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RESEARCH MEMORANDUM

MAXIMUM-LIFT INVESTIGATION OF A $\frac{1}{40}$-SCALE X-1 AIRPLANE

WING AT MACH NUMBERS FROM 0.60 TO 1.15

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON

April 21, 1950

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

MAXIMUM-LIFT INVESTIGATION OF A $\frac{1}{40}$-SCALE X-1 AIRPLANE WING AT MACH NUMBERS FROM 0.60 TO 1.15

By Thomas R. Turner

SUMMARY

An investigation at transonic speeds has been made in the Langley high-speed 7- by 10-foot tunnel to determine the maximum lift characteristics of a $\frac{1}{40}$-scale wing model of the X-1 airplane (8-percent-thick wing). Lift, drag, and pitching-moment data were also obtained and presented through a lift range from below zero lift to beyond maximum lift. The investigation covered a speed range from a Mach number of 0.60 to 1.15 with the Reynolds number varying from 0.415 to 0.533×10^6. The data presented are for wing alone as no fuselage or tail was used for the investigation.

The maximum normal-force coefficients were in good agreement with normal-force coefficients measured in flight. Maximum lift coefficient $C_{L_{max}}$ was greatly influenced by Mach number, increasing from 0.81 at a Mach number of 0.60 to 1.38 at a Mach number of 1.00, then decreasing with further increases in Mach number. Maximum lift was obtained at progressively higher angles of attack as the Mach number was increased from 0.60 to 1.05.

INTRODUCTION

A knowledge of the effects of Mach number on wing aerodynamic characteristics near maximum lift is becoming of great importance as the speeds and altitudes flown by modern aircraft continue to increase. High-speed, high-altitude aircraft fly at rather high lift coefficients and may reach or exceed the angle of attack for maximum lift of the aircraft in maneuvers. A limited amount of wind-tunnel data - showing the characteristics up to maximum lift of a swept wing - is currently available for Mach numbers up to 1.20 (reference 1). In order to increase this limited amount of available data the present investigation was made to determine the effects of Mach number on the maximum lift characteristics of a $\frac{1}{40}$-scale wing of the X-1 airplane, an unswept wing, through the transonic speed range. Lift, drag, and pitching-moment data were also obtained and presented through a lift range from below zero lift to beyond maximum lift. The investigation was made in the field of flow over the Langley high-speed 7- by 10-foot tunnel transonic bump at Mach numbers from 0.60 to 1.15 with the Reynolds number varying from approximately 0.415 to 0.533×10^6.

COEFFICIENTS AND SYMBOLS

C_L	lift coefficient (L/qS)
C_D	drag coefficient (D/qS)
C_m	pitching-moment coefficient $(m/qS\bar{c})$
L	twice measured lift of semispan model, pounds
D	twice measured drag of semispan model, pounds
m	twice pitching moment about $0.25\bar{c}$ of semispan model, foot-pounds
R	Reynolds number
M	Mach number (V/a)
M_l	local Mach number
α	angle of attack, degrees
q	dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho V^2\right)$
ρ	mass density of air, slugs per cubic foot
V	stream velocity, feet per second
a	velocity of sound, feet per second
S	twice area of semispan wing, square feet

$\bar{c}$ wing mean aerodynamic chord, feet $\left(\frac{2}{S}\int_{0}^{b/2} c^2 dy\right)$

b twice span of reflection-plane wing, feet

c local wing chord, feet

y spanwise distance from plane of symmetry, feet

C_{L_α} $(\partial C_L/\partial \alpha)$

$C_{L_{max}}$ maximum lift coefficient

$C_{N_{max}}$ maximum normal-force coefficient $(C_N = C_L \cos \alpha + C_D \sin \alpha)$

$C_{D_{min}}$ minimum drag coefficient

MODEL AND TEST TECHNIQUE

A $\frac{1}{40}$ - scale model of the left wing of the X-1 research airplane was used for this investigation. The wing had NACA 65-108 airfoil sections with the 40-percent-chord line normal to the plane of symmetry. Other geometric characteristics are shown in figure 1.

The investigation was made in the high-velocity field of flow over the Langley high-speed 7- by 10-foot tunnel transonic bump (fig. 2(a)) through a Mach number range from 0.60 to 1.15. Details of the end plate and gaps where the wing butt passed through the surface of the bump are shown in figure 2(b). The velocity distribution over the bump in the vicinity of the model is shown in figure 3. The test Mach number was the average Mach number over the span and chord of the model as determined from charts similar to figure 3. An electrical strain-gage balance mounted inside the bump with leads to the recording unit outside the tunnel test section was used for measuring the forces and moments on the model. No attempt has been made to take into account either the effect of Mach number gradient over the model or the effect of the end plate and gaps at the root of the model. The variation of Reynolds number with Mach number for the investigation is shown in figure 4.

RESULTS AND DISCUSSION

Lift characteristics.- The lift characteristics of the wing model are presented in figures 5, 6, and 7. The lift-curve slope C_{L_α}, taken through zero lift, increased with increase in Mach number, reaching a peak value of 0.100 at a Mach number of 0.80 (fig. 6). The experimental C_{L_α} curve for subcritical Mach numbers is in good agreement with the theoretical curve estimated by the method of reference 2. Maximum lift coefficient $C_{L_{max}}$ increased from 0.81 at a Mach number of 0.60 to 1.38 at a Mach number of 1.00, then decreased with further increase in Mach number. The large gain in $C_{L_{max}}$ at high subsonic Mach numbers has been observed also for a moderately swept wing (reference 1). The data of figures 5 and 6 show that the gain in $C_{L_{max}}$ in the high-subsonic Mach number range resulted from the higher angle of attack at which maximum lift coefficient occurred since C_{L_α} reached a maximum at a Mach number of 0.80. Up to a Mach number of approximately 0.90 the lift coefficient decreased only slightly after the angle of attack for maximum lift had been reached, although the angle of attack was increased to as much as 48° in one case (fig. 5).

A comparison of wind-tunnel and flight maximum normal-force coefficients is presented in figure 7. The flight data presented are from unpublished data obtained at the NACA High-Speed Flight Research Station at Edwards Air Force Base, California at Reynolds numbers between 2.5 and 12×10^6. The circled point is from unpublished data for a $\frac{1}{4}$-scale model of the X-1 airplane with the wing having NACA 65-110 (a = 1.0) sections, with the tail removed, and at a Reynolds number of 2.69×10^6. The flight normal-force coefficients are considered to be in very good agreement with the wind-tunnel values - considering the limits of accuracy for both flight and wind-tunnel measurements - even though the wind-tunnel results did not show the dip in the $C_{N_{max}}$ curve shown by the flight data at a Mach number of 0.80. The flight normal-force values above a Mach number of approximately 1.04 are the peak values measured but not necessarily the maximum values. The wind-tunnel results give higher maximum normal-force coefficients and indicate that the agreement between flight and wind-tunnel data in this Mach number range might have been better if the flight investigation had obtained maximum normal-force coefficients. The $C_{N_{max}}$ value at a Mach number of 0.35 as well as the $C_{N_{max}}$ curve of the present investigation (fig. 7) indicates that $C_{N_{max}}$ for this wing does not decrease as the Mach number is increased from zero to approximately 0.60 in contradistinction to most results for thicker wings. However, this small change in $C_{N_{max}}$ with increase in Mach number below a Mach number of 0.50 or 0.60 is probably to be expected for a thin wing (reference 3).

Drag characteristics.- The drag characteristics of the wing model are presented in figures 8 and 9. The minimum drag coefficient at a Mach number of 0.60 was 0.008 (fig. 9), and the rise of the minimum drag coefficient occurred at a Mach number of approximately 0.80 with $C_{D_{min}}$ reaching a peak value of 0.062 at a Mach number of 1.05. Above $M = 1.05$, $C_{D_{min}}$ decreased slightly with further increase in Mach number. The maximum lift-drag ratio decreased from a value of approximately 23 at a Mach number of 0.60 to a value of 5 at a Mach number of 1.00 and remained practically constant with further increase in Mach number. Maximum L/D occurred at a lift coefficient of 0.40, at Mach numbers below approximately 0.85. Above a Mach number of 0.85, C_L for maximum L/D increased with increases in Mach number and reached a peak value of 0.55 at approximately $M = 1.03$.

Pitching-moment characteristics.- The pitching-moment characteristics of the wing model are presented in figures 10 and 11. In general, the pitching-moment-coefficient curves became more stable ($\partial C_m/\partial C_L$ became more negative) as the Mach number was increased (fig. 10). The pitching-moment-coefficient curves broke in a stable direction (diving tendency) as $C_{L_{max}}$ was approached at Mach numbers below 0.90, above a Mach number of 0.90 the pitching-moment coefficients changed very little at $C_{L_{max}}$. Variation of the pitching-moment coefficient with Mach number for lift coefficients of zero and 0.40 are presented in figure 11. For a lift coefficient of zero the pitching-moment-coefficient curve has a sharp break or offset between a Mach number of 0.85 and 0.90. This effect decreases considerably at a lift coefficient of 0.40 - the lift coefficient for maximum L/D of the wing at Mach numbers below 0.90. The aerodynamic center of the wing moves from approximately $0.20\bar{c}$ at $M = 0.60$ to approximately $0.43\bar{c}$ at a Mach number of 1.15 for a lift coefficient of 0.40. At a lift coefficient of zero this rearward shift of the aerodynamic center is gradual up to a Mach number of 0.90 but moves rearward very fast between a Mach number of 0.90 and 1.00; however, at a lift coefficient of 0.40 this fast rearward movement of the aerodynamic center begins at a Mach number of approximately 0.80.

CONCLUSIONS

An investigation was made at Mach numbers from 0.60 to 1.15 of a $\frac{1}{40}$ - scale model of the X-1 airplane wing to determine the effect of

Mach number on the wing maximum lift characteristics. The following conclusions were indicated:

1. Maximum normal-force coefficients were in good agreement with flight results.

2. Maximum lift coefficients were greatly affected by Mach number, increasing from 0.81 at a Mach number of 0.60 to 1.38 at a Mach number of 1.00; however, above a Mach number of 1.00 the maximum lift coefficient decreased with further increase in Mach number.

3. Maximum lift was obtained at progressively higher angles of attack as the Mach number was increased from 0.60 to 1.05.

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1. Turner, Thomas R.: Maximum-Lift Investigation at Mach Numbers from 0.05 to 1.20 of a Wing with Leading Edge Swept Back 42°. NACA RM L9K03, 1949.

2. Polhamus, Edward C.: A Simple Method of Estimating the Subsonic Lift and Damping in Roll of Sweptback Wings. NACA TN 1862, 1949.

3. Cleary, Harold E.: Effects of Compressibility on Maximum Lift Coefficients for Six Propeller Airfoils. NACA ACR L4L21a, 1945.

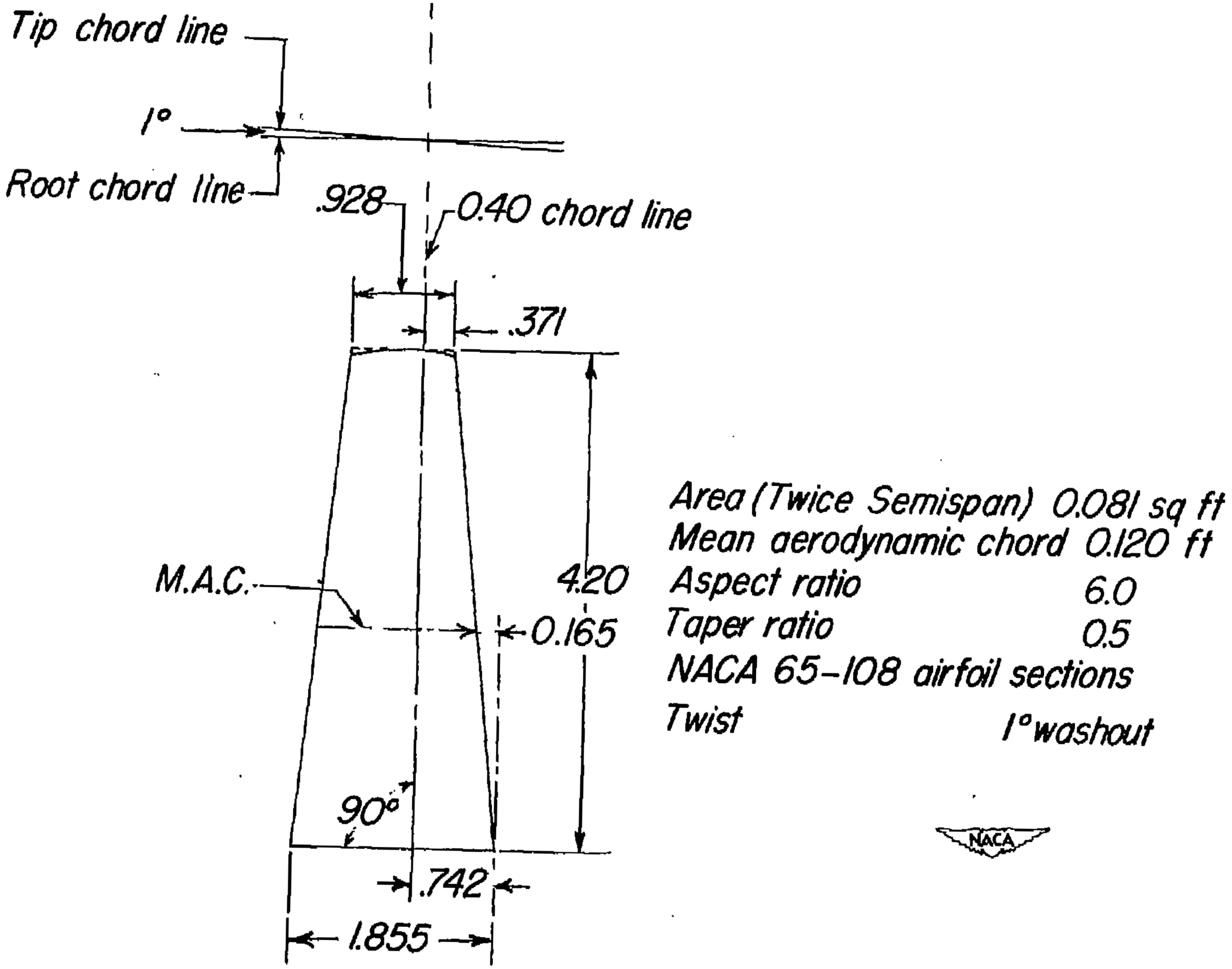

Figure 1.- Plan form of $\frac{1}{40}$ - scale X-1 airplane wing investigated.
(Dimensions in inches unless otherwise indicated.)

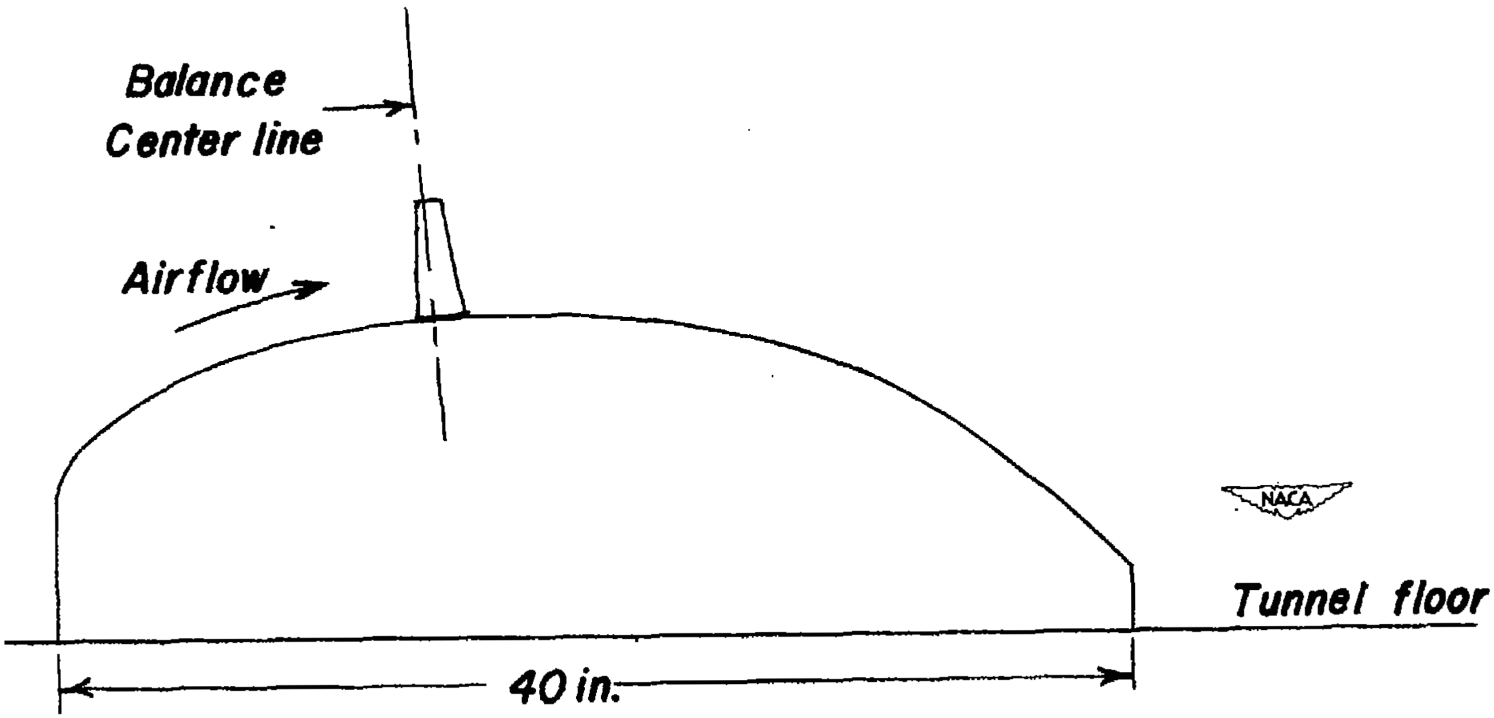

Figure 2a.- Schematic sketch of relative position of model, balance, and transonic bump as mounted in the Langley high-speed 7- by 10-foot tunnel.

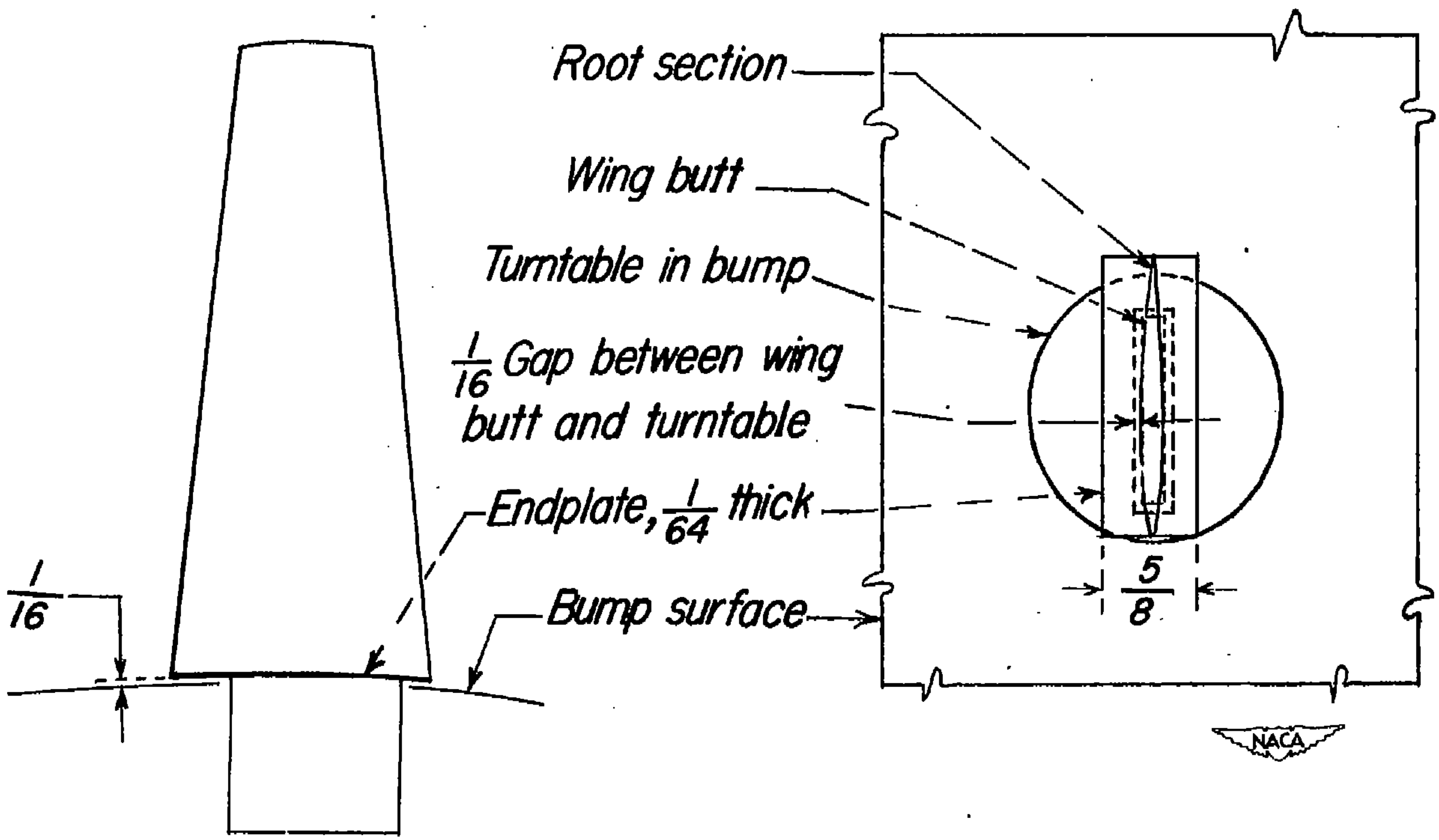

Figure 2b.- Details of end plate and gaps where wing butt passes through bump surface. (Dimensions in inches.)

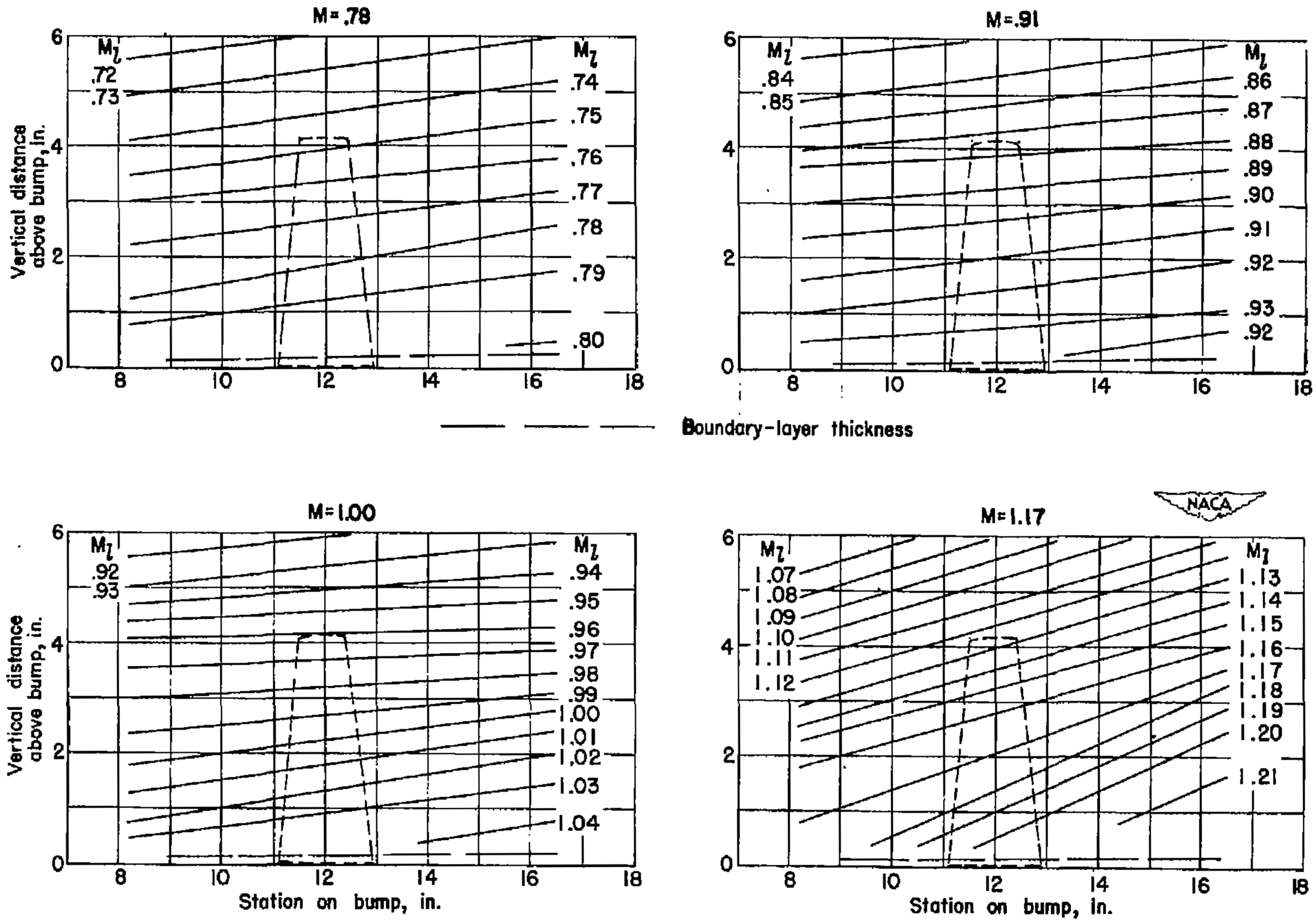

Figure 3.- Typical Mach number contours over transonic bump in region of model location.

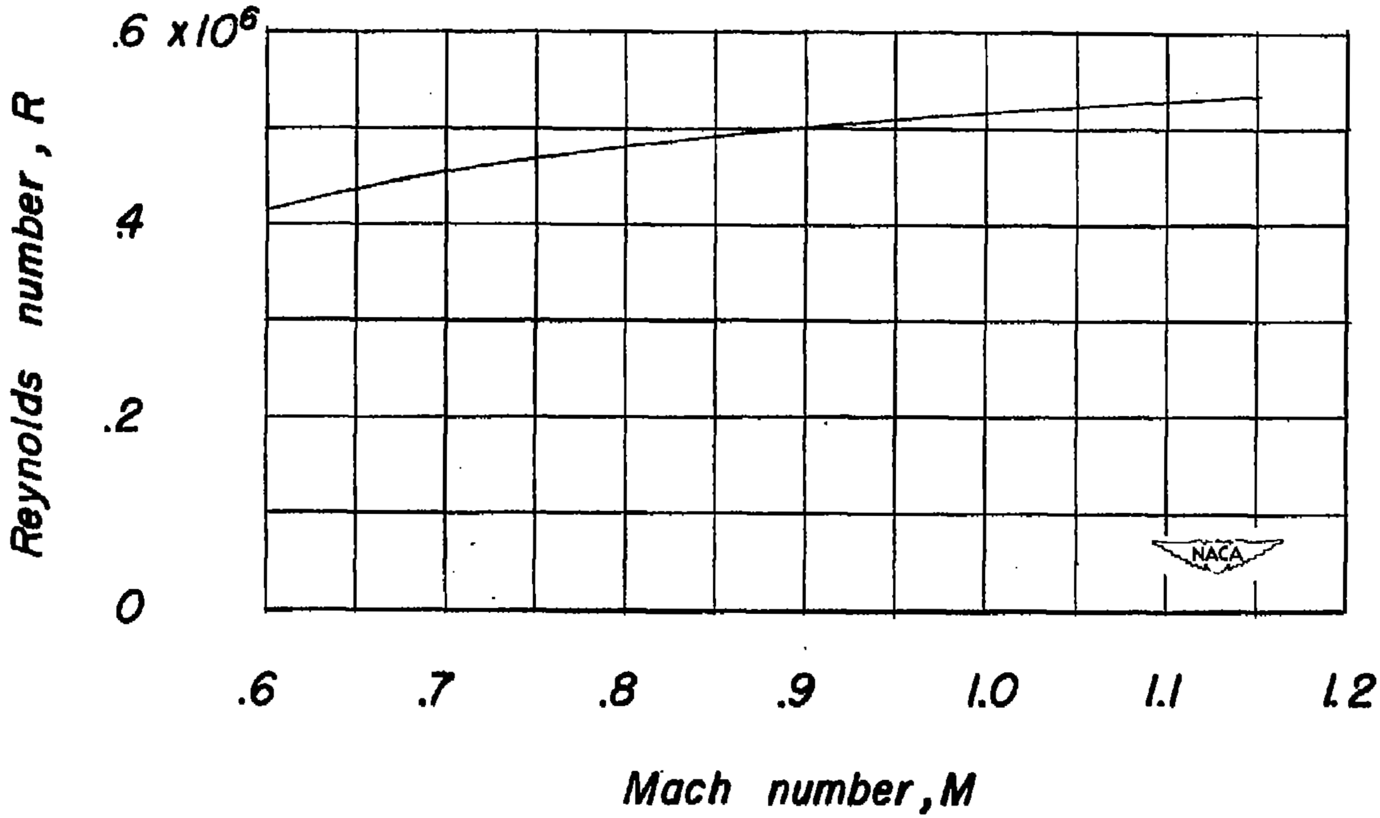

Figure 4.- Variation of Reynolds number with Mach number for the investigation.

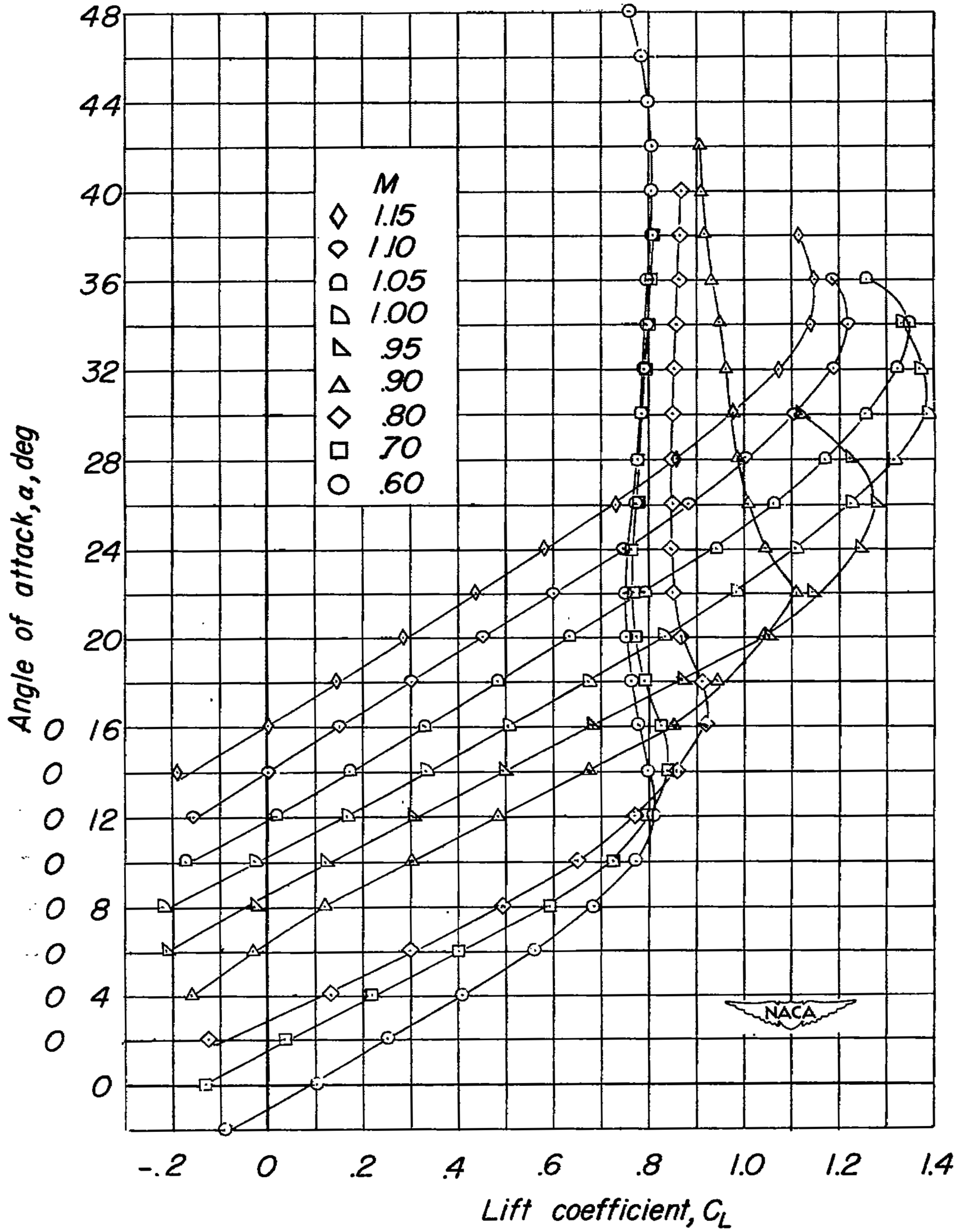

Figure 5.- Variation of lift coefficient with angle of attack at various Mach numbers for a $\frac{1}{40}$- scale X-1 airplane wing.

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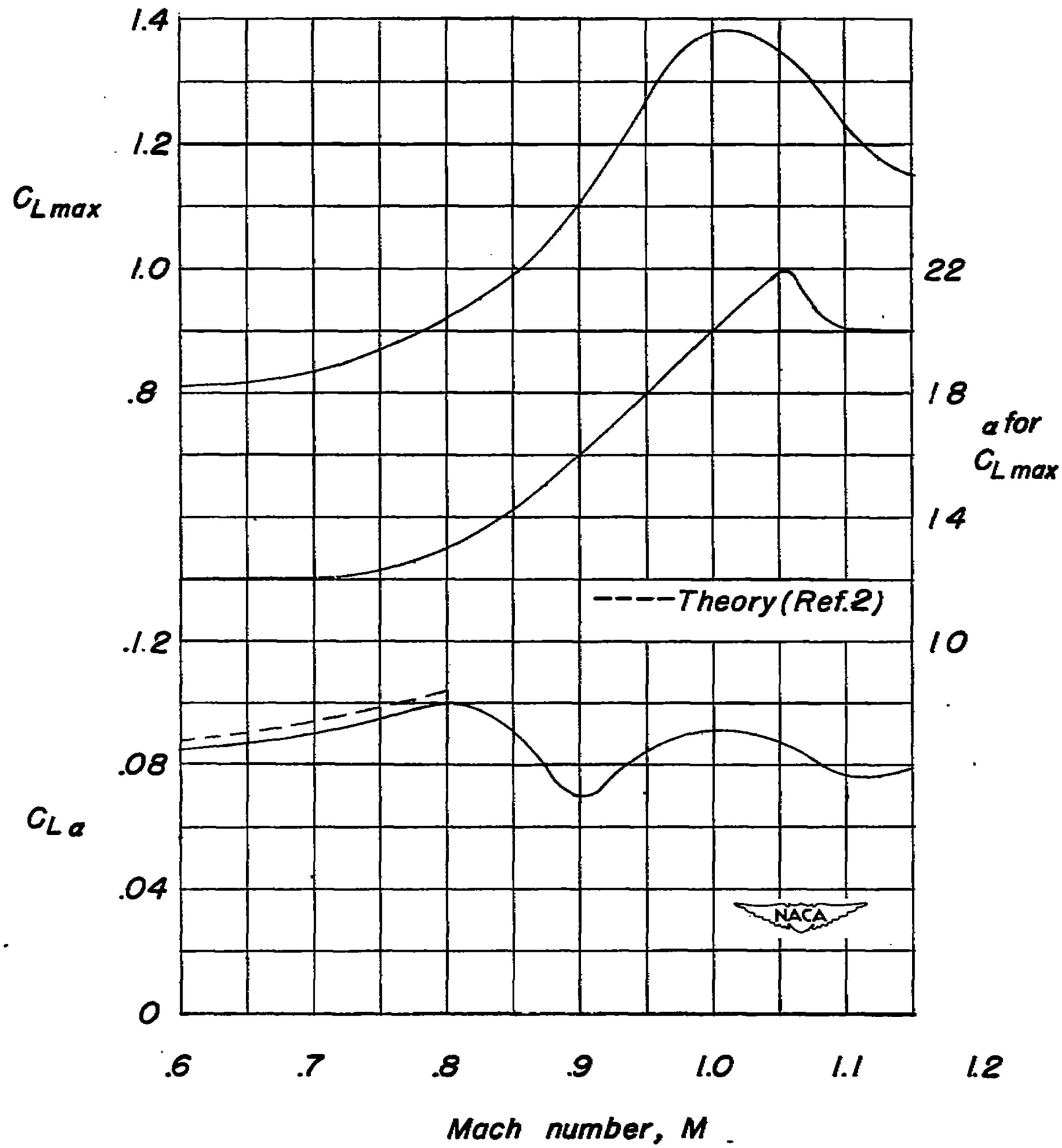

Figure 6.- Variation of some aerodynamic characteristics with Mach number for a $\frac{1}{40}$ - scale X-1 airplane wing.

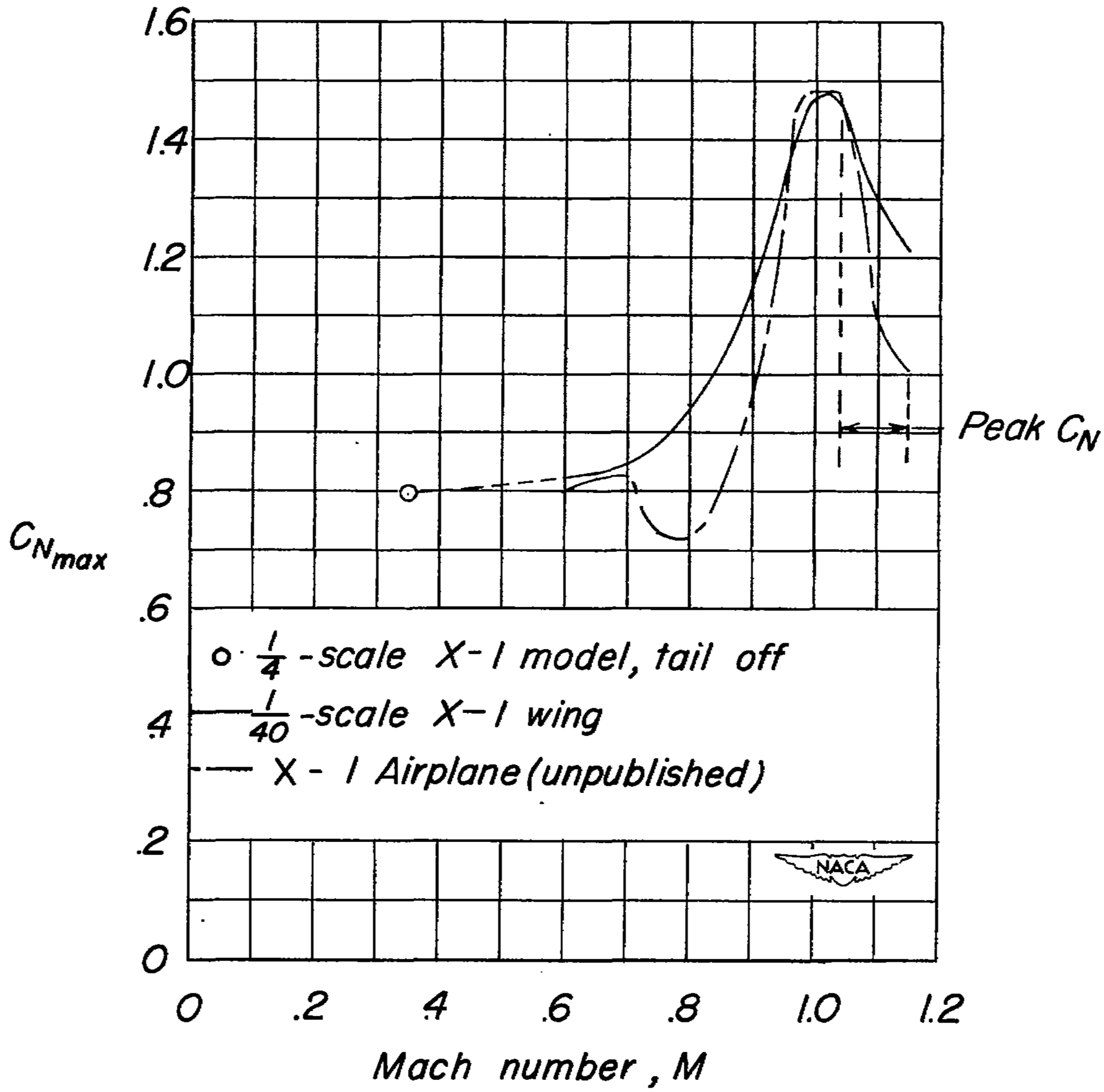

Figure 7.- Variation of flight and wind-tunnel maximum normal-force coefficients with Mach number.

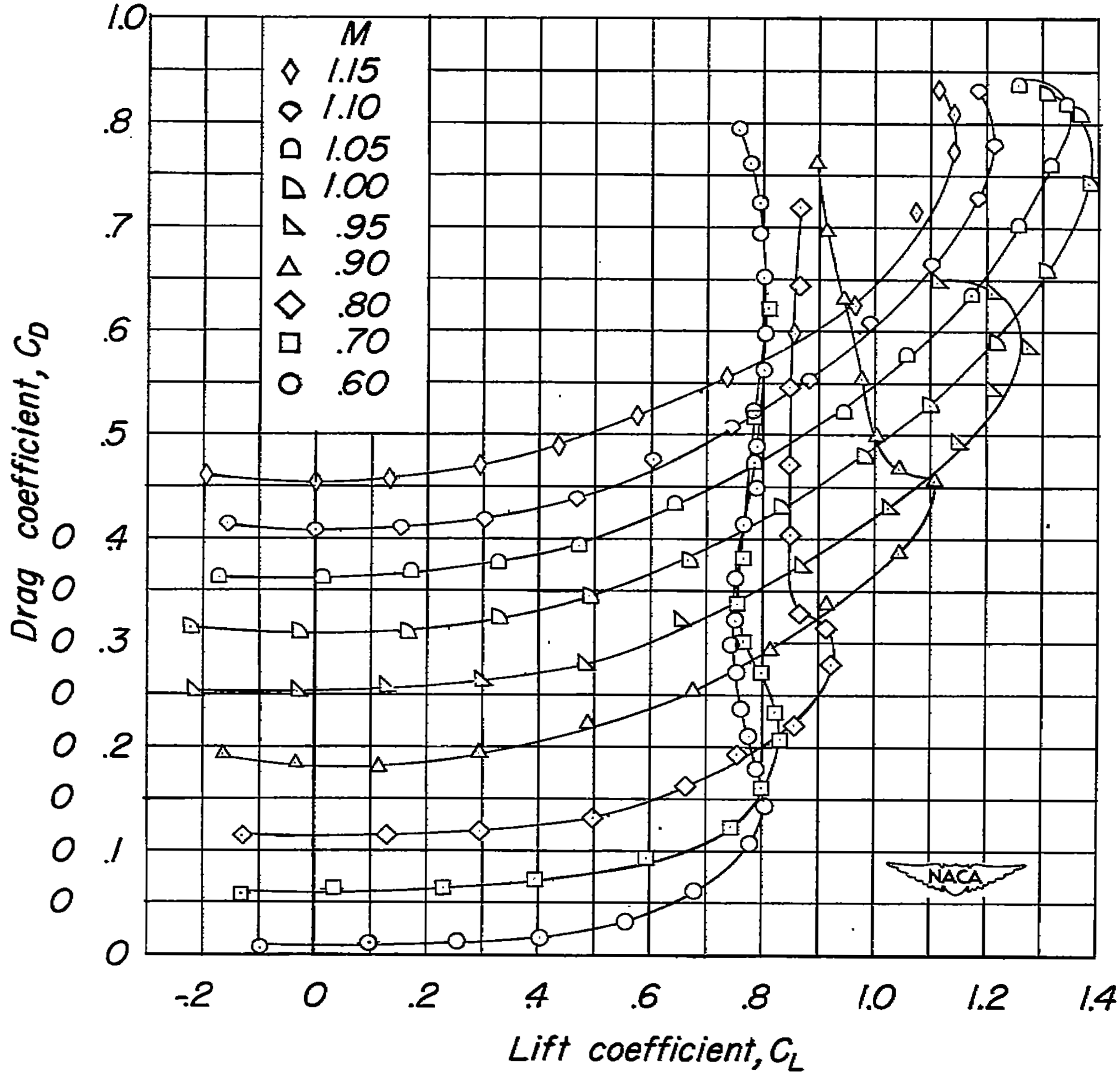

Figure 8.- Variation of drag coefficient with lift coefficient at various Mach numbers for a $\frac{1}{40}$- scale X-1 airplane wing.

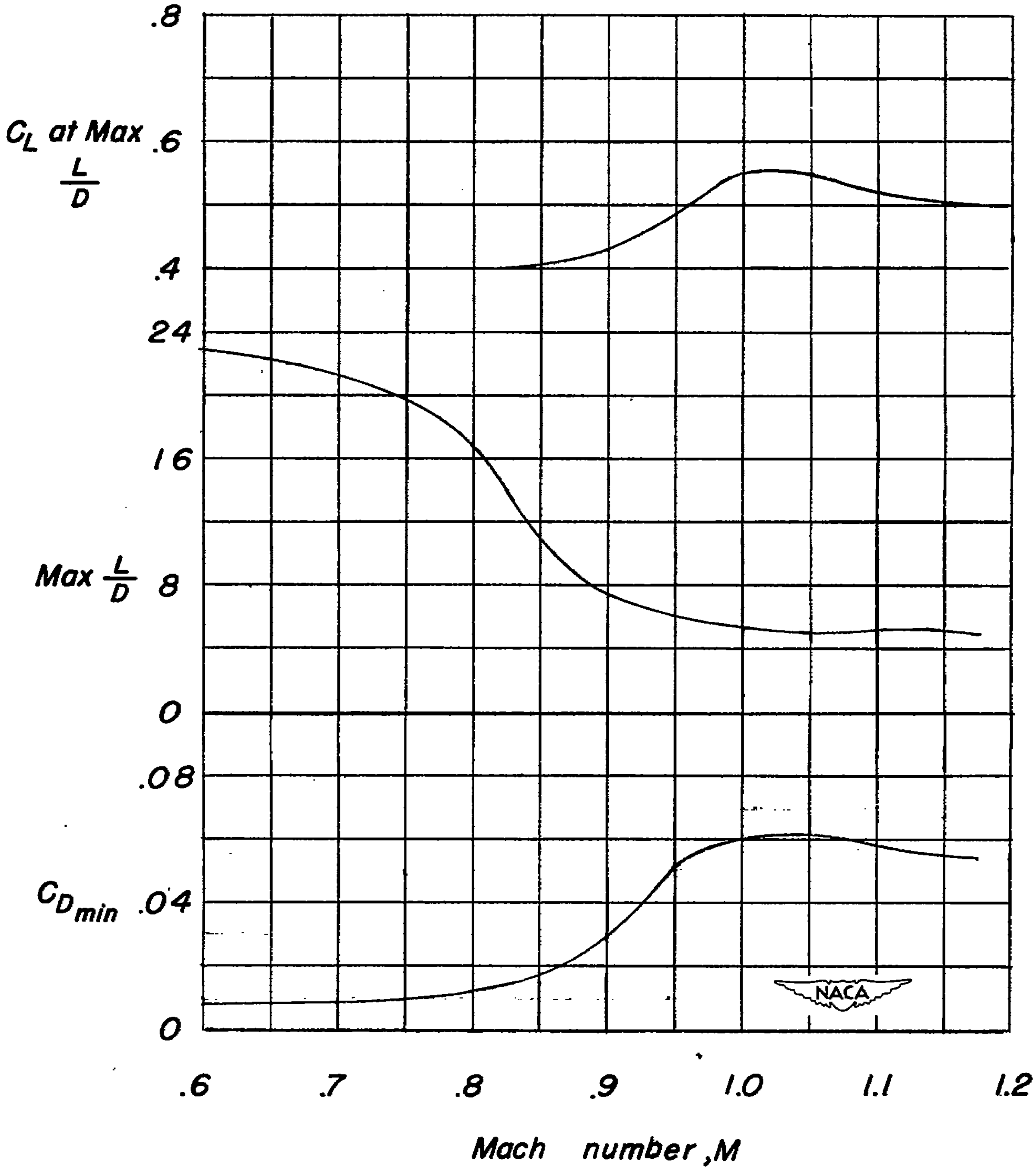

Figure 9.- Variation of some aerodynamic characteristics with Mach number for a $\frac{1}{40}$ - scale X-1 airplane wing.

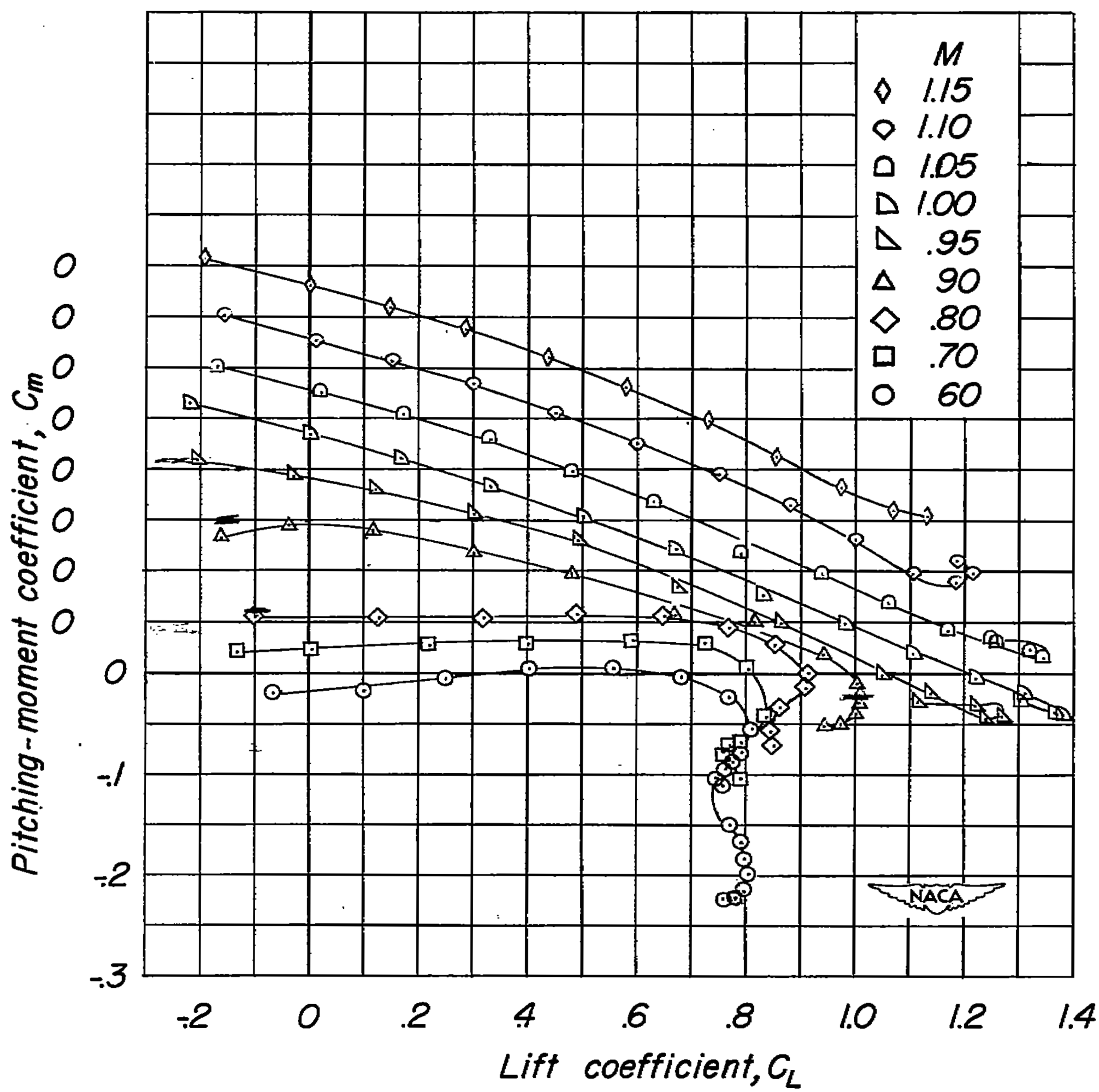

Figure 10.- Variation of pitching-moment coefficient with lift coefficient at various Mach numbers for a $\frac{1}{40}$- scale X-1 airplane wing.

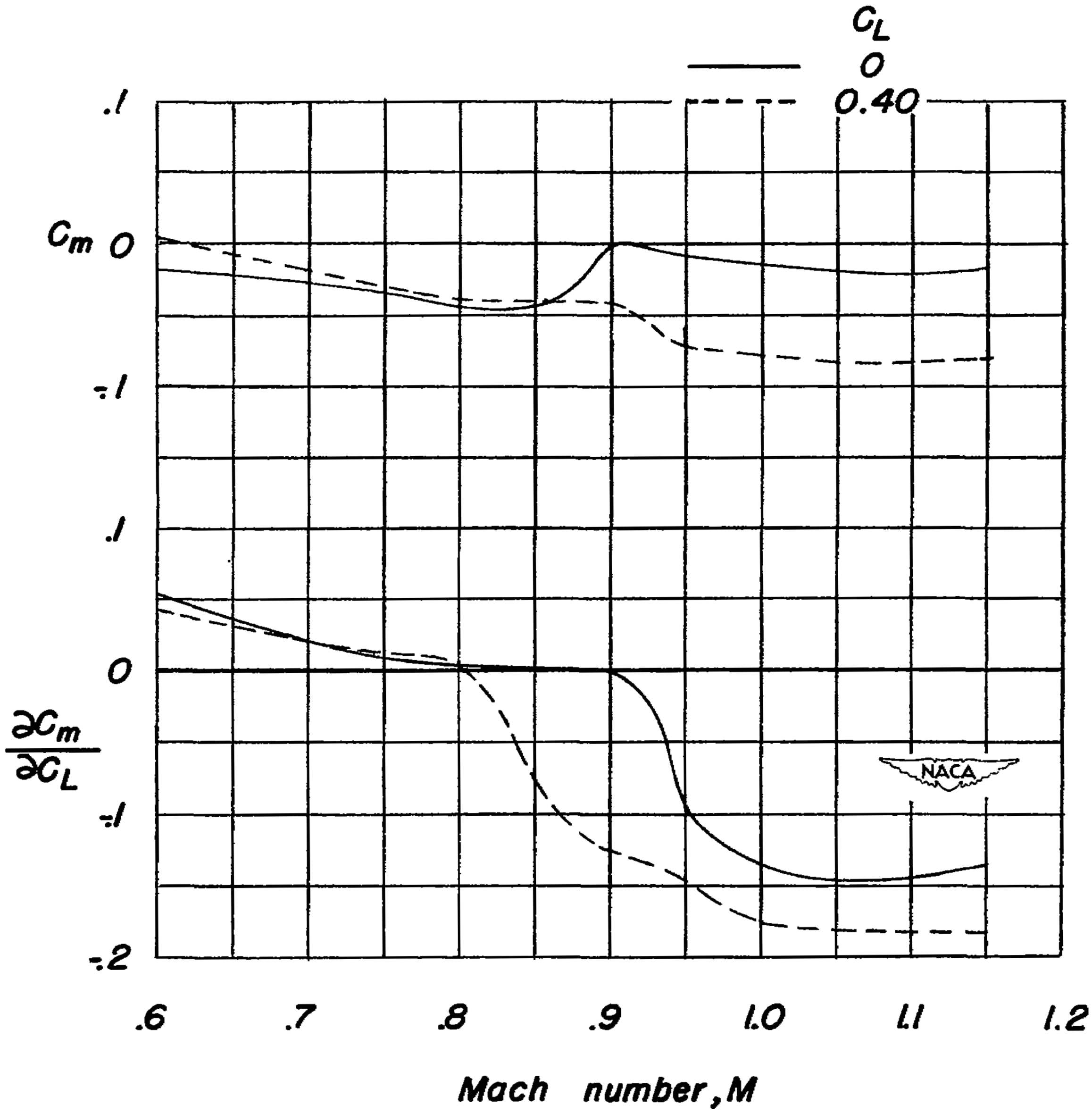

Figure 11.- Variation of pitching-moment characteristics with Mach number for a $\frac{1}{40}$- scale X-1 airplane wing.

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