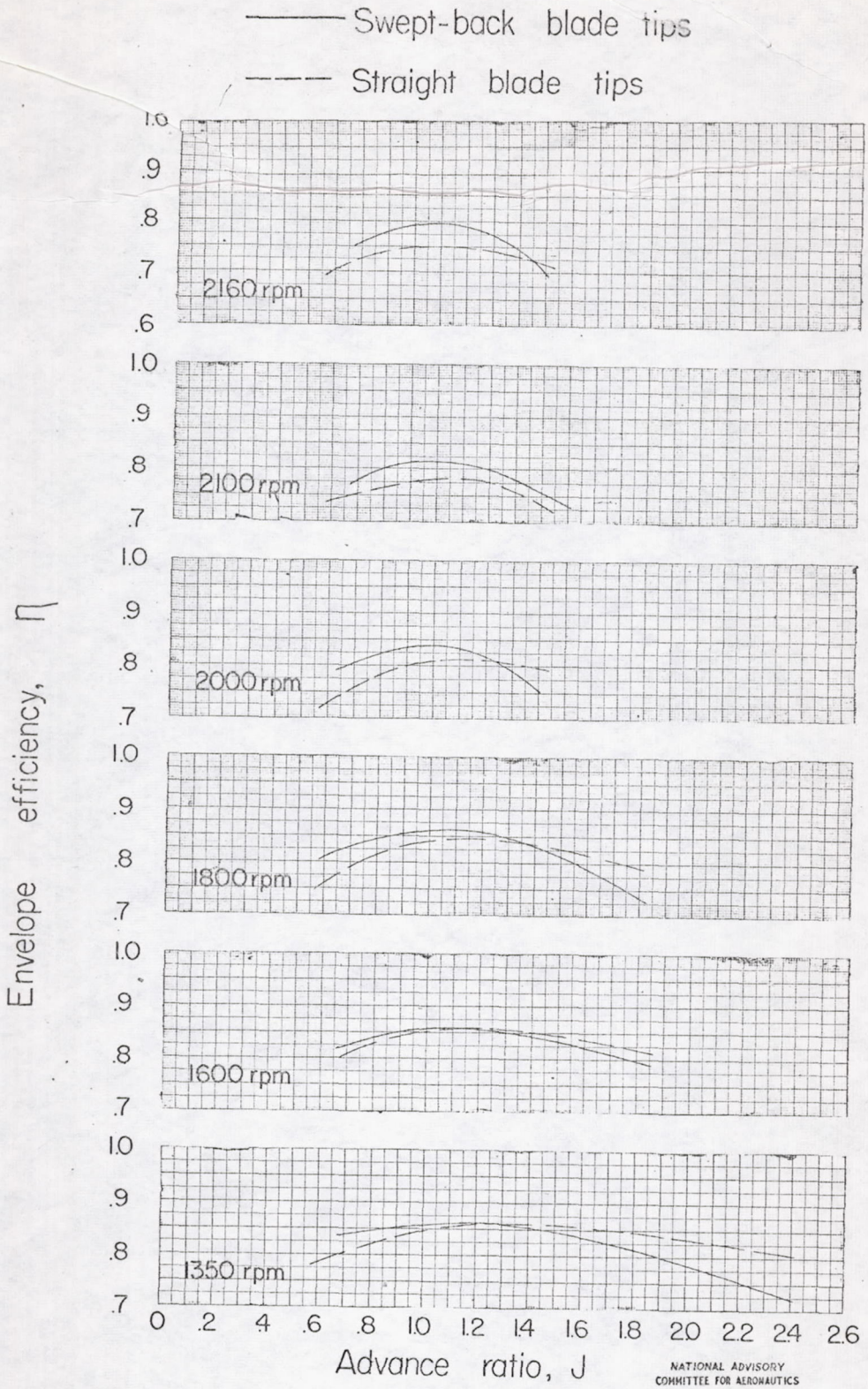


Figure 17.—Comparison of envelope efficiency curves for propeller with swept-back blade tips and straight blade tips at six rotational speeds.

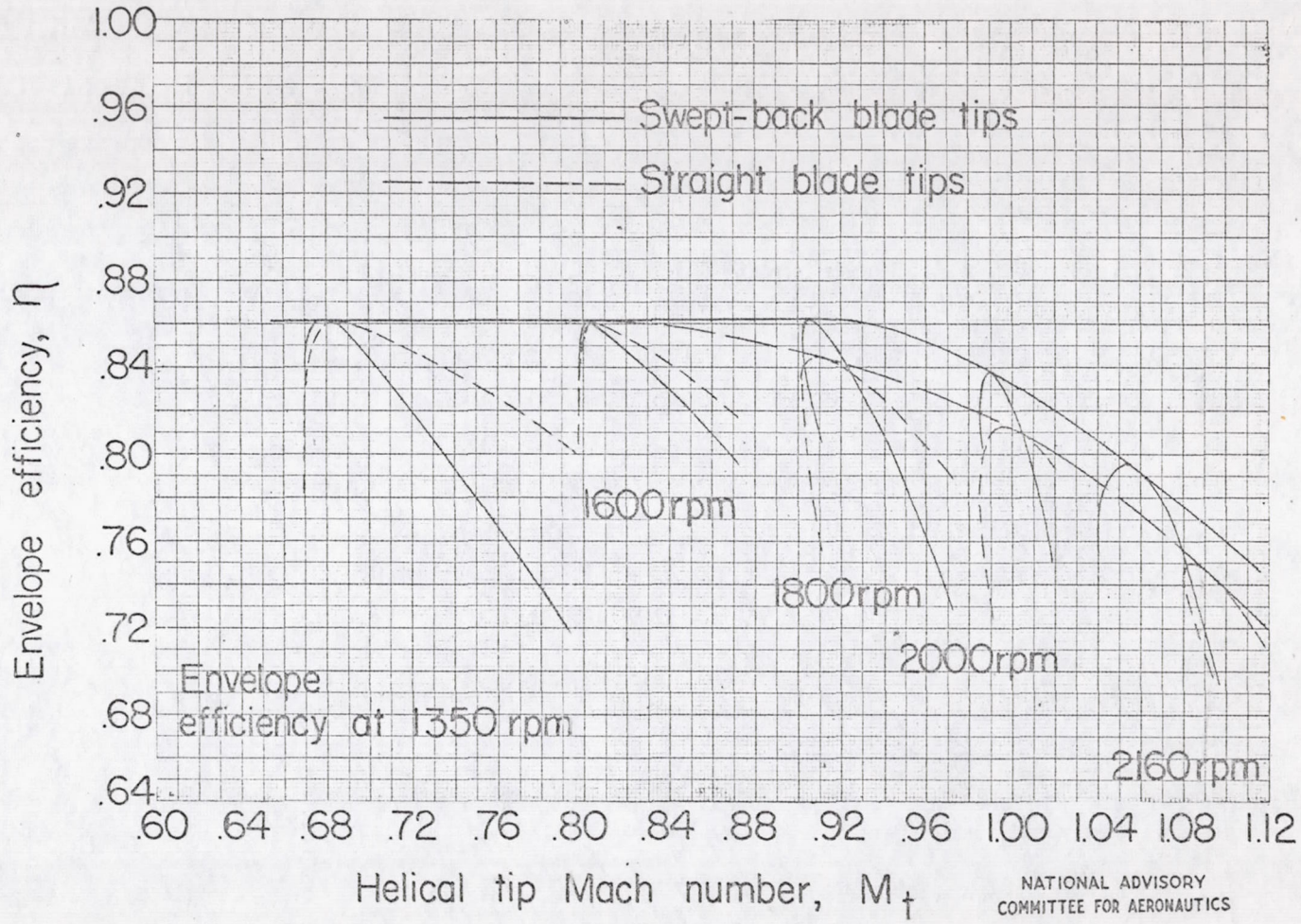
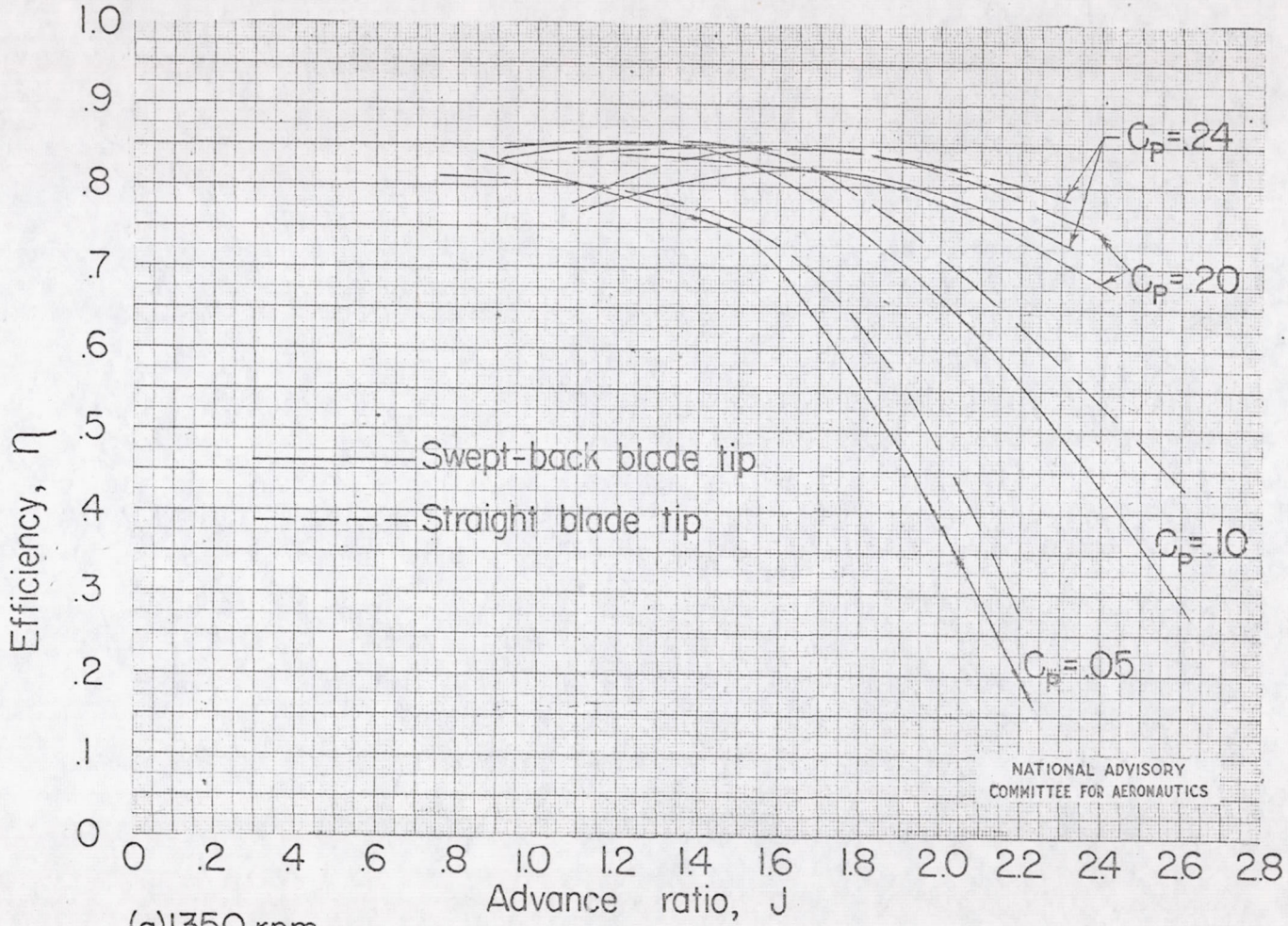
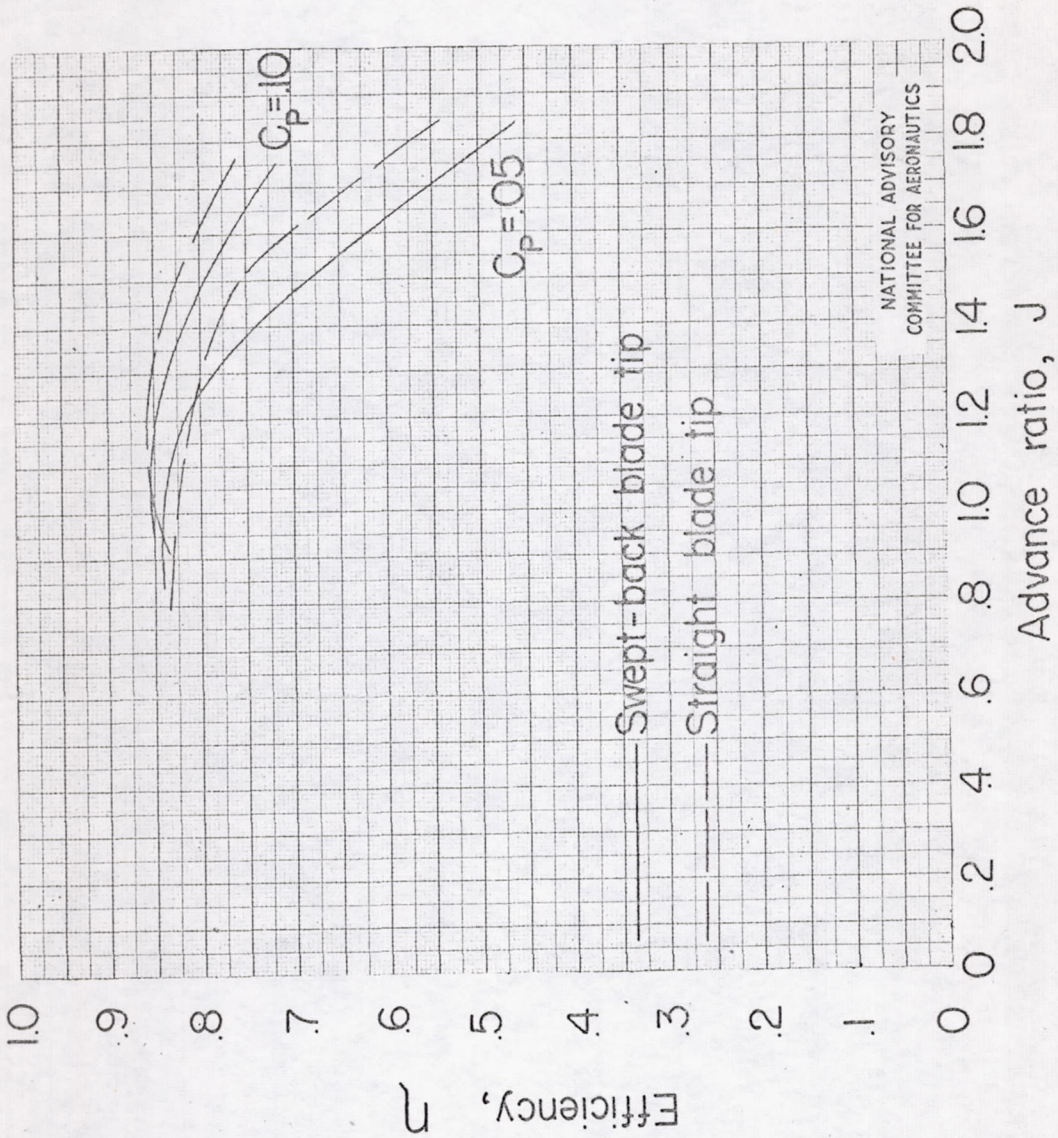


Figure 18.—Comparison of variation of envelopes of peak envelope efficiencies with helical tip Mach number for propeller with swept-back blade tips and straight blade tips.



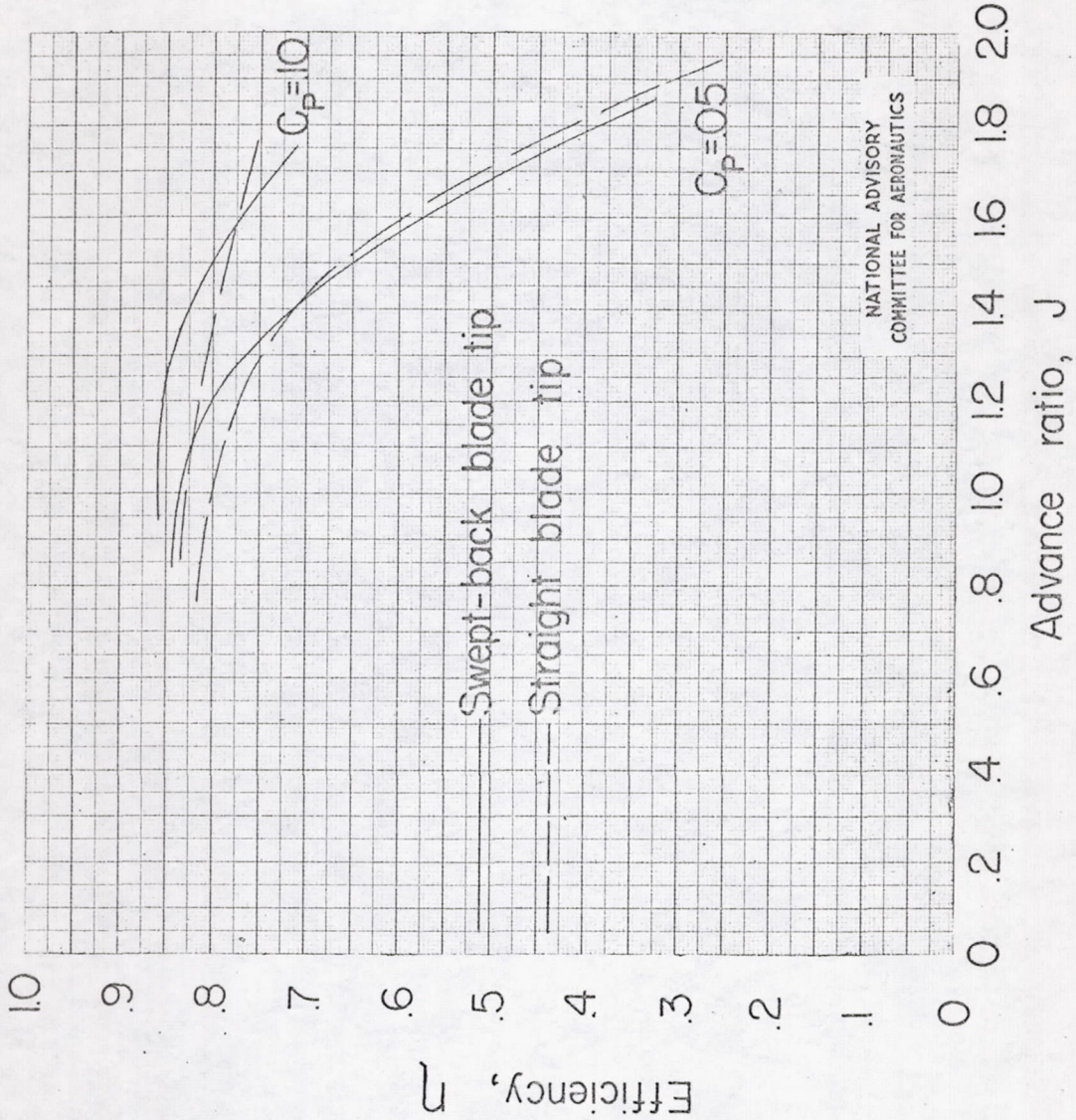
(a)1350 rpm.

Figure 19.—Comparison of propeller efficiency at several values of constant power coefficient and rotational speed for propeller with swept-back blade tips and straight blade tips.



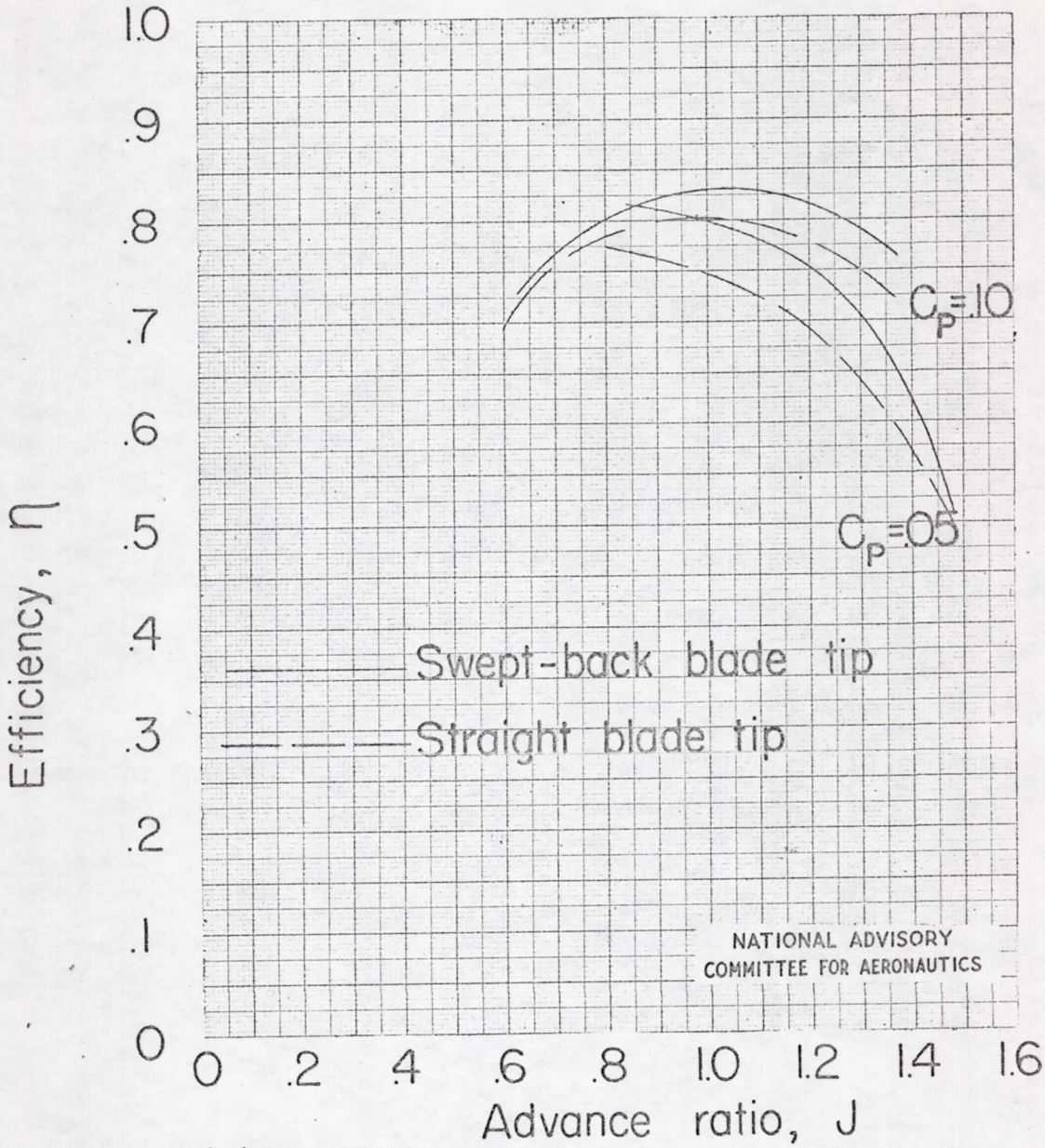
(b) 1600 rpm.

Figure 19. — Continued.



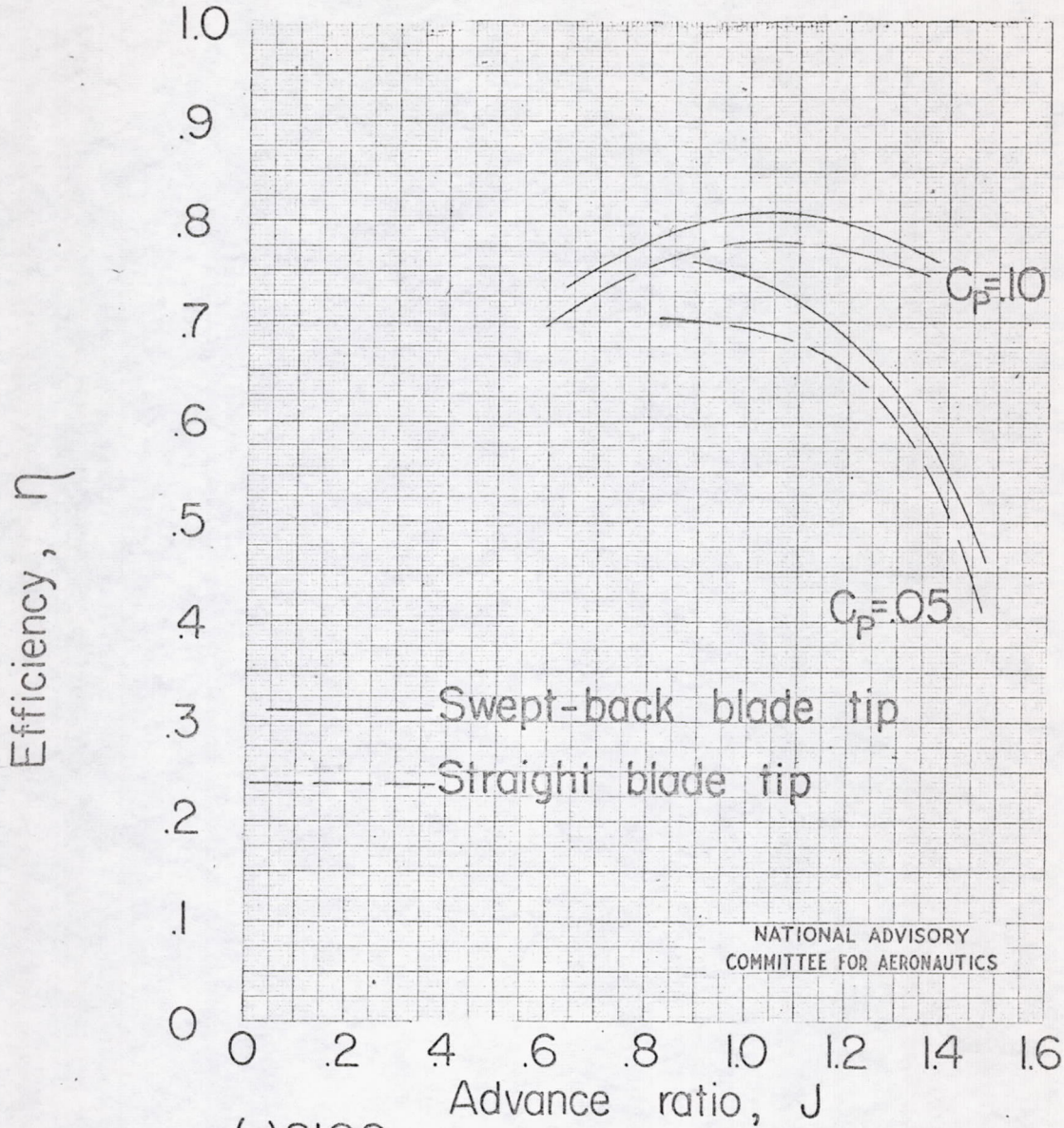
(c) 1800 rpm.

Figure 19. — Continued.



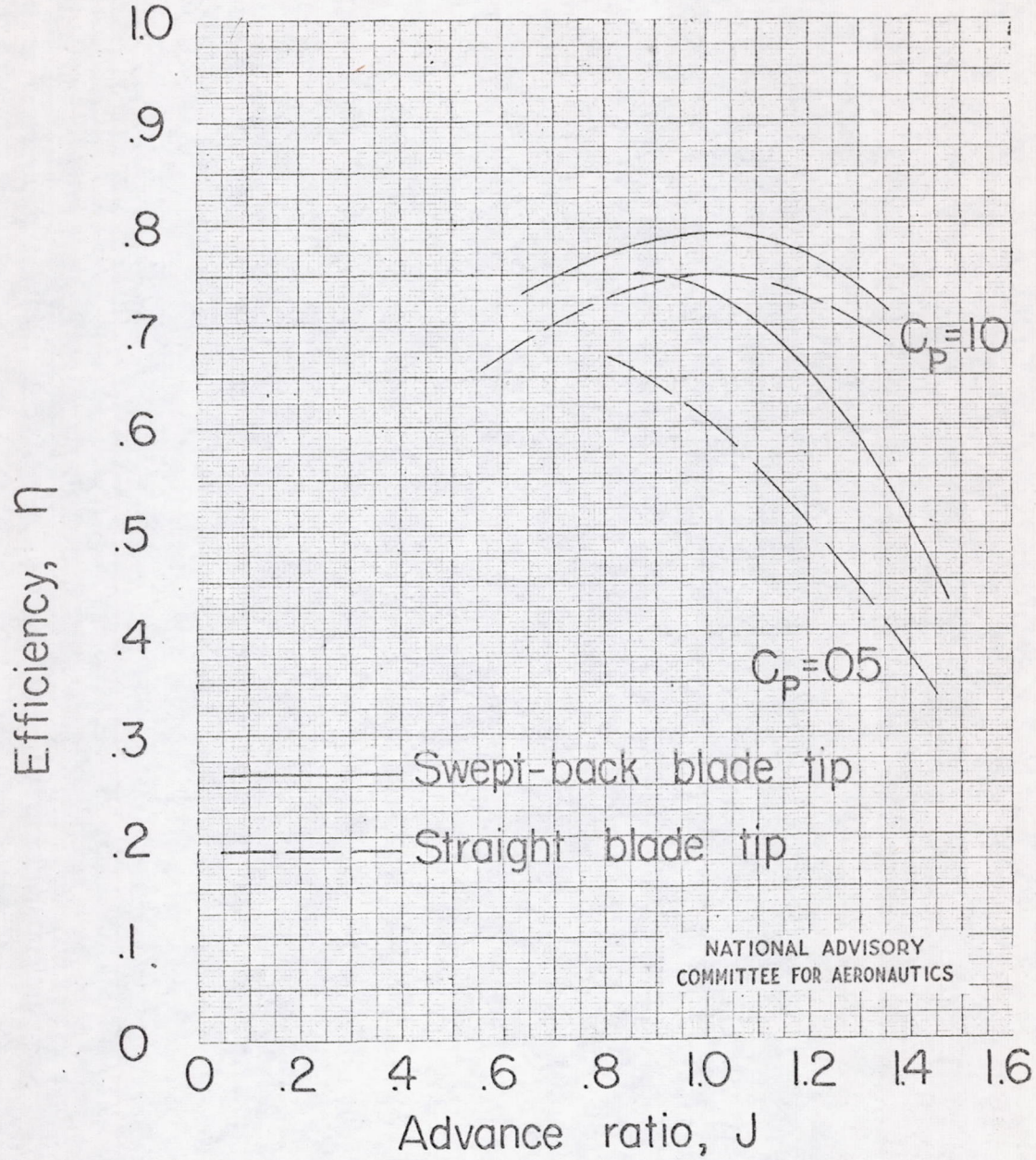
(d) 2000 rpm.

Figure 19 .—Continued.



(e) 2100 rpm.

Figure 19 .— Continued.



(f) 2160 rpm.

Figure 19.—Concluded.