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FULL-SCALE-TUNNEL INVESTIGATION OF A MULTIENGINE PUSHER-PROPELLER INSTALLATION

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FULL-SCALE-TUNNEL INVESTIGATION OF A MULTIENGINE PUSHER PROPELLER INSTALLATION

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SUMMARY

As part of the investigation in the NACA full-scale tunnel of the characteristics of propeller installations for multiengine airplanes, propellers designed specifically for pusher operation behind fixed contravanes have been tested on a large-scale model of a four-engine airplane. In this installation, the wing trailing edge was twisted to serve as a contravane and to produce the rotating inflow required for optimum propulsive efficiency. Tests of this propeller without wing twist and a conventional propeller were made for comparison.

Propulsive efficiencies of $88\frac{1}{2}$ percent were obtained for the pusher propellers with the contravanes, a value which was about $3\frac{1}{2}$ percent higher than that for the pusher propellers alone. The efficiency of the conventional pusher-propeller installation was about the same as that of the special propeller without contravanes and of the same order as that obtained with tractor installations.

INTRODUCTION

As part of the investigation in the NACA full-scale tunnel of the characteristics of propeller installations on a large-scale model of a four-engine airplane (reference 1), propellers designed particularly for pusher operation behind fixed contravanes have been tested. The propellers were designed to operate in a rotating inflow established by twisting the wing trailing edge. Airfoil shank sections were employed on these propellers and their pitch and blade-width distributions were chosen to minimize the axial and rotational momentum losses. The effect on the propeller performance of pretwisting the stream was determined by testing the propellers at two contravane angles and without the contravanes.

Comparative tests were also made with propellers of conventional round-shank design.

The tests included measurements of the propulsive characteristics of the different installations and surveys of the velocity and the angularity in the slipstream.

SYMBOLS

ρ	mass density of air
n	propeller rotational speed
V	airspeed
β	blade angle at 0.75R
D	propeller diameter
T	propeller thrust (tension in propeller shaft)
ΔD	increase in drag of model due to propeller
$T - \Delta D$	effective thrust
P	power input per propeller
C_T	thrust coefficient $\left(\frac{T - \Delta D}{\rho n^2 D^4}\right)$
C_P	power coefficient $\left(\frac{P}{\rho n^3 D^5}\right)$
η	propulsive efficiency $\left(\frac{(T - \Delta D)V}{P}\right)$
V/nD	advance-diameter ratio of propeller
R	resultant drag force on propeller-model combination
D_o	propeller-removed drag of model
ψ	yaw angle of air stream

q_o free-stream dynamic pressure

q local dynamic pressure

c wing chord

MODEL AND TEST EQUIPMENT

The four-engine midwing-airplane model on which the pusher propellers were installed had a span of 37.25 feet. The wing sections were symmetrical and tapered in thickness from 0.18c at the root to 0.10c at the tip. The original wing had a plan form tapered 4:1 with a root chord of 7.28 feet and an area of 172 square feet (reference 1) but, for these tests, the chord was extended 20 percent at the trailing edge by means of a thin sheet-metal flap that could be differentially deflected to serve as a contravane (figs. 1 and 2). The horizontal tail surfaces were removed to avoid interference with the apparatus used for the slipstream surveys.

Four 25-horsepower electric motors installed in the wings were used to drive the propellers and torques were obtained from an electrical calibration. Propeller speeds were measured with an electrical tachometer.

Blade characteristics for the two 42-inch-diameter propellers are given in figure 3. The conventional propeller had Clark Y blade sections and the special pusher design had NACA 16-series blade sections. The differential deflections of the trailing edge for the contravane tests are given in figure 4.

TESTS

At an angle of attack corresponding to the high-speed flight condition, propulsive characteristics were determined for a blade-angle range appropriate to the design conditions of the propellers for each installation. In this way, the peak of the envelope of the propulsive-efficiency curves was determined. The special pusher propeller had a design blade angle of 40° and, with the basic contravane twist (fig. 4), tests were made at $\beta = 40^\circ$ and 45°. With 83 percent of the basic twist, it was thought possible that the maximum efficiency might occur at a lower blade angle and accordingly tests were made at $\beta = 35^\circ$ and 40°. For the tests of this propeller without flap twist, the blade-angle range was extended to include values of from 25° to 40°. A similar range of blade angles from 25° to 40° was used for the tests of the conventional propeller.

In order to cover the range of V/nD for each propeller, the torque was held constant, the tunnel airspeed was increased in steps from 30 to 100 miles per hour, and the propeller speed was then reduced until zero thrust was reached. For each combination of tunnel speed and propeller speed, the motor torque and the aerodynamic forces on the model were recorded. Propeller-removed lift and drag tests for the determination of the effective thrusts were made at all tunnel speeds.

The surveys of the slipstream dynamic pressure and angularity were made along a vertical line through the propeller axis in order that the measured stream angles could be separated readily into yaw angles due to propeller rotation and pitch angles due to wing downwash.

RESULTS AND DISCUSSION

The characteristics of the propeller installations are given as values of the propulsive efficiency η and the thrust and power coefficients C_T and C_P. The effective thrust of the propeller combinations was determined from the relation.

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

in which $T - \Delta D$ is the effective thrust of the propeller installation, D_o is the drag of the model with the propellers removed, and R is the drag force measured with the propellers operating. Values of D_o obtained with the trailing-edge flaps undeflected were used in the computation of all the effective thrusts in order to charge the drag of the twisted flaps for the contravane tests against the propeller thrust.

The special pusher-propeller installation with the basic flap twist (fig. 4) gave a maximum propulsive efficiency of $88\frac{1}{2}$ percent at a blade angle of 40° and a V/nD of 1.8 (fig. 5). Reducing the flap twist to 83 percent of the basic value decreased the maximum efficiency to

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87 percent (fig. 6) and did not appreciably change the blade angle or the V/nD at which the peak occurred. Without the contravanes, the maximum propulsive efficiency was 85 percent (fig. 7) at a blade angle of 40° and occurred at the slightly higher V/nD of 1.84. The conventional propeller also gave a maximum efficiency of 85 percent, but at a blade angle of 35° and a V/nD of 1.45 (fig. 8). The propulsive characteristics for all installations are summarized in table I, which includes for comparison values obtained from the tests of reference 2 with a tractor installation of the special pusher propeller.

The reasons for the variations in efficiency of the pusher propeller are shown by the slipstream surveys (fig. 9). With the basic twist, the slipstream velocity as shown by the curves of slipstream dynamic pressure is uniform and the angularity is almost negligible except in the wake of the spinner and wing. This type of slipstream satisfies the requirements for low axial and rotational energy losses. With 83 percent of the basic twist, the angularity increases in the direction to account for the $1\frac{1}{2}$ percent decrease in the efficiency. With no twist, the angularity is about 8° at the edge of the spinner and the slipstream velocity is much less uniform substantiating the lower measured propulsive efficiency. The low airspeed in the center of the slipstream is the wake of the wing, the flaps, the spinner, and the blade-spinner junctures.

An additional effect of the contravanes is to increase the thrust and power coefficients of the propeller by varying amounts up to 40 percent at the 40° blade angle with the basic flap twist (table I). This increase is equivalent to an increase in solidity and results from the higher angles of attack and relative velocities of the propeller blade sections caused by the rotating inflow.

The lower blade angle for the maximum efficiency of the conventional propeller is due to its pitch distribution (fig. 3) and to the increased detrimental effects of the round blade shanks at high blade angles. In these respects, the conventional propeller is similar to most of the propellers in use at present. The thrust and power coefficients for this propeller were from 15 to 30 percent less than for the pusher propeller, owing to its considerably lower solidity.

The propulsive characteristics of the tractor installation given in table I have about the same values as for the pusher propeller without contravanes. The efficiencies shown are from 1 to 2 percent lower, but the tests lack sufficient experimental accuracy and similarity to justify a comparison of the relative merits of pusher and tractor installations. The results do serve to show, however, that no large difference is to be expected between aerodynamically clean pusher- and tractor-propeller installations in the blade-angle range of these tests.

For high-speed airplanes in which propeller blade angles in the range of 50° to 60° are required, the gains due to the use of contravanes with pusher-propeller installations may be somewhat larger than those measured in these tests.

SUMMARY OF RESULTS

The results of this investigation show that gains in efficiency of about $3\frac{1}{2}$ percent at a blade angle of 40° can be obtained by the use of contravanes with specially designed pusher propellers. The contravanes also give an increase in the power absorption of the propellers equivalent to an increase in the solidity. Without the contravanes, the special propeller gave a maximum propulsive efficiency of 85 percent at a blade angle of 40°, which was about the same as the peak efficiency obtained with a conventional pusher-propeller installation. The efficiencies obtained with the special and the conventional propellers without the contravanes were about the same as were obtained with the tractor installation of these propellers.

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REFERENCES

1. Silverstein, Abe, and Wilson, Herbert A., Jr.: Aerodynamic Characteristics of a 4-Engine Monoplane Showing Effects of Enclosing the Engines in the Wing and Comparisons of Tractor- and Pusher-Propeller Arrangements. NACA A.C.R., April 1938.

2. Harmon, Hubert N.: Wind-Tunnel Tests of Several Model Tractor-Propeller and Pusher-Propeller Wing Extension-Shaft Arrangements. NACA A.C.R., June 1941.

TABLE I

SUMMARY OF THE PROPULSIVE CHARACTERISTICS

Propeller installation	Blade angle, β (deg)	Characteristics at maximum efficiency			
		η (percent)	V/nD	C_P	C_T
Special pusher propeller with basic contravane twist	40	88.5	1.8	0.267	0.131
	45	85.5	2.2	.388	.151
Special pusher propeller with 83 percent of basic contravane twist	35	85	1.5	.180	.102
	40	87	1.8	.252	.122
Special pusher propeller without contravanes	25	80	.92	.104	.0905
	30	84	1.21	.130	.090
	35	84	1.41	.172	.103
	40	85	1.84	.193	.089
Conventional propeller in a pusher installation	25	84	1.00	.070	.059
	30	84.5	1.25	.090	.061
	35	85	1.45	.130	.076
	40	82	1.75	.160	.075
Special pusher propeller used in a tractor installation (from tests of reference 2)	35	84	1.56	.140	.075
	40	83	1.80	.206	.095
	45	83	2.05	.287	.116

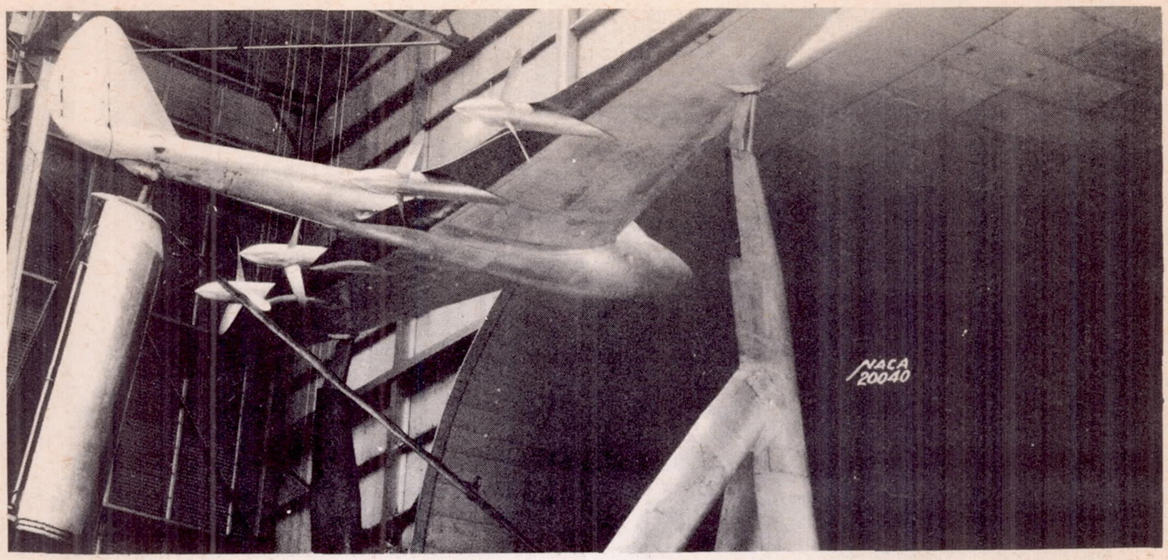


Figure 1.- The four-engine airplane model installed in the full-scale tunnel with special pusher propellers and twisted flaps.

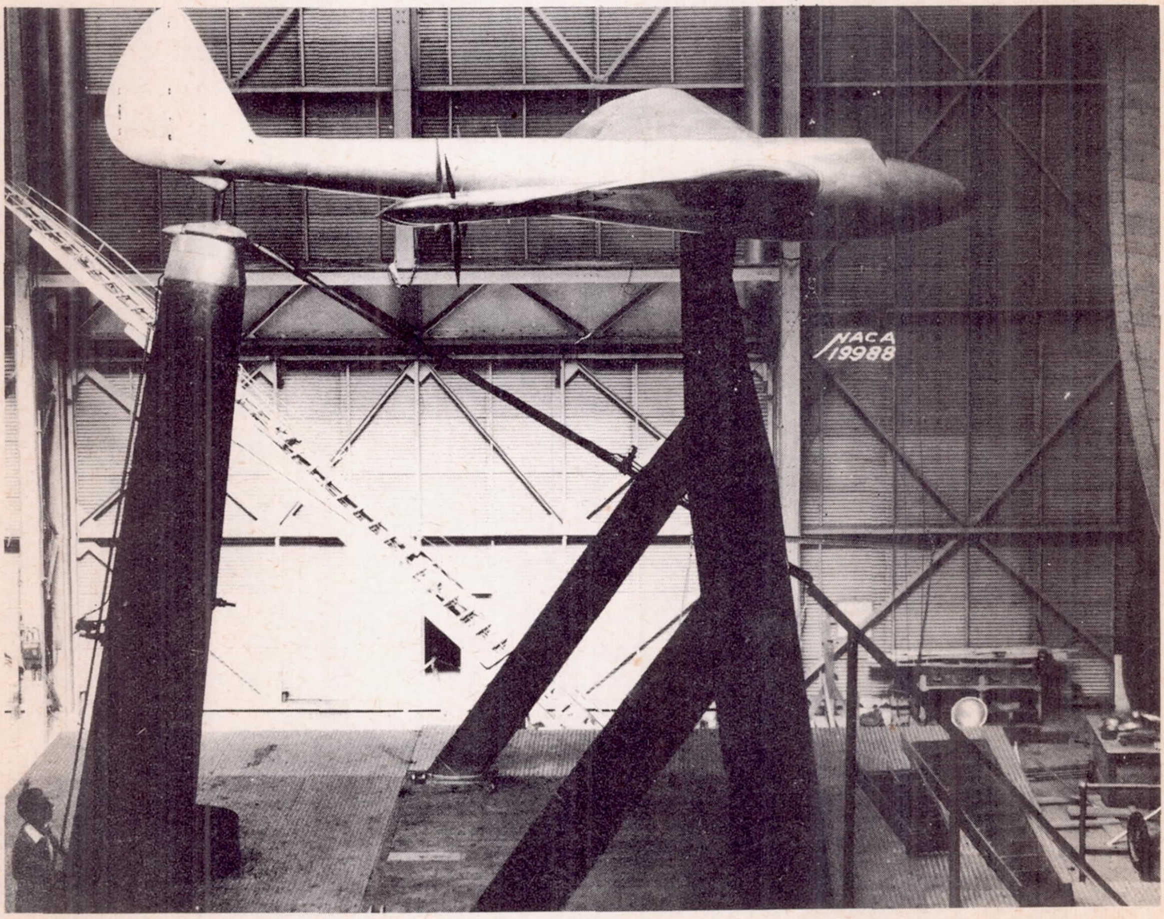


Figure 2.- The four-engine airplane model installed in the full-scale tunnel with conventional propellers and without flap twist.

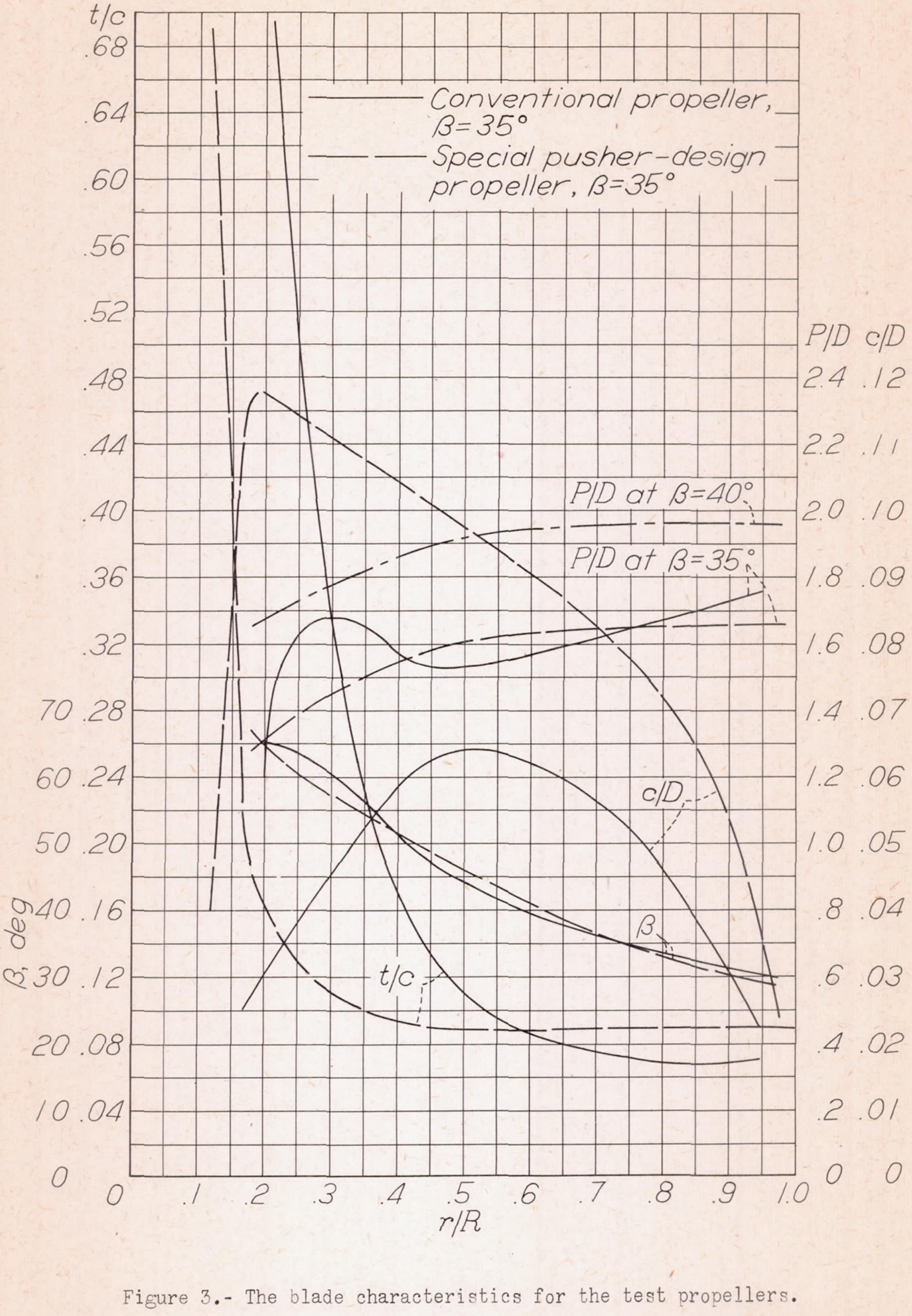


Figure 3.- The blade characteristics for the test propellers.

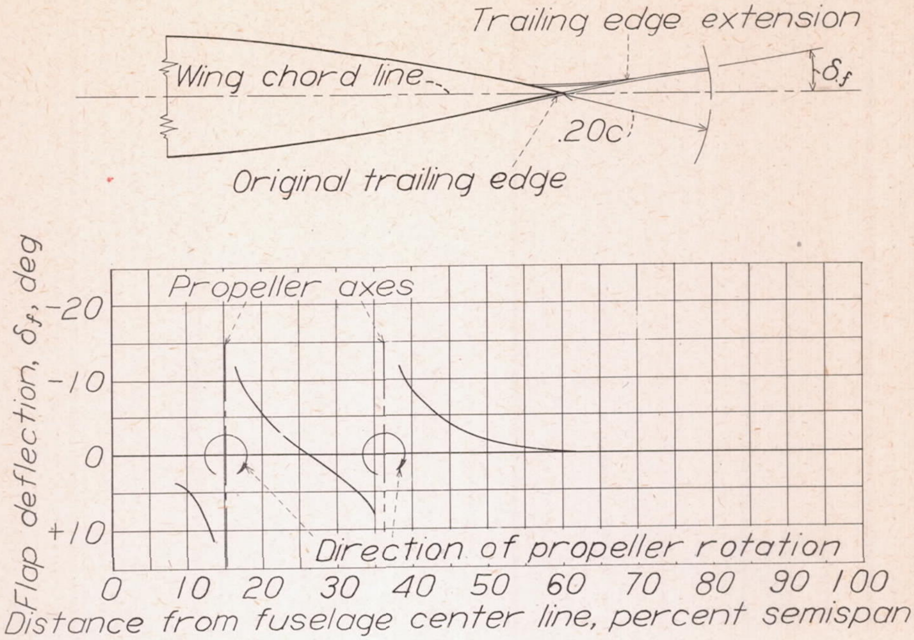
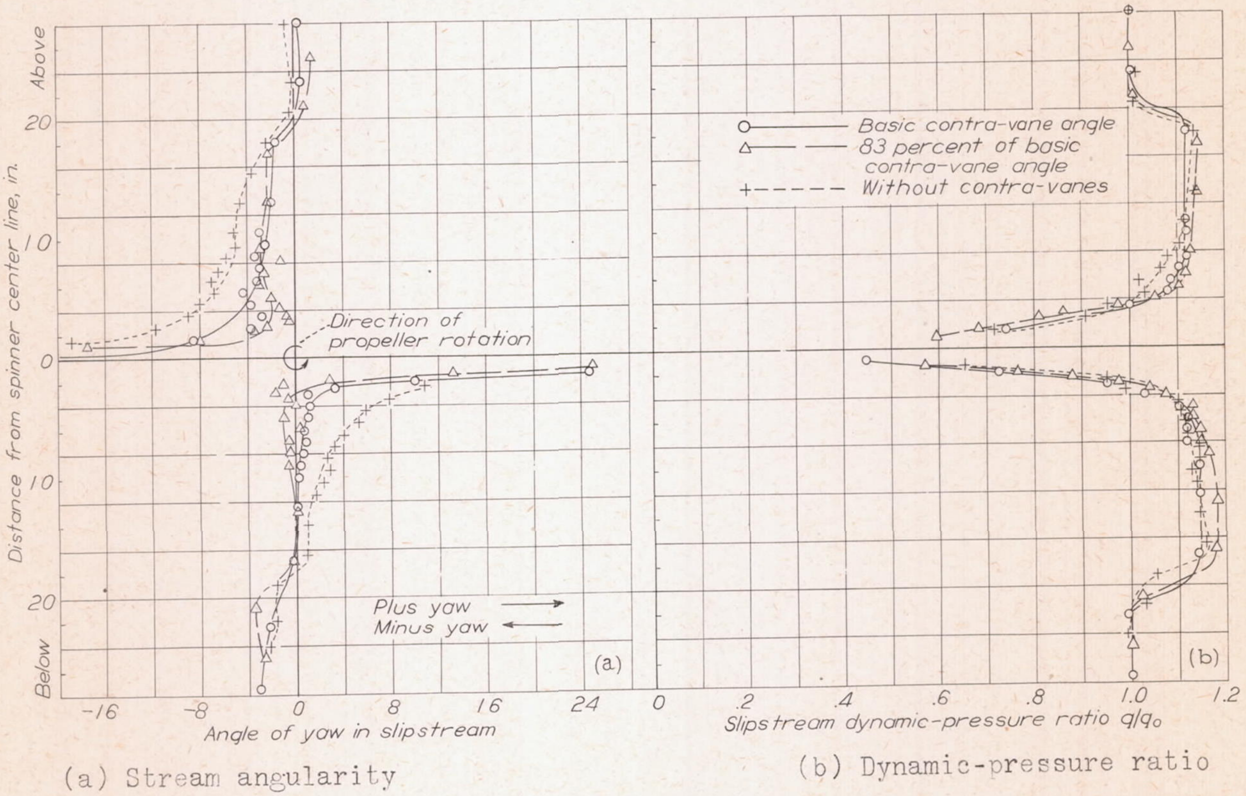


Figure 4.- The trailing-edge deflections for the basic flap twist.



(a) Stream angularity (b) Dynamic-pressure ratio

Figure 9.- Surveys of the air flow in the slipstream.

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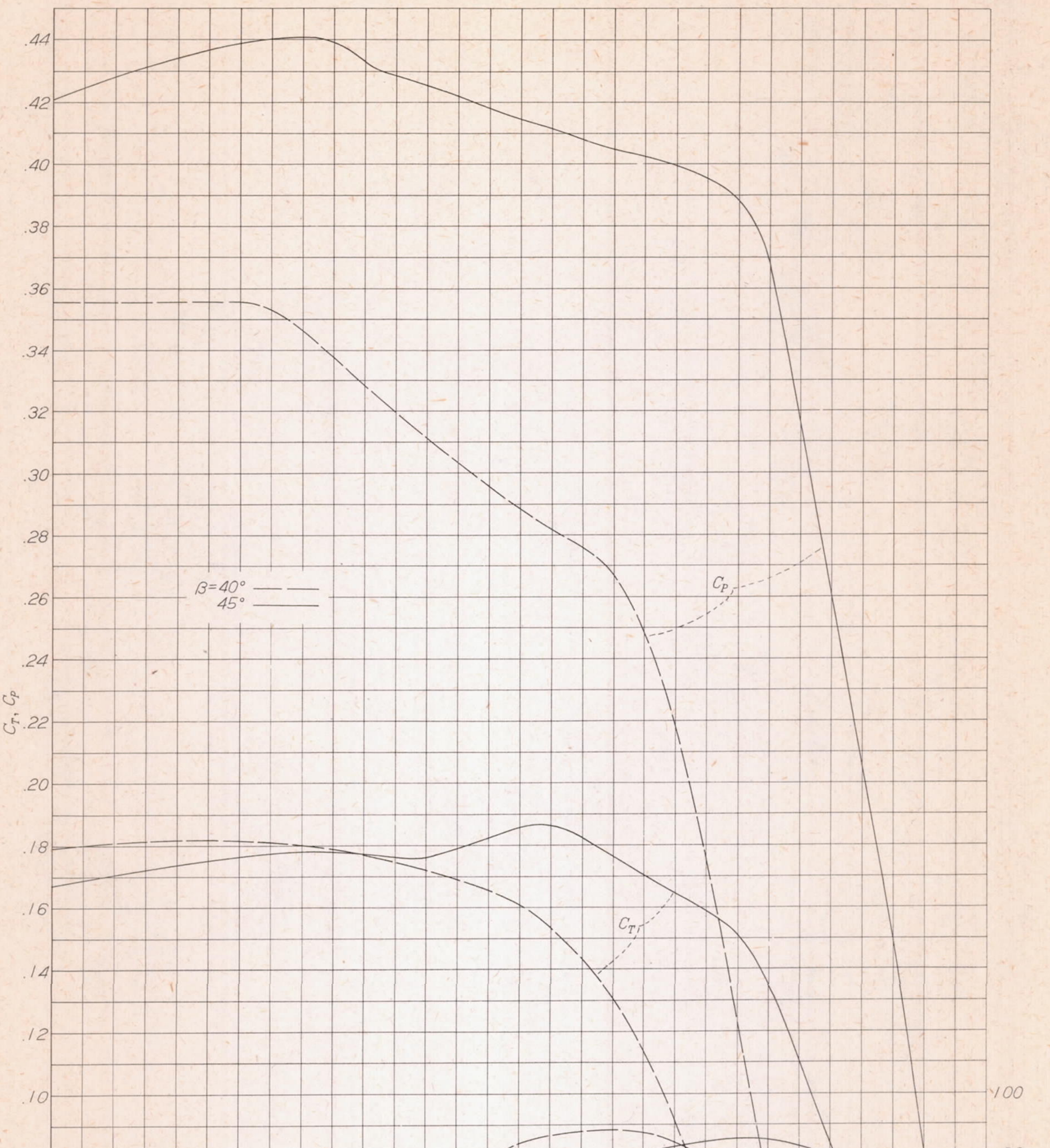

Figure 5.- Propulsive characteristics for the special pusher-design propeller with the basic flap twist.

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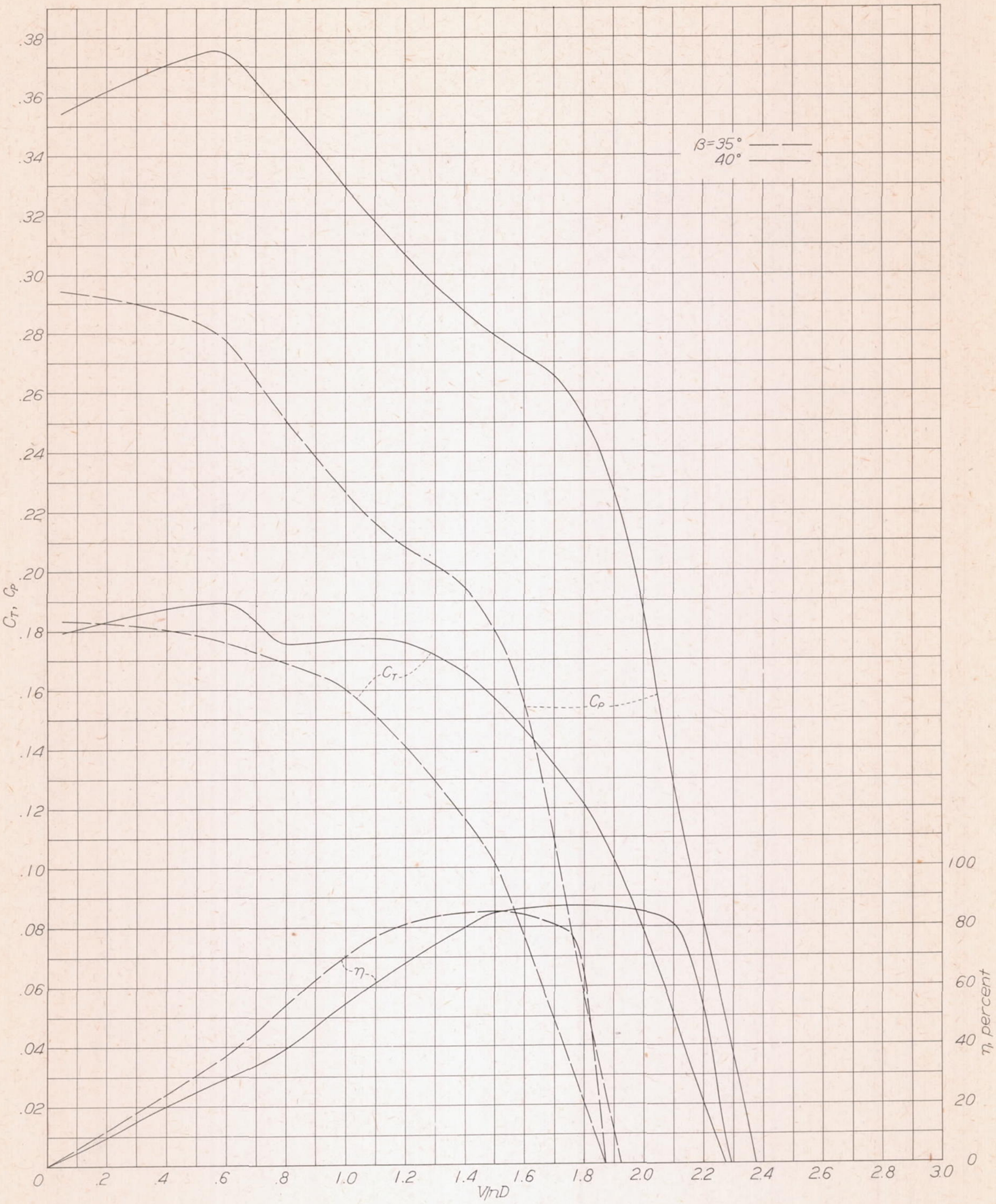

Figure 6.- Propulsive characteristics for the special pusher-design propeller with 0.83 of the basic flap twist.

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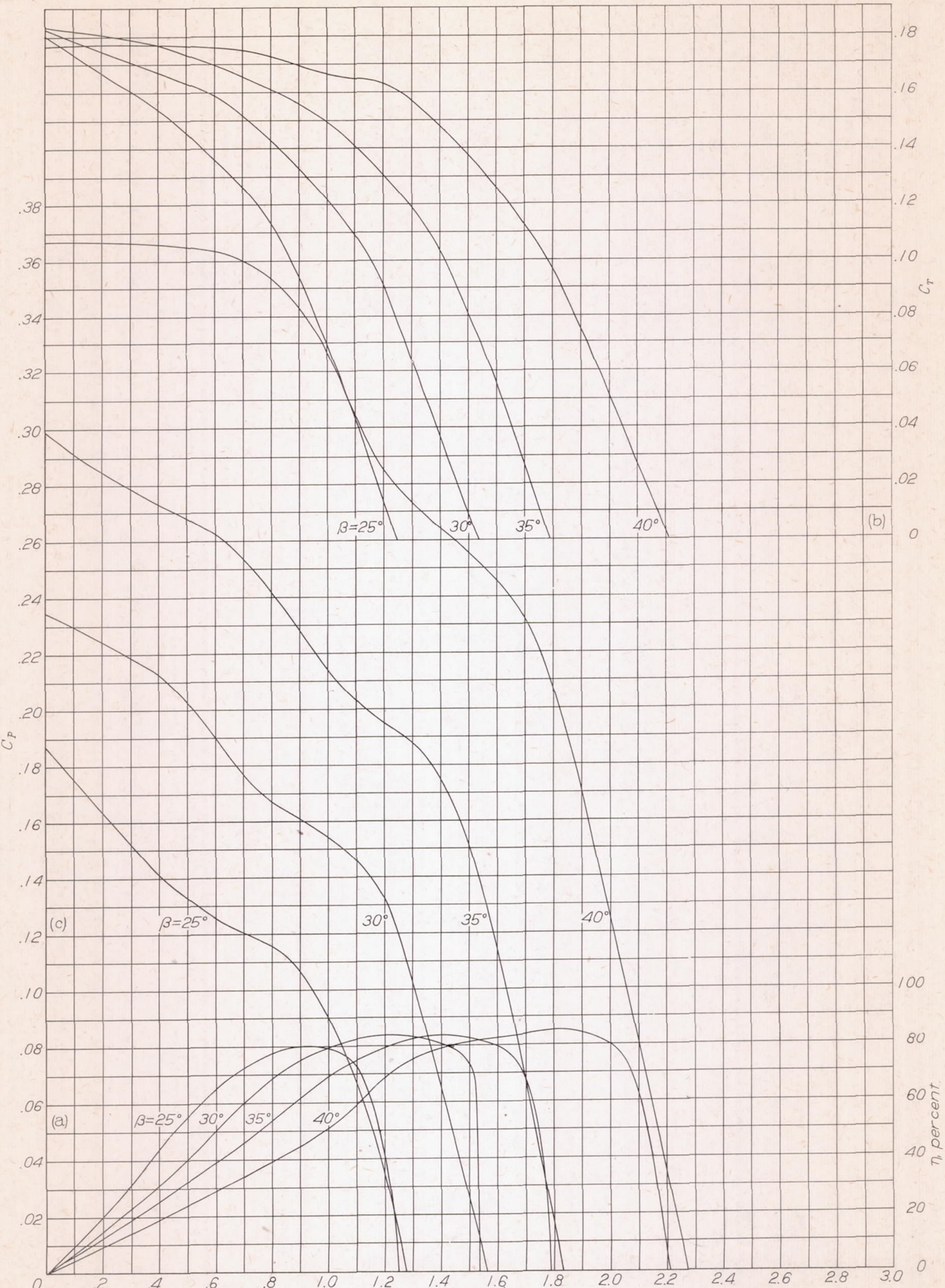

(a) Propulsive efficiency (b) Thrust coefficient (c) Power coefficient

Figure 7.- Propulsive characteristics for the special pusher-design propeller without the twisted flap.

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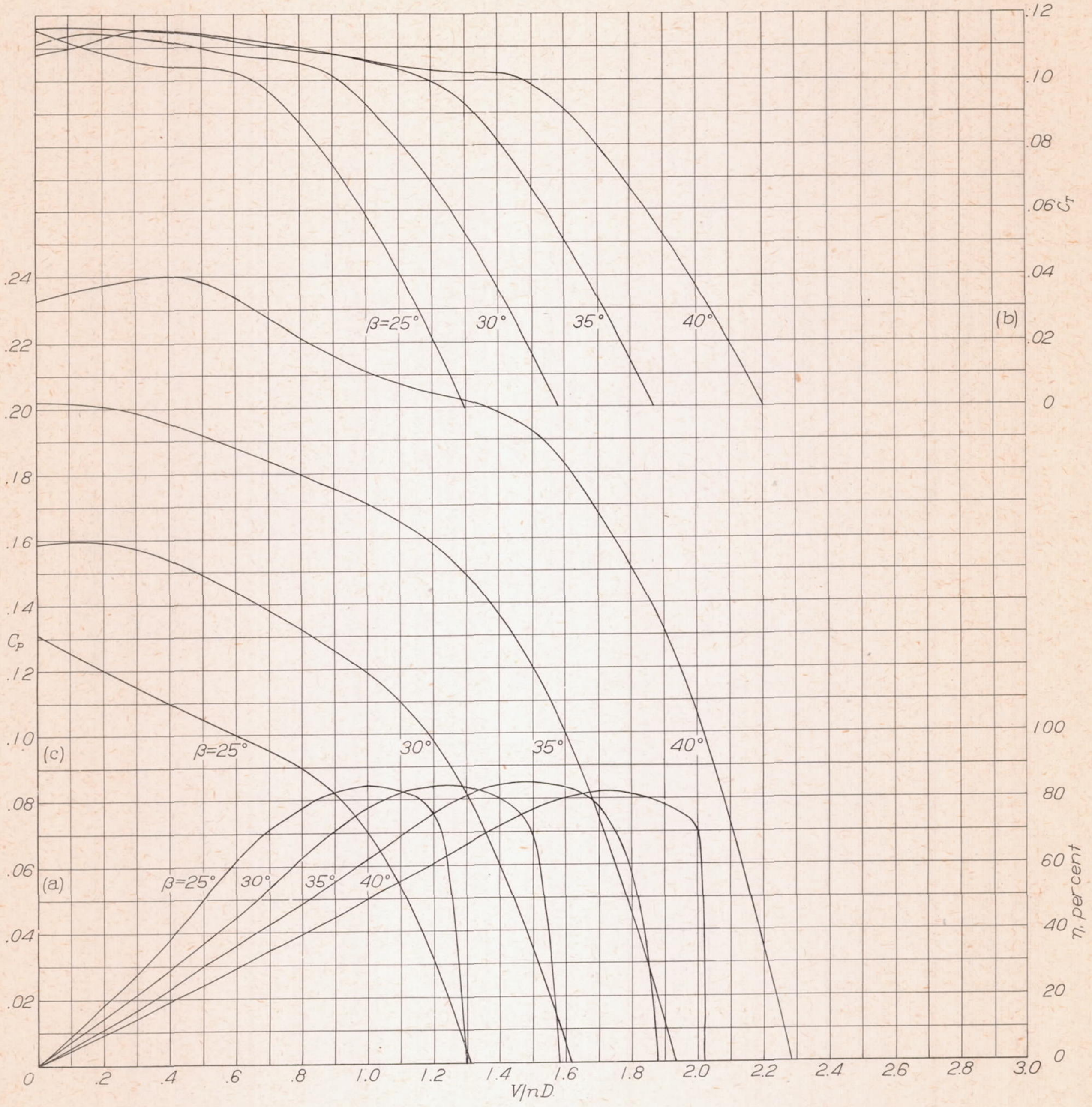

(a) Propulsive efficiency (b) Thrust coefficient (c) Power coefficient

Figure 8.- Propulsive characteristics for the conventional propeller.