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RESEARCH MEMORANDUM

EFFECT OF FULL-SPAN TRAILING-EDGE ELEVONS ON THE TRANSONIC LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF A WING-BODY COMBINATION HAVING A 3-PERCENT-THICK TRIANGULAR WING WITH 60° LEADING-EDGE SWEEP

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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EFFECT OF FULL-SPAN TRAILING-EDGE ELEVONS ON THE TRANSONIC LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF A WING-BODY COMBINATION HAVING A 3-PERCENT-THICK TRIANGULAR WING WITH 60° LEADING-EDGE SWEEP

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SUMMARY

An investigation to determine the effects of full-span trailing-edge flaps on the static longitudinal characteristics of a triangular wing-body combination was conducted in the Langley 16-foot transonic tunnel. This wing had a leading-edge sweep of 60°, an aspect ratio of 2.06, and NACA 65A003 airfoil sections. Force data were obtained for the basic configuration and for the wing with the control surfaces deflected for longitudinal control through a deflection range of -15° to 7.5°. Data were obtained at angles of attack generally from 0° to as high as 26° for Mach numbers ranging from 0.80 to 1.05. The Reynolds number varied from 9.8×10^6 to 10.5×10^6.

The untrimmed configuration exhibited only mild static longitudinal instability tendencies except for a rather abrupt increase in pitching moment near a lift coefficient of 0.84 at a Mach number of 0.94. Above this Mach number no instability was indicated for the range of lift coefficients investigated. Flap pitching-moment effectiveness indicated about 20-percent variation for the range of Mach numbers investigated.

Trimming the model about 0.35 of the mean aerodynamic chord of the wing increased the static longitudinal stability throughout the range of Mach numbers tested. The negative flap deflections required to trim the configuration resulted in reducing the lift-curve slope of the untrimmed condition by as much as 19 percent. The maximum trim-drag penalty for trimmed level flight for an assumed wing loading of 40 pounds per square foot at 35,000 feet was 0.0015 (at a Mach number of 1.03); at an altitude of 60,000 feet the higher flap deflection required to trim the model (about -4.5°) resulted in a maximum trim-drag penalty of about 0.0155 (at a Mach number of 1.00).

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INTRODUCTION

A general wing-study program is being conducted in the Langley 16-foot transonic tunnel to determine wing loads and control loads and effectiveness of a family of wings at transonic speeds. As part of this program, an investigation has been made of the static longitudinal and lateral stability characteristics of a wing-body combination having a thin triangular wing with constant-chord elevons. Force data, pressure distributions, and control loads were obtained for the basic wing and for the wing with ailerons and elevons deflected individually and in combination for longitudinal and lateral control. This paper presents the force data for the basic wing-body combination and for the wing with full-span trailing-edge elevons deflected for longitudinal control through a deflection range from -15° to 7.5° for Mach numbers between 0.80 and 1.05. The data were obtained for Reynolds numbers ranging from 9.8×10^{6} to 10.5×10^{6} and for angles of attack from -4° to 26°.

Subsonic and transonic aerodynamic data for a similar wing have been reported in references 1, 2, and 3.

SYMBOLS

A	aspect ratio
b	wing span
c	local wing chord
$\bar{c}$	mean aerodynamic chord of the wing
C_D	drag coefficient, $\frac{\text{Drag}}{qS}$
$\Delta C_{D,t}$	trim-drag-coefficient penalty
C_L	lift coefficient, $\frac{\text{Lift}}{qS}$
C_m	pitching-moment coefficient, about $0.35\bar{c}$, $\frac{\text{Pitching moment}}{qS\bar{c}}$
$C_{p,b}$	base-pressure coefficient

d	diameter
M	free-stream Mach number
q	free-stream dynamic pressure, $\frac{1}{2}\rho V^2$
r	radius
R	Reynolds number, based on $\bar{c}$
S	wing area, for wing as tested with rounded tips
V	free-stream velocity
$\frac{\partial C_L}{\partial \alpha}$	lift-curve slope per degree, averaged over linear portion of curve near $\alpha = 0^\circ$
$\frac{\partial C_L}{\partial \delta}$	lift effectiveness parameter, averaged for δ from -5° to 5° and α from 0° to 8°
$\frac{\partial C_m}{\partial C_L}$	static longitudinal stability parameter
$\frac{\partial C_m}{\partial \delta}$	pitch effectiveness parameter, averaged for δ from -5° to 5° and α from 0° to 8°
α	angle of attack of body center line relative to V
δ	control deflection angle, measured at right angles to hinge line and negative when trailing edge is up
$\Delta\delta$	deviation due to aerodynamic load of control-deflection angle from nominal setting
ρ	density of air

Subscript:

t	trim condition

APPARATUS AND MODEL

Apparatus

Tunnel.- The tests were conducted in the Langley 16-foot transonic tunnel, a single-return octagonal slotted-throat tunnel operating at atmosphere stagnation pressures. A detailed description of this tunnel is presented in reference 4 which gives the maximum variation of the average Mach number along the test-section center line in the vicinity of the model to be about ±0.002.

Model support system.- A single swept-cantilever strut supported the sting-mounted model for the present tests. This support system, described in detail in reference 5, held the model near the tunnel center line throughout the range of angle of attack.

Model

The wing for the present investigation was a triangular wing having a leading-edge sweep of 60°, an aspect ratio of 2.06 (based on rounded tips), and NACA 65A003 airfoil sections parallel to the plane of symmetry. This wing was made of steel and was designed to have no twist or incidence relative to the body center line. The wing was mounted in the midwing position on the body. The fuselage consisted of a cylindrical body of revolution with an ogival nose and a slightly boattailed afterbody.

The trailing-edge controls herein referred to as elevons were full-span constant-chord controls with leading-edge hinge line perpendicular to the model center line. The total exposed elevon area was 22.34 percent of the exposed wing area of 5.401 square feet.

The dimensional details of the model are given in figure 1 and a photograph of the model mounted in the tunnel is given as figure 2.

TESTS AND MEASUREMENTS

The configurations for the present investigation included the basic wing-body combination with elevons undeflected and deflected -15°, -7.5°, and 7.5°. The aerodynamic forces and moments for these configurations were measured for a range of Mach numbers from 0.80 to 1.05. Data were obtained for a range of angle of attack from -4° to a maximum of 26° in increments of 2°. Tunnel-drive power limited the maximum obtainable angle of attack at Mach numbers of 1.0 and above.

The Reynolds number for the present tests, based on a mean-aerodynamic-chord length of 2.519 feet, ranged from 9.8×10^6 to about 10.5×10^6. The variation of Reynolds number with Mach number over the speed range is presented in figure 3.

The forces and moments on the wing-body configuration were measured by an electrical strain-gage balance mounted within the body. Transition on the model was not fixed.

CORRECTIONS AND PRECISION

Force-Data Accuracy

The force data were not adjusted for wall-reflected disturbances since it has been established that these effects are very small in this slotted wind tunnel, at least for Mach numbers as high as 1.03 (ref. 6). The accuracy of the coefficients, based on balance accuracy and repeatability of data, is estimated to be within the following limits:

C_L . . . . ±0.01
C_D -
  At low lift coefficients . . . . ±0.001
  At high lift coefficients . . . . ±0.005
C_m . . . . ±0.005

The Mach numbers presented herein are accurate to within ±0.01.

Base Pressure

The base pressure was measured by three orifices located about 2 inches inside the base of the model. By use of these data, the drag data were adjusted to the condition of free-stream static pressure at the base of the model. The base-pressure coefficients for the four configurations of the present tests are presented in figure 4 as functions of angle of attack for the present range of Mach numbers. These coefficients, based on repeatability of measurements, are estimated to be accurate to within ±0.01. (A base-pressure coefficient of 0.1 corresponds to a drag coefficient for the present model of about 0.0026.)

Angle of Attack

The model angle of attack was measured by a pendulum-type strain-gage inclinometer. An adjustment for airstream misalinement (up flow angle of 0.30°) was made, and the angles of attack reported herein are estimated to be accurate to within ±0.1°.

Aeroelastic Effects and Flap-Load Deflection

The twisting characteristics of the wing were determined by use of influence coefficients obtained from static bench tests and from loading characteristics of the wing as reported in reference 7. The maximum twist of the wing at the $0.90\frac{b}{2}$ station was found to be about -0.5°. The force data of the present paper were not adjusted for this wing twist.

The elevon deflections due to aerodynamic loads were determined by use of data from static bench tests and unpublished control-load characteristics. The deviation of the elevon deflection angle from the nominal settings is shown in figure 5 as a function of angle of attack for each nominal elevon deflection for the range of Mach numbers. The maximum deviation for the extreme loading condition was -1.4°.

PRESENTATION OF RESULTS

The aerodynamic force and moment characteristics of the basic ($\delta = 0^{\circ}$) model and for the elevon-deflected configurations are presented in figure 6 uncorrected for control-surface deflection due to aerodynamic load. Corrected data for the basic wing are presented in figure 7 as functions of angle of attack and lift coefficient at constant Mach number. The variations with flap deflection of the lift, drag, and pitching-moment coefficients were obtained by cross-plotting the data for the flap deflected conditions and are presented for constant angle of attack and Mach number in figure 8.

The static longitudinal stability parameter and the flap pitch effectiveness parameter are presented as functions of Mach number in figure 9. The lift-curve slope and the flap lift effectiveness parameter are shown as functions of Mach number in figure 10.

The lift coefficients required for level flight of a hypothetical airplane at assumed wing loadings of 40 and 60 pounds per square foot have been calculated for altitudes of 35,000 and 60,000 feet and are presented in figure 11. The variations with Mach number of the untrimmed pitching-moment coefficient, flap deflection required to trim the model at 0.35$\bar{c}$, and the resulting drag penalty (as obtained from cross plots and interpolation) are presented in figure 12 for the previously mentioned lift coefficients and altitudes for a wing loading of 40 pounds per square foot.

Sliding scales have been used in figures 7 and 8 in order to present the data compactly and care should be taken in the selection of the proper zero axis for each curve.

Pitching-Moment Characteristics

Untrimmed model.- The pitching-moment curves for the untrimmed model presented in figure 7(c) indicate only mild instability tendencies except for a rather abrupt increase in pitching moment near a lift coefficient of 0.84 at a Mach number of 0.94. Above this Mach number no instability was indicated for the range of lift coefficients investigated.

The untrimmed static longitudinal stability parameter $\partial C_m/\partial C_L$ at zero lift coefficient shown as a function of Mach number in figure 9(a), varied from about -0.015 at a Mach number of 0.80 to about -0.110 at a Mach number of 1.05, indicating a 9.5-percent $\bar{c}$ rearward shift of the aerodynamic-center location.

Effects of elevon deflection.- The variation of pitching moment with control deflection at constant angles of attack, shown in figure 8(c) for the Mach number range, is essentially linear from $\delta = -5^\circ$ to $\delta = 5^\circ$ and for angles of attack up to 8° at a given Mach number. The value of $\partial C_m/\partial\delta$ averaged over this range of elevon deflection and angle of attack reached a maximum of about -0.0140 at a Mach number of 0.90 and, as shown in figure 9(b), indicated a variation with Mach number of about 20 percent for the range of Mach number investigated.

Lift coefficients necessary to maintain trimmed level flight of a hypothetical wing at altitudes of 35,000 and 60,000 feet for wing loadings of 40 and 60 pounds per square foot have been calculated and are presented in figure 11. The required control-deflection settings to trim the present wing (center of gravity at 0.35$\bar{c}$) at these lift coefficients and altitudes are presented for the Mach number range in figure 12 for a wing loading of 40 pounds per square foot. At an altitude of 35,000 feet the required control deflection for trim reached a maximum of about -1.0° at the higher Mach numbers. Increasing the altitude to 60,000 feet increased the control deflection required for trim to about -4.5° for Mach numbers between 0.98 and 1.05. This increase was the result of the increased out-of-trim pitching moment at the higher altitude also shown in figure 12.

Trimmed model.- A change from untrimmed to trimmed operation at a lift coefficient of 0.20 increased the longitudinal stability parameter $-\partial C_m/\partial C_L$ by as much as -0.02 over the entire range of Mach number of the tests (fig. 9(a)). At a lift coefficient of 0.40, the increase in $-\partial C_m/\partial C_L$ resulting from trimming the model was approximately -0.04 up to a Mach number of 0.94 and approximately -0.02 at higher speeds.

Lift Characteristics

Untrimmed model.- The lift curves for the untrimmed model were generally linear for angles of attack up to about 14°. (See fig. 7(a).) The lift-curve slope for the untrimmed model, averaged over the linear portion of the curve near zero lift, increased from about 0.049 at a Mach number of 0.80 to about 0.059 at a Mach number of 1.05 (fig. 10).

Effect of flap deflection.- The control lift effectiveness parameter $\partial C_L/\partial \delta$, as indicated by the rate of change in lift coefficient with elevon deflection at a given angle of attack and Mach number (fig. 8(a)), was essentially linear for a control-deflection range of -5° to 5° for angles of attack generally as high as 10°. The value of $\partial C_L/\partial \delta$ averaged over this range of elevon deflection and angle of attack reached a maximum of about 0.028 at a Mach number of 0.90 and decreased to about 0.020 at a Mach number of 1.05. (See fig. 10.)

Trimmed model.- As shown in figure 10, trimming the configuration reduced the untrimmed lift-curve slope $\partial C_L/\partial \alpha$ by about 2.5 percent at a Mach number of 0.80 and by about 19 percent at a Mach number of 1.03. These losses are the result of up-flap-type longitudinal control required to trim the model (shown in fig. 12) which decreases the lift at a given angle of attack.

Drag Characteristics

Untrimmed model.- The drag polars presented for the basic untrimmed model in figure 7(b) indicated the minimum drag occurred approximately at zero lift.

Trim-drag penalties.- The trim-drag penalties for trimmed level flight of the configuration (center of gravity at $0.35\bar{c}$) at altitudes of 35,000 and 60,000 feet were obtained for an assumed wing loading of 40 pounds per square foot and are presented in figure 12. At the lower altitude where the out-of-trim pitching moment was relatively small and the control deflection required for trim was consequently low (also shown in fig. 12), the trim-drag penalty was also small (about 0.0015, maximum). Increasing the altitude, however, to 60,000 feet increased the trim-drag penalty for the same wing loading to a maximum of approximately 0.0155 at a Mach number of 1.00. This increase was the result of the high control deflection (about -4.5°, maximum) required to trim the model at the higher altitude.

CONCLUSIONS

The following conclusions may be drawn from a wind-tunnel investigation of the effects of full-span trailing-edge flaps on the transonic longitudinal stability characteristics of a 3-percent-thick triangular wing with 60° leading-edge sweep:

1. The untrimmed configuration exhibited only mild static longitudinal instability tendencies except for a rather abrupt increase in pitching moment near a lift coefficient of 0.84 at a Mach number of 0.94. The lift curves for the untrimmed model were generally linear up to as high as 14° angle of attack; the value of the lift-curve slope was between 0.049 and 0.059 for the Mach number range tested.

2. Trimming the model (center of gravity at 0.35 mean aerodynamic chord of wing) increased the longitudinal stability parameter $-\partial C_m/\partial C_L$ of the untrimmed model by as much as -0.02 and -0.04, respectively, at lift coefficients of 0.2 and 0.4.

3. The negative flap deflections required to trim the model resulted in reducing the lift-curve slope of the untrimmed condition by as much as 19 percent.

4. The trim-drag penalty at an altitude of 60,000 feet, computed for an assumed wing loading of 40 pounds per square foot, increased from 0.0045 to 0.0155 through the speed range; at a lower altitude of 35,000 feet, the trim-drag penalty for the same wing loading was 0.0015.

5. The flap pitch effectiveness parameter, averaged over a control-deflection range of -5° to 5° and for angles of attack up to about 8°, was maximum at -0.014 at a Mach number of 0.90 and varied about 20 percent of this value through the Mach number range tested. The flap lift effectiveness parameter varied between 0.028 and 0.020 within the Mach number range tested.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., June 17, 1957.

REFERENCES

1. Wiggins, James W.: Wind-Tunnel Investigation at High Subsonic Speeds of the Static Longitudinal and Static Lateral Stability Characteristics of a Wing-Fuselage Combination Having a Triangular Wing of Aspect Ratio 2.31 and an NACA 65A003 Airfoil. NACA RM L53G09a, 1953.

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3. Wiley, Harleth G.: A Wind-Tunnel Investigation at High Subsonic Speeds of the Lateral Control Characteristics of Various Plain Spoiler Configurations on a 3-Percent-Thick 60° Delta Wing. NACA RM L54D01, 1954.

4. Ward, Vernon G., Whitcomb, Charles F., and Pearson, Merwin D.: Air-Flow and Power Characteristics of the Langley 16-Foot Transonic Tunnel With Slotted Test Section. NACA RM L52E01, 1952.

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6. Whitcomb, Charles F., and Osborne, Robert S.: An Experimental Investigation of Boundary Interference on Force and Moment Characteristics of Lifting Models in the Langley 16- and 8-Foot Transonic Tunnels. NACA RM L52L29, 1953.

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Body Ordinate			
x	r	x	r
0	0	26.00	4.54
2.00	0.56	30.00	4.72
4.00	1.09	33.33	4.76
6.00	1.59	78.58	4.76
8.00	2.04	80.00	4.73
10.00	2.45	83.50	4.56
14.00	3.18	87.00	4.35
18.00	3.77	90.97	4.07
22.00	4.22	104.30	3.14

Wing Data		
	Actual	Theoretical
A	2.06	2.31
S, ft^2	8.13	8.17
b/2	24.53	26.06
$\bar{c}$, in.	30.23	30.09
Section	NACA 65A003	NACA 65A003

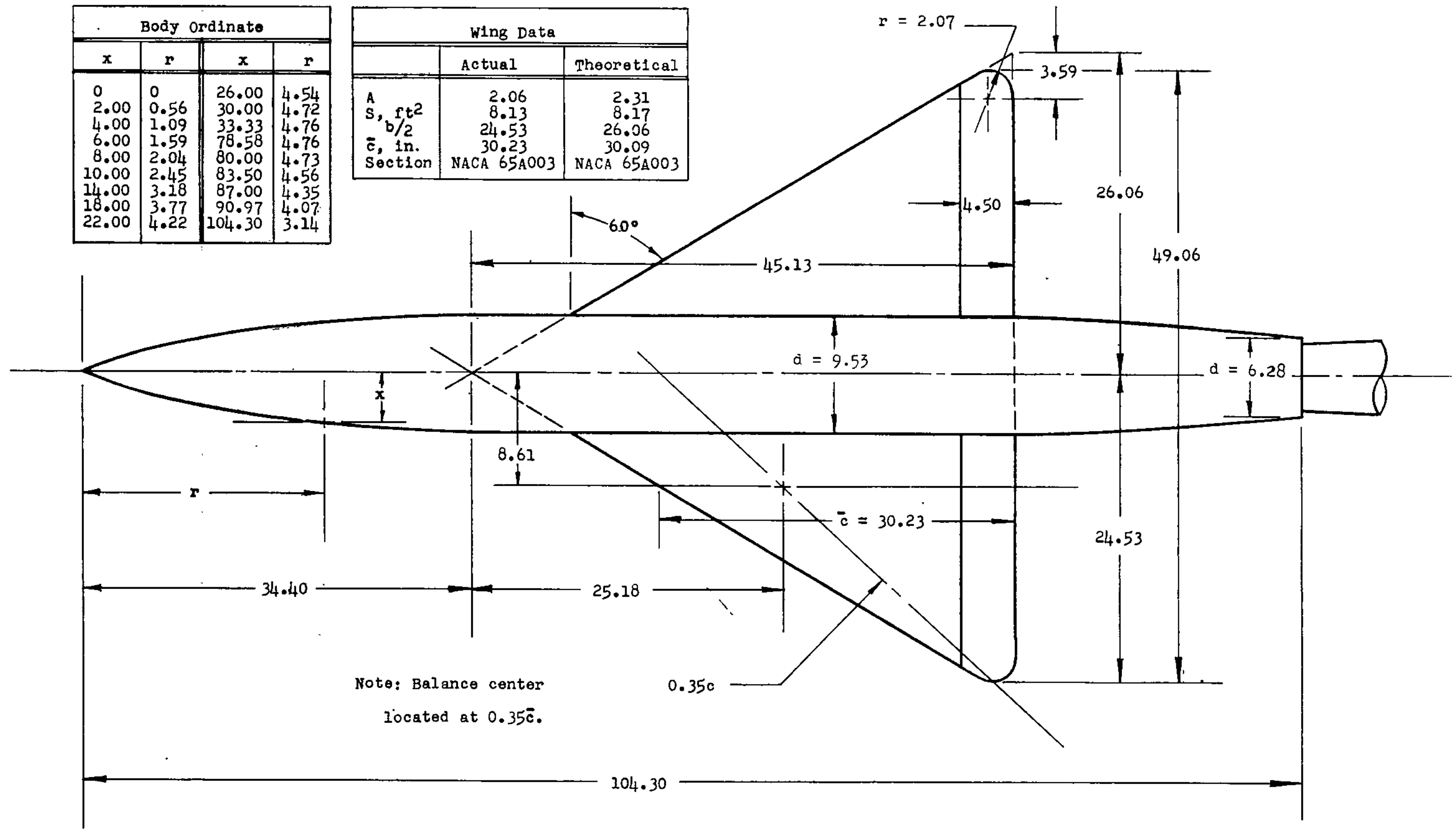

Figure 1.- Model details. All linear dimensions are in inches.

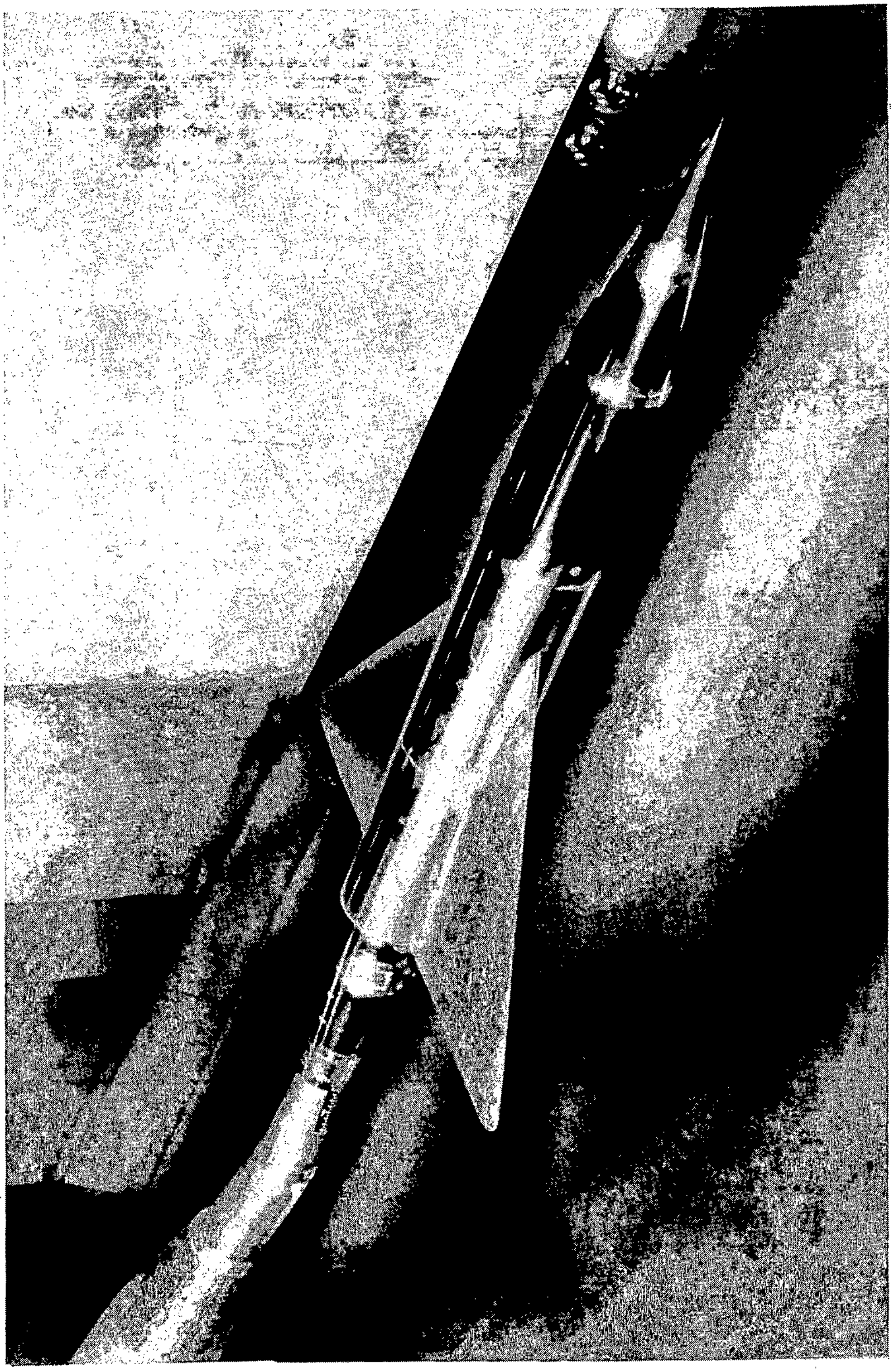

Figure 2.- Model in the Langley 16-foot transonic tunnel. L-88122.1

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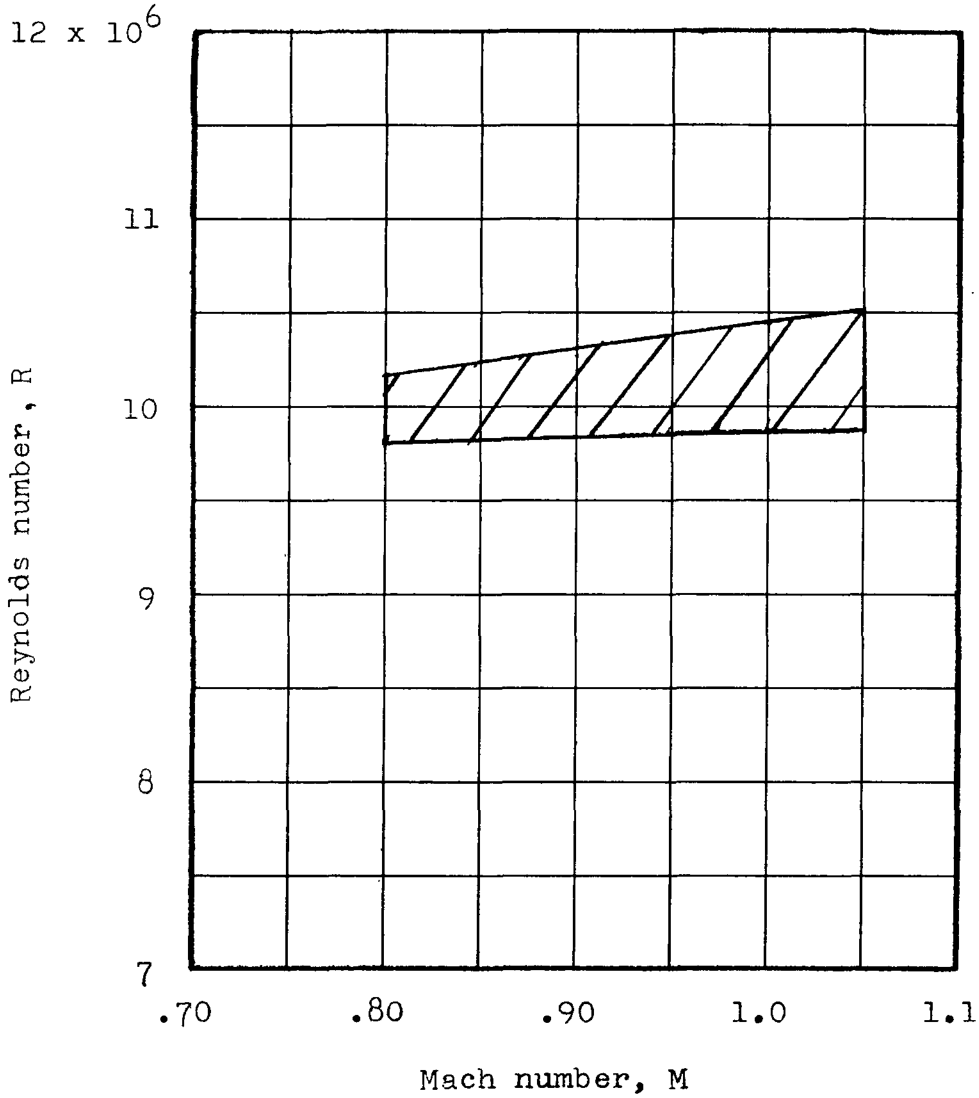


Figure 3.- The variation of the Reynolds number (based on the mean aerodynamic chord length) with Mach number in the Langley 16-foot transonic tunnel.

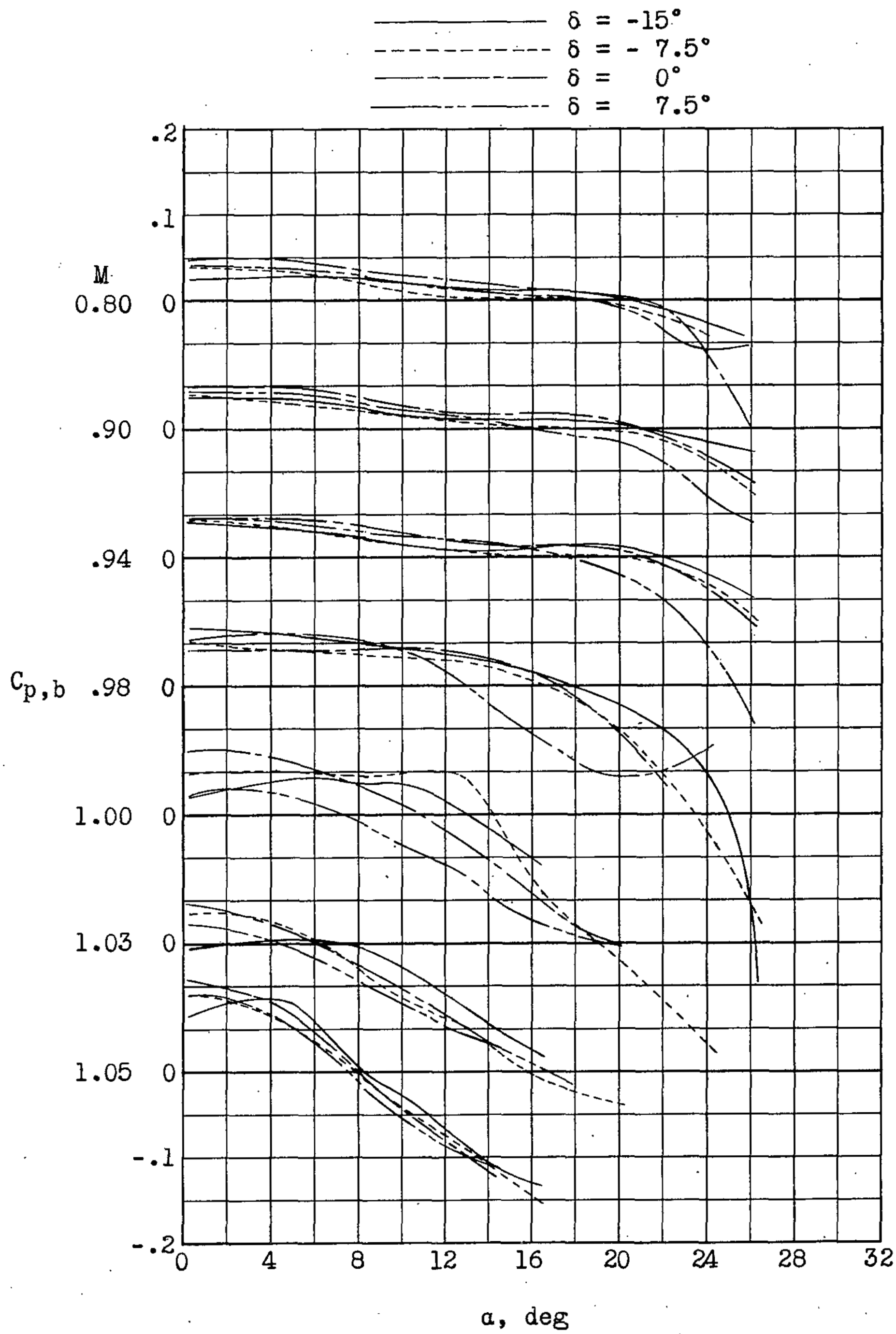


Figure 4.- Variation with angle of attack of base-pressure coefficients for wing with flaps at several deflection angles for various Mach numbers.

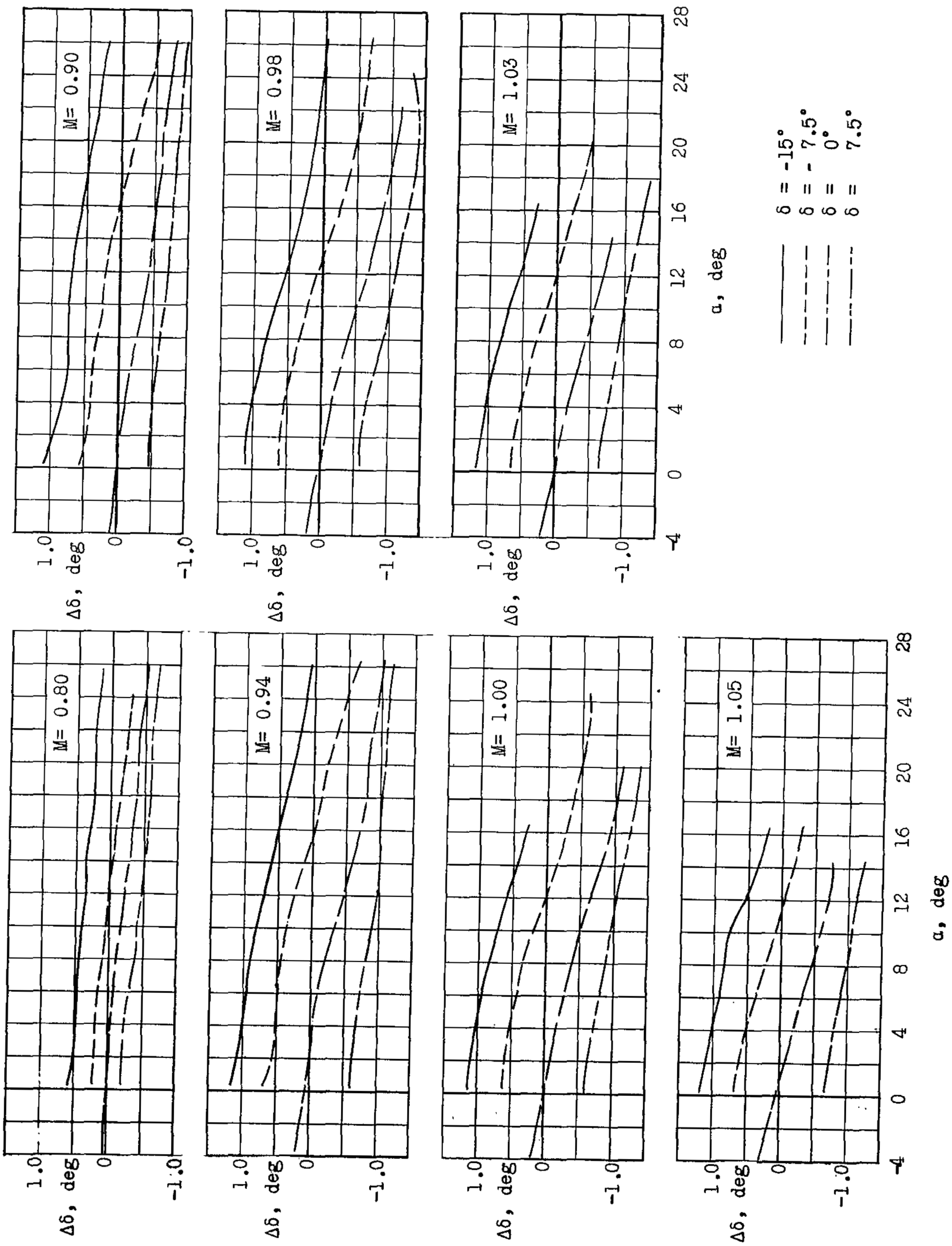
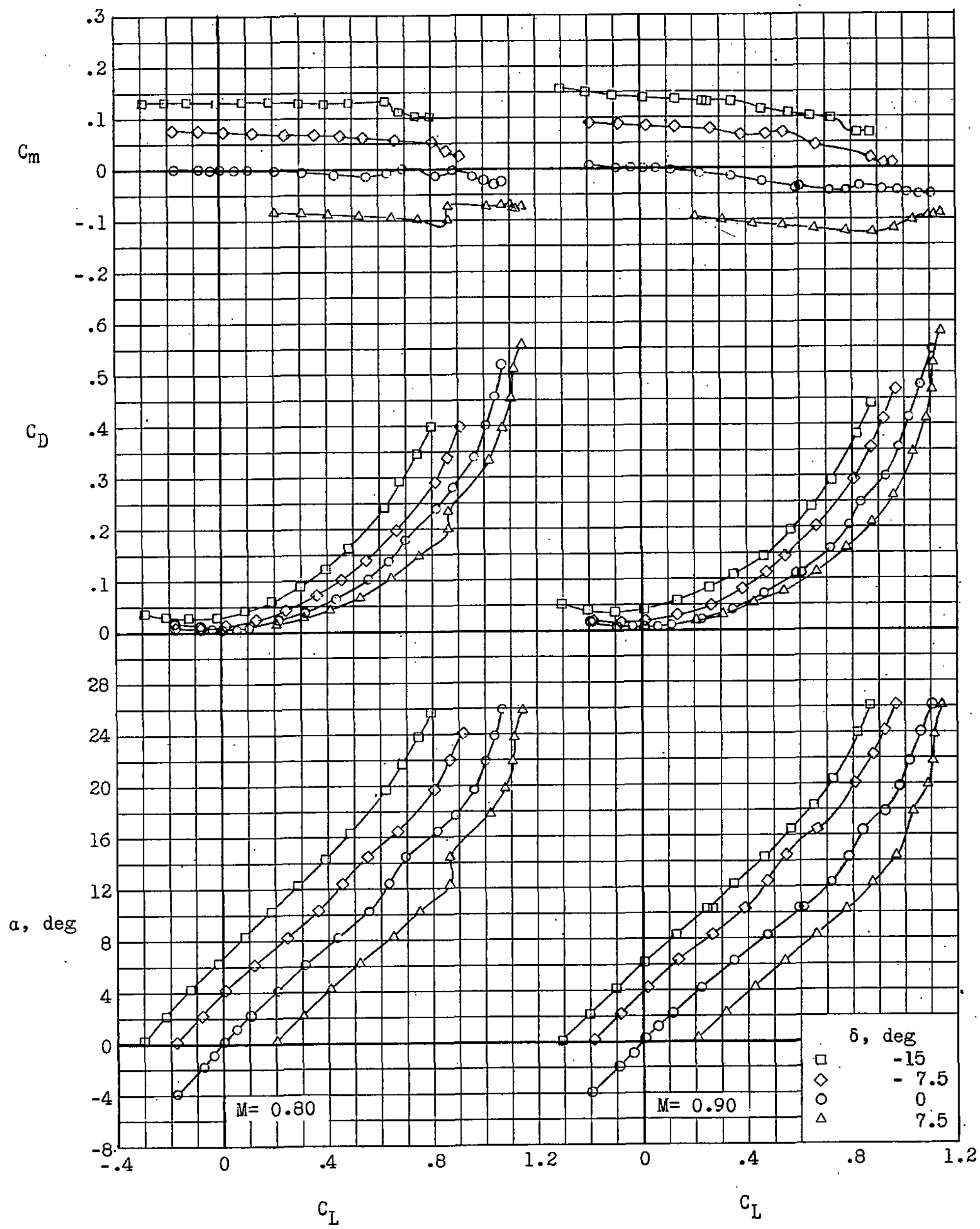
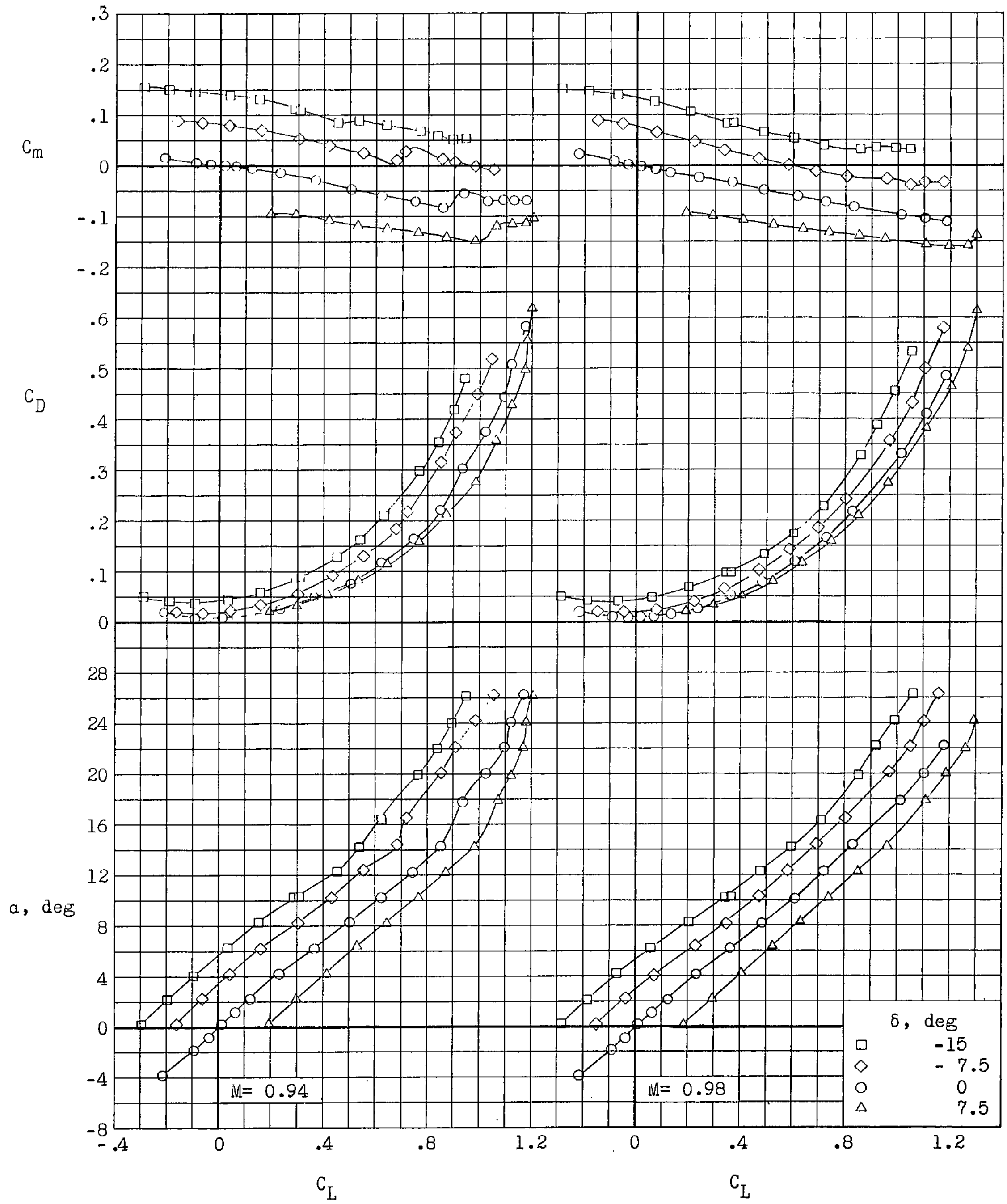


Figure 5.- Variation with angle of attack of deviation of elevon deflection angle from nominal settings for each test Mach number.



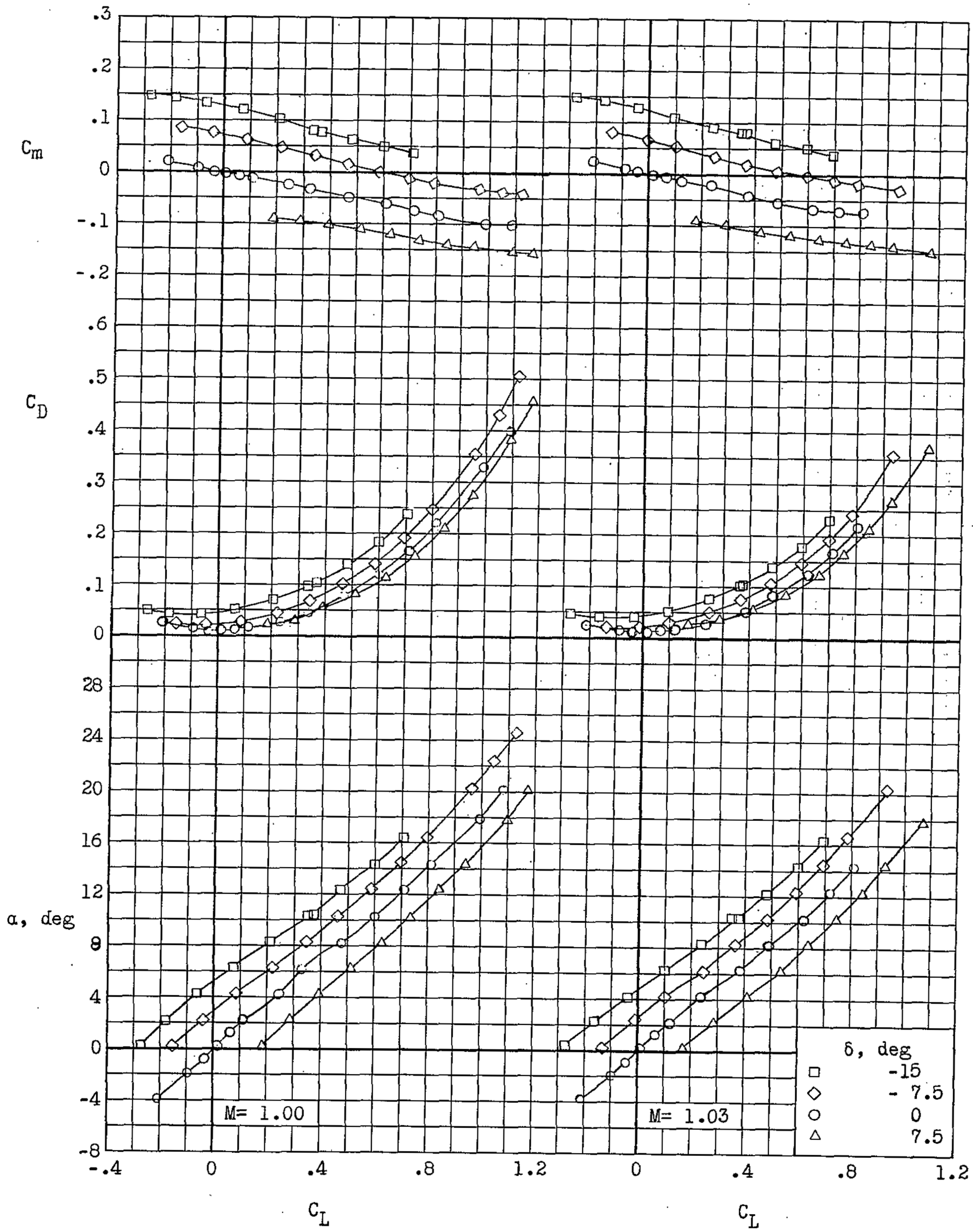
(a) M = 0.80 and 0.90.

Figure 6.- Longitudinal aerodynamic characteristics of basic tail-off model with all control surfaces at nominal deflections of -15°, -7.5°, 0°, and 7.5°. Data uncorrected for control-surface deflection due to load.



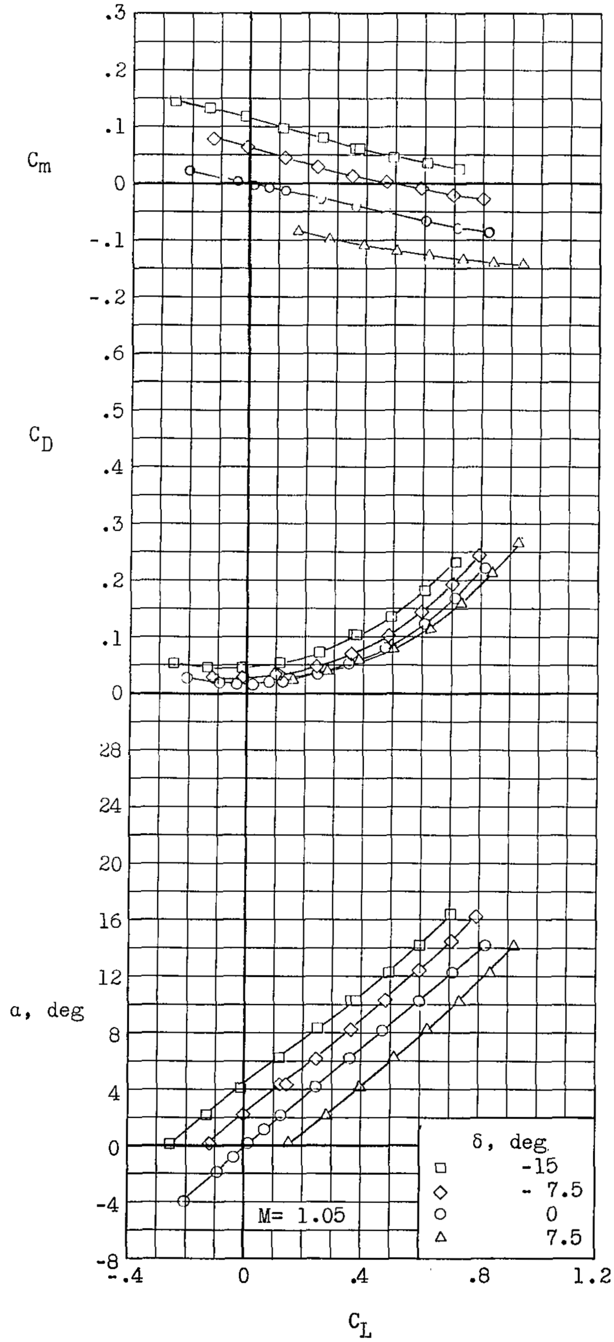
(b) M = 0.94 and 0.98.

Figure 6.- Continued.



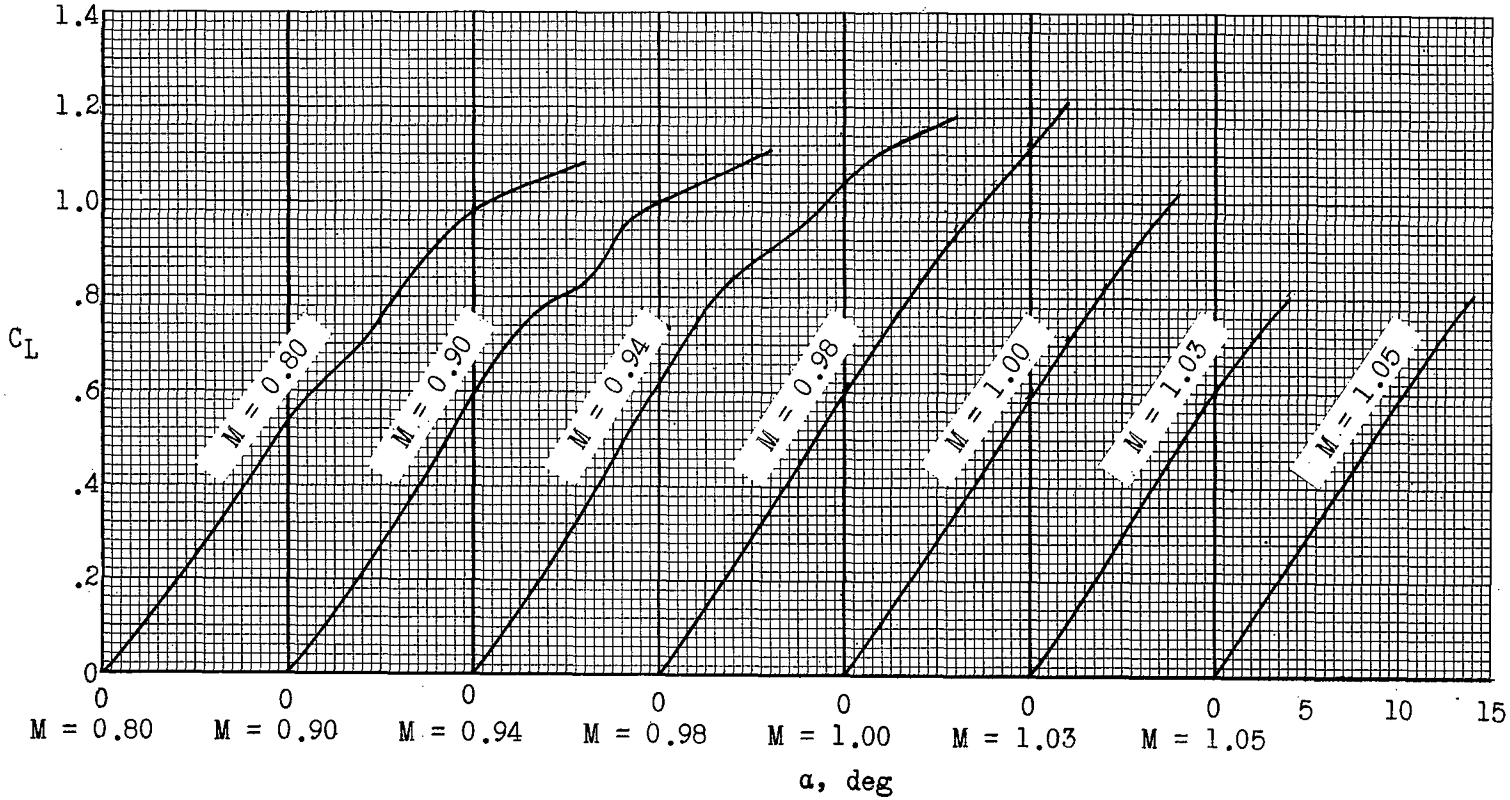
(c) M = 1.00 and 1.03.

Figure 6.- Continued.



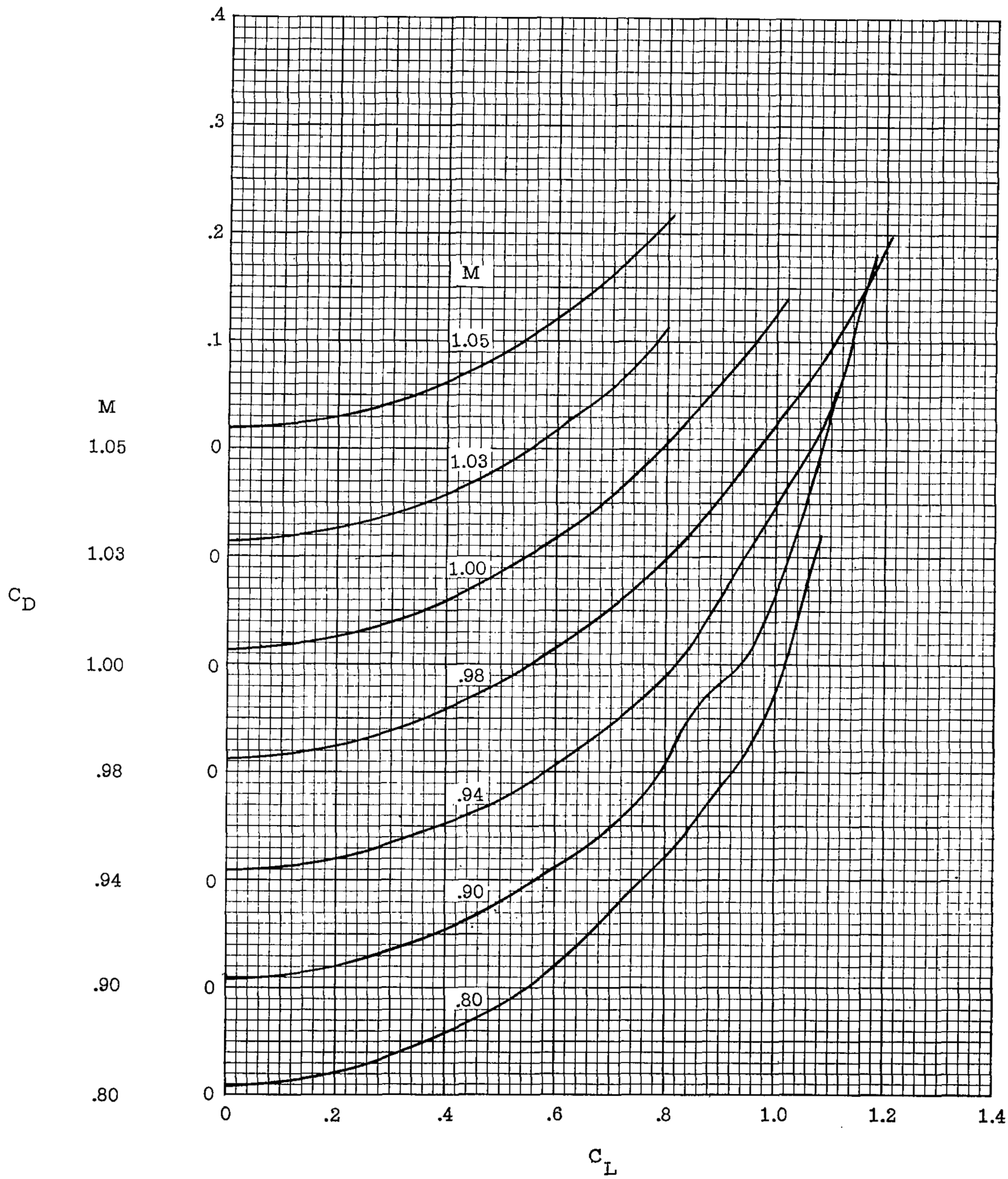
(d) M = 1.05.

Figure 6.- Concluded.



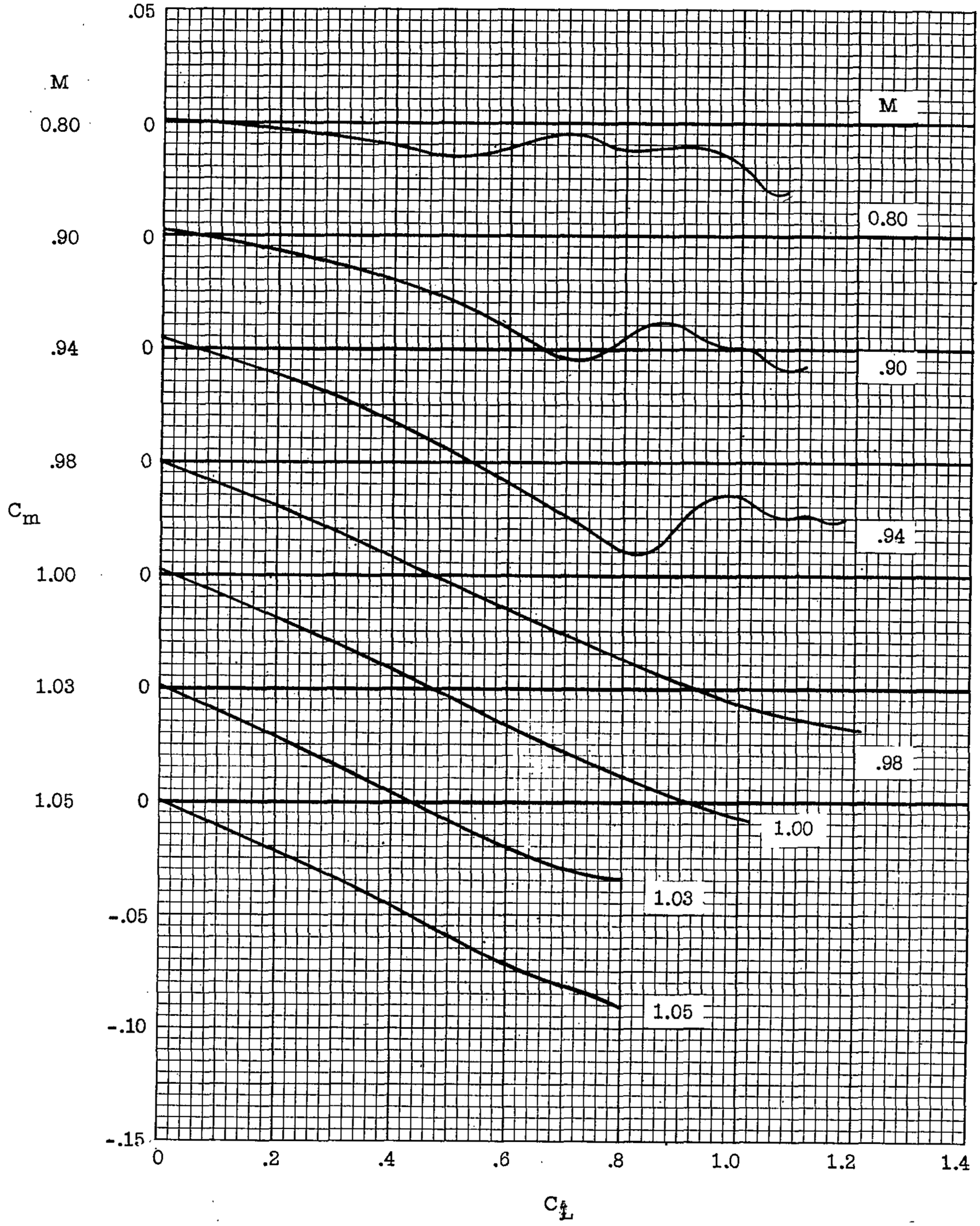
(a) The variation of C_L with α.

Figure 7.- Longitudinal aerodynamic characteristics of basic tail-off model with all controls at 0° deflection. Data corrected for control deflection due to load.



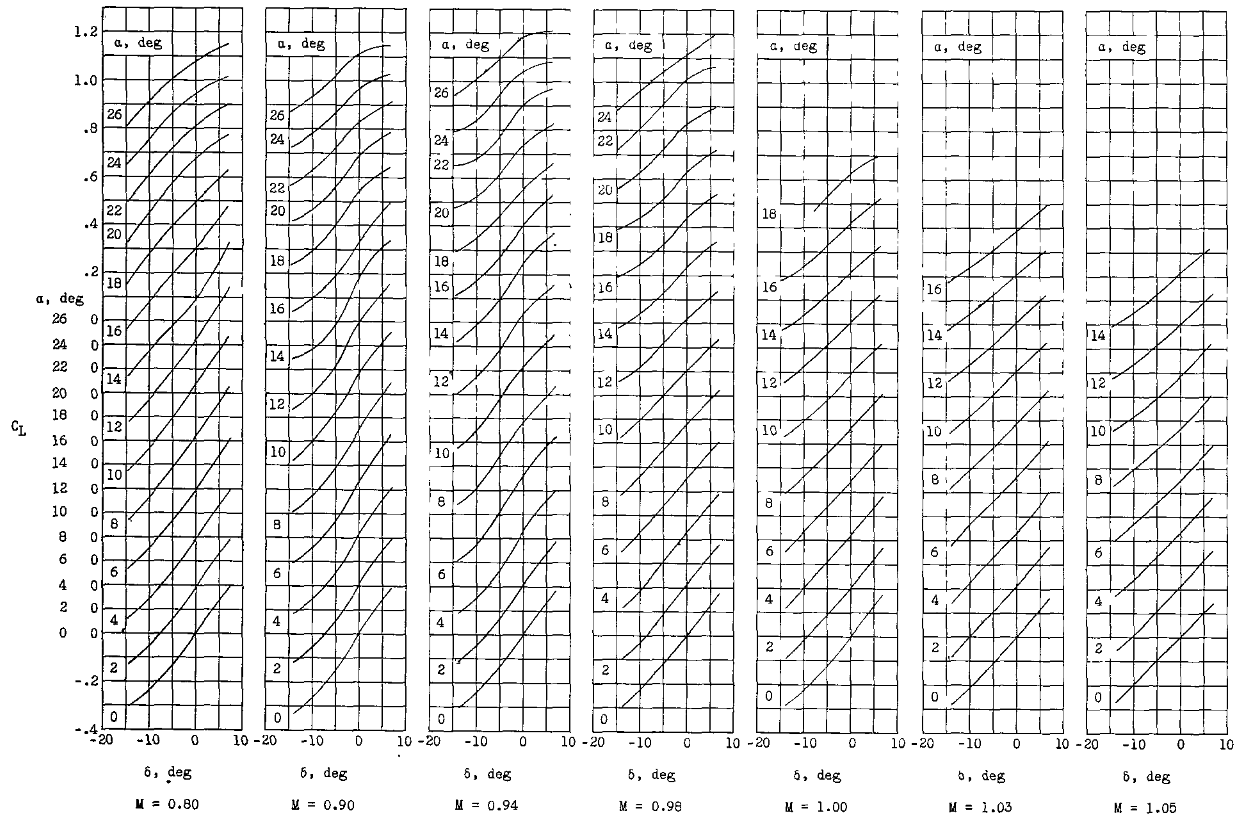
(b) The variation of C_D with C_L.

Figure 7.- Continued.



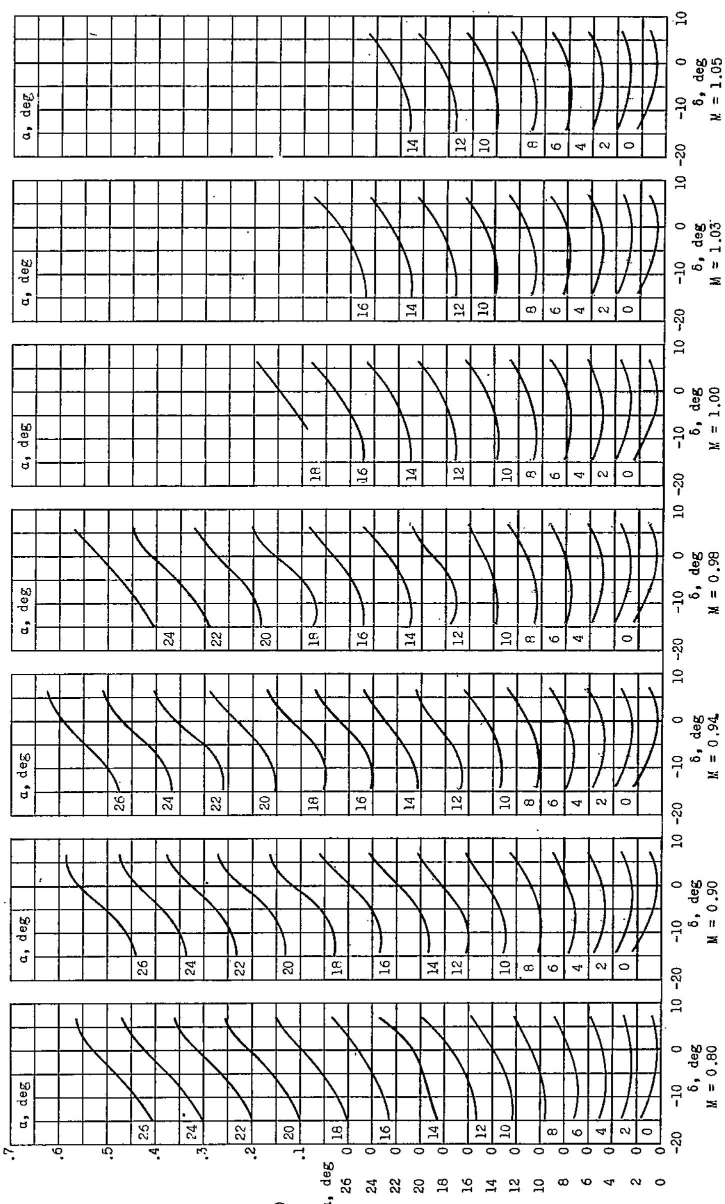
(c) The variation of C_m with C_L.

Figure 7.- Concluded.



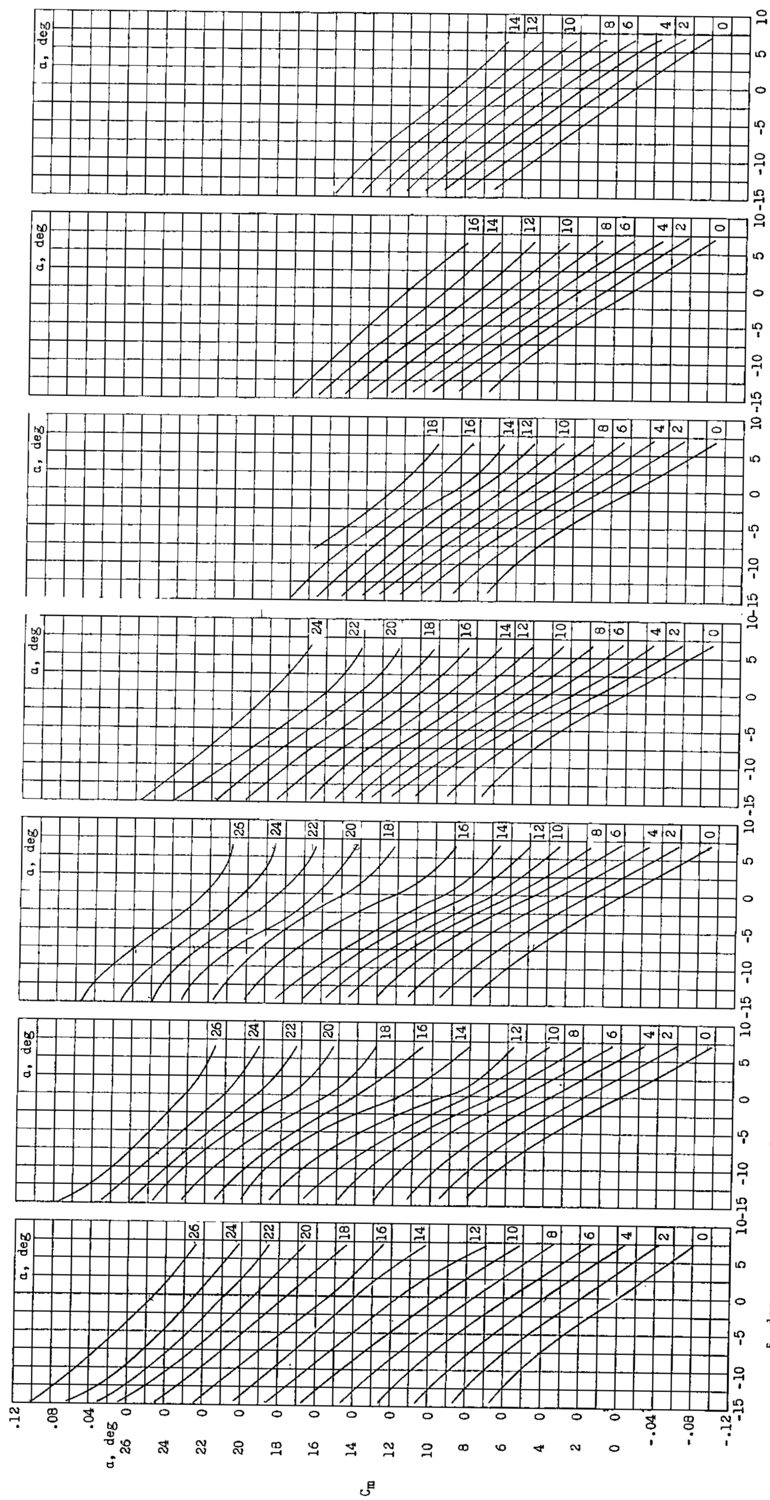
(a) The variation of C_L with δ.

Figure 8.- Variation of longitudinal aerodynamic characteristics with control deflection at various Mach numbers.



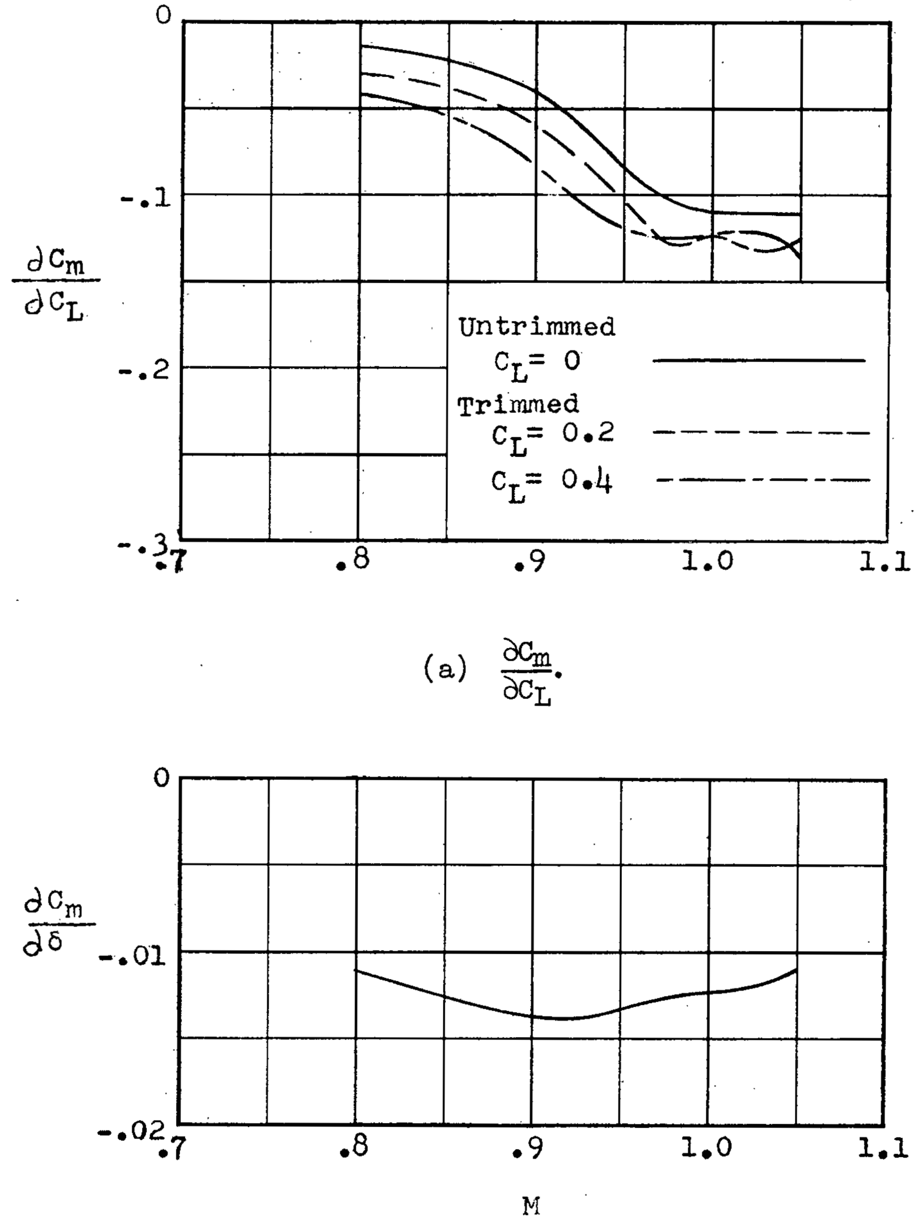
(b) The variation of C_D with δ.

Figure 8.- Continued.



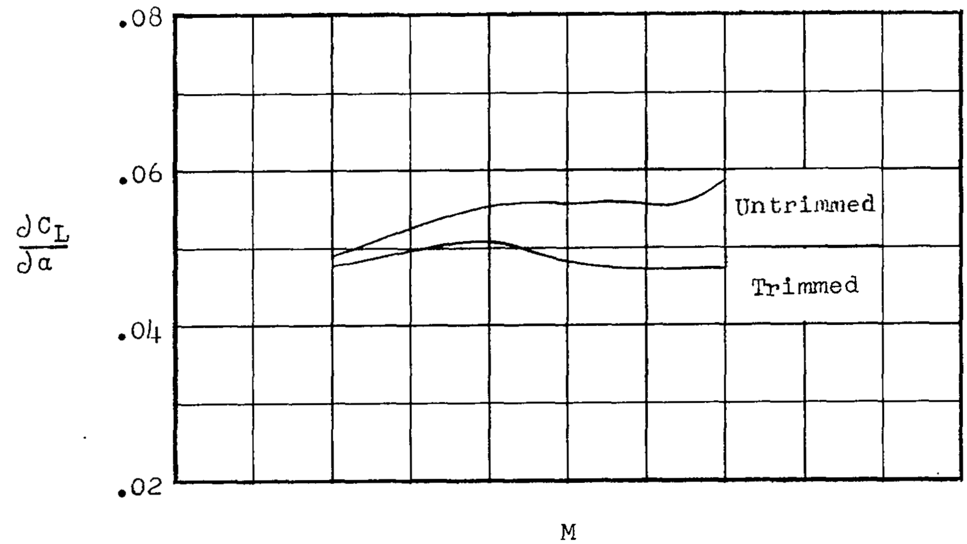
(c) The variation of C_m with δ.

Figure 8.- Concluded.

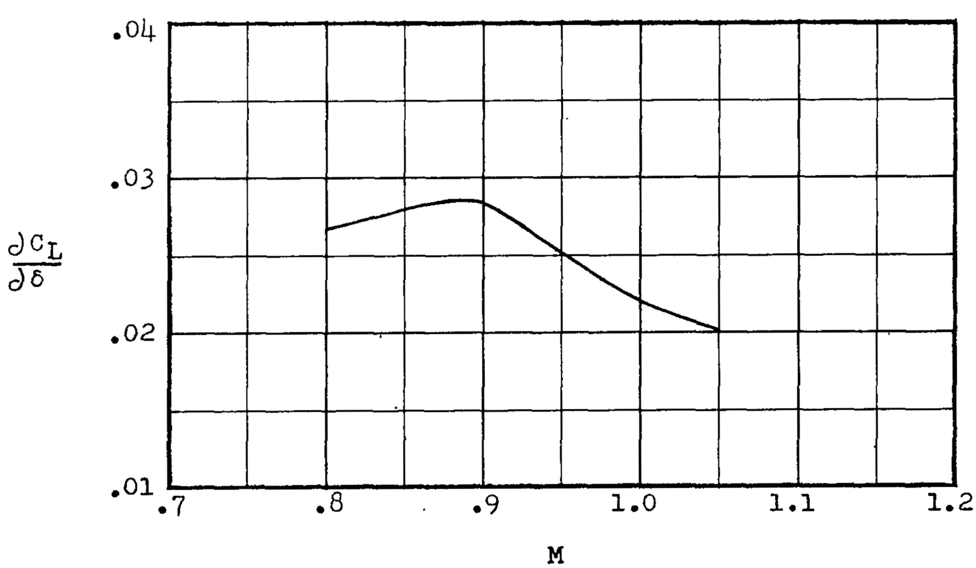


(b) $\frac{\partial C_m}{\partial \delta}$.

Figure 9.- Variation with Mach number of untrimmed and trimmed static longitudinal stability parameter at several lift coefficients and elevator pitch effectiveness parameter.



(a) $\frac{\partial C_L}{\partial \alpha}$.



(b) $\frac{\partial C_L}{\partial \delta}$.

Figure 10.- Variation with Mach number of lift-curve slope and elevator lift effectiveness parameter.

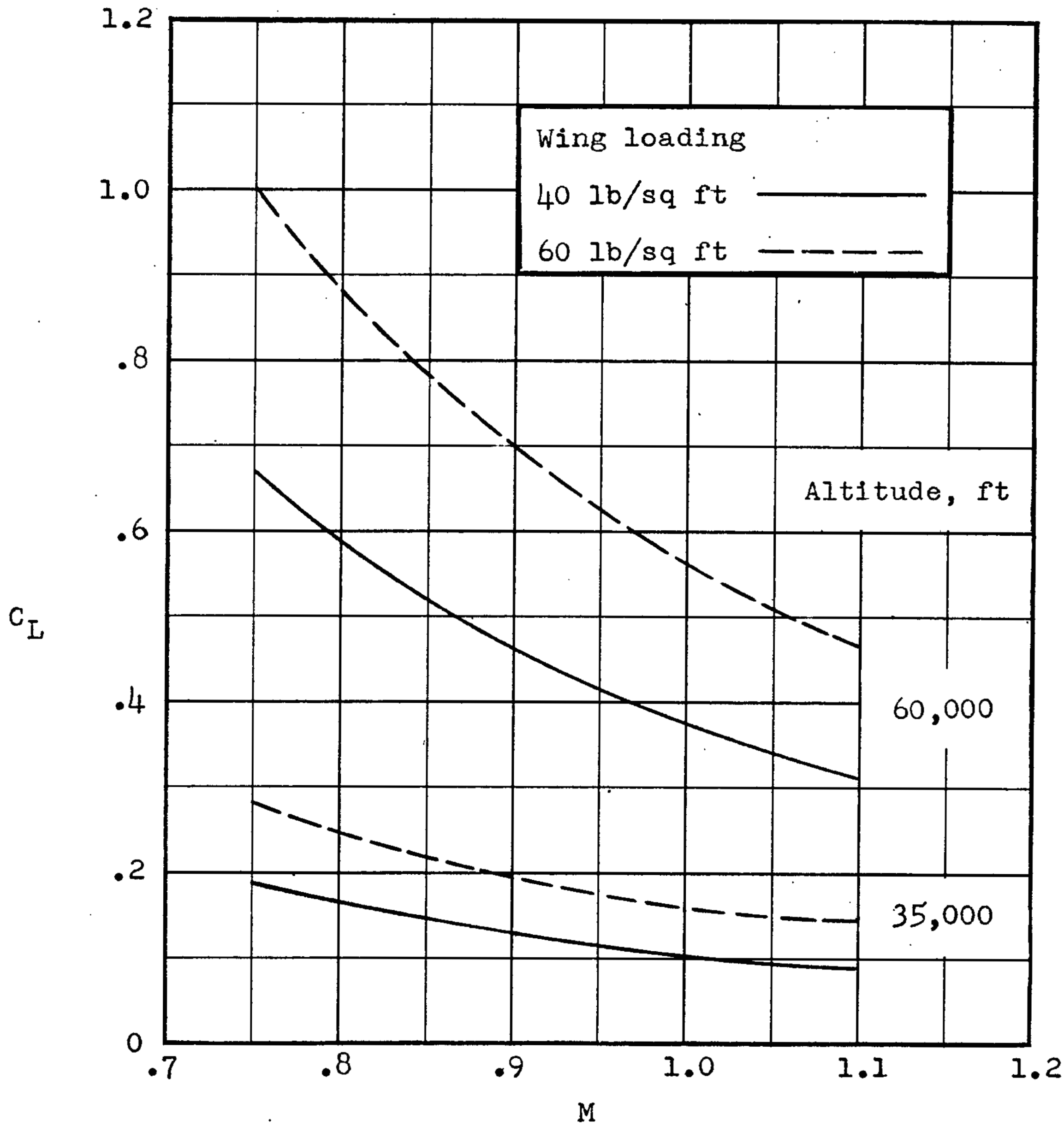


Figure 11.- Variation with Mach number of lift coefficient required for level flight at two altitudes for wing loadings of 40 and 60 pounds per square foot.

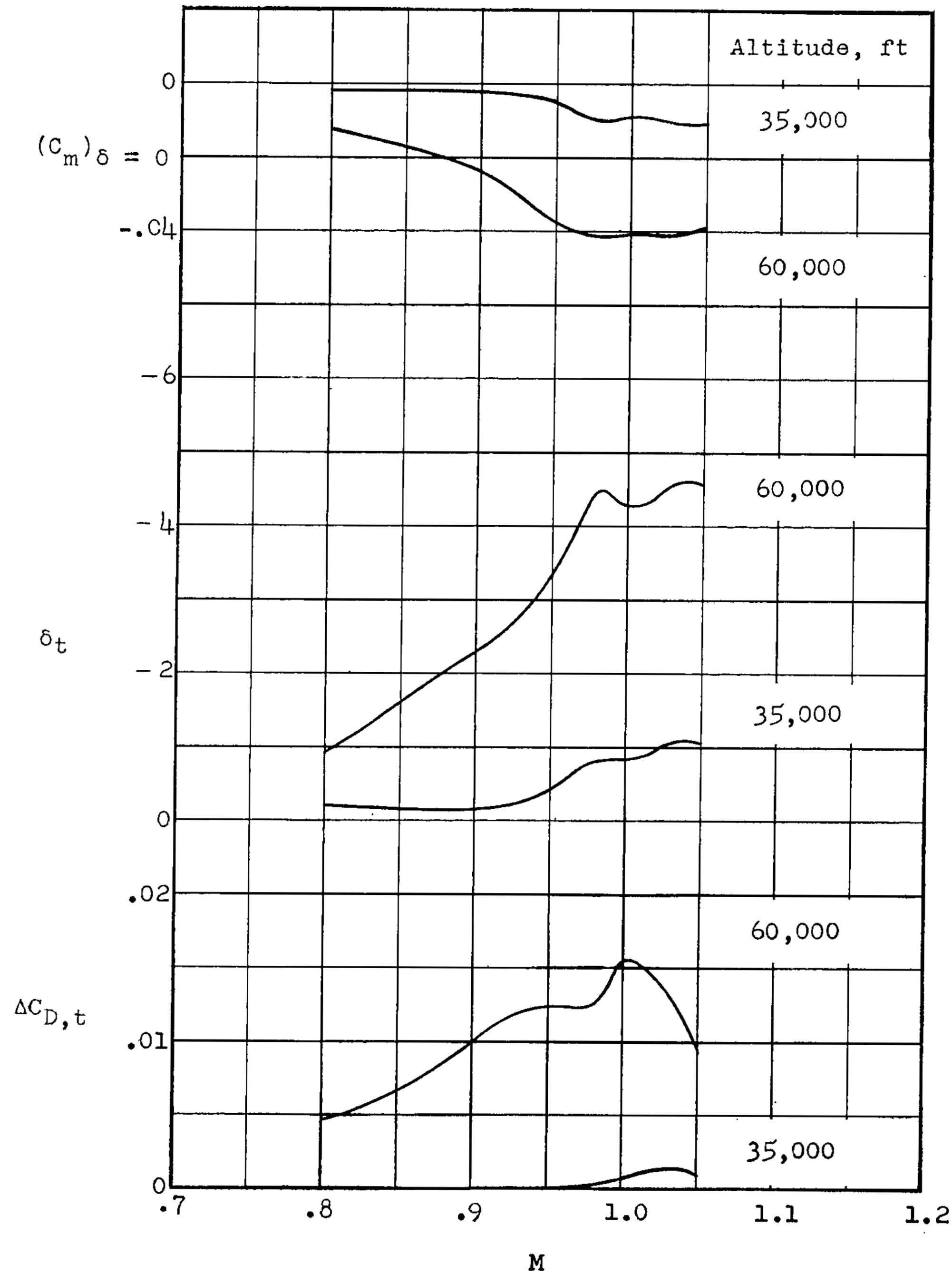


Figure 12.- Variation with Mach number of untrimmed pitching moment at lift coefficients required for level flight, flap deflection required for trim, and trim-drag penalty at two altitudes for wing loading of 40 pounds per square foot. (Center of gravity at $0.35\bar{c}$.)

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