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TECHNICAL NOTE

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THE LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF A SWEPTBACK WING-BODY COMBINATION WITH AND WITHOUT END PLATES AT MACH NUMBERS FROM 0.40 TO 0.93

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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THE LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF A SWEPTBACK WING-BODY COMBINATION WITH AND WITHOUT END PLATES AT MACH NUMBERS FROM 0.40 TO 0.93

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SUMMARY

An investigation was made at high subsonic speeds in the Langley high-speed 7- by 10-foot tunnel to determine the effect of end plates on the longitudinal aerodynamic characteristics of a sweptback wing-body combination with and without drooped chord-extensions. The wing had 45° sweepback of the quarter-chord line, an aspect ratio of 4, a taper ratio of 0.3, and NACA 65A006 airfoil sections parallel to the plane of symmetry, and was mounted near the rear of a body of revolution having a fineness ratio of approximately 8.

The results indicated that the addition of the end plates to either the wing with drooped chord-extensions or to the wing without drooped chord-extensions slightly increased the lift in the low angle-of-attack range but slightly decreased the lift at moderate and high angles of attack. The addition of the end plates to the wing without the chord-extensions caused a small increase in the maximum lift-drag ratio at Mach numbers below 0.65 and a slight decrease at the higher Mach numbers; however, for the addition of the end plates to the wing with the chord-extensions the maximum lift-drag ratio was slightly decreased below a Mach number of 0.88, while a slight increase occurred for the higher Mach numbers. The addition of the end plates to the wings with and without the chord-extensions caused the static longitudinal stability to increase considerably for all Mach numbers; however, only a slight reduction in the aerodynamic-center variation with Mach number was observed.

INTRODUCTION

Extensive research on the use of end plates to increase the effective aspect ratio of wings has been done in the past. (See refs. 1 to 11, for example.) In general, the results of these studies have indicated that although the effective aspect ratio could be increased considerably the profile drag of the end plates offset the reduced drag due to lift at low lift coefficients, and reductions in the overall drag were sometimes delayed until the lift coefficient corresponding to maximum lift-drag ratio was exceeded. Because of these results, end plates have seen little service on aircraft in the past. In recent years, however, interest in end plates has been renewed, especially in connection with sweptback wings where sufficient moment arm can be obtained so that the end plates can act as vertical tails. Utilization of end plates as vertical tails would have several beneficial effects. For example the overall drag penalty would probably not be as great as when the end plates are used in addition to a vertical tail. Also, the vertical surfaces would be removed from the adverse flow field induced by the fuselage forebody vortices. The possibility of favorable wave-drag interference at supersonic speeds has also been a consideration.

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Previous investigations of end plates on sweptback wings (refs. 6 to 11) were made with wings not equipped with the flow control devices (wing fixes) usually needed to provide satisfactory static longitudinal stability characteristics. However, the effect of end plates on the longitudinal stability and possibly on the drag due to lift of sweptback wings would be expected to be dependent upon the flow condition encountered in the tip region of the wing. It would appear, therefore, that the information available might not be entirely applicable to sweptback wings utilizing flow control devices such as fences, chord-extensions, or nose flaps. In view of this lack of information, a brief study of the effect of end plates on the longitudinal aerodynamic characteristics of a sweptback-wing configuration, both with and without drooped chord-extensions was made in the Langley high-speed 7- by 10-foot tunnel. The wing, which was of 6-percent-chord thickness, had an aspect ratio of 4, 45° sweepback of the quarter-chord line, and was mounted near the rear of a body of revolution having a fineness ratio of approximately 8. The tests were made at Mach numbers from 0.40 to 0.93.

SYMBOLS

The forces and moments measured on the model are presented about the wind axis (see following sketch) with the moment reference center in the plane of symmetry at a longitudinal position corresponding to the projection of the quarter-chord point of the wing mean aerodynamic chord.

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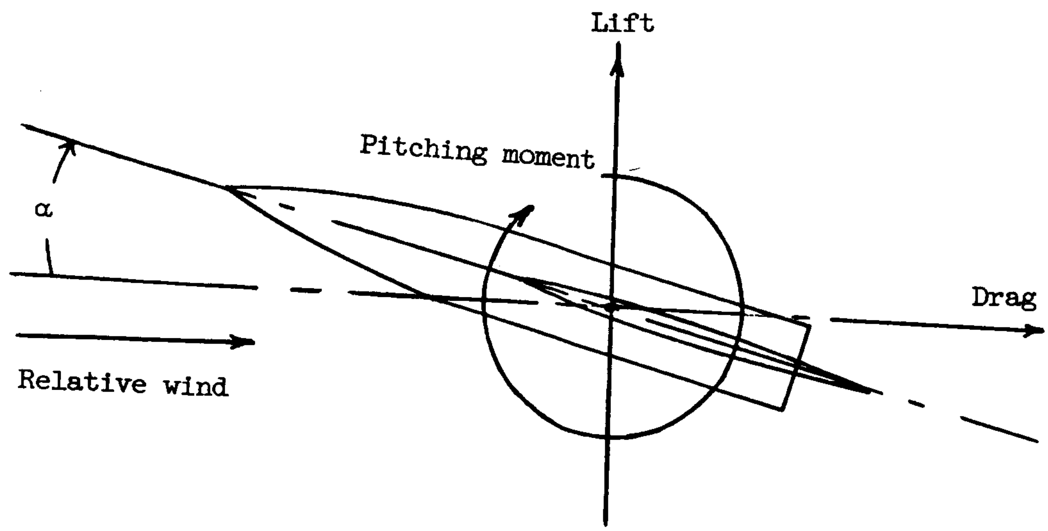

All coefficients presented herein are based on the plan form of the wing without drooped chord-extensions and end plates.

b — wing span, 3.042 ft

C_D — drag coefficient, $\frac{\text{Drag}}{qS}$

$(C_D)_{C_L=0}$ — drag coefficient at zero lift

$\frac{\partial C_D}{\partial C_L^2}$ — induced drag parameter, measured between $C_L = 0$ and $C_L = 0.2$

C_L — lift coefficient, $\frac{\text{Lift}}{qS}$

C_{L_α} — lift-curve slope, measured through zero angle of attack

C_m — pitching-moment coefficient, $\frac{\text{Pitching moment}}{qS\bar{c}}$

$C_{m_{C_L}}$ — longitudinal-stability parameter, measured between $C_L = -0.10$ and $C_L = +0.10$

c — local chord, ft

$\bar{c}$	mean aerodynamic chord, 0.823 ft
L/D	lift-drag ratio
$(L/D)_{max}$	maximum lift-drag ratio
M	Mach number
q	dynamic pressure, $\frac{1}{2}\rho V^2$, lb/sq ft
R	Reynolds number based on $\bar{c}$
S	wing area, sq ft
V	velocity, ft/sec
α	angle of attack of fuselage center line, deg
ρ	density, lb/cu ft

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MODEL AND APPARATUS

A drawing of the sweptback wing-body model with the end plates and drooped chord-extensions is shown in figure 1, and a photograph of the model mounted in the tunnel is shown in figure 2.

The wing was constructed of solid aluminum alloy; it had 45° sweepback of the quarter-chord line, an aspect ratio of 4, a taper ratio of 0.3, and NACA 65A006 airfoil sections parallel to the plane of symmetry, and was mounted near the rear of a body of revolution having a fineness ratio of approximately 8.

The end plates were constructed, to the dimensions shown in figure 1, of 1/4-inch aluminum alloy with rounded leading edge and beveled trailing edge.

The partial-span chord-extensions (outboard of 0.63b/2 to the wingtip) were of constant chord (approximately $0.10\bar{c}$) with a 6° leading-edge droop.

TEST AND CORRECTIONS

The investigation was made in the Langley high-speed 7- by 10-foot tunnel. Lift, drag, and pitching moment were measured throughout a Mach number range of 0.40 to 0.93. The angle-of-attack range varied from -2° to approximately 24° at the lower Mach numbers and from -2° to about 9° at $M = 0.93$. The angle of attack at the higher Mach numbers was limited by tunnel choking conditions. The variation of mean test Reynolds number (based on $\bar{c}$) with Mach number is presented in figure 3.

Blockage corrections were determined by the method of reference 12 and were applied to the dynamic pressure and Mach number. Jet-boundary corrections, applied to the angle of attack and drag, were calculated by the method of reference 13. The angle of attack has been corrected for deflection of the sting-support system under load and the drag data have been corrected to correspond to a pressure at the base of the fuselage equal to free-stream static pressure.

RESULTS AND DISCUSSION

Presentation of Results

The basic data, with and without end plates, is presented in figure 4 for the basic wing (without chord-extensions) and in figure 5 for the wing with the chord-extension. A summary of the longitudinal aerodynamic characteristics at low angles of attack is presented as a function of Mach number in figure 6 for the basic wing and for the wing with the chord-extensions in figure 7.

Discussion

This discussion is limited to the effect of the end plates; a discussion of the effect of chord-extensions is presented in reference 14.

Lift characteristics.- The addition of end plates to either the wing without chord-extensions or to the wing with chord-extensions slightly increased the lift at low angles of attack (figs. 4(a) and 5(a)) as a result of the increase in the effective aspect ratio of the wing associated with the end plates. At moderate and high angles of attack, however, the lift was slightly decreased by the addition of the end plates. This decrease is probably due to an earlier occurrence of tip stalling associated with the higher effective angle of attack at the wingtip resulting from the presence of the end plate. With the chord-extensions on, this decrease in lift due to the end plates was delayed to higher angles of attack at the lower Mach numbers. The variation of the lift-curve slope with Mach number is presented in figures 6 and 7; the results indicate that the end plates increased the lift-curve slope by about 10 percent with chord-extensions off and by approximately 15 percent with chord-extensions on. These increases appear to be relatively independent of the Mach number for the range of the investigation.

Drag characteristics.- The drag coefficient for a given lift coefficient was increased by the addition of the end plates to the wings, except in the intermediate lift-coefficient range (figs. 4(b) and 5(b)) where the reduction in the induced drag resulting from the increase in the effective aspect ratio of the wing exceeded the drag of the end plates. The increase in the drag at zero lift due to the addition of the end plates can best be seen in figures 6 and 7 where the drag at zero lift is presented as a function of Mach number. The results indicate that the end plates increased the drag at zero lift by approximately 27 percent for the wing with chord-extensions and by about 17 percent for the wing without chord-extensions. Since the end plates will contribute to the directional stability, their drag penalty may be offset by the elimination of a conventional vertical tail and its associated drag.

The addition of the end plates caused a decrease in the induced drag parameter for both the basic wing and the wing with the chord-extensions throughout the Mach number range (figs. 6 and 7). This decrease is due to the increase in effective aspect ratio of the wing resulting from the end plates.

The overall effect of end plates on the lift and drag is reflected in the variation of $(L/D)_{max}$ with Mach number as shown in figures 6 and 7. The addition of end plates to the basic wing caused a small increase in the maximum lift-drag ratio for Mach numbers below 0.65 and a slight decrease for the higher Mach numbers. However, for the addition of the end plates to the wing with the chord-extensions a slight decrease in maximum lift-drag ratio resulted below a Mach number of 0.88 while a slight increase occurred for the higher Mach numbers. At lift coefficients slightly below the lift coefficient for maximum lift-drag ratio greater losses in the lift-drag ratios due to the end plates are indicated for the wing with chord-extensions (fig. 5(d)).

Pitching-moment characteristics.- In general, the addition of the end plates resulted in an increase in the longitudinal stability below an angle of attack of about 5°, both with the chord-extensions on and off. The increase in longitudinal stability is due to an outboard and rearward shift of the center of pressure caused by the increase in load on the wingtip associated with the addition of the end plates. For the basic wing (fig. 4(c)) the addition of the end plates resulted in a somewhat earlier pitchup as might be expected due to the increased effective angle of attack at the wingtip associated with the addition of the end plates. While this is also true for the wing with chord-extensions (fig. 5(c)) the pitchup is not as severe as for the basic wing. The variation of the longitudinal stability with Mach number is shown in figures 6 and 7 and it will be noted that slightly less rearward shift of the aerodynamic center with Mach number is indicated with the end plates on.

CONCLUDING REMARKS

An investigation was made at high subsonic speeds in the Langley high-speed 7- by 10-foot tunnel to determine the effects of end plates on the longitudinal aerodynamic characteristics of a sweptback wing-body combination with and without drooped chord-extensions. The addition of the end plates to the wings with and without chord-extensions indicated the following effects:

1. The lift was increased slightly in the low angle-of-attack range but decreased slightly in the moderate and high angle-of-attack range.

2. The drag coefficient for a given lift coefficient was increased except in the intermediate lift-coefficient range. The induced drag was decreased throughout the Mach number range.

3. The maximum lift-drag ratio was slightly increased at Mach numbers below 0.65 and slightly decreased at the higher Mach numbers for the wing without the chord-extensions, however, for the wing with the chord-extensions the maximum lift-drag ratio was slightly decreased below a Mach number of 0.88 while a slight increase occurred for the higher Mach numbers.

4. The longitudinal stability was increased considerably for all Mach numbers, however, only a slight reduction in the aerodynamic-center variation with Mach number was observed.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., February 26, 1960.

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Basic Wing Physical Characteristics

Span, ft	3.042
Mean aerodynamic chord, ft	.823
Area, sq ft	2.25
Aspect ratio	4.0
Taper ratio	0.30
Airfoil section	NACA 65A006
Sweep 25c	45°

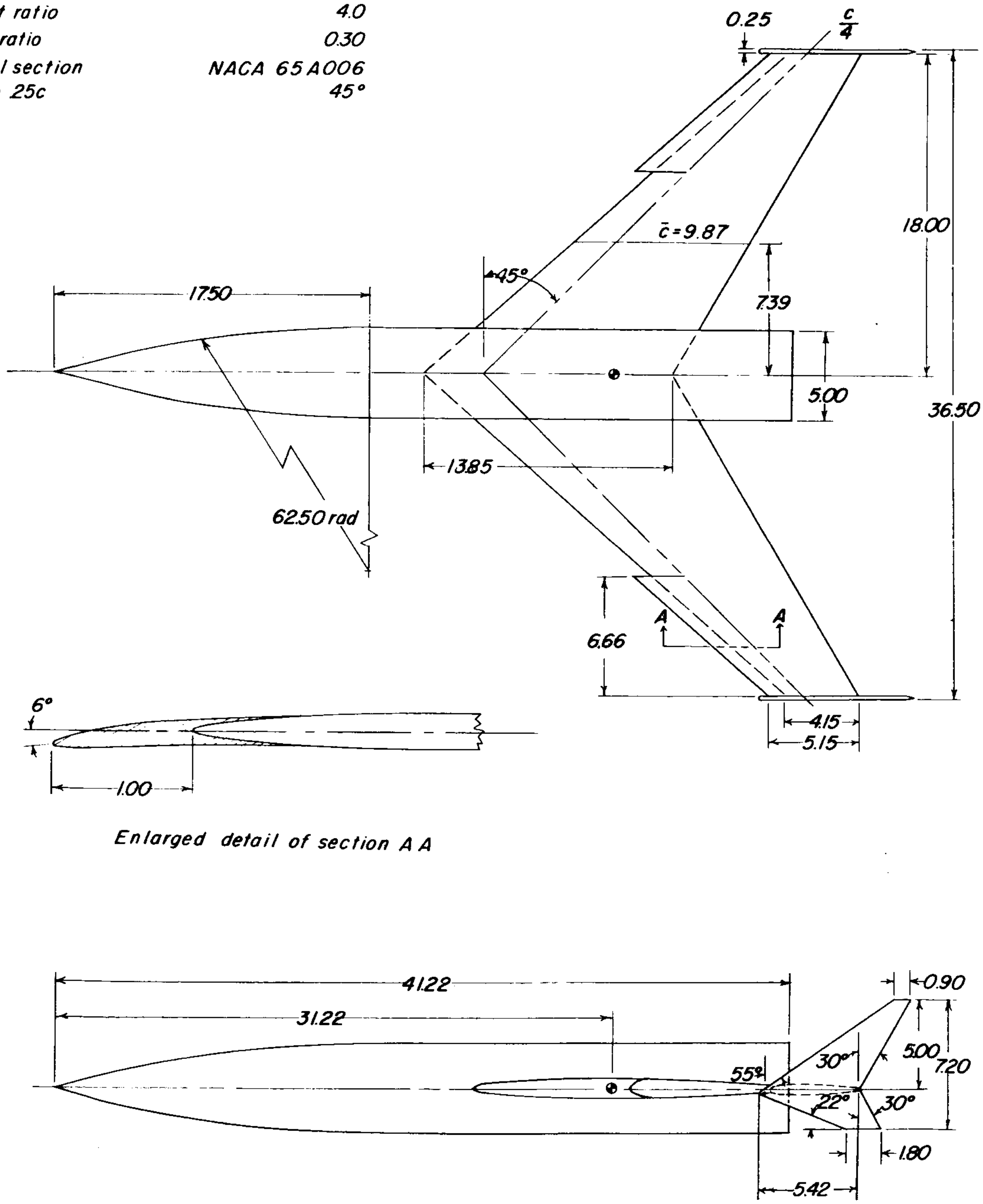

Figure 1.- Drawing of model. All dimensions in inches.

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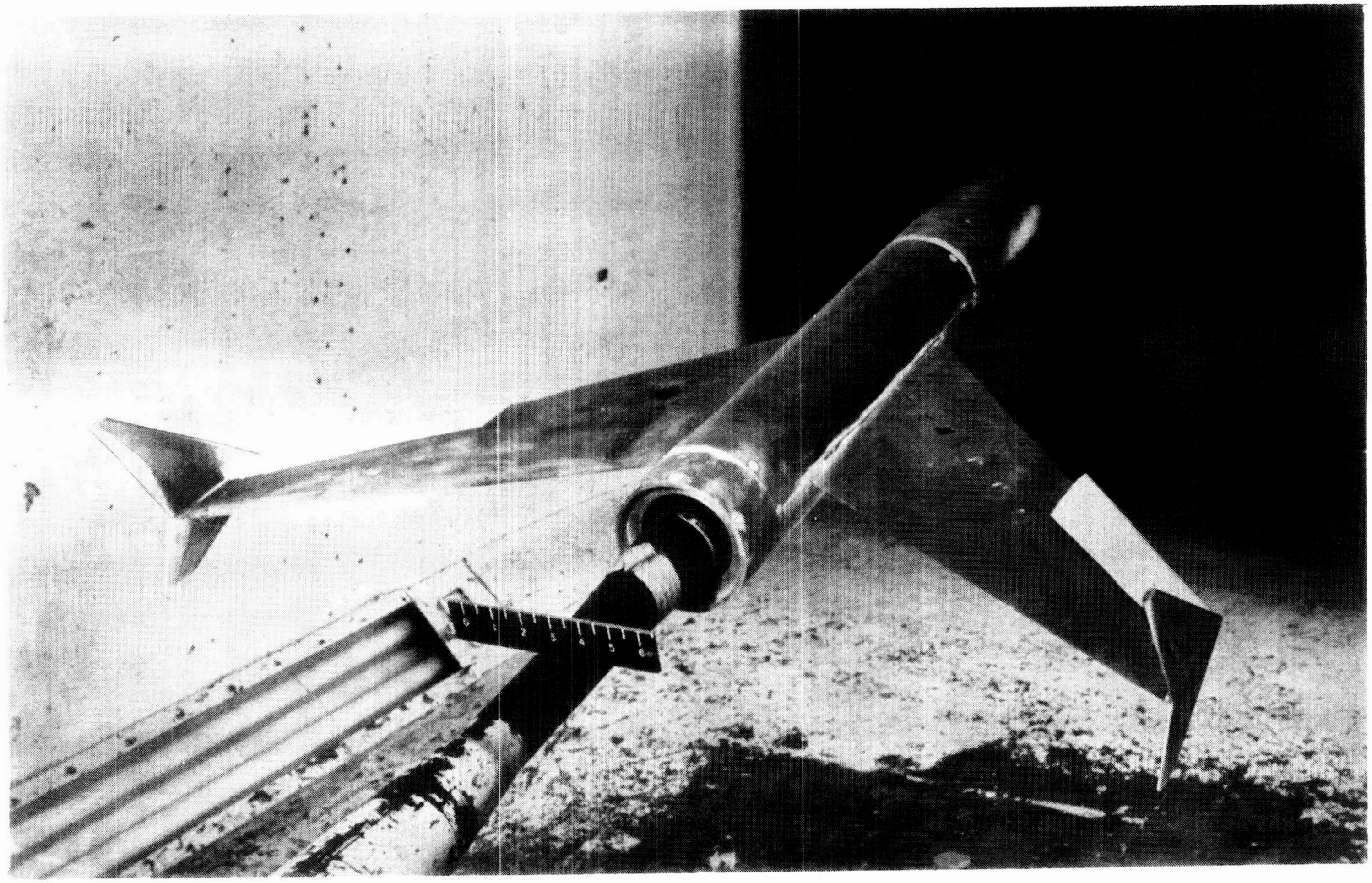

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Figure 2.- Photograph of model mounted in Langley high-speed 7- by 10-foot tunnel.

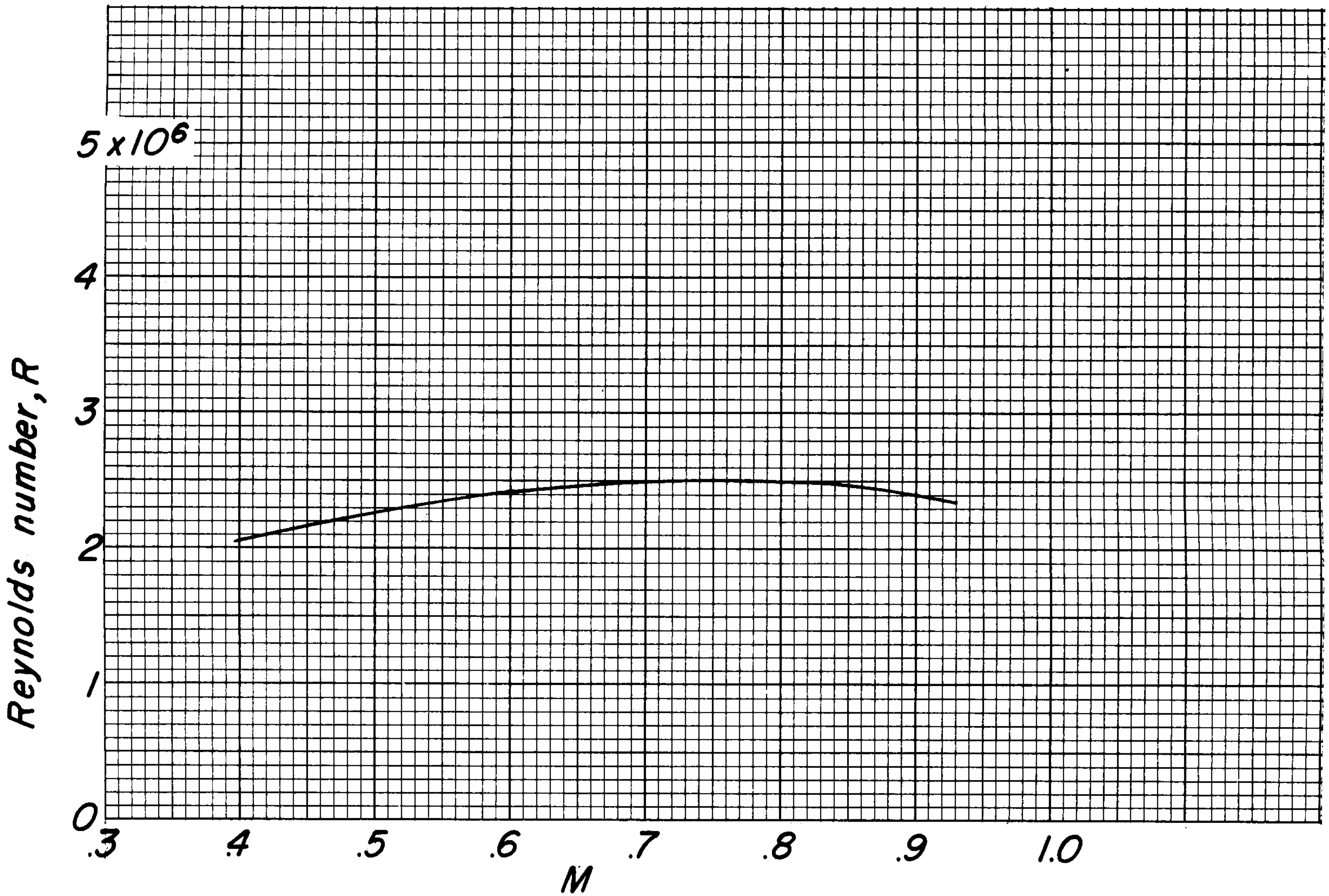
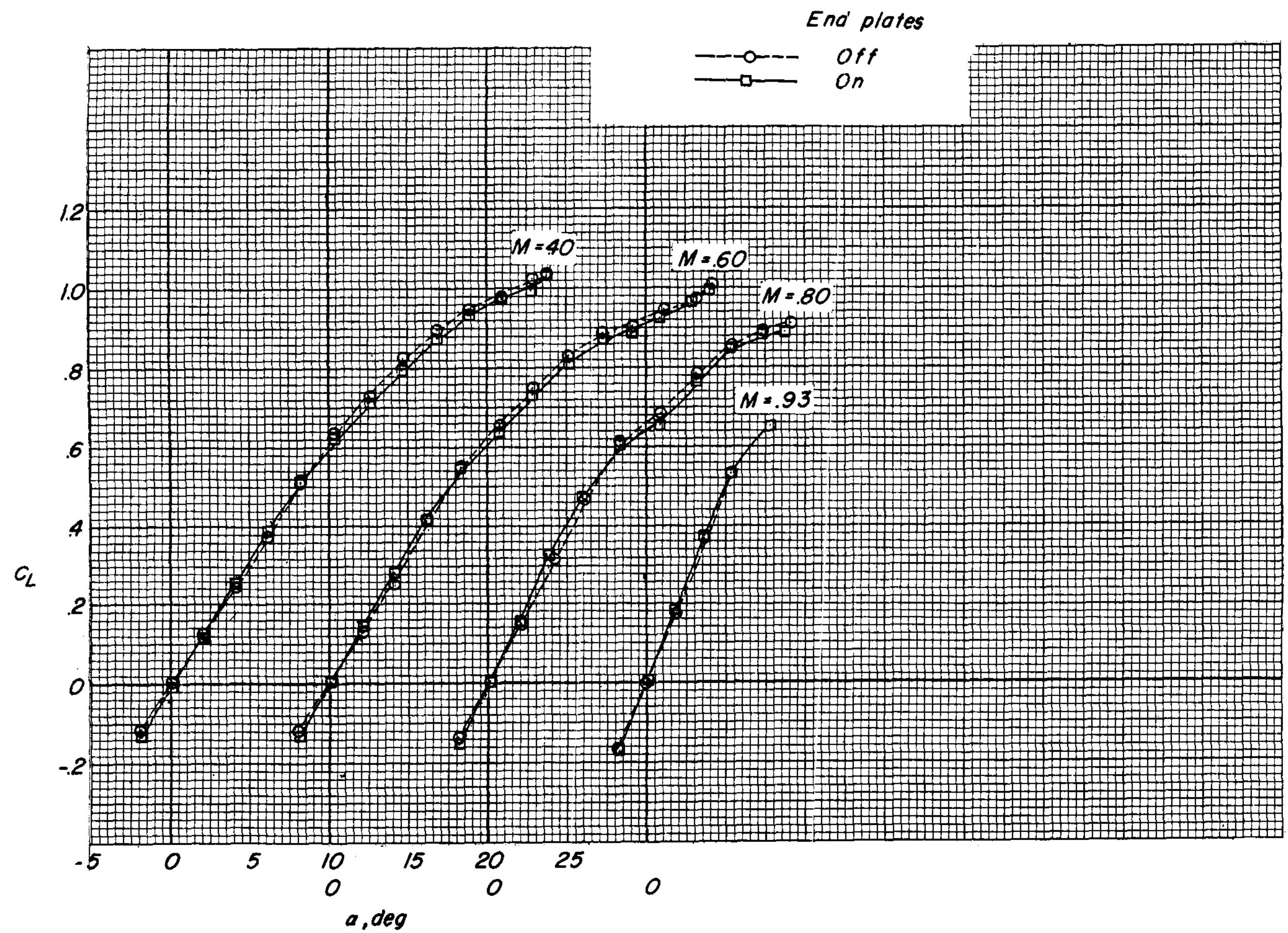
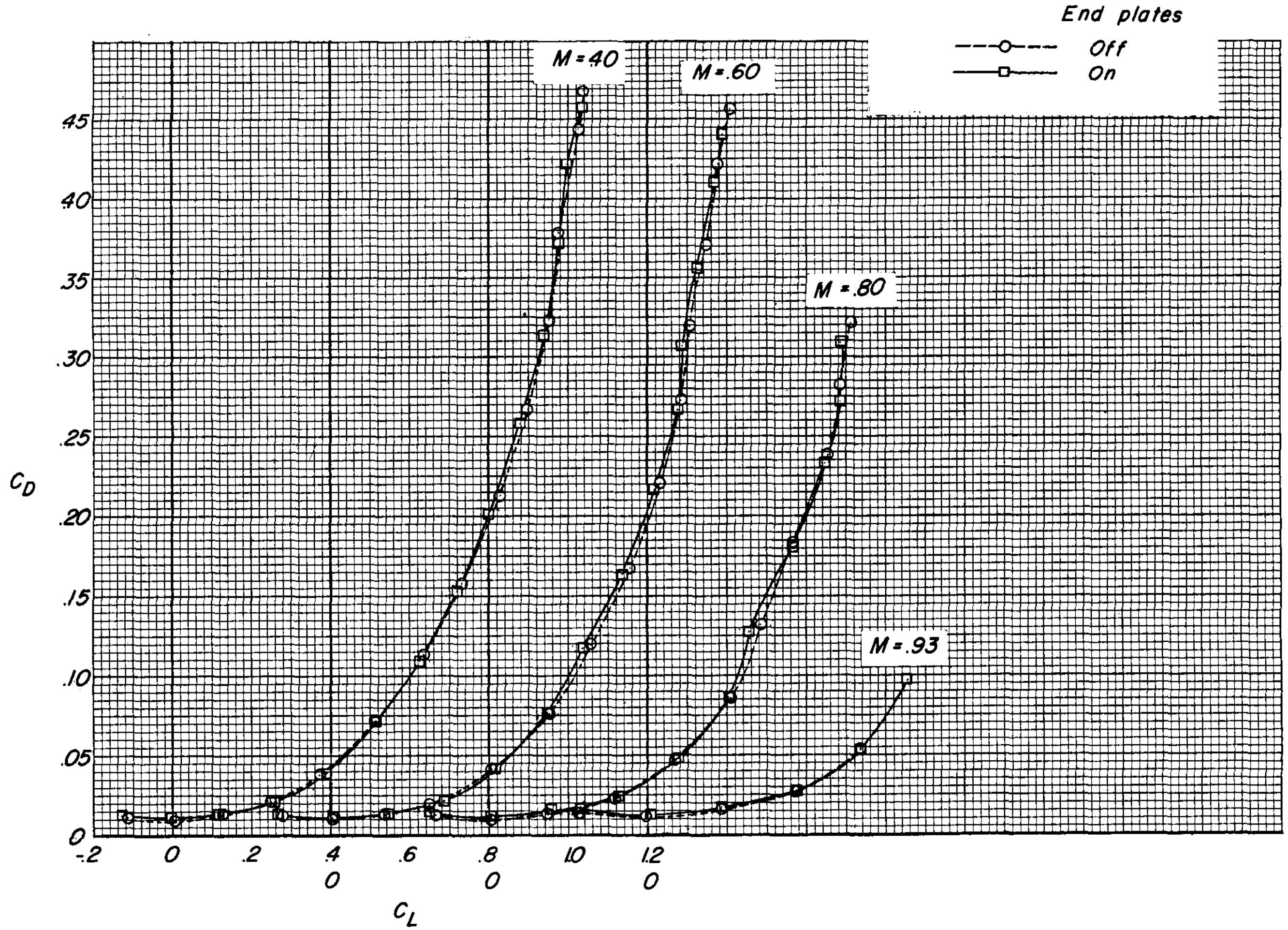


Figure 3.- Variation of mean test Reynolds number based on mean aerodynamic chord of wing with Mach number.



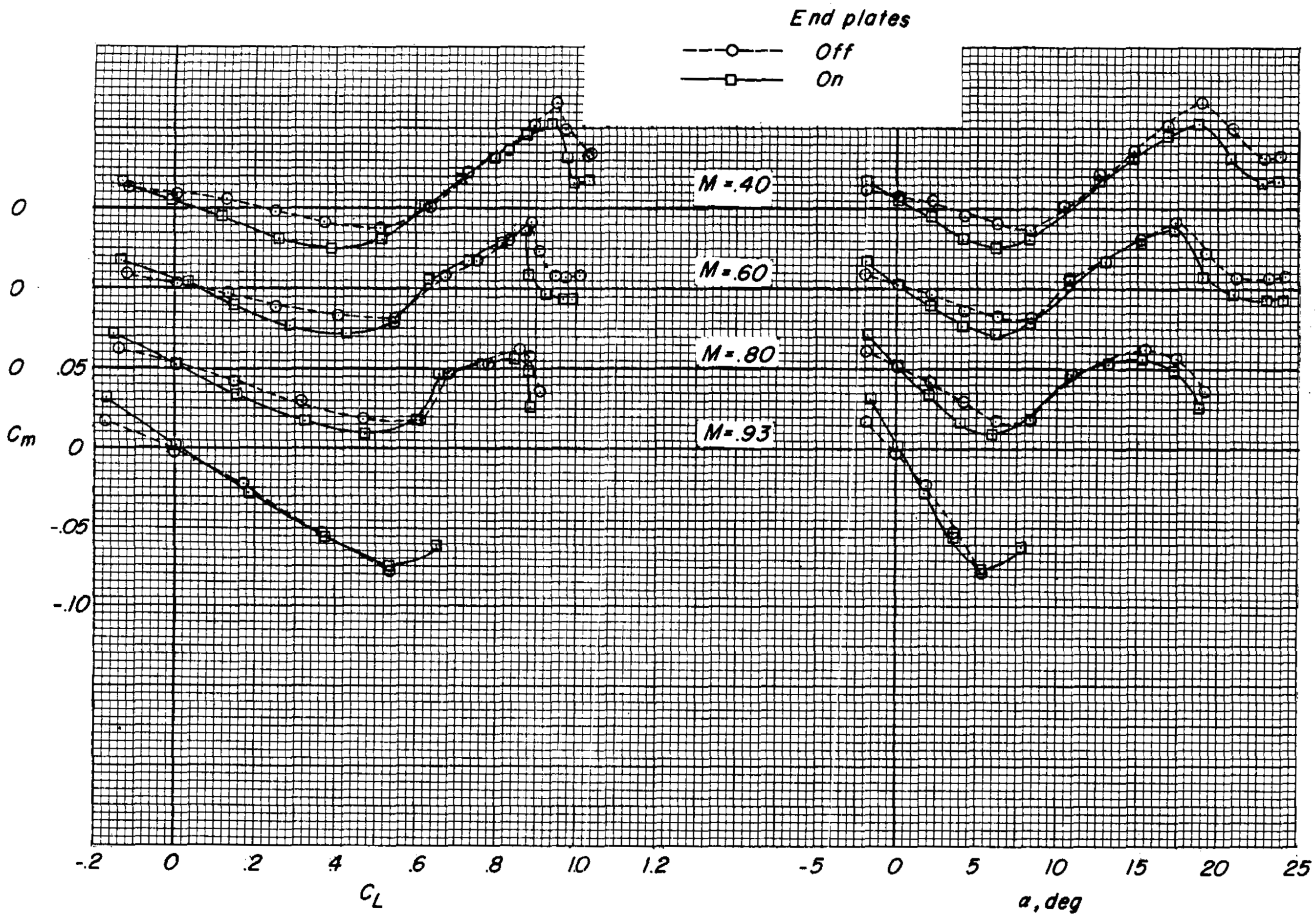
(a) Lift-coefficient curves.

Figure 4.- Effect of end plates on longitudinal aerodynamic characteristics. Chord-extension off.



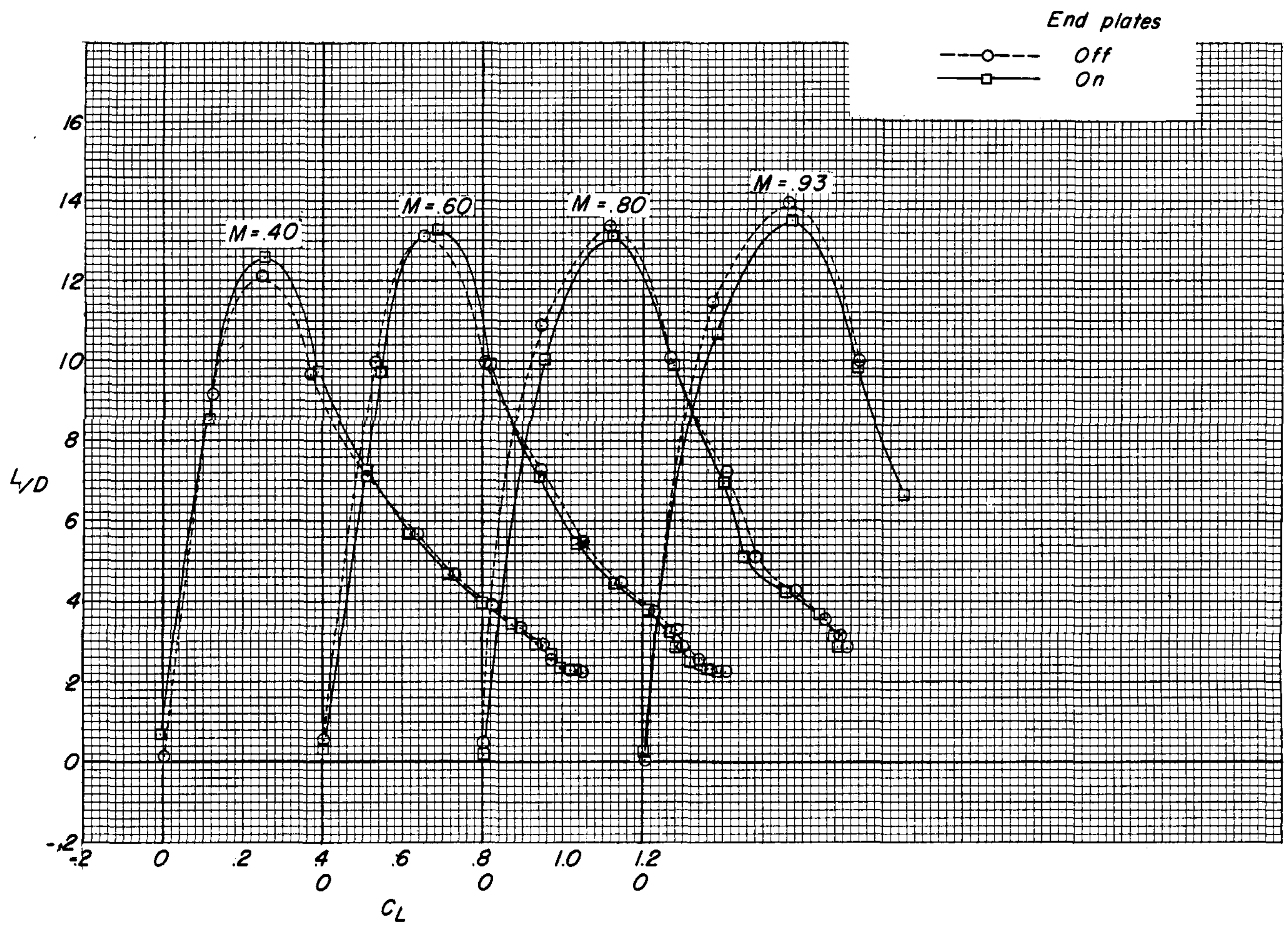
(b) Drag-coefficient curves.

Figure 4.- Continued.



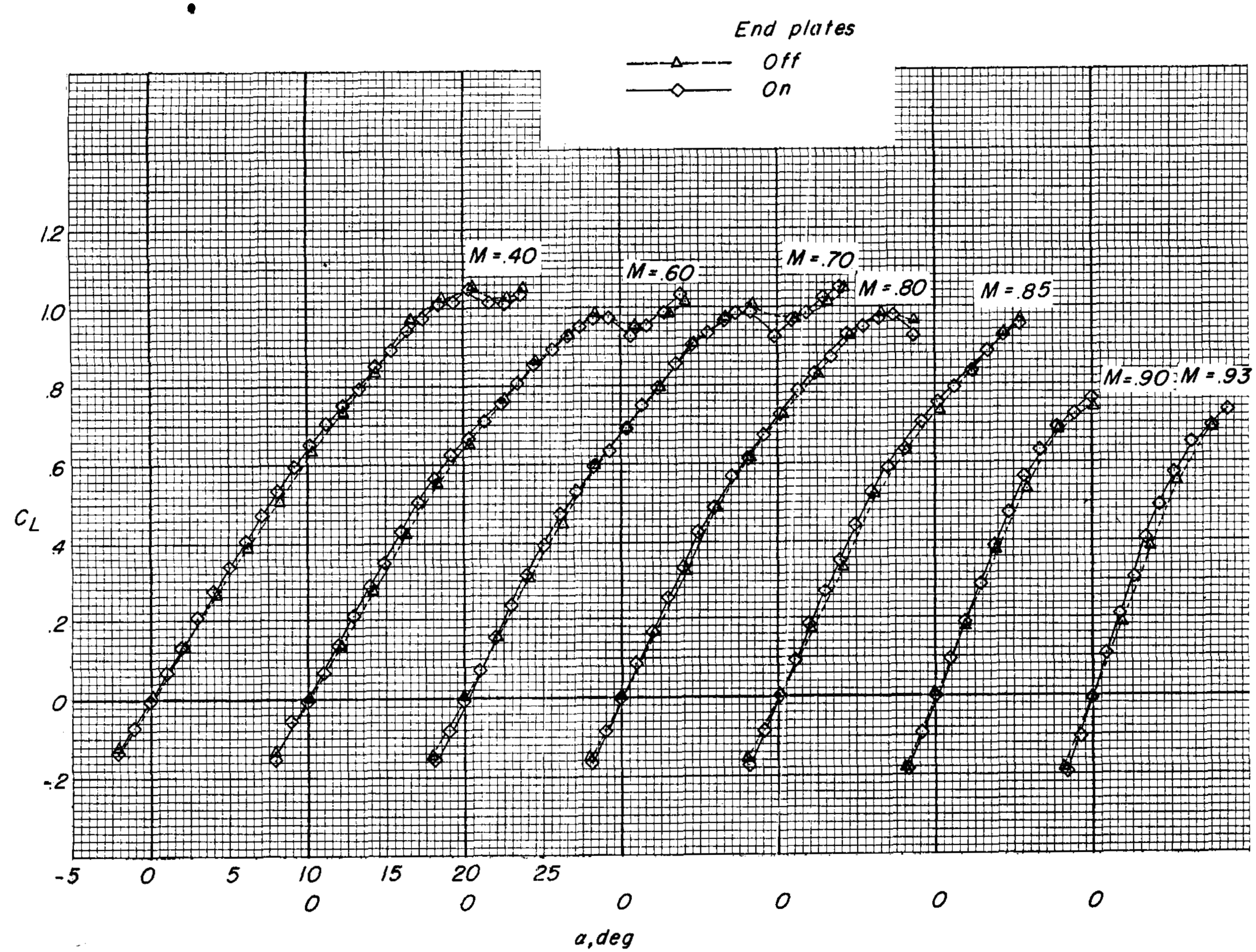
(c) Pitching-moment-coefficient curves.

Figure 4.- Continued.



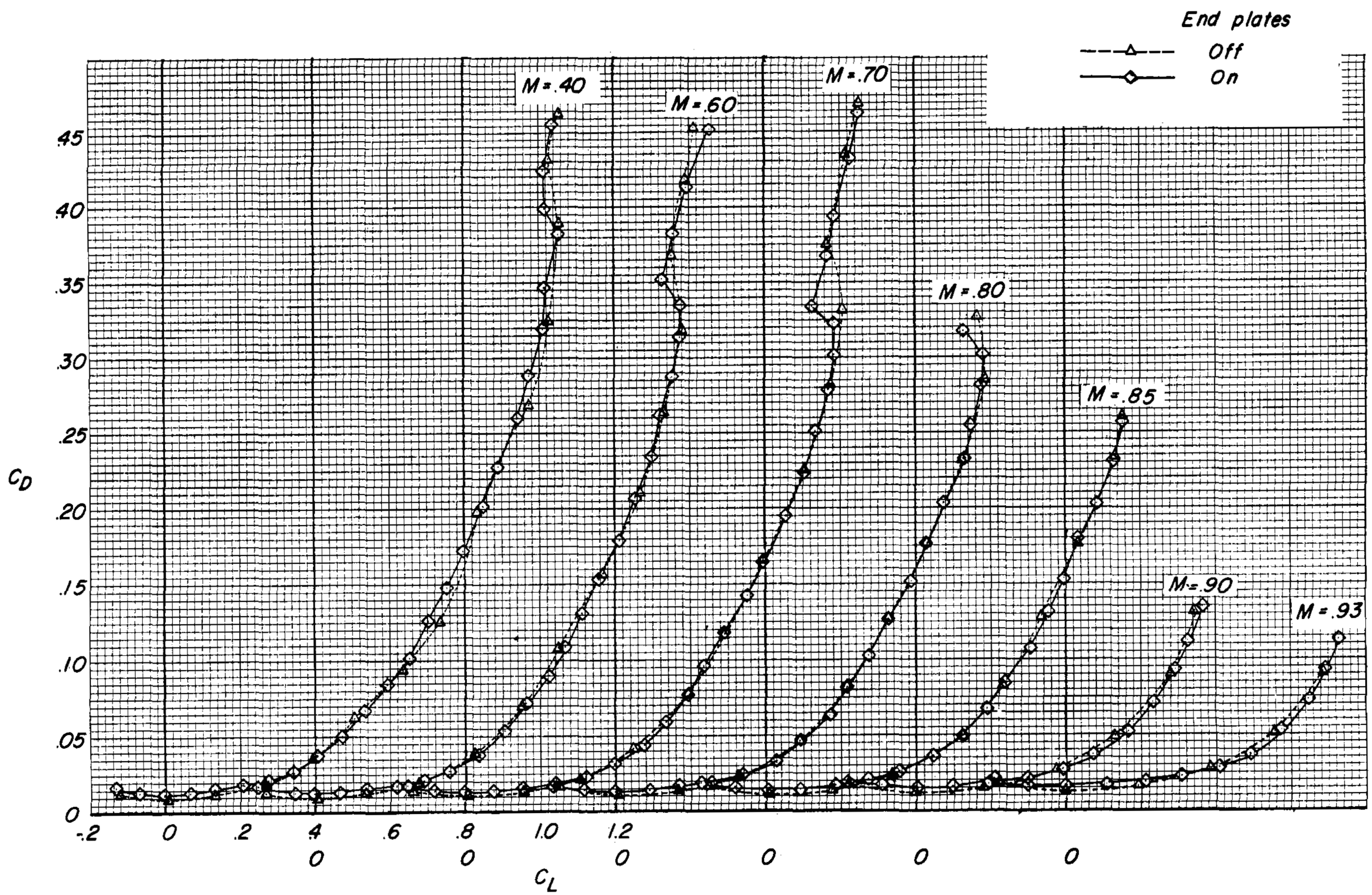
(d) Lift-drag ratios.

Figure 4.- Concluded.



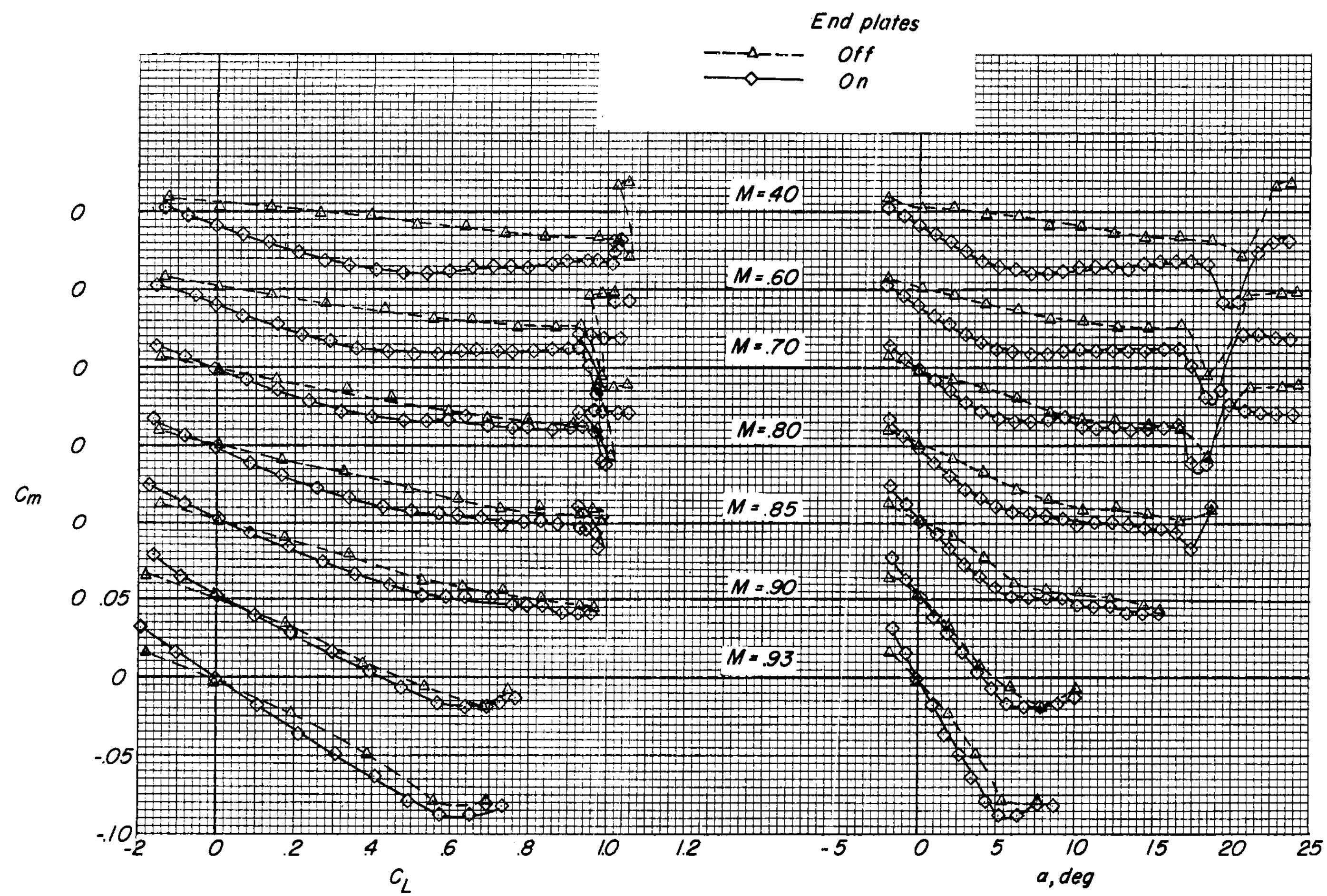
(a) Lift-coefficient curves.

Figure 5.- Effect of end plates on longitudinal aerodynamic characteristics. Chord-extension on.



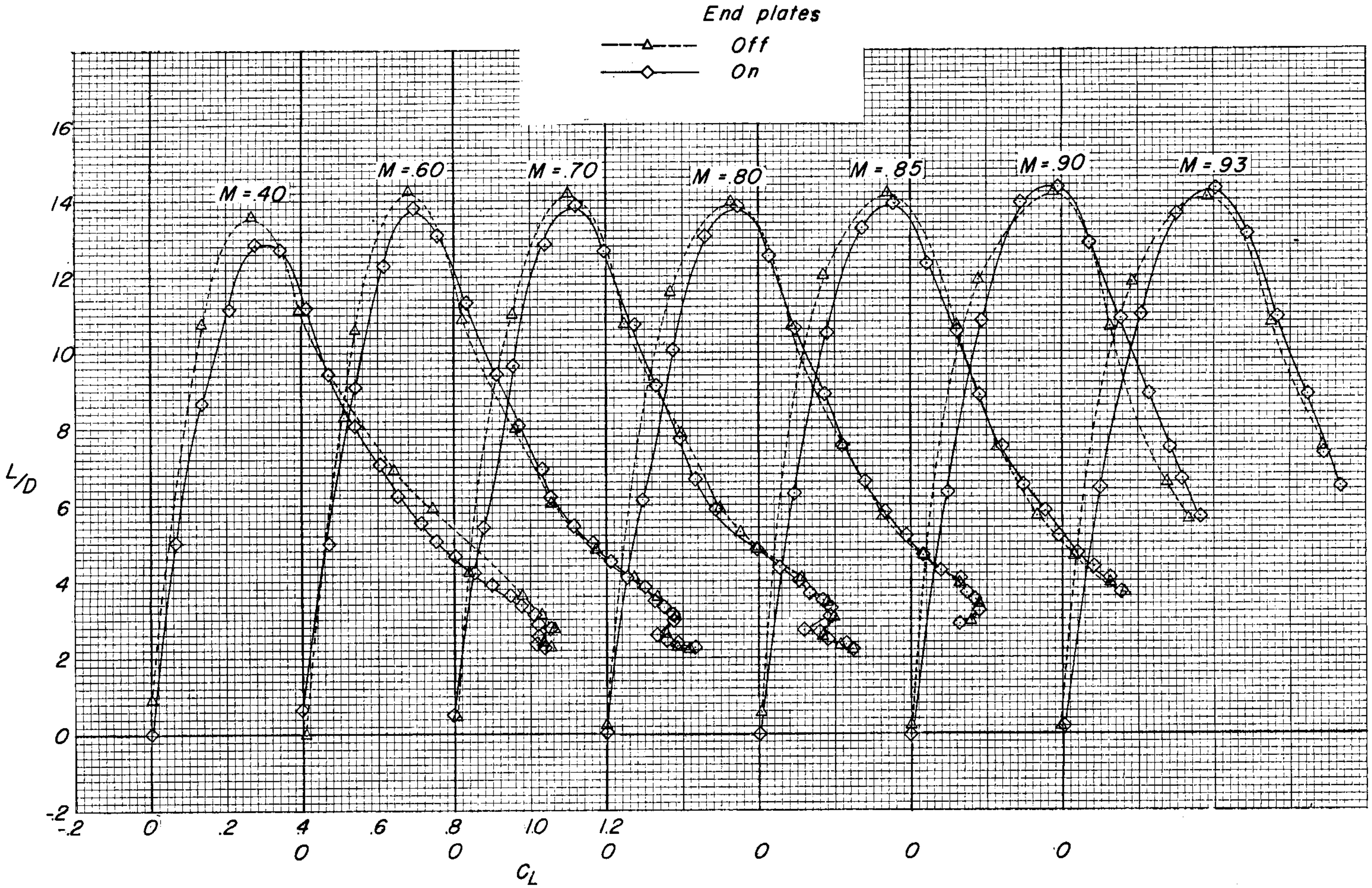
(b) Drag-coefficient curves.

Figure 5.- Continued.



(c) Pitching-moment-coefficient curves.

Figure 5.- Continued.



(d) Lift-drag ratios.

Figure 5.- Concluded.

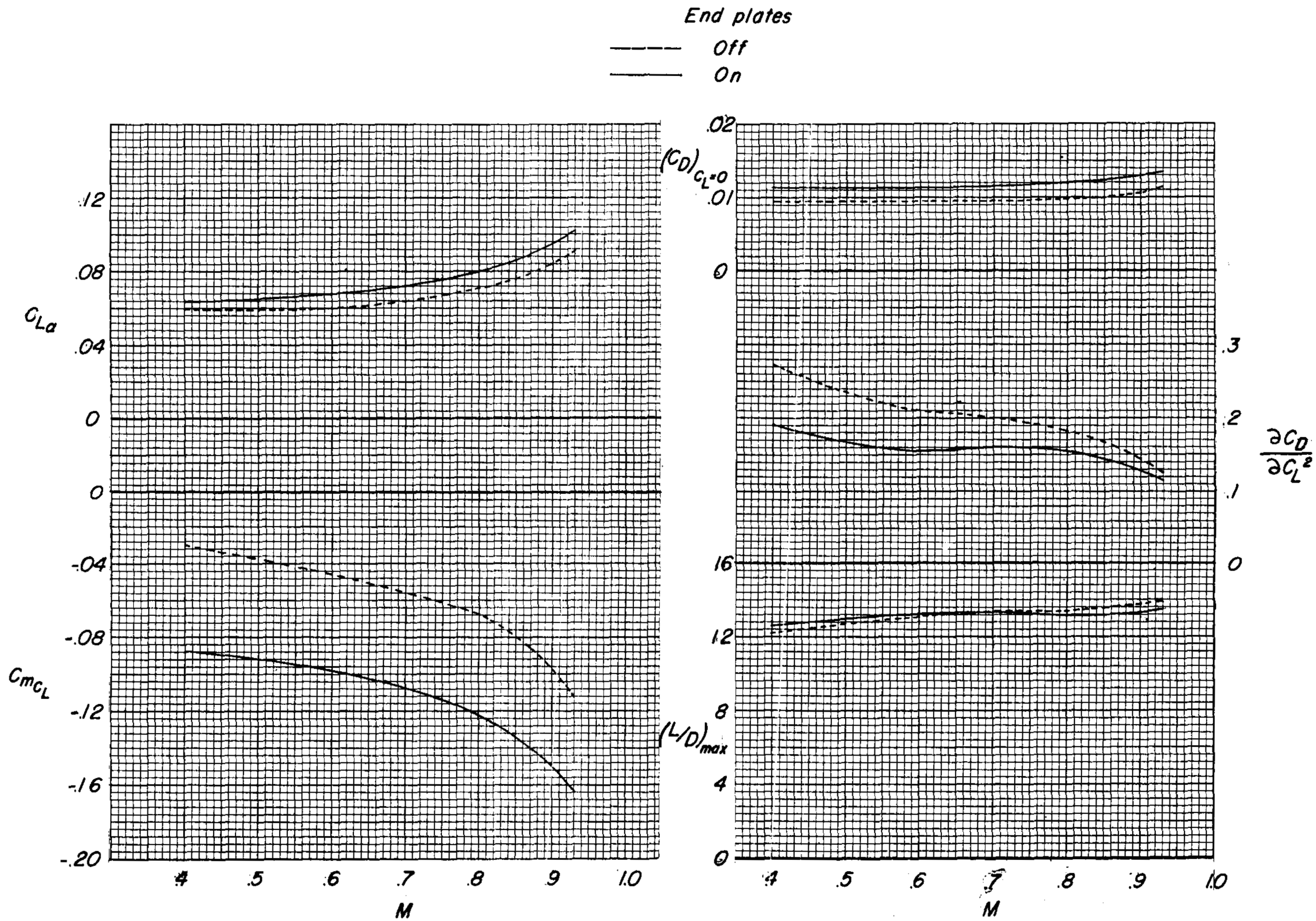


Figure 6.- Summary of the Mach number effects on longitudinal aerodynamic characteristics. Chord-extensions off.

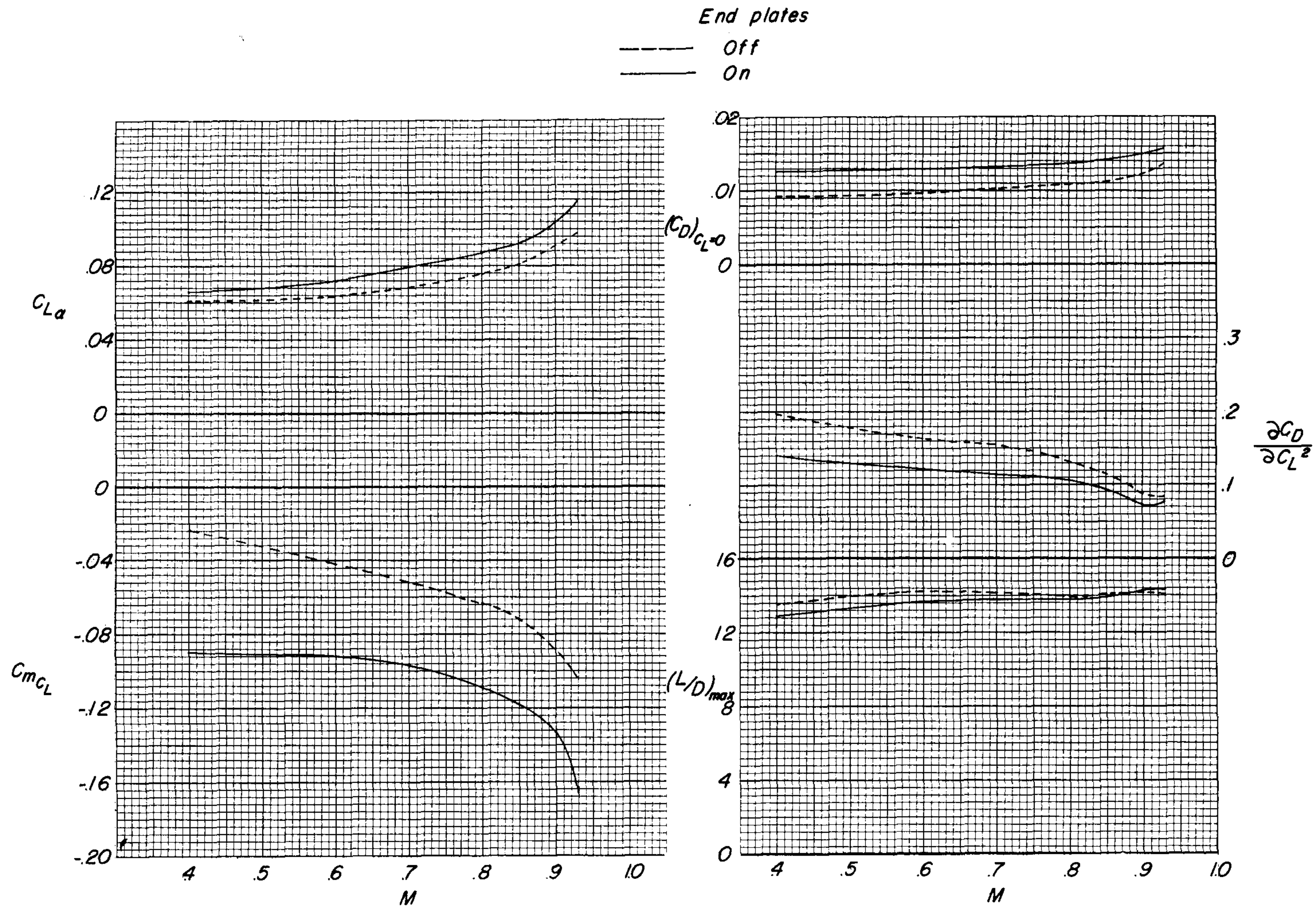


Figure 7.- Summary of Mach number effects on longitudinal aerodynamic characteristics. Chord-extensions on.

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