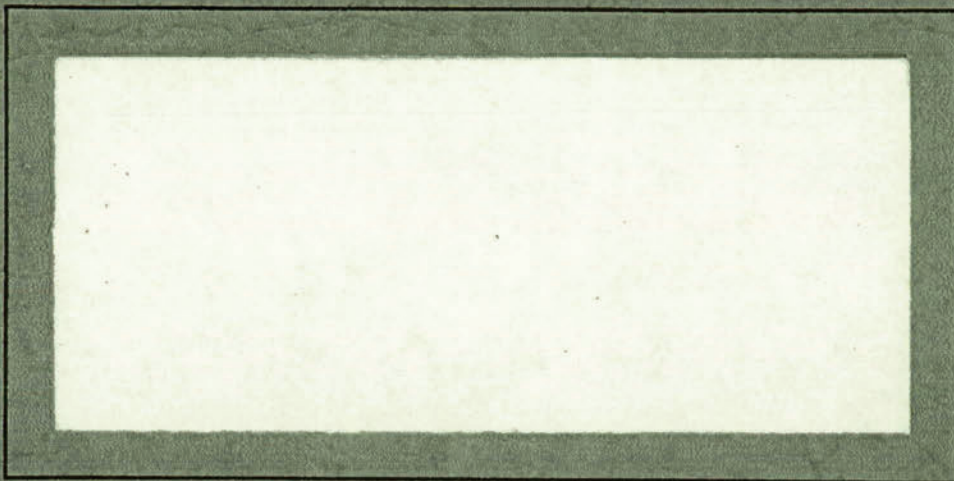


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NACA AMES AERONAUTICAL LABORATORY

MEMORANDUM REPORT

for the

Air Technical Service Command, U. S. Army Air Forces

APR 24 1946

MR No. A6D05

EFFECTS OF MACH NUMBER ON THE SPAN LOAD

DISTRIBUTION OF A 0.3-SCALE MODEL

OF THE REPUBLIC P-47D AIRPLANE

By Lee E. Boddy

SUMMARY

This report presents the results of high-speed pressure-distribution measurements on the wing of a 0.3-scale model of the P-47D airplane. The data indicate an outward shift of the air load on the wing at high Mach numbers, due to a loss of lift on the root section. The root section, being thicker and set at a higher angle of incidence, has a lower critical Mach number than the remainder of the wing.

INTRODUCTION

Satisfactory methods have been devised for predicting the low-speed air-load distribution on airplane wings. (See reference 1.) However, at the present time, experimental means must be resorted to in order to determine the air-load

distribution at high Mach numbers, especially at Mach numbers above the critical for the wing. This report presents the results of tests made to determine the effect of Mach number on the span load distribution of a 0.3-scale model of the Republic P-47D airplane. The results of tests made to determine the general aerodynamic characteristics of the model, including pressure distributions at two spanwise wing stations, are presented in reference 2. The tests were conducted in the Ames 16-foot high-speed wind tunnel at the request of the Air Technical Service Command, U.S. Army Air Forces.

MODEL AND APPARATUS

Figure 1 is a three-view drawing and figure 2 is a photograph of the model, which was designed and constructed at the Ames Aeronautical Laboratory. The model was built up of steel spars covered with mahogany, and incorporated four chordwise bands of pressure orifices in the left wing panel at stations 10.8, 30.0, 50.0 and 70.0 inches from the longitudinal center line. The pressure orifices were connected by rubber tubing to mercury-in-glass manometers.

The wing area of the model was 27.000 square feet, the span was 12.233 feet, and the mean aerodynamic chord was 2.187 feet. The airfoil section was the Republic S-3 throughout (similar to the NACA 230-series airfoil), with a thickness, twist, and chord distribution along the span as shown in figures 3 and 4.

Support for the model in the wind-tunnel test section (see fig.2) was provided by two 5-percent-thick unshielded struts connected to the wing 40 inches either side of the center line of the model, and a single 7-percent-thick unshielded strut connected to the after part of the fuselage. Angle-of-attack control was obtained by vertical movement of the rear strut.

SYMBOLS

The symbols used in this report are defined as follows:

V	free-stream velocity, feet per second
q	free-stream dynamic pressure ($\frac{1}{2}\rho V^2$), pounds per square foot
ρ	free-stream mass density, slugs per cubic foot
M	Mach number ($\frac{V}{\text{velocity of sound}}$)
P	pressure coefficient ($\frac{P - P_0}{q}$)
p	local static pressure on surface, pounds per square foot
p_0	free-stream static pressure, pounds per square foot
P_{cr}	critical pressure coefficient (P at which the local velocity equals the local velocity of sound)
M_{cr}	critical Mach number (free-stream Mach number at which P_{cr} is attained)
S	wing area, square feet
b	wing span, feet

M.A.C.	wing mean aerodynamic chord, feet
c_s	wing chord at any particular spanwise section, feet
y	distance of any particular section from the center line of symmetry, feet
C_L	trimmed lift coefficient $\left(\frac{\text{trimmed lift}}{qS} \right)$
C_N	wing normal-force coefficient $\left(\frac{\text{normal force}}{qS} \right)$
C_m	pitching-moment coefficient $\left(\frac{\text{pitching moment}}{qS \text{ M.A.C.}} \right)$
C_{bm}	bending-moment coefficient of the normal force $\left(\frac{\text{bending moment}}{q b^2 c_s} \right)$
c_n	section normal-force coefficient $\left(\frac{\text{section normal force}}{q c_s} \right)$
c_m	section pitching-moment coefficient $\left(\frac{\text{section pitching moment}}{q c_s^2} \right)$
α	angle of attack of the fuselage reference line, degrees
α_u	angle of attack of the fuselage reference line, uncorrected for tunnel-wall or support-strut interference, degrees
g	acceleration of gravity, feet per second per second

REDUCTION OF DATA

The results of the tests have been corrected for tunnel-wall and support-strut interference and for the constriction effects of the model. A complete description of the method

used for determining the various corrections may be found in reference 3. The relation between Mach number and Reynolds number for the model in the Ames 16-foot high-speed wind tunnel is given in figure 5.

The pitching moments were computed with respect to a center-of-gravity location which was 1.650 inches below the fuselage reference line of the model and directly above the 27.5-percent point of the mean aerodynamic chord. In determining the pitching-moment coefficients from the wing pressure distribution, the direction of the pressures was assumed to be normal to the chord line, their effect in the thicknesswise direction being neglected.

In order to facilitate plotting in carpet form, all the data were first plotted against Mach number. The ordinates were then replotted for even values of Mach number.

All the data for Mach numbers above 0.80 are shown dotted in the figures and should be treated with reserve, owing to the proximity of the tunnel-choking Mach number for the model and support combination tested.

RESULTS AND DISCUSSION

Typical pressure distributions for the Republic S-3 airfoil section are shown in figure 6. At low Mach numbers, the distribution conformed to that of conventional-type airfoils. However, as the critical Mach number was exceeded at moderate angles of attack, a localized disturbance

appeared on the upper surface of the wing near the position of the minimum pressure coefficient (at about 30 percent chord). The flow aft of this disturbed region appeared to be much the same as that at low speed until the critical Mach number was exceeded by about 0.15, beyond which Mach number the flow was separated over the entire after part of the chord and the pressure recovery was not complete. Apparently the pressure-recovery gradient over the after part of the chord was such that the critical Mach number had to be exceeded considerably before the disturbance of the compression shock was strong enough to cause complete separation of the flow. This behavior is substantiated by the tuft photographs of reference 2.

The critical Mach number at various spanwise stations of the P-47D model wing is given in figure 7. The root section, being thicker and set at a higher angle of incidence, has a lower critical Mach number for positive values of lift coefficient than the remainder of the wing.

Lift and Normal-Force Characteristics

In order to facilitate the transformation of the data into terms of operating conditions of the P-47D airplane, the characteristics are given as a function of the trimmed lift coefficient rather than tail-off lift coefficient or elevator-neutral lift coefficient. The trimmed lift coefficient carpet for the P-47D airplane model is given in figure 8, and the section normal-force coefficient carpets, obtained from

integration of the pressure distribution, are shown in figure 9. Figure 10 gives the total normal force on the wing as a function of the trimmed lift coefficient and Mach number. The root sections of the wing, having a lower critical Mach number, exhibited much greater effects of compressibility than the remainder of the wing; whereas the tip section exhibited no detrimental characteristics within the range of the tests. Figure 11 presents a résumé of the effects of Mach number on the lift characteristics of various span-wise locations of the wing. Below a Mach number of 0.80, the increase of section zero-lift angle of attack from root to tip was about one-half the twist of the wing-chord plane. The large change of section zero-lift angle of attack near the middle of the semispan above a Mach number of 0.80 is believed to be caused by local effects of the support strut.

Span Load Distribution

The predicted distribution of the normal load along the span of the P-47D airplane wing is given in figure 12 as the product of the section normal-force coefficient and the local chord. At a Mach number of 0.60 and a lift coefficient of between 0.7 and 0.8, the root section of the wing began to carry a smaller proportion of the total load than it did at low speed. This outward shift of the load occurred at successively lower lift coefficients as the Mach number was

increased. However, in terms of flight conditions of the airplane (fig. 13) the effect is not so severe, since the lift coefficient required for a given acceleration decreases as the Mach number is increased.

The outward shift of the load due to the loss of lift over the root section of the wing causes an increase in the bending moment at the wing root (fig. 14). This increase occurred at a Mach number of 0.60 and a lift coefficient of 0.30, or at a Mach number of 0.75 and a lift coefficient of 0.20. At a Mach number of 0.80 and a lift coefficient of 0.40 (corresponding to an 8g pull-up at sea level) the bending-moment coefficient at the wing root was 0.034, or over 13 percent greater than the low-speed value.

Torsion Characteristics

The predicted distribution of the torsion load along the span of the P-47D airplane wing is shown in figure 15 as the product of the section pitching-moment coefficient and the square of the local chord. Since the moment axis is a straight line passing through the 27.5-percent point of the mean aerodynamic chord, and the plan form of the wing is a distorted ellipse, the position of the axis in percent of local chord is not constant along the span of the wing. For instance, at the root the moment axis is at 29 percent of the local chord; at the middle of the semispan it is at 27.5 percent; and near the tip, it is at 38 percent. (See figure 4.)

The adverse effects of compressibility first appeared at the root section at a Mach number of 0.60 and a lift coefficient of about 0.70. At a Mach number of 0.80 the adverse effects were apparent all along the wing span. Integration of the span torsion load revealed the total torsion (pitching-moment coefficient of the wing) shown in figure 16. The results of force tests of the wing-fuselage combination are also given. Both sets of data indicate that the pitching moment of the wing became considerably more negative as the Mach number increased; whereas the rate of change of pitching-moment coefficient with lift coefficient changed from a positive value to a negative value. Although the destabilizing effect of the fuselage is included in the data from the force tests, the effect of Mach number on the wing pitching (or torsion) moment is clearly evident from both sets of data.

CONCLUSIONS

High-speed wind-tunnel tests to determine the span load distribution over the wing of a model of the P-47D airplane indicated the following:

1. The centroid of the air load on the wing shifted outward at high Mach numbers due to a loss of lift on the root sections. This loss of lift was largely a result of the thickness and twist distribution along the span of the wing.

2. The pitching-moment coefficient (torsion) of the wing became considerably more negative at high Mach numbers, and the rate of change of pitching-moment coefficient with lift coefficient changed from a positive value to a negative value.

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Aeronautical Engineer.

Approved:

Donald H. Wood

Donald H. Wood,
Aeronautical Engineer.

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1. Anon.: Spanwise Air-Load Distribution. ANC-1(1), Army-Navy-Commerce Committee on Aircraft Requirements, Apr. 1938.
2. Hamilton, William T., and Boddy, Lee E.: High-Speed Wind-Tunnel Tests of a 0.3-Scale Model of the P-47D Airplane. NACA ACR No. 5D20, 1945.
3. Boddy, Lee E.: The High-Speed Characteristics of Several Flaps and Spoilers on the Upper Surface of the Horizontal Stabilizer of a 0.3-Scale Model of the Republic P-47D Airplane. NACA CMR No. A5L07, 1945.

FIGURE LEGENDS

- Figure 1.- The 0.3-scale model of the P-47D airplane.
- Figure 2.- The P-47D airplane model in the Ames 16-foot high-speed wind tunnel.
- Figure 3.- The thickness and twist distribution of the P-47D airplane wing. (a) Thickness distribution. (b) Twist distribution.
- Figure 4.- The local chord and the chordwise position of the lateral axis passing through the 27.5-percent point of the M.A.C. of the P-47D airplane. (a) Local chord. (b) Position of lateral axis.
- Figure 5.- Variation of Reynolds number with Mach number for the P-47D airplane model in the Ames 16-foot high-speed wind-tunnel.
- Figure 6.- Effect of Mach number on the chordwise pressure distribution on the P-47D airplane model wing. $y/0.5b = 0.147$. (a) $\alpha_u = -1^\circ$.
- Figure 6.- Concluded. (b) $\alpha_u = 7^\circ$.
- Figure 7.- The critical Mach number of the P-47D airplane model wing at various spanwise locations and values of trimmed lift coefficient.
- Figure 8.- Trimmed-lift-coefficient carpet for the P-47D airplane model.
- Figure 9.- Section normal-force-coefficient carpet for the P-47D airplane model wing. (a) $y/0.5b = 0.147$.
- Figure 9.- Continued. (b) $y/0.5b = 0.409$.
- Figure 9.- Continued. (c) $y/0.5b = 0.681$.
- Figure 9.- Concluded. (d) $y/0.5b = 0.954$.
- Figure 10.- Predicted relationship between the normal-force coefficient of the wing and the trimmed lift coefficient of the P-47D airplane.

Figure 11.- Section lift-curve slope at zero lift and section zero-lift angle of attack for the P-47D airplane model wing.

Figure 12.- Predicted spanwise distribution of the normal load on the P-47D airplane wing for several values of the trimmed lift coefficient. (a) $M = 0.20$. (b) $M = 0.40$.

Figure 12.- Continued. (c) $M = 0.60$. (d) $M = 0.65$.

Figure 12.- Continued. (e) $M = 0.70$. (f) $M = 0.75$.

Figure 12.- Concluded. (g) $M = 0.80$. (h) $M = 0.84$.

Figure 13.- Predicted spanwise distribution of the normal force on the P-47D airplane wing (wing loading of 45 lb per sq ft) for several values of indicated normal acceleration at 10,000 ft altitude.

Figure 14.- Predicted variation with Mach number of the bending-moment coefficient at the root of the P-47D airplane wing for several values of the trimmed lift coefficient.

Figure 15.- Predicted spanwise variation of the torsion load on the P-47D airplane wing about the lateral axis passing through the 27.5-percent point of the M.A.C. (a) $M = 0.20$. (b) $M = 0.40$.

Figure 15.- Continued. (c) $M = 0.60$. (d) $M = 0.65$.

Figure 15.- Continued. (e) $M = 0.70$. (f) $M = 0.75$.

Figure 15.- Concluded. (g) $M = 0.80$.

Figure 16.- The pitching-moment coefficient of the P-47D airplane model wing for several values of the trimmed lift coefficient. (a) Data from force tests of the wing-fuselage combination. (b) Data from integration of the wing pressure distribution.

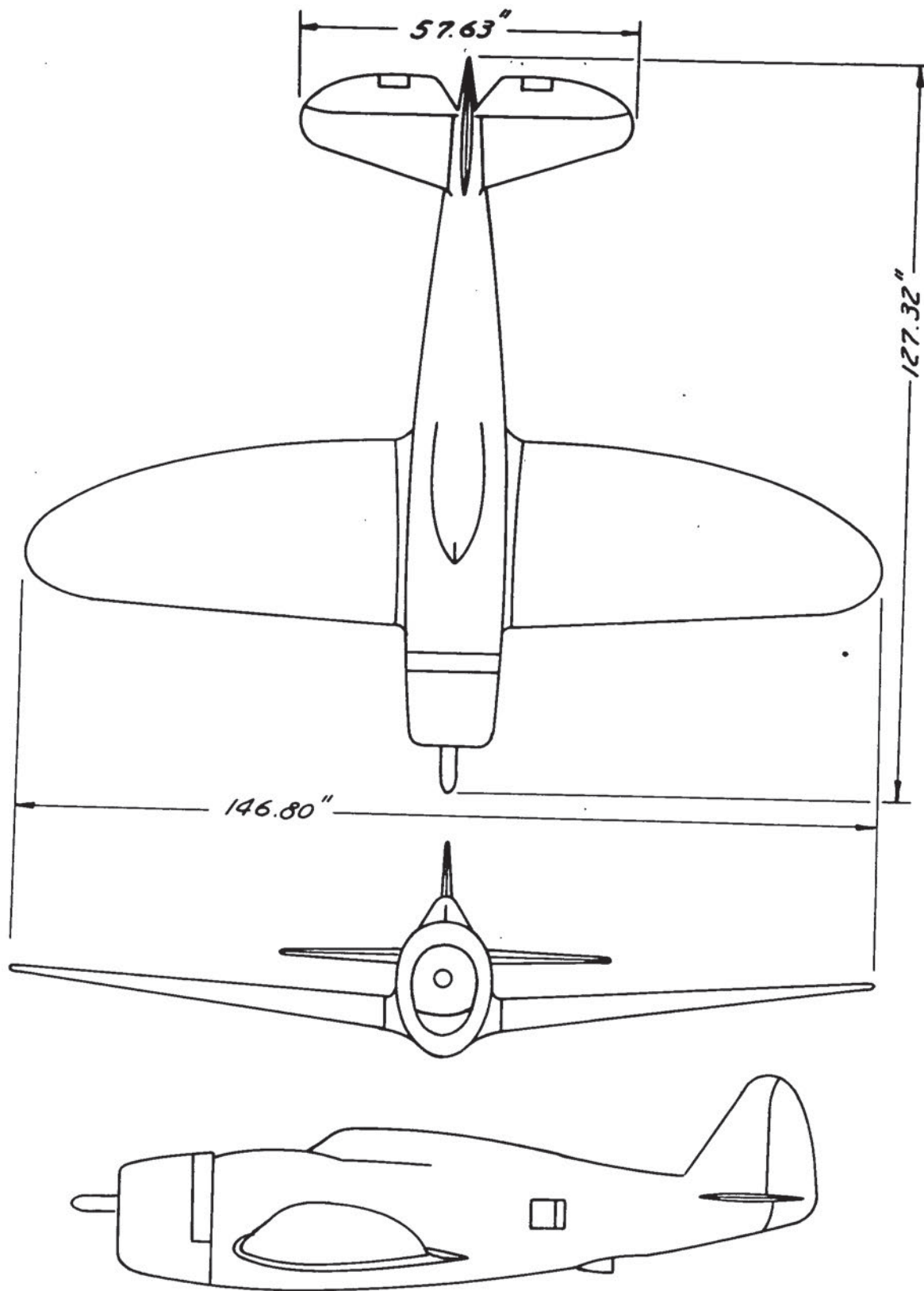
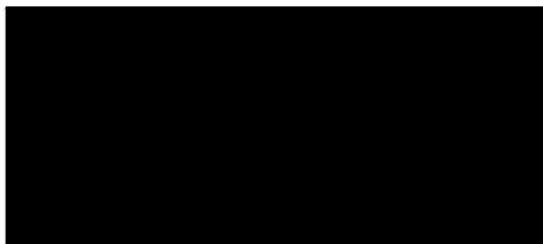
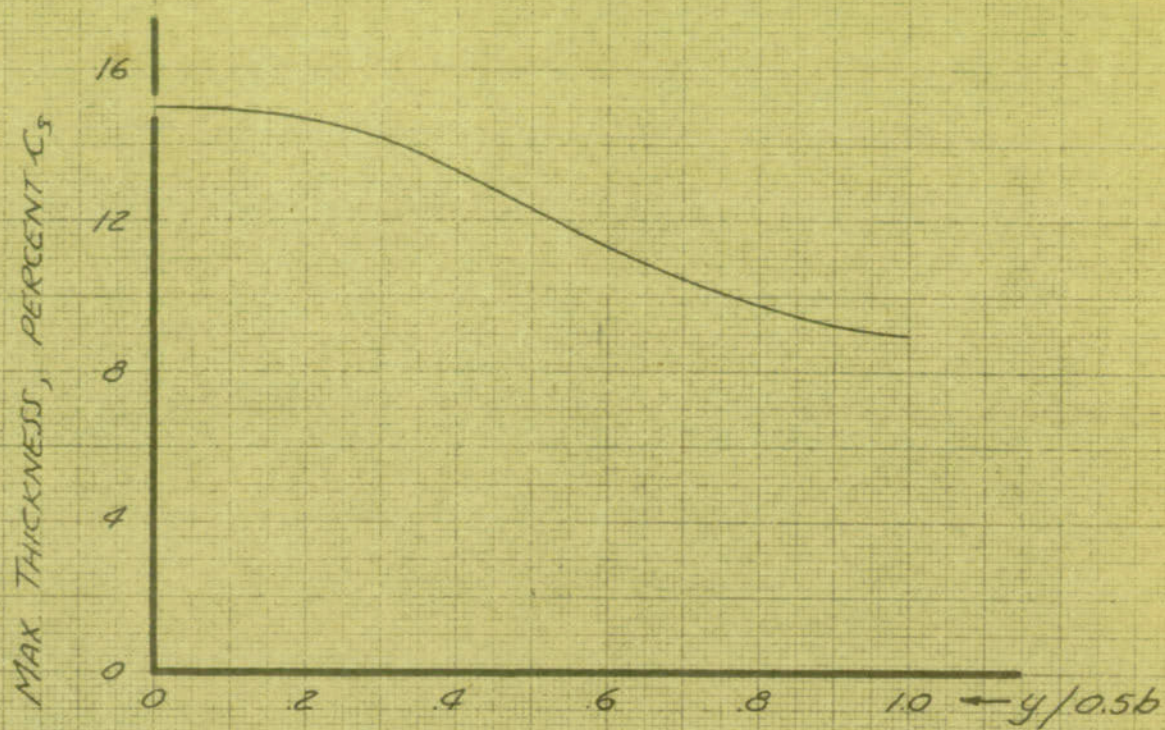


FIGURE 1.- THE 0.3-SCALE MODEL OF THE P-47D AIRPLANE
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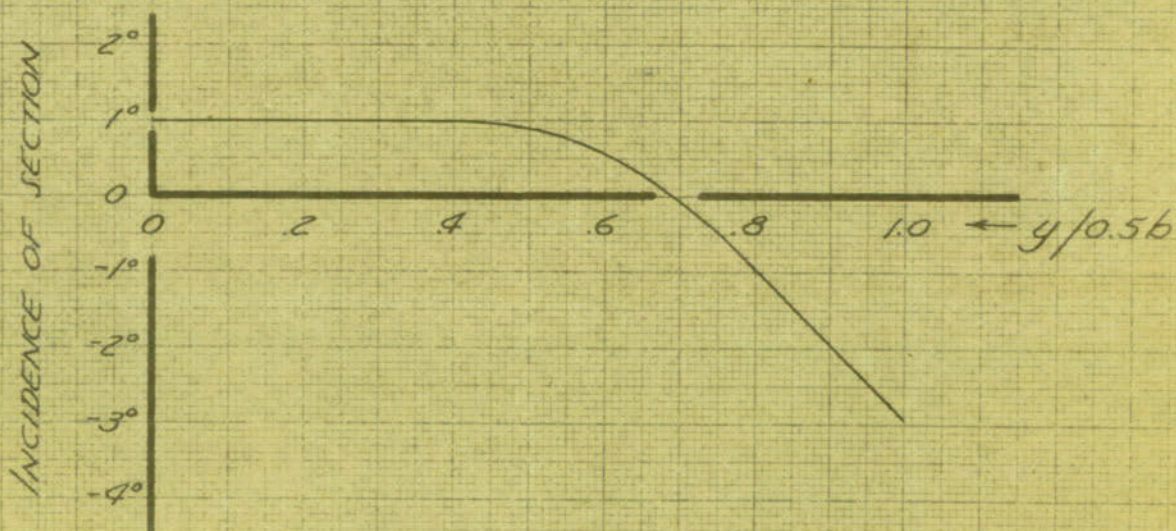


Figure 2.- The P-47D airplane model in the Ames 16-foot high-speed wind tunnel.



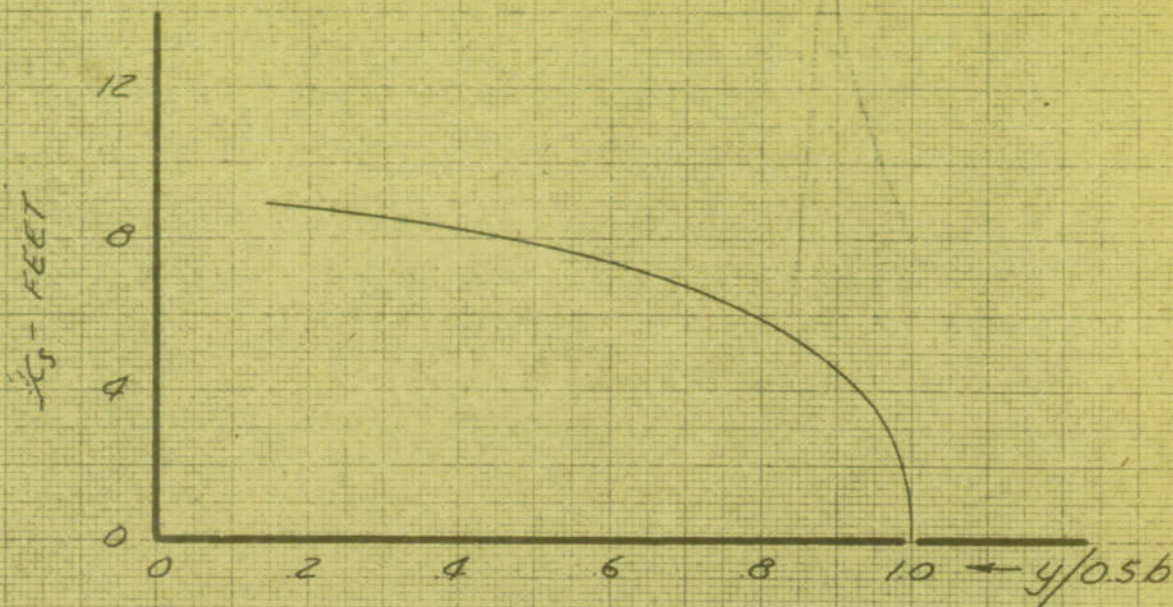


(a) THICKNESS DISTRIBUTION

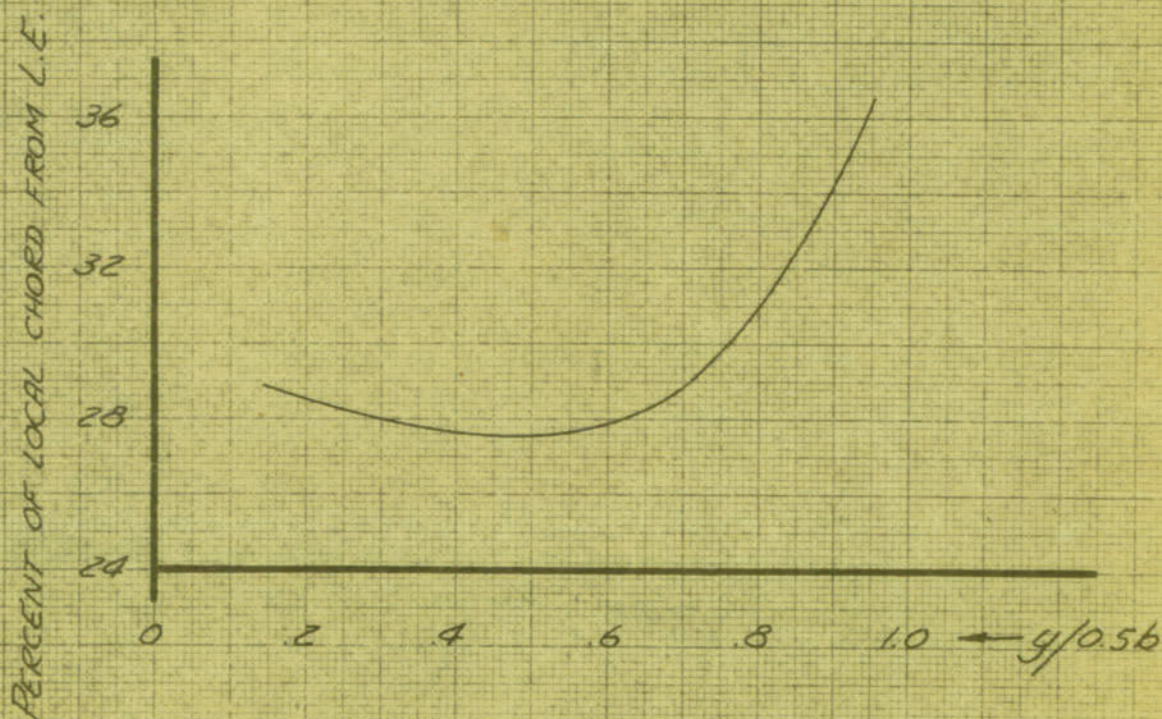


(b) TWIST DISTRIBUTION

FIGURE 3.- THE THICKNESS AND TWIST DISTRIBUTION OF THE P-47D AIRPLANE WING



(a) LOCAL CHORD



(b) POSITION OF LATERAL AXIS

FIGURE 4.- THE LOCAL CHORD AND THE CHORDWISE POSITION OF THE LATERAL AXIS PASSING THROUGH THE 27.5-PERCENT POINT OF THE M.A.C. OF THE P-47 D AIRPLANE.

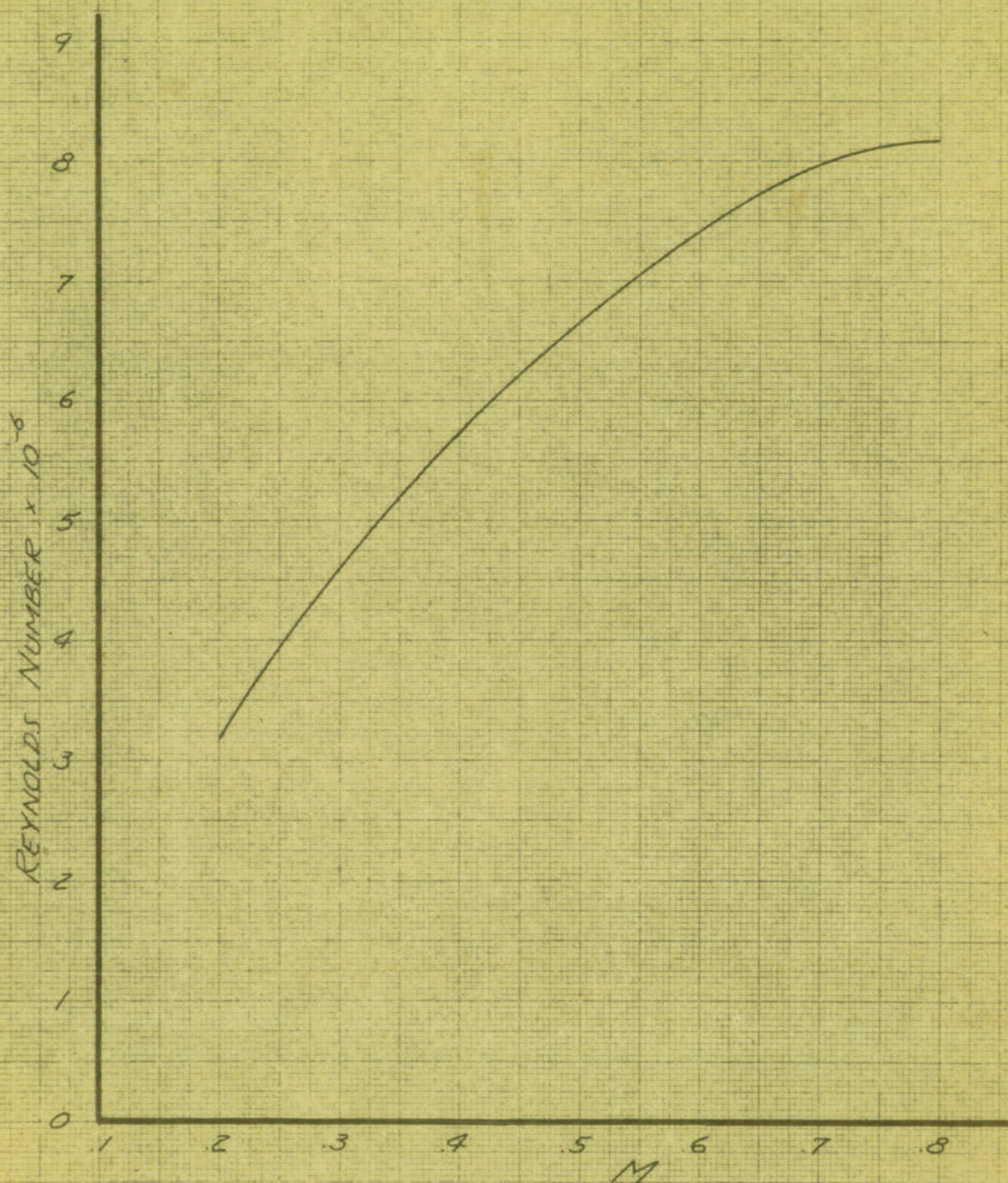


FIGURE 5: VARIATION OF REYNOLDS NUMBER WITH MACH NUMBER FOR THE P-47D AIRPLANE MODEL IN THE AMES 16-FOOT HIGH-SPEED WIND TUNNEL.

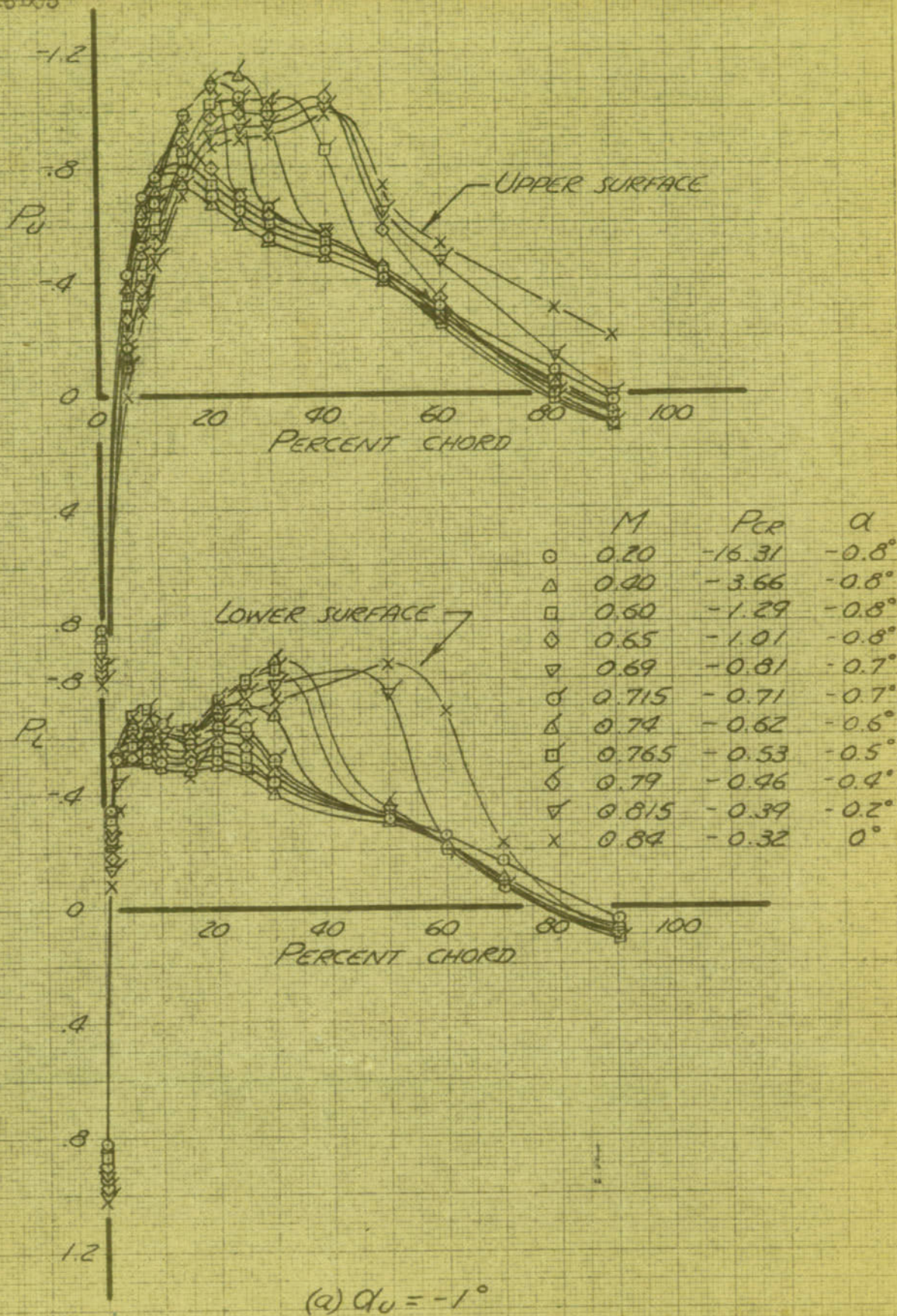


FIGURE 6.- EFFECT OF MACH NUMBER ON THE CHORD-WISE PRESSURE DISTRIBUTION ON THE P-47D AIRPLANE MODEL WING. $y/0.5b = 0.147$

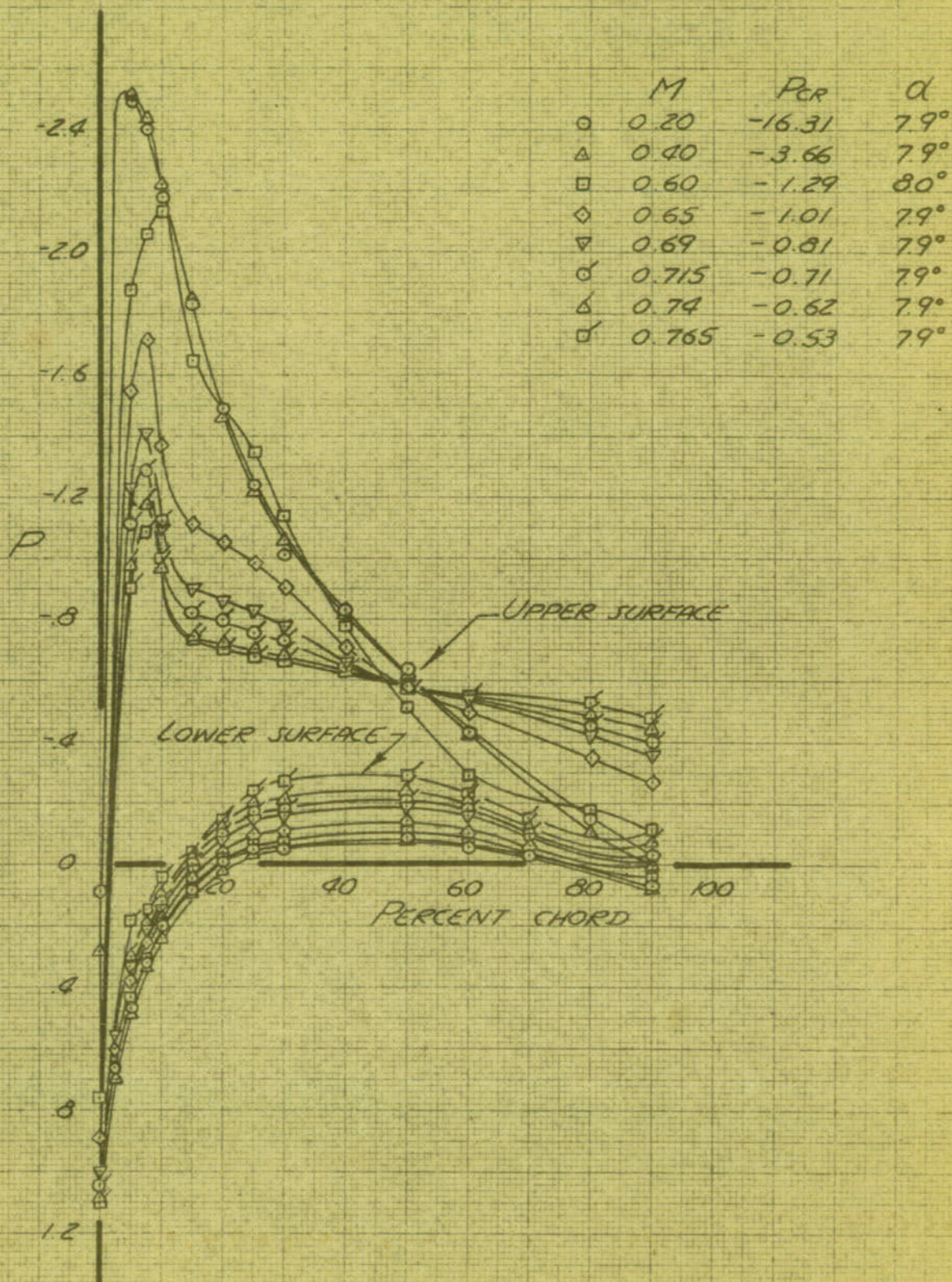
(b) $\alpha_0 = 7^\circ$

FIGURE 6 - (CONCLUDED)

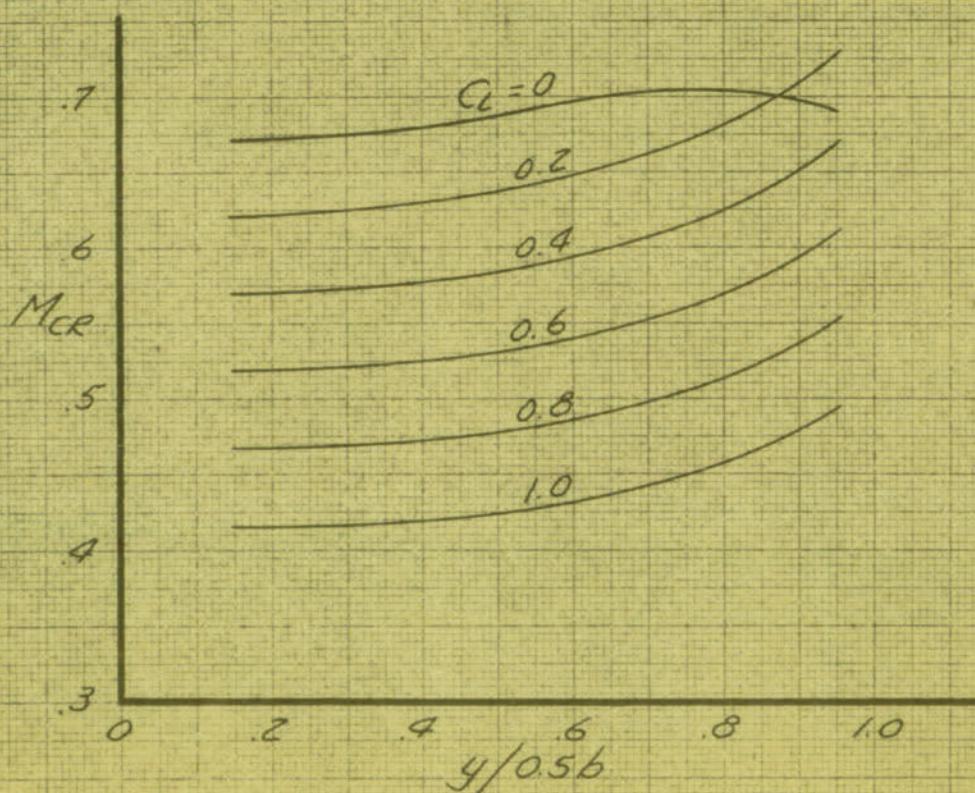
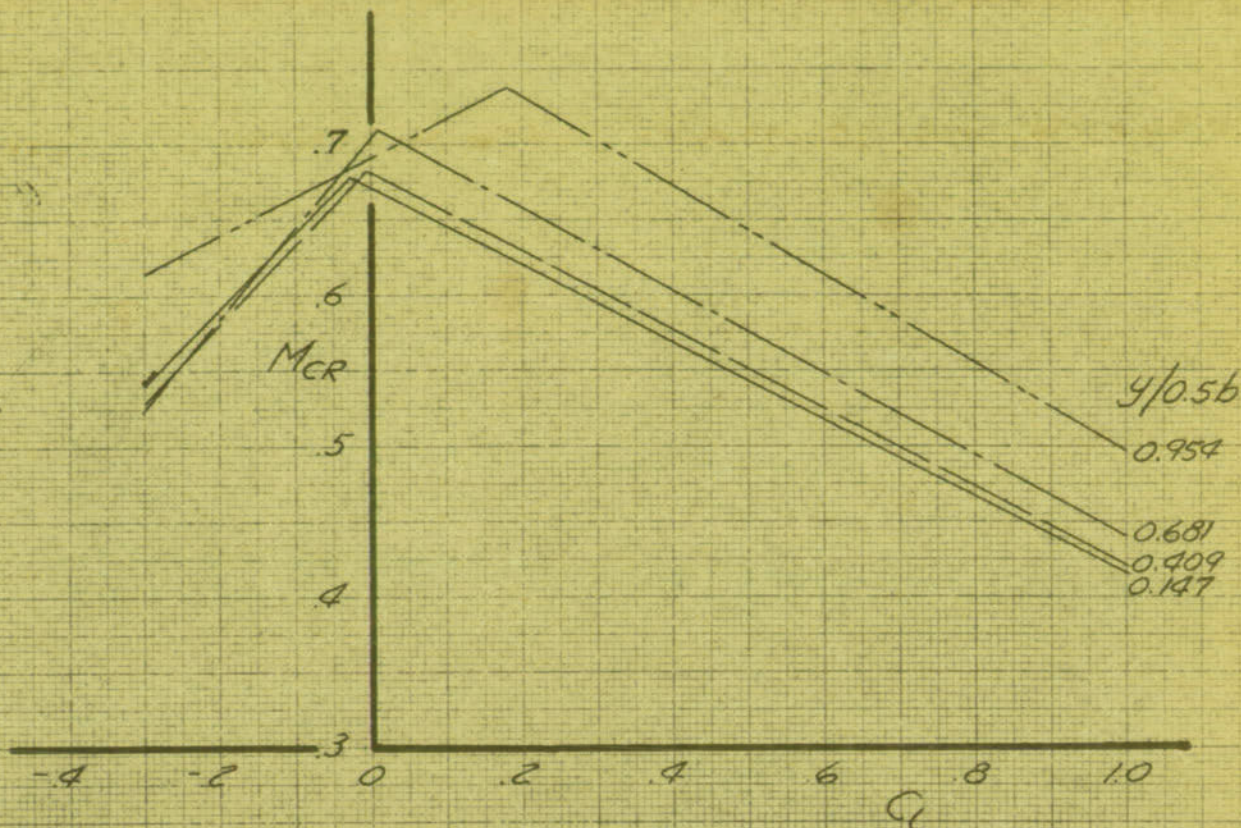


FIGURE 7.- THE CRITICAL MACH NUMBER OF THE P-47 D AIRPLANE MODEL WING AT VARIOUS SPANWISE LOCATIONS AND VALUES OF TRIMMED LIFT COEFFICIENT.

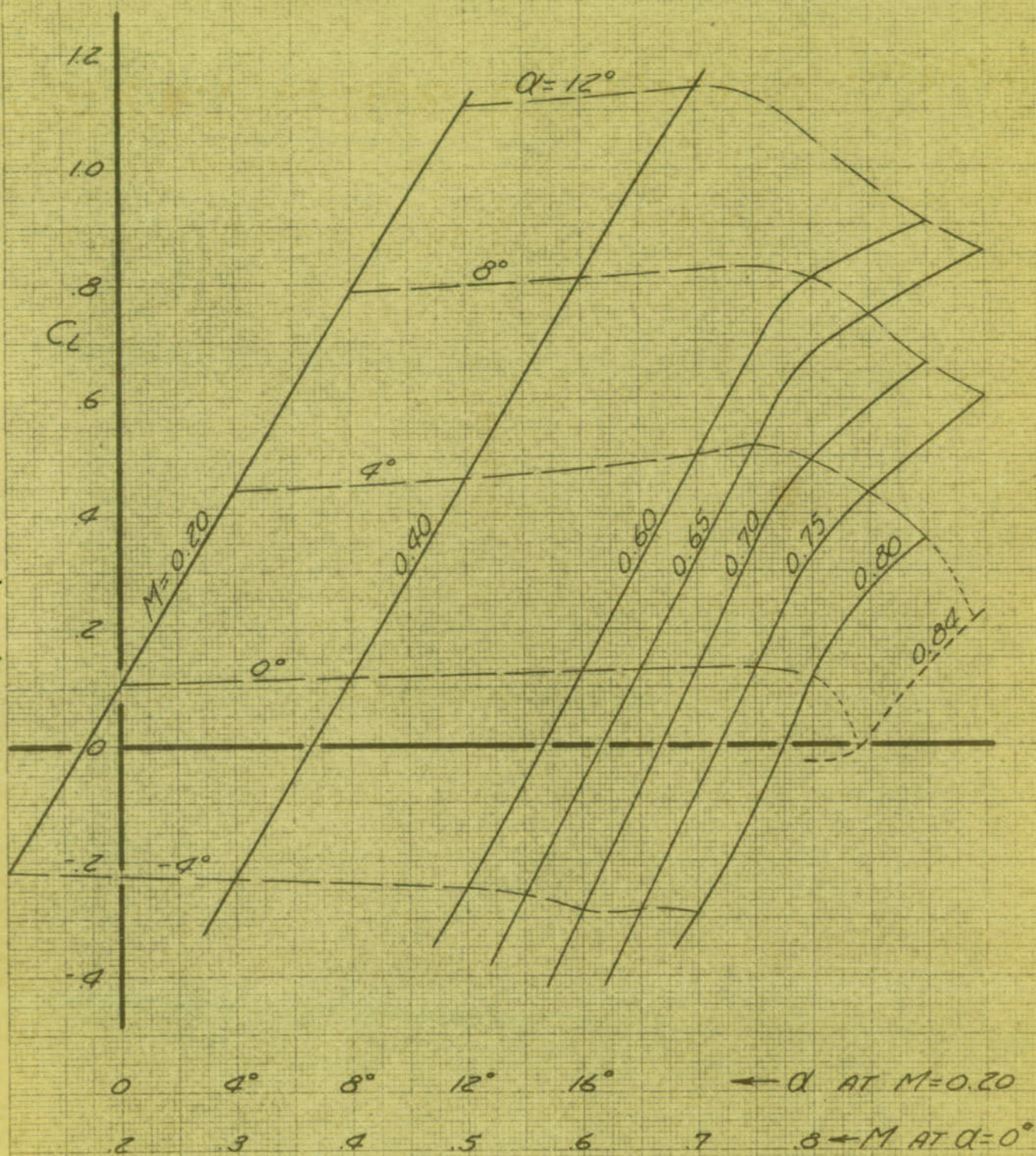
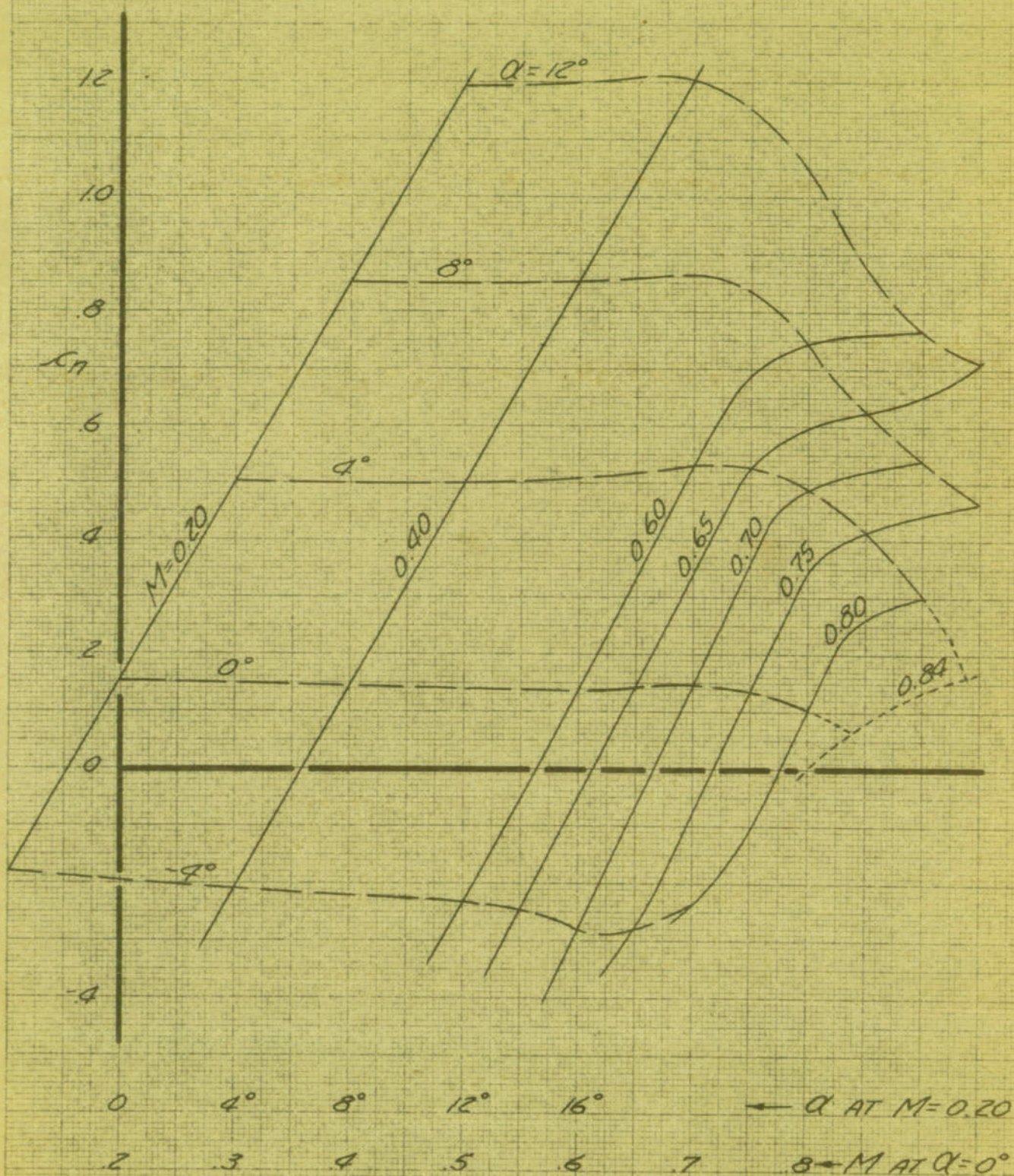
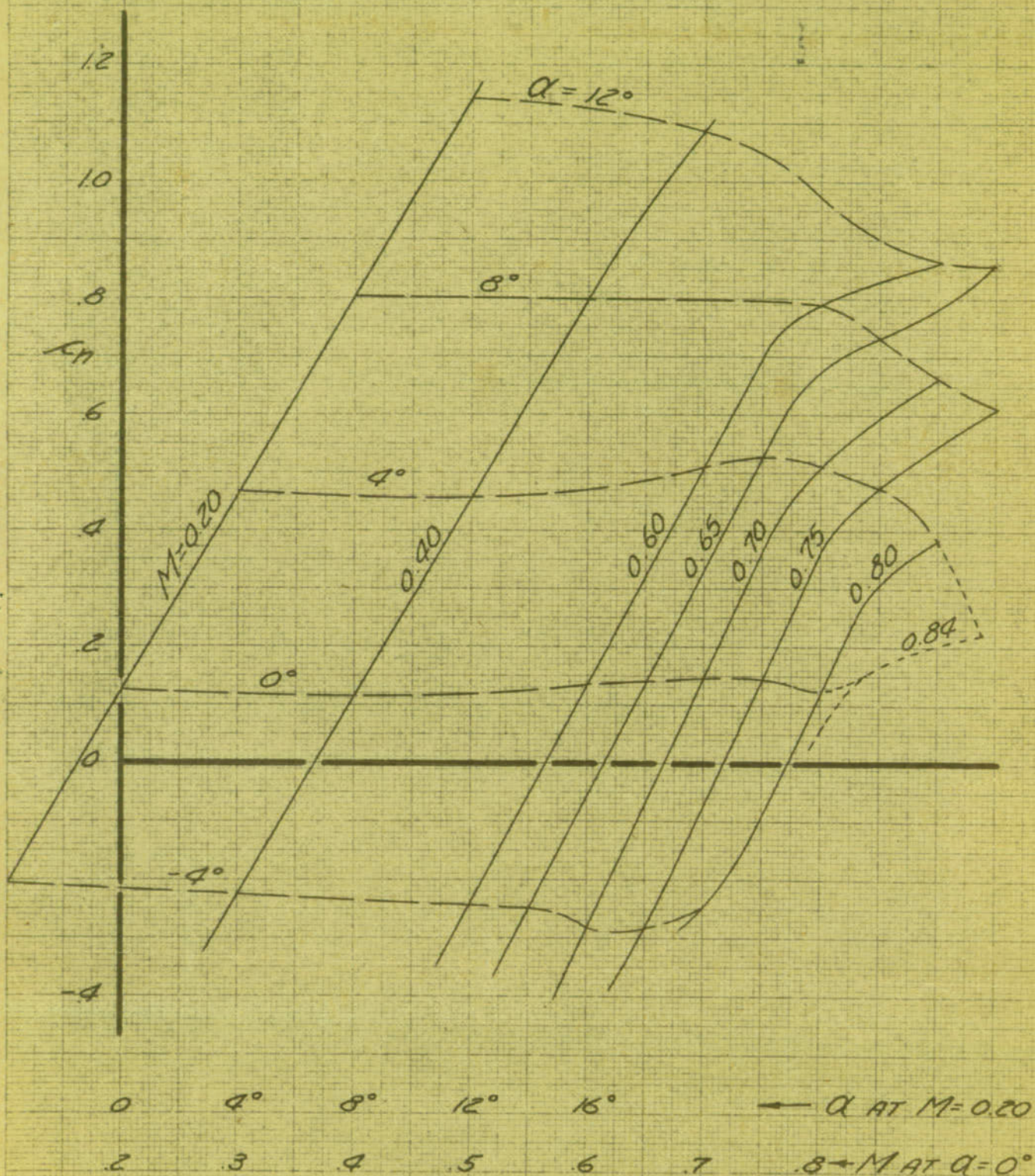


FIGURE 8.- TRIMMED-LIFT-COEFFICIENT CARPET FOR THE P-47D AIRPLANE MODEL.



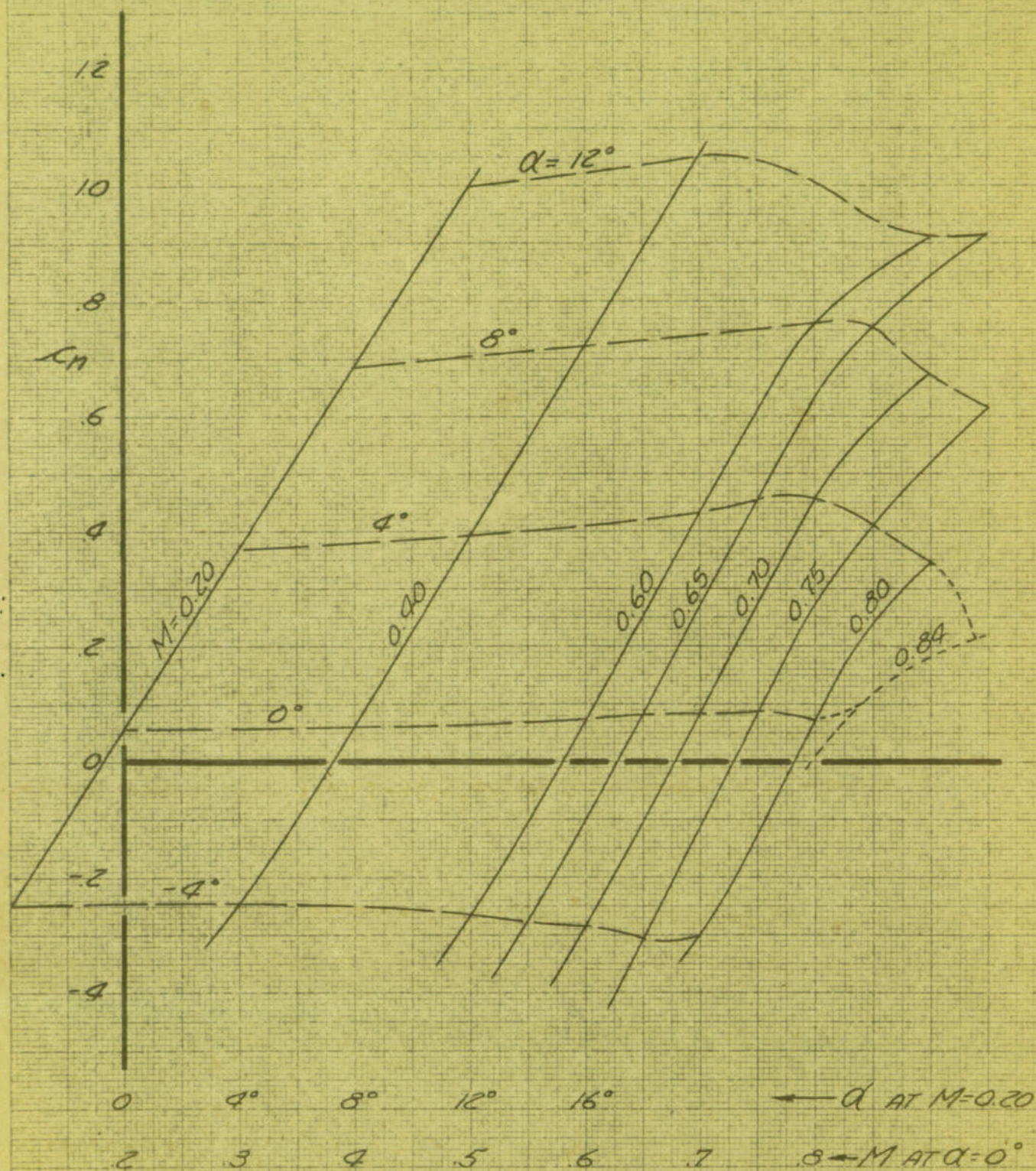
$$(a) y/0.5b = 0.147$$

FIGURE 9 - SECTION NORMAL-FORCE-COEFFICIENT CARPET FOR THE P-47 D AIRPLANE MODEL WING.



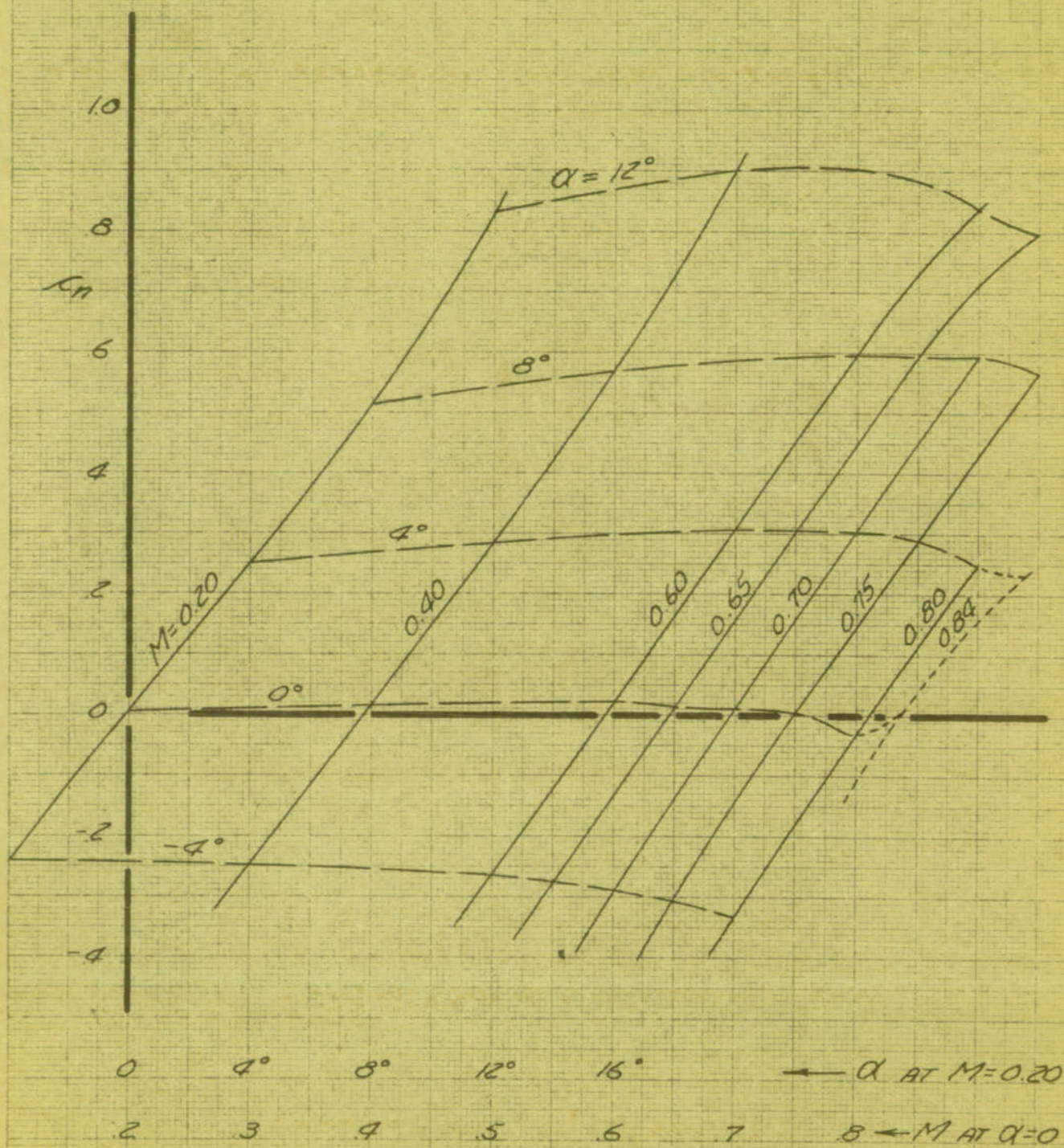
$$(b) \gamma/0.5b = 0.409$$

FIGURE 9 - (CONTINUED)



$$(c) y/0.5b = 0.681$$

FIGURE 9-(CONTINUED)



$$(d) y/0.5b = 0.954$$

FIGURE 9 - (CONCLUDED)

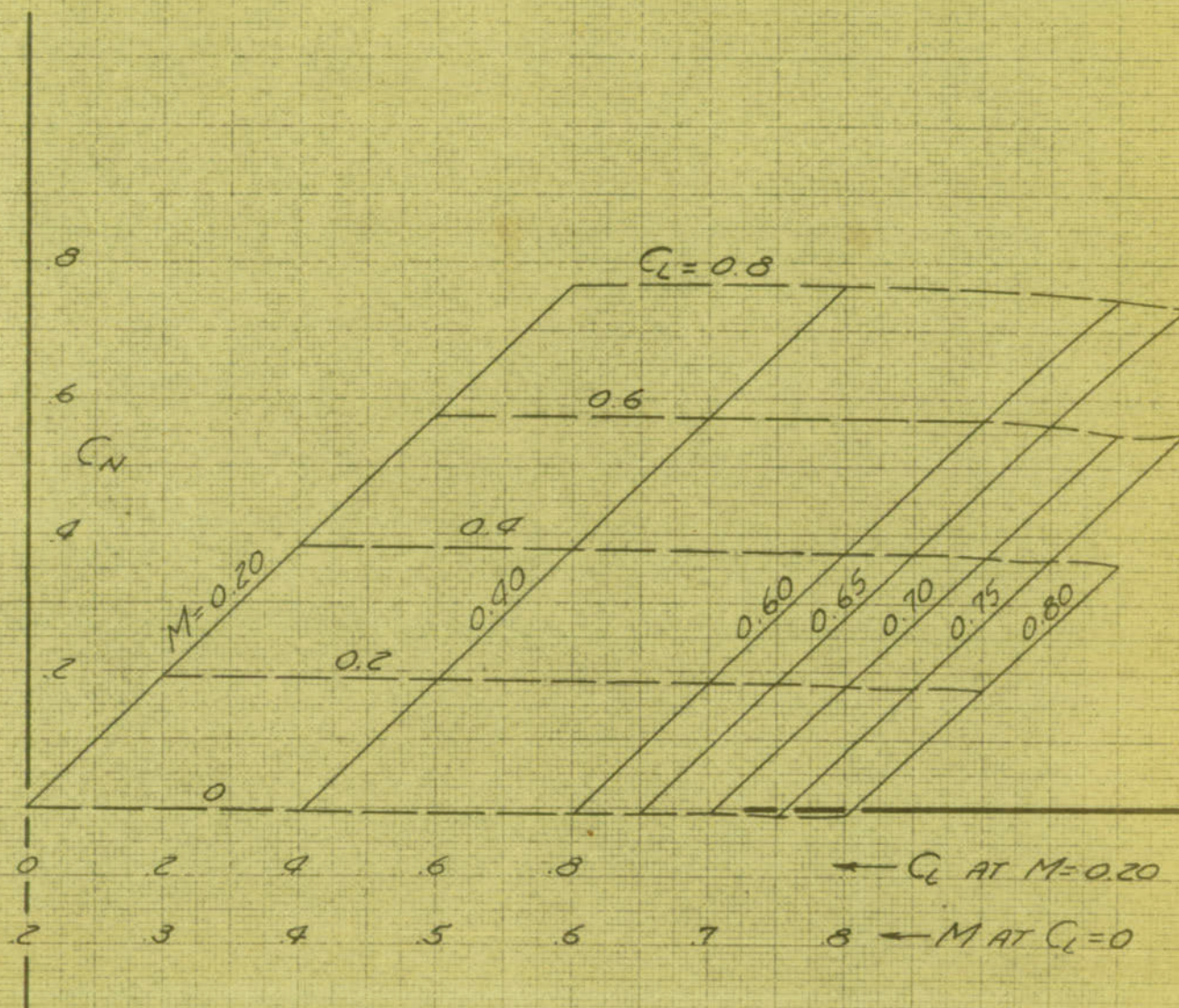


FIGURE 10.— PREDICTED RELATIONSHIP BETWEEN THE NORMAL-FORCE COEFFICIENT OF THE WING AND THE TRIMMED LIFT COEFFICIENT OF THE P-47D AIRPLANE.

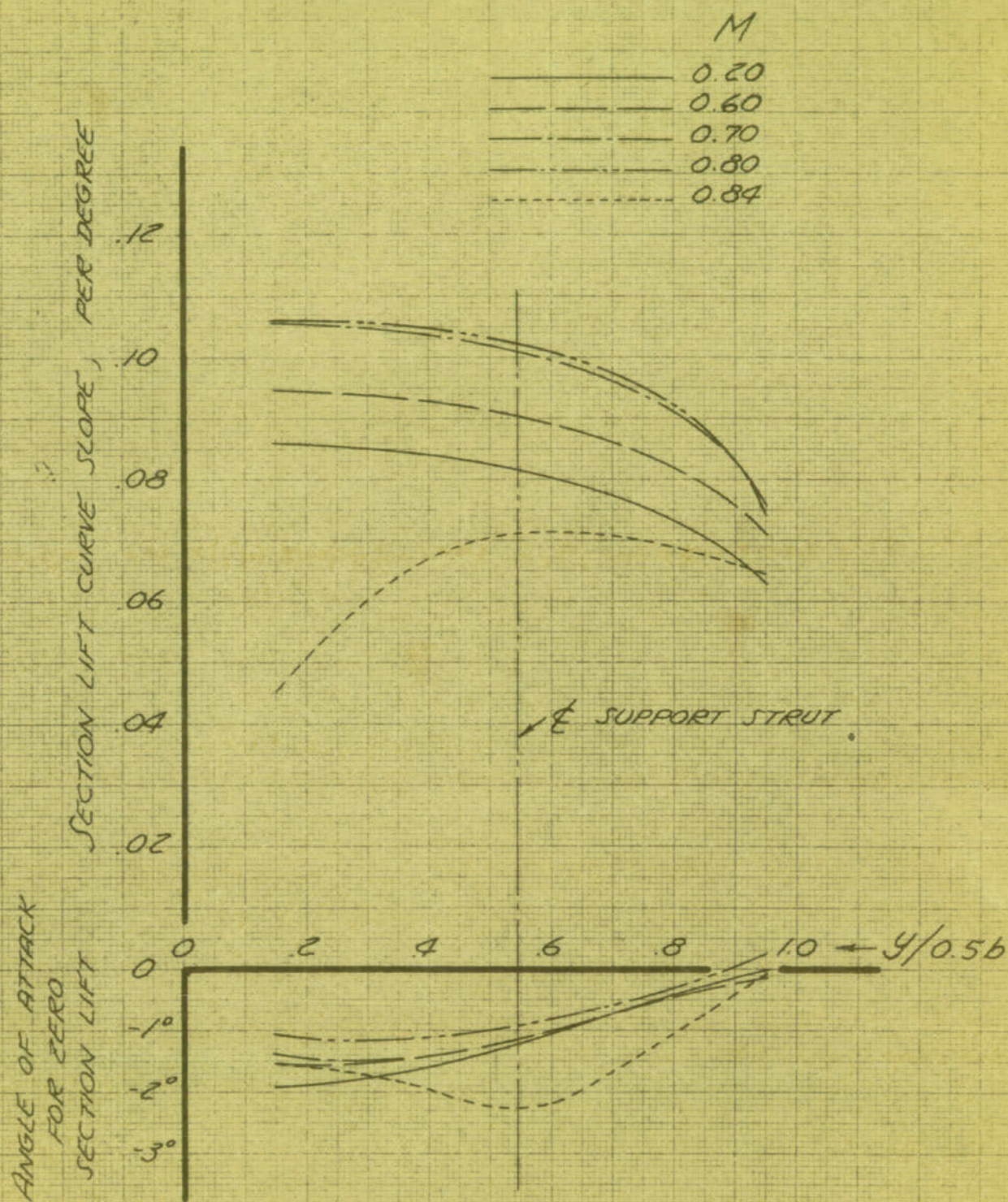


FIGURE 11 - SECTION LIFT-CURVE SLOPE AT ZERO LIFT AND SECTION ZERO-LIFT ANGLE OF ATTACK FOR THE P-47D AIRPLANE MODEL WING

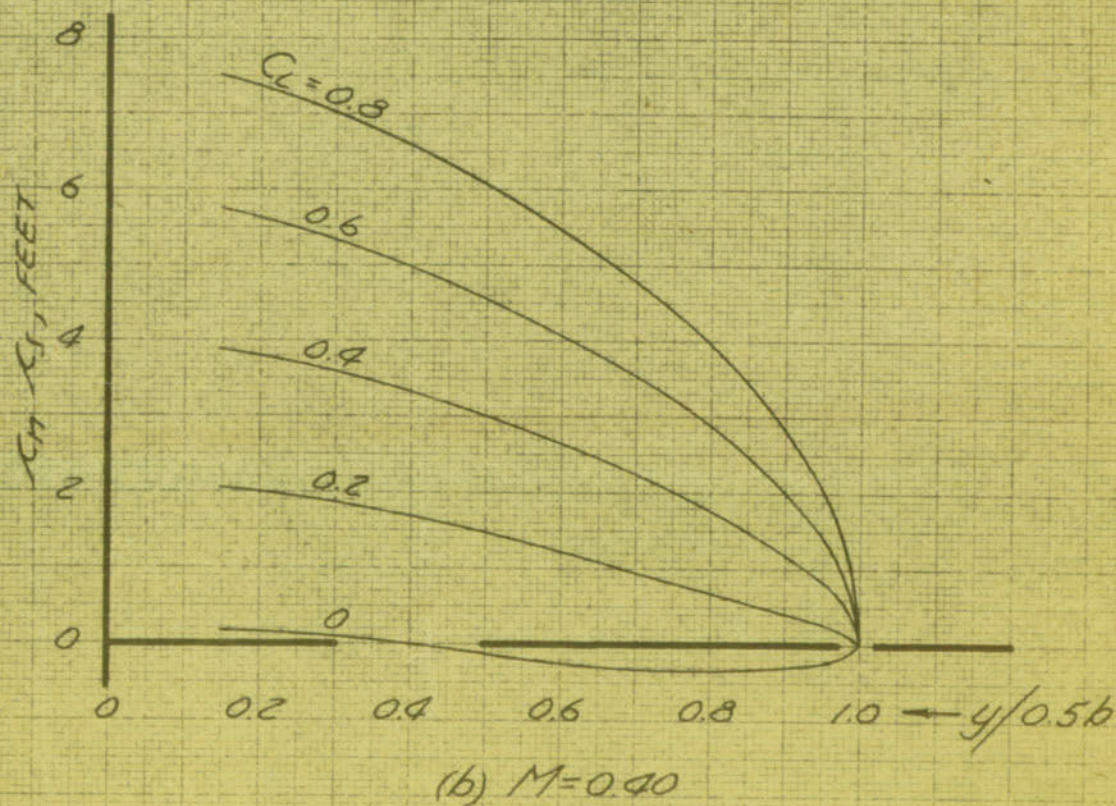
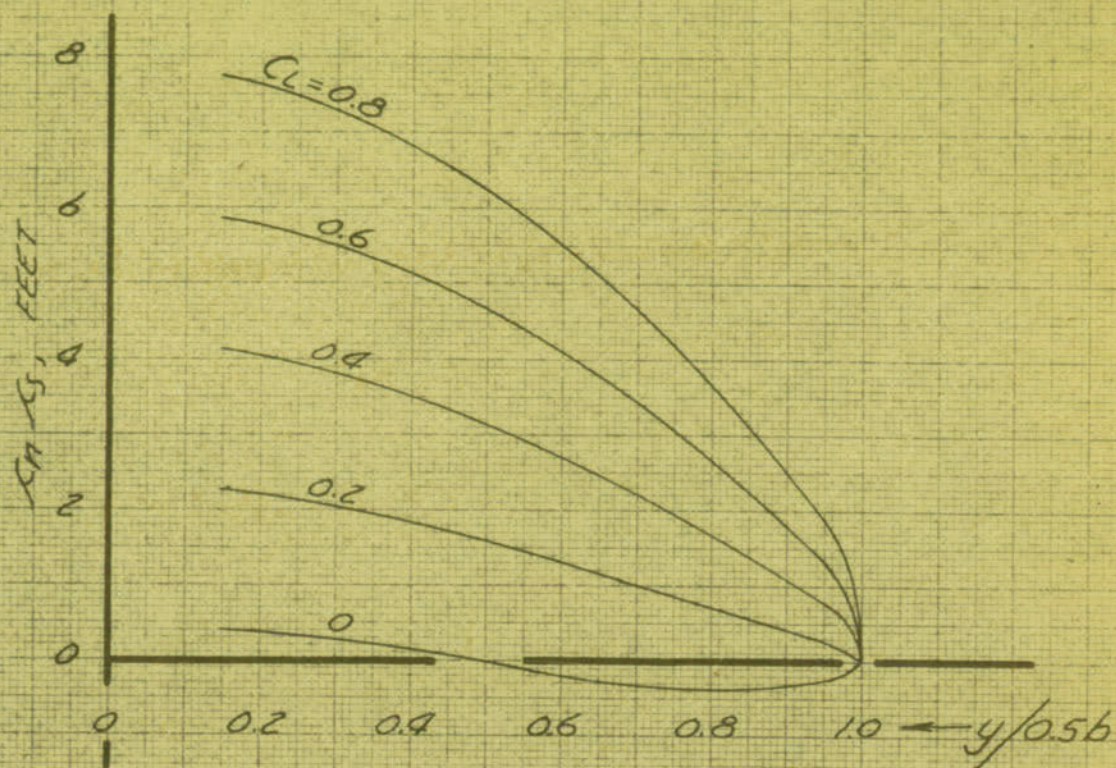


FIGURE 12.-PREDICTED SPANWISE DISTRIBUTION OF THE NORMAL LOAD ON THE P-47D AIRPLANE WING FOR SEVERAL VALUES OF THE TRIMMED LIFT COEFFICIENT

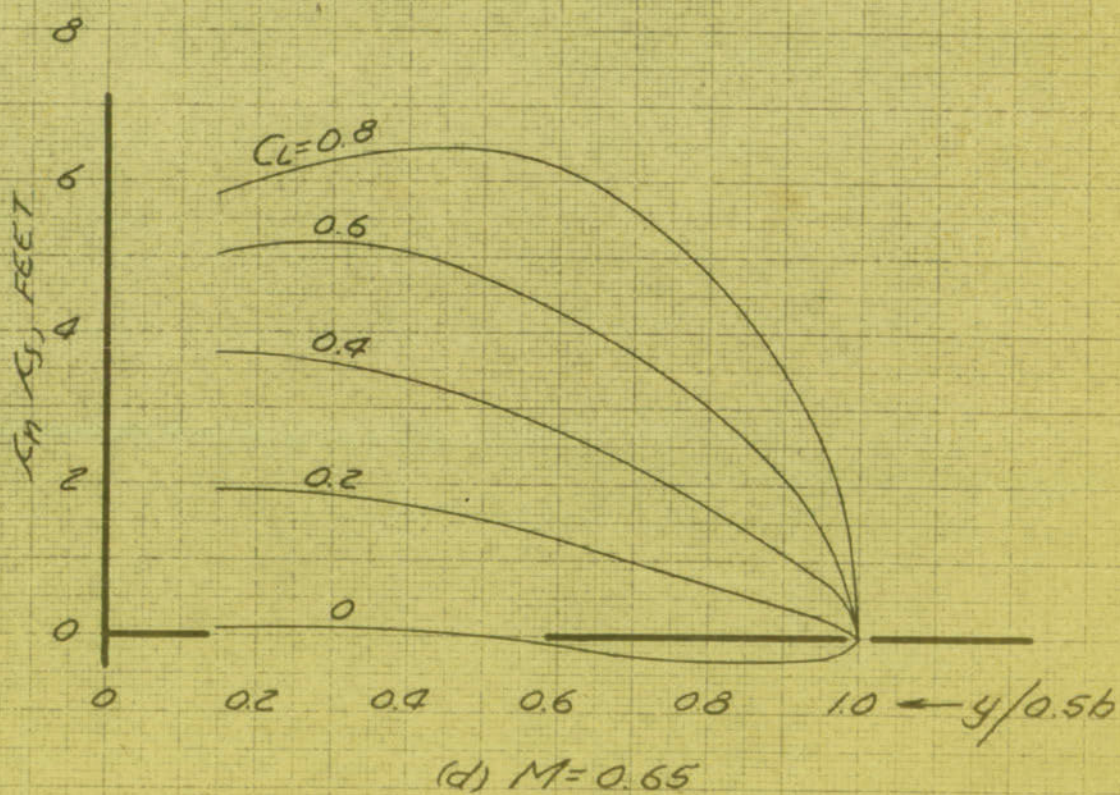
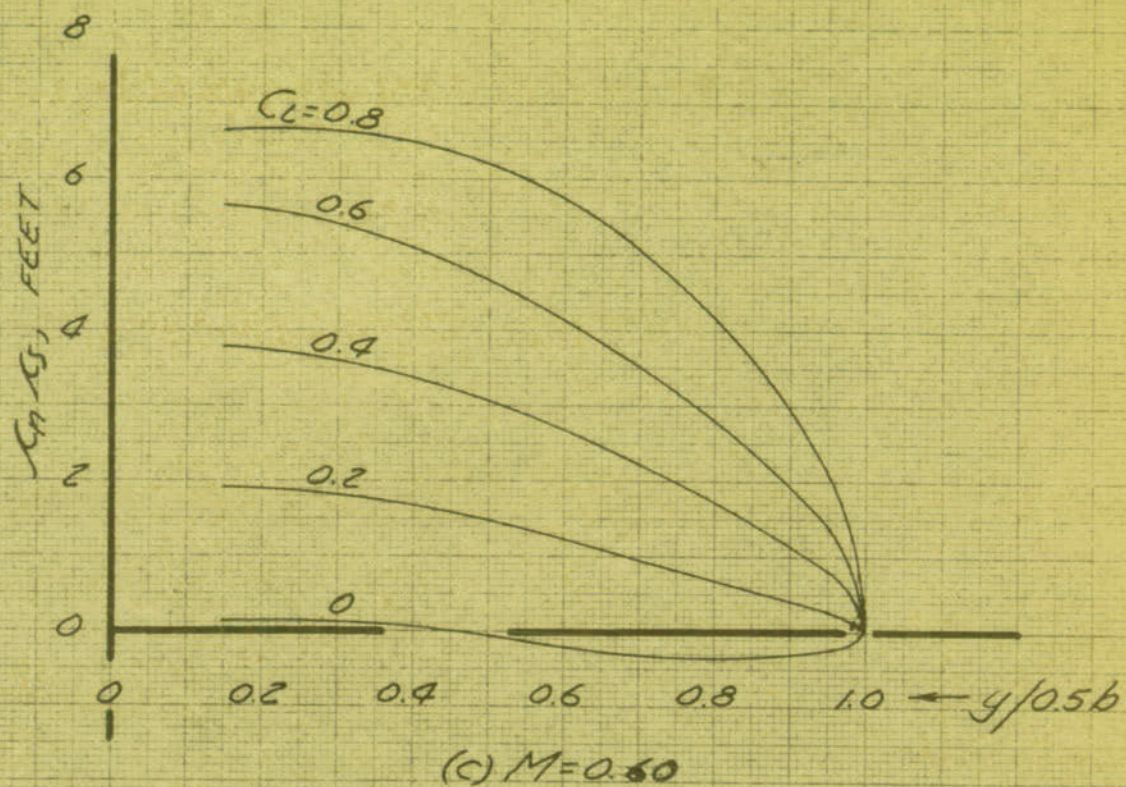


FIGURE 12-(CONTINUED)

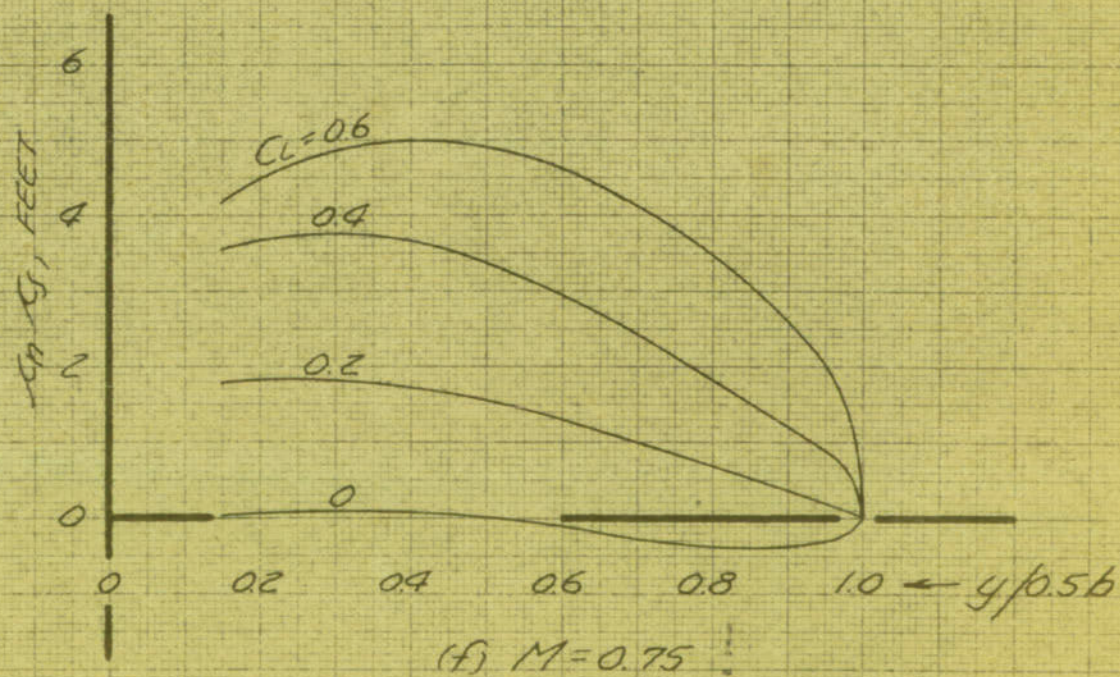
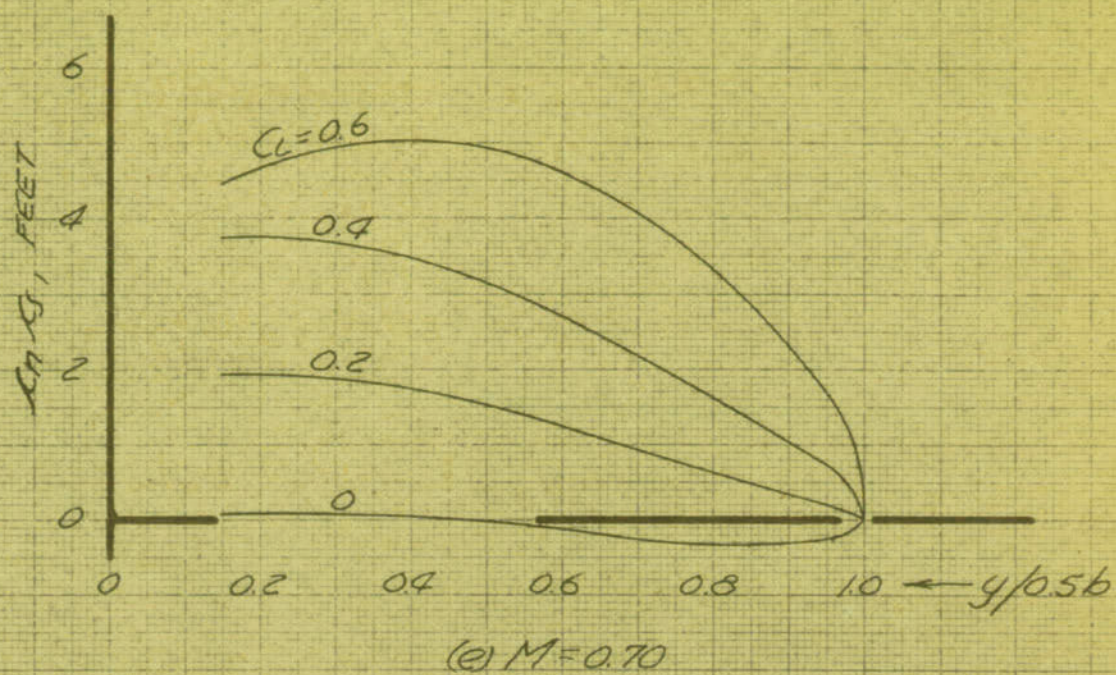


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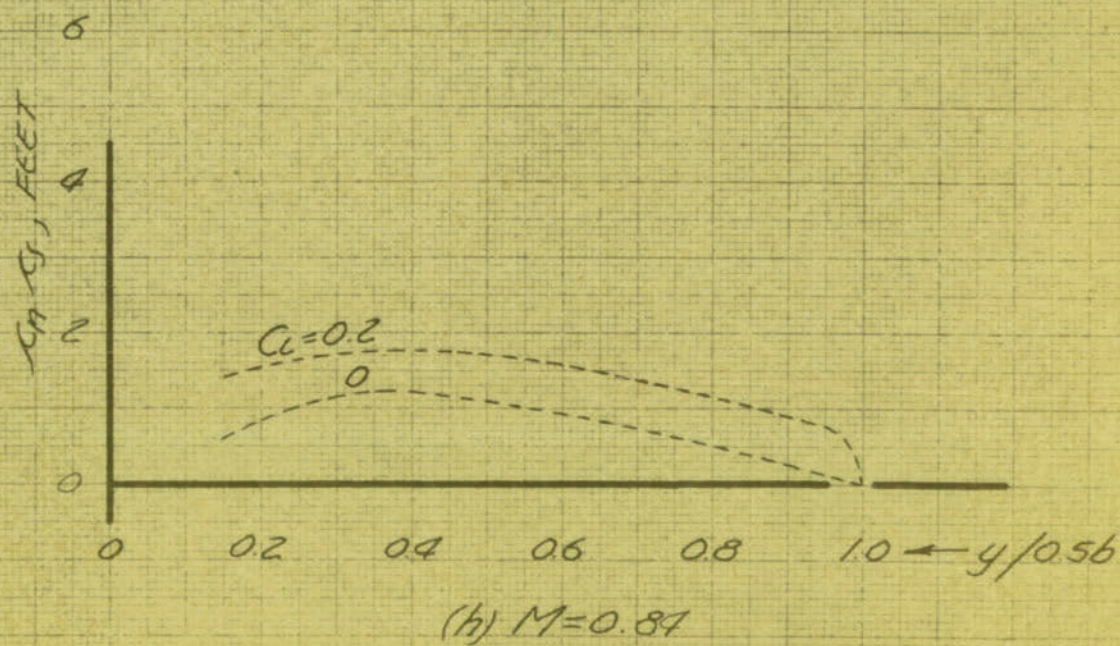
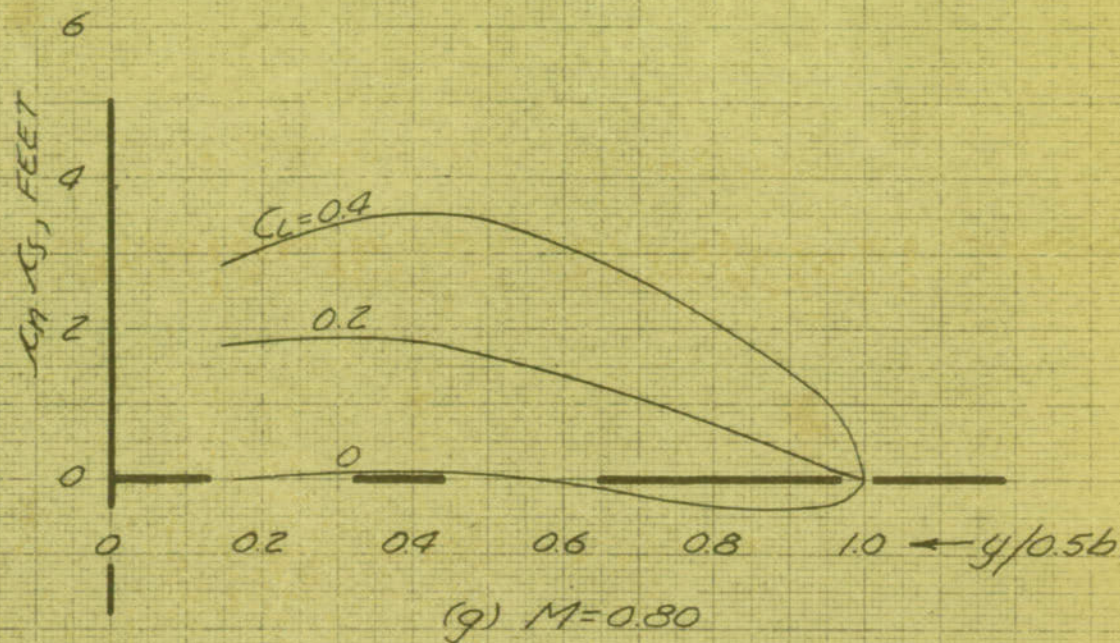


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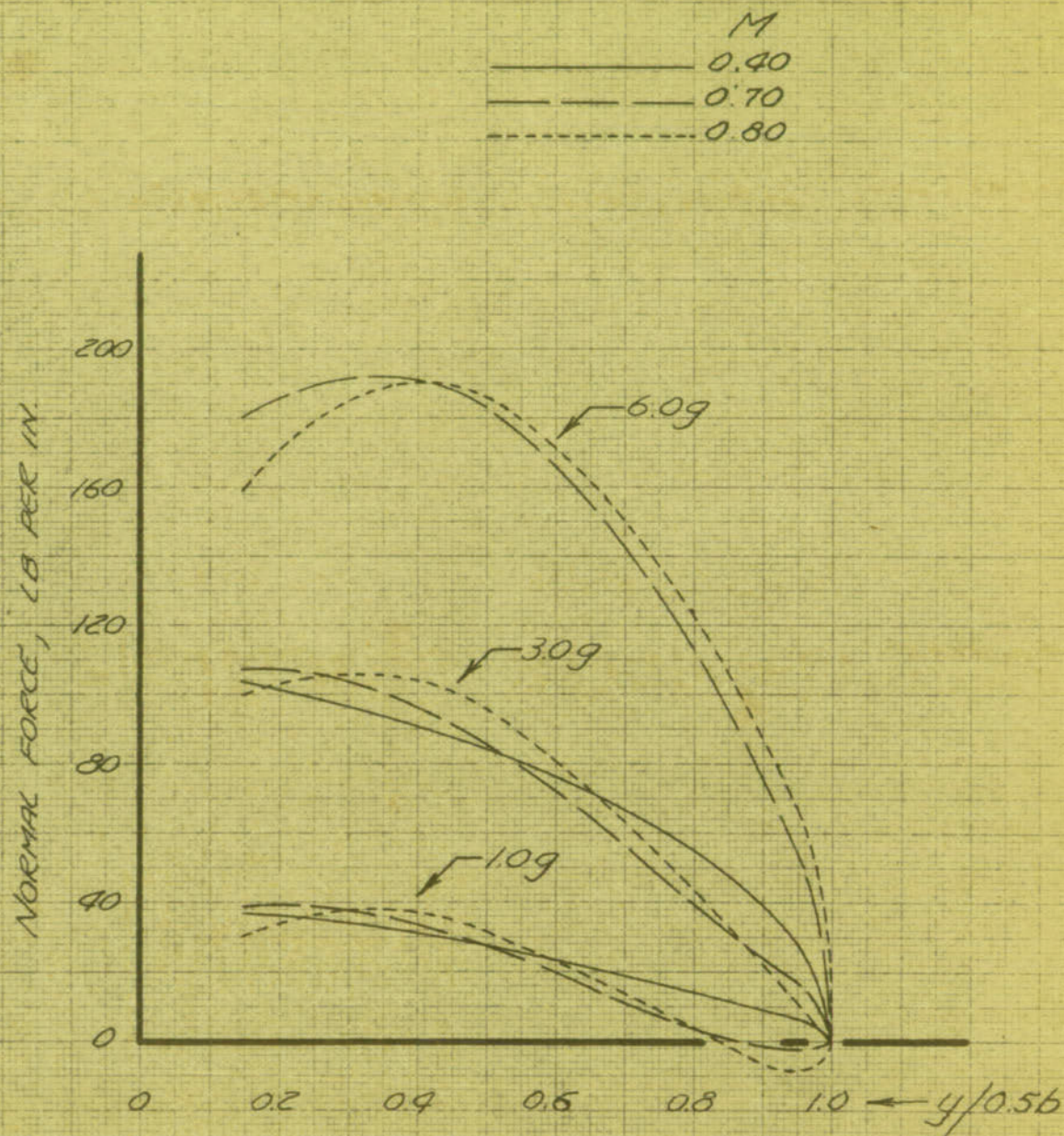


FIGURE 13.- PREDICTED SPANWISE DISTRIBUTION OF THE NORMAL FORCE ON THE P-47D AIRPLANE WING (WING LOADING OF 45 LB PER SQ FT) FOR SEVERAL VALUES OF INDICATED NORMAL ACCELERATION AT 10,000 FT ALTITUDE.

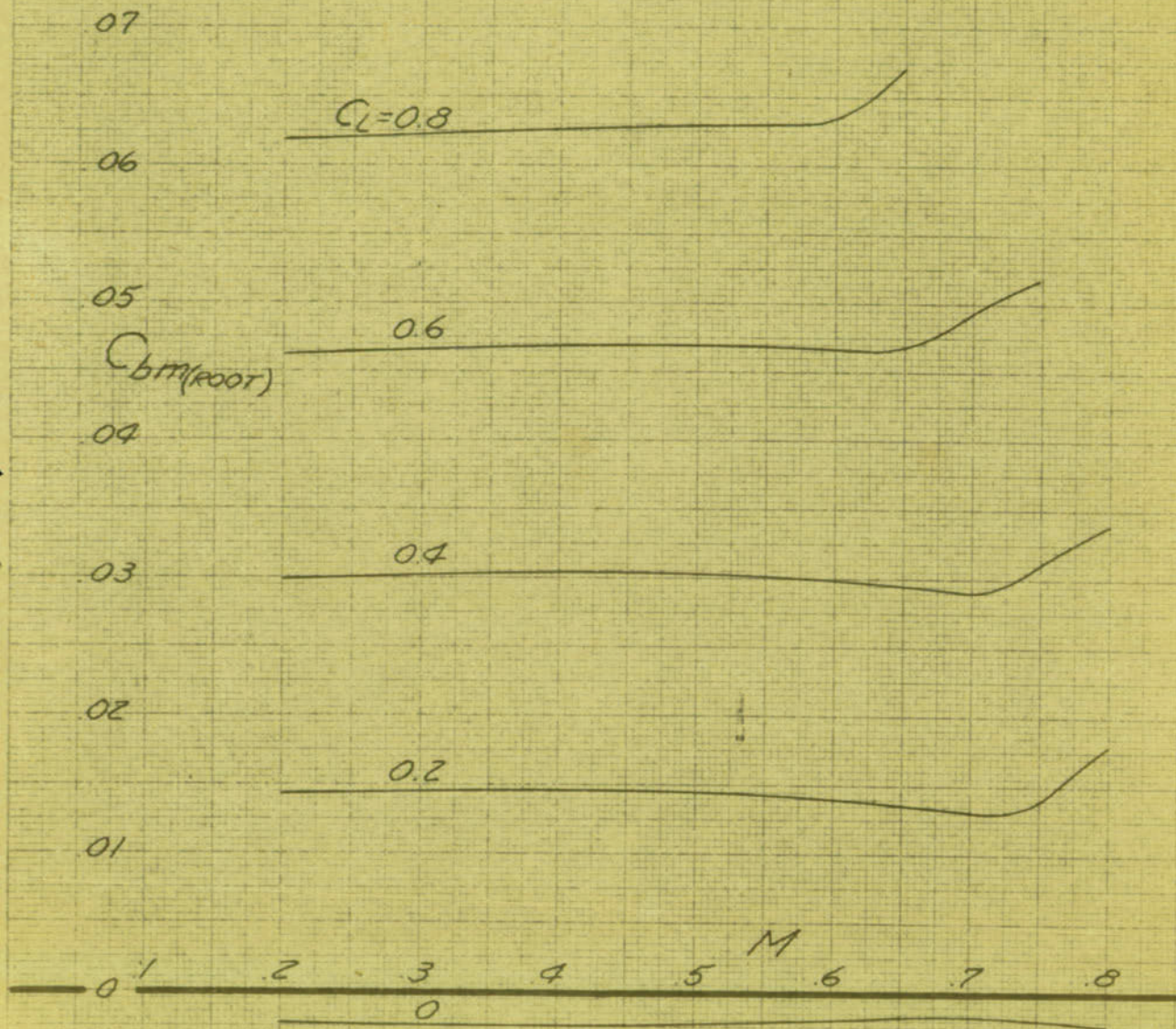


FIGURE 14.-PREDICTED VARIATION WITH MACH NUMBER OF THE BENDING-MOMENT COEFFICIENT AT THE ROOT OF THE P-47D AIRPLANE WING FOR SEVERAL VALUES OF THE TRIMMED LIFT COEFFICIENT.

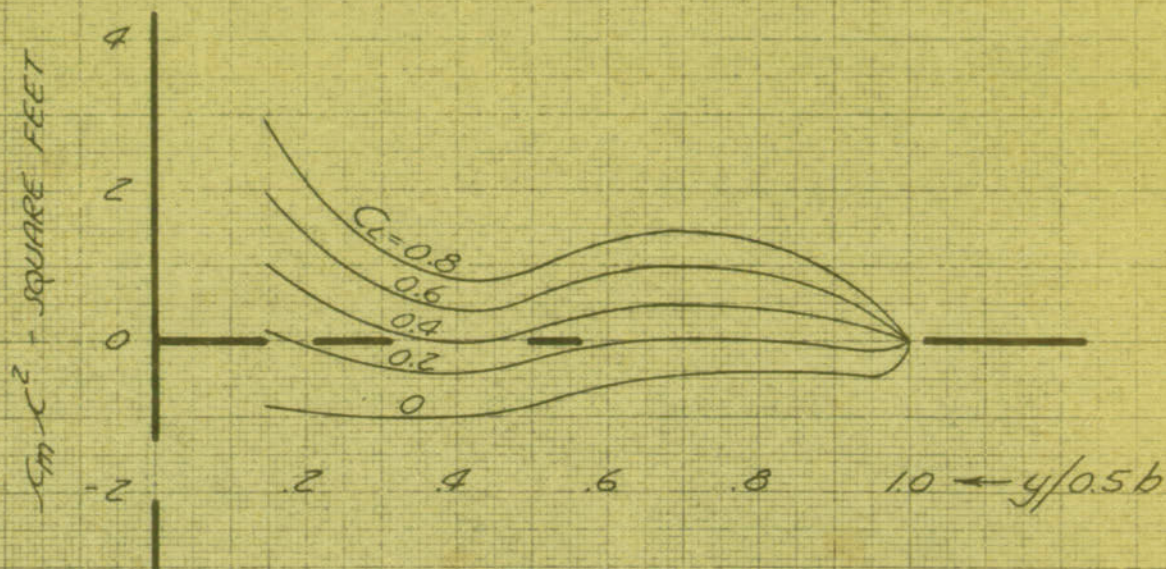
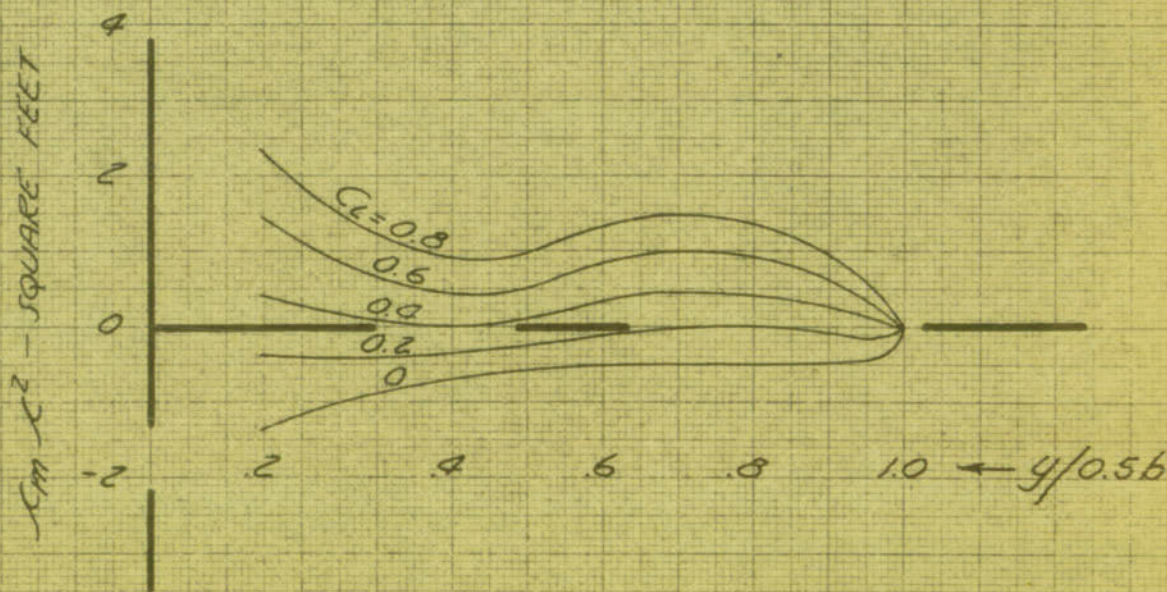
(a) $M = 0.20$ (b) $M = 0.40$

FIGURE 15.- PREDICTED SPANWISE VARIATION OF THE TORSION LOAD ON THE P-47D AIRPLANE WING ABOUT THE LATERAL AXIS PASSING THROUGH THE 27.5-PERCENT POINT OF THE M.A.C.

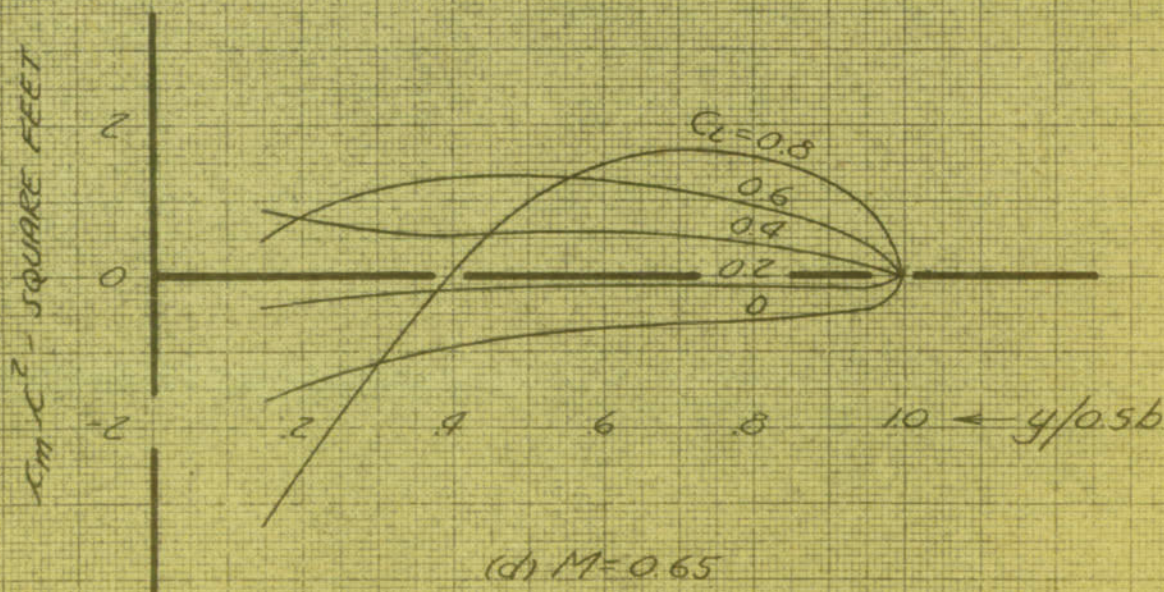
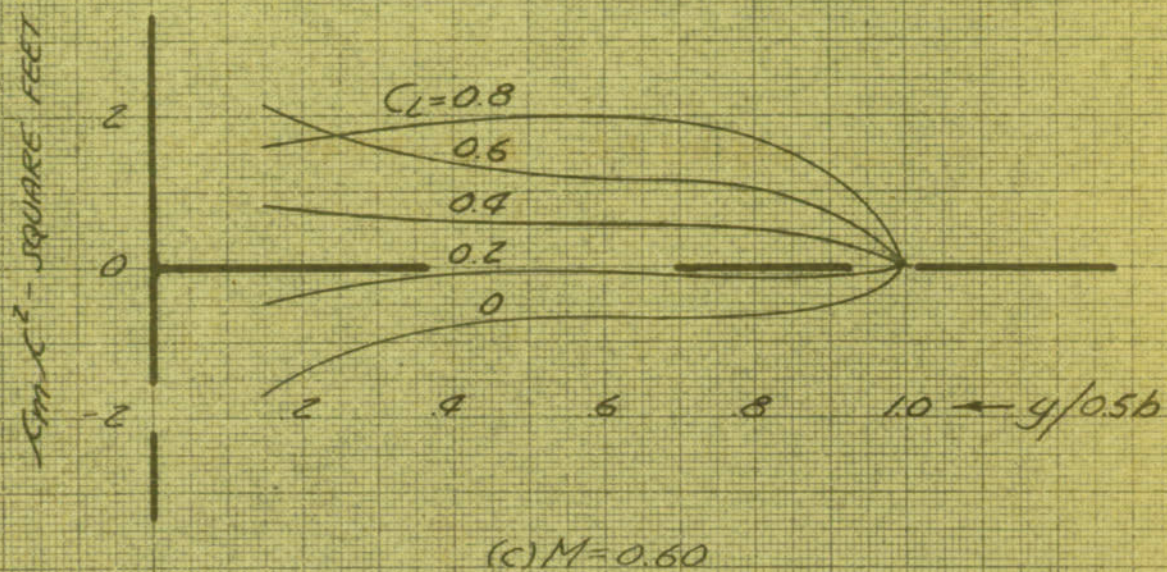


FIGURE 15.-(CONTINUED)

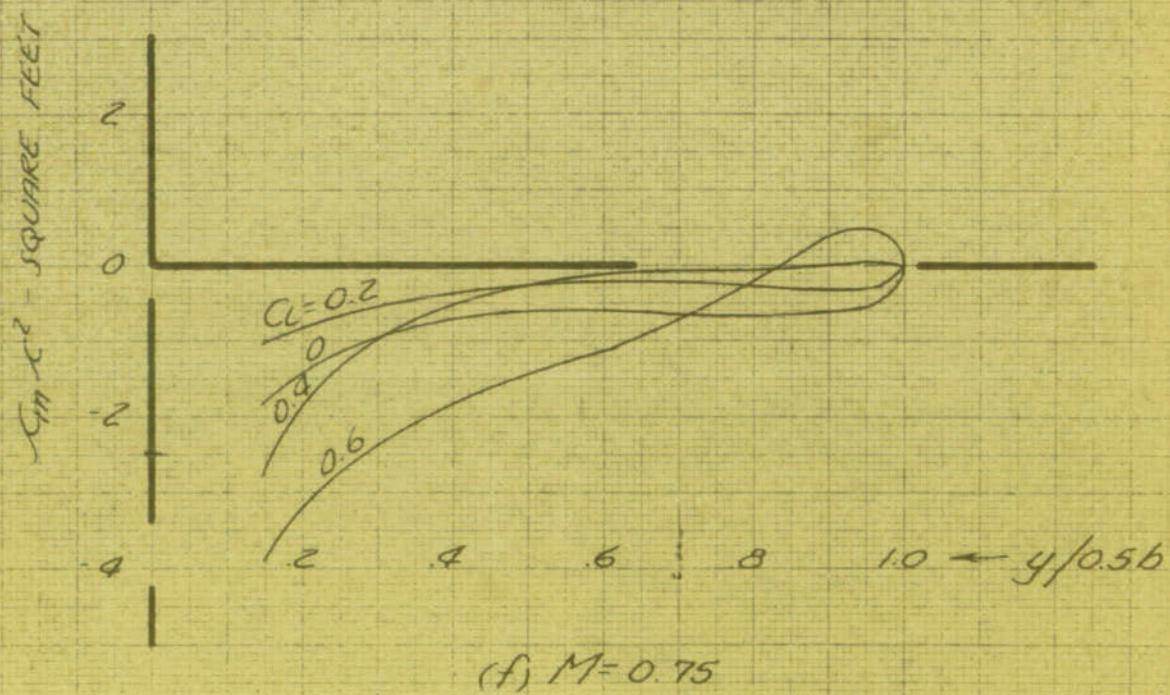
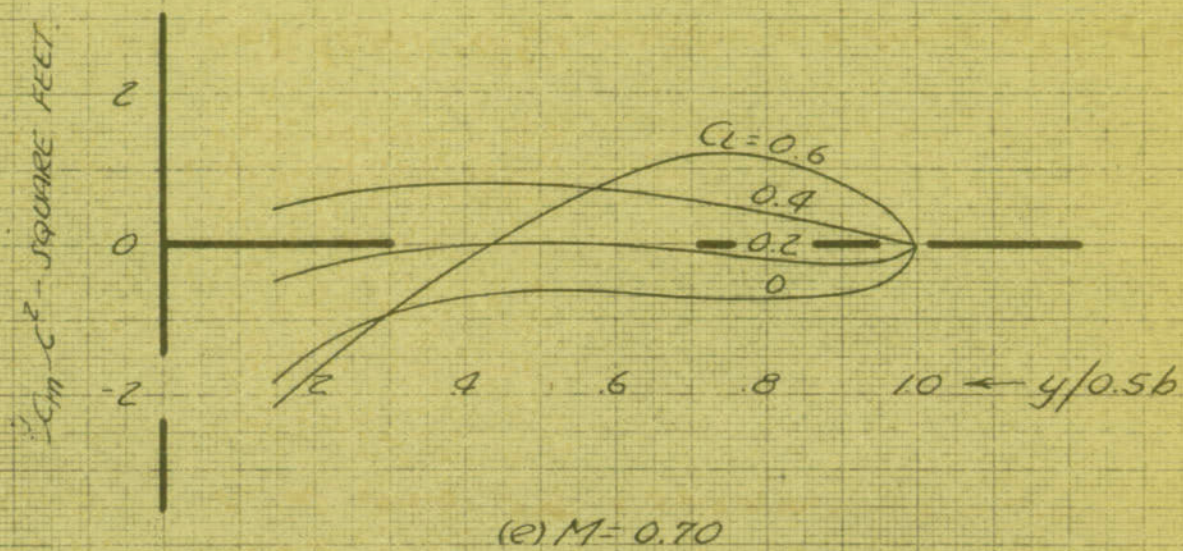


FIGURE 15.- (CONTINUED)

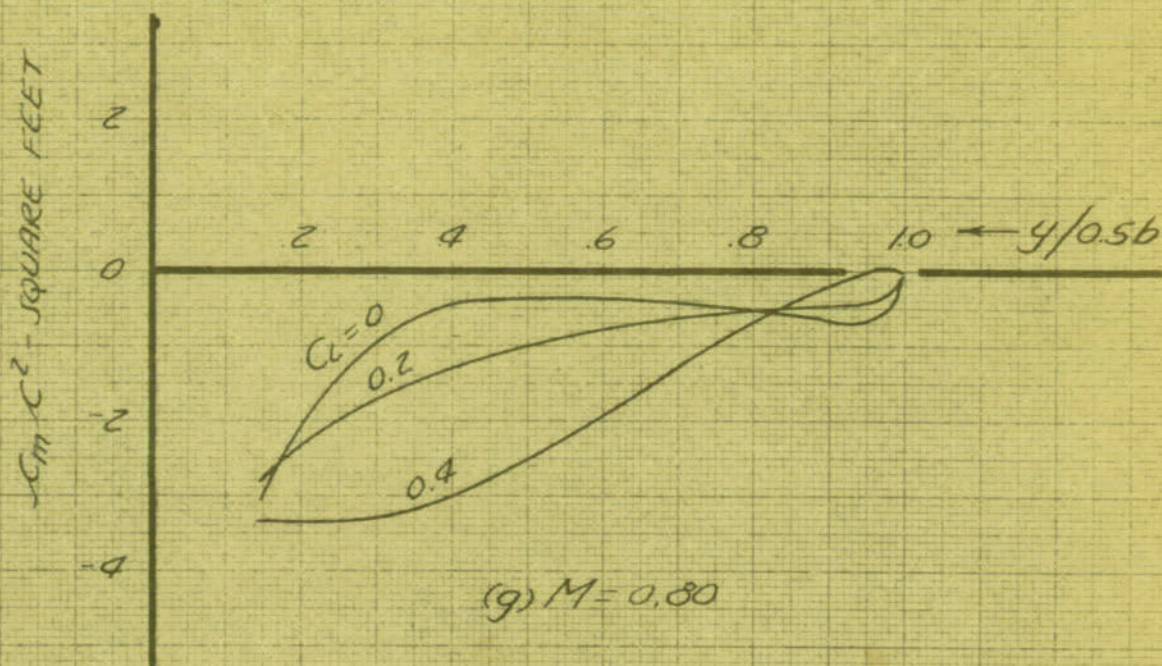
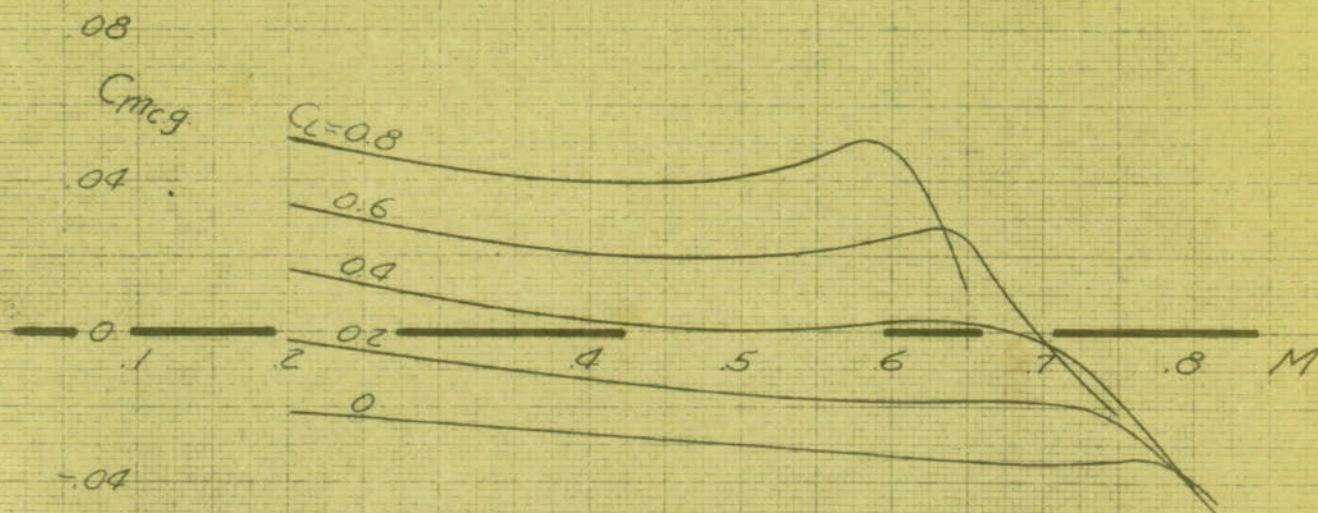
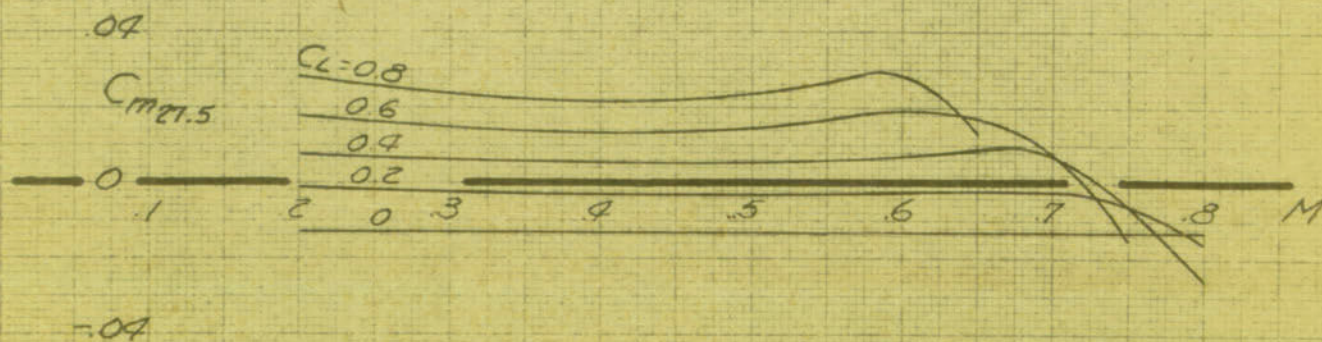


FIGURE 15.- (CONCLUDED)



(a) DATA FROM FORCE TESTS OF THE WING-FUSELAGE COMBINATION



(b) DATA FROM INTEGRATION OF THE WING PRESSURE DISTRIBUTION

FIGURE 16.- THE PITCHING-MOMENT COEFFICIENT OF THE P-47D AIRPLANE MODEL WING FOR SEVERAL VALUES OF THE TRIMMED LIFT COEFFICIENT.