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TECHNICAL MEMORANDUM

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THE EFFECTS OF HORIZONTAL-TAIL POSITION ON THE LONGITUDINAL AERODYNAMIC CHARACTERISTICS AT TRANSONIC SPEEDS OF A VARIABLE-SWEEP AIRCRAFT HAVING AN INBOARD PIVOT

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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TECHNICAL MEMORANDUM X-612

THE EFFECTS OF HORIZONTAL-TAIL POSITION ON THE LONGITUDINAL AERODYNAMIC CHARACTERISTICS AT TRANSONIC SPEEDS OF A VARIABLE-SWEEP AIRCRAFT HAVING AN INBOARD PIVOT*

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By Alexander D. Hammond and Edward C. Polhamus

SUMMARY

A variable-wing-sweep aircraft having an inboard pivot location and a chord-plane tail (configuration VII-C) has been tested at transonic speeds. The performance and longitudinal stability and control characteristics were determined over a Mach number range from 0.60 to 1.20 and for wing-sweep positions of 25°, 50°, and 85°. Comparisons with previously published data of the same configuration but with the horizontal tail in a low position (configuration VII-B) were made in order to evaluate the effect of tail height. The aerodynamic efficiency was highest for the low tail arrangement. The results indicated only minor effects of tail height on longitudinal stability except for the low-speed moderate lift condition with the wings in the 25° position where the chord-plane tail indicated a slight pitch-up tendency. The longitudinal control effectiveness of the chord-plane tail configuration decreased rather rapidly at supersonic speeds because an elevator had to be resorted to as a result of the wing-tail mating.

INTRODUCTION

A series of wind-tunnel studies are being made by the National Aeronautics and Space Administration to provide basic data for use in the preliminary design of variable-wing-sweep aircraft configurations. The reason for the current interest in variable-wing-sweep aircraft is the extremely large increase in the subsonic efficiency of aircraft capable of efficient supersonic cruise that is available by proper application of this principle. In addition, the usual compromise between efficient supersonic cruise and reasonable landing and take-off can be

*Title, Unclassified.

eliminated and thereby provide for possible improvements in supersonic efficiency. These studies are directed toward determining the effect of large sweep-angle variations on the aerodynamic characteristics and the relative importance of various design variables. A fairly large quantity of data on the effects of wing planform and pivot location is available and some of the published reports are listed as references 1 to 10. In the extremely high-sweep conditions required for low-level supersonic operation there is a considerable wing—horizontal-tail overlap. In order to determine the relative importance of the vertical location of the horizontal tail with regard to wing-tail interference for these overlap
conditions, configuration VII-B of reference 9 was modified by moving L
the tail from the low position to essentially a wing-chord-plane position 1
so that the wing and tail mated in the overlap condition. The wing over- 7
lap necessitated the use of elevators rather than an all-movable tail for 3
longitudinal control. The tail is referred to as a "chord-plane" tail 2
and the configuration is referred to as configuration VII-C. The results of supersonic tests at a Mach number of 2.2 are presented in reference 10. The purpose of the present paper is to present the results for this chord-plane tail at transonic speeds and some of the results of reference 9 to indicate the effect of tail height.

SYMBOLS

The force and moment coefficients are referred to the wind-axis system with the moment reference point located at body station 47 (see fig. 1) which also corresponds to the wing-pivot axis location. The coefficients and symbols used are defined as follows:

A	cross-sectional area, sq ft
c	reference chord, 1.00 ft
C_D	drag coefficient, $\frac{\text{Drag}}{qS}$
C_L	lift coefficient, $\frac{\text{Lift}}{qS}$
C_m	pitching-moment coefficient, $\frac{\text{Pitching moment}}{qSc}$
$C_{m,o}$	pitching-moment coefficient at $C_L = 0$
C_{L_α}	lift-curve slope per degree, $\left(\frac{\partial C_L}{\partial \alpha}\right)_{\alpha=0}$

$(C_{m_\alpha})_{tail}$	horizontal-tail contribution to longitudinal stability, $\left(\frac{\partial C_m}{\partial \alpha}\right)_{\substack{tail\\on}} - \left(\frac{\partial C_m}{\partial \alpha}\right)_{\substack{tail\\off}}$
$C_{m_{C_L}}$	static margin, $\left(\frac{\partial C_m}{\partial C_L}\right)_{C_L=0}$
$C_{m_{\delta_e}}$	elevator effectiveness per degree, $\left(\frac{\partial C_m}{\partial \delta_e}\right)_{\alpha=0}$
L/D	lift-drag ratio
$(L/D)_{max}$	maximum lift-drag ratio
M	free-stream Mach number
q	free-stream dynamic pressure, $\frac{1}{2}\rho V^2$, lb/sq ft
R	Reynolds number based on $c = 1.00$ ft
S	reference area, 1.00 sq ft
V	free-stream velocity, ft/sec
α	angle of attack referred to fuselage reference line, deg
δ_e	elevator deflection referred to horizontal-tail chord line in plane normal to tail and parallel to plane of symmetry, positive when trailing edge is down, deg
i_t	horizontal-tail incidence, positive when leading edge is up, deg
ρ	mass density of air, slugs/cu ft
Λ	sweep angle of leading edge of outer wing panel, deg

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MODEL DESCRIPTION

The wind-tunnel model was a 1/24-scale version of a twin-engine fighter-type aircraft, the pertinent geometric details of which are shown in figure 1. The wing pivot was located slightly inboard of the edge of the fuselage but the wing had a fairly large fixed portion forward of the pivot which has been found desirable as a means of reducing the longitudinal-stability variation with wing-sweep angle. Wing-sweep angles of 25°, 50°, and 85° were investigated. The details of the wing
outer panel are presented in figure 2. In figure 2 the wing is shown L
in the 17° sweep position since the selected airfoil ordinates are 1
parallel to the plane of symmetry at this sweep. The wing panel tapered 7
in thickness ratio from 9 percent at the pivot to 6 percent at the tip 3
and the airfoil ordinates are given in table I. 2

The horizontal tail (see fig. 1) was located so that, when the wing was in the high-sweep position, it lay on top of the tail and on the aircraft would probably be latched to the tail. The tail is referred to throughout the report as a "chord-plane" tail. The low-tail position that was also tested and reported in reference 9 is shown for comparison. Because of the wing-tail overlap an elevator had to be utilized for longitudinal control and the location of the hinge line is shown in figure 1. Both the horizontal and vertical tails had 2.5-percent-thick symmetrical airfoil sections.

The inlets, which were axisymmetrical translating spike-type inlets, were simulated on the model and designed and constructed to provide the proper mass flow for a Mach number of 1.20. The measured variation of mass-flow ratio is the same as for configuration VII-B and can be found in reference 9.

The total cross-sectional-area curves developed for the configuration are plotted in figure 3 and are compared with that for a Sears-Haack body of revolution having the same overall length and effective diameter and with the maximum area at the midlength. A discussion of the development of the area distribution is presented in reference 9.

Photographs of the model are presented in figure 4 for the three sweep positions tested. The model was constructed of plastic-impregnated fiber glass on a steel frame and was provided with outer wing panels which could be rotated about the wing-pivot axes.

APPARATUS AND PROCEDURES

Tunnel

The investigation was made in the Langley 8-foot transonic pressure tunnel which has a test section that is rectangular in cross section, the upper and lower walls being slotted longitudinally to allow continuous operation through the transonic speed range with negligible effects of choking and blockage. The stagnation temperature and dewpoint were maintained at values to preclude shock condensation effects and the tunnel was operated at the highest stagnation pressures consistent with the load limits of the model and balance. The stagnation pressure for each sweep condition along with the corresponding Reynolds numbers (based on a characteristic length of 1 foot) is shown in figure 5.

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Measurements

Forces and moments were measured by means of an electrical strain-gage balance located inside the fuselage. The measurements were taken over an angle-of-attack range for Mach numbers varying from 0.60 to 0.96 for the condition of the wing swept back 25° and from 0.60 to 1.20 for the conditions of the wing swept back 50° and 85°. Total-pressure and static-pressure measurements were taken at the exit of one duct to determine the mass-flow and internal axial-force coefficient. Duct flow was assumed to be symmetrical. The pressure in the balance chamber was measured and the same pressure was assumed to act over the small base area surrounding the sting and the duct exits.

All tests were conducted with fixed transition on the models according to the methods described in reference 11. The transition was fixed by applying 0.10-inch-wide strips of number 80 carborundum grains around the fuselage 3 inches back from the nose, at the leading edge of the inlets, at the 10-percent-chord location (perpendicular to the leading edge) of both surfaces of the wings for all wing sweeps, and at the 10-percent-chord location (streamwise) on all surfaces of the horizontal and vertical tails.

CORRECTIONS AND ACCURACY

No corrections to the free-stream Mach number and dynamic pressure for the effects of model and wake blockage are necessary for tests in the slotted test section of the Langley 8-foot transonic pressure tunnel. (See ref. 12.) There is a range of Mach numbers above a Mach number of 1.00 where the data are affected by reflected compressions and expansions from the test-section boundary. From considerations of the results of reference 13, it is believed that for Mach numbers up to approximately 1.03 the effects of these disturbances on the measurements made in the present investigation would be negligible. No test data, however, are presented in the range ($M = 1.03$ to $M = 1.15$) where the reflected boundary disturbances impinged upon the model.

The drag coefficient C_D was corrected by adjusting the static pressure at the base and balance chamber of the models to the free-stream value. Typical plots of the total base drag coefficient against angle of attack are given in figure 11 of reference 9. The drag coefficient also includes the correction for the internal axial-force coefficient due to the flow through the ducts. The variation of the internal axial-force coefficient with angle of attack is shown in figure 12 of reference 9. This axial-force coefficient is the total value for both nacelles.

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No sting interference corrections have been applied to the data except to the extent of the partial correction for sting interference inherent in the base-pressure correction.

The angles of attack have been corrected for the deflection of the balance and sting under load. An additional correction for flow angularity has been applied to the angle of attack. The angles of attack and sideslip are estimated to be accurate to within ±0.1°.

The estimated accuracy of the data based primarily on the static calibrations and the repeatability of the data are as follows:

C_L . . . . ±0.002
C_D . . . . ±0.0004
C_m . . . . ±0.0005

PRESENTATION OF RESULTS

The results of the basic tests and analysis are presented in the following figures:

	Figure
Basic data (chord-plane tail):	
$\Lambda = 25^\circ$	6
$\Lambda = 50^\circ$	7
$\Lambda = 85^\circ$	8

DISCUSSION

Effect of Wing-Sweep Position

Aerodynamic efficiency.- The effect of wing-sweep position on the aerodynamic efficiency is presented in figure 9 where the maximum lift-drag ratio is presented as a function of Mach number for several wing-sweep positions. The data for $M = 2.2$ were obtained from reference 10. The results indicate that a 30-percent improvement in the efficiency at $M = 0.60$, relative to the 50° sweep position (representative of a compromise sweep), is obtained as the wing span is extended by reducing the sweep to 25°. In addition, the results at $M = 2.2$ indicate that, by increasing the sweep position to 75°, improvement in the supersonic efficiency relative to the 50° position can be achieved.

The results for the 85° sweep position indicate the lowest efficiency throughout the Mach range investigated; however, for high-speed low-level flight where the aircraft will be operating near zero lift coefficient, the zero-lift drag gives a better indication of the aerodynamic efficiency. The measured values of the zero-lift drag coefficients (based on a common reference area) are presented as a function of Mach number in figure 9 and it can be seen that an appreciable reduction in drag is obtained by utilizing the 85° sweep position. This reduction is due both to a reduction in friction drag (through a reduction in wetted area and an increase in local Reynolds number) and a reduction in wave drag. It should be kept in mind that neither the drag nor lift-drag ratios have been corrected to correspond to full-scale skin-friction values.

Lift-curve slope.- The variation of lift-curve slope with Mach number for the various wing-sweep positions is presented in figure 10. High values of lift-curve slope are desirable at low speeds in order to reduce take-off and landing attitudes and low values are desired during low-level high-speed operation in order to reduce the gust-induced normal accelerations. The advantage of variable sweep in providing for a wide range in lift-curve slope can be seen in the fact that with the wing in the 85° sweep position the lift-curve slope is only about 40 percent of that for the 25° sweep position at $M = 0.6$. This advantage, in addition to the low drag (fig. 9), makes the 85° sweep position attractive for high-speed low-level operation.

Longitudinal stability and control.- With regard to longitudinal stability, the basic data (figs. 6 to 8) indicate no serious nonlinearities except possibly for the 25° sweep position at moderate lift coefficients and low Mach numbers. This condition will be discussed later in connection with the effect of horizontal-tail height. Probably the primary aerodynamic problem associated with variable-sweep aircraft is the tendency toward large increases in longitudinal stability as the wing is swept back which, when combined with the rearward shift of the wing aerodynamic center due to Mach number, can result in undesirably high levels of longitudinal stability for the supersonic cruise. The variation of the longitudinal static margin $C_{m_{C_L}}$ with Mach number for the various sweep positions tested is presented in figure 10. The results indicate that the increase in longitudinal static margin as the wing sweep was increased from 25° to 75° and the Mach number from 0.6 to 2.2 is approximately 12 percent of the reference chord. The 75° wing position was selected for the $M = 2.2$ condition because of its higher lift-drag ratios. (See fig. 9.) Although the change in stability is relatively small, it must be kept in mind that the wing span of this inboard pivot configuration was reduced relative to the corresponding outboard pivot configuration (see ref. 9) in order to achieve comparable stability variations and therefore does not develop lift-drag ratios at subsonic speeds as high as the outboard pivot configurations.

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Since the combination of a chord-plane tail and wing-tail overlap prohibits the use of an all-movable tail, a partial-chord elevator was used for longitudinal control and its effectiveness $C_{m_{\delta_e}}$ is presented in figure 10. At subsonic speeds the elevator effectiveness is comparable to the effectiveness of the all-movable low tail of reference 9, possibly because of a more complete carryover load on the fuselage due to the high-tail position. However, at supersonic speeds the large loss in effectiveness that is typical of elevator-type controls is in evidence.

Effect of Horizontal-Tail Height

Since configuration VII-B of reference 9 is identical to that of the present investigation except that the horizontal tail was mounted near the bottom of the fuselage, a comparison of the results will give an indication of the effect of horizontal-tail height.

Aerodynamic efficiency.- A comparison of the maximum untrimmed lift-drag ratios (fig. 9 of present paper and fig. 33 of ref. 9) for neutral elevators and stabilizers indicates considerably lower values for the chord-plane tail. However, as will be discussed later, the chord-plane tail contributes considerably more zero-lift pitching moment $C_{m,o}$ and therefore may provide a more comparable aerodynamic efficiency in trimmed flight. Although sufficient data are not available to make comparisons of trimmed maximum lift-drag ratios, some indication can be obtained from figure 11 where the lift-drag ratios are plotted as a function of lift coefficient for the 25° sweep position at a Mach number of 0.60. The data for the low tail are presented for two values of $C_{m,o}$ (corresponding to two stabilizer settings) which bracket the $C_{m,o}$ provided by the chord-plane tail with neutral elevator. The comparison indicates that even for the same $C_{m,o}$ the low tail would be expected to be somewhat superior to the chord-plane tail. The supersonic results of reference 10 also indicate that the low tail is superior to the chord-plane tail.

Longitudinal stability.- In figure 12 the effects of tail height on the longitudinal stability characteristics are presented in terms of the variation of pitching-moment coefficient with lift coefficient for the three sweep positions. The data for the low tail were obtained from reference 9. For the 25° sweep position the lowest Mach number ($M = 0.8$) at which reasonably high lift coefficients were reached was selected whereas for the two higher sweep positions a Mach number of 1.20 was selected. Two effects of tail height, a rather large positive trim shift as the tail is raised to the wing-chord plane accompanied by a slight increase in stability, exist for all three sweep positions. The trim shift is probably due, in part at least, to an increase in the downwash associated with the wing camber load as the tail is moved up into the proximity of the wake center line. The increase in stability may be due to an increase in the lift carried across the fuselage in the vicinity of the tail with the tail in the high position.

A third effect of tail height occurs in connection with the nonlinear nature of the pitching-moment characteristics at the higher lift coefficients with the wing in the 25° sweep position. For these conditions it will be noted that with the tail in the wing-chord plane the pitching moments are more nonlinear, a rather large reduction in stability occurring just prior to the large increase in stability. This is the usual effect of a chord-plane tail and is caused by the fact that the tail does not emerge from the high downwash rate at a low enough angle of attack to offset the wing pitch-up tendency. It should be kept in mind that the pitch-up tendency of this particular wing is not very severe and that for planforms exhibiting a more pronounced pitch-up tendency the chord-plane tail might be entirely inadequate.

The relative importance of tail height on the tail contribution to longitudinal stability can be seen from figure 13 where $\left(C_{m_\alpha}\right)_{tail}$ is presented as a function of wing sweep for both the low tail and the chord-plane tail at Mach numbers of 0.60, 1.20, and 2.20. The results indicate that the effect of tail height is small, the chord-plane tail being slightly more effective at Mach numbers of 0.60 and 1.20 and slightly less effective at a Mach number of 2.20. Apparently, at the lower Mach numbers the additional carryover of the high tail overpowers the increased downwash whereas at $M = 2.20$ the opposite is true since the carryover is confined within Mach lines. The effects of wing-sweep angle and Mach number are considerably more pronounced than the tail-height effects. L
The tail contribution to C_{m_α} at first decreases with increasing sweep 1
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because of the corresponding decrease in aspect ratio and ratio of wing 3
span to tail span; then the tail contribution to C_{m_α} increases with 2
sweep as the wing crosses the tail and results in an increasingly large portion of the tail being left in the upwash field outboard of the wing tip.

The fact that, even when the tail area is reduced by the effect of the wing overlapping the chord-plane tail, there is no reduction in $\left(C_{m_\alpha}\right)_{tail}$ relative to the low tail would tend to indicate that the low tail was operating in a downwash field having an effective downwash rate of unity over that portion of the tail.

CONCLUDING REMARKS

Comparisons of the characteristics of the chord-plane-tail configuration of the present investigation with the low-tail configuration of NASA TM X-559 and NASA TM X-585 indicated the following conclusions with regard to tail height:

1. The aerodynamic efficiency was higher for the low tail than for the chord-plane tail.

2. The results indicated only minor effects of tail height on longitudinal stability except for the low-speed moderate lift condition with the wings in the 25° position where the chord-plane tail indicated a slight pitch-up tendency.

3. The effectiveness of the elevator control, which had to be used in connection with the chord-plane tail because of wing-tail mating for the high-wing-sweep position, decreased rapidly with Mach number above a Mach number of 1.0.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Air Force Base, Va., September 13, 1961.

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TABLE I.- AIRFOIL COORDINATES FOR CONFIGURATION VII-C

Wing-pivot station		Tip station	
Abscissa, percent chord	Ordinate, percent chord	Abscissa, percent chord	Ordinate, percent chord
0	0.480	0	0.315
.500	1.422	.500	.964
.750	1.682	.750	1.135
1.250	2.121	1.250	1.436
2.500	2.913	2.500	1.964
5.000	3.921	5.000	2.626
7.500	4.764	7.500	3.182
10.000	5.4705	10.000	3.648
15.000	6.588	15.000	4.388
20.000	7.434	20.000	4.948
25.000	8.074	25.000	5.374
30.000	8.5395	30.000	5.684
35.000	8.8455	35.000	5.890
40.000	8.9925	40.000	5.992
45.000	8.9655	45.000	5.984
50.000	8.742	50.000	5.850
55.000	8.316	55.000	5.586
60.000	7.7145	60.000	5.204
65.000	6.981	65.000	4.728
70.000	6.136	70.000	4.174
75.000	5.2005	75.000	3.550
80.000	4.197	80.000	2.874
85.000	3.159	85.000	2.166
90.000	2.1195	90.000	1.454
95.000	1.0785	95.000	.740
100.000	.0375	100.000	.026
L.E. radius: 0.473 percent chord		**L.E. radius: 0.316 percent chord**	

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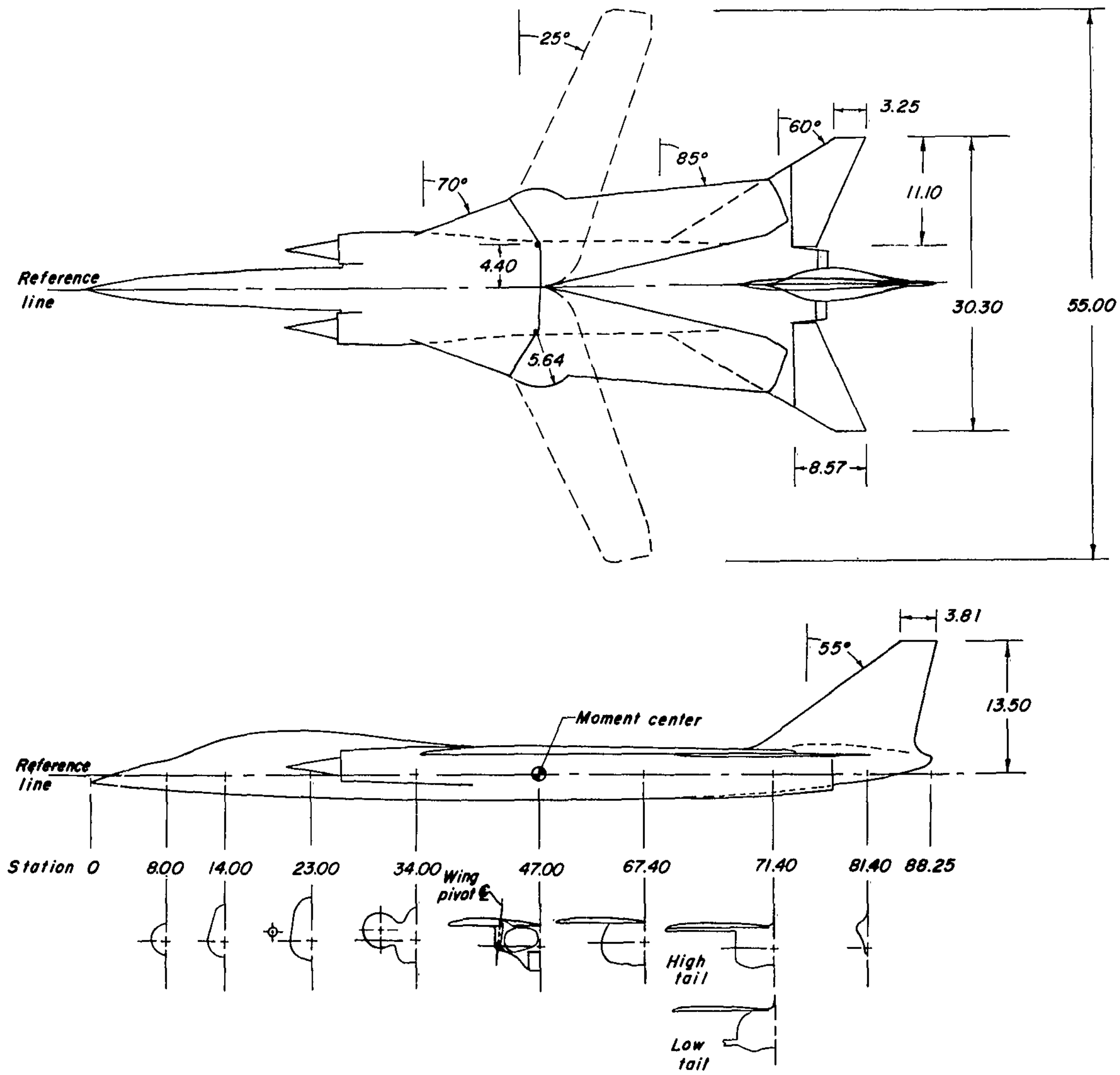

Figure 1.- General arrangement of configuration VII-C. All dimensions are in feet for full-scale airplane.

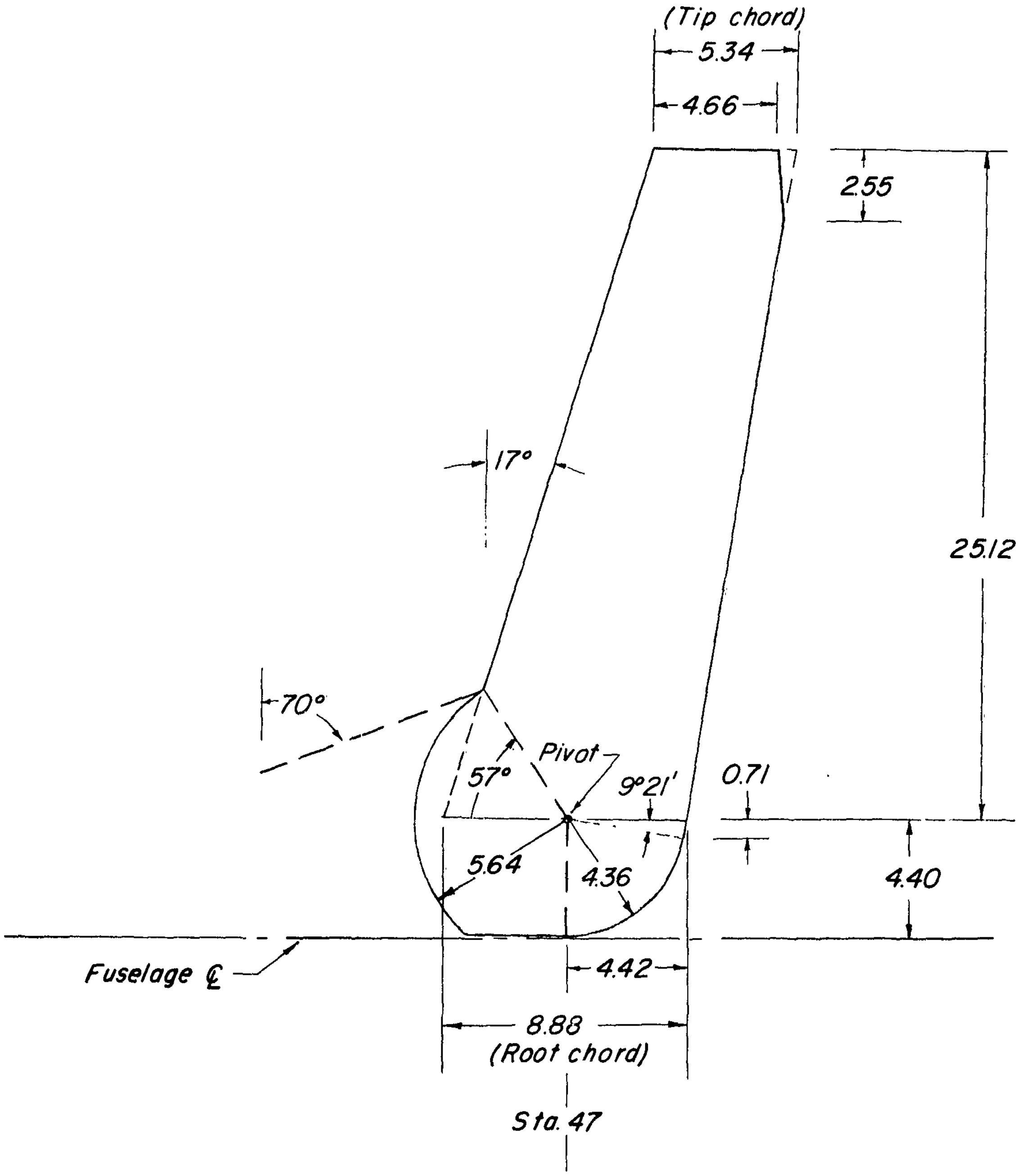

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Figure 2.- Details of wing outer panel.

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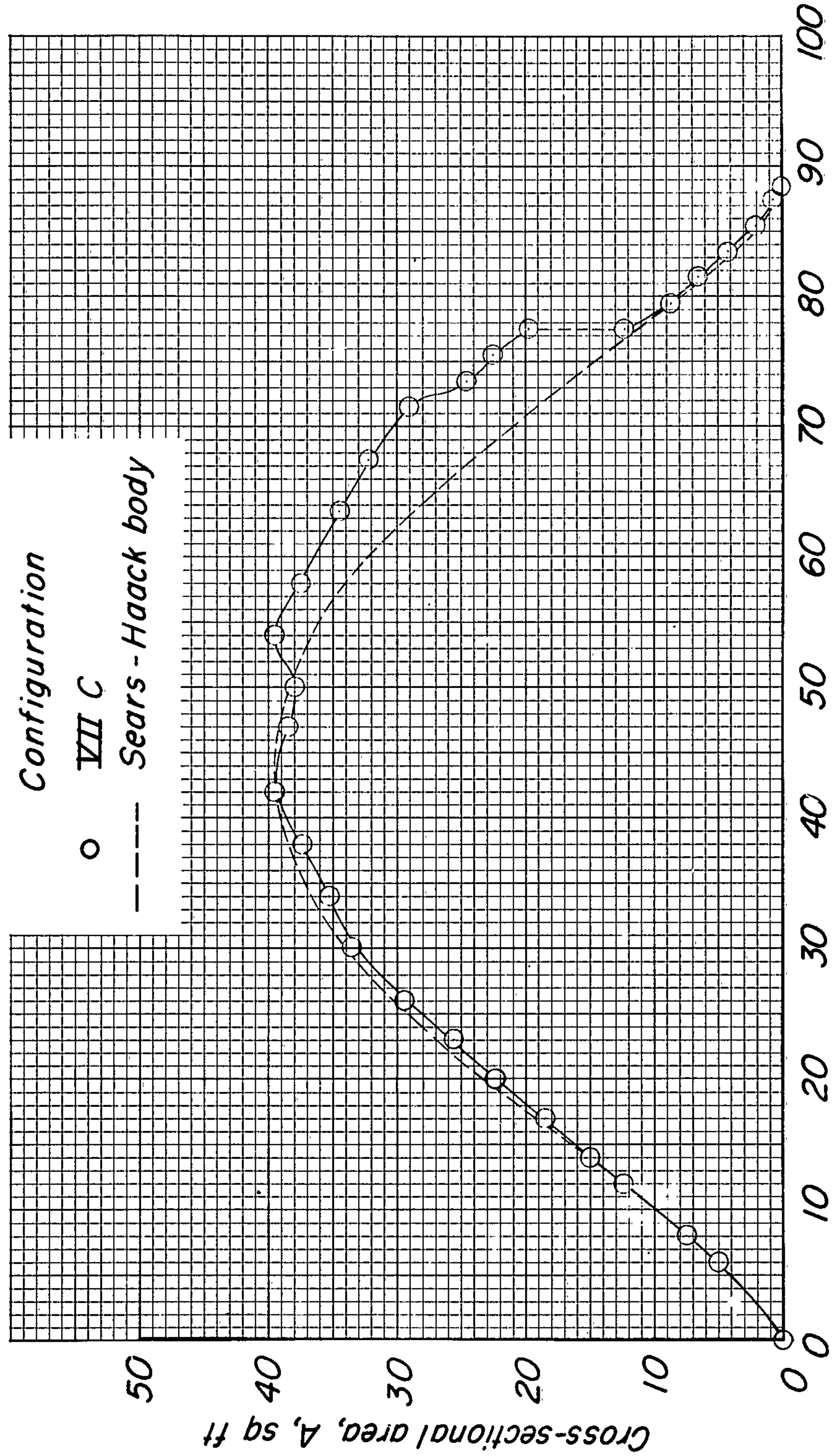
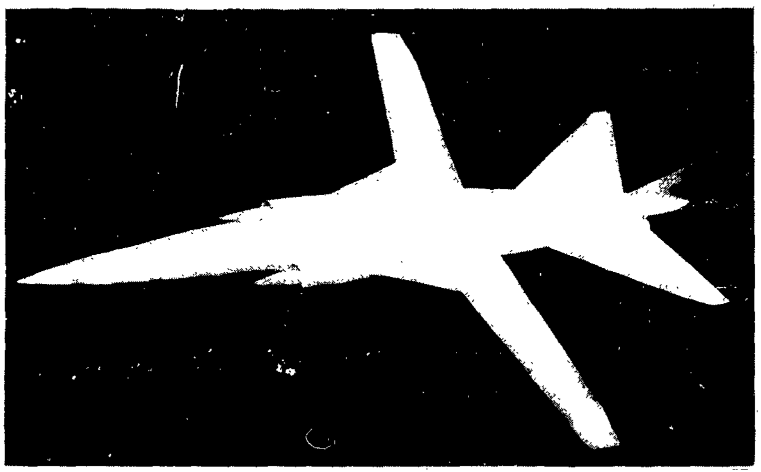
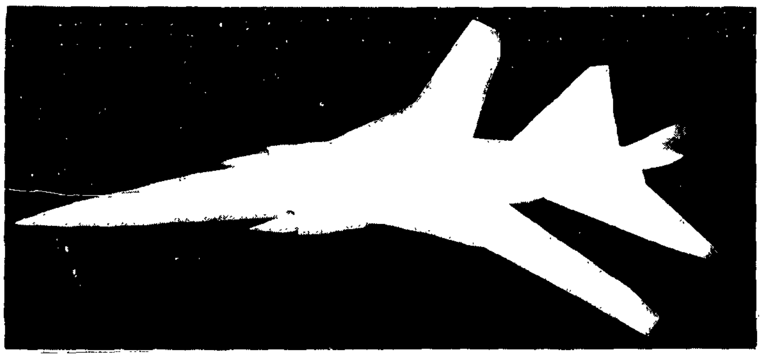


Figure 3.- Longitudinal distribution of cross-sectional area for configuration VII-C.



(a) $\Lambda = 25^{\circ}$. L-60-6059



(b) $\Lambda = 50^{\circ}$. L-60-6060

(c) $\Lambda = 85^{\circ}$. L-60-6061

Figure 4.- Wind-tunnel models with wings in the three sweep positions tested.

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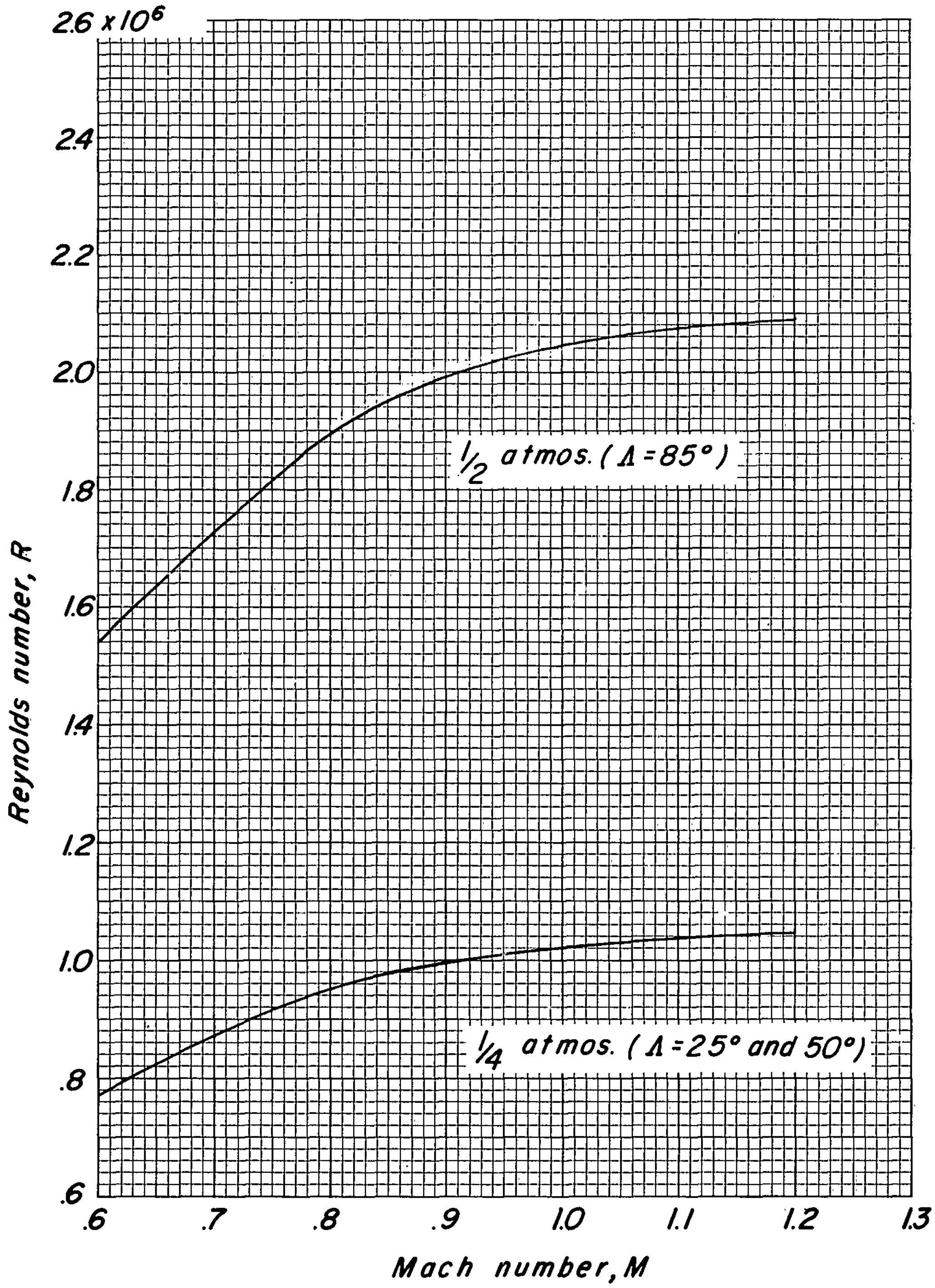

Figure 5.- Variation of test Reynolds number (based on reference chord of 1.0 foot) with Mach number.

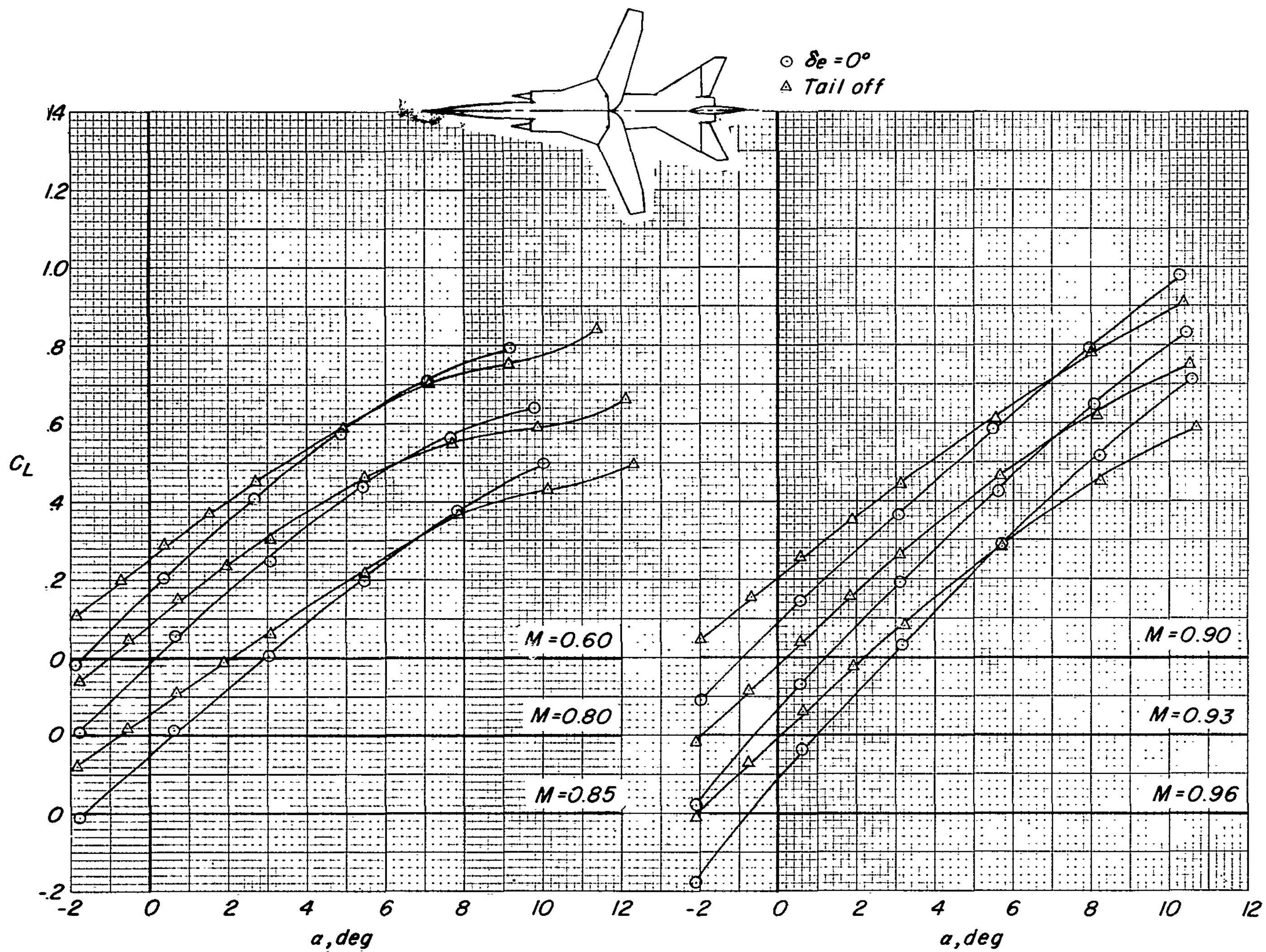

Figure 6.- Longitudinal aerodynamic characteristics with the wing in the 25° sweep condition.

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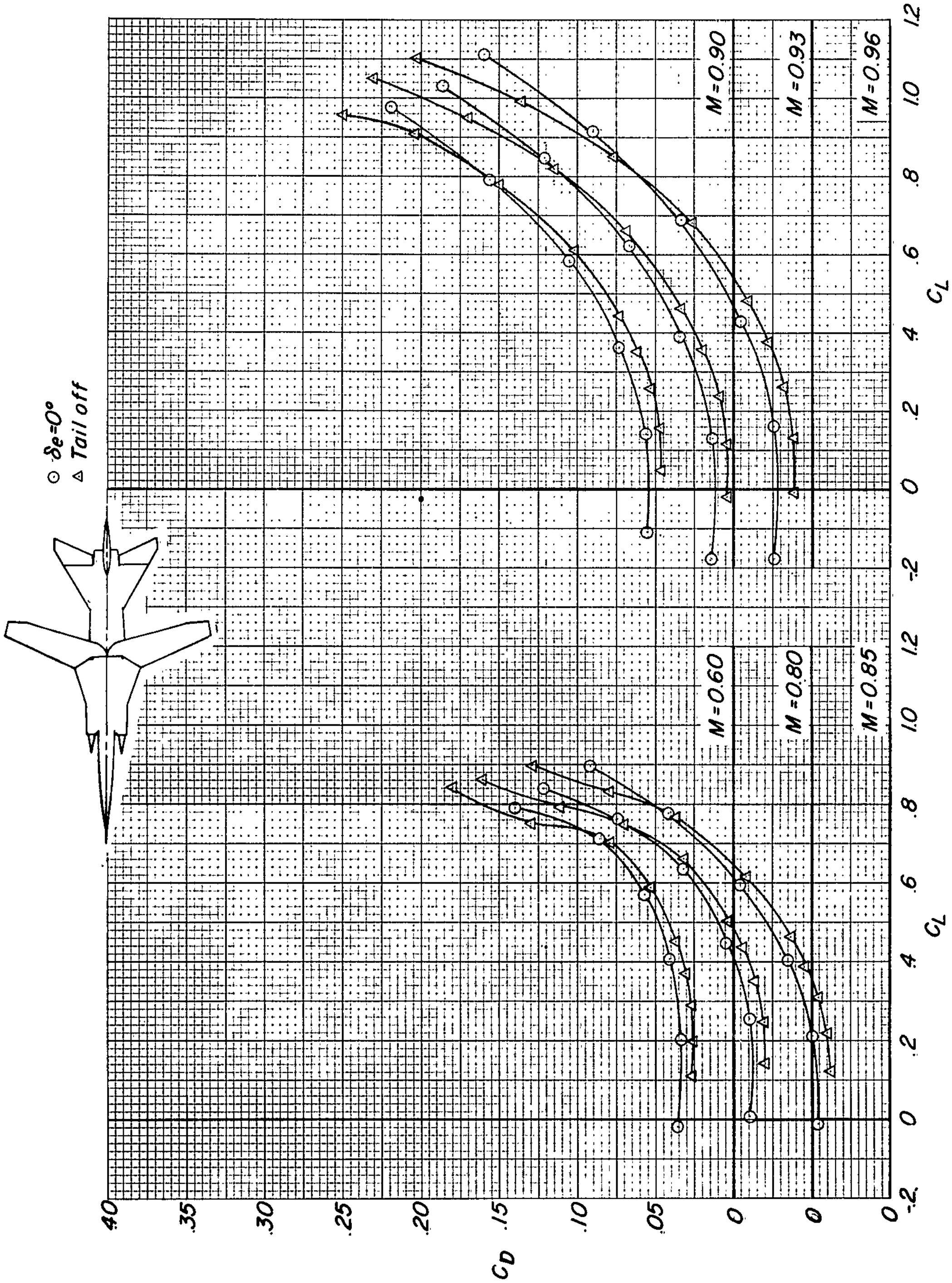

Figure 6.- Continued.

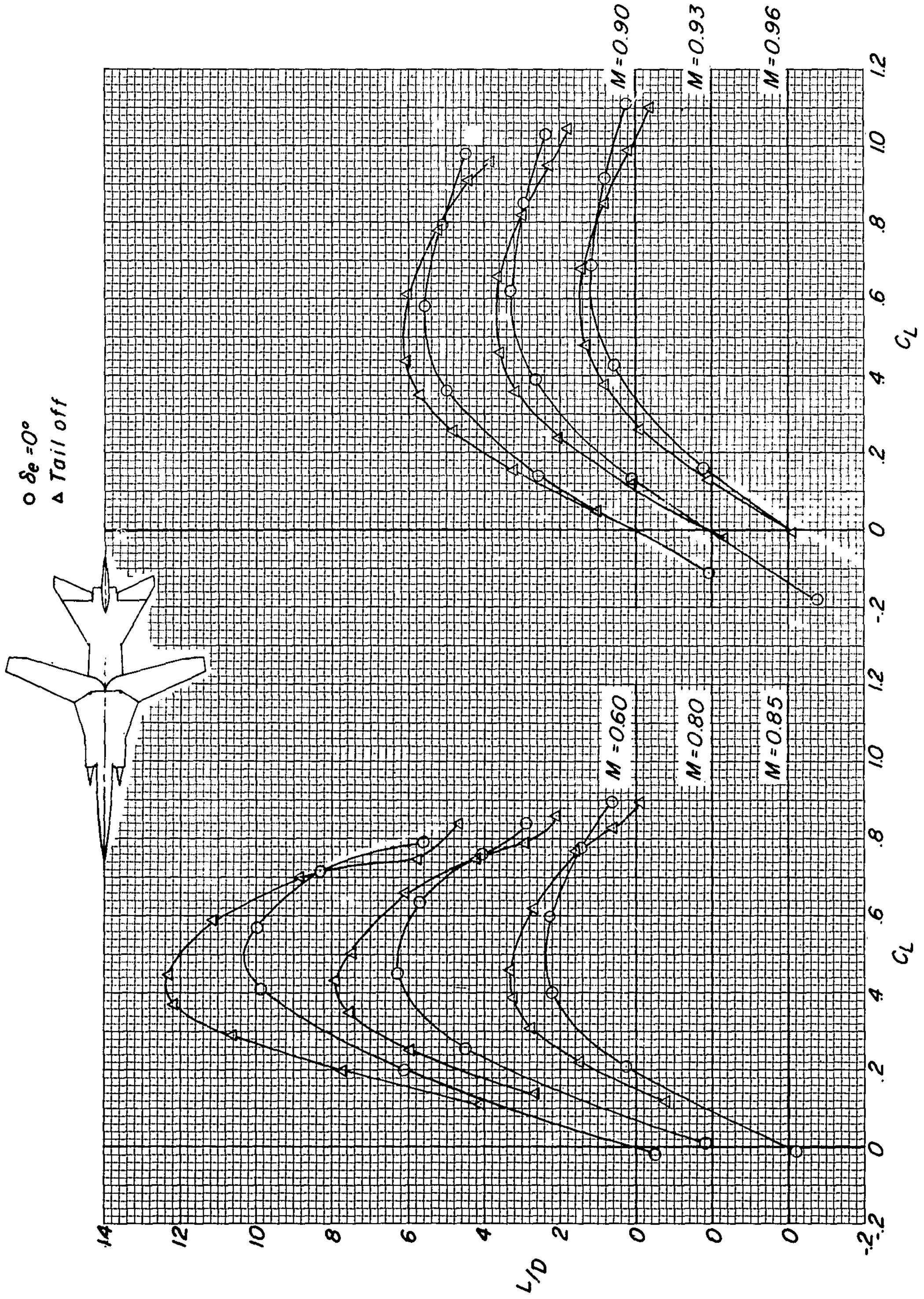

Figure 6.- Continued.

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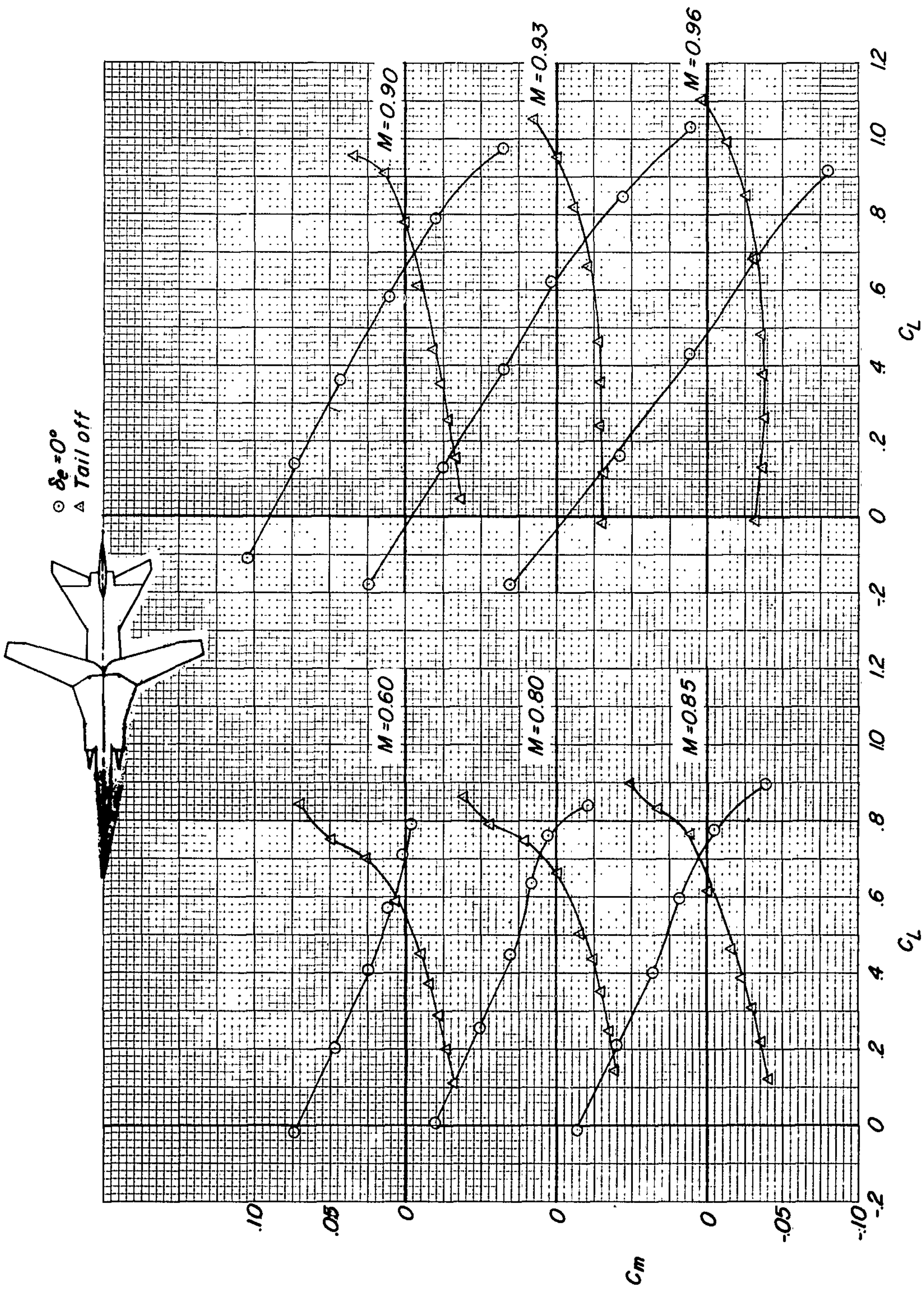

Figure 6.- Concluded.

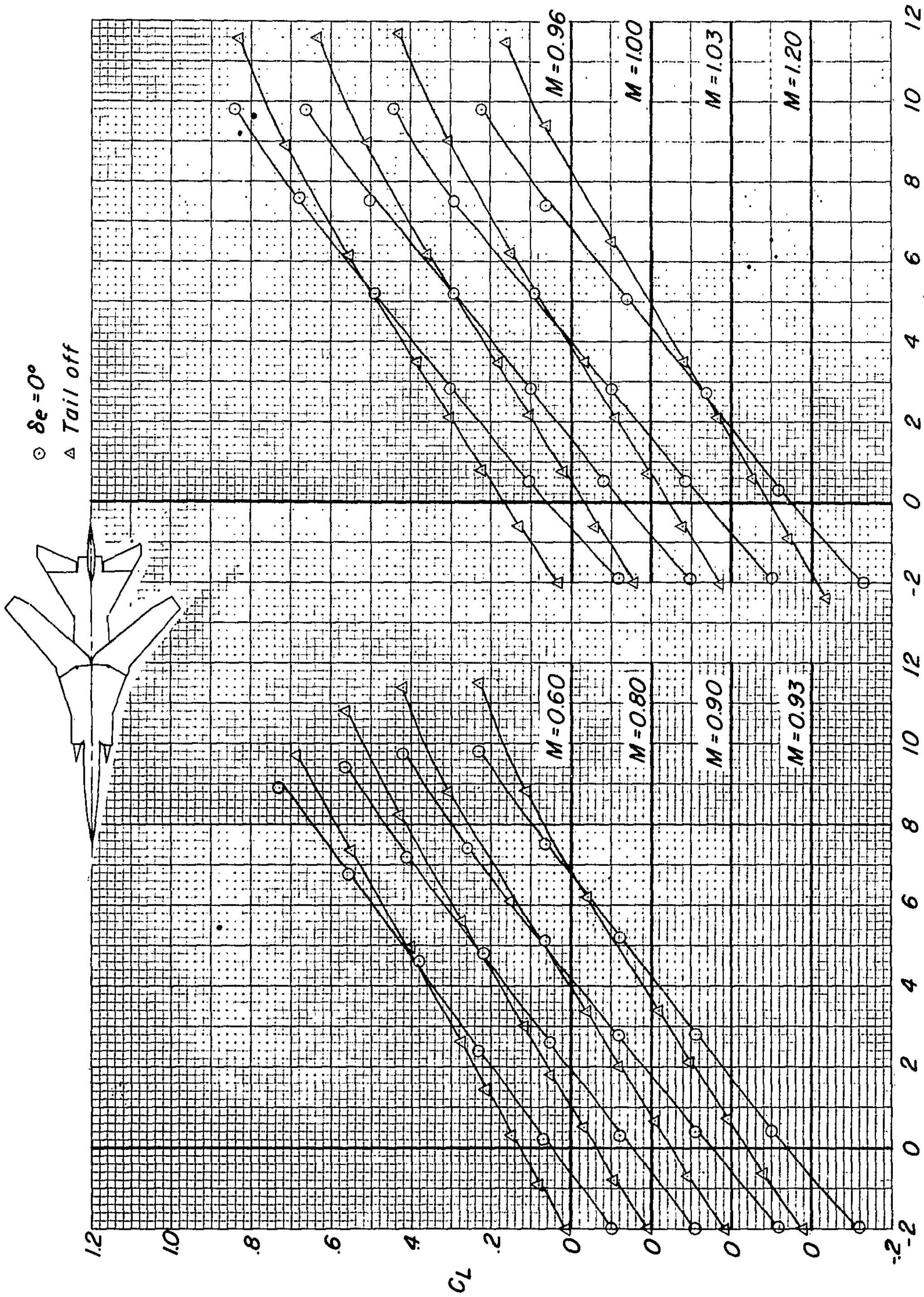

Figure 7.- Longitudinal aerodynamic characteristics with the wing in the 50° sweep condition.

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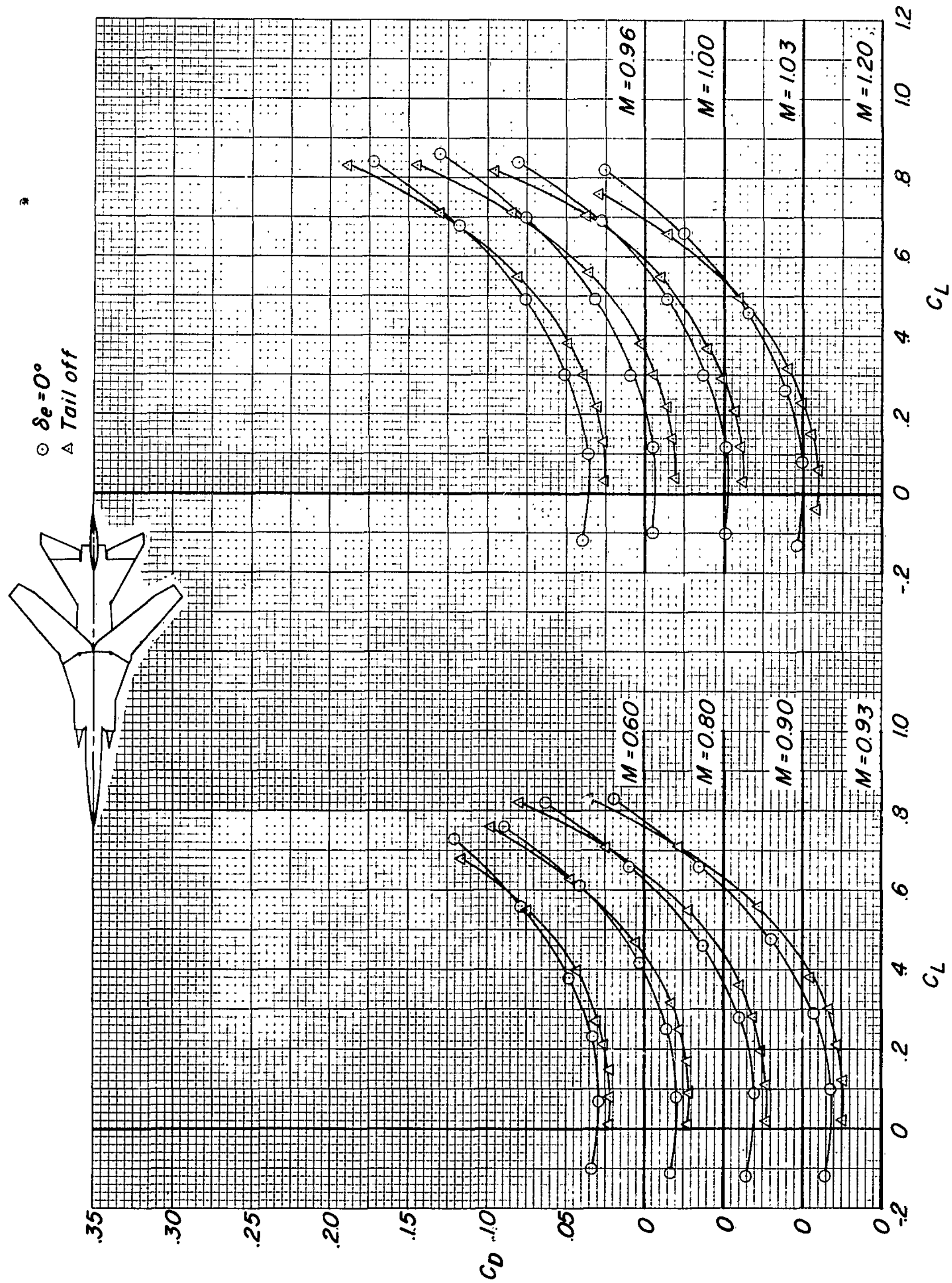

Figure 7.- Continued.

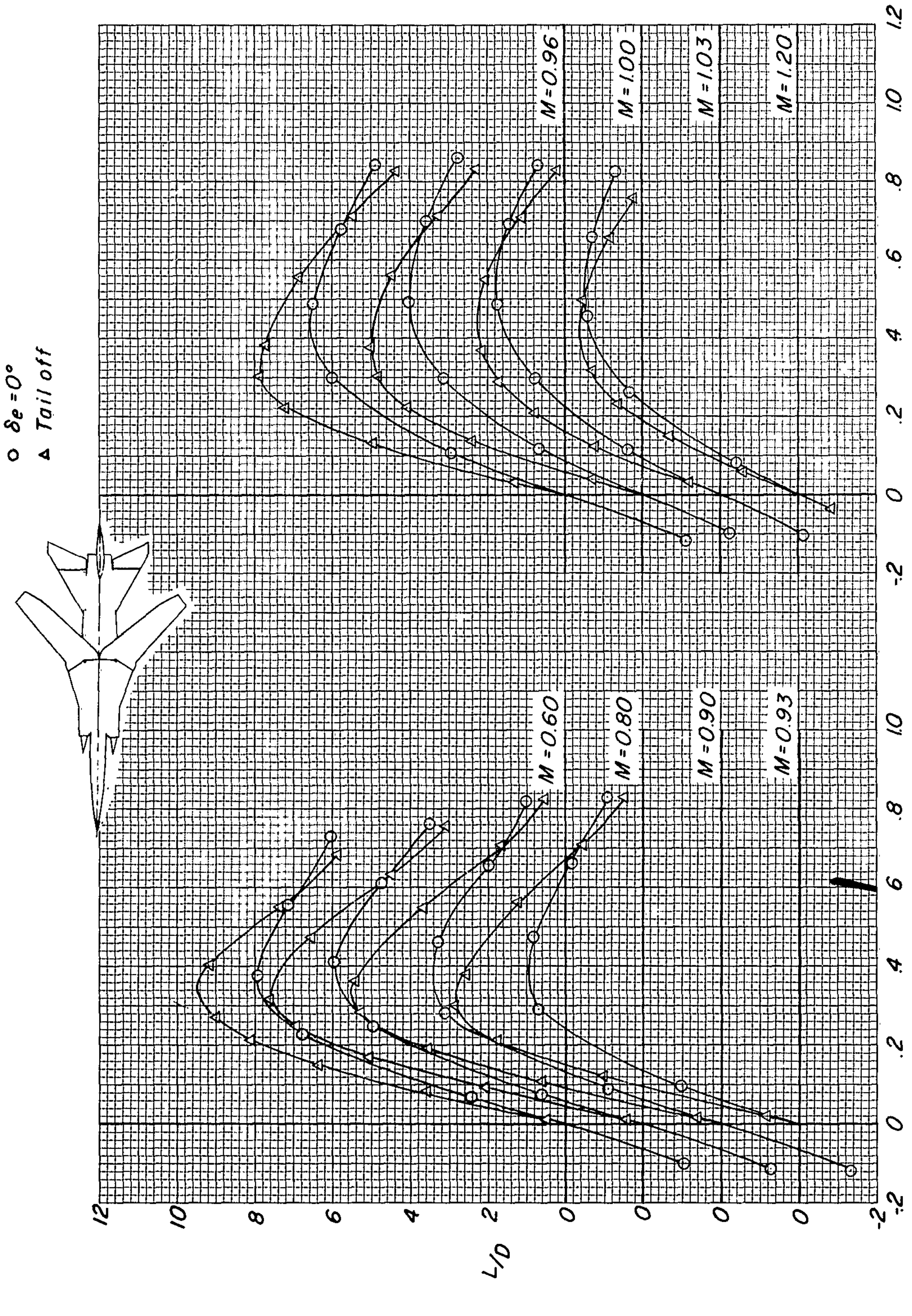

Figure 7.- Continued.

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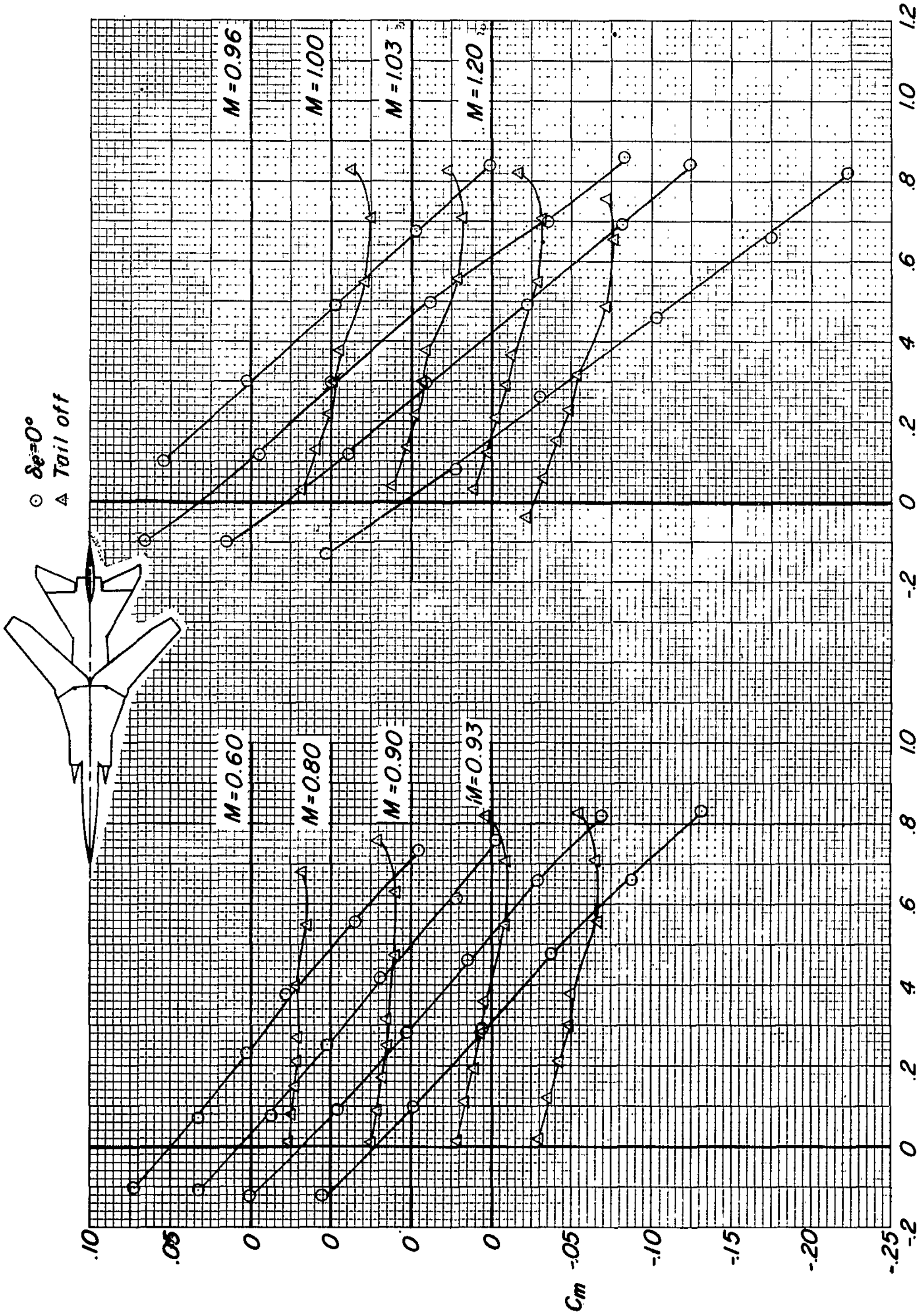

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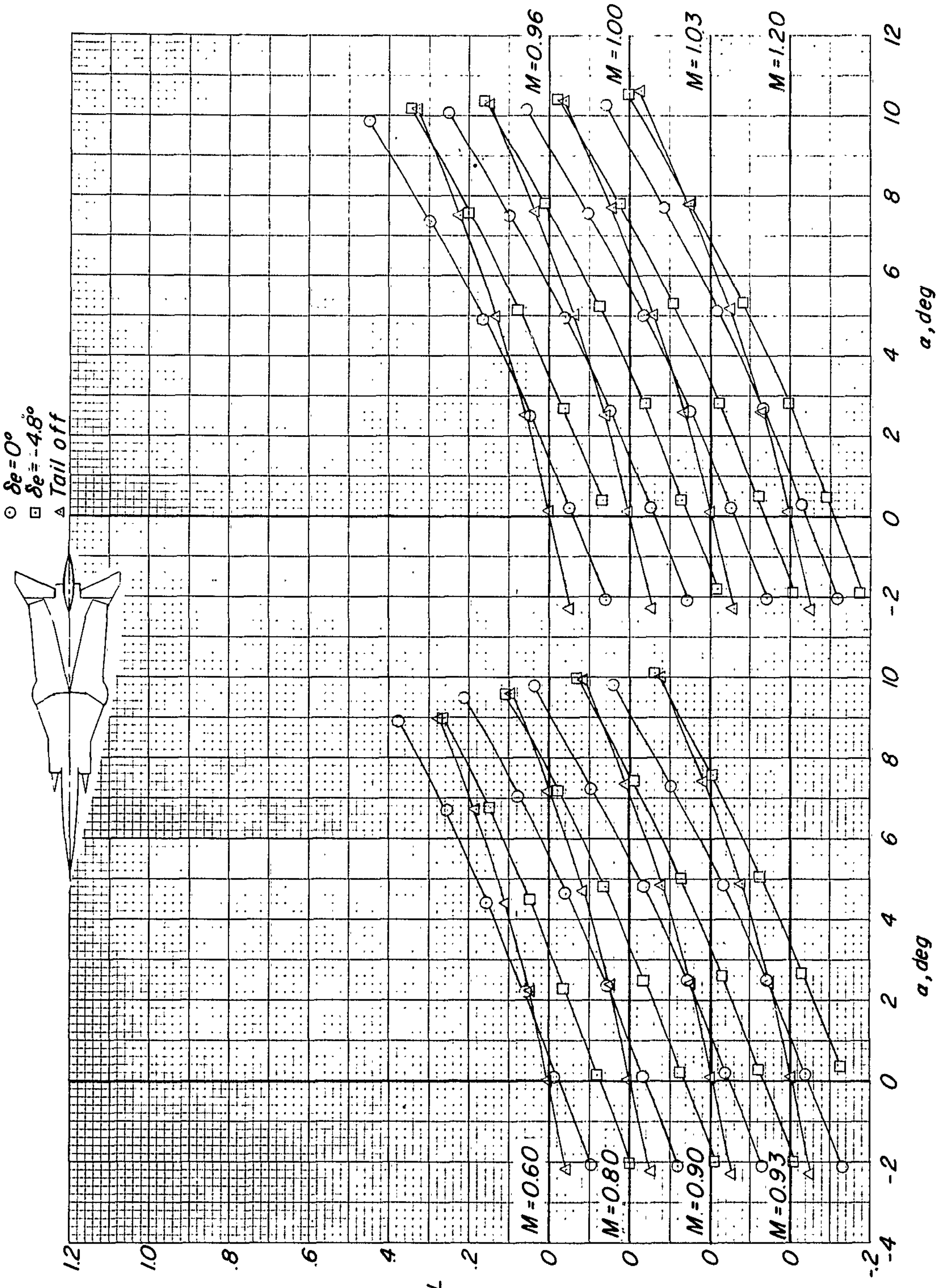

Figure 8.- Longitudinal aerodynamic characteristics with the wing in the 85° sweep condition.

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L-1732

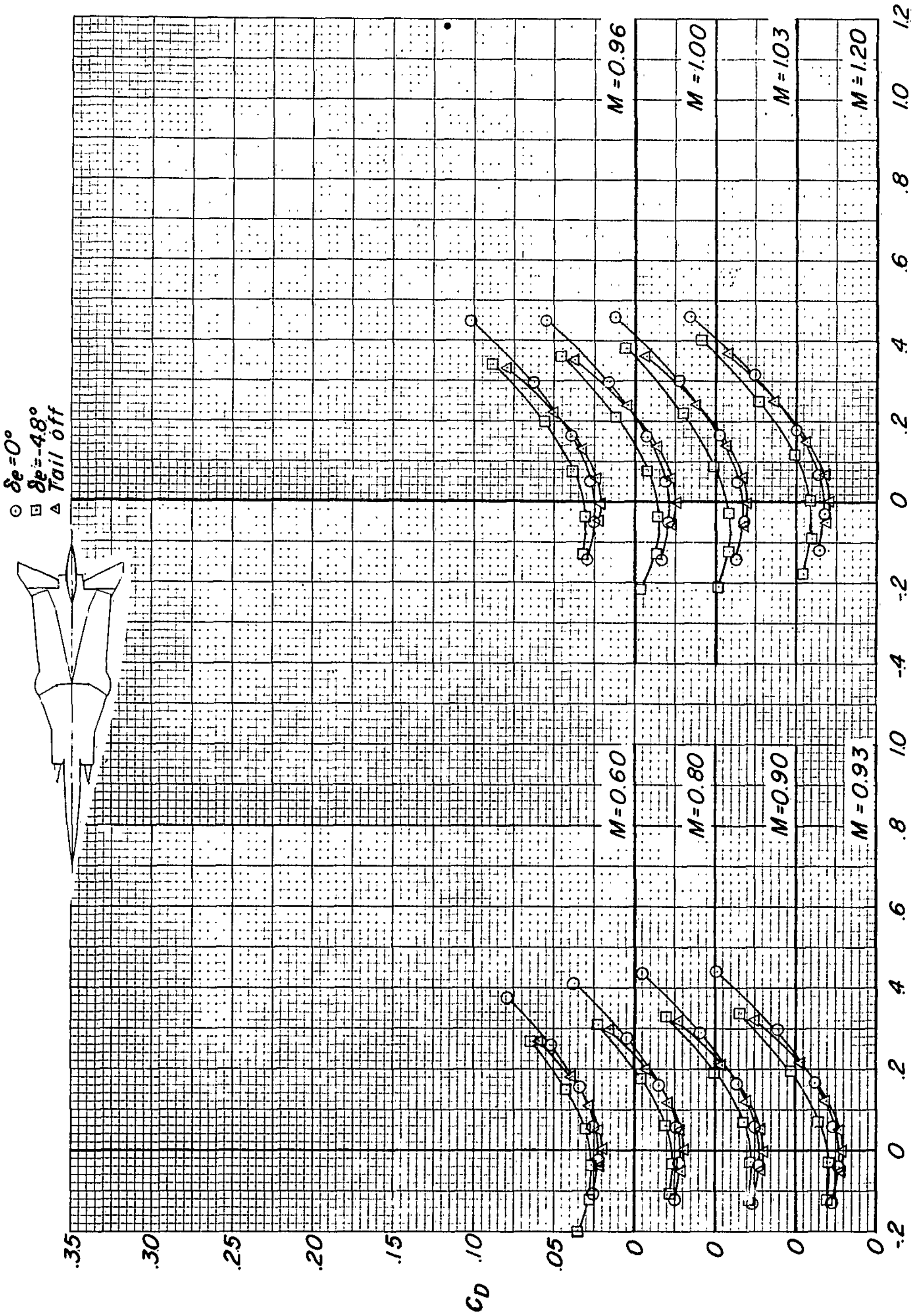

Figure 8.- Continued.

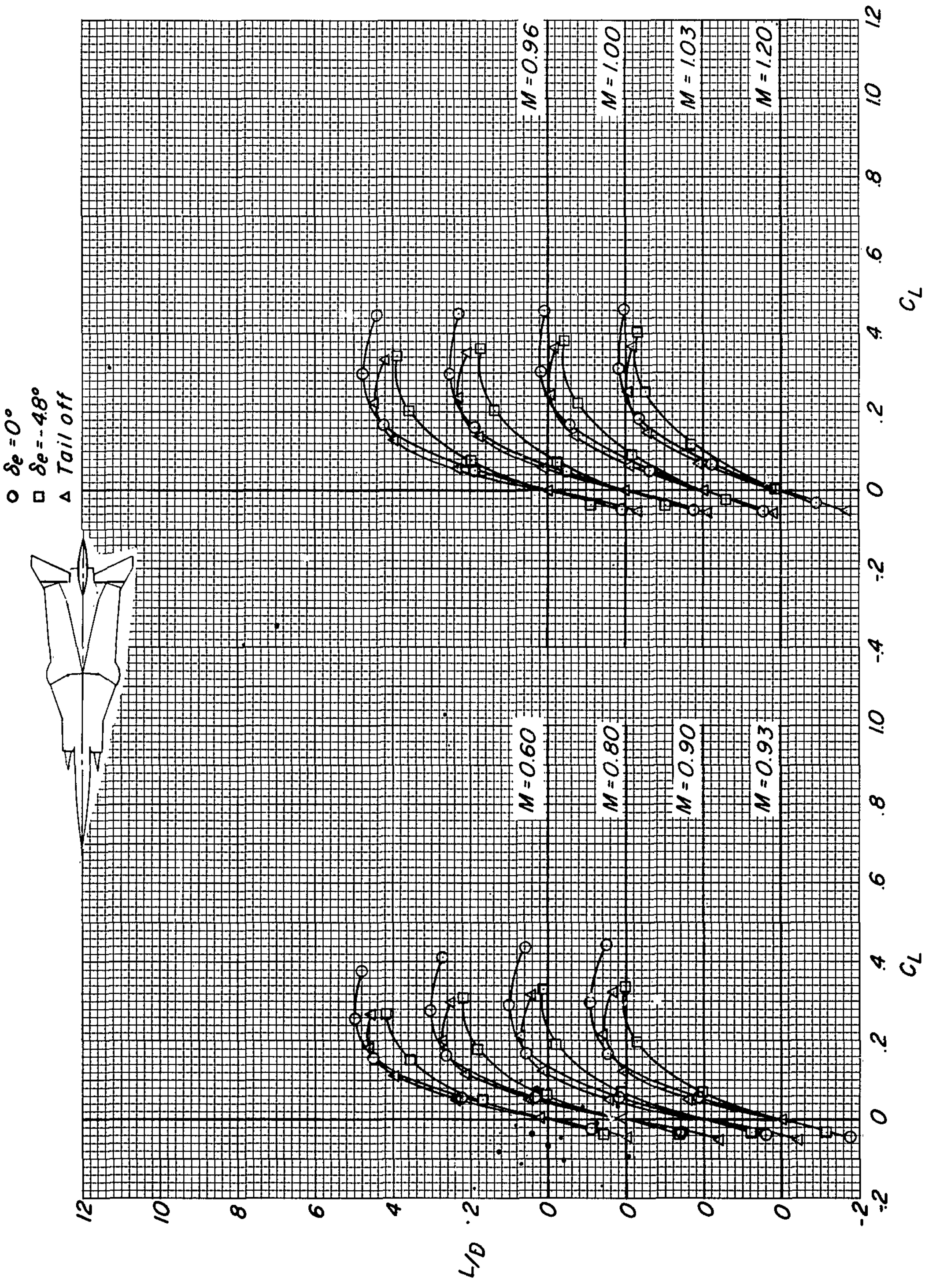

Figure 8.- Continued.

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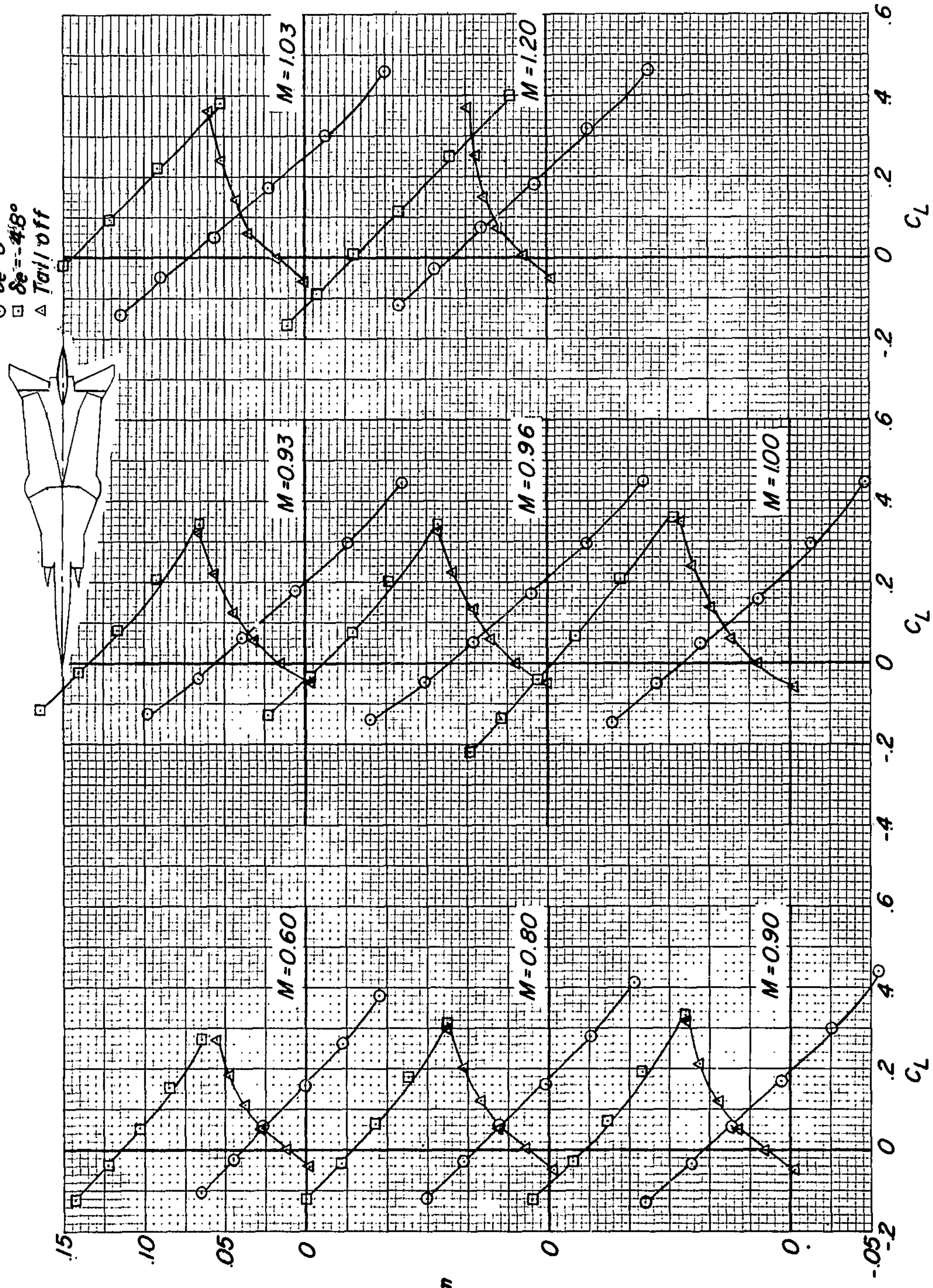

Figure 8.- Concluded.

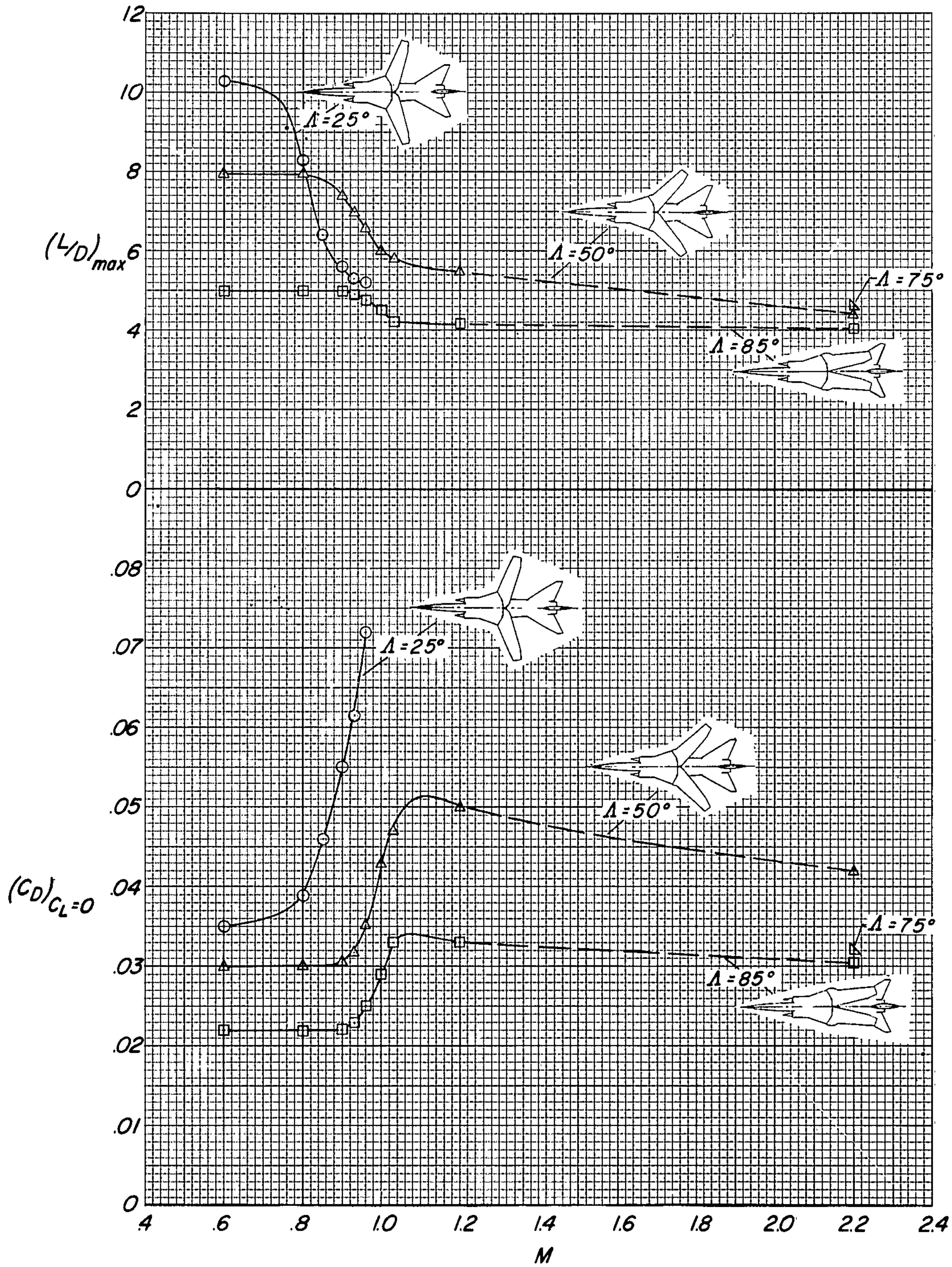

Figure 9.- Effect of wing-sweep position and Mach number on aerodynamic efficiency (chord-plane tail).

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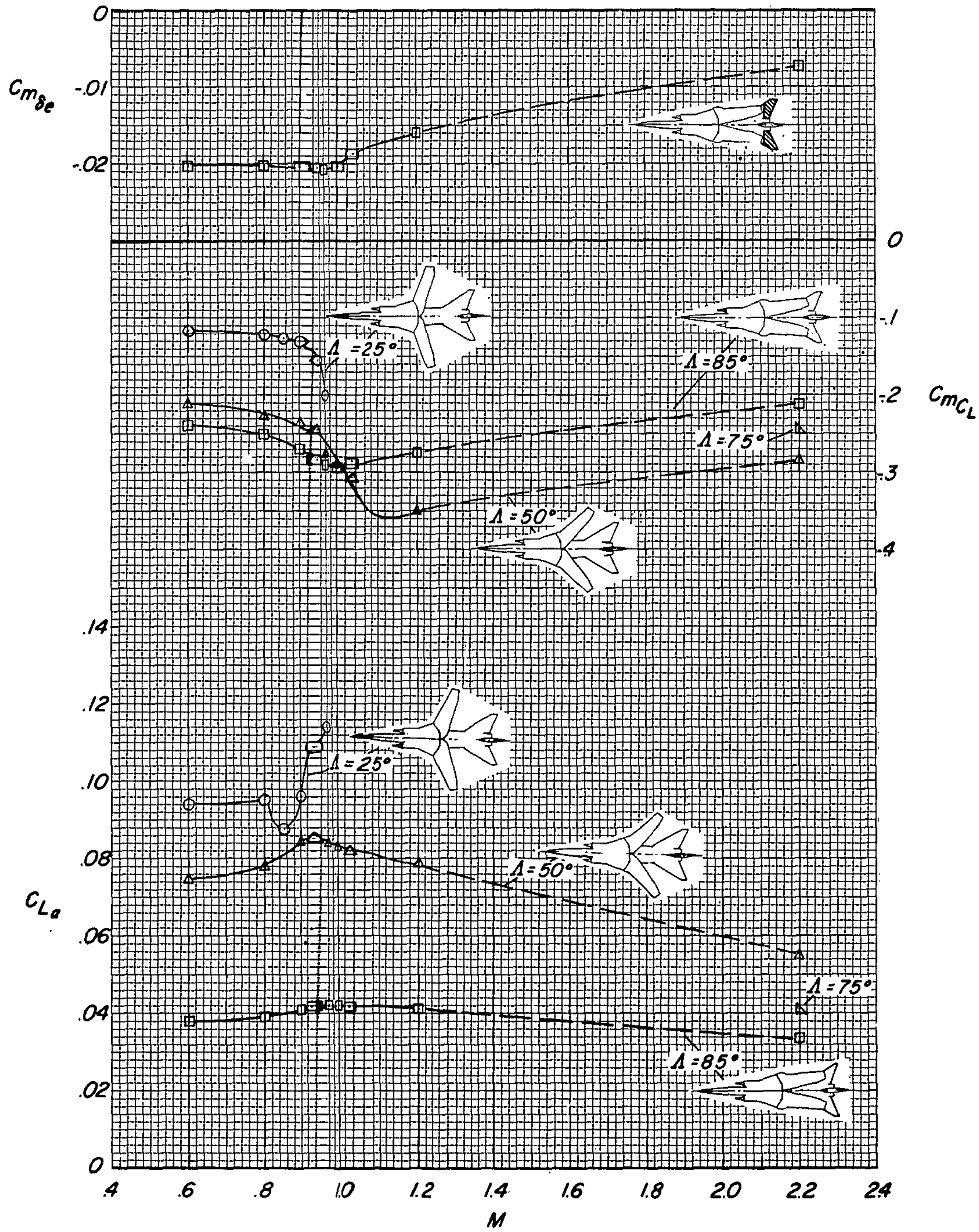

Figure 10.- Effect of wing-sweep position and Mach number on longitudinal stability and control characteristics (chord-plane tail).

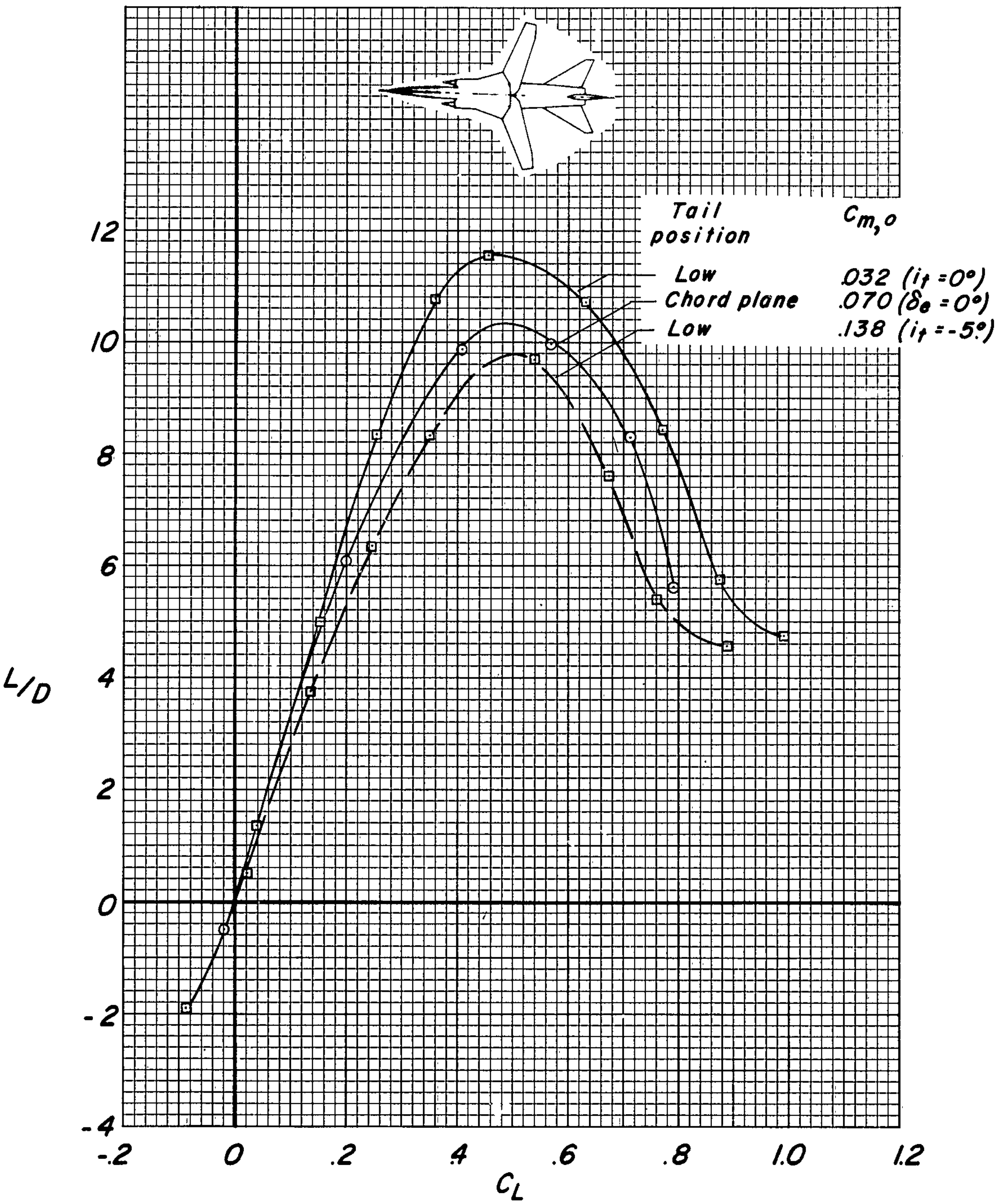

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Figure 11.- Effect of tail height on L/D. M = 0.60; $\Lambda = 25^{\circ}$.

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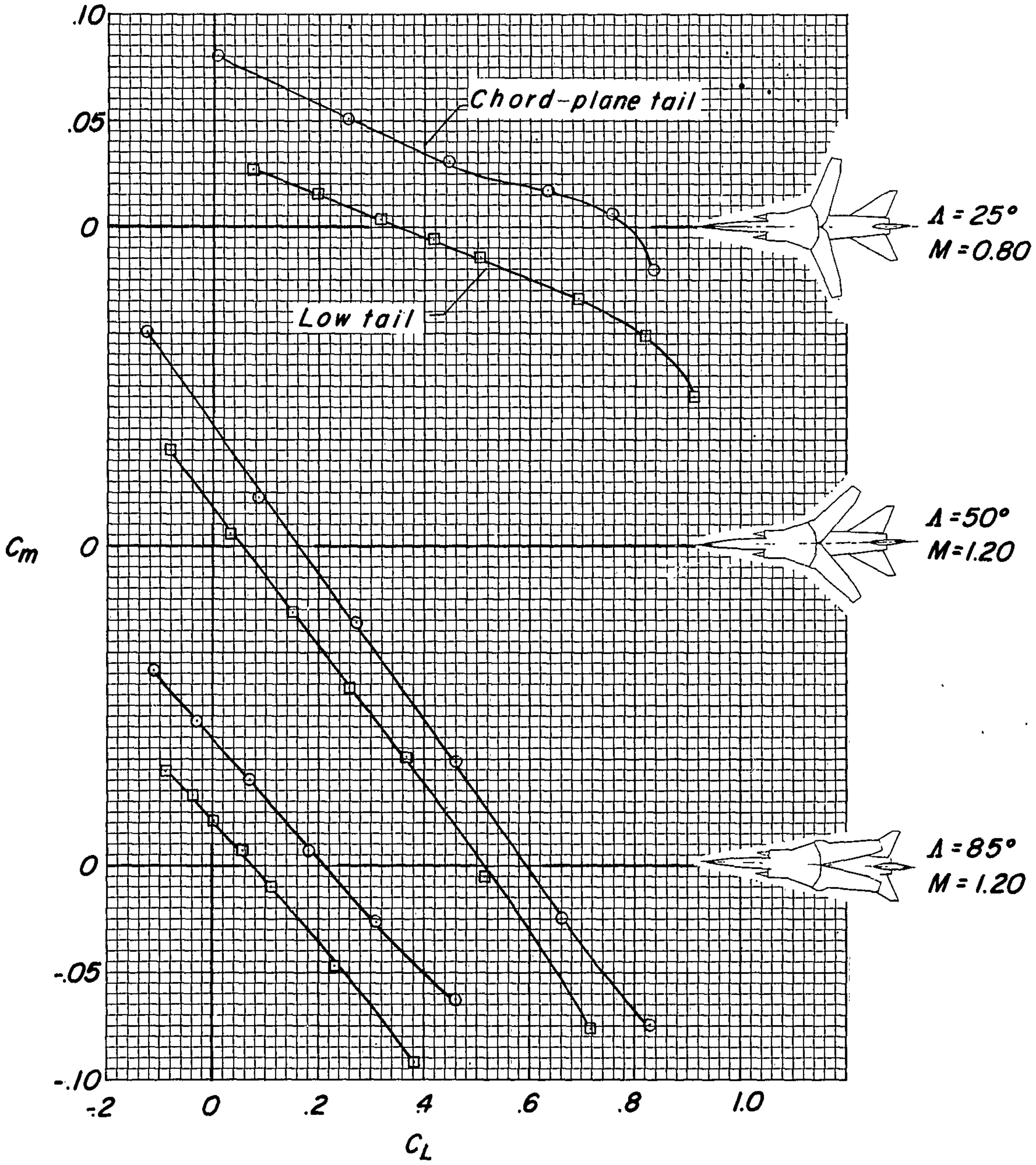

Figure 12.- Effect of tail height on pitching-moment characteristics.

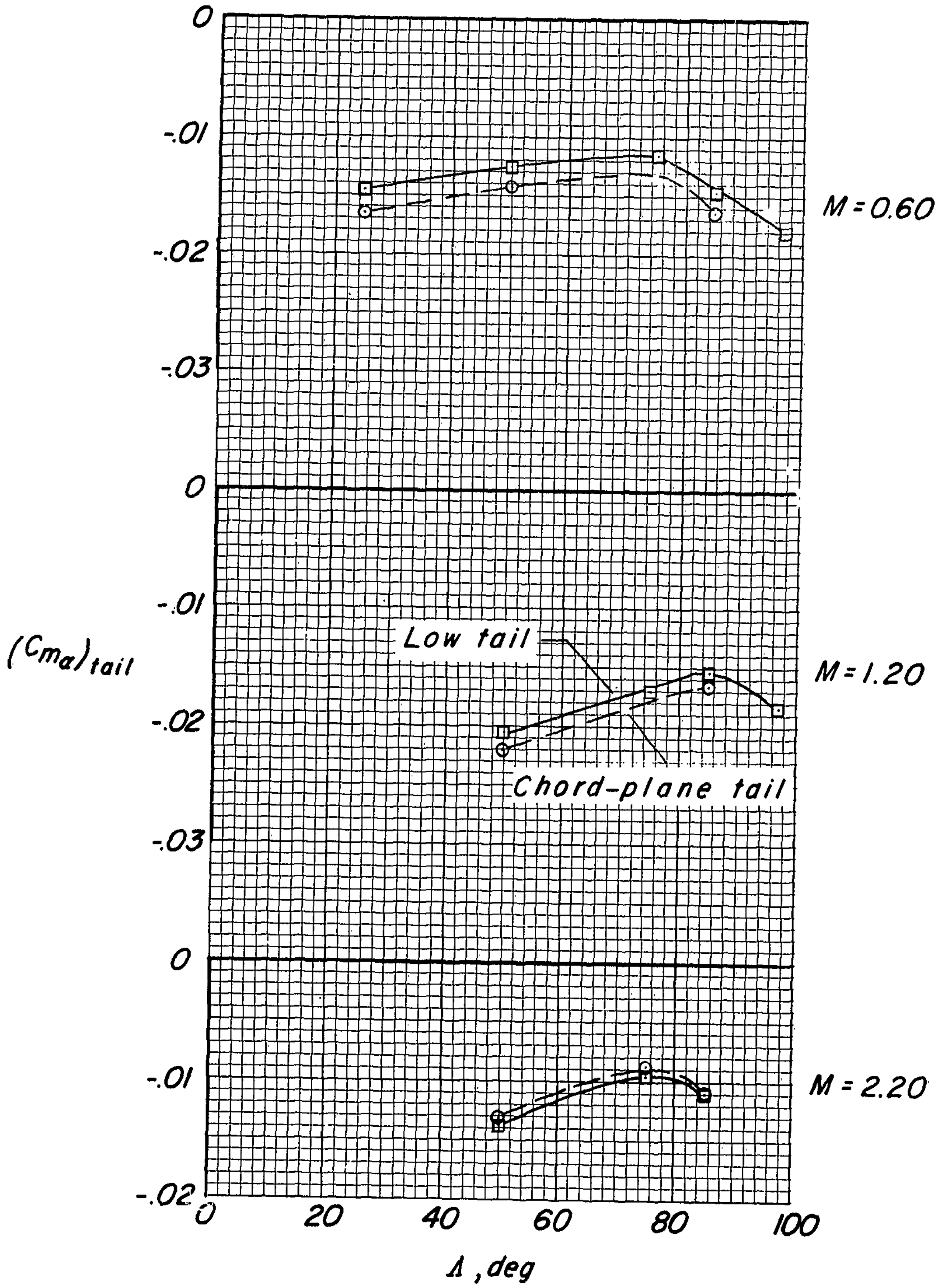

Figure 13.- Effect of wing sweep and tail height on $(C_{m_\alpha})_{tail}$.

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